Supplementary Data 2a
Detailed list of fossil calibrations

Important information on this file

This appendix was automatically generated and exported from PROTEUS v1.27beta12 on 14 August 2019.

This version of our calibration dataset is AngioCal v1.0 (we intend to release updated versions in the future). It includes 238 fossil calibrations for angiosperms compiled for the following paper:

Ramírez-Barahona S, Sauquet H, Magallón S. The delayed and geographically heterogeneous diversification of flowering plants families

For detailed information on how this dataset was assembled, see the section on Fossil calibration in the Supplementary Methods of this paper. For a summary list (table), see Supplementary Data 2b. For a mapping of these calibrations on the angiosperm phylogeny, see Supplementary Data 3 (for an overview, see Extended Data Fig. 1).

List of fossil calibrations included

Angiospermae

†earliest angiosperm-like pollen grains
†Hauterivian-Cactisulc
†Hauterivian-Colthick
†Retisulc-Muribeaded
†Retisulc-Muriverm

Austrobaileyales

†unnamed cuticle 3
†Anacostia marylandensis
†Anacostia portugallica

Nymphaeales

†Jaguariba wiersemana
†Scutifolium jordanicum
†Monetianthus mirus

Mesangiospermae

Ceratophyllales

†Donlesia dakotensis
†Montsechia vidalii

Chloranthales

†Canrightiopsis crassitesta
†Hedyosmum-like flowers (Asteropollis plant)
†unnamed Chloranthaceae androecium

Magnoliidae

Canellales

†Walkeripollis gabonensis

Laurales

†Araripia florifera
†Cohongarootonia hispida
†Lovellea wintonensis
†Mauldinia mirabilis
†Virginianthus calycanthoides
†Jerseyanthus calycanthoides
†Illigera eocenica
†Cinnamomum sezannense
†Potomacanthus lobatus
†Monimiophyllum callidentatum

Magnoliales

†Endressinia brasiliana
†Archaeanthus linnenbergeri
†Myristicoxylon princeps

Piperales

†Aristolochiacidites viluiensis
†Lactoripollenites africanus
†Saururus tuckerae

Monocotyledoneae

†Liliacidites sp. A

Alismatales

†Caldesia brandoniana
†Cardstonia toldmanii
†Aponogeton harryi
†Araciphyllites tertiarius
†Limnobiophyllum scutatum
†Mayoa portugallica
†Spixiarum kipea
†Stratiotes sp.
†Thalassotaenia debeyi

Asparagales

†Paracordyline kerguelensis
†Protoyucca shadishii
†Dianellophyllum eocenicum
†Astelia antiquua
†Dendrobium winikaphyllum
†Meliorchis caribea

Dioscoreales

†Dioscorea wilkinii

Liliales

†Luzuriaga peterbannisteri
†Petermanniopsis angleseaensis
†Ripogonum tasmanicum
†Smilax sp. 1

Pandanales

†Cyclanthus messelensis
†Pandanus sp.? cf. P. shiabensis

Commelinidae

Arecales

†Arengapollenites achinatus
†Mauritiidites crassibaculatus
†Sabalites carolinensis
†Tripylocarpa aestuaria

Commelinales

†Pollia tugenensis

Poales

†Ethela sargantiana
†Tillandsia-type pollen
†Volkeria messelensis
†Juncus vectensis
†Changii indicum
†Leersia seifhennersdorfensis
†Stipa florissanti
†Restiocarpum latericum
†Typha sp.

Zingiberales

†Spirematospermum chandlerae
†Zingiberopsis magnifolia

Eudicotyledoneae

†Hyrcantha decussata
†Tricolpites micromunus

Buxales

†Erdtmanipollis sp.
†Lusistemon striatus
†Spanomera marylandensis

Proteales

†Nelumbites extenuinervis
†Platanocarpus brookensis/Aquia brookensis (Sapindopsis)
†Platanus basicordata
†HUC11 Taxon 1
†Meliosma praealba
†Sabia menispermoides

Ranunculales

†Teixeiraea lusitanica
†Sargentodoxa globosa
†Menispina evidens
†Palaeoluna bogotensis
†Prototinomiscium vangerowii
†Stephania palaeosudamericanc
†Paleoactaea nagelii

Trochodendrales

†Nordenskioldia borealis

Pentapetalae

†Dakotanthus cordiformis

Dilleniales

†Tetracera eocenica

Superrosidae

Saxifragales

†Joffrea speirsii
†Tarahumara sophiae
†Allonia decandra
†Itea sp.

Rosidae

Crossosomatales

†Staphylea minutidens
†Turpinia uliginosa

Geraniales

†Rhynchotheca type

Myrtales

†Esgueiria futabensis
†Decodon tiffneyi
†Melastomites montanensis
†Flower type 3
†Paleomyrtinaea princetonensis
†Paleomyrtinaea sp.

Vitales

†Ampelocissus parvisemina
†Indovitis chitaleyae

Malvidae

Brassicales

†Dressiantha bicarpellata
†Akania sp.

Huerteales

†Tapiscia occidentalis

Malvales

†Cochlospermum previtifolium
†Albertipollenites kutchensis
†Foveotricolpites alveolatus
†Florissantia ashwillii
†Florissantia quilchenensis
†Javelinoxylon weberi
†Malvaciphyllum macondicus

Sapindales

†Choerospondias sheppeyensis
†Coahuiloxylon terrazasiae

†Bursericarpum aldwickense
†Toona sulcata
†Rutaspermum biornatum
†Aesculus hickeyi
†Sapindospermum nitidum
†Ailanthus confucii

Fabidae

Celastrales

†Celastrus comparabilis
†Lophopetalumoxylon indicum

Cucurbitales

†Combretocarpus rotundatus
†Begonia sp.
†Corynocarpus sp.
†Cucurbitospermum sheppeyense

Fabales

†Acacia eocaribbeanensis
†Barnebyanthus buchananensis
†Caesalpinia flumen-viridensis
†Cercis parvifolia
†Diplotropis-like leaves and fruits
†Hymenaea protera
†Leguminocarpon gardneri
†Protomimosoidea buchananensis
†Paleosecuridaca curtissi
†Suriana inordinata

Fagales

†Archaefagacea futabensis
†Caryanthus sp.
†Normapolles pollen
†Protofagacea allonensis
†Bedellia pusilla
†Palaeocarpinus dakotensis
†Gymnostoma antiquum
†Castaneoidea puryearensis
†Castanopsoidea columbiana
†Polyptera manningii
†Nothofagidites senectus

Malpighiales

†Chrysobalanus lacustris
†Pachydermites diederixi
†Paleoclusia chevalieri
†Ctenolophonidites costatus
†Hippomaneoidea warmanensis
†Humiriaceoxylon ocuensis
†Eoglandulosa warmanensis
†Tetrapterys harpyiarum
†Phyllanthus sp.
†Rhizophora sp.
†Zonocostites ramonae
†Populus tidwelli
†Populus wilmattae

Oxalidales

†Eucryphia falcata
†Lacinipetalum spectabilum
†Platydiscus peltatus
†Sloanea ungeri

Rosales

†Aphananthe cretacea
†Morus poolensis
†Coahuilanthus belindae
†Solanites pusilus
†Prunus wutuensis
†Cedrelospermum nervosum

Superasteridae

Caryophyllales

†Caryophylloflora paleogenica
†Coahuilacarpon phytolaccoides
†Polygonocarpum johnsonii

Santalales

†Cranwellia edmontonensis
†Cranwellia sachalinensis
†Anacolosidites meyeorum
†Schoepfia republicensis

Asteridae

Cornales

†Hironoia fusiformis
†Cornus hyperborea
†Hydrangea antica
†Beckettia samuelis

Ericales

†Actinocalyx bohrii
†Paleoenkianthus sayrevillensis
†Paradinandra suecica
†Pentapetalum trifasciculandricus
†Parasaurauia allonensis
†Austrodiospyros cryptostoma
†Leucothoe praecox
†Visnea minima
†Gilisenium hueberi
†unnamed Roridulaceae
†Chrysophyllum tertiarum
†Rehderodendron stonei
†Styrax transversa
†Symplocos grimsleyi
†Psilatricolporites crassus
†Andrewsiocarpon henryense

Campanulidae

Apiales

†Carpites ulmiformis
†Umbelliferospermum latahense
†Paleopanax oregonensis
†Toricellia bonensii

Aquifoliales

†Ilex hercynica

Asterales

†Raiguenrayun cura
†Tubulifloridites lilliei type A
†Campanula palaeopyramidalis
†Poluspissusites ramus
†Menyanthes cf. trifoliata

Dipsacales

†Diervilla echinata
†Diplodipelta reniptera
†Patrinia paleosibirica

Lamiidae

Boraginales

†Lithospermum dakotense
†Cordia platanifolia
†Ehretia clausentia

Garryales

†Eucommia eocenica
†Eucommia montana
†Garrya axelrodi

Gentianales

†Apocynospermum coloradensis
†Voyrioseminites magnus
†Emmenopterys dilcheri

Icacinales

†Icacinanthium tainiaphorum

Lamiales

†Acanthus rugatus
†unnamed cf. Avicennia
†Catalpa sp.
†Golden Grove Byblidaceae parc
†Ajuginucula smithii
†Melissa parva
†Fraxinus rupinarum
†Paulownia inopinata
†Trapella weylandi

Solanales

†Calystegiapollis microechinatus
†Physalis infinemundi
†Solanispermum reniforme

†earliest angiosperm-like pollen grains

Calibration at a glance	stem Angiospermae, min 132.1 Ma
ID number (NFos)	330

Fossil identity

Full taxon name	**†earliest angiosperm-like pollen grains Brenner**
Organs	Pollen
Specimens	Numbers not provided; Fig. 54A-D of Brenner 1996 (book chapter)
Locality	Kokhav 2 borehole, core 5, lower sand member (H1), Coastal Plain of Israel
Formation	Helez Formation
Country	Israel

Reference (description)

Brenner GJ. 1996. Evidence for the earliest stage of angiosperm pollen evolution: a paleoequatorial section from Israel. In: Taylor DW, Hickey LJ, eds. Flowering Plant Origin, Evolution & Phylogeny. New York, NY: Chapman & Hall, 91–115.

Fossil age

Safe minimum age	**132.1 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Hauterivian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	4 / revised (stratigraphic)

Age justification

Magallón et al 2015 (NewPhytol): "Possibly the oldest angiosperm pollen grains are small, circular and inaperturate (or possibly with a weak aperture, J. A. Doyle, pers. comm. to S.M., 2012), with a columellar and perforate to reticulate wall structure (Brenner, 1996), found in a core sample of the lower Sand Member (unit H1) of the Helez Formation, Israel. This unit is dated as late Valanginian to early Hauterivian on the basis of bracketing by early Hauterivian ammonites and Valanginian foraminifera and ostracods. Late Hauterivian sediments from the same cores contain a higher diversity of angiosperm pollen grains (Brenner, 1996)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Angiospermae**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

Node assignment revised from Magallón et al 2015 (NewPhytol), who concluded: "It is uncertain whether the Valanginian-early Hauterivian pollen grains with a columellar and perforate to reticulate wall structure are angiosperm stem representatives or crown group members. We here interpret them either as crown members, based on the distribution of ultrastructural attributes of the pollen wall among the earliest branches of extant angiosperms (i.e., Amborella, Nympnaeales, and Austrobaileyales + Mesangiospermae), or as stem representatives that existed shortly before the crown diversification of the group. The latter interpretation is supported by the unequivocal progressive and pronounced increase in diversity, abundance and distribution of angiosperm micro- and *macrofossils starting in immediately younger sediments, until they become ubiquitous ecologically and geograhically at a Global level. These pollen grains are considered to mark the earliest occurrence of crown group angiosperms in the fossil record, and to provide the minimum age of the group."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Hauterivian-Cactisulc

Calibration at a glance: stem Angiospermae, min 129.4 Ma
ID number (NFos): 378

Fossil identity

Full taxon name: **†Hauterivian-Cactisulc Hughes & McDougall**
Organs: Pollen
Specimens: Biorecord locality: Hunstanton borehole, HUN210; prep. X425, stub AM208, film AMD98. Plate V, 1-4.
Locality: Hunstanton borehole, Norfolk, England
Formation:
Country: UK

Reference (description)

Hughes NF, McDougall AB. 1987. Records of angiospermid pollen entry into the English Early Cretaceous succession. Review of Palaeobotany and Palynology 50: 255–272.

Fossil age

Safe minimum age: **129.4 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Hauterivian
Reference time scale: ICS (v2017/02)
Age quality score: 2 / unrevised (old source < 2000)

Age justification

Hughes & McDougall 1987 (RevPalPal): "Although our earliest angiospermid pollen (e.g. Warlingham 1415/6) was believed to be early Barremian in age, it was realised that there was no close stratigraphic control downhole. Quite recently Ian Harding (1986) has shown by the presence of the dinocyst Muderongia simplex in Warlingham 1416 that correlation with the marine succession at Speeton, Yorkshire places this and all lower samples below the C2C/C2D boundary there, and thus they are of Hauterivian age. Consequently some of the earliest angiospermid pollen is just of latest Hauterivian age. There are as yet no radiometric ages in this part of the column and values given are only raised from interpolations."

Reference (age)

Hughes NF, McDougall AB. 1987. Records of angiospermid pollen entry into the English Early Cretaceous succession. Review of Palaeobotany and Palynology 50: 255–272.

Fossil relationships

Node calibrated: **stem Angiospermae**
Node assignment score: 4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score: 3 / molecular tree only

Node justification

Node assignment revised from Magallón et al 2015 (NewPhytol), who concluded: "It is uncertain whether the Valanginian-early Hauterivian pollen grains with a columellar and perforate to reticulate wall structure are angiosperm stem representatives or crown group members. We here interpret them either as crown members, based on the distribution of ultrastructural attributes of the pollen wall among the earliest branches of extant angiosperms (i.e., Amborella, Nympnaeales, and Austrobaileyales + Mesangiospermae), or as stem representatives that existed shortly before the crown diversification of the group. The latter interpretation is supported by the

unequivocal progressive and pronounced increase in diversity, abundance and distribution of angiosperm micro- and macrofossils starting in immediately younger sediments, until they become ubiquitous ecologically and geograhically at a Global level. These pollen grains are considered to mark the earliest occurrence of crown group angiosperms in the fossil record, and to provide the minimum age of the group."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Hauterivian-Colthick

Calibration at a glance: stem Angiospermae, min 129.4 Ma
ID number (NFos): 377

Fossil identity

Full taxon name: **†Hauterivian-Colthick Hughes et al**
Organs: Pollen
Specimens: KCE 682 - KCE 787
Locality: Kingsclere borehole; also Warlingham borehole, Surrey, England (sample WM1488/7)
Formation:
Country: UK

Reference (description)

Hughes N, McDougall A, Chapman J. 1991. Exceptional new record of Cretaceous Hauterivian angiospermid pollen from Southern England. Journal of Micropalaeontology 10: 75–82.

Fossil age

Safe minimum age: **129.4 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Hauterivian
Reference time scale: ICS (v2017/02)
Age quality score: 2 / unrevised (old source < 2000)

Age justification

Hughes et al 1991 (JMicropal): "As indicated in Fig.3, the reference succession is that of the Warlingham borehole, Surrey, in which the sample WM 1416 contained dinocysts of latest Hauterivian age (Hughes and McDougall, 1987)."

Reference (age)

Hughes N, McDougall A, Chapman J. 1991. Exceptional new record of Cretaceous Hauterivian angiospermid pollen from Southern England. Journal of Micropalaeontology 10: 75–82.

Fossil relationships

Node calibrated: **stem Angiospermae**
Node assignment score: 4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score: 3 / molecular tree only

Node justification

Node assignment revised from Magallón et al 2015 (NewPhytol), who concluded: "It is uncertain whether the Valanginian-early Hauterivian pollen grains with a columellar and perforate to reticulate wall structure are angiosperm stem representatives or crown group members. We here interpret them either as crown members, based on the distribution of ultrastructural attributes of the pollen wall among the earliest branches of extant angiosperms (i.e., Amborella, Nympnaeales, and Austrobaileyales + Mesangiospermae), or as stem representatives that existed shortly before the crown diversification of the group. The latter interpretation is supported by the unequivocal progressive and pronounced increase in diversity, abundance and distribution of angiosperm micro- and macrofossils starting in immediately younger sediments, until they become ubiquitous ecologically and geograhically at a Global level. These pollen grains are considered to mark the earliest occurrence of crown group angiosperms in the fossil record, and to provide the minimum age of the group."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Retisulc-Muribeaded

Calibration at a glance	stem Angiospermae, min 129.4 Ma
ID number (NFos)	376

Fossil identity

Full taxon name	**†Retisulc-Muribeaded Hughes & McDougall**
Organs	Pollen
Specimens	Biorecord locality: Warlingham borehole, WM1456/5; prep. V958, stub JL57-300819, film GED B29/1.3.
Locality	Warlingham borehole, Surrey, England
Formation	
Country	UK

Reference (description)

Hughes NF, McDougall AB. 1987. Records of angiospermid pollen entry into the English Early Cretaceous succession. Review of Palaeobotany and Palynology 50: 255–272.

Fossil age

Safe minimum age	**129.4 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Hauterivian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Hughes & McDougall 1987 (RevPalPal): "Although our earliest angiospermid pollen (e.g. Warlingham 1415/6) was believed to be early Barremian in age, it was realised that there was no close stratigraphic control downhole. Quite recently Ian Harding (1986) has shown by the presence of the dinocyst Muderongia simplex in Warlingham 1416 that correlation with the marine succession at Speeton, Yorkshire places this and all lower samples below the C2C/C2D boundary there, and thus they are of Hauterivian age. Consequently some of the earliest angiospermid pollen is just of latest Hauterivian age. There are as yet no radiometric ages in this part of the column and values given are only raised from interpolations."

Reference (age)

Hughes NF, McDougall AB. 1987. Records of angiospermid pollen entry into the English Early Cretaceous succession. Review of Palaeobotany and Palynology 50: 255–272.

Fossil relationships

Node calibrated	**stem Angiospermae**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

Node assignment revised from Magallón et al 2015 (NewPhytol), who concluded: "It is uncertain whether the Valanginian-early Hauterivian pollen grains with a columellar and perforate to reticulate wall structure are angiosperm stem representatives or crown group members. We here interpret them either as crown members, based on the distribution of ultrastructural attributes of the pollen wall among the earliest branches of extant angiosperms (i.e., Amborella, Nympnaeales, and Austrobaileyales + Mesangiospermae), or as stem representatives that existed shortly before the crown diversification of the group. The latter interpretation is supported by the

unequivocal progressive and pronounced increase in diversity, abundance and distribution of angiosperm micro- and macrofossils starting in immediately younger sediments, until they become ubiquitous ecologically and geograhically at a Global level. These pollen grains are considered to mark the earliest occurrence of crown group angiosperms in the fossil record, and to provide the minimum age of the group."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Retisulc-Muriverm

Calibration at a glance	stem Angiospermae, min 129.4 Ma
ID number (NFos)	375

Fossil identity

Full taxon name	**†Retisulc-Muriverm Hughes & McDougall**
Organs	Pollen
Specimens	Biorecord: Hunstanton borehole, HUN 170; prep. X240, stub GD243-348799, film AMD98/91, 92.
Locality	Hunstanton borehole, Norfolk, England
Formation	
Country	UK

Reference (description)

Hughes NF, McDougall AB. 1987. Records of angiospermid pollen entry into the English Early Cretaceous succession. Review of Palaeobotany and Palynology 50: 255–272.

Fossil age

Safe minimum age	**129.4 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Hauterivian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Hughes & McDougall 1987 (RevPalPal): "Although our earliest angiospermid pollen (e.g. Warlingham 1415/6) was believed to be early Barremian in age, it was realised that there was no close stratigraphic control downhole. Quite recently Ian Harding (1986) has shown by the presence of the dinocyst Muderongia simplex in Warlingham 1416 that correlation with the marine succession at Speeton, Yorkshire places this and all lower samples below the C2C/C2D boundary there, and thus they are of Hauterivian age. Consequently some of the earliest angiospermid pollen is just of latest Hauterivian age. There are as yet no radiometric ages in this part of the column and values given are only raised from interpolations."

Reference (age)

Hughes NF, McDougall AB. 1987. Records of angiospermid pollen entry into the English Early Cretaceous succession. Review of Palaeobotany and Palynology 50: 255–272.

Fossil relationships

Node calibrated	**stem Angiospermae**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

Node assignment revised from Magallón et al 2015 (NewPhytol), who concluded: "It is uncertain whether the Valanginian-early Hauterivian pollen grains with a columellar and perforate to reticulate wall structure are angiosperm stem representatives or crown group members. We here interpret them either as crown members, based on the distribution of ultrastructural attributes of the pollen wall among the earliest branches of extant angiosperms (i.e., Amborella, Nympnaeales, and Austrobaileyales + Mesangiospermae), or as stem representatives that existed shortly before the crown diversification of the group. The latter interpretation is supported by the

unequivocal progressive and pronounced increase in diversity, abundance and distribution of angiosperm micro- and macrofossils starting in immediately younger sediments, until they become ubiquitous ecologically and geograhically at a Global level. These pollen grains are considered to mark the earliest occurrence of crown group angiosperms in the fossil record, and to provide the minimum age of the group."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†unnamed cuticle 3

Calibration at a glance	crown Austrobaileyales, min 113 Ma
ID number (NFos)	164

Fossil identity

Full taxon name	**†unnamed cuticle 3 Upchurch**
Organs	Dispersed cuticle
Specimens	UMMP 65126-56
Locality	Drewry's Bluff locality, Virginia
Formation	Potomac Zone I
Country	USA

Reference (first description)

Upchurch GR. 1984. Cuticular Anatomy of Angiosperm Leaves from the Lower Cretaceous Potomac Group. I. Zone I Leaves. American Journal of Botany 71: 192–202.

Reference (latest description)

Doyle JA, Upchurch GR. 2014. Angiosperm Clades in the Potomac Group: What Have We Learned since 1977? Bulletin of the Peabody Museum of Natural History 55: 111–134.

Fossil age

Safe minimum age	**113 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Aptian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Upchurch 1984b (AmJBot): "This sites located on the James River south of Richmond, Virginia, at Drewry's BluS, yields a pollen flora assignable to upper Zone I of Brenner (Aptian?), similar to one described by Doyle and Hickey (1976) from a compa- rable elevation at the south end ofthe exposure (Doyle, pers. commun.)."

Reference (age)

Upchurch GR. 1984. Cuticular Anatomy of Angiosperm Leaves from the Lower Cretaceous Potomac Group. I. Zone I Leaves. American Journal of Botany 71: 192–202.

Fossil relationships

Node calibrated	**crown Austrobaileyales**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Doyle & Upchurch 2014 (BullPeabodyMusNatHis): "Because most of the leaf traits discussed so far may be plesiomorphic, they are only consistent with the presence of plants at the ANITA grade and do not support a relationship with any particular clade. However, the dispersed cuticle record at Dutch Gap and Drewry's Bluff indicates the presence of crown group Austrobaileyales. Two cuticle types (Figure 3A–C) have a combination of features found in this order, including elliptic to round guard cell pairs, striate surface sculpture, and a variable pattern of subsidiary cell arrangement (Upchurch 1984a, 1984b; Carpenter 2005, 2006). The polarity of these characters is uncertain, although Carpenter (2006) proposed that striations may be a synapomorphy of Austrobaileyales and mesangiosperms. However, the fossils also have T-pieces at the stomatal poles, a feature *developed to varying degrees in Trimenia and Schisandraceae (sensu APG 2009), especially Illicium, but not reported in the basal genus Austrobaileya, other ANITA-grade taxa, Chloranthaceae, and magnoliids, indicating a position nested within Austrobaileyales (Figure 4)."*

Reference (relationships)

Doyle JA, Upchurch GR. 2014. Angiosperm Clades in the Potomac Group: What Have We Learned since 1977? Bulletin of the Peabody Museum of Natural History 55: 111–134.

†*Anacostia marylandensis*

Calibration at a glance	stem Schisandraceae (Austrobaileyales), min 107.7 Ma
ID number (NFos)	163

Fossil identity

Full taxon name	**†Anacostia marylandensis Friis, Crane & Pedersen**
Organs	Isolated fruits (carpels) with enclosed seeds and adhering pollen
Specimens	Holotype: PP44159 (sample 175 Kenilworth)
Locality	Kenilworth locality, Maryland (Washington East Quadrangle, 7.5 minute Series, 38°55'53"N; 76°55'45"W) Patapsco Formation, Potomac Group
Formation	Potomac Group, Patapsco Formation
Country	USA

Reference (description)

Friis EM, Crane PR, Pedersen KR. 1997. Anacostia, a new basal angiosperm from the Early Cretaceous of North America and Portugal with trichotomocolpate/patemonocolpate pollen. Grana 36: 225–244.

Fossil age

Safe minimum age	**107.7 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	middle Albian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	4 / revised (stratigraphic)

Age justification

Magallón et al 2015 (NewPhytol) state: "Anacostia marylandensis Friis, Crane & Pedersen, from the Kenilworth locality, Maryland (Friis et al., 1997), where the fruit and seed-bearing sediments are considered to correspond to the palynological subzone II-B of the Potomac Group sequence, corresponding to early-middle Albian (Friis et al., 2011 and references therein)". Doyle & Endress (2014) and Doyle & Upchurch (2014) also refer to a middle Albian age for this locality, citing the same reference (Friis et al. 1997). Note that the fossil from the Puddledock locality, Anacostia virginiensis, would provide a constraint of the same age (see Massoni et al 2015 (PE) on +Cohongarootonia hispida and +Virginianthus calycanthoides).

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Schisandraceae (Austrobaileyales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Doyle & Endress (2014) presented molecular backbone phylogenetic analyses of a fossil taxon identified as "Anacostia", which was presumably scored on the basis of the collective characters of the four known species (in particular the "Puddledock floral axis"). Their results supported a position nested in Austrobaileyales, either as sister to Schisandraceae or Schisandra alone. The same results were obtained in earlier analyses based on an older dataset (Doyle et al. 2008) and were summarized again by Doyle & Upchurch (2014). We here make the assumption that *these results apply to any of the constituent species of Anacostia.*

Reference (relationships)

Doyle JA, Endress PK. 2014. Integrating Early Cretaceous fossils into the phylogeny of living angiosperms: ANITA lines and relatives of Chloranthaceae. International Journal of Plant Sciences 175: 555–600.

†Anacostia portugallica

Calibration at a glance	stem Schisandraceae (Austrobaileyales), min 110.8 Ma
ID number (NFos)	359

Fossil identity

Full taxon name	**†Anacostia portugallica Friis, Crane, et Pedersen**
Organs	Fruiting units
Specimens	S105039 (sample Portugal 141 Vale de Agua)
Locality	Vale de Agua, ca. 5 km southwest of Batalha
Formation	
Country	Portugal

Reference (description)

Friis EM, Crane PR, Pedersen KR. 1997. Anacostia, a new basal angiosperm from the Early Cretaceous of North America and Portugal with trichotomocolpate/patemonocolpate pollen. Grana 36: 225–244.

Fossil age

Safe minimum age	**110.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	early Albian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	4 / revised (stratigraphic)

Age justification

Magallón et al 2015 (NewPhytol) state: "A. portugallica Friis, Crane & Pedersen, from the Vale de Agua locality, Portugal, considered to be late Aptian-early Albian (Heimhofer et al., 2007; Friis et al., 2011)". Doyle & Endress (2014) and Doyle & Upchurch (2014) also refer to an early Albian age for this locality, citing the same reference (Friis et al. 1997). Note that the fossil from the Famalicão locality, Anacostia teixeirae, would provide a constraint of the same age.

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Schisandraceae (Austrobaileyales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Doyle & Endress (2014) presented molecular backbone phylogenetic analyses of a fossil taxon identified as "Anacostia", which was presumably scored on the basis of the collective characters of the four known species (in particular the "Puddledock floral axis"). Their results supported a position nested in Austrobaileyales, either as sister to Schisandraceae or Schisandra alone. The same results were obtained in earlier analyses based on an older dataset (Doyle et al. 2008) and were summarized again by Doyle & Upchurch (2014). We here make the assumption that these results apply to any of the constituent species of Anacostia.

Reference (relationships)

Doyle JA, Endress PK. 2014. Integrating Early Cretaceous fossils into the phylogeny of living angiosperms: ANITA

lines and relatives of Chloranthaceae. International Journal of Plant Sciences 175: 555–600.

†Jaguariba wiersemana

Calibration at a glance	crown Cabombaceae+Nymphaeaceae, min 113 Ma
ID number (NFos)	166

Fossil identity

Full taxon name	**†Jaguariba wiersemana Coiffard, B.A.R. Mohr & Bernardes-de-Oliveira**
Organs	Complete plant
Specimens	Holotype: MB. Pb. 1997/1291 (Repository: Museum für Naturkunde, Berlin)
Locality	Nova Olinda, Region Araripe, open carst pit
Formation	Crato Formation, Nova Olinda member
Country	Brazil

Reference (description)

Coiffard C, Mohr BAR, Bernardes-de-Oliveira MEC. 2013. Jaguariba wiersemana gen. nov. et sp. nov., an Early Cretaceous member of crown group Nymphaeales (Nymphaeaceae) from northern Gondwana. Taxon 62: 141–151.

Fossil age

Safe minimum age	**113 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Aptian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Massoni et al 2015 (PE) on +Endressinia brasiliana: "The fossil considered here was collected from the Crato Formation in the Araripe sedimentary basin of northeastern Brazil (Mohr et al., 2013). Mohr and Bernardes-de-Oliveira (2004) assumed that the Crato Formation is late Aptian or early Albian in age, based on numerous previous estimates (e.g., Pons et al., 1996). Because of this uncertainty, Clarke et al. (2011) proposed a minimum age for the Crato of 98.7 Ma, the top of the Albian. However, evidence has been accumulating in favor of a late Aptian age (Coimbra et al., 2002). Most recently, using gymnosperm pollen and dinoflagellates to correlate with better-dated sections, Heimhofer and Hochuli (2010) concluded that the Aptian-Albian boundary lies above the Crato Formation, and this was accepted by Mohr et al. (2013). We therefore propose a minimum age of 112.6 Ma for Endressinia, the Aptian-Albian boundary (113 ±0.4 Ma; Ogg and Hinnov, 2012)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**crown Cabombaceae+Nymphaeaceae**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	2 / morphological tree only

Node justification

The phylogenetic analysis of Coiffard et al (2013) based on morphological data suggested a position nested in Nymphaeoideae, as sister to Barclaya (with weak support), which would justify an assignment to at least crown Nymphaeaceae. However, recent molecular phylogenetic analyses have challenged traditional relationships in the family, including the monophyly of the family as a whole (e.g., Gruenstaeudl et al. 2017), calling for caution in interpreting the results from the morphological analysis of Coiffard et al (2013). For this reason, we consider it safer *to assign this fossil to the crown node of the Cabombaceae+Nymphaeaceae clade, which is the same as the stem node of Nymphaeaceae if they are monophyletic.*

Reference (relationships)

Coiffard C, Mohr BAR, Bernardes-de-Oliveira MEC. 2013. Jaguariba wiersemana gen. nov. et sp. nov., an Early Cretaceous member of crown group Nymphaeales (Nymphaeaceae) from northern Gondwana. Taxon 62: 141–151.

†Scutifolium jordanicum

Calibration at a glance	stem Cabombaceae (Nymphaeales), min 100.5 Ma
ID number (NFos)	167

Fossil identity

Full taxon name	**†Scutifolium jordanicum Taylor, Brenner & Basha**
Organs	Leaves
Specimens	Holotype: 99–2B-Na,b Yale Peabody Museum (YPM)
Locality	Mahis locality in north-central Jordan at N 31°59’43.7’’, E 035°45’29.2’’
Formation	Jurash formation, Kurnub group
Country	Jordan

Reference (description)

Taylor DW, Brenner GJ, Basha SH. 2008. Scutifolium jordanicum gen. et sp. nov. (Cabombaceae), an aquatic fossil plant from the Lower Cretaceous of Jordan, and the relationships of related leaf fossils to living genera. American Journal of Botany 95: 340–352.

Fossil age

Safe minimum age	**100.5 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Albian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Taylor et al 2008a (AmJBot): "The age of the Kurnub Group is late Neocomian/early Barremian (130 Ma) to Albian (100 Ma) of the Early Cretaceous (Amireh, 1997 , 2000 ; Amireh and Abed, 1999) based on several lines of evidence. The lower age is constrained by Kurnub Group ’ s position above the Middle to Late Jurassic Carbonates (Basha, 1983; Amireh and Abed, 1999). The Neocomian age is based on the fern Weichselia reticulata (Edwards, 1926), and a palynomorphic study of the lower Kurnub Group (Al-Said and Mustafa, 1994). Based on pollen zonation (Brenner, 1976 , 1996), Brenner and Bickoff (1992) proposed a late Barremian age for the basal part of the Kurnub Group in Israel. The upper age constraint is based on the position of the Kurnub Group ’ s position below the Cenomanian Nodular Limestone Member of the Na ’ ur Formation of the Ajlun Group. The upper Albian age is based upon the ammonite Knemiceras and a glauconite marker bed in the Bir Fa ’ as Formation at the top of the Kurnub Group (Amireh, 1997 ; Amireh et al., 1998) dated at 96.1 ± 1.1 Ma (million years ago) (Amireh et al., 1998). Carbonaceous layers from the Upper Jarash Formation also contain Albian palynomorphs (G. J. Brenner, S. H. Basha and D. W. Taylor, unpublished data on palynology of several localities). The new fossil was collected from Meandering River facies of the upper Jarash Formation, below the glauconitic sandstone that is part of the Bir Fa ’ as Formation. Because the Bir Fa ’ as Formation is considered Albian in age (Amireh et al., 1998 ; G. J. Brenner, S. H. Basha and D. W. Taylor, unpublished pollen data), the specimen must be of Albian age (105 Ma) or older."

Reference (age)

Taylor DW, Brenner GJ, Basha SH. 2008. Scutifolium jordanicum gen. et sp. nov. (Cabombaceae), an aquatic fossil plant from the Lower Cretaceous of Jordan, and the relationships of related leaf fossils to living genera. American Journal of Botany 95: 340–352.

Fossil relationships

Node calibrated	**stem Cabombaceae (Nymphaeales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	2 / morphological tree only

Node justification

Taylor et al 2008a (AmJBot): "Comparisons to plants with centrally peltate leaves and palmate venation and to aquatic plants with fl oating leaves suggest that S. jordanicum belongs to the Cabombaceae lineage within the Nymphaeales. Cladistic analysis including the fossil and living members of the Nymphaeales shows that the S. jordanicum is basal to the living members of the family and has unique characters not found in any living genera."

Reference (relationships)

Taylor DW, Brenner GJ, Basha SH. 2008. Scutifolium jordanicum gen. et sp. nov. (Cabombaceae), an aquatic fossil plant from the Lower Cretaceous of Jordan, and the relationships of related leaf fossils to living genera. American Journal of Botany 95: 340–352.

†Monetianthus mirus

Calibration at a glance	stem Nymphaeaceae (Nymphaeales), min 110.8 Ma
ID number (NFos)	165

Fossil identity

Full taxon name	**†Monetianthus mirus Friis, Pedersen, von Balthazar, Grimm, Crane**
Organs	Flower
Specimens	Holotype: S122015
Locality	Near the village of Vale de Agua in western Portugal (39°37 15 N, 8°51 30 W)
Formation	Basal part (Famalicão Member) of the Figueira da Foz Formation
Country	Portugal

Reference (description)

Friis EM, Pedersen KR, von Balthazar M, Grimm GW, Crane PR. 2009. Monetianthus mirus gen. et sp. nov., a Nymphaealean Flower from the Early Cretaceous of Portugal. International Journal of Plant Sciences 170: 1086–1101.

Fossil age

Safe minimum age	**110.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	early Albian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	4 / revised (stratigraphic)

Age justification

The Vale de Agua locality has a Late Aptian to Early Albian age (e.g., Friis et al., 2011). Given this uncertainty, we consider the Early Albian to be the safe, oldest stratigraphic age for this fossil (see also Anacostia portugallica).

Reference (age)

Friis EM, Crane PR, Pedersen KR. 2011. Early flowers and angiosperm evolution. Cambridge University Press.

Fossil relationships

Node calibrated	**stem Nymphaeaceae (Nymphaeales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	4 / morphological and molecular trees compared

Node justification

Magallón et al 2015 (NewPhytol): "Monetianthus mirus represent the earliest unequivocal evidence, based on fossil floral structures and associated pollen, of fossil plants related to the earliest diverging angiosperm clades. The single specimen is coalified, structurally preserved and only slightly compressed laterally. The flower is radially symmetrical, perigynous and apparently bisexual. Several features of the fossil flower clearly indicate a close relationship with extant Nymphaeales. The arrangement of carpels around a central protrusion of the floral apex is a unique feature that is so far known only for some members of the Nymphaeaceae and for the Illiciaceae. However, flowers of Illiciaceae are hypogynous in contrast to the fossil flower, which is perygynous. Illiciaceae flowers also differ in having an 4 apocarpous gynoecium and a single ovule per carpel. The fossil is more similar to flowers of Nymphaeales, which are predominantly syncarpous, include perygynous or epigynous forms in all genera except Nuphar, and always have more ovules per carpel (Friis et al., 2001). Examination of the single specimen with Synchrotron Radiation X-Ray Tomographic Microscopy (SRXTM) provided information about placentation, ovule number and ovule size, which proved crucial to support a close relation with Nymphaeales (Friis et al., 2009). A *network analysis indicated the placement of Monetianthus being more closely related to Nymphaeaceae than to Cabombaceae (Friis et al., 2009). Monetianthus is here considered as a stem representative of Nymphaeaceae, and is used to calibrate the Nymphaeaceae stem group."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Donlesia dakotensis

Calibration at a glance	stem Ceratophyllaceae (Ceratophyllales), min 100.5 Ma
ID number (NFos)	182

Fossil identity

Full taxon name	**†Donlesia dakotensis Dilcher & Wang**
Organs	Fruits and leaves
Specimens	UF15708-5332, 5332'
Locality	Acme Brick Co. I locality, Kansas (UF15708)
Formation	Dakota Formation
Country	USA

Reference (description)

Dilcher DL, Wang H. 2009. An Early Cretaceous fruit with affinities to Ceratophyllaceae. American Journal of Botany 96: 2256–2269.

Fossil age

Safe minimum age	**100.5 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Albian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Dilcher & Wang 2009 (AmJBot): "The age of the plant-fossil-bearing sequences is Late Albian (latest Early Cretaceous) based on palynostratigraphic and sedimentological analyses (Brenner et al., 2000 ; Gr ö cke et al., 2006). Interpretations of sedimentary environments for these localities are fl oodplain lake and overbank (the Acme Brick Co. I and II locality, Kansas; UF15708 and UF18730). The interpretation of predominantly freshwater environments has been confi rmed by the presence of several other freshwater aquatic plants (Kovach and Dilcher, 1985 ; Skog and Dilcher, 1992, 1994 ; Skog et al., 1992 ; Wang and Dilcher, 2006 ; C. Mart í n- Closas (University of Barcelona) and D. Dilcher in press)."

Reference (age)

Dilcher DL, Wang H. 2009. An Early Cretaceous fruit with affinities to Ceratophyllaceae. American Journal of Botany 96: 2256–2269.

Fossil relationships

Node calibrated	**stem Ceratophyllaceae (Ceratophyllales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Dilcher & Wang 2009 (AmJBot) considered this fossil to be closer to section Ceratophyllum, but given the intuitive approach we prefer a more conservative assignment to Ceratophyllum as a whole, including stem lineage positions.

Reference (relationships)

Dilcher DL, Wang H. 2009. An Early Cretaceous fruit with affinities to Ceratophyllaceae. American Journal of Botany 96: 2256–2269.

†Montsechia vidalii

Calibration at a glance	stem Ceratophyllum (Ceratophyllaceae, Ceratophyllales), min 127.2 Ma
ID number (NFos)	358

Fossil identity

Full taxon name	**†Montsechia vidalii (Zeiller) Teixeira**
Organs	Whole plant
Specimens	LH02556, LH07198, LH 29265 [cited in Gomez et al 2015]
Locality	Pedrera quarry, Montsec chain, western Spanish Pyrenees, Lleida Province
Formation	
Country	Spain

Reference (description)

Gomez B, Daviero-Gomez V, Coiffard C, Martín-Closas C, Dilcher DL. 2015. Montsechia, an ancient aquatic angiosperm. Proceedings of the National Academy of Sciences 112: 10985–10988.

Fossil age

Safe minimum age	**127.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	lower Barremian
Age quality score	4 / revised (stratigraphic)

Age justification

Gomez et al (2015) write that "Based on the local stratigraphy and fossil charophyte and ostracod assemblages, La Pedrera and La Cabróa animal and plant fossils have been attributed to the lower Barremian (Fig. S2) (33–35)". The limits of the Barremian have changed slightly among recent GTS and we cannot use the limits of the informal boundaries provided by Ogg & Hinnov (2012). However, Fig. S2 of Gomez et al (2015) offers 130-127.2 as the range of the lower Barremian El Montsec locality, from which the oldest specimens were sampled. Therefore (until internal boundaries are further revised), we believe it is reasonably safe to use the upper limit of this range, 127.2, as a minimum age for this fossil.

Reference (age)

Gomez B, Daviero-Gomez V, Coiffard C, Martín-Closas C, Dilcher DL. 2015. Montsechia, an ancient aquatic angiosperm. Proceedings of the National Academy of Sciences 112: 10985–10988.

Fossil relationships

Node calibrated	**stem Ceratophyllum (Ceratophyllaceae, Ceratophyllales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

A molecular backbone analysis of the morphological matrix by Endress & Doyle (2009), supplemented with data for this fossil, and using the J&M backbone, reconstructed this fossil as sister to extant Ceratophyllum.

Reference (relationships)

Gomez B, Daviero-Gomez V, Coiffard C, Martín-Closas C, Dilcher DL. 2015. Montsechia, an ancient aquatic angiosperm. Proceedings of the National Academy of Sciences 112: 10985–10988.

†Canrightiopsis crassitesta

Calibration at a glance	stem Chloranthaceae (Chloranthales), min 113 Ma
ID number (NFos)	178

Fossil identity

Full taxon name	**†Canrightiopsis crassitesta Friis, Grimm, Mendes & Pedersen**
Organs	Fruit and pollen
Specimens	S174311 (sample Catefica 343) (Swedish Museum of Natural History)
Locality	Catefica
Formation	Almargem Formation
Country	Portugal

Reference (description)

Friis EM, Grimm GW, Mendes MM, Pedersen KR. 2015. Canrightiopsis, a new Early Cretaceous fossil with Clavatipollenites-type pollen bridge the gap between extinct Canrightia and extant Chloranthaceae. Grana 54: 184–212.

Fossil age

Safe minimum age	**113 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Aptian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Friis et al. (2015) mention that the age of the Almargem Formation is late Barremian-early Albian, but uncertainty remains on the actual age of the Catefica locality, from which this fossil was sampled (see discussion p. 185). Here, we follow Friis et al. (2015) in their suggestion that this locality is at least Aptian in age.

Reference (age)

Friis EM, Grimm GW, Mendes MM, Pedersen KR. 2015. Canrightiopsis, a new Early Cretaceous fossil with Clavatipollenites-type pollen bridge the gap between extinct Canrightia and extant Chloranthaceae. Grana 54: 184–212.

Fossil relationships

Node calibrated	**stem Chloranthaceae (Chloranthales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	4 / morphological and molecular trees compared

Node justification

Friis et al. (2015) analyzed the position of this fossil using a SPLITSTREE approach with the Doyle & Endress (2010) dataset, and found it to be most similar to Chloranthus and Sarcandra. Because this approach did not take into account molecular data and relies on pairwise distances, the results should be cautiously interpreted as total similarity evidence. For this reason, we conservatively assigned this fossil to the stem node of Chloranthaceae. However, we note that Doyle & Endress (2018) confirmed the position of this fossil as a stem relative of the clade of Chloranthus and Sarcandra, based on total evidence analysis (with a molecular backbone). Hence this fossil will be assigned to the crown node of Chloranthaceae in future versions of this dataset.

Reference (relationships)

Friis EM, Grimm GW, Mendes MM, Pedersen KR. 2015. Canrightiopsis, a new Early Cretaceous fossil with Clavatipollenites-type pollen bridge the gap between extinct Canrightia and extant Chloranthaceae. Grana 54: 184–212.

†*Hedyosmum-like flowers (Asteropollis plant)*

Calibration at a glance	stem Hedyosmum (Chloranthaceae, Chloranthales), min 123 Ma
ID number (NFos)	179

Fossil identity

Full taxon name	**†Hedyosmum-like flowers (Asteropollis plant)**
Organs	Flowers
Specimens	S101220, S101307 (Swedish Museum of Natural History)
Locality	Torres Vedras
Formation	Torres Vedras flora
Country	Portugal

Reference (description)

Friis EM, Pedersen KR, Crane PR. 1994. Angiosperm floral structures from the Early Cretaceous of Portugal (PK Endress and EM Friis, Eds.). Pl. Syst. Evol. Suppl. 8: 31–49.

Fossil age

Safe minimum age	**123 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Aptian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	4 / revised (stratigraphic)

Age justification

Magallón et al 2015 (NewPhytol): "The Torres Vedras locality is considered to correspond to the late Barremian to early Aptian (Heimhofer et al., 2007; Friis et al., 2011)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Hedyosmum (Chloranthaceae, Chloranthales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Phylogenetic analyses of this fossil (as "Asteropollis plant") resolved it as sister to Hedyosmum (Doyle & Endress 2014)

Reference (relationships)

Doyle JA, Endress PK. 2014. Integrating Early Cretaceous fossils into the phylogeny of living angiosperms: ANITA lines and relatives of Chloranthaceae. International Journal of Plant Sciences 175: 555–600.

†unnamed Chloranthaceae androecium

Calibration at a glance	stem Chloranthus+Sarcandra (Chloranthaceae, Chloranthales), min 100.5 Ma
ID number (NFos)	177

Fossil identity

Full taxon name	**†unnamed Chloranthaceae androecium Crane, Friis & Pedersen**
Organs	Androecium and pollen
Specimens	PP 34597 (Field Museum of Natural History)
Locality	West Brother Locality
Formation	Patapsco Formation (Potomac Group)
Country	USA

Reference (description)

Crane PR, Friis EM, Pedersen KR. 1989. Reproductive structure and function in CretaceousChloranthaceae. Plant Systematics and Evolution 165: 211–226.

Fossil age

Safe minimum age	**100.5 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Albian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Magallón et al 2015 (NewPhytol): "The West Brothers locality is assigned to the upper part of palynological subzone II-B of the Potomac Group succession, corresponding to the late Albian (Crane et al., 1989; Eklund et al., 2004, Friis et al., 2011)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Chloranthus+Sarcandra (Chloranthaceae, Chloranthales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Magallón et al 2015 (NewPhytol): "The fossil is an isolated androecium with no evidence of its attachment to the flower or inflorescence. "The androecium consists of three fleshy stamens arranged in a row and fused only at the base. The central stamen is longer than the lateral ones. Each stamen is swollen, gradually expanded distally and bears two thecae positioned opposite to each other. Each thecae is formed by two pollen sacs. The two pollen sacs on each stamen appear to be dorsiventrally arranged. Thecal deshiscence was valvate with the valves extending the full length of the thecae. Pollen grains are attached to the surface of the thecae. They are embedded in pollenkit-like material. Pollen grains were prolate, with three or more colpi arranged parallel to the polar axis of the grain. Wall structure was reticulate." (Crane et al., 1989). Crane et al. (1989) considered that this tripartite androecium is unlike any of the living genera of Chloranthaceae, but individually, each of the stamens, as well as pollen, are similar to Sarcandra. Collectively, the aggregation of stamens is similar to the three-lobed androecium of Chloranthus. A phylogenetic analysis based on morphological data placed this tripartite androecium in an unrresolved position *within a clade that also included sampled species of 7 Sarcandra (Eklund et al., 2004). On the basis of this result, we here consider this fossil to be most closely related to Sarcandra than to other living genera of Chloranthaceae, and use it to calibrate the stem node of Sarcandra." Here, we more conservatively use this fossil to constrain the stem node of the clade of Chloranthus and Sarcandra.*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Walkeripollis gabonensis

Calibration at a glance stem Winteraceae (Canellales), min 125 Ma

ID number (NFos) 5

Fossil identity

Full taxon name **†Walkeripollis gabonensis Doyle, Hotton et Ward**

Organs Pollen tetrads

Specimens Single-pollen grain preparation 2963-27 (holotype of Walkeripollis gabonensis). Doyle et al. (1990) stated that this specimen is deposited in the Elf-Aquitaine collection, but it is on loan to J.A. Doyle at the University of California, Davis. Because the company Elf-Aquitaine no longer exists, it will be deposited at the University of California (Berkeley) Museum of Paleontology (UCMP).
Additional Specimens. Sections, uncut block, and negatives, from Elf-Aquitaine preparation 2963, TM.1 (N'Toum No. 1) well, core 8, 939-944 m, Subzone C-VIIc, Gabon.

Locality upper part of Elf-Aquitaine palynological Zone C-VII (Subzone C-VIIc) in the Cocobeach sequence (Doyle et al., 1990), near the town N'Toum

Formation

Country Gabon

Reference (description)

Doyle JA, Hotton CL, Ward J V. 1990. Early Cretaceous tetrads, zonasulculate pollen, and Winteraceae. I. Taxonomy, morphology, and ultrastructure. American Journal of Botany 77: 1544–1557.

Fossil age

Safe minimum age **125 Ma**

Absolute age source stratigraphic (upper limit of oldest stratigraphic age)

Oldest stratigraphic age Barremian

Reference time scale ICS (v2017/02)

Age quality score 4 / revised (stratigraphic)

Age justification

Massoni et al 2015 (PE): "Walkeripollis gabonensis comes from the upper part of Elf-Aquitaine palynological Zone C-VII (Subzone C-VIIc) in the Cocobeach sequence (Doyle et al., 1990), near the town N'Toum in northern Gabon. The age of Zone C-VII is bracketed by late Aptian marine fossils in overlying units (Doyle et al., 1977, 1990). Doyle et al. (1977, 1982) dated Zone C-VII as early Aptian, but Doyle et al. (1990) and Doyle (1992) suggested it may be late Barremian, based on the occurrence of other taxa that appear in Zone C-VII, correlative rocks in Brazil, and better-dated Barremian rocks elsewhere, notably Afropollis and the first reticulate tricolpates (Doyle et al., 1982; Gübeli et al., 1984; Penny, 1989; Regali and Viana, 1989; Doyle, 1992). Additional evidence that favors a pre-Aptian age is the absence in Zone C-VII of two groups that appear in the overlying Zones C-VIII and C-IX and the Aptian of Egypt, namely striate tricolpates, which are not known until the Albian in Southern Laurasia but occur earlier in Northern Gondwana (Penny, 1988a; Hochuli et al., 2006; Heimhofer et al., 2007; Heimhofer and Hochuli, 2010), and the non-columellar reticulate monosulcate genus Pennipollis ("Retimonocolpites" peroreticulatus, etc.), which appears just above the base of the marine Aptian of England and has never been reported from well-dated pre-Aptian rocks (Penny, 1988b; Doyle, 1992; Hughes, 1994; Hochuli et al., 2006). We therefore believe it is safe to accept a late Barremian age for Walkeripollis gabonensis and thus propose 125.9 Ma, the upper boundary of the Barremian (126.3 ±0.4 Ma; Ogg and Hinnov, 2012), as a minimum age for this fossil."
(Absolute age of upper limit of Barremian revised according to the 2017 GTS)

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms.

Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**stem Winteraceae (Canellales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

See Massoni et al 2015 (PE). Although their original formulation of this calibration was as crown Canellales, we here formulate it as stem Winteraceae (supported by the analyses of Doyle & Endress 2000). These nodes are identical in all recent molecular phylogenies.

Reference (relationships)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

†Araripia florifera

Calibration at a glance	stem Laurales, min 113 Ma
ID number (NFos)	172

Fossil identity

Full taxon name	**†Araripia florifera Mohr & Eklund**
Organs	Twig, floral structures and leaves
Specimens	Holotype: part (slab A : MB.PB. 99/ 628) and counterpart (slab B: SMB 16.629) (Museum of Natural History, Institute of Palaeontology, Berlin, Germany)
Locality	South of Nova Olinda, Araripe Basin
Formation	Crato Formation
Country	Brazil

Reference (description)

Mohr BAR, Eklund H. 2003. Araripia florifera, a magnoliid angiosperm from the Lower Cretaceous Crato Formation (Brazil). Review of Palaeobotany and Palynology 126: 279–292.

Fossil age

Safe minimum age	**113 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Aptian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Massoni et al 2015 (PE) on +Endressinia brasiliana: "The fossil considered here was collected from the Crato Formation in the Araripe sedimentary basin of northeastern Brazil (Mohr et al., 2013). Mohr and Bernardes-de-Oliveira (2004) assumed that the Crato Formation is late Aptian or early Albian in age, based on numerous previous estimates (e.g., Pons et al., 1996). Because of this uncertainty, Clarke et al. (2011) proposed a minimum age for the Crato of 98.7 Ma, the top of the Albian. However, evidence has been accumulating in favor of a late Aptian age (Coimbra et al., 2002). Most recently, using gymnosperm pollen and dinoflagellates to correlate with better-dated sections, Heimhofer and Hochuli (2010) concluded that the Aptian-Albian boundary lies above the Crato Formation, and this was accepted by Mohr et al. (2013). We therefore propose a minimum age of 112.6 Ma for Endressinia, the Aptian-Albian boundary (113 ±0.4 Ma; Ogg and Hinnov, 2012)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**stem Laurales**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Mohr & Eklund 2003 (RevPalPal): "In floral and leaf characters the fossil shows similarities to some extant members of the Laurales. However, the character combination observed for the fossil is not found in any extant taxon, and the fossil may represent an extinct lineage within or close to the Laurales."

Reference (relationships)

Mohr BAR, Eklund H. 2003. Araripia florifera, a magnoliid angiosperm from the Lower Cretaceous Crato Formation (Brazil). Review of Palaeobotany and Palynology 126: 279–292.

†*Cohongarootonia hispida*

Calibration at a glance	crown core Laurales, min 107.7 Ma
ID number (NFos)	116

Fossil identity

Full taxon name	**†Cohongarootonia hispida Balthazar et al.**
Organs	Flower
Specimens	PP53716 in the Field Museum of Natural History, Chicago (holotype, flower)
Locality	Puddledock locality, Tarmac Lone Star Industries sand and gravel pit, located south of Richmond and east of Appomattox River in Prince George County, Virginia
Formation	Patapsco Formation, Potomac Group
Country	USA

Reference (description)

von Balthazar M, Crane PR, Pedersen KR, Friis EM. 2011. New flowers of Laurales from the Early Cretaceous (Early to Middle Albian) of eastern North America. In: Wanntorp L, Ronse De Craene LP, eds. Flowers on the Tree of Life. Cambridge, UK: Cambridge University Press, 49–87.

Fossil age

Safe minimum age	**107.7 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	middle Albian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	4 / revised (stratigraphic)

Age justification

Massoni et al 2015 (PE): "Cohongarootonia was collected from the Potomac Group at the same Puddledock locality, 9 km southwest of Hopewell, Virginia, as Virginianthus calycanthoides (Fossil 4). As discussed for that species, this locality has been correlated palynologically by R.A. Christopher (in Dischinger, 1987) with the lower part of Subzone II-B of Brenner (1963), which we argue is of middle Albian age. Therefore, we use the middle-late Albian boundary, 107.7 Ma (no uncertainty provided; Ogg and Hinnov, 2012), as a minimum age for Cohongarootonia."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**crown core Laurales**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Massoni et al 2015 (PE): "A molecular scaffold analysis by von Balthazar et al. (2011), using the morphological data set from Doyle and Endress (2010) and one of the same backbone trees, in which Lauraceae and Hernandiaceae form a clade sister to Monimiaceae, placed Cohongarootonia hispida in a single most parsimonious position as the sister group of Lauraceae + Hernandiaceae. Synapomorphies of the three taxa were whorled tepals, whorled stamens, and one carpel. As a result, von Balthazar et al. (2011) unequivocally assigned the fossil to the order Laurales. However, although all recent analyses agree that Lauraceae, Hernandiaceae, and Monimiaceae form a well-supported clade within Laurales, the relationships among these three families are still debated. In analyses by

Doyle and Endress (2000), a sister group relationship of Lauraceae and Hernandiaceae was strongly supported by morphological data and by combined morphological and molecular data, but analyses of molecular data alone have linked either Monimiaceae and Lauraceae or Monimiaceae and Hernandiaceae (Qiu et al., 1999, 2000, 2005, 2006, 2010; Renner, 1999; Doyle and Endress, 2000; Savolainen et al., 2000; Renner and Chanderbali, 2000; Hilu et al., 2003; Zanis et al., 2003; Soltis et al., 2011; Massoni et al., 2014). Until this conflict is resolved, we consider that Cohongarootonia hispida provides a minimum age for the stem node of the clade including Lauraceae, Monimiaceae, and Hernandiaceae, in other words the crown node of the clade of Laurales excluding Calycanthaceae (Figure 1)."

Reference (relationships)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

†Lovellea wintonensis

Calibration at a glance	crown Laurales, min 100.5 Ma
ID number (NFos)	114

Fossil identity

Full taxon name	**†Lovellea wintonensis Dettmann, Clifford, and Peters**
Organs	Flowers/fruits
Specimens	QMF51133 in the Palaeontological Collection of the Queensland Museum, Queensland, Australia (Holotype, originally a complete specimen, now consisting of portions of a permineralized (silicified) flower/fruit in rock matrix cut longitudinally into two slices and two thin sections: QMF51133 a-d). Additional Specimens. QMF51134, QMF51135, QMF51132. Other specimens used for the description (flowers/fruits).
Locality	48 km WNW of Winton, western Queensland
Formation	Winton Formation
Country	Australia

Reference (description)

Dettmann ME, Clifford HT, Peters M. 2009. Lovellea wintonensis gen. et sp. nov.- Early Cretaceous (late Albian), anatomically preserved, angiospermous flowers and fruits from the Winton Formation, western Queensland, Australia. Cretaceous Research 30: 339-355.

Fossil age

Safe minimum age	**100.5 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Albian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Massoni et al 2015 (PE): "Lovellea wintonensis comes from the basal part of the the Winton Formation, 48 km WNW of Winton, western Queensland, Australia (Dettmann et al., 2009). Dettmann et al. (2009) placed the sediments containing these fossils in the Coptospora paradoxa or Phimopollenites pannosus spore-pollen Zones of Helby et al. (1987) based on the co-occurrence of Cicatricosisporites, Crybelosporites, Clavatipollenites, and Phimopollenites, indicating that they are no older than middle Albian. Because the Winton Formation overlies the late Albian Mackunda Formation but no palynomorph taxa indicative of a Cenomanian or younger age are present, Dettmann et al. (2009) suggested a latest Albian age. Here we accept this age for Lovellea wintonensis and therefore use the upper boundary of the Albian, 100.1 Ma (100.5 ±0.4 Ma; Ogg and Hinnov, 2012), as a safe minimum age for this fossil."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**crown Laurales**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

A morphological parsimony analysis using the matrix of Doyle and Endress (2000), with the exclusion of several taxa (eudicots, Piperales, Nymphaeales, monocots, Austrobaileya, Schisandraceae, and Illicium), placed Lovellea wintonensis in one most parsimonious position sister to all Laurales excluding Calycanthaceae (Dettmann et al., 2009). This "core Laurales" clade was well supported in previous studies (Soltis et al., 1999, 2000a, 2000b, 2007, 2011; Qiu et al., 1999, 2000, 2005, 2006, 2010; Renner, 1999, 2004; Doyle and Endress, 2000; Savolainen et al., 2000; Zanis et al., 2002, 2003; Nickrent et al., 2002; Hilu et al., 2003). Relationships within the clade based on the morphological analysis were not identical to those found in molecular or combined morphological and molecular analyses (Doyle and Endress, 2000), but they are consistent in supporting the monophyly of the Hernandiaceae-Lauraceae-Monimiaceae clade (though with the addition of Siparunaceae) and the position of Atherospermataceae and Gomortegaceae as outgroups to this clade (though as two successive branches rather than a clade). We consider Lovellea wintonensis to provide a minimum age for crown-group Laurales, or the stem node of all Laurales except Calycanthaceae (Figure 1).

Reference (relationships)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

†Mauldinia mirabilis

Calibration at a glance: crown core Laurales, min 95.5 Ma
ID number (NFos): 117

Fossil identity

Full taxon name: **†Mauldinia mirabilis Drinnan et al.**
Organs: Inflorescence
Specimens: PP35297 in Field Museum of Natural History, Chicago, USA (holotype of Mauldinia mirabilis; inflorescence).
Additional Specimens. PP34733, PP34794, PP34796, PP34797, PP35002-PP35006, PP35008, PP35056, PP35061, PP35141, PP35295-PP35305, PP35338-PP35340. Other specimens of Mauldinia mirabilis cited in Drinnan et al. (1990) (inflorescence fragments with flowers).
PP34709-PP34715, PP34728-PP34732, PP34779, PP34780, PP34926, PP34927, PP34929, PP35007, PP35016-PP35019, PP35051-PP35055, PP35057-PP35060, PP35140, PP35150, PP35151, PP35306-PP35309, PP35315-PP35319. Other specimens of Mauldinia mirabilis cited in Drinnan et al. (1990) (flowers).
P34903-PP34925, PP35009, PP35050, PP35144. Other specimens of Mauldinia mirabilis cited in Drinnan et al. (1990) (dispersed stamens).
PP34781-PP34783, PP34795, PP34928, PP34930, PP34931, PP35010-PP35012, PP35142, PP35143. Other specimens of Mauldinia mirabilis cited in Drinnan et al. (1990) (dispersed carpels).
PP34932, PP34933, PP35024, PP35025, PP35026, PP42982, PP42983. Other specimens of Mauldinia mirabilis cited in Drinnan et al. (1990) (cuticle preparations).
PP42981. Other specimens of Mauldinia mirabilis cited in Drinnan et al. (1990) (unsorted fragments).
PP35023 (holotype of Paraphyllanthoxylon marylandense Herendeen, 1991; mature wood).
PP43591, PP43592, PP43617, PP43619, PP43620, PP43621, PP43622, PP43624, PP43625, PP43627, PP43629, PP43630, PP43631, PP43632, PP43636. Paratypes of Paraphyllanthoxylon marylandense Herendeen, 1991 (mature wood).
Locality: Mauldin Mountain locality in the upper Potomac Group (“Maryland Raritan”) of northeastern Maryland
Formation: Upper Potomac Group
Country: USA

Reference (description)

Drinnan AN, Crane PR, Friis EM, Pedersen KR. 1990. Lauraceous flowers from the Potomac Group (mid-Cretaceous) of Eastern North America. Botanical Gazette 151: 370–384.

Fossil age

Safe minimum age: **95.5 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Middle Cenomanian
Reference time scale: Ogg & Hinnov (2012)
Age quality score: 4 / revised (stratigraphic)

Age justification

Massoni et al 2015 (PE): "Mauldinia mirabilis and Paraphyllanthoxylon marylandense were described from the Mauldin Mountain locality in the upper Potomac Group (“Maryland Raritan”) of northeastern Maryland, USA

(Drinnan et al., 1990; Herendeen, 1991). These beds contain a palynoflora assigned to the lower part of Zone III of the Potomac sequence, which Doyle and Robbins (1977) dated as early Cenomanian. The age of Zone III is bracketed above by the appearance of triporate Normapolles pollen (Complexiopollis spp.) in the lower Raritan Formation of New Jersey (Zone IV) and the upper part of the Peruc Formation of Bohemia (Pacltová, 1971; Doyle and Robbins, 1977), and by late Cenomanian ammonites in the lower Raritan (Cobban and Kennedy, 1990). The Peruc Formation underlies marine sediments with late Cenomanian mollusks, and its upper part was correlated palynologically by Pacltová (1977) with late middle Cenomanian marine beds that contain the first Normapolles in England and France (Azéma et al., 1972; Laing, 1975); this agrees with studies of sequence stratigraphy in the Bohemian section by Uličný et al. (1997). The probable latest Albian age of Potomac Subzone II-C is discussed under Virginanthus. Because these data imply that the Zone III-IV boundary may lie within the middle Cenomanian, and the length of time between the base and top of Zone III is uncertain, it appears safest to conclude that Mauldinia could be of either early or middle Cenomanian age. Therefore, we propose the middle-late Cenomanian boundary, 95.5 Ma (no uncertainty provided; Ogg and Hinnov, 2012), as a conservative minimum age for Mauldinia."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**crown core Laurales**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Massoni et al 2015 (PE): "Because of identical features in the first formed wood of Paraphyllanthoxylon marylandense (Herendeen, 1991) and inflorescence axes of Mauldinia mirabilis (Drinnan et al., 1990), Doyle and Endress (2010) combined these two taxa in their analyses. Their molecular scaffold analysis, which used a backbone tree in which Lauraceae and Hernandiaceae formed a clade sister to Monimiaceae, placed this fossil in a single most parsimonious position, as the sister group of Lauraceae + Hernandiaceae. The three taxa were united by the following unequivocal synapomorphies: solitary vessels, inflorescences with lateral cymes, whorled tepals, whorled stamens, and one carpel. The basal position of Mauldinia relative to the two living taxa was supported by the absence of well-developed paratracheal parenchyma in the wood, the superior position of the ovary, and the presence of endosperm in the seed, while Lauraceae and Hernandiaceae are united by paratracheal parenchyma, an inferior ovary (reversed within Lauraceae: Rohwer and Rudolph, 2005), and lack of endosperm in the mature seed. A position sister to Lauraceae alone was four steps less parsimonious. However, as discussed for Cohongarootonia (Fossil 7), Lauraceae and Hernandiaceae are included together with Monimiaceae in a well-supported clade, but different analyses have found all possible relationships among the three families. When Doyle and Endress (2010) used a molecular backbone in which Monimiaceae were sister to Lauraceae, the single most parsimonious position of Mauldinia was sister to the whole clade of Hernandiaceae + Lauraceae + Monimiaceae. Doyle and Endress (2010) did not test the third alternative present in the literature (Lauraceae sister to the remaining two families), but using their data set we find that the most parsimonious position for Mauldinia under this arrangement is also sister to the three living taxa. Until this conflict is resolved, we consider Mauldinia mirabilis to provide a minimum age for the stem node of the clade of Lauraceae, Hernandiaceae, and Monimiaceae, in other words the crown node of the clade of Laurales excluding Calycanthaceae (Figure 1)."

Reference (relationships)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

†Virginianthus calycanthoides

Calibration at a glance	crown Laurales, min 107.7 Ma
ID number (NFos)	113

Fossil identity

Full taxon name	**†Virginianthus calycanthoides Friis, Eklund, Pedersen, Crane**
Organs	Flower with in situ pollen
Specimens	PP43703 in Field Museum of Natural History, Chicago (holotype; flower)
Locality	Potomac Group at the Puddledock locality in the Tarmac Lone Star Industries sand and gravel pit 9 km southwest of Hopewell, Prince George County, Virginia
Formation	Potomac Group
Country	USA

Reference (description)

Friis EM, Eklund H, Pedersen KR, Crane PR. 1994. Virginianthus calycanthoides gen. et sp. nov.-A Calycanthaceous Flower from the Potomac Group (Early Cretaceous) of Eastern North America. International Journal of Plant Sciences 155: 772–785.

Fossil age

Safe minimum age	**107.7 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	middle Albian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	4 / revised (stratigraphic)

Age justification

Massoni et al 2015 (PE): "The fossil flower described by Friis et al. (1994) comes from the Potomac Group at the Puddledock locality in the Tarmac Lone Star Industries sand and gravel pit 9 km southwest of Hopewell, Prince George County, Virginia, USA. Friis et al. (1994, 1995) and von Balthazar et al. (2011) considered this locality early or middle Albian, based on palynological correlation by R.A. Christopher (in Dischinger, 1987) with the basal part of Potomac Subzone II-B of Brenner (1963) and Doyle and Robbins (1977) and the suggestion of Doyle (1992) that Subzone II-B may begin in the early Albian. However, an early Albian age for Subzone II-B (and II-A) now appears unlikely in light of palynological correlations by Hochuli et al. (2006) with the well-dated marine Lower Cretaceous of Portugal and earlier work of Kemp (1970) on the marine Albian of England (cf. Doyle et al., 2008). These studies support correlation of upper Zone I with the basal early Albian of Portugal and the early Albian of England, based on the appearance in all these intervals of reticulate tricolpate pollen and Clavatipollenites rotundus (aff. Retimonocolpites dividuus of Doyle and Robbins, 1977), as argued by Doyle and Robbins (1977), but not striate tricolpates, which appear later in the early Albian of Portugal (Hochuli et al., 2006). Consistent with this, the Zone II index spore species Apiculatisporis babsae of Brenner (1963) appears at the base of the middle Albian in England (Kemp, 1970). The conclusion of Doyle (1992) that the Zone I/II boundary lies well down in the Aptian was based largely on comparisons with Pennipollis (Brenneripollis) species and Schrankipollis in Africa that appear to have involved too indirect correlations and incompletely controlled species ranges, as argued by Hochuli et al. (2006). Clarke et al. (2011) proposed a much younger minimum age for Puddledock, 92.7 Ma, or the top of the Cenomanian, based on the suggestion of Hochuli et al. (2006) that Zone II extends into the Cenomanian and the presence of late Cenomanian ammonites in the next younger unit, the Raritan Formation of New Jersey (Cobban and Kennedy, 1990). Hochuli et al. (2006) argued convincingly that there is a significant break between Zones I and II in the Potomac sequence, since the early to middle Albian interval in Portugal shows continuing higher diversity of angiosperm monosulcates than tricolpates, whereas tricolpates are already more diverse at the base of Zone II. They argued that Subzone II-B is late rather than middle Albian, based on the higher diversity of tricolpates than in the Portuguese middle Albian and the presence through Subzone II-B of the smooth tricolpate species Cupuliferoidaepollenites

(Tricolpopollenites) parvulus, which they noted has not been reported in dated sequences until the late Albian. However, the reliability of C. parvulus is uncertain, since this species is rare in Subzone II-B and easy to overlook (for example, it was not reported by Brenner, 1963). Furthermore, its first occurrences cited by Hochuli et al. (2006) are in Canada, in the Northern Laurasia province of Brenner (1976), where angiosperms were less abundant than in Southern Laurasia, and in deep sea cores. It is also possible that the higher diversity of angiosperms observed in the Potomac is partly a facies effect of comparing continental and marginal marine sequences. If angiosperms were locally dominant in some lowland habitats but subordinate to ferns and gymnosperms at the regional scale (cf. Pierce, 1961; Doyle and Hickey, 1976), more angiosperms (including rare species) might be detected in a fluvial sequence such as the Potomac Group than in marine deposits like those in Portugal, where they would be diluted by the higher regional production of fern spores and gymnosperm pollen. It is also likely that the contrast between diversity curves from the two sequences is exaggerated by the fact that the Portuguese curves were based on number of species per sample, whereas the Potomac curves were based on a range chart (Doyle and Robbins, 1977), so that species whose ranges pass through the horizon of a given sample but were not found in that sample were treated as present.

More positive evidence that much of Subzone II-B is middle Albian comes from palynological correlations with well-dated sequences in the US Gulf Coast and Western Interior, which were not considered by Hochuli et al. (2006). Doyle (1977) showed that the diverse angiosperm flora in the middle of Subzone II-B is especially similar at the species level to that described by Hedlund and Norris (1968) in the "Walnut" Clay and Antlers Sand (Fredericksburgian) of Oklahoma, which lies below the middle-late Albian boundary defined by ammonites in the overlying Goodland Limestone (Hedlund and Norris, 1968; Mancini and Puckett, 2005). Doyle and Robbins (1977) dated Subzone II-C as latest Albian, but Hochuli et al. (2006) argued that it is Cenomanian, based on the psilate tricolporate species Tricolporoidites (Tricolporopollenites) distinctus and Tricolporoidites (Tricolporopollenites) triangulus, which they stated first appear in the Cenomanian. However, most of the studies that Hochuli et al. (2006) cited considered only Cenomanian beds, not the latest Albian. More important, Ludvigson et al. (2010) listed psilate tricolporates (as Psilatricolporites sp.) in the latest Albian (Palynostratigraphic Unit 2) of the Dakota Formation (see discussion of Archaeanthus, Fossil 3), and Laing (1975) recorded triangular grains similar to T. triangulus as Psilatricolpites rectilatibus in the marine upper Albian of France (Laing distinguished P. rectilatibus from T. triangulus on lack of pores, but the bent shape of the colpi in the Cenomanian grain illustrated in his plate 90, figures 11-12 suggests that rudimentary pores were present). Together, these correlations lead us to consider that Virginianthus is of middle Albian age. Therefore, we use the middle-late Albian boundary, 107.7 Ma (no uncertainty provided; Ogg and Hinnov, 2012), as a minimum age for Virginianthus."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**crown Laurales**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Friis et al. (1994) assigned Virginianthus calycanthoides to the stem lineage of Calycanthaceae because it resembles extant Calycanthaceae (including Idiospermum) but is more plesiomorphic in characters such as monosulcate rather than disulculate pollen. This assignment was questioned by Crepet et al. (2005) based on a combined (total evidence) analysis of a data set of Renner (1999), which included 15 morphological characters, sequences of six molecular markers, 25 taxa of Laurales, and three outgroups. This analysis identified Virginianthus as the sister group of either Laurales as a whole or all Laurales other than Calycanthaceae. A molecular scaffold analysis by Doyle et al. (2008), incorporating 65 morphological characters and using the same backbone trees as Doyle and Endress (2010), found two alternative most parsimonious positions for this fossil, one sister to Calycanthaceae, the other sister to the clade formed by all remaining Laurales. The first position was supported by extended anther connective and the second by embedded pollen sacs. Positions sister to Laurales as a whole and nested within Calycanthaceae were one step less parsimonious. Here we follow the result of Doyle et al. (2008) because it is based on a data set that included far more characters than Crepet et al. (2005), many derived from in-depth analyses of gynoecial morphology (e.g., Igersheim and Endress, 1997). Both most parsimonious positions imply that Virginianthus provides *a minimum age for the crown node of Laurales (Figure 1).*

Reference (relationships)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

†*Jerseyanthus calycanthoides*

Calibration at a glance	crown Calycanthoideae (Calycanthaceae, Laurales), min 86.3 Ma
ID number (NFos)	115

Fossil identity

Full taxon name	**†Jerseyanthus calycanthoides Crepet, Nixon et Gandolfo**
Organs	Flower
Specimens	CUPC 1483 in the Paleobotany Collection of the L.H. Bailey Hortorium, Cornell University (holotype / flower). Additional Specimens. CUPC 1484-1502. Paratypes (flowers).
Locality	Old Crossman clay pit in Sayreville, New Jersey
Formation	Raritan Formation (South Amboy Fire Clay Member)
Country	USA

Reference (description)

Crepet WL, Nixon KC, Gandolfo MA. 2005. An extinct calycanthoid taxon, Jerseyanthus calycanthoides , from the Late Cretaceous of New Jersey. American Journal of Botany 92: 1475–1485.

Fossil age

Safe minimum age	**86.3 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Coniacian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Massoni et al 2015 (PE): "These fossils were collected from the South Amboy Fire Clay Member of the Raritan Formation at the Old Crossman clay pit in Sayreville, New Jersey, USA (Crepet et al., 2005). This unit was first studied palynologically by Groot et al. (1961), who considered it Turonian based on preliminary studies on European sequences, and subsequently by Doyle (1969b), Wolfe and Pakiser (1971), Doyle and Robbins (1977), and Christopher (1979). Building on the palynological zonation of the Potomac Group by Brenner (1963), to which Doyle (1969a) added Zone III (uppermost Potomac) and Zone IV (lower Raritan), Sirkin (1974) assigned South Amboy palynofloras to a new Zone V. This unit was renamed the Complexiopollis exigua - Santalacites minor Zone by Christopher (1979) and redefined by Christopher et al. (1999) as the lowest of three subzones of the Sohlipollis Taxon Range Zone. Wolfe and Pakiser (1971) and Sirkin (1974) considered the South Amboy late Cenomanian, not much younger than underlying Woodbridge Clay Member (Zone IV), but Doyle (1969b) and Doyle and Robbins (1977) argued that it is no older than middle Turonian, based on the presence of Normapolles genera that appear at that level in Europe (Góczán et al., 1967). Doyle and Robbins (1977) and Christopher (1979) allowed that it was "possibly Coniacian," but Crepet and Nixon (1994) and Crepet et al. (2005) accepted a late Turonian age. By contrast, Clarke et al. (2011) suggested a minimum age of the Santonian-Campanian boundary, 82.8 Ma. However, correlations by Christopher et al. (1999) and Christopher and Prowell (2010) with better-dated rocks in South Carolina imply that the Crossman locality is not this young; they correlate the C. exigua - S. minor Zone with calcareous nannofossil zones CC13 and CC14, which extend from late Turonian through Coniacian (Burnett, 1998; Ogg and Hinnov, 2012). We therefore believe there is enough evidence to consider that Jerseyanthus was at least of Coniacian age, which translates into a conservative minimum age of 85.8 Ma, the Coniacian-Santonian boundary (86.3 ±0.5 Ma; Ogg and Hinnov, 2012)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated **crown Calycanthoideae (Calycanthaceae, Laurales)**

Node assignment score 5 / phylogenetic analysis

Reconciliation score 5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Massoni et al 2015 (PE): "Using the combined morphological and molecular data set described for Virginianthus (Fossil 4), in which Calycanthaceae were represented by Idiospermum, Chimonanthus, and Calycanthus, Crepet et al. (2005) found one most parsimonious position for Jerseyanthus calycanthoides, as the sister group of Calycanthus. Addition of the fossil Virginianthus calycanthoides did not influence the position of Jerseyanthus. The relationships among the three extant genera of Calycanthaceae are well supported in the literature, with Idiospermum sister to Chimonanthus and Calycanthus (Renner, 1998, 1999; Zhou et al., 2006; Massoni et al., 2014). Jerseyanthus calycanthoides therefore provides a minimum age for crown-group Calycanthoideae, the clade that is sister to Idiospermum and contains Chimonanthus and Calycanthus (Figure 1)."

Reference (relationships)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

†Illigera eocenica

Calibration at a glance	crown Hernandiaceae (Laurales), min 41.2 Ma
ID number (NFos)	168

Fossil identity

Full taxon name	**†Illigera eocenica Manchester & Oleary**
Organs	Winged fruit
Specimens	Holotype. UF262-17682
Locality	White Cliffs, Jefferson County, Oregon
Formation	Clarno Formation
Country	USA

Reference (description)

Manchester SR, O'Leary EL. 2010. Phylogenetic distribution and identification of fin-winged fruits. Botanical Review 76: 1–82.

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Dillhoff et al 2009 (GSAFieldGuide) confirm an age of 44.23-44.5 Ma for the White Cliffs locality (e.g., "While some of these assemblages are well-dated, including the Clarno Nut Beds at 43.8 Ma (Retallack et al., 2000) and White Cliffs at 44.23 Ma (Manchester, 1990)"). Here, we conservatively used the equivalent stratigraphic age (but this will be revised in future versions of this dataset).

Reference (age)

Dillhoff RM, Dillhoff TA, Dunn RE, Myers JA, Strömberg CAE. 2009. Cenozoic paleobotany of the John Day Basin, central Oregon. Geological Society of America Field Guide 15: 135–164.

Fossil relationships

Node calibrated	**crown Hernandiaceae (Laurales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Manchester & Oleary 2010 (BotRev): "This species conforms to extant Illigera in general outline, the sinuous wing venation with intervening fine fabric of isodiametric polygonal areoles, the fusiform outline of the locular area, and the median ridge in the plane of bisymmetry. Illigera fruits develop from inferior ovaries, as is also inferred for the fossil. In addition, Illigera fruits can develop one or two small wings in addition to the two main ones, as has been demonstrated to occur in the fossil species as well (compare small median wing of Fig. 10f, with that exposed in the specimen of Fig. 22d)."

Reference (relationships)

Manchester SR, O'Leary EL. 2010. Phylogenetic distribution and identification of fin-winged fruits. Botanical Review 76: 1–82.

†*Cinnamomum sezannense*

Calibration at a glance	stem Lauraceae (Laurales), min 56 Ma
ID number (NFos)	169

Fossil identity

Full taxon name	**†Cinnamomum sezannense Watelet**
Organs	Leaf
Specimens	Pl. 66, fig. 2 in Brown (1962) [specimen number not provided here, nor in original description of French material]
Locality	4571: Sec. 36, T. 6 N., R. 26 E., southeast of Roundup, Montana
Formation	Fort Union Formation
Country	USA

Reference (first description)

Watelet A. 1866. Descriptions des plantes fossiles du bassin de Paris. Paris: J.B. Bailliere and Sons.

Reference (latest description)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Brown 1962 (GSPP) provided a very detailed review of the topic, summarizing: "In particular, the Fort Union of the northern areas, having been the subject of so much dispute and because the type section is not typical, has been redefined as follows and is thus virtually synonymous with Paleocene series in that region: The Fort Union formation in eastern Montana, western North and South Dakota, and eastern Wyoming is typified by the sequence of lignitic strata exposed in the right bank of the Yellowstone River from the top of the Cretaceous dinosaur-bearing Hell Creek formation [...]"

Reference (age)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

Fossil relationships

Node calibrated	**stem Lauraceae (Laurales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Brown 1962 (GSPP) tentatively accepted this taxon as part of Lauraceae: "Reference of these leaves to Oinnamomum is more than conjectural, for it is now known definitely that one or more species of cinnamon were present during the Cretaceous and Tertiary of the southern and western United States." Because of the doubts expressed on the relationship to extant Cinnamomum, we conservatively assign this fossil to the stem node of Lauraceae.

Reference (relationships)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

†Potomacanthus lobatus

Calibration at a glance	stem Lauraceae (Laurales), min 107.7 Ma
ID number (NFos)	11

Fossil identity

Full taxon name	**†Potomacanthus lobatus von Balthazar, Pedersen, Crane, Stampanoni, Friis**
Organs	Fragmentary trimerous flowers
Specimens	Holotype: PP44882
Locality	Puddledock locality, Tarmac Lone Star Industries sand and gravel pit, located south of Richmond and east of the Appomattox River in Prince George County, Virginia
Formation	
Country	USA

Reference (description)

von Balthazar M, Pedersen KR, Crane PR, Stampanoni M, Friis EM 2007 Potomacanthus lobatus gen. Et sp. Nov., a new flower of probable Lauraceae from the Early Cretaceous (Early to Middle Albian) of eastern North America. American Journal of Botany 94: 2041-2053.

Fossil age

Safe minimum age	**107.7 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	middle Albian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	4 / revised (stratigraphic)

Age justification

See Massoni et al 2015 (PE) on +Cohongarootonia hispida: "Cohongarootonia was collected from the Potomac Group at the same Puddledock locality, 9 km southwest of Hopewell, Virginia, as Virginianthus calycanthoides (Fossil 4). As discussed for that species, this locality has been correlated palynologically by R.A. Christopher (in Dischinger, 1987) with the lower part of Subzone II-B of Brenner (1963), which we argue is of middle Albian age. Therefore, we use the middle-late Albian boundary, 107.7 Ma (no uncertainty provided; Ogg and Hinnov, 2012), as a minimum age for Cohongarootonia."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**stem Lauraceae (Laurales)**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Potomacanthus lobatus is “characterized by a perianth comprising two whorls of three tepals each, an androecium consisting of two whorls of three stamens each, the bisporangiate stamens have valvate dehiscence, a gynoecium formed by a single carpel that is plicate in the style but ascidiate in the ovary, and a single pendent ovule" (von Balthazar et al., 2007). von Balthazar et al. (2007) considered that, among extant angiosperms, this combination of flower characters is only present in representatives of Lauraceae that have two of the normally three or four stamen whorls remaining. Potomacanthus lobatus, together with other material *described previously from the Puddledock locality (Crane et al., 1994), shows that variation in the form of the androecium was also a feature of early members of the lauraceous clade. Both tetrasporangiate and bisporangiate stamens, as well as androecia with and without staminal appendages were already present by the end of the Early Cretaceous. Among extant taxa where androecial structure can be considered along with vegetative and other features, its androecial variation is useful systematically. The reconstructions of androecial characters states among extant representatives show that ancestral androecia are composed of three whorls and possess staminodes. It is of interest that Potomacanthus differs from all other extant or fossil Lauraceae in the details of the androecium. It most likely represents a separate and now extinct taxon within the family Lauraceae or on the stem lineage to the extant group (von Balthazar et al., 2007). Based on the distribution of morphological characters discussed by von Balthazar et al. (2007), we consider Pothomacanthus lobatus as a stem or crown group member of Lauraceae, and is here used conservatively to calibrate the Lauraceae stem node."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Monimiophyllum callidentatum

Calibration at a glance	crown Monimiaceae (Laurales), min 52.22 Ma
ID number (NFos)	171

Fossil identity

Full taxon name	**†Monimiophyllum callidentatum C.L. Knight**
Organs	Leaves
Specimens	Holotype: MPEF-Pb 5630
Locality	Laguna del Hunco, Tufolitas Laguna del Hunco, Chubut Province, Patagonia
Formation	
Country	Argentina

Reference (description)

Knight C, Wilf P. 2013. Rare leaf fossils of Monimiaceae and Atherospermataceae (Laurales) from Eocene Patagonian rainforests and their biogeographic significance. Palaeontologia Electronica 16: 26A.

Fossil age

Safe minimum age	**52.22 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Knight & Wilf 2013 (PE): "40Ar-39Ar analyses of single sanidine crystals from primary ashfall tuffs, stratigraphically associated directly with the most densely fossiliferous horizons, produced the most reliable ages for the floras (LH: 52.22 ± 0.22 Ma; RP: 47.74 ± 0.05 Ma; Wilf et al., 2003, 2005; Wilf, 2012)."

Reference (age)

Knight C, Wilf P. 2013. Rare leaf fossils of Monimiaceae and Atherospermataceae (Laurales) from Eocene Patagonian rainforests and their biogeographic significance. Palaeontologia Electronica 16: 26A.

Fossil relationships

Node calibrated	**crown Monimiaceae (Laurales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Knight & Wilf 2013 (PE): "Leaf morphological characters show that M. callidentatum most closely resembles the living, derived Australian species Wilkiea hugeliana and, secondarily, the closely related New Guinea species Kairoa suberosa (Table 5; Figure 8). The fossil is thus the only one known that may be closely related to Wilkiea. The similarity of M. callidentatum to W. hugeliana is further supported by the fact that the fossil matches most species in the Wilkiea clade, but not other clades, for the following characters: ratio of midvein width to secondary vein width, (high) acuteness of basal secondary veins, number of tooth orders (1), and tooth occurrence in the basal quarter of the blade (Figure 3)."

Reference (relationships)

Knight C, Wilf P. 2013. Rare leaf fossils of Monimiaceae and Atherospermataceae (Laurales) from Eocene Patagonian rainforests and their biogeographic significance. Palaeontologia Electronica 16: 26A.

†Endressinia brasiliana

Calibration at a glance	crown Magnoliineae, min 113 Ma
ID number (NFos)	10

Fossil identity

Full taxon name	**†Endressinia brasiliana Mohr & Bernardes-de-Oliveira**
Organs	Branching axis with attached leaves and flowers
Specimens	MB. PB. 2001/1455 in Museum of Natural History, Institute of Paleontology, Berlin, Germany (holotype; branching axis with attached leaves and flowers).
Locality	Araripe sedimentary basin of northeastern Brazil (Mohr et al., 2013)
Formation	Crato Formation
Country	Brazil

Reference (description)

Mohr BAR, Bernardes-de-Oliveira MEC. 2004. Endressinia brasiliana, a magnolialean angiosperm from the Lower Cretaceous Crato Formation (Brazil). International Journal of Plant Sciences 165: 1121–1133.

Fossil age

Safe minimum age	**113 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Aptian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Massoni et al 2015 (PE): "The fossil considered here was collected from the Crato Formation in the Araripe sedimentary basin of northeastern Brazil (Mohr et al., 2013). Mohr and Bernardes-de-Oliveira (2004) assumed that the Crato Formation is late Aptian or early Albian in age, based on numerous previous estimates (e.g., Pons et al., 1996). Because of this uncertainty, Clarke et al. (2011) proposed a minimum age for the Crato of 98.7 Ma, the top of the Albian. However, evidence has been accumulating in favor of a late Aptian age (Coimbra et al., 2002). Most recently, using gymnosperm pollen and dinoflagellates to correlate with better-dated sections, Heimhofer and Hochuli (2010) concluded that the Aptian-Albian boundary lies above the Crato Formation, and this was accepted by Mohr et al. (2013). We therefore propose a minimum age of 112.6 Ma for Endressinia, the Aptian-Albian boundary (113 ±0.4 Ma; Ogg and Hinnov, 2012)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**crown Magnoliineae**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Massoni et al 2015 (PE): "A molecular scaffold analysis by Doyle and Endress (2010), including 64 extant taxa sampled across angiosperms and 142 morphological characters, placed Endressinia in seven different most parsimonious positions: all positions within the crown group of the clade Himantandraceae + Degeneriaceae + Eupomatiaceae + Annonaceae (each represented as one terminal), or as the sister group of this clade. These *relationships were supported by one unequivocal synapomorphy, the presence of glands on the stamens or staminodes (Doyle and Endress, 2010). A more recent molecular scaffold analysis (Mohr et al., 2013), which used a modified version of the morphological data set of Doyle and Endress (2010) reduced to Magnoliales, Laurales, and Canellales (as outgroup), placed Endressinia as the sister group of Schenkeriphyllum glanduliferum (another fossil from the same deposit, discussed below), with the clade of the two fossils being the sister group of Magnoliaceae. Endressinia and Schenkeriphyllum were united by sessile leaf blade (a new character) and linked with Magnoliaceae by sheathing leaf base and dry fruit wall. As noted by Mohr et al. (2013), Doyle and Endress (2010) did not score Endressinia as having a sheathing leaf base. This was probably because the sheath was formed from the unusual sessile leaf blade, rather than a leaf base separated from the blade by a petiole, but this difference does not rule out homology of the character. We have not attempted to resolve this conflict with a new analysis. The implications for dating are complicated by the fact that the position of Magnoliaceae within Magnoliales is still debated. Two alternative positions have been supported by most analyses: either as the sister group of a clade of Degeneriaceae + Himantandraceae (Soltis et al., 1999, 2007; Qiu et al., 2000, 2005, 2006; Savolainen et al., 2000; Zanis et al., 2002, 2003), or sister to a clade of Degeneriaceae + Himantandraceae + Eupomatiaceae + Annonaceae (Doyle and Endress, 2000; Sauquet et al., 2003). However, the results of both Doyle and Endress (2010) and Mohr et al. (2013) support a position of Endressinia within the crown group of Magnoliineae, the well-supported clade of five families that is sister to Myristicaceae (Sauquet et al., 2003), and each study alone leads to use of this fossil to calibrate the crown node of this clade. Therefore, Endressinia provides a safe minimum age for the crown node of Magnoliineae (Figure 1)."*

Reference (relationships)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

†Archaeanthus linnenbergeri

Calibration at a glance: stem Magnoliaceae (Magnoliales), min 96.5 Ma
ID number (NFos): 6

Fossil identity

Full taxon name: **†Archaeanthus linnenbergeri Dilcher & Crane**

Organs: Multifollicular fruit and proximal reproductive and vegetative portions of the same axis

Specimens: UF 15703-4152 in University of Florida, Gainesville, USA (holotype of Archaeanthus linnenbergeri Dilcher and Crane; multifollicular fruit and proximal reproductive and vegetative portions of the same axis).
Additional Specimens. UF 15703; 2300, 2317, 2318, 2590, 3022, 3837, 3907, 4105, 4112, 4134-4150, 4152, 4153, 4155-4158, 4163, 4164, 4166-4170, 4198, 4532-4534: other specimens of Archaeanthus linnenbergeri examined in Dilcher and Crane (1984).
UF 15703-3179 (holotype of Archaepetala beekeri Dilcher and Crane; perianth parts).
UF 15703-3882. Other specimen of Archaepetala beekeri examined in Dilcher and Crane (1984).
UF 15703-2266 (holotype of Archaepetala obscura Dilcher and Crane; perianth parts).
UF 15703-2747 (holotype of Kalymnanthus walkeri Dilcher and Crane; bud-scales).
UF 15703-4114, UF 15703-4115. Other specimens of Kalymnanthus walkeri examined in Dilcher and Crane (1984).
UF 15703-2272 (holotype of Liriophyllum kansense Dilcher and Crane; leaves).
UF 15703; 2267, 2271-2277, 2309, 2456, 2463-2466, 2469-2471, 2473, 2475-2477, 2479, 2480, 2482, 2484, 2485, 2487, 2488, 2492, 2493, 2679, 2948, 3443, 2813, 3816-3818, 3823, 3826, 3827, 3836, 3839, 3859, 3885, 3886, 3890, 3894, 3895, 3992, 4028, 4029, 4051, 4120. Other specimens of Liriophyllum kansense examined in Dilcher and Crane (1984).

Locality: Linnenberger Ranch in Russell County, central Kansas

Formation: Dakota Formation

Country: USA

Reference (description)

Dilcher DL, Crane PR. 1984. Archaenthus: An Early Angiosperm From the Cenomanian of the Western Interior of North America. Annals of the Missouri Botanical Garden 71: 351–383.

Fossil age

Safe minimum age: **96.5 Ma**

Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)

Oldest stratigraphic age: early Cenomanian

Reference time scale: Ogg & Hinnov (2012)

Age quality score: 4 / revised (stratigraphic)

Age justification

Massoni et al 2015 (PE): "All the specimens used to describe Archaeanthus linnenbergeri come from the Dakota Formation at the Linnenberger Ranch in Russell County, central Kansas, USA (Dilcher and Crane, 1984). This formation lies between the underlying Kiowa Shale of Albian age and the overlying Graneros Shale (Retallack and Dilcher, 2012) of Cenomanian age. It has been traditionally divided into two members, the Terra Cotta Clay Member below and the Jansen Clay Member above (Plummer and Romary, 1942). The beds containing the specimens considered here were assigned to the Jansen Clay Member (Dilcher and Crane, 1984). Dilcher and Crane (1984) considered the age of this locality to be latest Albian to earliest Cenomanian. However, D.L. Dilcher (pers. comm. in Doyle and Endress, 2010) argued that it is more likely latest Albian, based on a carbon isotope and sequence *stratigraphic study by Gröcke et al. (2006) at the Rose Creek locality in Nebraska, where a flora described by Upchurch and Dilcher (1990) lies just below the Albian-Cenomanian boundary, plus the fact that the Dakota is transgressive toward the east and sites such as Russell County are among its most western exposures. A latest Albian age was accepted by Doyle and Endress (2010) and reaffirmed without discussion by Romanov and Dilcher (2013). However, although the Rose Creek and Linnenberger Ranch floras were both assigned to the Jansen Clay Member and considered roughly coeval by Farley and Dilcher (1986), their equivalence needs reexamination in light of detailed sequence stratigraphic and palynological analyses of the Dakota Formation in Kansas, Nebraska, and Iowa by Ludvigson et al. (2010). This study showed that the Dakota does not represent a simple transgressive sequence but rather three transgressive-regressive cycles. The first two cycles (equivalent to Palynostratigraphic Units 1 and 2) are late Albian, while the third (Units 3 and 4) is early and middle Cenomanian; the boundary recognized by Gröcke et al. (2006), between the second and third cycles, falls within beds formerly assigned to the Jansen Clay Member. Unfortunately, this analysis did not extend as far west as Russell County, although in Lincoln County, just to the east, the lower part of the third cycle is represented by Dakota continental beds that interfinger with marine rocks to the west. Because we cannot exclude the possibility that the Linnenberger flora is from the lower part of the third cycle, which Ludvigson et al. (2010) dated as early Cenomanian, we propose a conservative minimum age of 96.5 Ma for Archaeanthus, the early-middle Cenomanian boundary (no uncertainty provided; Ogg and Hinnov 2012)."*

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**stem Magnoliaceae (Magnoliales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Massoni et al 2015 (PE): "The position of Archaeanthus linnenbergeri was investigated by Doyle and Endress (2010), in a molecular scaffold analysis in which the family Magnoliaceae (ca. 227 species) was split into two taxa: Magnolioideae, often treated by recent authors as the single genus Magnolia, and Liriodendron. This analysis placed Archaeanthus in three different most parsimonious positions: one as the sister group of Magnoliaceae as a whole, and two within crown-group Magnoliaceae, either sister to Liriodendron or sister to Magnolioideae. The clade of Archaeanthus and Magnoliaceae was supported by three unambiguous synapomorphies: sheathing leaf base, bilobed stipules, and elongate receptacle, while the positions within the family were supported by bilobed leaf apex (shared with Liriodendron) or dehiscent fruit (shared with Magnolioideae). By contrast, a recent cladistic analysis by Romanov and Dilcher (2013) positioned Archaeanthus sister to the Late Cretaceous seed genus Liriodendroidea (Frumin and Friis, 1996) and identified the clade made up of these two extinct genera as the sister group of Liriodendron, supported by four synapomorphies. This would imply that Archaeanthus provides a minimum age for crown-group Magnoliaceae. However, the taxonomic sampling of this analysis was very limited, as the extant taxa included only Magnoliaceae s.s. (= Magnolioideae) as a supra-specific terminal, Liriodendron, and Illicium (Austrobaileyales), which is many nodes more distant from Magnoliaceae than are other members of the order Magnoliales. In addition, one of the four proposed synapomorphies of Archaeanthus and Liriodendron, whorled perianth phyllotaxis, vs. spiral in Illicium and Magnolia, appears to be a symplesiomorphy in Magnoliales, where the perianth is basically whorled and trimerous (Endress and Doyle, 2009). Furthermore, although the perianth is spiral in some species of Magnolia s.l., in many species it is whorled (e.g., M. denudata : Erbar and Leins, 1981). Two other proposed synapomorphies, bilobed leaf apex and leaf lobation, are not independent characters, since the only lobation in the leaf of Archaeanthus is that of the apex; its origin requires only one change, not two. The status of the fourth synapomorphy, fruitlets shed from the receptacle, is uncertain, since Degeneria and most Annonaceae also have this feature (van Setten and Koek-Noorman, 1992). These observations imply that there are no more acceptable synapomorphies of Archaeanthus and Liriodendron in the Romanov and Dilcher (2013) data set than in Doyle and Endress (2010).
Even though we cannot dismiss the possibility that future analyses, based on denser taxon sampling and better knowledge of the phylogenetic position of Magnoliaceae, may eventually support a position of Archaeanthus within crown-group Magnoliaceae, we prefer to be conservative and recommend the use of Archaeanthus to serve as a

minimum age constraint for the stem node of Magnoliaceae. In the current consensus tree presented in Figure 1, this is the same node as crown-group Magnoliinae (the larger clade of five families found by Doyle and Endress, 2010; Sauquet et al., 2003). However, this is not the case in one of the resolved trees of Massoni et al. (2014) on which this consensus tree is based, in which Magnoliaceae are the sister group of the clade consisting of Degeneria (Degeneriaceae) and Galbulimima (Himantandraceae). Furthermore, maintaining a distinction between the two nodes may be useful because the association of Archaeanthus with Magnoliaceae appears to be more strongly supported than that of Endressinia (and Schenkeriphyllum) and less likely to change in future analyses."

Reference (relationships)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

†Myristicoxylon princeps

Calibration at a glance	stem Myristicaceae (Magnoliales), min 61.6 Ma
ID number (NFos)	174

Fossil identity

Full taxon name	**†Myristicoxylon princeps Boureau**
Organs	Wood
Specimens	Coll. Monod: 6025-2
Locality	Asselar, Sudanese Sahara
Formation	
Country	Sudan

Reference (description)

Boureau E. 1950. Étude paléoxylologique du Sahara (IX). Sur un Myristicoxylon princeps n. gen., n. sp., du Danien d'Asselar (Sahara soudanais). Bulletin du Muséum National d'Histoire Naturelle, 2e Série 22: 523–528.

Fossil age

Safe minimum age	**61.6 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Danian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Selon le collecteur (Th. Monod), ce bois qu Sahara soudanais provient des couches d' Asselar d'âge Danien certain, comme l'indiquent les débris de Crocodiliens et les dents de Ceratodus qui ont été découverts avec lui.

Reference (age)

Boureau E. 1950. Étude paléoxylologique du Sahara (IX). Sur un Myristicoxylon princeps n. gen., n. sp., du Danien d'Asselar (Sahara soudanais). Bulletin du Muséum National d'Histoire Naturelle, 2e Série 22: 523–528.

Fossil relationships

Node calibrated	**stem Myristicaceae (Magnoliales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Doyle et al 2004 (article): "Boureau (1950) described Myristicoxylon princeps from the earliest Paleocene (Danian) of the Sahara as wood of Myristicaceae. Comparison with the OCPN wood identification database (LaPasha and Wheeler 1987) indicates that Myristicaceae are the closest extant match for this wood, with the combination of marginal (circummedullary) parenchyma (a feature of most Magnoliales) and both scalariform and simple vessel perforations being most suggestive (E. A. Wheeler, personal communication). However, M. princeps cannot be related to any particular subgroup of Myristicaceae, implying that it could be a stem relative of the family." (see also Doyle et al. 2008)

Reference (relationships)

Doyle JA, Sauquet H, Scharaschkin T, Le Thomas A. 2004. Phylogeny, molecular and fossil dating, and biogeographic history of Annonaceae and Myristicaceae (Magnoliales). International Journal of Plant Sciences 165: S55–S67.

†Aristolochiacidites viluiensis

Calibration at a glance	stem Aristolochioideae (Aristolochiaceae, Piperales), min 72.1 Ma
ID number (NFos)	175

Fossil identity

Full taxon name	**†Aristolochiacidites viluiensis Hoffman & Zetter**
Organs	Pollen
Specimens	Holotype: 3830VB07-14/10/2
Locality	Tyung River, close to Locality 4215 of Vachrameev and Pushcharovski (1954), Siberia
Formation	Timerdyakhh Formation
Country	Russia

Reference (description)

Hofmann C-C, Zetter R. 2010. Upper Cretaceous sulcate pollen from the Timerdyakh Formation, Vilui Basin (Siberia). Grana 49: 170–193.

Fossil age

Safe minimum age	**72.1 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Campanian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Hofmann & Zetter 2010 (Grana): "For the present study, five samples (T9–T11, T14 and T15) are considered to be of latest Campanian to earliest Maastrichtian age; sample T2 indicates a ?younger Maastrichtian age. The sediments of the samples consist of very fine-grained to fine-grained floodplain deposits (including palaeosols with roots, clasts of small-scale coalified peaty horizons and floodbasin lake sediments) and probable natural levee deposits. However, these palynologically productive fine-grained or organic rich sediments have a restricted lateral extent in the outcrops, because the upper part of the the Timerdyakh Formation is characterised by an increased reworking of overbank fines by river channel migration, bank failures and channel-cannibalism and amalgamation (Spicer et al., 2008; Anders, pers. comm., 2007). For this reason, numerous intraformational clasts of mudstones ("mudball"), siltstones, organic sediments ("peatball") and slumped tree trunks are preserved within channel deposits. Consequently, the sedimentary succession has been interpreted to be the result of a hydrologically very active interval during the Upper Cretaceous in this area (Spicer et al., 2008)."

Reference (age)

Hofmann C-C, Zetter R. 2010. Upper Cretaceous sulcate pollen from the Timerdyakh Formation, Vilui Basin (Siberia). Grana 49: 170–193.

Fossil relationships

Node calibrated	**stem Aristolochioideae (Aristolochiaceae, Piperales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Hofmann & Zetter 2010 (Grana): "Inaperturate pollen grains in combination with this unique exine configuration and fitting size can be observed in the subfamily Aristolochioideae (Aristolochiaceae), particularly in the woody Thottea siliquosa (Lamkey) Ding Hou, 1981 (Tissot et al., 1994, plate 7, LM, SEM; H. Halbritter, unpublished) and also in the

Aristolochia rotunda L., 1753 group of Mulder (2003, plate 1, figures 1–4, plate 2, figures 1–2) and in some Aristolochia species from South America with thick sexines. Large, shallow, irregularly shaped verrucae, but unperforated and echinate with much shorter columellae, are visible in the Piperaceae, such as Peperomia rubella Hooker & Arnorld ex Candolle, 1869 (Halbritter, 2000a; H. Halbritter, unpublished) and P. columella Rauh & Hutchison, 1973 (Grayum, 1992, figures 590–591)."

Reference (relationships)

Hofmann C-C, Zetter R. 2010. Upper Cretaceous sulcate pollen from the Timerdyakh Formation, Vilui Basin (Siberia). Grana 49: 170–193.

†Lactoripollenites africanus

Calibration at a glance stem Lactoris (Aristolochiaceae, Piperales), min 72.1 Ma
ID number (NFos) 176

Fossil identity

Full taxon name **†Lactoripollenites africanus Zavada & Benson**
Organs Pollen
Specimens Holotype: Specimen is on SOEKOR palynology slide 7904B', coordinates L5-21
Locality OEKOR borehole K-El Orange Basin off shore Namaqualand
Formation
Country South Africa

Reference (description)

Zavada MS, Benson JM. 1987. First fossil evidence for the primitive angiosperm family Lactoridaceae. American Journal of Botany 74: 1590–1594.

Fossil age

Safe minimum age **72.1 Ma**
Absolute age source stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age Campanian
Reference time scale ICS (v2017/02)
Age quality score 2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Lactoripollenites africanus occurs in sediments that range from early Turonian to Campanian, but it is unkown in which part of the sequence the grains occur. Therefore, conservatively, we consider that the oldest sediments where Lactoripollenites is found are Campanian."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated **stem Lactoris (Aristolochiaceae, Piperales)**
Node assignment score 2 / intuitive or unspecified (trusted source)
Reconciliation score 3 / molecular tree only

Node justification

Lactoripollenites africanus represents the first occurrence of Lactoris pollen in the early Turonian of southern Africa. The fossil pollen is anasulcate, the aperture lenticular to ovoid (ulcerate) in shape. “The pollen is shed in permanent tetrahedral tetrads. The tetrads average 34-36 µm in diameter. Exine sculpture is scabrate with a conspicuous ridge located adjacent to the aperture. The conspicuous ridge adjacent to the aperture is formed by a separation of the foot layer (nexine) and the outer ektexine forming a saccus. In the proximal regions of each grain in the tetrad the outer ektexine (tectum and infratectal alyer) are absent, each grain being appressed to one another along their thick foot layer” (Zavada & Benson, 1987). Extant Lactoris pollen possess the following combiantion of features: anasulcate, lenticular to ovoid aperture; saccate condition; granular wall structure and pollen shed in tetrahedral tetrads. The fossil pollen Lactoripollenites africanus shares these characteres with extant Lactoris pollen, differing only in the thickness of the foot layer and the abundance of infrastructural granules (Zavada & Benson, 1987).

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Saururus tuckerae

Calibration at a glance	stem Saururus (Saururaceae, Piperales), min 44.3 Ma
ID number (NFos)	118

Fossil identity

Full taxon name	**†Saururus tuckerae Smith & Stockey**
Organs	Inflorescence
Specimens	P1631 Bbot a in the University of Alberta (Edmonton) Paleobotanical Collections (UAPC) (holotype; inflorescence). Additional Specimens. P1631 Btop a, Btop b, Btop f, Btop h, Bbot c, Cbot e; P5831 Bbot; P5839 A; P5937 Gbot b; P5991 B. Paratypes (isolated flowers).
Locality	8.4 km south of Princeton, British Columbia
Formation	Princeton Chert, Allenby Formation, Princeton Group
Country	Canada

Reference (description)

Smith SY, Stockey RA. 2007. Establishing a fossil record for the perianthless Piperales: Saururus tuckerae sp. nov. (Saururaceae) from the Middle Eocene Princeton Chert. American Journal of Botany 94: 1642–1657.

Fossil age

Safe minimum age	**44.3 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Massoni et al 2015 (PE): "Fossils described by Smith and Stockey (2007) come from the Princeton Chert, 8.4 km south of Princeton, British Columbia, Canada, which is part of the Princeton Group, Allenby Formation (Boneham, 1968). The Princeton Chert consists of a series of alternating layers of coal and chert. The paleontological record supports a middle Eocene age, such as an amiid fish correlated with the occurrence of comparable fossils in British Columbia and in the Klondike Mountain Formation of Washington State (Wilson, 1982), and teeth of the mammal group Tillodontia (Russell, 1935). In addition, potassium-argon dating studies have provided comparable ages for the Allenby Formation: 48 ± 2 Ma (Rouse and Mathews, 1961; Mathews, 1964), between 47 ± 2 and 50 ± 2 Ma (Hills and Baadsgaard, 1967), and 46.2 ± 1.9 Ma and 49.4 ± 2 Ma (Read, 2000). With a different method (U-Pb age from zircons), Moss et al. (2005) suggested an age of 52.08 ± 0.12 Ma for the Allenby Formation. Finally, Smith and Stockey (2007) report a personal communication from H. Baadsgaard (University of Alberta, 1999) that supports an age of 48.7 Ma for the ash of Layer #22 of the Princeton Chert. Because the 7.5 m of the Princeton Chert sequence (incorporating the layer where the fossil was collected) may have accumulated in 15,000 years or less (Mustoe, 2011), this latter age is probably the closest to the real age of the fossil. However, in order to be conservative regarding the uncertainty of the age of this formation, and the fact that no uncertainty is associated with the latter age, Saururus tuckerae provides a safe minimum age of 44.3 Ma (the youngest age given by potassium-argon dating minus the associated error of 1.9 Ma)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**stem Saururus (Saururaceae, Piperales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Massoni et al 2015 (PE): "A morphological parsimony analysis using 24 morphological characters modified from matrices of Tucker et al. (1993), Tucker and Douglas (1996), and Meng et al. (2003) placed Saururus tuckerae in a single most parsimonious position within the family Saururaceae, as the sister group of a clade formed by the two extant species of Saururus (Smith and Stockey, 2007). The relationship of the fossil with extant Saururus, one of four genera in Saururaceae, was supported by the following synapomorphies: basally connate carpels, 1-2 ovules per carpel, and marginal placentation (Smith and Stockey, 2007). This study indicated that the genus Saururus was sister to Gymnotheca, and Anemopsis was sister to Houttuynia, relationships supported by other molecular and morphological studies (Meng et al., 2002, 2003; Jaramillo et al., 2004; Neinhuis et al., 2005; Wanke et al., 2007b; Massoni et al., 2014). Outside the Saururaceae, the relationships are compatible with molecular studies (e.g., Qiu et al., 2005, 2006; Soltis et al., 1999, 2000a, 2000b, 2007, 2011; Mathews and Donoghue, 1999, 2000; Qiu et al., 1999, 2000; Doyle and Endress, 2000; Savolainen et al., 2000; Zanis et al., 2002, 2003; Borsch et al., 2003; Hilu et al., 2003; Kelly and González, 2003; Jaramillo et al., 2004; Wanke et al., 2007a, 2007b; Massoni et al., 2014). We thus consider Saururus tuckerae to provide a minimum age for the stem node of the extant genus Saururus, which is also the crown node of Gymnotheca + Saururus (Figure 1)."

Reference (relationships)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

†Liliacidites sp. A

Calibration at a glance	crown Monocotyledoneae, min 113 Ma
ID number (NFos)	121

Fossil identity

Full taxon name	**†Liliacidites sp. A Doyle & Hickey**
Organs	Pollen
Specimens	3215, slide no. 71-8-1d (USNM)
Locality	Trent's Reach, VA
Formation	Patuxent Formation
Country	USA

Reference (description)

Doyle JA, Hickey LJ. 1976. Pollen and leaves from the mid-Cretaceous Potomac Group and their bearing on early angiosperm evolution. In: Beck C, ed. Origin and early evolution of angiosperms. New York: Columbia University Press, 139–206.

Fossil age

Safe minimum age	**113 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Aptian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Iles et al 2015 (BJLS): "Aptian, biostratigraphy (Doyle, 1973; Hochuli et al., 2006; Doyle et al., 2008)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Monocotyledoneae**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Iles et al 2015 (BJLS): "The earliest records of Liliacidites with clear monocot affinity (showing the above mentioned features) are from the Trent's Reach locality of Virginia (Doyle, 1973; Doyle & Hickey, 1976; Doyle & Robbins, 1977; Doyle et al., 2008), part of the Patuxent Formation and corresponding to the base of Zone I, (early?) Aptian (113–125 Ma; Doyle, 1973; Hochuli, Heimhofer & Weissert, 2006). These were originally described as Retimonocolpites sp. C by Doyle (1973) and later reinterpreted as Liliacidites sp. A by Doyle & Hickey (1976). A phylogenetic analysis placed these fossils either on the stem of monocots or equally parsimoniously anywhere in the included monocots (Doyle et al., 2008)."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†*Caldesia brandoniana*

Calibration at a glance	crown Alismataceae (Alismatales), min 23.03 Ma
ID number (NFos)	122

Fossil identity

Full taxon name	**†Caldesia brandoniana Haggard & Tiffney**
Organs	Fruits and seeds
Specimens	Holotype: 51406 (Paleobotanical C, Harvard U)
Locality	Forestdale, ca. 7 km east of Brandon, Vermont
Formation	Brandon Lignite
Country	USA

Reference (description)

Haggard KK, Tiffney BH. 1997. The Flora of the Early Miocene Brandon Lignite, Vermont, USA. VIII. Caldesia (Alismataceae). American Journal of Botany 84: 239–252.

Fossil age

Safe minimum age	**23.03 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Oligocene
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Iles et al 2015 (BJLS): "Terrestrial biostratigraphy (Tiffney, 1994; Traverse, 1994)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Alismataceae (Alismatales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Haggard & Tiffney (1997) described fossil fruits assignable to the extant genus Caldesia Parl. from the Brandon Lignite of Vermont based on 'horseshoe'-shaped seeds, thin exocarp and thick exocarp consisting of one layer of radially aligned lignified cells and ribs on the pericarp. Caldesia is well embedded in the Alismataceae clade (G. Ross, University of British Columbia, and S.W.G., unpubl. data). In terms of seed and fruit characters it may be closest to Limnophyton Miquel (Haggard & Tiffney, 1997), which has yet to be sampled in a molecular analysis."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Cardstonia toldmanii

Calibration at a glance	stem Alismataceae (Alismatales), min 72.1 Ma
ID number (NFos)	123

Fossil identity

Full taxon name	**†Cardstonia toldmanii M.G.Riley & Stockey**
Organs	Leaves
Specimens	Holotype. UAPC-ALTA S55138 Paratypes. UAPC-ALTA S50947, S52263, S52279, S52268, S52266, S52272, S50989.
Locality	Cardston, Alberta
Formation	St. Mary River Formation
Country	Canada

Reference (description)

Riley MG, Stockey RA. 2004. Cardstonia tolmanii gen. et sp. nov. (Limnocharitaceae) from the Upper Cretaceous of Alberta, Canada. International Journal of Plant Sciences 165: 897–916.

Fossil age

Safe minimum age	**72.1 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Campanian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Riley & Stockey 2004 (IJPS): "Outcrops are part of the St. Mary River Formation, Upper Cretaceous, and are Late Campanian–Early Maastrichtian in age (Nadon 1988; Hamblin 1998; A.R.Sweet, personal communication, 2003)."

Reference (age)

Riley MG, Stockey RA. 2004. Cardstonia tolmanii gen. et sp. nov. (Limnocharitaceae) from the Upper Cretaceous of Alberta, Canada. International Journal of Plant Sciences 165: 897–916.

Fossil relationships

Node calibrated	**stem Alismataceae (Alismatales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Fossils with similarities to Alismataceae (including Limnocharitaceae) occur from the Late Cretaceous onward (Stockey, 2006; Smith, 2013). The best characterized of these are Cardstonia tolmanii M.G.Riley & Stockey, Haemanthophyllum Budantzev and Heleophyton helobiaeoides D.M.Erwin & Stockey (Erwin & Stockey, 1989; Golovneva, 1997; Riley & Stockey, 2004). These fossils show strong similarities to extant Alismataceae. However, the preserved characters do not reliably allow their placement in the crown clade of the family. Additionally, some of these genera also share characters with other alismatalean families (such as Aponogetonaceae and Butomaceae)." We note that this fossil was not included in the shortlist of calibrations presented by the authors in Table 1.

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Aponogeton harryi

Calibration at a glance	stem Aponogetonaceae (Alismatales), min 81.13 Ma
ID number (NFos)	120

Fossil identity

Full taxon name	**†Aponogeton harryi Grímsson, Zetter, Halbritt. & G. Grimm**
Organs	Pollen
Specimens	Holotype: IPUW 2012–0008 (Dept. Palaeontology, UVienna)
Locality	Elk Basin, Park County, WY
Formation	Upper Eagle Beds, Eagle Fm
Country	USA

Reference (description)

Grímsson F, Zetter R, Halbritter H, Grimm GW. 2014. Aponogeton pollen from the Cretaceous and Paleogene of North America and West Greenland: Implications for the origin and palaeobiogeography of the genus. Review of Palaeobotany and Palynology 200: 161–187.

Fossil age

Safe minimum age	**81.13 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "40Ar/39Ar radiometry (Hicks, 1993)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**stem Aponogetonaceae (Alismatales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Suite of characters (Grímsson et al., 2014)"

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†*Araciphyllites tertiarius*

Calibration at a glance	stem Monsteroideae (Araceae, Alismatales), min 47 Ma
ID number (NFos)	124

Fossil identity

Full taxon name	**†Araciphyllites tertiarius (Engelh.) V.Wilde, Kvacek & Bogner**
Organs	Leaves
Specimens	Holotype: ME 477 (HLMD)
Locality	Messel Pit, near Darmstadt
Formation	Messel Formation
Country	Germany

Reference (description)

Wilde V, Kvaček Z, Bogner J. 2005. Fossil Leaves of the Araceae from the European Eocene and Notes on Other Aroid Fossils. International Journal of Plant Sciences 166: 157–183.

Fossil age

Safe minimum age	**47 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "40Ar/39Ar radiometry and sedimentation rate (Franzen, 2005; Mertz & Renne, 2005)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**stem Monsteroideae (Araceae, Alismatales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Suite of characters (Wilde et al., 2005)"

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Limnobiophyllum scutatum

Calibration at a glance	stem Lemnoideae (Araceae, Alismatales), min 66 Ma
ID number (NFos)	125

Fossil identity

Full taxon name	**†Limnobiophyllum scutatum (Dawson) Krassilov**
Organs	Vegetative plants
Specimens	Specimen: 6083 and others (YPM)
Locality	Five localities, ND & SD
Formation	Hell Creek and lower Fort Union Formations
Country	USA

Reference (description)

Kvaček Z. 1995. Limnobiophyllum Krassilov - a fossil link between the Araceae and the Lemnaceae. Aquatic Botany 50: 49–61.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Cretaceous–Palaeogene boundary
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Iles et al 2015 (BJLS): "The best preserved material, which includes in situ pollen (originally described as Pandaniidites Elsik; see Stockey et al., 1997; Hesse & Zetter, 2007) is from Alberta and is of middle Palaeocene age (Stockey et al., 1997). Slightly older material corresponding to the Cretaceous–Palaeogene boundary is known from Asia (Krassilov, 1973) and North America (Johnson, 2002). The North American material is represented by 99 specimens from five localities in south-western North Dakota and north-western South Dakota from the Hell Creek and lower Fort Union Formations (Johnson, 2002). These localities closely straddle the Cretaceous–Palaeogene boundary (Hicks et al., 2002; Johnson, 2002) and we can therefore confidently calibrate the stem node of Lemnoideae to 66 Ma."

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**stem Lemnoideae (Araceae, Alismatales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Iles et al 2015 (BJLS): "Fossil members of Lemnoideae were reviewed recently by Bogner (2009), who noted the presence of fossil seeds and plants of the extant genus Lemna L. from the Oligocene onwards. In particular, he focused on the extinct Limnobiophyllum scutatum (Dawson) Krassilov, found from the latest Cretaceous of Asia and North America. Morphological and palynological work suggests that Limnobiophyllum is closely related to subfamily Lemnoideae, although it is less reduced morphologically (Kvacˇek, 1995; Stockey, Hoffman & Rothwell, 1997; Hesse & Zetter, 2007; Bogner, 2009). A morphology-based phylogenetic analysis was used to place the genus as the sister *group to extant Lemnoideae, although taxon sampling was scanty (Stockey et al., 1997)."*

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Mayoa portugallica

Calibration at a glance	stem Monsteroideae (Araceae, Alismatales), min 123 Ma
ID number (NFos)	4

Fossil identity

Full taxon name	**†Mayoa portugallica Friis, Pedersen et Crane**
Organs	Pollen
Specimens	S136663 (only specimen)
Locality	Open-cast clay pit northeast of Torres Vedras (39°06'13"N, 9°14'47"W)
Formation	basal member of the Almargem Formation
Country	Portugal

Reference (description)

Friis EM, Pedersen KR, Crane PR. 2004. Araceae from the Early Cretaceous of Portugal: evidence on the emergence of monocotyledons. Proceedings of the National Academy of Sciences of the United States of America 101: 16565–16570.

Fossil age

Safe minimum age	**123 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Aptian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

The Almargem Formation is divided into an upper and a lower member separated by a ferruginous crust. Rey (23) assigned the lower member to the Late Barremian–Early Aptian (Bedoulian) and the upper member to the Aptian (Gargasian). Subsequent stratigraphic correlations indicate that the upper member may be of Late Aptian–Early Albian age (24) or Early to Late Albian (25). Sample 44, which yielded the fossil specimen described here, was collected from a sandy, lignitic horizon just below the ferruginous crust in sediments corresponding to the basal member of the Almargem Formation, indicating a Late Barremian–Early Aptian age.

Reference (age)

Friis EM, Pedersen KR, Crane PR. 2004. Araceae from the Early Cretaceous of Portugal: evidence on the emergence of monocotyledons. Proceedings of the National Academy of Sciences of the United States of America 101: 16565–16570.

Fossil relationships

Node calibrated	**stem Monsteroideae (Araceae, Alismatales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	4 / morphological and molecular trees compared

Node justification

Magallón et al 2015 (NewPhytol): "The striate and inaperturate pollen grains are similar in detail to the pollen of genera of Monsteroideae (Araceae), such as Holochlamys and Spathiphyllum. "The surface of the pollen wall is striate with densely spaced ribs (muri) separated by narrow grooves (striae). Ribs are arranged in a distinctive pattern in which two sets of ribs each radiate from a pair of divergence points. Main axes of the two sets of ribs are at an angle of 45–90° to each other. Pollen wall is thin and consists of an outer exine of solid ribs supported by a very thin granular infratectal layer and an inner thin granular endexine that forms a continuous layer under the ribs"

(Friis, et al., 2004). Friis et al. (2004) consider that "The most distinctive feature of this pollen is its inaperturate condition, the crossed pattern of narrow, straight ribs, and the easily detached ektexine that rest on a thin, inconspicuous 16 granualr endexine. Among Araceae, inaperturate, striate pollen occurs in two subfamilies: Monsteroideae and Aroideae. In Monsteroideae these features occur together in both genera of Spathiphylleae (Holochlamys, Spathiphyllum). The strongest resemblance between the fossil pollen and pollen of extant Araceae is with the two very closely related genera of Spathiphylleae: Spathiphyllum and Holochlamys. Both have inaperturate, striate pollen of medium size (mean size, 32 and 33 µm, respectively). The pollen wall consists mainly of acetolysis-resistant ribs (formed from ektexine), a very thin, granular (Holochlamys) to weakly columellate (Spathiphyllum) infratectal layer, and a very thin granular endexine (Friis et al., 2004). Pollen of some species of Spathiphyllum has very fine ribs similar to the fossil, but in those species surveyed (Friis et al., 2004), the ribs run in only one direction extending between two distinct divergence points. In Holochlamys the same crossed pattern of ribs is present as in the fossil material. The ribs radiate from two pairs of more or less asymmetrically placed divergence points." (Friis, et al., 2004). Based on the assignment of Mayoa to tribe Spathiphylleae (Monsteroideae, Araceae) by Friis et al. (2004), we here use it to calibrate the stem group of Monsteroideae, which is represented only by Spathiphyllum in our analysis."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Spixiarum kipea

Calibration at a glance	stem Orontioideae (Araceae, Alismatales), min 113 Ma
ID number (NFos)	151

Fossil identity

Full taxon name	**†Spixiarum kipea Coiffard, BAR Mohr & Bernardes-de-Oliveira**
Organs	Rhizome and leaves
Specimens	Holotype: (Museum für Naturkunde, Berlin, MB. Pb. X1)
Locality	open cast pits close to the town of Nova Olinda, between Nova Olinda and Santana do Cariri (State of Ceará),
Formation	basal part of the Nova Olinda Member, Crato Formation
Country	Brazil

Reference (description)

Coiffard C, Mohr BAR, Bernardes-de-Oliveira MEC. 2013. The Early Cretaceous Aroid, Spixiarum kipea gen. et sp. nov., and implications on early dispersal and ecology of basal monocots. Taxon 62: 997–1008.

Fossil age

Safe minimum age	**113 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Aptian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

See Massoni et al 2015 (PE) on +Endressinia brasiliana: "The fossil considered here was collected from the Crato Formation in the Araripe sedimentary basin of northeastern Brazil (Mohr et al., 2013). Mohr and Bernardes-de-Oliveira (2004) assumed that the Crato Formation is late Aptian or early Albian in age, based on numerous previous estimates (e.g., Pons et al., 1996). Because of this uncertainty, Clarke et al. (2011) proposed a minimum age for the Crato of 98.7 Ma, the top of the Albian. However, evidence has been accumulating in favor of a late Aptian age (Coimbra et al., 2002). Most recently, using gymnosperm pollen and dinoflagellates to correlate with better-dated sections, Heimhofer and Hochuli (2010) concluded that the Aptian-Albian boundary lies above the Crato Formation, and this was accepted by Mohr et al. (2013). We therefore propose a minimum age of 112.6 Ma for Endressinia, the Aptian-Albian boundary (113 ±0.4 Ma; Ogg and Hinnov, 2012)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**stem Orontioideae (Araceae, Alismatales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Coiffard et al 2013b (Taxon): "Only Araceae display the unique combination of a costa, several orders of parallel veins and well-developed transverse veins that cross higher-order parallel veins (e.g., Lysichiton Schott, Fig. 7B). Among Araceae, the stomata are usually paracytic, but anomocytic stomata occur in Aroideae (Biarum Schott, Dracunculus Miller) and are more common in early diverging lineages such as Lemnoideae (all genera) and

Orontioideae (Orontium L.) (Keating, 2003) as well as in the closely related family Tofieldiaceae (Kubitzki, 1998b). In most, but not all cases, Araceae display a mesophyll differentiated into adaxial palisade and abaxial spongy layers (Keating, 2003). Systematic affinity within Araceae. — According to Bogner & al., (2007), Orontioideae are an exception among Araceae owing to their simplified leaf morphology and venation. The combination displayed by Spixiarum, of welldeveloped higher-order parallel venation in association with strong cross primaries and eucamptodromous marginal venation, is very similar to that of extant Oronti oideae."

Reference (relationships)

Coiffard C, Mohr BAR, Bernardes-de-Oliveira MEC. 2013. The Early Cretaceous Aroid, Spixiarum kipea gen. et sp. nov., and implications on early dispersal and ecology of basal monocots. Taxon 62: 997–1008.

†Stratiotes sp.

Calibration at a glance: crown Hydrocharitaceae (Alismatales), min 55.9 Ma
ID number (NFos): 126

Fossil identity

Full taxon name: **†Stratiotes sp.**
Organs: Seeds
Specimens: Private collection, M. Collinson, Royal Holloway U London
Locality: Felpham, West Sussex
Formation: Felpham Lignite Bed, Reading Formation
Country: UK

Reference (first description)

Bone D. 1986. The stratigraphy of the Reading Beds (Palaeocene), at Felpham, West Sussex. Tertiary Research 8: 17–32.

Reference (latest description)

Sille NP, Collinson ME, Kucera M, Hooker JJ. 2006. Morphological Evolution of Stratiotes through the Paleogene in England: An Example of Microevolution in Flowering Plants. Palaios 21: 272–288.

Fossil age

Safe minimum age: **55.9 Ma**
Absolute age source: radioisotopic
Age quality score: 5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "Terrestrial biostratigraphy and carbon isotope excursion (Bone, 1986; Collinson, 2000; Collinson & Cleal, 2001; Collinson et al., 2003)"
(Here I suggest a literal reading of their suggested age even though it is very close to the Thanetian actual upper limit)

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated: **crown Hydrocharitaceae (Alismatales)**
Node assignment score: 3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score: 3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "The oldest of these belong to Stratiotes L. (Stockey, 2006; Smith, 2013), which extends into the Palaeocene of England (Sille et al., 2006). As Stratiotes may be the sister taxon of the rest of the family (Iles, Smith & Graham, 2013; but see Les, Moody & Soros, 2006), the oldest known Stratiotes fossil can most confidently be utilized for calibrating the stem node of Stratiotes, or potentially the crown node of Hydrocharitaceae."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Thalassotaenia debeyi

Calibration at a glance: stem Posidoniaceae (Alismatales), min 66 Ma
ID number (NFos): 155

Fossil identity

Full taxon name	**†Thalassotaenia debeyi Van der Ham et Van Konijnenburg- Van Cittert**
Organs	Leaves
Specimens	Type material: NHMM LI 451 and 452 (Natuurhistorisch Museum Maastricht, The Netherlands)
Locality	Former CPL SA quarry near Hallembaye (NE Belgium)
Formation	Lanaye Member and the base of the Maastricht Formation
Country	Belgium

Reference (description)

van der Ham RWJM, van Konijnenburg-van Cittert JHA, Indeherberge L. 2007. Seagrass foliage from the Maastrichtian type area (Maastrichtian, Danian, NE Belgium, SE Netherlands). Review of Palaeobotany and Palynology 144: 301–321.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

van der Ham et al 2007 (RevPalPal): "Type stratum: The residual chert deposit ('flint eluvium') that originated by dissolution of the chalky matrix from the top of the Lanaye Member and the base of the Maastricht Formation (Late Maastrichtian, Belemnitella junior Zone; Fig. 2)."

Reference (age)

van der Ham RWJM, van Konijnenburg-van Cittert JHA, Indeherberge L. 2007. Seagrass foliage from the Maastrichtian type area (Maastrichtian, Danian, NE Belgium, SE Netherlands). Review of Palaeobotany and Palynology 144: 301–321.

Fossil relationships

Node calibrated	**stem Posidoniaceae (Alismatales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

van der Ham et al 2007 (RevPalPal): "Because Amphibolis, Thalassodendron and Posidonia, as a group, show the greatest resemblance, Thalassotaenia might be considered as an ancestor of the Cymodoceaceae–Posidoniaceae(–Ruppiaceae) clade found in several phylogenetic analyses (Les et al., 1997; Bremer, 2000; Janssen and Bremer, 2004). However, Thalassotaenia shows some features not found in any of the extant seagrasses: fiber strands that alternate with the veins and a well-delimited hypodermis. A hypodermis is also lacking in Posidonia perforata from the Paleocene of Belgium (Stockmans, 1932), besides Thalassotaenia the only known anatomically preserved fossil seagrass. The phylogenetic analyses mentioned above have demonstrated the polyphyletic origin of the seagrasses in three separate clades: besides the Cymodoceaceae–

Posidoniaceae(–Ruppiaceae) clade also the Hydrocharitaceae clade and the Zosteraceae clade. Therefore, Thalassotaenia could also represent another, extinct clade of seagrasses."

Reference (relationships)

van der Ham RWJM, van Konijnenburg-van Cittert JHA, Indeherberge L. 2007. Seagrass foliage from the Maastrichtian type area (Maastrichtian, Danian, NE Belgium, SE Netherlands). Review of Palaeobotany and Palynology 144: 301–321.

†Paracordyline kerguelensis

Calibration at a glance	crown Lomandroideae (Asparagaceae, Asparagales), min 22 Ma
ID number (NFos)	132

Fossil identity

Full taxon name	**†Paracordyline kerguelensis Conran**
Organs	Leaves
Specimens	Holotype: v.23718 (BMNH)
Locality	Port Jeanne d'Arc, La Grande Terre, Basaltic interbedded ash and fluvial sediments
Formation	
Country	Kerguélen Islands

Reference (description)

Conran JG. 1997. Paracordyline kerguelensis, an Oligocene monocotyledon macrofossil from the Kerguélen Islands. Alcheringa: An Australasian Journal of Palaeontology 21: 129–140.

Fossil age

Safe minimum age	**22 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "22–26 Ma; Rb/Sr radiometry of basaltic flows (Giret et al., 1989)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Lomandroideae (Asparagaceae, Asparagales)**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Fossil leaves similar to those of extant Cordyline Comm. ex R.Br. have been recovered from the Oligocene and Eocene of the Kerguélen Islands in the southern Indian Ocean and Australia (Conran, 1997; Conran & Christophel, 1998). The older of these, Paracordyline aureonemoralis Conran & Christophel, comes from the early Eocene (Golden Grove, 56.0–47.8 Ma) of Australia (Conran & Christophel, 1998), whereas the younger, P. kerguelensis Conran, is from ash sediments between basalt flows (26–22 Ma; Giret et al., 1989) on La Grande Terre in the Kerguélen Archipelago (Conran, 1997). Although these fossils are in general similar to each other and to Cordyline, and the younger fossil shares a cuticular sculpturing apomorphy with a subclade of Cordyline, other assignments are also possible (Conran, 1997; Conran & Christophel, 1998). Additional fossil material for Cordyline comes from the early Miocene Foulden Maar of New Zealand, which has yet to be formally described (Lee et al., 2012). As P. kerguelensis shares an apomorphy with some members of Cordyline it can be used to calibrate the stem node of Cordyline to 22 Ma. More inclusively, it can be used to calibrate the crown node of subfamily Lomandroideae (see Steele et al., 2012 for a reference phylogenetic tree)."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†*Protoyucca shadishii*

Calibration at a glance	crown Agavoideae (Asparagaceae, Asparagales), min 14.5 Ma
ID number (NFos)	131

Fossil identity

Full taxon name	**†Protoyucca shadishii Tidwell & L.R.Parker**
Organs	Vegetative plants
Specimens	Holotype: 3245 (BYU)
Locality	Humbolt County, NV
Formation	Virginia Valley Formation
Country	USA

Reference (description)

Tidwell WD, Parker LR. 1990. Protoyucca shadishii gen. et sp. nov., an arborescent monocotyledon with secondary growth from the Middle Miocene of Northwestern Nevada, U.S.A. Review of Palaeobotany and Palynology 62: 79–95.

Fossil age

Safe minimum age	**14.5 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "14.5–16.2 Ma; 40Ar/39Ar radiometry (Perkins et al., 1998)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Agavoideae (Asparagaceae, Asparagales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Stems, roots and leaves that appear to be of an arborescent monocot are known from the Miocene Virgin Valley Formation of Nevada (Tidwell & Parker, 1990). Tidwell & Parker (1990) compared these anatomically preserved fossils with extant groups of woody monocots, and on that basis suggested a close relationship to Yucca L., especially Y. brevifolia Engelm. (Joshua tree), describing them as Protoyucca shadishii Tidwell & L.R.Parker. We agree with their assessment and suggest that Protoyucca be used to calibrate the stem node of Yucca or, more inclusively, the crown node of subfamily Agavoideae."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Dianellophyllum eocenicum

Calibration at a glance	crown Asphodelaceae (Asparagales), min 41.2 Ma
ID number (NFos)	136

Fossil identity

Full taxon name	**†Dianellophyllum eocenicum Conran, Christophel & L.K.Cunn.**
Organs	Leaves
Specimens	Holotype: L050 (ADU)
Locality	Nelly Creek, ca 1 km south of the southern shore of Lake Eyre South, ca 55 km NW of Marree, South Australia
Formation	Eyre Formation
Country	Australia

Reference (description)

Conran JG, Christophel DC, Cunningham L. 2003. An Eocene moncotyledon from Nelly Creek, Central Australia, with affinities to Hemerocallidaceae (Lilianae: Asparagales). Alcheringa 27: 107–115.

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Iles et al 2015 (BJLS): "The Eyre Formation is dated to the middle Eocene (38.0–47.8 Ma) based on biostratigraphy (Alley, Krieg & Callen, 1996)."

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Asphodelaceae (Asparagales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "A single fossil leaf, Dianellophyllum eocenicum Conran, Christophel & L.K.Cunn., from the Nelly Creek locality, Eyre Formation, Australia, has multiple characters that suggest an affinity with subfamily Hemerocallidoideae, particularly with the modern genera Dianella Lam. ex Juss. and Thelionema R.J.F.Hend. (Conran, Christophel & Cunningham, 2003).[...] Dianellophyllum eocenicum can be used to calibrate the stem node of subfamily Hemerocallidoideae, or more inclusively, the crown node of Xanthorrhoeaceae (see Seberg et al., 2012 for a reference phylogenetic tree)."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†*Astelia antiquua*

Calibration at a glance	crown Asteliaceae (Asparagales), min 23.2 Ma
ID number (NFos)	133

Fossil identity

Full taxon name	**†Astelia antiquua Maciunas, Conran, Bannister, R.Paull & D.E.Lee**
Organs	Leaves
Specimens	Holotype: FH617 (OU32892) (Geology M., U. Otago)
Locality	Near Middlemarch, South Island
Formation	Foulden Maar Diatomite
Country	New Zealand

Reference (description)

Maciunas E, Conran JG, Bannister JM, Paull R, Lee DE. 2011. Miocene Astelia (Asparagales: Asteliaceae) macrofossils from southern New Zealand. Australian Systematic Botany 24: 19–31.

Fossil age

Safe minimum age	**23.2 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "40Ar/39Ar radiometry (Lindqvist & Lee, 2009)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Asteliaceae (Asparagales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Iles et al 2015 (BJLS): "Suite of characters and phylogenetic analysis (Maciunas et al., 2011)"

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Dendrobium winikaphyllum

Calibration at a glance: crown Epidendroideae (Orchidaceae, Asparagales), min 23.2 Ma
ID number (NFos): 134

Fossil identity

Full taxon name: **†Dendrobium winikaphyllum Conran, Bannister & D.E.Lee**
Organs: Leaves
Specimens: Holotype: OU32218 (Geology M., U. Otago)
Locality: Near Middlemarch, South Island
Formation: Foulden Hills Diatomite
Country: New Zealand

Reference (description)

Conran JG, Bannister JM, Lee DE. 2009. Earliest orchid macrofossils: Early Miocene Dendrobium and Earina (Orchidaceae: Epidendroideae) from New Zealand. American Journal of Botany 96: 466–474.

Fossil age

Safe minimum age: **23.2 Ma**
Absolute age source: radioisotopic
Age quality score: 5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "40Ar/39Ar radiometry (Lindqvist & Lee, 2009)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated: **crown Epidendroideae (Orchidaceae, Asparagales)**
Node assignment score: 2 / intuitive or unspecified (trusted source)
Reconciliation score: 3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Additional evidence for early Miocene (or late Oligocene) fossil leaves (Conran et al., 2009a) comes from the early Miocene Foulden Maar of New Zealand (23.2 Ma; Lindqvist & Lee, 2009). Conran et al. (2009a) assigned these fossils to two extant genera in subfamily Epidendroideae based on multiple morphological characters. However, the higher-order phylogeny of Epidendroideae is largely unresolved and assigning these genera to subclades is therefore problematic (e.g. Cameron, 2004; Freudenstein et al., 2004; van den Berg et al., 2005; Neubig et al., 2008; Górniak, Paun & Chase, 2010)."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Meliorchis caribea

Calibration at a glance	crown Orchidoideae (Orchidaceae, Asparagales), min 15 Ma
ID number (NFos)	135

Fossil identity

Full taxon name	**†Meliorchis caribea S.R.Ramírez, Gravend., R.B.Singer, C.R. Marshall & Pierce**
Organs	Pollinium
Specimens	Holotype: 31141 (MCZ)
Locality	Near Santiago
Formation	Dominican Amber
Country	Dominican Republic

Reference (description)

Ramirez SR, Gravendeel B, Singer RB, Marshall CR, Pierce NE. 2007. Dating the origin of the Orchidaceae from a fossil orchid with its pollinator. Nature 448: 1042–1045.

Fossil age

Safe minimum age	**15 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	early Middle Miocene
Age quality score	4 / revised (stratigraphic)

Age justification

Iles et al 2015 (BJLS): "15–20 Ma; Marine and terrestrial biostratigraphy (Iturralde-Vinent & MacPhee, 1996)"
Ramírez et al 2007 (Nature): "Since the precise mine of origin of Meliorchis caribea is not known, we used both the oldest and youngest age bounds of Dominican amber (15-20 My) as minimum age constraints for the Goodyerinae."
Vinent & MacPhee (1996): "In combination, these data indicate that the amber-bearing deposits of the Dominican Republic are uniformly late Early to early Middle Miocene in age (15 to 20 million years ago)."
Here, we follow these three publications in using 15 Ma as the approximate upper limit of the "early Middle Miocene", which is very close (and slightly more conservative) than the upper limit of the Burdigalian (15.97) in the ICS v2017/02 (geologic time scale).

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Orchidoideae (Orchidaceae, Asparagales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Iles et al 2015 (BJLS): "Meliorchis caribea S.R.Ramírez, Gravend., R.B.Singer, C.R. Marshall & Pierce is a pollinium mass attached to its pollinator preserved in Dominican amber (Ramírez et al., 2007). Phylogenetic analysis of pollinia characters suggested a placement with subtribe Goodyerinae (subfamily Orchidoideae)"

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Dioscorea wilkinii

Calibration at a glance	stem Dioscorea (Dioscoreaceae, Dioscoreales), min 27.23 Ma
ID number (NFos)	137

Fossil identity

Full taxon name	**†Dioscorea wilkinii A.D.Pan, B.F.Jacobs & Currano**
Organs	Leaves
Specimens	Holotype: CH40-110 (N. M. Ethiopia)
Locality	Chilga Woreda
Formation	Guang River Flora
Country	Ethiopia

Reference (description)

Pan AD, Jacobs BF, Currano ED. 2014. Dioscoreaceae fossils from the late Oligocene and early Miocene of Ethiopia. Botanical Journal of the Linnean Society 175: 17–28.

Fossil age

Safe minimum age	**27.23 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Pan et al 2014 (BJLS): "The flora is preserved in a 22–36 cm thick massive dark grey to yellow–green mudstone. Its age is well constrained by an ash that is correlated stratigraphically and dated by 206Pb/238U analysis of zircon crystals at 27.23 ± 0.1 Ma (Pan, 2010)."

Reference (age)

Pan AD, Jacobs BF, Currano ED. 2014. Dioscoreaceae fossils from the late Oligocene and early Miocene of Ethiopia. Botanical Journal of the Linnean Society 175: 17–28.

Fossil relationships

Node calibrated	**stem Dioscorea (Dioscoreaceae, Dioscoreales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "The fossil leaf D. wilkinii A.D.Pan, B.F.Jacobs & Currano from the Guang River flora (27.23 Ma; Pan, 2010; Pan, Jacobs & Currano, 2014) of Ethiopia is closely related to extant species of Dioscorea section Lasiophyton Uline (Pan et al., 2014). We therefore assign D. wilkinii to the stem node of Dioscorea section Lasiophyton (for phylogenetic placement, see Wilkin et al., 2005)."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Luzuriaga peterbannisteri

Calibration at a glance	crown Alstroemeriaceae (Liliales), min 23.2 Ma
ID number (NFos)	139

Fossil identity

Full taxon name	**†Luzuriaga peterbannisteri Conran, Bannister, Mildenh. & D.E.Lee**
Organs	Leaves and possibly floral remains
Specimens	Holotype: FH 437 (OU32666) (Geology M., U. Otago)
Locality	Near Middlemarch, South Island
Formation	Foulden Maar Diatomite
Country	New Zealand

Reference (description)

Conran JG, Bannister JM, Mildenhall DC, Lee DE, Chacón J, Renner SS. 2014. Leaf fossils of Luzuriaga and a monocot flower with in situ pollen of Liliacidites contortus Mildenh. & Bannister sp. nov. (Alstroemeriaceae) from the Early Miocene. American Journal of Botany 101: 141–155.

Fossil age

Safe minimum age	**23.2 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "40Ar/39Ar radiometry (Lindqvist & Lee, 2009)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Alstroemeriaceae (Liliales)**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Recognition of the extinct taxon Luzuriaga peterbannisteri Conran, Bannister, Mildenh. & D.E.Lee was based on the presence of resupinate leaves, venation patterns and cuticular details that closely agree with Luzuriaga (Conran et al., 2014). The associated fossil flower was not organically connected to the leaves and was excluded from the species description. However, its characters also suggest association to Luzuriaga (Conran et al., 2014). The placement of L. peterbannisteri was further explored within Alstroemeriaceae using phylogenetic approaches, where it was found to be either sister to extant Luzuriaga, or nested in Luzuriaga. We follow Conran et al. (2014) and conservatively consider that this fossil may be sister to extant members of the genus and therefore useful for calibrating the stem node of Luzuriaga."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†*Petermanniopsis angleseaensis*

Calibration at a glance	stem Petermannia (Petermanniaceae, Liliales), min 33.9 Ma
ID number (NFos)	153

Fossil identity

Full taxon name	**†Petermanniopsis angleseaensis Conran JG, Christophel DC, Scriven L**
Organs	Leaves
Specimens	Holotype: ADU 2600A (University of Adelaide)
Locality	Site II Lens B Alcoa Anglesea Coal Mine, Victoria
Formation	
Country	Australia

Reference (description)

Conran J, Christophel D. 1999. A redescription of the Australian Eocene fossil monocotyledon Petermanniopsis (Lilianae: aff. Petermanniaceae). Transactions of the Royal Society of South Australia 123:61-67.

Fossil age

Safe minimum age	**33.9 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Eocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Conran & Christophel 1999 (TransRoySocSAust): "Late Middle Eocene fossiliferous clay lens (Conran et al. 1994). The geology of this deposit has been described by Christophel et al. (1987)."

Reference (age)

Conran J, Christophel D. 1999. A redescription of the Australian Eocene fossil monocotyledon Petermanniopsis (Lilianae: aff. Petermanniaceae). Transactions of the Royal Society of South Australia 123:61-67.

Fossil relationships

Node calibrated	**stem Petermannia (Petermanniaceae, Liliales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	2 / morphological tree only

Node justification

Leaf architectural and cuticular characters place it closest to Petermanniaceae (Conran et al 1994)

Reference (relationships)

Conran J, Christophel D. 1999. A redescription of the Australian Eocene fossil monocotyledon Petermanniopsis (Lilianae: aff. Petermanniaceae). Transactions of the Royal Society of South Australia 123:61-67.

†*Ripogonum tasmanicum*

Calibration at a glance	stem Ripogonaceae (Liliales), min 51 Ma
ID number (NFos)	140

Fossil identity

Full taxon name	**†Ripogonum tasmanicum Conran, R.J.Carp. & G.J.Jord.**
Organs	Leaves
Specimens	Holotype: LR42 (School of Plant Science, U. Tasmania)
Locality	Lowana Road exposure, Macquarie Harbour, Tasmania
Formation	Maquarie Harbour Formation
Country	Australia

Reference (description)

Conran JG, Carpenter RJ, Jordan GJ. 2009. Early Eocene Ripogonum (Liliales: Ripogonaceae) leaf macrofossils from southern Australia. Australian Systematic Botany 22: 219–228.

Fossil age

Safe minimum age	**51 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	mid-Ypresian
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "Marine and terrestrial biostratigraphy date the Macquarie Harbour Formation to the mid-Ypresian (early Eocene, 51–52 Ma; Carpenter, Jordan & Hill, 2007)."

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**stem Ripogonaceae (Liliales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	4 / morphological and molecular trees compared

Node justification

Iles et al 2015 (BJLS): "A phylogenetic analysis placed R. tasmanicum within the crown clade of Ripogonum (Conran et al., 2009b). However, bootstrap support for this relationship is poor (< 50%) and so we only consider it suitable for calibrating the stem node of Ripogonum."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Smilax sp. 1

Calibration at a glance	stem Smilacaceae (Liliales), min 37.8 Ma
ID number (NFos)	152

Fossil identity

Full taxon name	**†Smilax sp. 1 Dilcher & Lott**
Organs	Leaves
Specimens	UF18810-34415 (University of Florida)
Locality	Powers Clay Pit, Weakley County, Tennessee
Formation	Claiborne Group
Country	USA

Reference (description)

Dilcher DL, Lott TA. 2005. A middle Eocene fossil plant assemblage (Powers Clay Pit) from western Tennessee. Bulletin of the Florida Museum of Natural History 45: 1–43.

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Bartonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Sauquet et al 2012 (SystBiol) on +Castanopsoidea columbiana (in Appendix S2): "Oldest Claiborne beds are in calcaraeous nannoplankton zone NP12, and youngest are in zone NP17 but also within the Bartonian marine stage (e.g., Dockery 1998). Using GTS 2004, base of NP12 is 52.3 Ma (+/- about 0.2 Ma) and end of Bartonian is 37.2 +/- 0.1 Ma." Here, we have revised the absolute age using the ICS v2017/02 geologic time scale.

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**stem Smilacaceae (Liliales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

*Dilcher & Lott 2005 (BullFloridaMusNatHist): "The general shape, size, margin, and prominent basal acrodromous venation is similar to Smilacaceae, Rhamnaceae, and Dioscoreaceae. In Rhamnaceae, such as Ziziphus cinnamomum Triana & Planch. (Heald 2002), there are three prominent basal acrodromous veins, but they lack the outer less promi- nent basal acrodromous veins present in Smilacaceae (Conran 1998). In Dioscoreaceae, such as Dioscorea decipiens J. D. Hooker (Zhizun & Gilbert 2000) and D. bull*fera L. (UF6173), the tertiary venation is distinctly opposite percurrent. The presence offive prominent basal acrodromous veins, and tertiary veins ofmixed opposite and alternate percurrent is characteristic of Smilacaceae, and is similar to Berry 's Smilax wilcoxensis (1930) of the Wilcox Flora, but the basal characters are different from our specimen. Berry's type material is incomplete, but diagramed to show that the secondary veins arise from the midvein independently. This is not the case with Smilax* *sp . 1 , as a pair of secondary veins arise from the very base of the midvein and then each bifurcates into the lateral acrodromous veins. If this character is demonstrated to be one of species importance, and if the details of Berry's S. wilcoxensis can be determined from other material, then we can ascertain whether these are conspecific."*

Reference (relationships)

Dilcher DL, Lott TA. 2005. A middle Eocene fossil plant assemblage (Powers Clay Pit) from western Tennessee. Bulletin of the Florida Museum of Natural History 45: 1–43.

†*Cyclanthus messelensis*

Calibration at a glance	crown Cyclanthaceae (Pandanales), min 47 Ma
ID number (NFos)	141

Fossil identity

Full taxon name	**†Cyclanthus messelensis S.Y.Sm., M.E.Collinson & Rudall**
Organs	Fruits
Specimens	Holotype: SM.B.Me 2005 (SMF)
Locality	Messel Pit, near Darmstadt
Formation	Messel Formation
Country	Germany

Reference (description)

Smith SY, Collinson ME, Rudall PJ. 2008. Fossil Cyclanthus (Cyclanthaceae, Pandanales) from the eocene of Germany and England. American Journal of Botany 95: 688–699.

Fossil age

Safe minimum age	**47 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "40Ar/39Ar radiometry and sedimentation rate (Franzen, 2005; Mertz & Renne, 2005)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Cyclanthaceae (Pandanales)**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Recent evaluation of infructescences and seeds from the Messel Pit of Germany (47 Ma; Franzen, 2005; Mertz & Renne, 2005) and the re-evaluation of isolated seeds from several Ypresian–Lutetian (early Eocene) localities in the UK demonstrated that they are most closely related to modern Cyclanthus Poit. ex A.Rich. (Smith, Collinson & Rudall, 2008b). Although the isolated seeds designated as C. lakensis (Chandler) S.Y.Sm., M.E.Collinson & Rudall probably represent Cyclanthus, they lack the apomorphies of the fossil infructescences C. messelensis S.Y.Sm., M.E.Collinson & Rudall, which directly link the latter to Cyclanthus. Therefore, C. messelensis can be used to calibrate the stem node of Cyclanthus or, more inclusively, the crown node of Cyclanthaceae."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Pandanus sp.? cf. P. shiabensis

Calibration at a glance	stem Pandanus (Pandanaceae, Pandanales), min 56 Ma
ID number (NFos)	156

Fossil identity

Full taxon name	**†Pandanus sp.? cf. P. shiabensis**
Organs	Pollen
Specimens	Slide No. 1-4-2; co-ord. 8.2/90 (Research Council of Alberta)
Locality	RCA Corehole 65-1, Alberta
Formation	Paskapoo Formation
Country	Canada

Reference (description)

Snead RG. 1969. Microfloral diagnosis of the Creaceous-Tertiary boundary, Central Alberta. Research Council of Alberta Bulletin 25: 1-84

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Snead 1969 (ResCouncilAlbertaBull): "Microfloral "zone" C spans beds just above the basal sandstone of the Paskapoo Formation (Fig. 2). Thirty-one new microfloral entities make their first appearance in this "zone" (Fig. 3). None of the older microfloral entities, except the long-ranging forms which are present throughout the studied sections, are present in "zone" C. The "zone" C microfloral assemblage is entirely different from that of "zone" A and indicates a Paleocene age for the basal Paskapoo succession."

Reference (age)

Snead RG. 1969. Microfloral diagnosis of the Creaceous-Tertiary boundary, Central Alberta. Research Council of Alberta Bulletin 25: 1-84

Fossil relationships

Node calibrated	**stem Pandanus (Pandanaceae, Pandanales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

No justification provided in original decription

Reference (relationships)

Snead RG. 1969. Microfloral diagnosis of the Creaceous-Tertiary boundary, Central Alberta. Research Council of Alberta Bulletin 25: 1-84

†Arengapollenites achinatus

Calibration at a glance	stem Caryoteae (Arecaceae, Arecales), min 47.8 Ma
ID number (NFos)	130

Fossil identity

Full taxon name	**†Arengapollenites achinatus R. H. Kar**
Organs	Pollen
Specimens	Holotype: slide no. 8236/2 (Birbal Sahni I. Palaeobotany)
Locality	Panandhro, Kachchh
Formation	Panandhro Lignite, Naredi Formation
Country	India

Reference (description)

Kar R. 1985. The fossil floras of Kachchh – IV. Tertiary palynostratigraphy. Palaeobotanist 34: 1–279.

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Ypresian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Iles et al 2015 (BJLS): "Marine biostratigraphy (Saraswati et al., 2012)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**stem Caryoteae (Arecaceae, Arecales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Suite of characters (Kar, 1985; Harley, 2006; Dransfield et al., 2008)"

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†*Mauritiidites crassibaculatus*

Calibration at a glance	crown Calamoideae (Arecaceae, Arecales), min 66 Ma
ID number (NFos)	128

Fossil identity

Full taxon name	**†Mauritiidites crassibaculatus van Hoeken-Klinkenberg**
Organs	Pollen
Specimens	Plates 6: figs 4–10; Plate 12: figs 6–10 (not deposited)
Locality	Hed-Hed locality
Formation	Yesomma Formation
Country	Somalia

Reference (description)

van Hoeken-Klinkenberg P. 1964. A palynological investigation of some Upper Cretaceous sediments in Nigeria. Pollen et Spores 6: 209–231.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Iles et al 2015 (BJLS): "Maastrichtian–?Campanian, biostratigraphy (Schrank, 1994; Fantozzi & Kassim Mohamed, 2002) [...] The earliest known occurrences of M. crassibaculatus are from the Maastrichtian of Nigeria and the slightly older Yesomma Formation (van Hoeken-Klinkenberg, 1964; Schrank, 1994)."

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Calamoideae (Arecaceae, Arecales)**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "The other group, Mauritiidites, is characterized by intectate monosulcate pollen with spines 'embedded' in the foot layer, causing a bulge below the spine in the pollen wall (van Hoeken-Klinkenberg, 1964; Harley, 2006). This pollen type also characterizes Mauritia L.f., and is similar to the pollen of the remaining members of subtribe Mauritiinae (tribe Lepidocaryeae) (Harley, 2006; Dransfield et al., 2008). It can therefore be considered to be an apomorphy for this subtribe. [...] As Calameae and Lepidocaryeae are sister taxa, the crown-node placement of Mauritiidites in Lepidocaryeae (i.e. the stem node of subtribe Mauritiinae) makes it more informative than the stem-node placement of Dicolpopollis in tribe Calameae. We agree with Couvreur et al. (2011) and consider Mauritiidites to be appropriate for calibrating the stem node of subtribe Mauritiinae."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses.

Botanical Journal of the Linnean Society 178: 346–374.

†*Sabalites carolinensis*

Calibration at a glance	stem Arecaceae (Arecales), min 83.6 Ma
ID number (NFos)	129

Fossil identity

Full taxon name	**†Sabalites carolinensis E.W. Berry**
Organs	Leaves
Specimens	Syntype: PAL 175717/P 38208 (USNM)
Locality	Near Langley locality, SC
Formation	Middendorf Formation
Country	USA

Reference (description)

Berry E. 1914. The Upper Cretaceous and Eocene floras of South Carolina and Georgia. Washington, DC: United States Geological Survey.

Fossil age

Safe minimum age	**83.6 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Santonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Iles et al 2015 (BJLS): "83.6–86.3 Ma; Santonian, marine biostratigraphy (Gohn et al., 1992)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**stem Arecaceae (Arecales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS) suggest stem Coryphoideae: "Costapalmate induplicate leaves are an apomorphy of subfamily Coryphoideae, and we therefore consider S. carolinensis to calibrate the stem node of Coryphoideae to the Santonian. As it is the oldest crown clade member of Arecaceae, it can also be used to calibrate the crown node of Arecaceae." However, we have doubts that Sabalites can be assigned to crown Arecaceae and therefore use this fossil as a constrain on the stem node of the family instead.

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Tripylocarpa aestuaria

Calibration at a glance	crown Arecoideae (Arecaceae, Arecales), min 63.49 Ma
ID number (NFos)	127

Fossil identity

Full taxon name	**†Tripylocarpa aestuaria Gandolfo & Futey**
Organs	Fruits
Specimens	Holotype: Pb-3766 (MPEF-Pb)
Locality	Las Violetas, Patagonia
Formation	Salamanca Formation
Country	Argentina

Reference (description)

Futey MK, Gandolfo MA, Zamaloa MC, Cúneo R, Cladera G. 2012. Arecaceae fossil fruits from the Paleocene of Patagonia, Argentina. Botanical Review 78: 205–234.

Fossil age

Safe minimum age	**63.49 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "Palaeomagnetic data from several sections of the Salamanca Formation have been assigned to Chrons C28n and C29n; specifically, the diverse palaeoflora has been determined as belonging to Chron C28n, indicating that the age of the flora is between 63.49 and 64.67 Ma (Clyde et al., 2014)."

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Arecoideae (Arecaceae, Arecales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "The permineralized fruits were placed within a new fossil species, Tripylocarpa aestuaria Gandolfo & Futey, the taxonomic position of which was explored using phylogenetic analyses of molecular sequences combined with morphological data. The results of these analyses confirmed the taxonomic placement suggested by the morphological and anatomical characters preserved in the fossils (Futey et al., 2012). Tripylocarpa is the first confirmed record for subtribe Attaleinae worldwide and can confidently be used to calibrate the stem node of Attaleinae (or equivalently the crown node of Cocoseae, see Baker et al., 2009); more inclusively it could date the crown node of Arecoideae."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†*Pollia tugenensis*

Calibration at a glance	stem Pollia (Commelinaceae, Commelinales), min 12.2 Ma
ID number (NFos)	157

Fossil identity

Full taxon name	**†Pollia tugenensis Jacobs & Kabuye**
Organs	Leaves
Specimens	Holotype: Kenya KNMP-BN 10769 (National Museums of Kenya)
Locality	Ngorora Formation type section at Kabarsero (0°53'N, 35°48'E) in the Tugen Hills, Baringo District
Formation	Ngorora Formation
Country	Kenya

Reference (description)

Jacobs, BF, Kabuye CHS. 1989. An extinct species of Pollia Thunberg (Commelinaceae) from the Miocene Ngorora Formation, Kenya. Review of Palaeobotany and Palynology 59: 67-76.

Fossil age

Safe minimum age	**12.2 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Jacobs & Kabuye 1989 (RevPalPal): "The age of this unit is well placed at 12.2 Ma based on a series of K/Ar dates and concordant paleomagnetic data (Tauxe et al., 1985)."

Reference (age)

Jacobs, BF, Kabuye CHS. 1989. An extinct species of Pollia Thunberg (Commelinaceae) from the Miocene Ngorora Formation, Kenya. Review of Palaeobotany and Palynology 59: 67-76.

Fossil relationships

Node calibrated	**stem Pollia (Commelinaceae, Commelinales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Jacobs & Kabuye 1989 (RevPalPal): "Pollia tugenensis shares leaf anatomical characters with several living PolZia species but appears to share the greatest number of diagnostic characters with P. zollingeri (Hasskarl) C.B. Clarke, an Asian endemic (Table I)."

Reference (relationships)

Jacobs, BF, Kabuye CHS. 1989. An extinct species of Pollia Thunberg (Commelinaceae) from the Miocene Ngorora Formation, Kenya. Review of Palaeobotany and Palynology 59: 67-76.

†Ethela sargantiana

Calibration at a glance stem Cyperaceae+Juncaceae, min 44.3 Ma
ID number (NFos) 333

Fossil identity

Full taxon name **†Ethela sargantiana Erwin & Stockey**
Organs Stems with attached roots, lateral branches and sheathing leaves
Specimens Holotype: P 1382 A 1 (pl. 1 fig. 1)
Locality Princeton, British Columbia
Formation Princeton Chert, Allenby Formation, Princeton Group
Country Canada

Reference (description)

Erwin DM, Stockey RA. 1992. Vegetative body of a permineralized monocotyledon from the Middle Eocene Princeton Chert of British Columbia. Courier Forschungsinstitut Senckenberg 147: 309–327.

Fossil age

Safe minimum age **44.3 Ma**
Absolute age source radioisotopic
Age quality score 5 / revised (radioisotopic)

Age justification

See Massoni et al 2015 (PE) on +Saururus tuckerae: "Fossils described by Smith and Stockey (2007) come from the Princeton Chert, 8.4 km south of Princeton, British Columbia, Canada, which is part of the Princeton Group, Allenby Formation (Boneham, 1968). The Princeton Chert consists of a series of alternating layers of coal and chert. The paleontological record supports a middle Eocene age, such as an amiid fish correlated with the occurrence of comparable fossils in British Columbia and in the Klondike Mountain Formation of Washington State (Wilson, 1982), and teeth of the mammal group Tillodontia (Russell, 1935). In addition, potassium-argon dating studies have provided comparable ages for the Allenby Formation: 48 ± 2 Ma (Rouse and Mathews, 1961; Mathews, 1964), between 47 ± 2 and 50 ± 2 Ma (Hills and Baadsgaard, 1967), and 46.2 ± 1.9 Ma and 49.4 ± 2 Ma (Read, 2000). With a different method (U-Pb age from zircons), Moss et al. (2005) suggested an age of 52.08 ± 0.12 Ma for the Allenby Formation. Finally, Smith and Stockey (2007) report a personal communication from H. Baadsgaard (University of Alberta, 1999) that supports an age of 48.7 Ma for the ash of Layer #22 of the Princeton Chert. Because the 7.5 m of the Princeton Chert sequence (incorporating the layer where the fossil was collected) may have accumulated in 15,000 years or less (Mustoe, 2011), this latter age is probably the closest to the real age of the fossil. However, in order to be conservative regarding the uncertainty of the age of this formation, and the fact that no uncertainty is associated with the latter age, Saururus tuckerae provides a safe minimum age of 44.3 Ma (the youngest age given by potassium-argon dating minus the associated error of 1.9 Ma)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated **stem Cyperaceae+Juncaceae**
Node assignment score 2 / intuitive or unspecified (trusted source)
Reconciliation score 3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The vegetative remains consist of stems with attached roots, lateral branches and sheathing leaves similar to those of Juncaceae or Cyperaceae. These fossils could be most closely related to either of the two extant families, or belong to the stem lineage of the clade including Cyperaceae plus Juncaceae. They are here used to calibrate the stem node of the clade including Cyperaceae plus Juncaceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Tillandsia-type pollen

Calibration at a glance	crown Bromeliaceae (Poales), min 41.2 Ma
ID number (NFos)	154

Fossil identity

Full taxon name	**†Tillandsia-type pollen Graham**
Organs	Pollen
Specimens	Pan D 4-1, W-30, 2-4; Pan D 2-1, T-28; Pan D 4-1, M-30, 2-4 (England Slide Finder coordinates, Kent State University)
Locality	Locality D
Formation	Gatuncillo Formation
Country	Panama

Reference (description)

Graham A. 1985. Studies in Neotropical Paleobotany. IV. The Eocene Communities of Panama. Annals of the Missouri Botanical Garden 72: 504–534.

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Graham 1985 (AMBG): "Woodring (1957-1982) has studied the mol- lusks of the Gatuncillo Formation, and Cole (1952) studied the larger foraminifera. On the basis of the stratigraphic distribution of these fossils in other Caribbean deposits, both authors conclude the Gatuncillo is middle(?) to late Eocene in age. The possibility of a middle Eocene age is considered because three of the larger fo- raminifera are known elsewhere in strata of this age, and two (Yaberinella jamaicensis and Fa- biania cubensis) are known only from the middle Eocene."

Reference (age)

Graham A. 1985. Studies in Neotropical Paleobotany. IV. The Eocene Communities of Panama. Annals of the Missouri Botanical Garden 72: 504–534.

Fossil relationships

Node calibrated	**crown Bromeliaceae (Poales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Graham 1985 (AMBG): "The assignment of these grains to the Bro- meliaceae is based on similarity to several species of Tillandsia. The specimen illustrated in Figure 19, for example, is especially similar to some grains of T. excelsa Griesb. (Ocampo 001159, Costa Rica, CR). Other fossil specimens are com- parable in morphology but differ slightly in mi- nor, quantitative features (e.g., almost immea- surable, minute differences in diameter of the lumen, wall thickness, height and/or width of the columellae, etc.). These differences are difficult to record accurately and consistently, but they do impart a different aspect to the grains that can be discerned visually. Consequently, the specimens are assigned to the next higher taxo- nomic rank (family Bromeliaceae), then com- pared (cf.) to the genus Tillandsia."

Reference (relationships)

Graham A. 1985. Studies in Neotropical Paleobotany. IV. The Eocene Communities of Panama. Annals of the Missouri Botanical Garden 72: 504–534.

†Volkeria messelensis

Calibration at a glance	crown Cyperaceae (Poales), min 47 Ma
ID number (NFos)	143

Fossil identity

Full taxon name	**†Volkeria messelensis S.Y.Sm., M.E.Collinson, D.A.Simpson, Rudall, Marone & Stampa**
Organs	Infructescences
Specimens	Holotype: Sm.B.Me 16474 (SMF)
Locality	Messel Pit, near Darmstadt
Formation	Messel Formation
Country	Germany

Reference (description)

Smith SY, Collinson ME, Simpson DA, Rudall PJ, Marone F, Stampanoni M. 2009. Elucidating the affinities and habitat of ancient, widespread Cyperaceae: Volkeria messelensis gen. et sp. nov., a fossil mapanioid sedge from the Eocene of Europe. American Journal of Botany 96: 1506–1518.

Fossil age

Safe minimum age	**47 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "40Ar/39Ar radiometry and sedimentation rate (Franzen, 2005; Mertz & Renne, 2005)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Cyperaceae (Poales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Recently, Volkeria messelensis S.Y.Sm., M.E.Collinson, D.A.Simpson, Rudall, Marone & Stampanoni was described from the Messel Pit of Germany (47 Ma; Franzen, 2005; Mertz & Renne, 2005), and is represented by complete infructescences with pollen and fruits that can be unambiguously assigned to subfamily Mapanioideae (Smith et al., 2009). Therefore, V. messelensis can be used to calibrate the stem node of Mapanioideae, or equivalently the crown node of Cyperaceae, as Mapanioideae are the sister group of the rest of the family (Simpson et al., 2006)."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Juncus vectensis

Calibration at a glance	stem Juncus (Juncaceae, Poales), min 27.82 Ma
ID number (NFos)	158

Fossil identity

Full taxon name	**†Juncus vectensis ME Collinson**
Organs	Seeds
Specimens	TYPE: Holotype V.60909, Fig. 17; Paratypes V.60910; V.60900(1), Fig. 32; and other specimens on V.60900. Specimen numbers British Museum (Nat. Hist.) eight seeds
Locality	Hamstead Ledge, National Grid Refs SZ 400918-404920. Isle of Wight, England
Formation	Bembridge Marls
Country	UK

Reference (description)

Collinson ME. 1983. Palaeofloristic assemblages and palaeoecology of the Lower Oligocene Bembridge Marls, Hamstead Ledge, Isle of Wight. Botanical Journal of the Linnean Society 86: 177-225.

Fossil age

Safe minimum age	**27.82 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Oligocene (Rupelian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Collinson 1983 (BotJLinnSoc): "In this paper, which describes quantitative and qualitative analyses of macroand microfloral remains, I follow Cooper (1976) and Curry et al. (1978) in placing the Eocene/Oligocene boundary at the base of the Bembridge Marls. Cavelier (1979), Chiteauneuf (1980) and Ollivier-Pierre (1980) place the boundary at the base of the overlying Hamstead Beds. A discussion of the controversy may be found in Curry et al. (1978)"

Reference (age)

Collinson ME. 1983. Palaeofloristic assemblages and palaeoecology of the Lower Oligocene Bembridge Marls, Hamstead Ledge, Isle of Wight. Botanical Journal of the Linnean Society 86: 177-225.

Fossil relationships

Node calibrated	**stem Juncus (Juncaceae, Poales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Collinson 1983 (BotJLinnSoc): "All features of these seeds are consistent with assignment to the family Juncaceae and to the extant genus Juncus (Fig. 27). Dickson (1970), Watts (1959) and Korber-Grohne (1964) have provided keys to identify certain species of Juncus seeds. There are, however, over 300 species in this genus and, in view of the limited features available, it is very unlikely that this Oligocene seed could be clearly excluded from all, or included in any one, modern species. (The problem is similar to that for Rhododendron seeds as discussed by Collinson & Crane, 1978.) Some genera in the family such as Luzula have distinct seeds but others may be similar to those of Juncus. For this reason the determination is only provisional."

Reference (relationships)

Collinson ME. 1983. Palaeofloristic assemblages and palaeoecology of the Lower Oligocene Bembridge Marls, Hamstead Ledge, Isle of Wight. Botanical Journal of the Linnean Society 86: 177-225.

†Changii indicum

Calibration at a glance	stem Ehrhartoideae (Poaceae, Poales), min 66 Ma
ID number (NFos)	144

Fossil identity

Full taxon name	**†Changii indicum V.Prasad, Strömberg, Leaché, B.Samant, R.Patnaik, L.Tang, Mohabey,**
Organs	Epidermis and phytoliths
Specimens	Holotype: slide 13160, coordinates: Q-14-3 (Birbal Sahni I. Palaeobotany)
Locality	Coprolites from Red clays; Pisdura East and Pisdura South
Formation	Lameta Formation, Deccan Traps
Country	India

Reference (description)

Prasad V, Strömberg CAE, Leaché AD, Samant B, Patnaik R, Tang L, Mohabey DM, Ge S, Sahni A. 2011. Late Cretaceous origin of the rice tribe provides evidence for early diversification in Poaceae. Nature Communications 2: 480.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "The age of the Deccan beds has been contentious. Here we follow Courtillot & Renne (2003) who reviewed the radiometric and magnetostragraphic evidence over the extent of the basaltic flows and suggest that the bulk of the flows closely straddled the Cretaceous–Palaeogene boundary. As C. indicum was recovered from dinosaur coprolites in horizons containing dinosaur bones (Prasad et al., 2011), we consider this fossil to be latest Maastrichtian (66 Ma)."

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**stem Ehrhartoideae (Poaceae, Poales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Iles et al 2015 (BJLS): "The oldest definitive fossils of Poaceae are from the Maastrichtian–Danian Deccan beds of India (Prasad et al., 2005, 2011). These are phytoliths formed in the short cells of grass leaf epidermis, belonging to ten form species with affinities to a number of clades and subfamilies of Poaceae (Prasad et al., 2005, 2011). Two of these phytolith form species, Changii indicum V.Prasad, Strömberg, Leaché, B.Samant, R.Patnaik, L.Tang, Mohabey, S.Ge & A.Sahni and Tateokai deccana V.Prasad, Strömberg, Leaché, B.Samant, R.Patnaik, L.Tang, Mohabey, S.Ge & A.Sahni, have been placed with tribe Oryzeae, subfamily Ehrhartoideae, using a Bayesian phylogenetic approach (Prasad et al., 2011); the remainder have not been analysed in this manner and so we do not consider them further. The epidermal fragment of the holotype of C. indicum is exceptionally well preserved and we consider it to be *suitable in dating the stem node of Oryzeae or, equivalently, the crown node of Ehrhartoideae (the former tribe is the sister group of the remainder of the latter subfamily; Grass Phylogeny Working Group II, 2012)."*

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Leersia seifhennersdorfensis

Calibration at a glance: crown Ehrhartoideae (Poaceae, Poales), min 30.44 Ma
ID number (NFos): 145

Fossil identity

Full taxon name: **†Leersia seifhennersdorfensis H.Walther**
Organs: Inflorescence
Specimens: Holotype: MMG, Sf. 12a; others: Sf. 154/ 71, Sf. 156/71 (MMG)
Locality: Seifhennersdorf
Formation: Seifhennersdorf Diatomite
Country: Germany

Reference (description)

Walther H. 1974. Ergänzung zur Flora von Seifhennersdorf/ Sachsen. II. Teil. Abhandlungen des Staatlichen Museums für Mineralogie und Geologie zu Dresden 21: 143–185.

Fossil age

Safe minimum age: **30.44 Ma**
Absolute age source: radioisotopic
Age quality score: 5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "K/Ar radiometry (Bellon et al., 1998)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated: **crown Ehrhartoideae (Poaceae, Poales)**
Node assignment score: 3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score: 3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Suite of characters (Walther, 1974; Walther & Kvacek, 2007)"

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†*Stipa florissanti*

Calibration at a glance	stem Pooideae (Poaceae, Poales), min 34.07 Ma
ID number (NFos)	146

Fossil identity

Full taxon name	**†Stipa florissanti (Knowlt.) MacGinitie**
Organs	Fruits
Specimens	Syntypes: 34750, 34751 (USNM)
Locality	Florissant and Florissant Fossil Beds National Monument, CO
Formation	Florissant Formation
Country	USA

Reference (description)

MacGinitie HD. 1953. Fossil plants of the Florissant Beds, Colorado. Washington, DC: Carniegie Institution of Washington.

Fossil age

Safe minimum age	**34.07 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "34.07–36.7 Ma; 40Ar/39Ar radiometry (Evanoff et al., 2001)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**stem Pooideae (Poaceae, Poales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "In Pooideae grass fruits described as Stipa florissanti (Knowlt.) MacGinitie are known from the Eocene Florissant Formation of Colorado (MacGinitie, 1953; Manchester, 2001). These fossils were compared closely with the extant Mexican species Nassella mucronata (Kunth) R.W.Pohl and other New World members of Stipeae [MacGinitie, 1953; Manchester, 2001; note that extant Stipa L. s.s. is considered to be restricted to the Old World (Romaschenko et al., 2010), and so this fossil may not necessarily fit the modern circumscription of Stipa]. The age of the Florissant Formation is constrained by radiometric dating to 34.07–36.70 Ma (Evanoff, Mcintosh & Murphey, 2001). As tribe Stipeae is clearly nested in Pooideae (Grass Phylogeny Working Group II, 2012), we consider Stipa florissanti from Colorado to constrain the stem node age of Stipeae or, more inclusively, the crown age of Pooideae." Here, we more conservatively use this fossil to constrain the stem node of Pooideae.

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Restiocarpum latericum

Calibration at a glance	stem Restionaceae (Poales), min 27.7 Ma
ID number (NFos)	147

Fossil identity

Full taxon name	**†Restiocarpum latericum M.E.Dettmann & Clifford**
Organs	Seeds
Specimens	Holotype: M110/S10, QMF50038 (Queensland Museum, Brisbane, Australia)
Locality	Rockhampton 1 locality, Queensland
Formation	Casuarina Beds
Country	Australia

Reference (description)

Dettmann ME, Clifford HT. 2000. Monocotyledon fruits and seeds, and an associated palynoflora from Eocene–Oligocene sediments of coastal central Queensland, Australia. Review of Palaeobotany and Palynology 110: 141–173.

Fossil age

Safe minimum age	**27.7 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "K/Ar radiometry and terrestrial biostratigraphy (Sutherland et al., 1977; Noon, 1980; Dettmann & Clifford, 2000)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**stem Restionaceae (Poales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS) assigned this fossil to the stem node of Centrolepidaceae + Restionaceae, based on a suite of characters (citing Dettmann & Clifford, 2000; Briggs & Linder, 2009). However, recent molecular phylogenies have confirmed that Centrolepidaceae are nested in Restionaceae, and the circumscription of the latter has now been expanded in APG IV (2016). Although the assignment of Iles et al. (2015) could be converted to the crown node of Restionaceae s.l., we believe further examination of the characters in light of the current phylogeny is necessary and prefer a more conservative assignment to the stem node of Restionaceae s.l.

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Typha sp.

Calibration at a glance	crown Typhaceae (Poales), min 51.66 Ma
ID number (NFos)	148

Fossil identity

Full taxon name	**†Typha sp.**
Organs	Inflorescence
Specimens	Specimen: PP33654 (FMNH)
Locality	Near Fossil Butte National Monument, Fossil Lake, WY
Formation	'18 inch' layer, Fossil Butte Mb, Green River Formation
Country	USA

Reference (description)

Grande L. 1984. Paleontology of the Green River Formation, with a review of the fish fauna, second edition. Geological Survey of Wyoming Bulletin 63: 1–333.

Fossil age

Safe minimum age	**51.66 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Iles et al 2015 (BJLS): "40Ar/39Ar radiometry of the K-feldspar tuff (Smith et al., 2008a; Buchheim et al., 2011)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated	**crown Typhaceae (Poales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Typha seeds are characterized as being elongate with a mucronate lid-like operculum that is one cell thick, a thin, membraneous seed coat with only two layers, longitudinally orientated integumentary cells and a small cone-shaped chalazal chamber (Dettmann & Clifford, 2000; M. E. Collinson, Royal Holloway University of London, pers. comm., 2014). The chemistry of Typha and Sparganium seed coats is distinctive and could also be used to strengthen the identity of fossil seeds (Collinson & van Bergen, 2004). The European Cretaceous (Maastrichtian) Typha specimens (Knobloch & Mai, 1986) are probably Typhaceae, but require additional study to demonstrate key features (Crepet et al., 2004; Friis et al., 2011). Although somewhat younger, one of the best preserved specimens consists of a complete inflorescence (cattail) from the early Eocene of Wyoming (Grande, 1984). The Fossil Lake locality is part of the Green River Formation and the fossil-bearing stratum ('18 inch' layer) is overlain by a K-feldspar tuff that has been radiometrically dated to 51.66 Ma (Smith, Carroll & Singer, 2008a; Buchheim, Cushman & Biaggi, 2011). This unnamed Typha cattail is considered suitable for calibrating the stem node of Typha or, equivalently, the crown node of Typhaceae."

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Spirematospermum chandlerae

Calibration at a glance: crown Zingiberales, min 72.1 Ma
ID number (NFos): 149

Fossil identity

Full taxon name: **†Spirematospermum chandlerae E.M. Friis**
Organs: Seeds
Specimens: Holotype: 401634 (USNM)
Locality: Neuse River, Goldsboro, NC
Formation: Tar Heels Formation
Country: USA

Reference (description)

Friis EM. 1988. Spirematospermum chandlerae sp. nov., an extinct species of Zingiberaceae from the North American Cretaceous. Tertiary Research 9: 7–12.

Fossil age

Safe minimum age: **72.1 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Campanian
Reference time scale: ICS (v2017/02)
Age quality score: 4 / revised (stratigraphic)

Age justification

Iles et al 2015 (BJLS): "72.1–83.6 Ma; (Early) Campanian, marine biostratigraphy (Owens & Sohl, 1989; Sohl & Owens, 1991; Mitra & Mickle, 2007)"

Reference (age)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

Fossil relationships

Node calibrated: **crown Zingiberales**
Node assignment score: 3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score: 3 / molecular tree only

Node justification

Iles et al 2015 (BJLS): "Spirematospermum M.Chandler, which has been variously assigned to Musaceae and Zingiberaceae, has an extensive fossil record covering Eurasia and North America from the Late Cretaceous nearly to the present day (Fischer et al., 2009; Friis et al., 2011). The oldest occurrence of the genus, S. chandlerae E.M.Friis, is from the early Campanian Tar Heels Formation of Neuse River, North Carolina (Friis, 1988; Owens & Sohl, 1989; Sohl & Owens, 1991; Mitra & Mickle, 2007; Friis et al., 2011). Its placement in a particular family has been contentious, but current evidence tends to point to an association with crown Zingiberaceae (S.Y.S., M. Collinson, Royal Holloway University of London, J. Benedict, University of Michigan & C. Specht, University of California, Berkeley, unpubl. data). Despite the uncertainty in its systematic placement, we consider this fossil useful for calibrating the stem of Zingiberaceae to the Campanian (72.1–83.6 Ma)." See also Magallón et al 2015 (NewPhytol), who used this fossil as a more conservative age constraint on stem Zingiberales.

Reference (relationships)

Iles WJD, Smith SY, Gandolfo MA, Graham SW. 2015. Monocot fossils suitable for molecular dating analyses. Botanical Journal of the Linnean Society 178: 346–374.

†Zingiberopsis magnifolia

Calibration at a glance	stem Zingiberaceae (Zingiberales), min 66 Ma
ID number (NFos)	159

Fossil identity

Full taxon name	**†Zingiberopsis magnifolia (Knowlton) Hickey**
Organs	Leaves
Specimens	NDO3-1.2 (Johnsrud Paleontology Laboratory at the North Dakota Heritage Center)
Locality	ND03-1, Emmons County, North Dakota (46.32N, 100.28W)
Formation	Linton Member of the Fox Hills Formation
Country	USA

Reference (first description)

Knowlton F. 1917. Fossil floras of the Vermejo and Raton formations of Colorado and New Mexico. U.S. Geological Survey Professional Paper 101: 223–435.

Reference (latest description)

Peppe DJ, Erickson JM, Hickey LJ. 2007. Fossil leaf species from the Fox Hills Formation (Upper Cretaceous: North Dakota, USA) and their paleogeographic significance. Journal of Paleontology 81: 550–567.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Peppe et al 2007 (JPalaeont): "The Fox Hills locality ND03-1/A140 is approximately 70 m below the Cretaceous–Tertiary (K-T) boundary, and the Hell Creek locality, ND05-10, lies approximately 35 m below the K-T boundary and about 2 m above the Breien Member of the Hell Creek Formation."

Reference (age)

Peppe DJ, Erickson JM, Hickey LJ. 2007. Fossil leaf species from the Fox Hills Formation (Upper Cretaceous: North Dakota, USA) and their paleogeographic significance. Journal of Paleontology 81: 550–567.

Fossil relationships

Node calibrated	**stem Zingiberaceae (Zingiberales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Hickey & Peterson 1978 (CanJBot): "A number of features of monocotyledon leaves with predominantly parallel ve nation belonging to the genus Zingiberopsis proved to be of unexpected value for their taxonomic determination. Most important of these was the division of the parallel ve nation into from one to several width classes and the arrangement of these in a definite sequence capable of expression as a formula. The three species of Zingiberopsis discussed here appear to represent a reduction series in which the four width subsets of parallel veins found in the late Cretaceous species are reduced to a single subset by late Paleocene time. Although Alpinia of the Zingiberaceae proved to be a clase match for the leaf architecture of the fos sils described here, high variability in the position of parallel vein origin and their early courses, as well as lack of evidence for petiolar ligules in Zingiberopsis, precluded *its assignment to that modern genus. In addition, no modern s pecies of Alpinia or of the ginger family reaches the extreme in reduction ofparallel veins to a single width subset that occurs in Zingiberopsis isonervosa. However, the development of substantial criteria upan which to base this familial determination permits us to regard the Late Cretaceous occurrence of Zingiberopsis rnagnifolia as documented evidence for the emergence of the Zingiberaceae by that time."*

Reference (relationships)

Hickey LJ, Peterson RK. 1978. Zingiberopsis, a fossil genus of the ginger family from Late Cretaceous to early Eocene sediments of Western Interior North America. Canadian Journal of Botany 56: 1136–1152.

†Hyrcantha decussata

Calibration at a glance: stem Eudicotyledoneae, min 125 Ma
ID number (NFos): 12

Fossil identity

Full taxon name: **†Hyrcantha decussata (Leng et Friis) Dilcher, Sun, Ji et Li**
Organs: Fragments of infructescences, attached and isolated fruits, and leaves
Specimens: Holotype – B0162
Locality: Dawangzhangzi Village, Songzhangzi Town, Lingyuan County, Chaoyang District, Liaoning Province
Formation: Yixian Formation, Jehol Group
Country: China

Reference (first description)

Leng Q, Friis EM. 2003. Sinocarpus decussatus gen. et sp. nov., a new angiosperm with basally syncarpous fruits from the Yixian Formation of Northeast China. Plant Systematics and Evolution 241: 77–88.

Reference (latest description)

Dilcher DL, Sun G, Ji Q, Li H. 2007. An early infructescence Hyrcantha decussata (comb. nov.) from the Yixian Formation in northeastern China. Proceedings of the National Academy of Sciences 104: 9370–9374.

Fossil age

Safe minimum age: **125 Ma**
Absolute age source: radioisotopic
Age quality score: 5 / revised (radioisotopic)

Age justification

Dilcher et al 2007 (PNAS): "The geological age of the fossil-bearing horizons, i.e., the age of the lower part of the Yixian Formation, has previously been considered to range from 122 to 145 Ma, but now a growing consensus accepts an age of ca. 125 Ma (2, 22–27)."

Reference (age)

Dilcher DL, Sun G, Ji Q, Li H. 2007. An early infructescence Hyrcantha decussata (comb. nov.) from the Yixian Formation in northeastern China. Proceedings of the National Academy of Sciences 104: 9370–9374.

Fossil relationships

Node calibrated: **stem Eudicotyledoneae**
Node assignment score: 3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score: 3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fossils are infrutescence fragments with several attached fruits, as well as isolated fruits and leaves. Infructescences are compound, with a branching system of at least two orders, perhaps combining alternate and opposite phyllotaxis, and seeds arranged in two rows, each row with about ten anatropous seeds. (Leng & Friis, 2006). Dilcher et al. (2007) considered Synocarpus decussatus congeneric with Hyrcantha karatscheensis from western Kazakhstan, except that the Chinese species has larger carpels that contain more seeds. These authors described it as follows "Plant erect, 20–25 cm tall, with predominately alternate branching of 30–45°, rarely ternate branching three to four times. Pedicels of the fruits, 1.5–2.7 cm long, ensheathed by an ocrea. Gynoecium superior with two to four oval-elongate carpels, in a decussate arrangement. Carpels have an 24 enlarged terminal mass that is filled with numerous resinous bodies. Two crests extend approximately one-eighth of *the carpel length, as well as a well defined adaxial suture extending approximately one-half of the carpel length. Each carpel contains 10–16 ovules/seeds attached along the adaxial linear placentae. Ovules/ seeds may occur in pairs. Ovules/seeds oval to oblong, anatropous, slightly pointed hilar region and rounded to truncate antihilar region" (Dilcher et al., 2007). Dilcher et al. (2007) indicated that several attributes of the fossil suggest it was an aquatic plant with emergent reproductive organs. Pollen has not been found in association with Sinocarpus decussatus/Hircantha decussata (Dilcher et al., 2007), therefore, unequivocal indication of its affinity with eudicots is unavailable. However, its combined morphological features suggest an affinity within eudicots, namely, the presence of inflorescences with decussate branching and the possibly tetramerous flower (Leng & Friis, 2003). The incomplete fusion of the carpels, the likely absence of a compitum, the superior ovary, the three or four carpels, and the possible long decurrent stigmatic region indicate that this fossil does not belong to the advanced eudicots, but rather represents a basal eudicot lineage (Leng & Friis, 2003). The leaves show distinct attributes that support a "dicot" affinity, namely, a distinct juncture between petiole and lamina, leaf venation of at least three discrete orders of veins forming a reticulate network, and the presence of glandular teeth with at least two orders of tooth venation (Hickey & Wolfe 1975; in Leng & Friis, 2006). Based on the morphological characters of the infructescence, particularly the superior and basally syncarpous gynoecium and the opposite-decussate phyllotaxis, and of the leaves, Leng & Friis (2003, 2006) considered this fossil as a basal eudicot or basal core eudicot, particularly resembling members of Ranunculaceae, Myrothamnaceae and Buxaceae. Dilcher et al. (2007) considered that, whereas the morphological attributres of Sinocarpus decussatus/Hircantha decussata are not found in any one species of Ranunculaceae, they correspond to various taxa over the entire family. Characteristics that are shared include paniculate inflorescences, unisexual flowers, few carpels (1–10) that are free to slightly connate, carpels with very short stalks, a stigma with two low crests extending down along the ventral suture, a well defined ventral suture extending down approximately one-half of the carpel length, and a placenta that is linear, lateral, and marginal (Dilcher et al., 2007). Sinocarpus decussatus/Hyrcantha decussata shows a number of features that relate it with Ranunculaceae, but also a combination that does not occur in this family (Dilcher et al., 2007). Leng & Friis (2003, 2006) found it resembles members of Ranunculaceae, Myrothmnaceae and Buxaceae, and considered it most likely represents a basal eudicot lineage. The morphological features of this fossil are found dispersed among members of eraly diverging eudicot lineages, hence, it might correspond to an eudicot crown group member. However, the possibility that it is an eudicot stem representative cannot be ruled out, especially because its pollen grains are unknown. Hence, Sinocarpus decussatus/Hyrcantha decussata is here used to calibrate the eudicot stem node."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Tricolpites micromunus

Calibration at a glance	stem Eudicotyledoneae, min 125 Ma
ID number (NFos)	183

Fossil identity

Full taxon name	**†Tricolpites micromunus (Groot & Penny) Burger**
Organs	Pollen
Specimens	Zone C-VII, well TM.1, 837.5-838.6 m (fig. 15-16)
Locality	Zone CVII, N'Toum No. 1 well near Libreville
Formation	N'Gwanze Formation
Country	Germany

Reference (first description)

Groot JJ, Penny JS. 1960. Plant microfossils and age of nonmarine Cretaceous sediments of Maryland and Delaware. Micropaleontology 6: 225–236.

Reference (latest description)

Doyle JA, Biens P, Doerenkamp A, Jardiné S. 1977. Angiosperm pollen from the pre-Albian lower Cretaceous of Equatorial Africa. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine 1: 451-473.

Fossil age

Safe minimum age	**125 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Barremian-Aptian boundary
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Tricolpate pollen referred to as aff. Tricolpites micromurus and aff. Tricolpites crassimurus from Pollen Zone C-VII of the Cocobeach sequence, Gabon, corresponding closely to the Barremian-Aptian boundary (Doyle et al., 1977, in Doyle & Hotton, 1991)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Eudicotyledoneae**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Angiosperms possesing tricolpate pollen (i.e., excluding the Illicium-type pollen) consistently form a well-supported clade, referred to as Eudicotyledoneae, in phylogenetic analyses (e.g., Donoghue and Doyle, 1989; Soltis et al., 2011). Thus, tricolpate pollen can be unequivocally related to the eudicot clade. The oldest fossil ocurrences of tricolpate pollen are in sediments closely corresponding to the Barremian-Aptian boundary. However, in slightly younger sediments, tricolpate pollen becomes more frequent, and undergoes a major diversification between the late Early Cretaceous and the onset of the Late Cretaceous. The single pollen grain from Barremian sediments in the Atherfield Wealden Bed 35 in the English succession is reported as being very small (16 ?m), with simple apertures and muri, and reticulate ornamentation (Hughes & McDougall, 1990). Its preservation is *similar to that of other pollen grains in the same assemblage (Hughes & McDougall, 1990), thus suggesting it does not represent an instance of contamination. A different type of tricolpate pollen, represented also by a single grain, is reported from the middle of Fitton's Group IV, Ferruginous Sands of the Atherfield succession, corresponding to the Aptian (Hughes & McDougall, 1990). The tricolpate pollen grains from the Cocobeach sequence in Gabon have a reticulate-columellate pollen wall. Grains referred to as aff. Tricolpites micromurus are reported as being small, about 16 µm long and 12 µm in diameter; and those referred to as aff. Tricolpites crassimurus as being larger, about 30 µm in diameter. Tricolpate-reticulate pollen becomes more diverse in Aptian sediments of the Cocobeach sequence, and includes grain referred to as to 'Retitricolpites' geranioides, cf. Tricolpites georgensis and Tricolpites sp. 2 (Doyle et al., 1977, cited in Friis et al., 2011, also cited in Doyle & Hotton, 1991). 'Retitricolpites' geranioides is about 50 µm long, and represents the largest of the tricolpate grains in this sequence. Tricolpate-striate pollen is reported from the early part of Pollen Zone VIII (Early Aptian) of the Cocobeach sequence (Doyle, 1999). Tricolpate pollen most likely evolved on the stem lineage of eudicots. The oldest fossil tricolpate pollen grains lack any distinctive features to link them to a particular living group within eudicots, and very possibly represent stem lineage relatives of eudicots as a whole. Hence, these grains are here used to calibrate the stem eudicot node."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Erdtmanipollis sp.*

Calibration at a glance	crown Buxaceae (Buxales), min 66 Ma
ID number (NFos)	185

Fossil identity

Full taxon name	**†Erdtmanipollis sp. Chmura**
Organs	Pollen
Specimens	Plate 27: AE36; L12.0, + 3.2; AE36; L12.4, +14.3
Locality	Localities: 1,3,4,5,6,7,8,9,10 (in Chmura 1973), San Joaquin Valley
Formation	Moreno Formation
Country	USA

Reference (description)

Chmura CA. 1973. Upper Cretaceous (Campanian-Maastrichtian) angiosperm pollen from the western San Joaquin Valley, California, U.S.A. Palaeontographica Abteilung B 141: 89–171.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Chmura 1973 (PalAbtB): "Ages of the samples range from the E provincial foraminiferal zone (Campanian) through the C provincial foraminiferal zone (Maastrichtian)."

Reference (age)

Chmura CA. 1973. Upper Cretaceous (Campanian-Maastrichtian) angiosperm pollen from the western San Joaquin Valley, California, U.S.A. Palaeontographica Abteilung B 141: 89–171.

Fossil relationships

Node calibrated	**crown Buxaceae (Buxales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

modern pollen of this unique type is as far is known confined to the two genera Pachysandra and Sarcococca in the Buxaceae.

Reference (relationships)

Chmura CA. 1973. Upper Cretaceous (Campanian-Maastrichtian) angiosperm pollen from the western San Joaquin Valley, California, U.S.A. Palaeontographica Abteilung B 141: 89–171.

†Lusistemon striatus

Calibration at a glance	stem Buxaceae (Buxales), min 110.8 Ma
ID number (NFos)	184

Fossil identity

Full taxon name	**†Lusistemon striatus Pedersen**
Organs	Fragmentary staminate flowers and many isolated stamens
Specimens	S122091 from sample Vale de Agua 141
Locality	Clay pit complex near the village of Vale de Agua, western Portugal (39°379150N, 8°519300W)
Formation	Figueira da Foz Formation (Famalicao Member)
Country	Portugal

Reference (description)

Pedersen KR, von Balthazar M, Crane PR, Friis EM. 2007. Early Cretaceous floral structures and in situ tricolpate-striate pollen: New early eudicots from Portugal. Grana 46: 176–196.

Fossil age

Safe minimum age	**110.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	early Albian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	4 / revised (stratigraphic)

Age justification

The Vale de Agua locality has a Late Aptian to Early Albian age (e.g., Friis et al., 2011). Given this uncertainty, we consider the Early Albian to be the safe, oldest stratigraphic age for this fossil (see also Anacostia portugallica).

Reference (age)

Friis EM, Crane PR, Pedersen KR. 2011. Early flowers and angiosperm evolution. Cambridge University Press.

Fossil relationships

Node calibrated	**stem Buxaceae (Buxales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Pedersen et al 2007 (Grana): "Lusistemon and Lusicarpus display a mosaic of characters that are found in various extant eudicot families, predominantly among early diverging eudicots and core eudicots, as well as in some Saxifragales. Floral characters are particularly similar to those of Buxaceae, but are also similar to those of the distantly related Daphniphyllaceae. Flowers of Buxaceae, like those of several other early diverging eudicots, are characterized by a low level of synorganisation between floral organs. In contrast, in the context of other Saxifragales, the flowers of Daphniphyllaceae are adapted to a specific pollination syndrome (i.e. wind-pollination). Pollen in the fossil material is distinct and shows a greater similarity to pollen of other members of early diverging eudicots. The combined evidence from reproductive structures and pollen indicates that the fossil is probably best placed among the early diverging lineages of eudicots and probably close to extant Buxaceae."

Reference (relationships)

Pedersen KR, von Balthazar M, Crane PR, Friis EM. 2007. Early Cretaceous floral structures and in situ tricolpate-

striate pollen: New early eudicots from Portugal. Grana 46: 176–196.

†Spanomera marylandensis

Calibration at a glance — stem Buxaceae (Buxales), min 100.5 Ma
ID number (NFos) — 19

Fossil identity

Full taxon name — **†Spanomera marylandensis Drinnan, Crane, Friis, Pedersen**
Organs — Inflorescences
Specimens — Holotype-PP42978
Locality — West Brothers clay pit, eastern Marylan
Formation — Patapsco Formation, Potomac Group
Country — USA

Reference (description)

Drinnan AN, Crane PR, Friis EM, Pedersen KR. 1991. Angiosperm flowers and tricolpate pollen of buxaceous affinity from the Potomac Group (Mid-Cretaceous) of Eastern North America. American Journal of Botany 78: 153–176.

Fossil age

Safe minimum age — **100.5 Ma**
Absolute age source — stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age — Late Albian
Reference time scale — ICS (v2017/02)
Age quality score — 2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Flowers and isolated flower parts assigned to Spanomera marylandensis Drinnan, Crane, Friis & Pedersen, from the West Brothers pit (Patapsco Formation, Potomac Group, Maryland, USA), assigned to upper part of palynological Subzone II-B of the Potomac succession, corresponding to the late Albian (Drinnan et al., 1991; Doyle & Endress, 2010; Friis et al., 2011)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated — **stem Buxaceae (Buxales)**
Node assignment score — 5 / phylogenetic analysis
Reconciliation score — 5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Magallón et al 2015 (NewPhytol): "Spanomera marylandensis is known from receptacles of staminate flowers, dispersed stamens, and a few fragments of pistillate flowers (Drinnan et al., 1991). Each of these separate floral parts is very similar to those of Spanomera mauldiniensis Drinnan, Crane, Friis & Pedersen, known from the younger Mauldin Mountain locality, Elk Neck Beds, Potomac Group, Maryland, USA, from palynological Zone III of the Potomac succession, corresponding to the early Cenomanian (Drinnan et al., 1991). The genus Spanomera consists of inflorescences with staminate and pistillate flowers, all with a clear opposite-decussate organization. Staminate flowers have (2+2) or (2+3) tepals and stamens. The anthers have thecae that are ventrally displaced, and dehiscence is through a slit. Pistillate flowers are bicarpellate. Each carpel is semicircular in outline, with a decurrent stigma along most of the curved ventral margin (Drinnan et al., 1991). Both species of Spanomera are very similar and differ mostly in size and in the number of parts in the staminate flowers. Pollen similar to that produced by

Spanomera marylandensis is common in many Potomac Group samples and has been referred to the dispersed pollen species Striatopollis vermimurus (Brenner) Srivastava, which is tricolpate, prolate, with clearly delimited colpi that extend approximately 2/3 of the grain, with semitectate, with widely spaced muri that result in a coarse striate-rugulate to reticulate-rugulate structure (Drinnan et al., 1991). Drinnan et al. (1991) considered that the morphological and structural features of Spanomera suggest a relationship with Buxaceae, especially the opposite and decussate organization of inflorescences and flowers, and the presence of a well-developed pistillode in the center of staminate flowers. Doyle & Endress (2010) included Spanomera in a morphology-based phylogenetic analysis, where its most parsimonious position was as sister to Buxaceae. In this analysis, Didymeles, the sister taxon to other Buxales was not included. On the basis of specialized features of the pollen present in Didymeles and in Buxaceae, and on the simple apertures in the pollen of Spanomera, it is thought that the fossil genus diverged before the split of Didymeles (Doyle & Endress, 2010), and thus is a stem representative of Buxales. Spanomera is here used to calibrate the Buxales stem node."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Nelumbites extenuinervis

Calibration at a glance	stem Nelumbonaceae (Proteales), min 100.5 Ma
ID number (NFos)	186

Fossil identity

Full taxon name	**†Nelumbites extenuinervis Upchurch, Crane & Drinnan**
Organs	Reproductive structures, leaves and rizomes
Specimens	USNM (Mount Vernon locality; illustrated by Fontaine in Ward, 1895, Pl 4, fig. 7; and by Fontaine in Ward, 1905, Pl 109, fig 2)
Locality	Quantico locality (Potomac Group), Virginia
Formation	Potomac Group
Country	USA

Reference (description)

Upchurch GR, Crane PR, Drinnan AN. 1994. The megaflora from the Quantico locality (upper Albian) Lower Cretaceous Potomac Group of Virginia. Memoirs of the Virginia Museum of Natural History 4:1-57.

Fossil age

Safe minimum age	**100.5 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Albian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Leaves assigned to Nelumbites extenuinervis Upchurch, Crane & Drinnan and stratigraphically associated dispersed tepals, floral receptacle and rhizome from the Quantico locality of the Potomac Formation, Virginia, U.S.A. (Upchurch et al., 1994), corresponding to the upper part of palynological Subzone II-B of the Potomac Group, which is thought to correspond to the late middle to early late Albian (Doyle & Endress, 2010)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Nelumbonaceae (Proteales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Upchurch et al. (1994) consider that "The features of foliar architecture preserved in Nelumbites extenuinervis are consistent with postulated affinities to extant Nelumbonaceae and indicate similar leaf physiognomy. Physiognomic analysis of 30 Nelumbites extenuinervis foliage from Quantico indicates that this species probably had a growth habit similar to that of extant Nelumbo. Three lines of evidence support this conclusion. First, the leaf lamina shows strong tendencies toward orbicular shape, the point of petiole attachment is displaced towards the center of the leaf, and the petiole attaches to the blade at a high angle. Second, the primary venation shows strong radial organization, the primary and secondary veins bifurcate well within the margin, several series of excostal loops are developed within the margin. Third, growth habit is laminar shape in the vertical dimension.". A second type of *leaves, of smaller size, referred to as Nelumbites cf. N. minimus Vakhrameev was also recorded from the Quantico locality (Upchurch et al., 1994). Reproductive remains similar to those of extant Nelumbo also occur in the Quantico locality, strengthening the relationship with this living taxon. These include "laminar units with similarities in venation, shape, and preservational features to tepals and axial structures with similarities to Nelumbo floral receptacles at fruiting stage. The venation in the fossil tepals is similar to that in tepals of extant Nelumbo but less complex, perhaps due to their smaller size. Additional reproductive structures comprise three impressions that preserve features suggestive of a floral axis. The structures preserved may be readily interpreted in terms of the characteristic morphology of fruiting receptacles of Nelumbo." (Upchurch et al., 1994). Doyle & Endress (2010) included Nelumbites and associated rizomes and reproductive structures in a phylogenetic analysis based on morphology. Nelumbites was most parsimoniously placed as sister to Nelumbo. On the basis of the morphological vegetative and reproductive similarities of Nelumbites and associated rhizomes and reproductive structures with Nelumbo, and on the results of the phylogenetic analysis by Doyle & Endress (2010), these fossils can be used to calibrate the stem node of Nelumbonaceae. However, because an immeditaely nested node is calibrated with an older age (see Calibration 35), the calibration to stem node Nelumbonaceae is not included.*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Platanocarpus brookensis/Aquia brookensis (Sapindopsis)

Calibration at a glance	stem Platanaceae (Proteales), min 107.7 Ma
ID number (NFos)	188

Fossil identity

Full taxon name	**†Platanocarpus brookensis/Aquia brookensis (Sapindopsis)**
Organs	Staminate and pistillate inflorescences, flowers
Specimens	Platanocarpus brookensis PP42988
Locality	Bank near Brooke, Maryland
Formation	Patapsco Formation, Potomac Group
Country	USA

Reference (description)

Crane PR, Pedersen KR, Friis EM, Drinnan AN. 1993. Early Cretaceous (early to middle Albian) platanoid inflorescences associated with Sapindopsis leaves from the Potomac Group of Eastern North America. Systematic Botany 18: 328–344.

Fossil age

Safe minimum age	**107.7 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	middle Albian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	4 / revised (stratigraphic)

Age justification

Doyle & Endress 2010 (JSystEvol): "Palynological correlations place Brooke in lower Subzone II-B, thought to be middle Albian (Doyle & Hickey, 1976; Doyle & Robbins, 1977)."

Reference (age)

Doyle JA, Endress PK. 2010. Integrating Early Cretaceous fossils into the phylogeny of living angiosperms: Magnoliidae and eudicots. Journal of Systematics and Evolution 48: 1–35.

Fossil relationships

Node calibrated	**stem Platanaceae (Proteales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Doyle & Endress 2010 (JSystEvol): "Sapindopsis leaves are preserved as compressions and impressions. They are pinnatifid to nearly compound (Doyle & Endress, 2010). The staminate inflorescences assigned to Aquia brookensis "consist of globose aggregations of flowers containing stamens with long filaments, and anthers with valvate dehiscence and a massive connective. Anthers contain tricolpate foveo-reticulate pollen." (Crane et al., 1993). The 31 psitillate inflorescences and infructescences assigned to Platanocarpus brookensis "consist of flowers in globose aggregations that are borne directly on the inflorescence axis. Individual flowers are sessile and each consist of five free carpels, surrounded by a prominent perianth." (Crane et al., 1993). Evidence of association between the leaves and both types of reproductive organs is provided by cuticular structure and the presence of Aquia-type pollen on carpels of Platanocarpus brookensis (Crane et al., 1993). Doyle & Endress (2010) included the "Aquia plant" in a phylogenetic analysis based on morphological characters, which showed it is most parsimoniously placed as sister to *extant Platanus. Based on vegetative and reproductive similarities of Sapindopsis, Platanocarpus brookensis and Aquia brookensis with extant Platanaceae, attributes of many additional Cretaceous Platanaceae, and the result of Doyle & Endress (2010) phylogenetic analysis, these fossils are interpreted as stem group members of Platanaceae, and are used to calibrate the stem node of Platanaceae."*

Reference (relationships)

Doyle JA, Endress PK. 2010. Integrating Early Cretaceous fossils into the phylogeny of living angiosperms: Magnoliidae and eudicots. Journal of Systematics and Evolution 48: 1–35.

†*Platanus basicordata*

Calibration at a glance	crown Platanaceae (Proteales), min 56 Ma
ID number (NFos)	187

Fossil identity

Full taxon name	**†Platanus basicordata Budantsev**
Organs	Leaves and infructescences
Specimens	No. 3736-6/426, No. 3736-6/42a (Paleontological Institute, Moscow)
Locality	Western Kamchatka, Chemurnaut Bay
Formation	Tropovaya Formation
Country	Russia

Reference (description)

Maslova NP. 1996. Genus Platanus L. (Platanaceae Dumortier) in the Paleocene of Kamchatka. Paleontol. J. 2:88-93.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Stratigraphic (Serov et al. 1989)

Reference (age)

Maslova NP. 1996. Genus Platanus L. (Platanaceae Dumortier) in the Paleocene of Kamchatka. Paleontol. J. 2:88-93.

Fossil relationships

Node calibrated	**crown Platanaceae (Proteales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	3 / molecular tree only

Node justification

Suite of characters

Reference (relationships)

Maslova NP. 1996. Genus Platanus L. (Platanaceae Dumortier) in the Paleocene of Kamchatka. Paleontol. J. 2:88-93.

†HUC11 Taxon 1

Calibration at a glance	crown Proteaceae (Proteales), min 72.1 Ma
ID number (NFos)	189

Fossil identity

Full taxon name	**†HUC11 Taxon 1 Carpenter, Macphail, Jordan & Hill**
Organs	Leaves with cuticle
Specimens	No specimen number provided in original description (housed at School of Biological Sciences, University of Adelaide)
Locality	Bundey Basin (HUC11 sediments), located ~140 km northeast of Alice Springs, Northern Territory (~22°39'25''S, 135°15'04''E; Fig. 1)
Formation	
Country	Australia

Reference (description)

Carpenter RJ, Macphail MK, Jordan GJ, Hill RS. 2015. Fossil evidence for open, proteaceae-dominated heathlands and fire in the late cretaceous of Australia. American Journal of Botany 102: 2092–2107.

Fossil age

Safe minimum age	**72.1 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Campanian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Carpenter et al 2015 (AmJBot): "Microfossils from the HUC11 samples were generally well-preserved, abundant and diverse (Table 1), providing an extensive resource for dating the sediments. The presence of Quadraplanus brossus (Fig. 3A), a more sparsely ornamented variant of Q . brossus referred to here as Quadraplanus sp. cf. Q . brossus and Tricolporites lilliei (Fig. 3B), demonstrates that the sediments from 96.00 to 108.14 m were deposited during the Late Campanian to Maastrichtian (Forcipites longus Zone Equivalent time). Within this interval, the section from 96.00 to 98.04 m is dated as late Late Maastrichtian (Upper Forcipites longus Zone Equivalent time; ~67– 65.5 Myr old) and the section from 99.82 to 108.14 m as Late Campanian to early Late Maastrichtian (Lower Forcipites longus Zone Equivalent; ~75–67 Myr old), based on the presence or absence of Stereisporites (al. Tripunctisporis) maastrichtiensis (Fig. 3C), respectively (Table 2)."
It is not entirely clear where exactly +HUC11 Taxon 1 came from, however we consider the extensive collection of Proteaceae microfossils and mesofossils reported in this paper in general, and the oldest records of Proteaceae microfossils (sampled interval 12) as sufficient evidence for presence in the Campanian.

Reference (age)

Carpenter RJ, Macphail MK, Jordan GJ, Hill RS. 2015. Fossil evidence for open, proteaceae-dominated heathlands and fire in the late cretaceous of Australia. American Journal of Botany 102: 2092–2107.

Fossil relationships

Node calibrated	**crown Proteaceae (Proteales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Carpenter et al 2015 (AmJBot) reported on a large number of Proteaceae microfossils and mesofossils assigned to the family of subclades of it based primarily on general similarity. Here we chose +HUC11 Taxon 1 as a representative placeholder for these fossils. +HUC11 Taxon 1 is a leaf cuticle proposed to belong in subfamily Proteoideae. Because of the lack of an adequate phylogenetic evaluation of this fossil, we here use it more conservatively to constrain the crown node of Proteaceae as a whole.

Reference (relationships)

Carpenter RJ, Macphail MK, Jordan GJ, Hill RS. 2015. Fossil evidence for open, proteaceae-dominated heathlands and fire in the late cretaceous of Australia. American Journal of Botany 102: 2092–2107.

†Meliosma praealba

Calibration at a glance	crown Sabiaceae (Proteales), min 66 Ma
ID number (NFos)	195

Fossil identity

Full taxon name	**†Meliosma praealba Knobloch & Mai**
Organs	Endocarps
Specimens	Holotype: MMG (9246)
Locality	Walbeck, graue Tone
Formation	
Country	Germany

Reference (description)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Endocarps assigned to Meliosma prealba Knobloch & Mai & Sabia microsperma Knobloch & Mai from Walbeck, Germany; and Sabia praeovalis Knobloch & Mai from Eisleben, Germany, both localities corresponding to the Maastrichtian (Knobloch & Mai, 1986)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**crown Sabiaceae (Proteales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The endocarps of Sabiaceae are distinctive, and generic differences between Sabia and Meliosma can be identified. Endocarps of Sabiaceae are reported from Upper Cretaceous sediments of Europe and from several early Tertiary localities of North America (Manchester, 1999). Because Sabia an Meliosma can be distinguished by attributes of the endocarps, the fossils are considered as representatives of these two living genera, and are used to calibrate the crown node of Sabiaceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Sabia menispermoides*

Calibration at a glance crown Sabiaceae (Proteales), min 89.8 Ma
ID number (NFos) 196

Fossil identity

Full taxon name **†Sabia menispermoides Knobloch & Mai**
Organs Endocarps
Specimens Holotype: UUG (EK 55)
Locality Klikov-Schichtenfolge
Formation
Country Czech Republic

Reference (description)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil age

Safe minimum age **89.8 Ma**
Absolute age source stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age Turonian
Reference time scale ICS (v2017/02)
Age quality score 2 / unrevised (old source < 2000)

Age justification

Knobloch & Mai 1986 (Praha): "Blätterfunde wurden von NEMEJC (1957, 1961), KNOBLOCH (1964) und NEMEJC - KVACEK (1975), die Pollen von PACLTOVA. (1961, 1981) bearbeitet. Einen ausführlichen Überblick über die paläobotanischbiostratigraphische Problematik gibt KNOBLOCH (1985), der die Klikov-Schichtenfolge anhand paläokarpologischer Belege in das Oberturon bis Santon stellt."

Reference (age)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil relationships

Node calibrated **crown Sabiaceae (Proteales)**
Node assignment score 2 / intuitive or unspecified (trusted source)
Reconciliation score 1 / pre-molecular era (before 1990)

Node justification

No detailed justification provided in original description

Reference (relationships)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

†Teixeiraea lusitanica

Calibration at a glance	stem Ranunculales, min 110.8 Ma
ID number (NFos)	194

Fossil identity

Full taxon name	**†Teixeiraea lusitanica von Balthazar, Pedersen and Friis**
Organs	Staminate flower
Specimens	S125001
Locality	Near the village of Vale de Agua in western Portugal (39 37¢15¢¢N, 8 51¢30¢¢W)
Formation	Figueira da Foz Formation
Country	Portugal

Reference (description)

von Balthazar M, Pedersen KR, Friis EM. 2005. Teixeiraea lusitanica, a new fossil flower from the Early Cretaceous of Portugal with affinities to Ranunculales. Plant Systematics and Evolution 255: 55–75.

Fossil age

Safe minimum age	**110.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	early Albian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

von Balthazar et al 2005 (PlantSystEvol): "Early Cretaceous (late Aptian or early Albian), basal part (Famalicao Member) of the Figueira da Foz Formation."

Reference (age)

von Balthazar M, Pedersen KR, Friis EM. 2005. Teixeiraea lusitanica, a new fossil flower from the Early Cretaceous of Portugal with affinities to Ranunculales. Plant Systematics and Evolution 255: 55–75.

Fossil relationships

Node calibrated	**stem Ranunculales**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The flower of Teixeiraea lusitanica "is actinomorphic and unisexually male. At the base of the bud there are several bracts of different sizes, which are followed by sepal-like and petal-like tepals. Bracts and perianth organs seem to be arranged spirally and to exhibit transitions between different organ categories. The androecium has numerous stamens of two sizes, but with unclear arrangement. Pollen is small and tricolpate with a perforate tectum and a densely columellate infratectal layer. No carpels or remains of carpels could be observed on the floral axis" (von Balthazar et al., 2005). Von Balthazar et al. (2005) considered that Teixeiraea lusitanica shows most affinities to members of Ranunculales, but it is also similar to some core eudicots, namely to Hamamelidaceae and Daphniphyllaceae (Saxifragales), and to Berberidopsis (Berberidopsidaceae, Berberidopsidales). The membership of Teixeiraea lusitanica with eudicots is indicated by the presence of tricolpate pollen. According to von Balthazar et al. (2005), it displays a mosaic of characters that, among extant taxa, are predominantly found in Ranunculales (Lardizabalaceae, Menispermaceae, Berberidaceae and Papaveraceae). However, the fossil is also characterized by some unique features, such as the two categories of stamens sizes or the *arrangement of thecae, which are not present in any of these extant families of Ranunculales (von Balthazar et al., 2005). These authors considered that this fossil probably represents a separate, now extinct phylogenetic lineage within the crown group of Ranunculales or along its stem lineage (von Balthazar et al., 2005). Because von Balthazar et al. (2007) considered Teixeiraea lusitanica to be most similar to Lardizabalaceae, Menispermaceae, Berberidaceae and Papaveraceae, we here consider it to be a stem lineage member of the least inclusive clade that includes all these exant families. Hence, it is used to constrain crown group Ranunculales." Here, we more conservatively use this fossil to constrain the stem node of Ranunculales.*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Sargentodoxa globosa

Calibration at a glance	crown Lardizabalaceae (Ranunculales), min 41.2 Ma
ID number (NFos)	190

Fossil identity

Full taxon name	**†Sargentodoxa globosa (Manchester) Manchester**
Organs	Seeds
Specimens	Holotype: USNM 424644
Locality	Clarno nut beds, Oregon
Formation	Nut Beds Flora, Clarno Formation
Country	USA

Reference (first description)

Manchester SR. 1994. Fruits and Seeds of the Middle Eocene Nut Beds Hora, Clarno Formation, Oregon. Paleontographica Americana 58: 1-205

Reference (latest description)

Manchester SR. 1999. Biogeographical relationships of North American Tertiary floras. Annals of the Missouri Botanical Garden 86: 472–522.

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Summarized by Sauquet et al 2012 (SystBiol) on Castanopsis crepetii: "40Ar–39Ar weighted mean age of 43.8 ± 0.3 Ma, and Bridgerian mammal fossils (Manchester 1994)" Here, we conservatively used the equivalent stratigraphic age (but this will be revised in future versions of this dataset).

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**crown Lardizabalaceae (Ranunculales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The seeds assigned to Sargentodoxa globosa were described originally as Bumelia? globosa by Manchester (1994). Subsequently, Manchester indicated that these structures correspond to internal molds of the seed coat of Sargentodoxa, as they perfectly match the placement of the raphe, microphyle, and chalaza in this genus (Manchester, 1999). Sargentodoxa globosa could belong to the stem lineage or the crown group of Lardizabalaceae, and is here used to calibrate the Lardizabalaceae stem node." Here, we less conservatively use this fossil to constrain the crown node of Lardizabalaceae, on th eassumtption that it is more closely related to Sargentodoxa than members of subfamily Lardizabaloideae.

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Menispina evidens

Calibration at a glance	stem Cissampelideae (Menispermaceae, Ranunculales), min 56 Ma
ID number (NFos)	336

Fossil identity

Full taxon name	**†Menispina evidens Herrera, Manchester, Hoot, Wefferling, Carvalho & Jaramillo**
Organs	Endocarps
Specimens	BF19-ING-0014
Locality	Checua mine, Nemocón, Cundinamarca state
Formation	Bogotá Formation
Country	Colombia

Reference (description)

Herrera F, Manchester SR, Hoot SB, Wefferling KM, Carvalho MR, Jaramillo C. 2011. Phytogeographic implications of fossil endocarps of Menispermaceae from the Paleocene of Colombia. American Journal of Botany 98: 2004–2017.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	late Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Herrera et al (2011) reviewed the age of the Bogota Formation, indicating a possible age from middle to late Paleocene. As Magallón et al (2015), we here consider the late Paleocene as the safe oldest stratigraphic age for this fossil.

Reference (age)

Herrera F, Manchester SR, Hoot SB, Wefferling KM, Carvalho MR, Jaramillo C. 2011. Phytogeographic implications of fossil endocarps of Menispermaceae from the Paleocene of Colombia. American Journal of Botany 98: 2004–2017.

Fossil relationships

Node calibrated	**stem Cissampelideae (Menispermaceae, Ranunculales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

The molecular backbone analysis by Herrera et al (2011) clearly places this fossil taxon as sister to or within the Stephania-Cissampelos-Cyclea ("S-C-C") clade, which is well nested in crown Menispermaceae (see Fig. 50 of Herrera et al 2011). The phylogeny presented by Ortiz et al (2016) appears to be generally consistent with the molecular backone used in these analyses and recognizes the S-C-C clade as tribe Cissampelideae, hence our attribution of this fossil to the stem node of Cissampelideae.

Reference (relationships)

Herrera F, Manchester SR, Hoot SB, Wefferling KM, Carvalho MR, Jaramillo C. 2011. Phytogeographic implications of fossil endocarps of Menispermaceae from the Paleocene of Colombia. American Journal of Botany 98: 2004–2017.

†*Palaeoluna bogotensis*

Calibration at a glance	stem Cissampelideae (Menispermaceae, Ranunculales), min 56 Ma
ID number (NFos)	360

Fossil identity

Full taxon name	**†Palaeoluna bogotensis Herrera, Manchester, Hoot, Wefferling, Carvalho et Jaramillo**
Organs	Endocarp
Specimens	B F20-IN G-00 1 9 (Fig. 13); BF20-ING-0018 (Fig. 16); BF20-ING-0024 (Fig. 14); BF20-ING-G0026 (Fig. 15)
Locality	Checua mine, Nemocón locality, Cundinamarca State
Formation	Bogotá Formation
Country	Paleocene

Reference (description)

Herrera F, Manchester SR, Hoot SB, Wefferling KM, Carvalho MR, Jaramillo C. 2011. Phytogeographic implications of fossil endocarps of Menispermaceae from the Paleocene of Colombia. American Journal of Botany 98: 2004–2017.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	late Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Herrera et al (2011) reviewed the age of the Bogota Formation, indicating a possible age from middle to late Paleocene. As Magallón et al (2015), we here consider the late Paleocene as the safe oldest stratigraphic age for this fossil.

Reference (age)

Herrera F, Manchester SR, Hoot SB, Wefferling KM, Carvalho MR, Jaramillo C. 2011. Phytogeographic implications of fossil endocarps of Menispermaceae from the Paleocene of Colombia. American Journal of Botany 98: 2004–2017.

Fossil relationships

Node calibrated	**stem Cissampelideae (Menispermaceae, Ranunculales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

The molecular backbone analysis by Herrera et al (2011) clearly places this fossil taxon as sister to or within the Stephania-Cissampelos-Cyclea ("S-C-C") clade, which is well nested in crown Menispermaceae (see Fig. 50 of Herrera et al 2011). The phylogeny presented by Ortiz et al (2016) appears to be generally consistent with the molecular backbone used in these analyses and recognizes the S-C-C clade as tribe Cissampelideae, hence our attribution of this fossil to the stem node of Cissampelideae.

Reference (relationships)

Herrera F, Manchester SR, Hoot SB, Wefferling KM, Carvalho MR, Jaramillo C. 2011. Phytogeographic implications of fossil endocarps of Menispermaceae from the Paleocene of Colombia. American Journal of Botany 98: 2004–2017.

†Prototinomiscium vangerowii

Calibration at a glance stem Menispermaceae (Ranunculales), min 89.8 Ma
ID number (NFos) 192

Fossil identity

Full taxon name	**†Prototinomiscium vangerowii Knobloch & Mai**
Organs	Endocarp
Specimens	Holotype: SEM, UUG (EK 3126)
Locality	Aachen, grauer Basiston [type]; Klikov-Schichtenfolge
Formation	
Country	Czech Republic

Reference (first description)

Knobloch E, Mai DH. 1984. Neue Gattungen nach Früchten und Samen aus dem Cenoman bis Maastricht (Kreide) von Mitteleuropa. Feddes Repertorium 95: 3–41.

Reference (latest description)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil age

Safe minimum age	**89.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Turonian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Knobloch & Mai 1986 (Praha): "Blätterfunde wurden von NEMEJC (1957, 1961), KNOBLOCH (1964) und NEMEJC - KVACEK (1975), die Pollen von PACLTOVA. (1961, 1981) bearbeitet. Einen ausführlichen Überblick über die paläobotanischbiostratigraphische Problematik gibt KNOBLOCH (1985), der die Klikov-Schichtenfolge anhand paläokarpologischer Belege in das Oberturon bis Santon stellt." (For presence of this fossil in the Klikov-Schichtenfolge locality, see Tabelle 10)

Reference (age)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil relationships

Node calibrated	**stem Menispermaceae (Ranunculales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Friis et al 2011 (book): "The endocarps are characterized by a distinct keel that indicates a relationship with extant members of the section Tinosporeae."

Reference (relationships)

Friis EM, Crane PR, Pedersen KR. 2011. Early flowers and angiosperm evolution. Cambridge University Press.

†Stephania palaeosudamericana

Calibration at a glance	stem Cissampelideae (Menispermaceae, Ranunculales), min 60 Ma
ID number (NFos)	191

Fossil identity

Full taxon name	**†Stephania palaeosudamericana Herrera, Manchester, Hoot, Wefferling, Carvalho & J**
Organs	Endocarp
Specimens	CJ85-ING-1412
Locality	Tabaco Extensión Cogua
Formation	Cerrejón Formation
Country	Colombia

Reference (description)

Herrera F, Manchester SR, Hoot SB, Wefferling KM, Carvalho MR, Jaramillo C. 2011. Phytogeographic implications of fossil endocarps of Menispermaceae from the Paleocene of Colombia. American Journal of Botany 98: 2004–2017.

Fossil age

Safe minimum age	**60 Ma**
Absolute age source	radioisotopic
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Herrera et al 2011 (AmJBot): "The Cerrejón Formation has been dated as middle to late Paleocene (~60 Ma) based on pollen zonation, correlations with stable carbon isotopic data, and marine microfossils (Jaramillo et al., 2007 ; 2011)."
(Here I suggest a literal reading of this recent source, even though our conversion rule of middle Paleocene would reach a very similar age, but in theory middle to late Paleocene is uncertainty)

Reference (age)

Herrera F, Manchester SR, Hoot SB, Wefferling KM, Carvalho MR, Jaramillo C. 2011. Phytogeographic implications of fossil endocarps of Menispermaceae from the Paleocene of Colombia. American Journal of Botany 98: 2004–2017.

Fossil relationships

Node calibrated	**stem Cissampelideae (Menispermaceae, Ranunculales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

The molecular backbone analysis by Herrera et al (2011) clearly places this fossil taxon as sister to or within the Stephania-Cissampelos-Cyclea ("S-C-C") clade, which is well nested in crown Menispermaceae (see Fig. 50 of Herrera et al 2011). The phylogeny presented by Ortiz et al (2016) appears to be generally consistent with the molecular backone used in these analyses and recognizes the S-C-C clade as tribe Cissampelideae, hence our attribution of this fossil to the stem node of Cissampelideae.

Reference (relationships)

Herrera F, Manchester SR, Hoot SB, Wefferling KM, Carvalho MR, Jaramillo C. 2011. Phytogeographic implications of fossil endocarps of Menispermaceae from the Paleocene of Colombia. American Journal of Botany 98: 2004–2017.

†Paleoactaea nagelii

Calibration at a glance	crown Coptidoideae+Thalictroideae+Ranunculoideae (Ranunculaceae, Ranunculales), mi
ID number (NFos)	193

Fossil identity

Full taxon name	**†Paleoactaea nagelii Pigg & DeVore**
Organs	Fruits
Specimens	UWSP 1572
Locality	Almont and Beicegel Creek floras, North Dakota
Formation	Almont and Beicegel Creek floras, Sentinel Butte Formation
Country	USA

Reference (description)

Pigg KB, DeVore ML. 2005. Paleoactaea gen. nov. (Ranunculaceae) Fruits from the Paleogene of North Dakota and the London Clay. American Journal of Botany 92: 1650–1659.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Palaeocene
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Pigg & deVore 2005 (AmJBot): "Fruits of Paleoactaea nagelii are anatomically preserved in silicified shale from two areas in central and western North Dakota (Bluemle, 1983, 2000). Most are from the original Almont site, Morton County, central North Dakota (Crane et al., 1990), with one specimen from Beicegel Creek, MacKenzie County, approximately 120 km to the west (Manchester et al., 2004). Both collecting sites occur within the Sentinel Butte Formation and are considered Late Paleocene (Tiffanian) based on mammal correlations (Kihm and Hartman, 1991)."

Reference (age)

Pigg KB, DeVore ML. 2005. Paleoactaea gen. nov. (Ranunculaceae) Fruits from the Paleogene of North Dakota and the London Clay. American Journal of Botany 92: 1650–1659.

Fossil relationships

Node calibrated	**crown Coptidoideae+Thalictroideae+Ranunculoideae (Ranunculaceae, Ranunculales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Pigg & deVore 2005 (AmJBot): "Fruits are 5–7 mm wide, 4.5–6 mm high, 10–13 mm long, and bilaterally symmetrical, containing 10–17 seeds attached on the upper margin in 2–3 rows. A distinctive honeycomb pattern is formed where adjacent seeds with prominent palisade outer cell layers abut. Seeds are flattened, ovoid, and triangular. To the inside of the palisade cells, the seed coat has a region of isodiametric cells that become more tangentially elongate toward the center. The embryo cavity is replaced by an opaline cast. This fruit bears a striking resemblance to extant Actaea, the baneberry (Ranunculaceae), an herbaceous spring wildflower of North Temperate regions."

Reference (relationships)

Pigg KB, DeVore ML. 2005. Paleoactaea gen. nov. (Ranunculaceae) Fruits from the Paleogene of North Dakota and the London Clay. American Journal of Botany 92: 1650–1659.

†Nordenskioldia borealis

Calibration at a glance	stem Trochodendrales, min 66 Ma
ID number (NFos)	197

Fossil identity

Full taxon name	**†Nordenskioldia borealis Heer emend. Crane, Manchester, and Dilcher**
Organs	Infructescences
Specimens	Lectotype: S.100666
Locality	Cap Staratschin, Spitsbergen [type locality, not oldest record]
Formation	Hell Creek Formation
Country	USA

Reference (description)

Crane PR, Manchester SR, Dilcher DL. 1991. Reproductive and vegetative structure of Nordenskioldia (Trochodendraceae), a vesselless dicotyledon from the Early Tertiary of the Northern Hemisphere. American Journal of Botany 78: 1311–1334.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Magallón et al 2015 (NewPhytol): "Nordenskioldia was widespread during the Paleocene, but it is also known from Upper Cretaceous localities in Asia and North America (Manchester, 1999), including for example, the Hell Creek Formation, Montana, North Dakota, South Dakota and Wyoming, USA (K. Johnson, pers. comm. to S. Magallón, 1999; Magallón et al., 1999). Considering the report of Nordenskioldia in the upper Cretaceous, we implemented 65.5 Ma, the upper limit of the Maastrichtian, as a minimum age"

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Trochodendrales**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Nordenskioldia was initially described from Paleocene sediments of Spitzbergen by Heer (1870). An affinity with Trochodendrales was first suggested by Kryshtofovich (1956, 1958, in Crane et al., 1991). Crane et al. (1991) convincingly reinterpreted Nordenskioldia as fruits produced by an extinct member of Trochodendrales, most closely related to extant Trochodendron, based on well-preserved material from Almont, (North Dakota); Melville (Montana); and Monarch (Wyoming), USA, all correspnding to the Paleocene. The fruits of Nordenskioldia are "schizocarpic, and individual fruitlets also dehisce to release reticulate seeds. Anatomical details of infructescence axes are identical to those of co-occurring distinctive long and short soot systems, and neither the axes or shoots have vessels in the secondary xylem." (Crane et al., 1991). On the basis of stratigraphic co-

occurrences, and comparisons of floras from Paleocene localities from Asia, Europe and North America, Crane et al. (1991) reconstructed the reproductive and vegetative characters, including association with leaves assigned to different form genera of the “Cocculus type” (treated as Ziziphoides), of the Nordenskioldia plant. The Nordenskioldia plant was assigned to Trochodendrales by Crane et al. (1991), who considered it to be closely related to the extant genus Trochodendron. We consided Nordenskioldia to be a stem lineage member of Trochodendrales, and use it to calibrate the Trochodendrales stem node."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Dakotanthus cordiformis

Calibration at a glance	stem Pentapetalae, min 100.5 Ma
ID number (NFos)	325

Fossil identity

Full taxon name	**†Dakotanthus cordiformis (Lesq.) Manchester, Dilcher, Judd & Basinger**
Organs	Flower
Specimens	USNM 50016 (Lesquereux 1892, pl. 22, fig. 9; refigured here pl. 3, fig. 11)
Locality	Rose Creek locality (locality number IU 15713), Nebraska
Formation	Dakota Formation
Country	USA

Reference (first description)

Basinger JF, Dilcher DL. 1984. Ancient bisexual flowers. Science 224: 511–513.

Reference (latest description)

Manchester SR, Dilcher DL, Judd WS, Corder B, Basinger JF 2018. Early Eudicot flower and fruit: Dakotanthus gen. nov. from the Cretaceous Dakota Formation of Kansas and Nebraska, USA. Acta Palaeobotanica, 58: 27-40.

Fossil age

Safe minimum age	**100.5 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Albian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Manchester et al 2018 (ActaPaleobot): "The Dakota Formation is considered to be late Albian toCenomanian in age, ca 100 Ma (Upchurch & Dilcher 1990, Brenner et al. 2000, Ludvigson et al. 2010). Although radiometric dates from zircon are available from Dakota Formation sites along the western side of the Epicontinental Seaway in Utah, indicating Middle to Late Cenomanian age (Barclay et al. 2015), the dating of floras on the eastern side of the seaway relies mainly on biostratigraphic correlation. Numerous specimens were collected by David Dilcher and colleagues and students from shales of the Dakota Formation from a quarry 6 miles south of Fairbury, southeastern Nebraska; they are deposited at the Florida Museum of Natural History. Referred to as the Rose Creek locality (Rose Creek pit sensu Gröcke et al. 2006), this site includes a diverse leaf flora and was considered by Upchurch & Dilcher (1990) to be early to middle Cenomanian. However, Gröcke et al. (2006) have proposed, based on palynology and carbon isotope investigations through the local 10-m-thick section, that the Rose Creek pit straddles the Albian-Cenomanian boundary, with the leaf and flower megafossils occurring below the boundary."

Reference (age)

Manchester SR, Dilcher DL, Judd WS, Corder B, Basinger JF 2018. Early Eudicot flower and fruit: Dakotanthus gen. nov. from the Cretaceous Dakota Formation of Kansas and Nebraska, USA. Acta Palaeobotanica, 58: 27-40.

Fossil relationships

Node calibrated	**stem Pentapetalae**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

See discussion in Magallón et al (2015), as 'Rose Creek flower'. Sauquet et al. (2017) showed that the general *morphology of this fossil is probably ancestral for Pentapetalae as a whole, but it remains uncertain where exactly it originated. According to the ML results from the C tree series, perianth pentamery most likely originated between the stem and the crown node of Pentapetalae, whereas differentiation originated along a deeper branch (the stem lineage of core eudicots, or Gunneridae). Although further analyses are required to pinpoint the origin of the Pentapetalae floral groundplan and to formally include this fossil in phylogenetic analyses, these results suggest that this fossil should calibrate the stem node of Pentapetalae.*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Tetracera eocenica*

Calibration at a glance crown Dilleniaceae (Dilleniales), min 47.8 Ma
ID number (NFos) 262

Fossil identity

Full taxon name **†Tetracera eocenica Reid & Chandler**
Organs Seed
Specimens Holotype. V. 22842
Locality Island of Sheppey
Formation London Clay Flora
Country UK

Reference (description)

Reid EM, Chandler MEJ. 1933. The London Clay flora. British Museum (Natural History), London, UK.

Fossil age

Safe minimum age **47.8 Ma**
Absolute age source stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age Ypresian
Reference time scale ICS (v2017/02)
Age quality score 2 / unrevised (old source < 2000)

Age justification

Chandler 1961a (book) clearly places the London Clay Flora in the Ypresian, an age that has apparently not been challenged since.

Reference (age)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Fossil relationships

Node calibrated **crown Dilleniaceae (Dilleniales)**
Node assignment score 2 / intuitive or unspecified (trusted source)
Reconciliation score 3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Seeds like those of modern Hibbertia and Tetracera were recorded in the Early Eocene of England, UK (Chandler, 1964). We use these fossils to calibrate the crown node of Dilleniaceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Joffrea speirsii*

Calibration at a glance	stem Cercidiphyllaceae (Saxifragales), min 56 Ma
ID number (NFos)	198

Fossil identity

Full taxon name	**†Joffrea speirsii Crane**
Organs	Vegetative axes with long and short shoots, leaves, pistillate inflorescences, seeds
Specimens	UAPC-ALTA S11437A & B
Locality	Joffre Bridge locality 14 km east of Red Deer, Alberta
Formation	Paskapoo Formation
Country	Canada

Reference (description)

Crane PR, Stockey RA. 2010. Growth and reproductive biology of Joffrea speirsii gen. et sp. nov., a Cercidiphyllum -like plant from the Late Paleocene of Alberta, Canada. Canadian Journal of Botany 63: 340–364.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Thanetian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Crane & Stockey 1985 (CanJBot): "Plants occur in a road cut on the west bank of the Red Deer River in sediments dated as Tiffanian (Late Paleocene) on the basis of fossil mammals (Fox 1984; Krause 1978)"

Reference (age)

Crane PR, Stockey RA. 2010. Growth and reproductive biology of Joffrea speirsii gen. et sp. nov., a Cercidiphyllum -like plant from the Late Paleocene of Alberta, Canada. Canadian Journal of Botany 63: 340–364.

Fossil relationships

Node calibrated	**stem Cercidiphyllaceae (Saxifragales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Joffrea speirssii is known from pistillate inflorescences with attached carpels, folliculate infrutescences, seeds, seedlings, leaves and shoots. It is similar to the widespread Upper Cretaceous and early Tertiary fossil Nyssidium arcticum. Crane & Stockey (1985) found substantial similarity between Joffrea and the extant genus Cercidiphyllum in the "organization of the pistillate inflorescence, leaf morphology, phyllotaxy and seed morphology. In both Joffrea and Cercidiphyllum the pistillate inflorescence is produced from an axillary bud, but the mode of short shoot growth and leaf production is very different. The arrengement of long shoot leaves in Joffrea is unknown, but the opposite leaves of short shoots and seedlings are comparable with the opposite to subopposite leaf arrangement seen in long shoots of Cercidiphyllum. Externally the long shoots of Joffrea had distinct circular lenticels similar to those of extant Cercidiphyllum. Leaves of Joffrea are strikingly similar to those of extant Cercidiphyllum in gross morphology, major and fine venation and details of the marginal glands." (Crane & Stockey, 1985)." Crane & Stockey (1985) found similarities between the bud scales at the base of inflorescences in Joffrea and in Cercidiphyllum, but noted some differences in the details on the lateral veins of the follicles of the two genera.

There are also similarities in the seeds, which are “winged and have a raphe which extends into the wing before turning abruptlyand entering the chalaza of the seed body, but differ considerabñy in other features. Those of Joffrea vary in the form of the wing but are generally crescent shaped and always have the seed body positioned 60 proximally and towards the convex margin. Seeds of Cercidiphyllum are more angular and rarely crescent shaped, and the position of the seed body varies considerably. Frequently the seed body is placed centrally within the wing. In addition, the surface of Joffrea seeds is finely striated, whereas that of extant Cercidiphyllum is reticulate and composed of large equiaxial cells with prominent periclinal walls.” (Crane & Stockey, 1985). On the basis of the detailed similarity between Joffrea speirsii and Cercidiphyllum, Crane & Stockey (1985) interpreted the fossil as an extinct representative of the family Cercidiphyllaceae. We accept this interpretation, and use Joffrea to calibrate the stem node of this family."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Tarahumara sophiae

Calibration at a glance	stem Haloragaceae (Saxifragales), min 72.1 Ma
ID number (NFos)	200

Fossil identity

Full taxon name	**†Tarahumara sophiae Hernández-Castillo & Cevallos-Ferriz**
Organs	Fruiting structures
Specimens	Paleontological Collection of the Instituto de Geología, UNAM LPB 3434
Locality	Huepac chert locality, Sonora
Formation	Tarahumara Formation (Huepac Chert)
Country	Mexico

Reference (description)

Hernandez-Castillo GR, Cevallos-Ferriz SRS. 1999. Reproductive and vegetative organs with affinities to Haloragaceae from the Upper Cretaceous Huepac Chert Locality of Sonora, Mexico. American Journal of Botany 86: 1717.

Fossil age

Safe minimum age	**72.1 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Campanian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Hernandez-Castillo & Cevallos-Ferriz 1999 (AmJBot): "The volcanicsedimentary sequence in southern Sonora is dated by the U-Pb method as 70 million years (m.y.) (McDowell et al., 1994). The sequence is composed of rhyolitic rocks towards the base and alternating cycles of limestone, stromatolitic limestone, and chert towards the top of the section (Fig. 1)."

Reference (age)

Hernandez-Castillo GR, Cevallos-Ferriz SRS. 1999. Reproductive and vegetative organs with affinities to Haloragaceae from the Upper Cretaceous Huepac Chert Locality of Sonora, Mexico. American Journal of Botany 86: 1717.

Fossil relationships

Node calibrated	**stem Haloragaceae (Saxifragales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Tarahumara sophiae is known from inflorescences/infructescences, and isolated flowers and fruits. "The flowers of Tarahumara sophiae are similar to those of extant Haloragaceae in morphology and anatomy. They share a reduced perianth composed of four carpels with one anatropous, pendulous ovule per carpel and an inferior ovary. Further similarities between Tarahumara sophiae and Haloragaceae are seen in fruitlet anatomy. Fossil flowers and fruits of Tarahumara sophiae are similar to those of the Tribe Myriophylleae (Meziella and Myriophyllum, the two genera of this tribe) where the ovary is differentiated into four separated carpels (Orchard & Keighery, 1993). In Meziella the carpels are surrounded by persistent, long sepals that are fused to form a terminal corona (Orchard & Keighery, 1993). The presence of this structure in Meziella resembles the floral cup of Tarahumara sophiae, which surrounds *the four-apocarpic-syncarpic carpels" (Hernández-Castillo & Cevallos-Ferriz, 1999). When comparing this fossil with extant genera, Hernández-Castillo & Cevallos-Ferriz (1999) considered that "From the third verticil on, Tarahumara sophiae has a terminal simple dichasia with opposite branches resembling those of extant Haloragodendron. The inflorescence of Haloragodendron is a simple determinate dichasium. A dichasium, and more often the compound dichasium, is the basic unit of the indeterminate inflorescences/infructescences in Haloragaceae (Orchard, 1975). However, it is important to remark that the first two nodes have 63 verticillate axile flowers, resembling the position of the flowers of almost all extant species of Myriophyllum." The stems assigned to Obispocaulis myriophylloides have "epidermis composed of semi-obloid cells with thin cuticle. The stems can be found isolated, or in groups of two or three, and are surrounded by ensheathing leaves. The presence of more than one stem in certain zones of these axes where stems ramify resembles the condition in the nodes of extant genera in the Haloragaceae. The anatomy of this fossil stems is very characteristic and similar of those of submerged stems of the genus Myriophyllum. The fossil stems are characterized by having an epidermis, a single circle of large lacunae separated by radially arranged chains of parenchyma cells connecting the inner and outer cortex, a welldeveloped endodermis, and a nonlacunate central stele with tracheids and some vessels. Among aquatic or subaquatic plants there are some genera with similar aerenchyma in their stems, but their architecture is quite different from that observed in Obispocaulis myriophylloides" (Hernández-Castillo & Cevallos-Ferriz, 1999). Hernández-Castillo & Cevallos-Ferriz (1999) considered that the plant represented by Tarahumara sophiae plus Obispocaulis myriophylloides "represents an extinct taxon with a mosaic of characters that can be found today in two or three extant genera (Myriophyllum, Meziella, and Haloragodendron) of the Haloragaceae. Documenting this situation is important since the history of the family based on the fossil record alludes to the presence of fruits and pollen grains that have been referred to extant taxa. The new fossil plant (T. sophiae + O. myriophylloides) broadens the morphology of reproductive and vegetative structures among Haloragaceae." We consider that the fossil plant was a stem representative of Haloragaceae, and use it to calibrate the stem node of this family.*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Allonia decandra

Calibration at a glance	crown Hamamelidaceae (Saxifragales), min 83.6 Ma
ID number (NFos)	201

Fossil identity

Full taxon name	**†Allonia decandra**
Organs	Flower
Specimens	PP44595 Paleobotanical Collections of the Field Museum. Chicago
Locality	Approximately 9.5 km southeast of Roberta, Georgia; South pit of the Atlanta Sand and Supply Company at Gaillard, rawford County, Georgia (Knoxville Quadrangle, 32°37'47"N, 83059 ' 1if'W)
Formation	Gaillard Formation (Buffalo Creek Member, Allon Flora)
Country	USA

Reference (description)

Magallón-Puebla S, Herendeen PS, Endress PK. 1996. Allonia decandra: Floral remains of the tribe Hamamelideae (Hamamelidaceae) from Campanian strata of southeastern USA. Plant Systematics and Evolution 202: 177–198.

Fossil age

Safe minimum age	**83.6 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Santonian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón-Puebla et al 1996 (PlantSystEvol): "The sediments belong to the Buffalo Creek Member of the Gaillard Formation, and based on palynological analyses, are thought to be of Late Santonian to earliest Campanian age (CHRISTOPHER 1979, HUDDLESTUN & HETTRICK 1991)."

Reference (age)

Magallón-Puebla S, Herendeen PS, Endress PK. 1996. Allonia decandra: Floral remains of the tribe Hamamelideae (Hamamelidaceae) from Campanian strata of southeastern USA. Plant Systematics and Evolution 202: 177–198.

Fossil relationships

Node calibrated	**crown Hamamelidaceae (Saxifragales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	2 / morphological tree only

Node justification

Magallón-Puebla et al 1996 (PlantSystEvol): "The fossil flower is actinomorphic, pentacyclic and pentamerous. Irregular sepals are preserved as lobes of the floral cup, and petals are narrow, with parallel margins. The androecium has two whorls of functional stamens. Anthers are tetrasporangiate, dehisce through two valves, and have strongly elongate connective protrusions which converge over the center of the flower. The organizational and architectural features of the fossil document its affinity within subtribe Loropetalinae (Hamamelideae, Hamamelidoideae). Cladistic phylogenetic analyses using parsimony were conducted to explore the relationships between the fossil flower and extant genera of the tribe Hamamelideae. The strict consensus of the four most parsimonious trees shows Hamamelideae and Loropetalinae as well-supported monophyletic taxa. The fossil flower is clearly included within the Loropetalinae, and is placed as sister taxon to the southeastern Asian genus Maingaya."

Reference (relationships)

Magallón-Puebla S, Herendeen PS, Endress PK. 1996. Allonia decandra: Floral remains of the tribe Hamamelideae (Hamamelidaceae) from Campanian strata of southeastern USA. Plant Systematics and Evolution 202: 177–198.

†Itea sp.

Calibration at a glance	crown Iteaceae (Saxifragales), min 48 Ma
ID number (NFos)	199

Fossil identity

Full taxon name	**†Itea sp. Wolfe & Wehr**
Organs	Leaf
Specimens	UW 31262, 39725.
Locality	Locality 8428, Republic, NE Washington
Formation	Klondike Mountain Formation
Country	USA

Reference (description)

Wolfe JA, Wehr WC. 1987. Middle Eocene dicotyledonous plants from Republic, northeastern Washington. United States Geological Survey Bulletin 1597: 1–25.

Fossil age

Safe minimum age	**48 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Wolfe & Wehr 1987 (USGeolSurveyBull): "Radiometric ages from the Klondike Mountain Formation range from 42.3 ±2.0 to 50.3 ±1.7 m.y. (Pearson and Obradovich, 1977). The three samples dated are from flows, and all samples came from the same stratigraphic position about 300 m above the plant-bearing unit in the Torada graben. Two of the samples had three analyses each; these analyses produced an average apparent age of 48.1 ± 1.8 m.y. for one sample and 49.4 ± 1.6 m.y. for the second sample. The third sample, on which two analyses were made, produced an average apparent age of 42.4 ±1.8 m.y. The two older apparent ages are in close agreement and are accepted as the upper age limit for the Republic flora. Because the Sanpoil Volcanics are 51-52 m.y. old and are unconformable beneath the Klondike Mountain, the Republic flora is probably closer in age to 48-49 m.y. than to 51-52 m.y."

Reference (age)

Wolfe JA, Wehr WC. 1987. Middle Eocene dicotyledonous plants from Republic, northeastern Washington. United States Geological Survey Bulletin 1597: 1–25.

Fossil relationships

Node calibrated	**crown Iteaceae (Saxifragales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Wolfe & Wehr 1987 (USGeolSurveyBull): "Three fragments all representing foliar apices have the characters diagnostic of Itea: (1) strongly eucamptodromous, strongly curving secondary veins, (2) somewhat sinuous tertiary veins that are all approximately perpendicular to the midrib, and (3) a finely serrate margin that has teeth that are uniformly spaced and markedly point apically."

Reference (relationships)

Wolfe JA, Wehr WC. 1987. Middle Eocene dicotyledonous plants from Republic, northeastern Washington. United States Geological Survey Bulletin 1597: 1–25.

†Staphylea minutidens

Calibration at a glance	crown Staphyleaceae (Crossosomatales), min 56 Ma
ID number (NFos)	240

Fossil identity

Full taxon name	**†Staphylea minutidens (Knowlton) Brown**
Organs	Leaf
Specimens	5686, 5714, 5799 [Brown 1962 (GSPP)]
Locality	One-half of a mile east of Abeton, CO (5686); At Turner mine, 1 1/2 miles north of Wooton, CO (5714); 5 miles northwest of Weston, CO (5799)
Formation	Raton Formation
Country	USA

Reference (first description)

Knowlton F. 1917. Fossil floras of the Vermejo and Raton formations of Colorado and New Mexico. U.S. Geological Survey Professional Paper 101: 223–435.

Reference (latest description)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Stratigraphy (Brown 1948, 1962)

Reference (age)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

Fossil relationships

Node calibrated	**crown Staphyleaceae (Crossosomatales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

No formal description of the fossil, but Brown 1962 (GSPP) reassigned it to Staphylea with the following justification (formerly described in Juglans): "The long petioles of these leaflets are not harmonious with an assignment to Juglans, whose leaflets are generally sessile or nearly so."

Reference (relationships)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

†Turpinia uliginosa

Calibration at a glance	crown Staphyleaceae (Crossosomatales), min 27.82 Ma
ID number (NFos)	345

Fossil identity

Full taxon name	**†Turpinia uliginosa Tiffney**
Organs	Seed
Specimens	"The holotype is assigned number 51389 and the paratype number 51390 in the Paleobotanical Collections of the Botanical Museum of Harvard University"
Locality	Vermont
Formation	Brandon Lignite
Country	USA

Reference (description)

Tiffney BH. 1979. Fruits and seeds of the Brandon Lignite III. Turpinia (Staphyleaceae). Brittonia 31: 39–51.

Fossil age

Safe minimum age	**27.82 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	early Oligocene (Rupelian)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Seeds assigned to Turpinia uliginosa Tiffney from the Brandon Lignite, Vermont, USA, corresponding to the early Oligocene (Rupelian) (Tiffney, 1979)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**crown Staphyleaceae (Crossosomatales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Two seeds collected from the lignitic facies of the Brandon lignite "show a distinctive multiperforate hilium that links them with Staphylea and Turpinia. The faceted nature of the smaller fossil indicates a derivation from a locule bearing a number of closely packed seeds, a condition found only in the latter genus." (Tiffney, 1979). Tiffney (1979) compared the fossil seeds with those of Malaysian and New World species of Turpinia, and on the basis of the degree of angularity of the seeds (as a result of how tightly they are packed in the fruit), he suggested that the fossils might have been more closely related to the New World members of the genus, although an exact similarity with an extant species could not be found. We consider that these seeds were closely related to Turpinia (= Staphylea), and use them to calibrate the crown group of Staphyleaceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Rhynchotheca type

Calibration at a glance	crown Francoaceae (Geraniales), min 15.97 Ma
ID number (NFos)	241

Fossil identity

Full taxon name	**†Rhynchotheca type Palazzesi, Gottschling, Barreda & Weigend**
Organs	Pollen
Specimens	Specimen: BaPal ex CIRGEO 940 (G37-1)
Locality	Patagonia
Formation	Chenque Formation
Country	Argentina

Reference (description)

Palazzesi L, Gottschling M, Barreda V, Weigend M. 2012. First Miocene fossils of Vivianiaceae shed new light on phylogeny, divergence times, and historical biogeography of Geraniales. Biological Journal of the Linnean Society 107: 67–85.

Fossil age

Safe minimum age	**15.97 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Burdigalian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Palazzesi et al 2012 (BiolJLinnSoc): "The most complete fossil assemblage of Geraniales comes from the Miocene of eastern Patagonia (Argentina), representing the first record of Vivianiaceae. These are Balbisia sect. Wendtia type and Rhynchotheca type from the early Middle Miocene (15.97 ± 0.05 Mya) and Balbisia sect. Balbisia type, Viviania marifolia type, and Viviania albiflora type from the Late Miocene (10 ± 0.3 Mya) Scasso et al. (2001)."

Reference (age)

Palazzesi L, Gottschling M, Barreda V, Weigend M. 2012. First Miocene fossils of Vivianiaceae shed new light on phylogeny, divergence times, and historical biogeography of Geraniales. Biological Journal of the Linnean Society 107: 67–85.

Fossil relationships

Node calibrated	**crown Francoaceae (Geraniales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Palazzesi et al 2012 (BiolJLinnSoc): "The morphology of these specimens resembles Rhynchotheca spinosa."

Reference (relationships)

Palazzesi L, Gottschling M, Barreda V, Weigend M. 2012. First Miocene fossils of Vivianiaceae shed new light on phylogeny, divergence times, and historical biogeography of Geraniales. Biological Journal of the Linnean Society 107: 67–85.

†Esgueiria futabensis

Calibration at a glance	stem Combretaceae (Myrtales), min 86.3 Ma
ID number (NFos)	248

Fossil identity

Full taxon name	**†Esgueiria futabensis Takahashi, Crane, Ando**
Organs	Flower
Specimens	Holotype: PP45389
Locality	Kamikitaba plant mesofossil assemblage (sample F16), along a tributary of the Kitaba River in Kamikitaba, Hirono-machi, (Study Route B of Ando ef al. 1995 3712'N, 140'57'E).
Formation	Asamigawa Member, Ashizawa Formation
Country	Japan

Reference (description)

Takahashi M, Crane PR, Ando H. 1999. Esgueiria futabensis sp. nov., a new angiosperm flower from the Upper Cretaceous (Lower Coniacian) of northeastern Honshu, Japan. Paleontological Research 3: 81–87.

Fossil age

Safe minimum age	**86.3 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Coniacian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Takahashi et al 1999 (PalRes): "The Ashizawa Formation is the lowermost formation in the Futaba Group, and is overlain by the Kasamatsu Formation, which itself is overlain by the Tamayama Formation. Based on the occurrence of lower Coniacian ammonites and inoceramids in the middle of the Ashizama Formation, and a lower Santonian inoceramid (lnoceramus amakusensis) in the upper part of the Tamayama Formation, the Futaba Group is thought to range in age from early Coniacian to early Santonian. The age of the plantbearing sediments in the Asamigawa Member is probably early Coniacian (ca. 89 million years before present ; Gradstein et al., 1995), whereas the age of the plant-bearing sediments in the Tamayama Formation is probably early Santonian (ca. 85 million years before present; Gradstein et al., 1995)."

Reference (age)

Takahashi M, Crane PR, Ando H. 1999. Esgueiria futabensis sp. nov., a new angiosperm flower from the Upper Cretaceous (Lower Coniacian) of northeastern Honshu, Japan. Paleontological Research 3: 81–87.

Fossil relationships

Node calibrated	**stem Combretaceae (Myrtales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Esgueiria futabensis shows the diagnostic characters of the genus, which was previously know from the Mira locality, Portugal (Friis et al., 1992). The flowers are described as “small, epigynous and bisexual with the perianth and androecium organized on a basically pentamerous plan. There is a calyx of five free sepals and an androecium with more than five stamens. The ovary is unilocular with three styles. The *indumentum consists of simple stiff hairs and the characteristic multicellular, peltate trichomes." (Takahashi et al., 1999). Other flowers of Esgueiria are known from slighly younger localities in Japan (Takahashi et al., 1999). Esgueiria could be a stem representative or crown group member of Combretaceae. We use it calibrate the stem node of this family."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Decodon tiffneyi

Calibration at a glance	crown Lythraceae (Myrtales), min 72.1 Ma
ID number (NFos)	249

Fossil identity

Full taxon name	**†Decodon tiffneyi Estrada-Ruiz, Calvillo-Canadell & Cevallos-Ferriz**
Organs	Seed
Specimens	Holotype: IGM-PB 1285
Locality	Cerro del Carmen, Rincón Colorado, General Cepeda Municipality, Coahuila
Formation	Cerro del Pueblo Formation
Country	Mexico

Reference (description)

Estrada-Ruiz E, Calvillo-Canadell L, Cevallos-Ferriz SRS. 2009. Upper Cretaceous aquatic plants from Northern Mexico. Aquatic Botany 90: 282–288.

Fossil age

Safe minimum age	**72.1 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Campanian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Estrada-Ruiz et al 2009 (AquaBot): "The Cerro del Pueblo Formation forms part of a set of seven formations in the Parras Basin in western and south-central Coahuila. It is composed mainly of siltstone, sandstones, and few conglomerates with rounded limestone pebbles (McBride et al., 1974). Paleobotanical and paleomagnetic observations suggest this formation is late Campanian in age (Eberth et al., 2004)."

Reference (age)

Estrada-Ruiz E, Calvillo-Canadell L, Cevallos-Ferriz SRS. 2009. Upper Cretaceous aquatic plants from Northern Mexico. Aquatic Botany 90: 282–288.

Fossil relationships

Node calibrated	**crown Lythraceae (Myrtales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The seeds of Decodon tiffneyi are described as “small, anatropous, pyramidal with acute to rounded corners, valve occupying c. three-fourth of a concave ventral surface forming a well-marked keel, and having well-marked valve flexure. … Their ventral and dorsal surfaces are concave, the ventral seed surface is ornamented with longitudinal grooves, has a rectangular valve that occupies c. three-fourth of its surface, tends to be central, and forms a prominent keel. … On one seed the raphe is observable along the dorsal surface.” (Estrada-Ruíz, et al., 2009). Estrada-Ruíz et al. (2009) considered that the fossil seeds are similar to those of extant Decodon verticillatus (L.) Ell. in detailed morphological features, togethet with the presence in the same locality of valves with features also indicative of Decodon. We consider that these seeds were closely related to extant Decodon, and use them to calibrate the crown group of Lythraceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Melastomites montanensis*

Calibration at a glance	stem Melastomataceae (Myrtales), min 56 Ma
ID number (NFos)	250

Fossil identity

Full taxon name	**†Melastomites montanensis Brown**
Organs	Leaf
Specimens	Plate 56, figures 1, 2, 5, 6 [specimen numbers not provided in original description]
Locality	Localities: (5716); (7005); (8519); (8897)
Formation	Fort Union Formation and Ferris Formation
Country	USA

Reference (description)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Extensively reviewed by Brown 1962, concluding: "In particular, the Fort Union of the northern areas, having been the subject of so much dispute and because the type section is not typical, has been redefined as follows and is thus virtually synonymous with Paleocene series in that region"

Reference (age)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

Fossil relationships

Node calibrated	**stem Melastomataceae (Myrtales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Justification not provided in original publication

Reference (relationships)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

†Flower type 3

Calibration at a glance	stem Myrtaceae (Myrtales), min 83.6 Ma
ID number (NFos)	253

Fossil identity

Full taxon name	**†Flower type 3 Eklund**
Organs	Flower
Specimens	Specimens: DJ.755.1.30, R.2959.27.53, R.2959.27.54
Locality	Table Nunatak, close to the Kenyon Peninsula on the eastern side of the Antarctic Peninsula (68 27 S, 62 43 W) Table Nunatak Formation
Formation	Table Nunatak Formation
Country	Antarctica

Reference (description)

Eklund H. 2003. First Cretaceous flowers from Antarctica. Review of Palaeobotany and Palynology 127: 187-217.

Fossil age

Safe minimum age	**83.6 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Santonian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Eklund 2003 (RevPalPal): "The succession is interpreted as representing shallow-marine deposition at the mouth of an estuary or a deltaic distributary channel, and it has been dated, using dinofagellate cysts, as late Santonian in age (Hathway et al., 1998)."

Reference (age)

Eklund H. 2003. First Cretaceous flowers from Antarctica. Review of Palaeobotany and Palynology 127: 187-217.

Fossil relationships

Node calibrated	**stem Myrtaceae (Myrtales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Eklund 2003 (RevPalPal): "Flowers with a cup-shaped and calyptrate receptacle occur in female £owers of some extant Monimiaceae (P.K. Endress, personal communication) and in Eucalyptus L'He¤rit (Myrtaceae). Flowers of Monimiaceae di¡er, however, from the fossil in having an apocarpous gynoecium with many carpels distributed over the inner surface of the receptacle (Philipson, 1993; Endress and Igersheim, 1997). In general outline, £ower type 3 is similar to buds of Eucalyptus (Myrtaceae). In Eucalyptus, however, £owers are bisexual, with a few exceptions (e.g. Carr et al., 1971), and the buds consist of a cup-shaped hypanthium which is covered by one or two caducous cap-like opercula (House, 1997). The gynoecium is inferior and enclosed by the cup-shaped hypanthium. The stamens are arranged in whorls and borne on a staminal ring on the apical margin of the £oral cup (e.g. House, 1997). The elongated style protrudes in the centre of the androecium. Since the operculum in Eucalyptus is derived from fusion of the tetramerous calyx or corolla (Williams and Brookner, 1997), it seems unlikely that it is homologous with the cap-like apical structure in the fossil £owers, which have three style- or stigma-lobes in a central position.

Furthermore, there are no indications of stamens below the cap-like structure. Within the Myrtaceae, however, unisexual £owers with extremely short stigmas occur in the genus Psiloxylon. It is thus possible that the fossil has a⁄nity to extant Psiloxylon, or, alternatively, that it represents an extinct early lineage in the Myrtaceae."

Reference (relationships)

Eklund H. 2003. First Cretaceous flowers from Antarctica. Review of Palaeobotany and Palynology 127: 187-217.

†Paleomyrtinaea princetonensis

Calibration at a glance: crown Myrtoideae (Myrtaceae, Myrtales), min 44.3 Ma
ID number (NFos): 251

Fossil identity

Full taxon name: **†Paleomyrtinaea princetonensis Pigg, Stockey & Maxwell**
Organs: Fruits and seeds
Specimens: Holotype: P5677 A side (University of Alberta, Paleobotanical Collection, UAPC-ALTA)
Locality: East Bank of the Similkameen River, 8.4. km south of Princeton, British Columbia
Formation: Princeton Chert
Country: Canada

Reference (description)

Pigg KB, Stockey RA, Maxwell SL. 1993. Paleomyrtinaea, a new genus of permineralized myrtaceous fruits and seeds from the Eocene of British Columbia and Paleocene of North Dakota. Canadian Journal of Botany 71: 1–9.

Fossil age

Safe minimum age: **44.3 Ma**
Absolute age source: radioisotopic
Age quality score: 5 / revised (radioisotopic)

Age justification

See Massoni et al 2015 (PE) on +Saururus tuckerae: "Fossils described by Smith and Stockey (2007) come from the Princeton Chert, 8.4 km south of Princeton, British Columbia, Canada, which is part of the Princeton Group, Allenby Formation (Boneham, 1968). The Princeton Chert consists of a series of alternating layers of coal and chert. The paleontological record supports a middle Eocene age, such as an amiid fish correlated with the occurrence of comparable fossils in British Columbia and in the Klondike Mountain Formation of Washington State (Wilson, 1982), and teeth of the mammal group Tillodontia (Russell, 1935). In addition, potassium-argon dating studies have provided comparable ages for the Allenby Formation: 48 ± 2 Ma (Rouse and Mathews, 1961; Mathews, 1964), between 47 ± 2 and 50 ± 2 Ma (Hills and Baadsgaard, 1967), and 46.2 ± 1.9 Ma and 49.4 ± 2 Ma (Read, 2000). With a different method (U-Pb age from zircons), Moss et al. (2005) suggested an age of 52.08 ± 0.12 Ma for the Allenby Formation. Finally, Smith and Stockey (2007) report a personal communication from H. Baadsgaard (University of Alberta, 1999) that supports an age of 48.7 Ma for the ash of Layer #22 of the Princeton Chert. Because the 7.5 m of the Princeton Chert sequence (incorporating the layer where the fossil was collected) may have accumulated in 15,000 years or less (Mustoe, 2011), this latter age is probably the closest to the real age of the fossil. However, in order to be conservative regarding the uncertainty of the age of this formation, and the fact that no uncertainty is associated with the latter age, Saururus tuckerae provides a safe minimum age of 44.3 Ma (the youngest age given by potassium-argon dating minus the associated error of 1.9 Ma)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated: **crown Myrtoideae (Myrtaceae, Myrtales)**
Node assignment score: 2 / intuitive or unspecified (trusted source)
Reconciliation score: 3 / molecular tree only

Node justification

Pigg et al 1993 (CanJBot): "Affinities of these fruits are with the berrylike guavas of the Myrtaceae, tribe Myrteae, subtribe Myrtinae, and in particular, with the closely related genera Mosiera Small and Psidium L."

Reference (relationships)

Pigg KB, Stockey RA, Maxwell SL. 1993. Paleomyrtinaea, a new genus of permineralized myrtaceous fruits and seeds from the Eocene of British Columbia and Paleocene of North Dakota. Canadian Journal of Botany 71: 1–9.

†*Paleomyrtinaea sp.*

Calibration at a glance	crown Myrtoideae (Myrtaceae, Myrtales), min 56 Ma
ID number (NFos)	252

Fossil identity

Full taxon name	**†Paleomyrtinaea sp. (Crane, Dilcher & Manchester) Pigg, Stockey & Maxwell**
Organs	Fruits and seeds
Specimens	Specimens: IU6177, PP34465, UND13058, PP34560
Locality	Almont: locality 15722, North Dakota
Formation	Sentinel Butte Formation, Fort Union Group
Country	USA

Reference (first description)

Crane PR, Manchester SR, Dilcher DL. 1990. A preliminary survey of fossil leaves and well-preserved reproductive structures from the Sentinel Butte Formation (Paleocene) near Altmont, North Dakota. Fieldiana Geology 20: 1–63.

Reference (latest description)

Pigg KB, Stockey RA, Maxwell SL. 1993. Paleomyrtinaea, a new genus of permineralized myrtaceous fruits and seeds from the Eocene of British Columbia and Paleocene of North Dakota. Canadian Journal of Botany 71: 1–9.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "The Sentinel Butte Formation corresponds to the late Paleocene (Clarkforkian, Lerud, 1982) (Crane et al., 1990; Pigg et al., 1993)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**crown Myrtoideae (Myrtaceae, Myrtales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Crane et al. (1990) considered that the fossil fruits and seeds closely resemble those of the extant Psidium guineense, but there are some differences in the thickness of the fruit wall, and lacks a dorsal layer of columnar cells that occur in the fossil. On the basis of Crane et al. (1990) observation that this fossil fruit reliably appears to belong to subfamily Myrtoideae, we use it to calibrate the crown group of Myrtaceae." (see also Pigg et al 1993)

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Ampelocissus parvisemina

Calibration at a glance	crown Vitaceae (Vitales), min 56 Ma
ID number (NFos)	344

Fossil identity

Full taxon name	**†Ampelocissus parvisemina Chen & Manchester**
Organs	Seed
Specimens	Holotype: UF 34705
Locality	Silica Summit Butte at Beicegal Creek, North Dakota 47822.37 N, 103826.29 W (UF locality 18972)
Formation	Bullion Creek Formation
Country	USA

Reference (description)

Chen I, Manchester SR. 2007. Seed morphology of modern and fossil Ampelocissus (Vitaceae) and implications for phytogeography. American Journal of Botany 94: 1534–1553.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Chen & Manchester 2007 (AmJBot): "The North American sites from which fossil Ampelocissus seeds were identified include the Beicegal Creek locality in North Dakota and the Nut Beds locality in Oregon. The Beicegal Creek locality is considered Late Paleocene based on stratigraphic position and floristic composition (Manchester et al., 2004)."

Reference (age)

Chen I, Manchester SR. 2007. Seed morphology of modern and fossil Ampelocissus (Vitaceae) and implications for phytogeography. American Journal of Botany 94: 1534–1553.

Fossil relationships

Node calibrated	**crown Vitaceae (Vitales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The seed of Ampelocissus parvisemina are “round to pyriform, roundtriangular in transverse view; 3–4 mm wide, 3–4 mm high, and 2–3 mm thick; apical notch inconspicuous; beak triangular, sharply pointed. Ventral infolds broad, deep, cup-shaped, and smooth, occupying most of the area of the ventral surface. Dorsal surface smooth, some specimens have faint radiating marks; chalazal knot oval, positioned centrally on the dorsal side. A pair of suture lines running along the lateral margins of the dorsal side. Endosperm in cross section m-shaped, chalazal knot not sunken. Chalazal-apex and -base grooves present but very shallow. Testa 90 µm thick, testa on the lateral margins slightly thicker than on the dorsal and ventral faces.” (Chen & Manchester, 2007). Chen & Manchester (2007) indicate that these seeds are similar to those of the extant A. robinsonii from Central America, but note that they differ in that the dorsal radiating marks characteristic of the extant species are not always present in the fossil. Both species are similar in overall shape to Vitis, although distinguished from Vitis by the *wider ventral infolds. Chen & Manchester 64 (2007) considered that A. parvisemina may represent an early member of the Ampelocissus clade retaining some characters shared with its common ancestor to Vitis (Chen & Manchester, 2007). We use this fossil to calibrate the crown group of Vitaceae."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Indovitis chitaleyae

Calibration at a glance: crown Vitaceae (Vitales), min 61.6 Ma
ID number (NFos): 202

Fossil identity

Full taxon name: **†Indovitis chitaleyae Manchester, Kapgate & Wen**
Organs: Fruits and seeds
Specimens: Holotype: UF19279-56220
Locality: Mahurzari, about 14 km from Nagpur at N21°13.280’, E79°0.84’
Formation: Deccan Intertrappean Beds
Country: India

Reference (description)

Manchester SR, Kapgate DK, Wen J. 2013. Oldest fruits of the grape family (Vitaceae) from the Late Cretaceous Deccan Cherts of India. American Journal of Botany 100: 1849–1859.

Fossil age

Safe minimum age: **61.6 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Danian
Reference time scale: ICS (v2017/02)
Age quality score: 3 / unrevised (recent source >= 2000)

Age justification

Manchester et al 2013 (AmJBot): "The period of Deccan volcanism bracketed the Cretaceous-Tertiary boundary, and is considered to have extended over about three million years (ca. 67–64 mya; chrons 30N–29N; Hooper et al., 2010). The basalts at these sites lack crystals suitable for precise radiometric dating but the Mohgaonkalan flora is considered to be late Maastrichtian based on continuity of outcrops with the main Deccan basalt fl ows exposed in the Jhilmili section, where the chronology has been constrained by overlying Danian Zone PIa planktic foraminifera (Keller et al., 2009 ; Keller, Princeton University, personal communication, 2011). Floristic similarities among these sites are interpreted to indicate that they are approximately contemporaneous, so that all of these sources of vitaceous seeds are most likely late Maastrichtian, approximately 66 million years old. In the absence of precise dating, it remains possible; however, that some of the sites were deposited in the Early Paleocene, but this would not change the ranking of these fossils as the oldest confi rmed representatives of the Vitales and would not alter the biogeographic signifi cance of this occurrence."
Here we conservatively use the Danian as a safe minimum age for this fossil.

Reference (age)

Manchester SR, Kapgate DK, Wen J. 2013. Oldest fruits of the grape family (Vitaceae) from the Late Cretaceous Deccan Cherts of India. American Journal of Botany 100: 1849–1859.

Fossil relationships

Node calibrated: **crown Vitaceae (Vitales)**
Node assignment score: 3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score: 3 / molecular tree only

Node justification

Manchester et al 2013 (AmJBot): "Indovitis chitaleyae conforms closely to extant Vitis in a suite of characters that includes seeds smooth, chalazal knot oval, ventral infolds short and parallel (except V. rotundifolia Michx. which has *long parallel infolds), sclerotesta composed of columnar cells in a biseriate arrangement (Fig. 3B, E), and sclerotesta maintaining moderate thickness throughout the ventral infold (Fig. 3A, C, D, I). However, one of the features characteristic of most species of Vitis (excluding V. rotundifolia) and the related genus Ampelocissus , i.e., a cylindrical, terminally truncate basal beak (Figs. 3O, 4A, C), is not developed in I. chitaleyae . If viewed as a synapomorphy for Vitis and Ampelocissus , the absence of this character in I. chitaleyae could indicate a more plesiomorphic condition that would allow this fossil to be placed at an earlier diverging position. Another feature of the fossil that tends to distinguish it from Vitis and Ampelocissus is the smoothly rounded apical margin, with no hint of an apical groove (Fig. 3L, M). Most species of Vitis and Ampelocissus have a groove in this position (e.g., Fig. 4A ; Chen and Manchester 2007, 2011), although in some species of Vitis it may be only weakly developed (Figs. 3O, 4C)."*

Reference (relationships)

Manchester SR, Kapgate DK, Wen J. 2013. Oldest fruits of the grape family (Vitaceae) from the Late Cretaceous Deccan Cherts of India. American Journal of Botany 100: 1849–1859.

†Dressiantha bicarpellata

Calibration at a glance	stem Brassicales, min 86.3 Ma
ID number (NFos)	239

Fossil identity

Full taxon name	**†Dressiantha bicarpellata Gandolfo, Nixon and Crepet**
Organs	Flower
Specimens	Holotype: CUPC 1075 (Stubs 349, 362, 363).
Locality	Old Crossman Clay Pit, Sayreville, New Jersey
Formation	Raritan Formation
Country	USA

Reference (description)

Gandolfo MA, Nixon KC, Crepet WL. 1998. A new fossil flower from the Turonian of New Jersey: Dressiantha bicarpellata gen. et sp. nov. (Capparales). American Journal of Botany 85: 964–974.

Fossil age

Safe minimum age	**86.3 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Coniacian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Massoni et al 2015 on +Jerseyanthus calycanthoides: "These fossils were collected from the South Amboy Fire Clay Member of the Raritan Formation at the Old Crossman clay pit in Sayreville, New Jersey, USA (Crepet et al., 2005). This unit was first studied palynologically by Groot et al. (1961), who considered it Turonian based on preliminary studies on European sequences, and subsequently by Doyle (1969b), Wolfe and Pakiser (1971), Doyle and Robbins (1977), and Christopher (1979). Building on the palynological zonation of the Potomac Group by Brenner (1963), to which Doyle (1969a) added Zone III (uppermost Potomac) and Zone IV (lower Raritan), Sirkin (1974) assigned South Amboy palynofloras to a new Zone V. This unit was renamed the Complexiopollis exigua - Santalacites minor Zone by Christopher (1979) and redefined by Christopher et al. (1999) as the lowest of three subzones of the Sohlipollis Taxon Range Zone. Wolfe and Pakiser (1971) and Sirkin (1974) considered the South Amboy late Cenomanian, not much younger than underlying Woodbridge Clay Member (Zone IV), but Doyle (1969b) and Doyle and Robbins (1977) argued that it is no older than middle Turonian, based on the presence of Normapolles genera that appear at that level in Europe (Góczán et al., 1967). Doyle and Robbins (1977) and Christopher (1979) allowed that it was “possibly Coniacian,” but Crepet and Nixon (1994) and Crepet et al. (2005) accepted a late Turonian age. By contrast, Clarke et al. (2011) suggested a minimum age of the Santonian-Campanian boundary, 82.8 Ma. However, correlations by Christopher et al. (1999) and Christopher and Prowell (2010) with better-dated rocks in South Carolina imply that the Crossman locality is not this young; they correlate the C. exigua - S. minor Zone with calcareous nannofossil zones CC13 and CC14, which extend from late Turonian through Coniacian (Burnett, 1998; Ogg and Hinnov, 2012). We therefore believe there is enough evidence to consider that Jerseyanthus was at least of Coniacian age, which translates into a conservative minimum age of 85.8 Ma, the Coniacian-Santonian boundary (86.3 ±0.5 Ma; Ogg and Hinnov, 2012)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated **stem Brassicales**

Node assignment score 5 / phylogenetic analysis

Reconciliation score 4 / morphological and molecular trees compared

Node justification

Magallón et al (2015) state: "The flowers of Dressiantha bicarpellata “exhibit a unique combination of characters relative to extant taxa, including the presence of a gynophore, 2 + 2 arrangementof the sepals, unequal petals, monothecal anthers, and a bicarpellate gynoecium” (Gandolfo et al., 1998). Gandolfo et al. (1998) noted that, among extant angiosperms, this character combination only occurs among the traditional Capparales, namely, with hypogynous, bisexual flowers, sepals commonly opposite and decussate, petals with imbricate, convolute, or valvate aestivation, between two and 12 stamens, tricolporate pollen grains, and in several taxa an ovary borne on a short gynophore. Gandolfo et al. (1998) noted thatthe gynoecia of Dressiantha and Brassicaceae are bicarpellate and the ovaries are bilocular, and pollen grains are tricolporate, and globose to prolate. We consider that Dressiantha could be a stem representative or crown member of Brassicales, and use it to calibrate the stem node of this order." Furthermore, it should be noted that the original authors conducted a phylogenetic analysis based on morphological data that suggested a position well nested in Brasssicales, but relationships among extant families in their tree, and rooting of the order, are so different from current understanding based on molecular data that a stem node rather than crown node assignment is warranted for now, until further phylogenetic investigation has been conducted.

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Akania sp.

Calibration at a glance	crown Akaniaceae (Brassicales), min 61.6 Ma
ID number (NFos)	238

Fossil identity

Full taxon name	**†Akania sp. Iglesias**
Organs	Leaf
Specimens	MPEF-Pb-2020 (Museo Paleontológico Egidio Feruglio)
Locality	Palacio de los Loros, Chubut, Patagonia
Formation	Salamanca Formation
Country	Argentina

Reference (description)

Iglesias A, Wilf P, Johnson KR, Zamuner AB, Cúneo NR, Matheos SD, Singer BS. 2007. A Paleocene lowland macroflora from Patagonia reveals significantly greater richness than North American analogs. Geology 35:

Fossil age

Safe minimum age	**61.6 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Danian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Iglesias et al 2007 (Geol): "The Salamanca Formation is generally assigned to the Danian stage, based on forami nif era and ostracoda from the northern and eastern parts of the basin (Méndez, 1966; Bertels, 1975). Specifi cally, the foraminifera species present, including Globanomalina (Turborotalia) compressa and Globoconusa daubjergensis, reliably indicate an upper Danian age (zone P1c) for the marine Salamanca (following Olsson et al., 1999). There are three less reliable but consistent radiometric ages, all from whole-rock K-Ar analyses. [...] Based on this evidence and the lack of signifi cant hiatuses observed between the relevant units, the Palacio de los Loros megafl oras, which locally overlie the marine Salamanca and underlie the Banco Negro Inferior, can be well constrained to an age near the Danian- Selandian boundary. This is equivalent to the magnetic polarity chron 26–27 boundary at 61.7 ± 0.2 Ma (Gradstein et al., 2004). However, a more precise age assignment for the Palacio de los Loros fl oras requires additional work, with particular attention to western strata of the San Jorge Basin."

Reference (age)

Iglesias A, Wilf P, Johnson KR, Zamuner AB, Cúneo NR, Matheos SD, Singer BS. 2007. A Paleocene lowland macroflora from Patagonia reveals significantly greater richness than North American analogs. Geology 35:

Fossil relationships

Node calibrated	**crown Akaniaceae (Brassicales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	3 / molecular tree only

Node justification

Unspecified, no formal description of the fossil

Reference (relationships)

Iglesias A, Wilf P, Johnson KR, Zamuner AB, Cúneo NR, Matheos SD, Singer BS. 2007. A Paleocene lowland

macroflora from Patagonia reveals significantly greater richness than North American analogs. Geology 35: 947–950.

†Tapiscia occidentalis

Calibration at a glance	crown Tapisciaceae (Huerteales), min 41.2 Ma
ID number (NFos)	242

Fossil identity

Full taxon name	**†Tapiscia occidentalis Manchester**
Organs	Fruits and seeds
Specimens	Holotype: IU 5200
Locality	The Nut Beds locality, Wheeler County, Oregon
Formation	Nut Beds Flora, Clarno Formation
Country	USA

Reference (description)

Manchester SR. 1988. Fruits and seeds of Tapiscia (Staphylaceae) from the Middle Eocene of Oregon U.S.A. Tertiary Research 9: 59-66.

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Summarized by Sauquet et al 2012 (SystBiol) on Castanopsis crepetii: "40Ar–39Ar weighted mean age of 43.8 ± 0.3 Ma, and Bridgerian mammal fossils (Manchester 1994)" Here, we conservatively used the equivalent stratigraphic age (but this will be revised in future versions of this dataset).

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**crown Tapisciaceae (Huerteales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The seeds are considered to resemble closely those of the extant Tapiscia sinensis, a species from mixed mesophytic forests from China (Manchester, 1988). Several fossil species of Tapisicia are also known from Eocene sediments in Europe (e.g., Mai, 1976). Based on the similarityies between fossils and the extant genus recognized by Manchester (1988), we use this fossil to calibrate the crown group of Tapisiciaceae." In addition, Steve Manchester further noted in a comment (dated 22/12/2011) made on a PDF version of the original description: "Author's note. Tapiscia and Huartea are no longer placed in Staphyleaceae. Rather, they are are now placed in their own family, Tapisciaceae within the Malvids. Nevertheless, I still stand by the identification of these fossils to Tapiscia. Additional images including sections of permineralized specimens were published later, in the Nut Beds fruit and seed monograph, Paleontographica Americana 1994."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Cochlospermum previtifolium

Calibration at a glance: crown Bixaceae (Malvales), min 15.97 Ma
ID number (NFos): 243

Fossil identity

Full taxon name: **†Cochlospermum previtifolium Berry**
Organs: Leaves and associated fruit
Specimens: Plates 37-39 in Berry 1938 (book) [specimen numbers not provided in original description]
Locality: valley of the Rio Pichileufu about thirty miles east of Lago Nahuel Huapi in Latitude 41°10' south and Longitude 70°52' west in Rio Negro Territory
Formation:
Country: Argentina

Reference (first description)

Berry EW. 1935. A fossil Cochlospermum from Northern Patagonia. Bulletin of the Torrey Botanical Club 62: 65–67.

Reference (latest description)

Berry EW. 1938. Tertiary flora from the RioPichileufu, Argentina. Geological Society of America, Volume 12.

Fossil age

Safe minimum age: **15.97 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Burdigalian
Reference time scale: ICS (v2017/02)
Age quality score: 2 / unrevised (old source < 2000)

Age justification

Berry 1938 (book): "[...] I therefore conclude that the Rio Pichileufu flora, that from Mirhoja, in Chub'ut Territory, that from Rio Chalia, in Santa Cruz Territory, and that from the Concepci6n-Arauco coal measures of Chile are all of lower Miocene age (Aquitanian-Burdigalian)."

Reference (age)

Berry EW. 1938. Tertiary flora from the RioPichileufu, Argentina. Geological Society of America, Volume 12.

Fossil relationships

Node calibrated: **crown Bixaceae (Malvales)**
Node assignment score: 1 / intuitive or unspecified
Reconciliation score: 1 / pre-molecular era (before 1990)

Node justification

Berry 1938 (book): "The species is well characterized, and although there are suggestions of malvaceous or araliod resemblances, the fossil material agrees so closely with the recent American species of Cochlospermum that I have no hesitation in so identifying it. Making assurance doubly sure is the presence of a specimen and counterpart of a subspherical capsular fruit with a stout peduncle preserved for a length of 3£ centimeters, which had dehisced before or was crushed during burial and which shows the impression of the silky fibers associated with the seeds. This capsule is about 3.75 centimeters across, and, as far as its features are preserved, it agrees so perfectly with the recent fruits of Cochlospermum that I feel entirely j ustified in referring it to the same botanical species as the leaves. The fossil is very similar to and may well be the ancestor of the living Cochlospermum vitifolium (Willdenow) Krug, a shrub or small tree widely distributed in the American Tropics, where it ranges from Mexico through Central

America, the West Indies, and northern South America to eastern Bolivia and central Brazil. I have seen recent material from all these regions, and it may well be that the species extends southward into Paraguay and the humid tropical part of northern Argentina, as Hauman (1919, p. 594) recently recorded a species of Cochlospermum from that region."

Reference (relationships)

Berry EW. 1938. Tertiary flora from the RioPichileufu, Argentina. Geological Society of America, Volume 12.

†Albertipollenites kutchensis

Calibration at a glance	crown Dipterocarpaceae (Malvales), min 47.8 Ma
ID number (NFos)	244

Fossil identity

Full taxon name	**†Albertipollenites kutchensis Mandal & Rao**
Organs	Pollen
Specimens	Holotype: Slide BSIP 6351 (Birbal Sahni Institute of Paleobotany); Sample V-04-03 and Slide BSIP 3585 (in Dutta et al 2011)
Locality	Vastan lignite mine (21°25'47'' N: 73°07'30'' E), Cambay [type locality: Near Rataria (sub-surface), southern Kutch, Gujarat]
Formation	Cambay Formation
Country	India

Reference (first description)

Mandal J, Rao MR. 2001. Taxonomic revision of tricolpate pollen from Indian Tertiary. Palaeobotanist 50: 341–368.

Reference (latest description)

Dutta S, Tripathi SM, Mallick M, Mathews RP, Greenwood PF, Rao MR, Summons RE. 2011. Eocene out-of-India dispersal of Asian dipterocarps. Review of Palaeobotany and Palynology 166: 63–68.

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Eocene (Ypresian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Although Dutta et al. (2011) suggest that this record is at least 53 Ma, we here conservatively use an early Eocene stratigraphic age for this fossil.
Dutta et al 2011 (RevPalPal): "The age diagnostic benthic foraminifera Nummulites burdigalensis burdigalensis which occurs in the upper half of the Vastan sequence (Fig. 1) indicates an early Cuisian (ca. 53 Ma) age of the fossil resin-bearing horizon (Punekar and Saraswati 2010). Dinoflagellate cysts suggest an early Eocene (ca. 54–55 Ma) age for the resin-bearing lignites (Garg et al. 2008). Recently, Clementz et al. (2010) reported the second Eocene Thermal Maximum (ETM2; ca. 53.7 Ma.) from the middle part of the mine section based on organic carbon δ13C data which corroborates the biostratigraphic age of the resin-bearing lignite section."

Reference (age)

Dutta S, Tripathi SM, Mallick M, Mathews RP, Greenwood PF, Rao MR, Summons RE. 2011. Eocene out-of-India dispersal of Asian dipterocarps. Review of Palaeobotany and Palynology 166: 63–68.

Fossil relationships

Node calibrated	**crown Dipterocarpaceae (Malvales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	3 / molecular tree only

Node justification

Dutta et al 2011 (RevPalPal): "Many pollen grains recovered from the lower part of the Vastan mine section have strong morphological affinities with extant Dipterocarpaceae pollen (Plate I). Pollen grains of modern

Dipterocarpaceae are 25–85 µm in size, subspherical in shape, tricolpate and possess finely reticulate to grano-rugulate sexine (Tissot et al. 1994). [...] Affinity —Dipterocarpus indicus"

Reference (relationships)

Dutta S, Tripathi SM, Mallick M, Mathews RP, Greenwood PF, Rao MR, Summons RE. 2011. Eocene out-of-India dispersal of Asian dipterocarps. Review of Palaeobotany and Palynology 166: 63–68.

†Foveotricolpites alveolatus

Calibration at a glance	crown Dipterocarpaceae (Malvales), min 56 Ma
ID number (NFos)	245

Fossil identity

Full taxon name	**†Foveotricolpites alveolatus Mandal & Rao**
Organs	Pollen
Specimens	Holotype: Slide BSIP 8784 (Birbal Sahni Institute of Paleobotany); Sample V-04-1A and Slide BSIP 3639 (in Dutta et al. 2011)
Locality	Meghalaya
Formation	Therria Formation
Country	India

Reference (first description)

Mandal J, Rao MR. 2001. Taxonomic revision of tricolpate pollen from Indian Tertiary. Palaeobotanist 50: 341–368.

Reference (latest description)

Dutta S, Tripathi SM, Mallick M, Mathews RP, Greenwood PF, Rao MR, Summons RE. 2011. Eocene out-of-India dispersal of Asian dipterocarps. Review of Palaeobotany and Palynology 166: 63–68.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Mandal & Rao 2001 (RevPalPal): "Palaeocene, Therria Formation, Meghalaya (Tripathi & Singh, 1985)."

Reference (age)

Mandal J, Rao MR. 2001. Taxonomic revision of tricolpate pollen from Indian Tertiary. Palaeobotanist 50: 341–368.

Fossil relationships

Node calibrated	**crown Dipterocarpaceae (Malvales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	3 / molecular tree only

Node justification

Dutta et al 2011 (RevPalPal): "Many pollen grains recovered from the lower part of the Vastan mine section have strong morphological affinities with extant Dipterocarpaceae pollen (Plate I). Pollen grains of modern Dipterocarpaceae are 25–85 µm in size, subspherical in shape, tricolpate and possess finely reticulate to grano-rugulate sexine (Tissot et al. 1994). [...] Affinity —Dipterocarpus indicus"

Reference (relationships)

Dutta S, Tripathi SM, Mallick M, Mathews RP, Greenwood PF, Rao MR, Summons RE. 2011. Eocene out-of-India dispersal of Asian dipterocarps. Review of Palaeobotany and Palynology 166: 63–68.

†Florissantia ashwillii

Calibration at a glance	stem Malvaceae (Malvales), min 33.9 Ma
ID number (NFos)	346

Fossil identity

Full taxon name	**†Florissantia ashwillii Manchester**
Organs	Flowers and pollen
Specimens	Holotype-UF 11740, from Sheep Rock Creek, Oregon. Other specimens- From Sheep Rock Creek: UF 1 1 739, 11741, 11742, 11749. From Sumner Spring, Gray Butte, Oregon: UF 1 1743, 11744. From the Goshen flora, west- ern Oregon: UCMP 278. Approximately 45 specimens were examined.
Locality	Sheep Rock Creek, Oregon, USA
Formation	?Clarno Formation
Country	USA

Reference (description)

Manchester SR. 1992. Flowers, fruits, and pollen of Florissantia, an extinct malvalean genus from the Eocene and Oligocene of Western North America. American Journal of Botany 79: 996–1008.

Fossil age

Safe minimum age	**33.9 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	late Eocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Manchester 1992 (AmJBot): "Many well-preserved specimens of Florissantia ash- willii sp. nov., including the holotype, were collected from the Sheep Rock Creek locality in central Oregon (Manchester, 1990). Although this pond deposit is isolated from strata suitable for radiometric dating, the presence of a palm leaf fragment suggests that it belongs to the Clarno Formation and is consistent with middle or late Eocene age. Numerous additional specimens were collected from the Sumner Spring localities on Gray Butte (Ashwill, 1983; McFadden, 1986). The Sumner Spring shales probably belong to the John Day Formation and are probably lower Oligocene. Specimens from the lower Oligocene Goshen flora of Oregon (Chaney and Sanbom, 1933) were bor- rowed for study from UCMP and UWBM."

Reference (age)

Manchester SR. 1992. Flowers, fruits, and pollen of Florissantia, an extinct malvalean genus from the Eocene and Oligocene of Western North America. American Journal of Botany 79: 996–1008.

Fossil relationships

Node calibrated	**stem Malvaceae (Malvales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al (2015) state that "The flowers of Florissantia are described as actinomorphic, hypogynous, bisexual, with a basally connate calyx, petals are free or absent, with a dense indument at the base of the perianth, an androgynophore, pentamerous calyx, corolla, carpels and stamens, with a single style, and filaments basally united *into a tube around the ovary, and brevicolporate and reticulate pollen (Manchester, 1992). Manchester (1992) indicates that these features are characteristic of Malvales, and are shared by various genera of the traditional Malvaceae (including Tiliaceae, Bombacaceae and Sterculiaceae). Nevertheless, the combination of characters of Florissantia is not found among any extant genus (Manchester, 1992). Because it shows features of different families within Malvales, we consider Florissantia a crown member of Malvales, and use it to calibrate the crown group of this order." However, because all the families compared to this fossil now correspond to Malvaceae sensu APG, we here consider it a reasonably safe approach to assign this fossil to stem Malvaceae, rather than crown Malvales.*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Florissantia quilchenensis

Calibration at a glance	stem Malvaceae (Malvales), min 37.8 Ma
ID number (NFos)	361

Fossil identity

Full taxon name	**†Florissantia quilchenensis (Mathewes & Brook) Manchester**
Organs	Flower, pollen
Specimens	Holotype-SFU Q-97 from Quilchena, British Columbia. Other specimens-From Republic: UWBM 57556, 57558, 56529, SR87-26-4. Approximately 135 specimens were examined.
Locality	Republic, northeastern Washington
Formation	Republic flora, ?Klondike Mountain Formation
Country	USA

Reference (description)

Manchester SR. 1992. Flowers, fruits, and pollen of Florissantia, an extinct malvalean genus from the Eocene and Oligocene of Western North America. American Journal of Botany 79: 996–1008.

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	middle Eocene (Bartonian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Manchester 1992 (AmJBot): "The type material of Florissantia quilchenensis from the Eocene of Quilchena, British Columbia (Mathewes and Brooke, 1971) was borrowed from Simon Fraser University (SFU) through the courtesy of R. Mathewes. Numerous specimens of the same species were examined from the Republic flora of northeastern Washington through the courtesy of Wesley Wehr, Burke Museum, University of Washington, Seattle (UWBM), and Stone- rose Interpretive Center, Republic, Washington (SR). The Republic flora is considered to be of middle Eocene age (Wolfe and Wehr, 1987)."

Reference (age)

Manchester SR. 1992. Flowers, fruits, and pollen of Florissantia, an extinct malvalean genus from the Eocene and Oligocene of Western North America. American Journal of Botany 79: 996–1008.

Fossil relationships

Node calibrated	**stem Malvaceae (Malvales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al (2015) state that "The flowers of Florissantia are described as actinomorphic, hypogynous, bisexual, with a basally connate calyx, petals are free or absent, with a dense indument at the base of the perianth, an androgynophore, pentamerous calyx, corolla, carpels and stamens, with a single style, and filaments basally united into a tube around the ovary, and
brevicolporate and reticulate pollen (Manchester, 1992). Manchester (1992) indicates that
these features are characteristic of Malvales, and are shared by various genera of the

traditional Malvaceae (including Tiliaceae, Bombacaceae and Sterculiaceae). Nevertheless, the combination of characters of Florissantia is not found among any extant genus (Manchester, 1992). Because it shows features of different families within Malvales, we consider Florissantia a crown member of Malvales, and use it to calibrate the crown group of this order." However, because all the families compared to this fossil now correspond to Malvaceae sensu APG, we here consider it a reasonably safe approach to assign this fossil to stem Malvaceae, rather than crown Malvales.

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Javelinoxylon weberi

Calibration at a glance: stem Malvaceae (Malvales), min 72.1 Ma
ID number (NFos): 247

Fossil identity

Full taxon name: **†Javelinoxylon weberi Estrada-Ruiz, Martínez-Cabrera & Cevallos-Ferriz**
Organs: Wood
Specimens: Holotype: IGM-LPB 4547-4561
Locality: Trinity Factory, near Sabinas, Coahuila. N 27° 47′ 021.1′′ and W 101° 07′ 27.1′′
Formation: Olmos Formation
Country: Mexico

Reference (description)

Estrada-Ruiz E, Martínez-Cabrera HI, Cevallos-Ferriz SRS. 2007. Fossil woods from the late Campanian-early Maastrichtian Olmos Formation, Coahuila, Mexico. Review of Palaeobotany and Palynology 145: 123–133.

Fossil age

Safe minimum age: **72.1 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Campanian
Reference time scale: ICS (v2017/02)
Age quality score: 4 / revised (stratigraphic)

Age justification

Estrada-Ruiz et al 2007 note a "late Campanian– early Maastrichtian" age for the Olmos Formation, based on their review of the literature. Here we optimistically use the upper linit of the Campanian as a minimum age for this fossil, but acknowledge that uncertainty remains (i.e., deposit could be slightly younger).

Reference (age)

Estrada-Ruiz E, Martínez-Cabrera HI, Cevallos-Ferriz SRS. 2007. Fossil woods from the late Campanian-early Maastrichtian Olmos Formation, Coahuila, Mexico. Review of Palaeobotany and Palynology 145: 123–133.

Fossil relationships

Node calibrated: **stem Malvaceae (Malvales)**
Node assignment score: 2 / intuitive or unspecified (trusted source)
Reconciliation score: 3 / molecular tree only

Node justification

Estrada-Ruiz et al 2007 (RevPalPal): "Storied rays, septate fibres, vessel-ray and vesselparenchyma pits with reduced borders and scarce axial parenchyma are common in Malvaceae s.l. (Wheeler et al., 1994). The presence of vessel multiples of 3 (2–7), simple perforation plates, vessel-parenchyma and vesselray pits larger than intervascular ones, scanty paratracheal parenchyma, septate fibres, and storied rays typical of this Olmos Formation wood are seen in the Cretaceous Javelinoxylon multiporosum (Wheeler et al., 1994). However, some features (Table 2) of the Olmos Formation wood differ from those of J. multiporosum, the type species (Wheeler et al., 1994). Quantitative deviations in vessel diameter, density and grouping, differences in the number of cells of the uniseriate extension, width of the multiseriate rays, exclusively septate fibres, and irregular ray storeying support the recognition of a new taxon. Several other fossil woods assigned to the malvalean families have been described (e.g., Müller-Stoll and Müller-Stoll, 1949; Beauchamp et al., 1973; Manchester, 1979, 1980; Privé-Gill and Pelletier, 1981; Guleria, 1983; Crawley, 1989; Wheeler and Lehman, 2000), but none has the combination of characters exhibited by Javelinoxylon

(Wheeler et al., 1994).We agree with Wheeler et al. (1994) that indicated that Javelinoxylon shares more characters with Tiliaceae (Grewioideae, Tilioideae; Bayer et al., 1999) and Sterculiaceae than with Malvaceae and Bombacaceae (Sterculioideae, Malvoideae and Bombacoideae, respectively; Bayer et al., 1999); nevertheless we include the wood in Malvaceae s.l., because recent phylogenetic analyses have resulted in the Malvaceae s.l. including members of Malvaceae, Sterculiaceae, Tiliaceae, and Bombaceae."

Reference (relationships)

Estrada-Ruiz E, Martínez-Cabrera HI, Cevallos-Ferriz SRS. 2007. Fossil woods from the late Campanian-early Maastrichtian Olmos Formation, Coahuila, Mexico. Review of Palaeobotany and Palynology 145: 123–133.

†Malvaciphyllum macondicus

Calibration at a glance	stem Malvatheca clade, min 59.2 Ma
ID number (NFos)	246

Fossil identity

Full taxon name	**†Malvaciphyllum macondicus Carvalho**
Organs	Leaves
Specimens	Holotype: ING 1410
Locality	Pit Tabaco 1, locality 0317 (11.14 N, 72.57 W), Cerrejón coal mine Ranchería Basin
Formation	Cerrejón Formation
Country	Colombia

Reference (description)

Carvalho MR, Herrera FA, Jaramillo CA, Wing SL, Callejas R. 2011. Paleocene Malvaceae from northern South America and their biogeographical implications. American Journal of Botany 98: 1337–1355.

Fossil age

Safe minimum age	**59.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Selandian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Carvalho et al 2011 (AmJBot): "The Cerrejón Formation is a 700 m thick sequence of coal beds, fluvial sandstones, and lacustrine siltstones; these deposits have been dated as mid to late Paleocene based on isotopic and biostratigraphic correlations (Jaramillo et al., 2007)." Here, we use the upper boundary of the Selandian (mid Paleocene) as an age constraint for this fossil.

Reference (age)

Carvalho MR, Herrera FA, Jaramillo CA, Wing SL, Callejas R. 2011. Paleocene Malvaceae from northern South America and their biogeographical implications. American Journal of Botany 98: 1337–1355.

Fossil relationships

Node calibrated	**stem Malvatheca clade**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	4 / morphological and molecular trees compared

Node justification

Carvalho et al 2011 (AmJBot): "Despite convergence of overall leaf architecture among many Malvaceae, Malvaciphyllum macondicus sp. nov. can be assigned to the clade Eumalvoideae because of distal and proximal bifurcations of the costal secondary and agrophic veins, a synapomorphy for this clade." Here, we more conservatively assign this fossil to the broader Malvatheca clade (Bombacoideae + Malvaceae0, in which Eumalvoideae is nested.

Reference (relationships)

Carvalho MR, Herrera FA, Jaramillo CA, Wing SL, Callejas R. 2011. Paleocene Malvaceae from northern South America and their biogeographical implications. American Journal of Botany 98: 1337–1355.

†Choerospondias sheppeyensis

Calibration at a glance	crown Anacardiaceae (Sapindales), min 47.8 Ma
ID number (NFos)	254

Fossil identity

Full taxon name	**†Choerospondias sheppeyensis (Reid & Chandler) Chandler**
Organs	Fruit and seed
Specimens	Holotype: V.22554
Locality	Island of Sheppey
Formation	London Clay Flora
Country	UK

Reference (first description)

Reid EM, Chandler MEJ. 1933. The London Clay flora. British Museum (Natural History), London, UK.

Reference (latest description)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Ypresian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Chandler 1961a (book) clearly places the London Clay Flora in the Ypresian, an age that has apparently not been challenged since.

Reference (age)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Fossil relationships

Node calibrated	**crown Anacardiaceae (Sapindales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Chandler 1961a (book): "The relationship to living genera was discussed by Reid & Chandler (1933: 306). These fruits most resemble Sclerocarya and Choerospondias in form, but the number of locules is greater than in the living Sclerocarya, and there are no woody plugs closing their apices as in that genus. Choerospondias has similar locules but a larger endocarp, it also has longitudinal rows of small holes on the lateral surfaces between the locules, but the holes in the fossils are few and somewhat irregular. Nevertheless the most nearly allied living species appears to be C. axillaris (Roxb.)."
(see also Manchester et al. 2009; Magallón et al 2015)

Reference (relationships)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora

(Supplement). Text and Atlas. London: British Museum (Natural History).

†Coahuiloxylon terrazasiae

Calibration at a glance	stem Anacardiaceae (Sapindales), min 72.1 Ma
ID number (NFos)	255

Fossil identity

Full taxon name	**†Coahuiloxylon terrazasiae Estrada-Ruiz, Martínez-Vabrera & Cevallos-Ferriz**
Organs	Wood
Specimens	Holotype: IGM-PB 1295, LPB 4679-4693
Locality	Atascoso Ranch, 7 km N of Melchor Múzquiz town, Múzquiz Municipality, Coahuila
Formation	Olmos Formation
Country	Mexico

Reference (description)

Estrada-Ruiz E, Martínez-Cabrera HI, Cevallos-Ferriz SRS. 2010. Upper Cretaceous woods from the Olmos Formation (late Campanian-early Maastrichtian), Coahuila, Mexico. American Journal of Botany 97: 1179–1194.

Fossil age

Safe minimum age	**72.1 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Campanian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Estrada-Ruiz et al 2010 (AmJBot): "An early Maastrichtian age has been assigned to the Olmos Formation based on foraminifers, dinoflagellates, acritarchs, and pollen (Pessagno, 1969 ; Zaitzeff and Cross, 1970; Martínez-Hernández et al., 1980) In Piedras Negras, Coahuila, near the contact of the Escondido and Olmos Formations, F. Vega-Vera (Universidad Nacional Autónoma de México, personal communication, 2006) found bivalves like Exogyra costata Say and Pycnodonte mutabilis Morton, both index fossils of the early Maastrichtian. Flores- Espinoza (1989) proposed a late Campanian age based on ammonites. Therefore, in this paper, we use late Campanian-early Maastrichtian (Estrada-Ruiz, 2009)."

Reference (age)

Estrada-Ruiz E, Martínez-Cabrera HI, Cevallos-Ferriz SRS. 2010. Upper Cretaceous woods from the Olmos Formation (late Campanian-early Maastrichtian), Coahuila, Mexico. American Journal of Botany 97: 1179–1194.

Fossil relationships

Node calibrated	**stem Anacardiaceae (Sapindales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Estrada-Ruiz et al 2010 (AmJBot): "The wood structure of Coahuiloxylon terrazasiae resembles that of Anacardiaceae and Burseraceae. Among the wood features that relate C. terrazasiae with both families are the presence of indistinct growth rings, septate and/or nonseptate fi bers, alternate intervessel pits and vessel-ray parenchyma pits with reduced borders, simple perforation plates, scanty paratracheal, vasicentric and apotracheal diffuse axial parenchyma, and heterocellular rays. Molecular and morphological/ anatomical analyses (Terrazas, 1994, 1999; Martínez- Millán, 2000, 2003; APG II, 2003) support common ancestry of these two families. There is no single wood anatomical character separating these two families. Presence of both nonseptate and septate fi bers *occurs in some members of the Anacardiaceae tribes Rhoeae (e.g., Loxostylis , Mauria, and Smodingium) and Anacardieae (e.g., Androtium , Buchanania) and Dobineae (Dobinea . Relationship of C. terrazasiae with members of the tribes Semecarpeae and Spondiadeae is precluded by the presence of exclusively nonseptate and exclusively septate fi bers respectively (Terrazas, 1994). Rays in Anacardiaceae are heterogeneous type IIA and IIB (Terrazas, 1994), though type III are present in some species of Anacardium and if homogeneous rays are present these are of the type I; Coahuiloxylon has heterogeneous type IIA rays, and occasional uniseriate rays. Androtium and Buchanania of the Anacardieae have heterogeneous rays type IIA (Terrazas, 1994), but in contrast to Coahuiloxylon only paratracheal parenchyma is present. Some genera in the Rhoeae (Loxostylis , Mauria, Smodingium) resemble Coahuiloxylon in having both paratracheal (scanty to vasicentric) and apotracheal (diffuse) parenchyma. However, only Mauria has type IIA rays. While radial canals are present in ca. 60% of the family (Terrazas, 1994), these are absent in Coahuiloxylon , a character shared with Mauria. Coahuiloxylon and Mauria share other important diagnostic features within Anacardiaceae such as presence of both nonseptate and septate fi bers, paratracheal and apotracheal parenchyma, and heterogeneous type IIA rays, but the particular mosaic of characters in C. terrazasiae precludes its inclusion in an extant taxon."*

Reference (relationships)

Estrada-Ruiz E, Martínez-Cabrera HI, Cevallos-Ferriz SRS. 2010. Upper Cretaceous woods from the Olmos Formation (late Campanian-early Maastrichtian), Coahuila, Mexico. American Journal of Botany 97: 1179–1194.

†Bursericarpum aldwickense

Calibration at a glance	crown Burseraceae (Sapindales), min 47.8 Ma
ID number (NFos)	256

Fossil identity

Full taxon name	**†Bursericarpum aldwickense Chandler**
Organs	Pyrene and seeds
Specimens	Holotype: v.30054
Locality	Upper Fish Tooth Bed, Bognor, Sussex
Formation	London Clay Flora
Country	UK

Reference (description)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Ypresian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Chandler 1961a (book) clearly places the London Clay Flora in the Ypresian, an age that has apparently not been challenged since.

Reference (age)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Fossil relationships

Node calibrated	**crown Burseraceae (Sapindales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Bursericarpum aldwickense has been considered to be related to Protieae on the basis of the number of pyrenes per fruit (Weeks et al., 2005; Daly et al., 2011). Protocommiphora europaea "has a bifacial pyrene and is assignable to Commiphora or Bursera subg. Elaphrium." Daly et al. (2011). Both fossils show closer relationships to particular extant genera within Burseraceae, hence, we use them to calibrate the crown group of this family. Because Burseraceae is represented in this study by a single taxon, the calibrated node is equal to the stem group of Burseraceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Toona sulcata

Calibration at a glance	crown Meliaceae (Sapindales), min 47.8 Ma
ID number (NFos)	257

Fossil identity

Full taxon name	**†Toona sulcata (Bowerbank) Reid & Chandler**
Organs	Fruit and seed
Specimens	No holotype (Reid & Chandler 1933); Neotype: V.22492
Locality	Island of Sheppey
Formation	London Clay Flora
Country	UK

Reference (description)

Reid EM, Chandler MEJ. 1933. The London Clay flora. British Museum (Natural History), London, UK.

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Ypresian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Chandler 1961a (book) clearly places the London Clay Flora in the Ypresian, an age that has apparently not been challenged since.

Reference (age)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Fossil relationships

Node calibrated	**crown Meliaceae (Sapindales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The remains assigned to Toona sulcata are reported as sharing morphological features of the modern genera Toona and Cedrela, including the insertion of the seed on the columella (Muellner et al., 2010 and references therein), and were used to calibrate the minimum age of the stem of Cedrelae (Muellner et al., 2007). Based on this assignment, we use these fossils to date the crown group of Meliaceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Rutaspermum biornatum

Calibration at a glance	stem Amyridoideae (Rutaceae, Sapindales), min 66 Ma
ID number (NFos)	258

Fossil identity

Full taxon name	**†Rutaspermum biornatum Knobloch & Mai**
Organs	Seeds
Specimens	Holotype: MMG (9231)
Locality	Walbeck, graue Tone
Formation	
Country	Germany

Reference (description)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Seeds assigned to Rutaspermum biornatum Knobloch & Mai from Walbeck, Germany, corresponding to the Maastrichtian (Knobloch & Mai, 1986)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Amyridoideae (Rutaceae, Sapindales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The seeds of Rutaspermum biornatum are considered to be the oldest representatives of Rutaceae. The genus is also known from younger sediments, including the London Clay Flora (Friis et al., 2011, and references therein). Rutaspermum is thought to be closely related to subfamily Zanthoxyleae, especially to Zanthoxylon and Fagara (Friis et al., 2011)." However, contrary to Magallón et al 2015, we here constrain the stem node of Amyridoideae (= Zanthoxyleae) rather than the crown node of Rutaceae.

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Aesculus hickeyi

Calibration at a glance	crown Sapindaceae (Sapindales), min 56 Ma
ID number (NFos)	259

Fossil identity

Full taxon name	**†Aesculus hickeyi Manchester**
Organs	Leaves, fruits and seeds
Specimens	Holotype: UF 30618
Locality	Farmers Butte, North Dakota (UF locality 18744)
Formation	Fort Union Formation
Country	USA

Reference (description)

Manchester SR. 2001. Leaves and fruits of Aesculus (Sapindales) from the Paleocene of North America. International Journal of Plant Sciences 162: 985-998.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Stratigraphy

Reference (age)

Manchester SR. 2001. Leaves and fruits of Aesculus (Sapindales) from the Paleocene of North America. International Journal of Plant Sciences 162: 985-998.

Fossil relationships

Node calibrated	**crown Sapindaceae (Sapindales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The leaves of Aesculus hickeyi were initially known as isolated leaflets from the Golden Valley Formation and Farmers Butte locality, which were previously assigned to Carya antiquorum (Juglandaceae; Hickey, 1977). Manchester (2001) obtained complete palmately compound leaves from the Farmers Butte site, and recognized the affinity of the leaves with Sapindaceae, and particularly, with Aesculus. We accept the assignment by Manchester (2001) and use this fossil taxon to calibrate the crown node of Sapindaceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Sapindospermum nitidum*

Calibration at a glance	stem Sapindaceae (Sapindales), min 89.8 Ma
ID number (NFos)	260

Fossil identity

Full taxon name	**†Sapindospermum nitidum Knobloch & Mai**
Organs	Seeds
Specimens	Holotype: UUG EK 39618)
Locality	Trebec Tj-4a, 76-77 m, graue Schluffe, Klikov-Schichtenfolge
Formation	
Country	Czech Republic

Reference (description)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil age

Safe minimum age	**89.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Turonian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Knobloch & Mai 1986 (Praha): "Blätterfunde wurden von NEMEJC (1957, 1961), KNOBLOCH (1964) und NEMEJC - KVACEK (1975), die Pollen von PACLTOVA. (1961, 1981) bearbeitet. Einen ausführlichen Überblick über die paläobotanischbiostratigraphische Problematik gibt KNOBLOCH (1985), der die Klikov-Schichtenfolge anhand paläokarpologischer Belege in das Oberturon bis Santon stellt."

Reference (age)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil relationships

Node calibrated	**stem Sapindaceae (Sapindales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

No detailed justification provided in original description

Reference (relationships)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

†Ailanthus confucii

Calibration at a glance	crown Simaroubaceae (Sapindales), min 41.2 Ma
ID number (NFos)	261

Fossil identity

Full taxon name	**†Ailanthus confucii Unger**
Organs	Winged fruit
Specimens	Specimens: SM.B Me 4006, 4232, 4233, 4747, 4785, 4786, 16837, 21808, 23395, 24010.
Locality	Messel Pit, Messel oil shale, Messel
Formation	Messel Formation
Country	Germany

Reference (description)

Collinson ME, Manchester SR, Wilde V. 2012. Fossil fruits and seeds of the Middle Eocene Messel biota, Germany. Abh. Senckenberg Ges. Naturforsch. 570: 1–251.

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Collinson et al 2012 (AbhSenckenbergGesNat): "During early studies the biostratigraphic age of the fossil bearing oil shale at Messel was recognised as Middle Eocene by characteristic vertebrates (Haupt 1911). This was confirmed by later studies and specified as early Middle Eocene age (Tobien 1968) or lower Geiseltalian (MP 11) in the European vertebrate chronology (Franzen 2005a, b). A lower Middle Eocene age was also obtained from palynological studies (Thiele-Pfeiffer 1988; Krutzsch 1992, SPP-Zone 14/15). The core Messel 2001 finally offered the chance for radiometric dating of the underlying volcaniclastic material (47.8 million years ago (mya); Mertz & Renne 2005). We continue to use the geochronologic term "Tertiary" as appropriate according to longstanding tradition and continuing usefulness, as defined in numerous dictionaries."

Reference (age)

Collinson ME, Manchester SR, Wilde V. 2012. Fossil fruits and seeds of the Middle Eocene Messel biota, Germany. Abh. Senckenberg Ges. Naturforsch. 570: 1–251.

Fossil relationships

Node calibrated	**crown Simaroubaceae (Sapindales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Collinson et al 2012 (AbhSenckenbergGesNat): "The Messel specimens belong to a widespread morphospecies which is also known from North America and Asia (Corbett & Manchester 2004). Although the majority of specimens in Messel are relatively small in size (less than 15 mm in length) compared to most specimens from other floras, a single specimen (SM.B Me 21808, pl. 38m) with a length of 25 mm indicates that the population from Messel is consistent with the range of dimensions normally covered by the species. Comparisons with the extant species by Corbett & Manchester (2004) indicate the closest similarity with A. altissima of China."

Reference (relationships)

Collinson ME, Manchester SR, Wilde V. 2012. Fossil fruits and seeds of the Middle Eocene Messel biota, Germany. Abh. Senckenberg Ges. Naturforsch. 570: 1–251.

†Celastrus comparabilis

Calibration at a glance: crown Celastraceae (Celastrales), min 37.8 Ma
ID number (NFos): 203

Fossil identity

Full taxon name: **†Celastrus comparabilis Hollick**
Organs: Leaf
Specimens: Lectotype: USNM 38956; Hypotypes: USNM 38744, 43356, 43357, 245728.
Locality: locs. 3846, 3847, 11158, 11159, 11166
Formation: Kushtaka Formation
Country: USA

Reference (description)

Hollick A. 1936. The Tertiary floras of Alaska. U.S. Geological Survey Professional Paper 182: 1–185.

Fossil age

Safe minimum age: **37.8 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Middle Eocene (Bartonian assumed)
Reference time scale: ICS (v2017/02)
Age quality score: 2 / unrevised (old source < 2000)

Age justification

Wolfe 1977 (USGeolSurvProfPap): "Paleobotanical correlations indicate that the lowest plant assemblage is of late middle Eocene (early Ravenian) age"

Reference (age)

Wolfe JA. 1977. Paleogene floras from the Gulf of Alaska region. U.S. Geol. Surv. Profess. Pap. 997: 1-108.

Fossil relationships

Node calibrated: **crown Celastraceae (Celastrales)**
Node assignment score: 2 / intuitive or unspecified (trusted source)
Reconciliation score: 1 / pre-molecular era (before 1990)

Node justification

Wolfe 1977 (USGeolSurvProfPap): "Rollick's (1936) determination of this species as a member of Celastrus is valid. The characters of the fossils that indicate such a relationship are: a uniformly, closely serrate margin; several widely spaced, camptodrome secondary veins; two series of loops near the margin; intercostal tertiary veins that bifurcate and that are typically almost perpendicular in orientation to the midrib; branches from the tertiary veins that tend to thin and form a highly irregular pattern of fourth order venation; some tertiary veins that depart from the midrib and fork more than once, each fork joining the next most basal secondary vein. These characteristics also indicate a close relationship to extant members of the subgenus Celastrus, which is distributed in Madagascar, southeast Asia, Melanesia, and eastern United States; the subgenus, however, has its current center in the tropical and subtropical region of southeastern Asia (Hou, 1955, p. 223). The fossils appear to be most closely related to C. monospermoides Loes., which is widely distributed from New Guinea to the Philippine Islands and Malaya. Lectotype. USNM"

Reference (relationships)

Wolfe JA. 1977. Paleogene floras from the Gulf of Alaska region. U.S. Geol. Surv. Profess. Pap. 997: 1-108.

†Lophopetalumoxylon indicum

Calibration at a glance	stem Celastraceae (Celastrales), min 46.3 Ma
ID number (NFos)	204

Fossil identity

Full taxon name	**†Lophopetalumoxylon indicum Mehrotra, Prakash & Bande**
Organs	Wood
Specimens	B.S.I.P. Museum no. 35535
Locality	Ghughua near Shahpura, Mandla district, Madhya Pradesh
Formation	Deccan Intratrappean beds
Country	India

Reference (description)

Mehrotra RC, Prakash U, Bande MB. 1984. Fossil woods of Lophopetalum and Artocarpus from the Deccan Intertrappean Beds of Mandla district, Madhya Pradesh, India. Palaeobotanist 32: 310–320.

Fossil age

Safe minimum age	**46.3 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

The Deccan Intratrappean beds formation where the fossil was found has been dated at 54.4 ± 8.1 Ma using the F-T dating method (Srivastava et al. 1986). Because the error on this age is substantial, we here substract it to provide a safe minimum age for this fossil: 54.4 - 8.1 = 46.3 Ma.

Reference (age)

Srivastava A, Rajagopalan G, Ambwani K. 1986. Fission-track dating of fossil palm wood from Shahpura, Mandla District, Madhya Pradesh. Geophytology 16: 136–137.

Fossil relationships

Node calibrated	**stem Celastraceae (Celastrales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Mehrotra et al 1984 (Paleobotanist): "Important anatomical characters of the fossil wocd, namely small to medium-sized vessels, apotracheal bands of parencyma, fine, homogeneous xylem rays, and non-septate fibres strongly indicate its affinities with the family Celastraceae (Pearson & Brown, 1932; Metcalfe & Chalk, 1950; Nigam, 1963). Further, it also shows a superficial resemblance with the '!loder.n woods of Sapindaceae. However, m this family the parenchyma is paratracheal banded and terminal as against the apotracheal bands of parenchyma present in our fossil wood (Pearson & Brown, 1932; Metcalfe & Chalk, 1950; Ramesh Rao, 1963)."

Reference (relationships)

Mehrotra RC, Prakash U, Bande MB. 1984. Fossil woods of Lophopetalum and Artocarpus from the Deccan Intertrappean Beds of Mandla district, Madhya Pradesh, India. Palaeobotanist 32: 310–320.

†Combretocarpus rotundatus

Calibration at a glance	crown Anisophylleaceae (Cucurbitales), min 11.63 Ma
ID number (NFos)	205

Fossil identity

Full taxon name	**†Combretocarpus rotundatus (Miq.) Danser**
Organs	Pollen
Specimens	[specimen number not provided in original description]
Locality	Berakas coal layer, Kianggeh Valley, near Brunei town
Formation	Belait Formation
Country	Brunei

Reference (description)

Anderson JAR, Muller J. 1975. Palynological study of a holocene peat and a miocene coal deposit from NW Borneo. Review of Palaeobotany and Palynology 19: 291–351.

Fossil age

Safe minimum age	**11.63 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Miocene (Serravallian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Anderson & Muller 1975 (RevPalPal) note that "This type is frequent in the upper part of the Marudi peat, but only one grain has been found in Berakas (no. 16)." Because the Berakas deposit (Miocene) is older than the Marudi peat (Holocene), we tentatively use the Berakas record as an age constraint. A middle Miocene age for this species is taken literally from Fig. 2 of Morley 1977 (ProcPetroleumAss), presumably based on stratigraphic correlations. For additional discussion of the Berakas coal age, see Anderson & Muller 1975 (RevPalPal).

Reference (age)

Morley RJ. 1977. Palynology of Tertiary and Quaternary sediments in southeast Asia. Proc. Petroleum Association 6th Annual Convention, pp. 255–276.

Fossil relationships

Node calibrated	**crown Anisophylleaceae (Cucurbitales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Anderson & Muller 1975 (RevPalPal): "This pollen type differs from that of other genera of the family and is easily recognized by its prolate shape, medium size (25--30 ~m), long ektoapertures with indistinct, polarly elongated endoapertures and thin wall which is distinctly subdivided into a thin endexine, a layer of very small columellae and a finely, evenly reticulate tectum (lumina <0.5 um in diameter)." The fossil pollen, attributed to the extant species, was originally listed under Rhizophoraceae, but Combretocarpus now belongs to Anisophylleaceae.

Reference (relationships)

Anderson JAR, Muller J. 1975. Palynological study of a holocene peat and a miocene coal deposit from NW Borneo. Review of Palaeobotany and Palynology 19: 291–351.

†*Begonia sp.*

Calibration at a glance: crown Begoniaceae (Cucurbitales), min 2.58 Ma
ID number (NFos): 206

Fossil identity

Full taxon name	**†Begonia sp. Stults & Axsmith**
Organs	Winged fruit
Specimens	Sc66a and Sc66b in the USAM herbarium
Locality	Scarborough locality (informal designation; 30°43.74’N, 88°8.57’W)
Formation	Citronelle Formation
Country	USA

Reference (description)

Stults DZ, Axsmith BJ. 2011. First macrofossil record of Begonia (Begoniaceae). American Journal of Botany 98: 150–153.

Fossil age

Safe minimum age	**2.58 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Pliocene
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Stults & Axsmith 2011 (AmJBot): "Recent studies support a Pliocene age and indicate deposition to have occurred between about 3.4 and 2.7 Ma (Otvos, 1997 ; 1998)"

Reference (age)

Stults DZ, Axsmith BJ. 2011. First macrofossil record of Begonia (Begoniaceae). American Journal of Botany 98: 150–153.

Fossil relationships

Node calibrated	**crown Begoniaceae (Cucurbitales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "This fossil fruit is considered as the first reliable macrofossil of Begoniaceae (Stults & Axsmith, 2011). It is interpreted as “an unequal three-winged capsule, although only two wings are visible. One large main wing is fully preserved to the left of the locule, and a much smaller second wing occurs to the right. It is assumed that a third wing would have occurred perpendicular to the plane of the other two wings and was associated with the opened locule. Venation patterns on the main wing show the strongest veins to be predominantly parallel along its length, some of them forming long loops, the bottom-most of these only slightly arcing downward at the outermost edge of the wing.” (Stults and Axsmith, 2011). We use this fossil to calibrate the crown node of Begoniaceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Corynocarpus sp.

Calibration at a glance	crown Corynocarpaceae (Cucurbitales), min 15.97 Ma
ID number (NFos)	207

Fossil identity

Full taxon name	**†Corynocarpus sp. Campbell**
Organs	Fruits
Specimens	OU 31128 G45/f64, OU 31135 G45/f93, OU 31146 (Department of Geology, University of Otago)
Locality	silcrete on Landslip Hill (NZMS 260 G45/128529), near Pukerau, north-east of Gore, eastern Southland
Formation	Gore Lignite Measures
Country	New Zealand

Reference (description)

Campbell, JD. 2002. Angiosperm fruit and leaf fossils from Miocene silcrete, Landslip Hill, northern Southland, New Zealand. J. R. Soc. New Zealand 32: 149–154.

Fossil age

Safe minimum age	**15.97 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Miocene (Burdigalian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Lindqvist 1990 (NZJGeolGeophys): "Silcrete exposed at Landslip Hill forms part of the Early Miocene Gore Lignite Measures."

Reference (age)

Lindqvist JK. 1990. Deposition and diagenesis of landslip hill silcrete, gore lignite measures (Miocene), New Zealand. New Zealand Journal of Geology and Geophysics 33: 137–150.

Fossil relationships

Node calibrated	**crown Corynocarpaceae (Cucurbitales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Campbell 2002 (JRoySocNZ): "The characters observed in the fossils are generally consistent with those of dried fruits of Corynocarpus laevigatus except that the testa veins in laevigatus are more diffuse, veinlets in mature fruit of the living plants join to form a well-developed anastomosing pattern between the poles."

Reference (relationships)

Campbell, JD. 2002. Angiosperm fruit and leaf fossils from Miocene silcrete, Landslip Hill, northern Southland, New Zealand. J. R. Soc. New Zealand 32: 149–154.

†Cucurbitospermum sheppeyense

Calibration at a glance	stem Cucurbitaceae (Cucurbitales), min 47.8 Ma
ID number (NFos)	208

Fossil identity

Full taxon name	**†Cucurbitospermum sheppeyense Chandler**
Organs	Seeds
Specimens	Holotype: V30463
Locality	Warden Point, Sheppey, England
Formation	London Clay Flora
Country	UK

Reference (description)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Ypresian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Chandler 1961a (book) clearly places the London Clay Flora in the Ypresian, an age that has apparently not been challenged since.

Reference (age)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Fossil relationships

Node calibrated	**stem Cucurbitaceae (Cucurbitales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Chandler 1961a (book): "Form and structure point to relationship with Cucurbitaceae, although normally in this family the seeds are bisymmetric, the two broad surfaces corresponding exactly, whereas in the fossil one surface is flat and the other convex. The small size and unrimmed form are also unusual in the family but occur in Escallonia which is the most comparable genus yet seen; its seeds are more narrowly oval than the fossil and show the typical biconvex section."

Reference (relationships)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

†*Acacia eocaribbeanensis*

Calibration at a glance crown The mimosoid clade, min 15 Ma
ID number (NFos) 368

Fossil identity

Full taxon name **†Acacia eocaribbeanensis Dilcher, Herendeen & Huber**
Organs Flowers
Specimens Holotype USNM 458372
Locality Amber deposit from the Palo Alto mine
Formation Dominican Amber, Altamira Formation
Country Dominican Republic

Reference (description)

Dilcher DL, Herendeen PS, Hueber F. 1992. Fossil Acacia flowers with attached anther glands from Dominican Republic amber. In: Herendeen PS, Dilcher DL, eds. Advances in legume systematics, part 4, the fossil record. Royal Botanic Gardens, Kew, UK, 33–42.

Fossil age

Safe minimum age **15 Ma**
Absolute age source stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age early Middle Miocene
Age quality score 4 / revised (stratigraphic)

Age justification

Lavin et al 2005 (SystBiol): "Dilcher et al. (1992) detailed the floral and leaflet morphology of specimens preserved in Dominican Republic amber from the Palo Alto mine. These mimosoid flowers come from sediments dated at the Oligocene-Miocene boundary. Dilcher et al. (1992) argue that the amber has been weathered out of older sediments and redeposited in this Oligocene-Miocene sediment. In contrast, Iturralde-Vinent and MacPhee (1996) presented evidence for the deposition of Dominican Amber during an interval 15 to 20 million years ago. Thus, the minimum age of the Acacia stem clade is 15 Ma."
Here, we follow these publications in using 15 Ma as the approximate upper limit of the "early Middle Miocene", which is very close (and slightly more conservative) than the upper limit of the Burdigalian (15.97) in the ICS v2017/02 (geologic time scale). (See also +Meliorchis caribea)

Reference (age)

Lavin M, Herendeen PS, Wojciechowski MF. 2005. Evolutionary rates analysis of Leguminosae implicates a rapid diversification of lineages during the Tertiary. Systematic Biology 54: 575–594.

Fossil relationships

Node calibrated **crown The mimosoid clade**
Node assignment score 3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score 3 / molecular tree only

Node justification

Lavin et al 2005 (SystBiol) assign this fossil to the stem node of the 'Acacia clade', which is not defined yet in PROTEUS. For this reason, we provisionally consider this fossil a safe minimum age constraint for the crown node of the large mimosoid clade, to which the Acacia clade belongs.
Lavin et al 2005 (SystBiol): "The assignment of the amber fossils to the Acacia stem (i.e., the first branching Acacia-containing lineage within the mimosoid crown) can be made because these fossils clearly show diagnostic

apomorphic characters, such as numerous stamens with free filaments each with an anther bearing a stalked gland. Associated leaf pinnae bearing numerous small leaflets by themselves are not diagnostic, but they bear hairs identical to those on the flowers. The amber Acacia flowers are the only mimosoid fossils that unequivocally constrain a node nested within the mimosoid crown."

Reference (relationships)

Lavin M, Herendeen PS, Wojciechowski MF. 2005. Evolutionary rates analysis of Leguminosae implicates a rapid diversification of lineages during the Tertiary. Systematic Biology 54: 575–594.

†Barnebyanthus buchananensis

Calibration at a glance: stem Faboideae (Fabaceae, Fabales), min 37.8 Ma
ID number (NFos): 369

Fossil identity

Full taxon name: **†Barnebyanthus buchananensis Crepet & Herendeen**
Organs: Flowers
Specimens: Holotype: B577a, B577b (part and counterpart)
Locality: Buchanan Clay Pit, Henry Co., western Tennessee
Formation: Claiborne Formation
Country: USA

Reference (description)

Crepet WL, Herendeen PS. 1992. Papilionoid flowers from the early Eocene of southeastern North America. In: Herendeen PS, Dilcher DL, eds. Advances in legume systematics, part 4, the fossil record. Royal Botanic Gardens, Kew, UK, 43–55.

Fossil age

Safe minimum age: **37.8 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Bartonian
Reference time scale: ICS (v2017/02)
Age quality score: 4 / revised (stratigraphic)

Age justification

See Sauquet et al 2012 (SystBiol) on +Castanopsoidea columbiana (in Appendix S2): "Oldest Claiborne beds are in calcaraeous nannoplankton zone NP12, and youngest are in zone NP17 but also within the Bartonian marine stage (e.g., Dockery 1998). Using GTS 2004, base of NP12 is 52.3 Ma (+/- about 0.2 Ma) and end of Bartonian is 37.2 +/- 0.1 Ma." Here, we have revised the absolute age using the ICS v2017/02 geologic time scale.

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated: **stem Faboideae (Fabaceae, Fabales)**
Node assignment score: 5 / phylogenetic analysis
Reconciliation score: 4 / morphological and molecular trees compared

Node justification

Lavin et al 2005 (SystBiol): "The flowers of Barnebyanthus buchananensis are the earliest generalized papilionoid fossils from the Late Paleocene to Early Eocene sediments of the Buchanan Clay Pit, western Tennessee (Crepet and Herendeen, 1992). In addition to bilateral symmetry, these fossil flowers clearly show a connate calyx with five small calyx lobes, an adaxial median sepal, a differentiated standard petal that is positioned outside the wing petals, and distinct wing and keel petals, the latter of which are not fused. Crepet and Herendeen included Barnebyanthus in a cladistic analysis of traits scored also for selected genera of the tribe Sophoreae and concluded that Barnebyanthus was sister to the genistoid genera Bowringia and Clathrotropis. Although these fossil flowers show synapomorphies associated with the basic papilionoid zygomorphic flower, they actually lack other floral synapomorphies (e.g., fused *keel petals, connate filaments) that could serve to unequivocally constrain their position within the papilionoid crown clade. Thus, the fossils are consistent with several lineages within "Sophoreae" and other papilionoids with free petals and filaments. This analysis of Crepet and Herendeen illustrates that legume fossils, because they include mainly disarticulated leaves, leaflets, flowers, and fruits, generally comprise few apomorphic characters."*

Reference (relationships)

Lavin M, Herendeen PS, Wojciechowski MF. 2005. Evolutionary rates analysis of Leguminosae implicates a rapid diversification of lineages during the Tertiary. Systematic Biology 54: 575–594.

†Caesalpinia flumen-viridensis

Calibration at a glance	crown Caesalpinia (Fabaceae, Fabales), min 48.5 Ma
ID number (NFos)	367

Fossil identity

Full taxon name	**†Caesalpinia flumen-viridensis Herendeen and Dilcher**
Organs	Fruits
Specimens	Holotype-IU 15882-7388, 7388' (Figs. 13, 14).
Locality	Little Mountain flora, southwestern Wyoming (I.U. Locality 15882: NW 1/4 SE 1/4 Sec. 23, T13N, R106W, Sweet-water Co.)
Formation	Green River Formation
Country	USA

Reference (description)

Herendeen PS, Dilcher DL. 1991. Caesalpinia Subgenus Mezoneuron (Leguminosae, Caesalpinioideae) from the Tertiary of North America. American Journal of Botany 78: 1–12.

Fossil age

Safe minimum age	**48.5 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Green River Formation was deposited between ca. 53.5 Ma and 48.5 Ma, based on 40Ar-39Ar (Smith et al. 2003)

Reference (age)

Smith ME. 2003. 40Ar/39 Ar geochronology of the Eocene Green River Formation, Wyoming. Geological Society of America Bulletin: 549–565.

Fossil relationships

Node calibrated	**crown Caesalpinia (Fabaceae, Fabales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Lavin et al 2005 (SystBiol): "Several species of Mezoneuron (or Caesalpinia subg. Mezoneuron) are reported from North America and England as Middle Eocene to Miocene in age, even though Mezoneuron is presently confined to the Paleotropics (Herendeen and Zarucchi, 1990; Herendeen and Dilcher, 1991). The apomorphic traits that allow assignment of these fossils to the Mezoneuron stem include a membranous indehiscent pod with multiple ovules, and a broad placental wing with looping to longitudinal venation."

Reference (relationships)

Lavin M, Herendeen PS, Wojciechowski MF. 2005. Evolutionary rates analysis of Leguminosae implicates a rapid diversification of lineages during the Tertiary. Systematic Biology 54: 575–594.

†Cercis parvifolia

Calibration at a glance	stem Cercis (Fabaceae, Fabales), min 34.07 Ma
ID number (NFos)	363

Fossil identity

Full taxon name	**†Cercis parvifolia Lesquereux**
Organs	Leaf and fruits
Specimens	Princeton Museum, Nos. 766, 767
Locality	Florissant Beds, Colorado
Formation	Florissant Formation
Country	USA

Reference (first description)

Lesquereux L. 1883. Contributions to the fossil flora of the Western Territories-Part 3, The Cretaceous and Tertiary floras. U.S. Geological Survey of the Territories 8: 1–283.

Reference (latest description)

Brown RW. 1936. Additions to some fossil floras of the western United States. U.S. Geological Survey Professional Paper: 161–206.

Fossil age

Safe minimum age	**34.07 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

40Ar/39Ar radioisotopic date (34.07 ± 0.10 Ma) from Evanhoff et al. (2001) (see also Manchester 2001)

Reference (age)

Evanhoff E, McIntosh W, Murphey P. 2001. Stratigraphic summary and 40Ar/39Ar geochronology of the Florissant Formation, Colorado. Proceedings of the Denver Museum of Nature & Science 4: 1–16.

Fossil relationships

Node calibrated	**stem Cercis (Fabaceae, Fabales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Lavin et al (2005): "Fossils showing apomorphic traits of Cercis come from the Late Eocene of Sheep Rock Creek, Oregon (Herendeen and S. Manchester, unpublished data; site information provided in Wolfe and Tanai, 1987; McClain and Manchester, 2001). Fossils from this locality reveal a combination of apomorphies allowing assignment to Cercis, including unifoliolate leaves (i.e., with a lower pulvinus and upper pulvini), a thickish texture to the orbiculate-acuminate lamina, and a palmate primary venation combined with a pinnate secondary venation. Also found are thin-walled pods bearing a narrow non-vascularized placental wing suggestive of the fruits of Cercis. Additional leaf and fruit fossils also assigned to Cercis come from the Late Eocene Florissant Beds, Colorado (MacGinite, 1953; Manchester, 2001). Several types of legume fruits at Florissant have been identified as Cercis, however; and further study is required before these fossils can be definitively utilized here."

Reference (relationships)

Lavin M, Herendeen PS, Wojciechowski MF. 2005. Evolutionary rates analysis of Leguminosae implicates a rapid

diversification of lineages during the Tertiary. Systematic Biology 54: 575–594.

†Diplotropis-like leaves and fruits

Calibration at a glance	crown Faboideae (Fabaceae, Fabales), min 56 Ma
ID number (NFos)	371

Fossil identity

Full taxon name	**†Diplotropis-like leaves and fruits**
Organs	Leaves and fruits
Specimens	[not provided]
Locality	northwestern Bighorn Basin of Wyoming
Formation	Willwood Formation
Country	USA

Reference (description)

Herendeen PS, Wing S. 2001. Papilionoid legume fruits and leaves from the Paleocene of northwestern Wyoming. Botany 2001 Abstracts, published by Botanical Society of America (http://www.botany2001.org/).

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Herendeen & Wing 2001 (abstract): "Mammalian fossils from above and below the plant site indicate a latest Paleocene age, probably not more than 100 ky prior to the carbon isotope excursion that marks the Paleocene/Eocene boundary. Other fossil plants from the site are consistent with a late Paleocene age, including, Acer silberlingii, Deviacer, Metasequoia, Corylites, Platanus raynoldsii, and Macginitiea gracilis."

Reference (age)

Herendeen PS, Wing S. 2001. Papilionoid legume fruits and leaves from the Paleocene of northwestern Wyoming. Botany 2001 Abstracts, published by Botanical Society of America (http://www.botany2001.org/).

Fossil relationships

Node calibrated	**crown Faboideae (Fabaceae, Fabales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Lavin et al 2005 (SystBiol) assign this fossil to the stem node of the 'Diplotropis clade', which is not defined yet in PROTEUS. For this reason, we provisionally consider this fossil a safe minimum age constraint for the crown node of Faboideae, to which the Diplotropis clade belongs.
Lavin et al 2005 (SystBiol): "Fossil leaves and pods very similar to Bowdichia and Diplotropis are known from the Late Paleocene of western Wyoming (Herendeen and Wing, 2001), as well as the Middle Eocene of southeastern USA (Herendeen and Dilcher, 1990b). The apomorphic traits that suggest an affinity of these fossils to Bowdichia and Diplotropis include membranous pod valves, numerous seeds that are transversally oriented, a narrow wing on the placental suture, strong lateral nerves that demarcate the body (seed-containing region) from the placental and lower margins, and leaflets variably alternate to opposite (Calpurnia and Maackia of this same clade also have similar fruits). In the matK phylogeny (Fig. 2), the difference between the Bowdichia-Diplotropis stem and the

Genistoid crown clade is trivial such that assignment of these fossils to one or the other node makes little difference with respect to rate and age estimation."

Reference (relationships)

Lavin M, Herendeen PS, Wojciechowski MF. 2005. Evolutionary rates analysis of Leguminosae implicates a rapid diversification of lineages during the Tertiary. Systematic Biology 54: 575–594.

†Hymenaea protera

Calibration at a glance: stem Hymenaea (Fabaceae, Fabales), min 33.9 Ma
ID number (NFos): 364

Fossil identity

Full taxon name	**†Hymenaea protera**
Organs	Flower
Specimens	Holotype specimen H-O-2 (Poinar collection of Dominican amber residing at the University of California at Berkeley)
Locality	La Toca Mines amber
Formation	Dominican amber
Country	Dominican Republic

Reference (description)

Poinar GO. 1991. Hymenaea protera sp.n. (Leguminosae, Caesalpinioideae) from Dominican amber has African affinities. Experientia 47: 1075–1082.

Fossil age

Safe minimum age	**33.9 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Eocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Lavin et al 2005 (SystBiol): "Graham (1992) validated H. protera as bona fide Hymenaea with a minimum age of Late Eocene or 34 Ma."

Reference (age)

Lavin M, Herendeen PS, Wojciechowski MF. 2005. Evolutionary rates analysis of Leguminosae implicates a rapid diversification of lineages during the Tertiary. Systematic Biology 54: 575–594.

Fossil relationships

Node calibrated	**stem Hymenaea (Fabaceae, Fabales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	3 / molecular tree only

Node justification

Lavin et al 2005 (SystBiol): "Hueber and Langenheim (1986) and Poinar (1991) place the fossil Hymenaea flower from La Toca Mines amber (Dominican Republic), formally named Hymenaea protera, as sister to the African Hymenaea verrucosa. Graham (1992) validated H. protera as bona fide Hymenaea with a minimum age of Late Eocene or 34 Ma. Poinar et al. (1993) further validated the generic assignment of H. protera with "fossil" rbcL sequence data. Only the Hymenaea crown clade, however, is well supported in their rbcL study.As it turns out, the Hymenaea rbcL sequences are small partial fragments, and contain certain sequence anomalies that need to be verified. In addition, proper outgroups were not sampled in Poinar et al. (1993), so the distinction of the Hymenaea stem and crown cannot be made. The above assignment, therefore, is the most precise possible given inadequate molecular sampling of Hymenaea and closely related genera."

Reference (relationships)

Lavin M, Herendeen PS, Wojciechowski MF. 2005. Evolutionary rates analysis of Leguminosae implicates a rapid diversification of lineages during the Tertiary. Systematic Biology 54: 575–594.

†Leguminocarpon gardneri

Calibration at a glance	stem Fabaceae (Fabales), min 56 Ma
ID number (NFos)	209

Fossil identity

Full taxon name	**†Leguminocarpon gardneri (Chandler) Herendeen & Crane**
Organs	Infructescence
Specimens	Holotype: V.15340
Locality	Reading Beds, Reading, Berkshire, England
Formation	Reading Formation
Country	UK

Reference (description)

Herendeen PS, Crane PR. 1992. Early caesalpinioid fruits from the Palaeogene of southern England. Pp. 57-68 in P.S. Herendeen and D.L. Dilcher (eds.) Advances in legume systematics. Pt. 4. The fossil Record. Royal Botanic Gardens, Kew, U.K.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

The Reading Formation is generally regarded as oflate Palaeocene age (Curry et al., 1978) although some authors (e.g., Knox, 1984) place the Palaeocene-Eocene boundary within the formation and below the non-marine sediments in which the plant fossils occur (Crane & Goldring, 1991).

Reference (age)

Herendeen PS, Crane PR. 1992. Early caesalpinioid fruits from the Palaeogene of southern England. Pp. 57-68 in P.S. Herendeen and D.L. Dilcher (eds.) Advances in legume systematics. Pt. 4. The fossil Record. Royal Botanic Gardens, Kew, U.K.

Fossil relationships

Node calibrated	**stem Fabaceae (Fabales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Leguminocarpon gardneri is described as “Infructescence racemose bearing alternate to subopposite, stipitate fruits; perianth persistent (details unclear); fruits symmetrical to asymmetrical, with a narrow wing along the placental suture; valve venation transverse, converging toward the center to form an irregular reticulum; seeds 1-2 per fruit, shape unclear, orientation in fruit oblique to transverse.” (Herendeen & Crane, 1992). These authors considered that the fossil exhibits a combination of features observed in different genera within Caesalpinioideae, particularly Peltogyne and Caesalpinia s.l. However, they considered that lack of details in the fossil, especially regarding calyx structure, preculde a more accurate placement (Herendeen & Crane, 1992). Some genera of 73 the taxonomic Caesalpinioideae form a grade at the base of Fabaceae, and, because Leguminocarpon cannot be securely related with an extant genus, we consider it is difficult to determine if it was a stem representative or a crown member of

Fabaceae. Hence, we use it to calibrate the stem node of Fabaceae.

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Protomimosoidea buchananensis

Calibration at a glance	stem The mimosoid clade, min 37.8 Ma
ID number (NFos)	350

Fossil identity

Full taxon name	**†Protomimosoidea buchananensis Crepet**
Organs	Inflorescence and flowers with in situ pollen
Specimens	Holotype: UCPC B605a, b; Fig. 3, 4, 12, 16, 17, 18, 20.
Locality	Buchanan, Puryear and Warman localities, western Tennessee, USA
Formation	Claiborne Formation [formerly Wilcox Formation]
Country	USA

Reference (description)

Crepet WL, Taylor DW. 1986. Primitive mimosoid flowers from the Paleocene-Eocene and their systematic and evolutionary implications. American Journal of Botany 73: 548–563.

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Bartonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Sauquet et al 2012 (SystBiol) on +Castanopsoidea columbiana (in Appendix S2): "Oldest Claiborne beds are in calcaraeous nannoplankton zone NP12, and youngest are in zone NP17 but also within the Bartonian marine stage (e.g., Dockery 1998). Using GTS 2004, base of NP12 is 52.3 Ma (+/- about 0.2 Ma) and end of Bartonian is 37.2 +/- 0.1 Ma." Here, we have revised the absolute age using the ICS v2017/02 geologic time scale.

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**stem The mimosoid clade**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (see also Lavin et al 2005): "Protomimosoideae buchananensis is a racemose inflorescence formed by “alternately arranged hermaphroditic flowers. Flowers small (pedicel 3.5 mm; perianth length 3.9 mm) and actinomorphic. Calyx lobes elongate and rounded at the ends. Petals 5, valvate, free. Filaments not conante and free from the petals, often varying in length. Anthers fertile, versatile. Ovary superior and unicarpelalte with sparse pubescence of elongate hairs. Young fruit apaprently a capsule (pod). Pollen shed in monades, tricolporate, prolate.” (Crepet & Taylor, 1986). Crepet & Taylor (1986) discussed that the fossil flower has a combination of charaters that are considered plesiomorphic within tribe Mimoseae, and exhibits two diagnostic attributes of the subfamily: valvate petals and a tubular stigma. Crepet & Taylor (1986) also noted that P. buchananensis shares some characters with the Dimorphandra group, including sagittate anthers and uneven stamen length. While the relationship of P.

buchananensis with the traditional Mimosoideae is strong, the presence of a character combination that is unknown among extant groups indicates that this fossil taxon could be a stem representative or a crown member of Mimosoideae. We use it to calibrate the stem node of Mimosoideae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Paleosecuridaca curtissi

Calibration at a glance	crown Polygalaceae (Fabales), min 56 Ma
ID number (NFos)	349

Fossil identity

Full taxon name	**†Paleosecuridaca curtissi Pigg, DeVore & Wojciechowski**
Organs	Fruits
Specimens	Holotype. PP34562 (fig. 2C; fig. 3A, 3D, 3E; fig. 23B of Crane et al. 1990). Paratypes. Figured: USWP 3149 (fig. 2A; fig. 3C, 3F, 3G); PP 34197 (fig. 2D; fig. 23C of Crane et al. 1990); UWSP 3329 (fig. 2E); UWSP 2674 (fig. 2F); UWSP 3677 (fig. 2G); ASU 1600 (fig. 2H). Not figured in this article: PP 34492a, b (fig. 23A of Crane et al. 1990), PP 34562, PP 45489, PP 45490, PP 45492, PP 45498, PP45499a, b, PP 45507a, b, UWSP 2676, UWSP 2679, UWSP 3447, UWSP 3149, UWSP 3447, UWSP 3599, UWSP 3759, UWSP 3891A, UWSP 3971, UWSP 3986, UWSP Borrowed specimen, ASU 5/01-1, ASU 5/01-3, ASU 5/01-65, ASU 5/01-2, ASU 7/99-1, ASU 7/02-1, ASU 7/02 No. 63, ASU 9/99A, ASU 10268, ASU 10267, ASU 10183, ASU 2008-1.
Locality	One mile (1.6 km) north of New Salem (Morton County), North Dakota
Formation	Almont and Beicegel Creek floras, Sentinel Butte Formation
Country	USA

Reference (description)

Pigg KB, DeVore ML, Wojciechowski MF. 2008. Paleosecuridaca curtisii gen. et sp. nov., Securidaca-Like Samaras (Polygalaceae) from the Late Paleocene of North Dakota and Their Significance to the Divergence of Families within the Fabales. International Journal of Plant Sciences 169: 1304–1313.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Magallón et al (2015): "Fruits assigned to Paleosecuridaca curtissi Pigg, DeVore & Wojciechowski from the Almont and Beicegel Creek floras, Sentinel Butte Formation, North Dakota, USA (Pigg et al., 2008). Both localities are considered to correspond to the Late Paleocene (Tiffanian 3) on the basis of mammal and molluscan correlations (Kihm and Hartman 1991; in Pigg et al., 2008)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**crown Polygalaceae (Fabales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Pigg et al. (2008) formally described Paleosecuridaca curtisii based on anatomically preserved, asymmetric, nonschizocarpic samaras that greatly resemble the extant genus Securidaca (Polygalaceae), which had been previously mentioned by Crane et al. (1990). The fruits are described as "2.5–3.6 cm long (x= 3.0 cm, n= 16) with a central ovoid nut 0.6–1.25 cm long (x= 0.9 cm, n= 26), 0.35–0.8 cm wide (x= 0.6 cm, n= 26), and 0.25–0.3 cm thick attached to a broad wing with a small secondary wing on its upper surface. The wing is vascularized by several veins running parallel to its long axis at the top and others in the main body of the wing arching downward and outward, with a few interreticulations occurring between the major veins. The nut contains a single, large locule with two well-developed seeds, each with a seed coat that has a prominent palisade layer like that of many extant genera of Polygalaceae." (Pigg et al., 2008). Pigg et al. (2008) found greater similarities between the fossil samara and those of extant Securidaca considering "(1) a lack of a broad attachment surface that would be expected in schizocarpic samaras; (2) the presence of a peduncle; (3) the presence of a wing with parallel venation apically that curves downward and outward in the body of the wing, with occasional interreticulations; (4) a proximal locule position with respect to the wing; and (5) presence of a small wing on the upper surface of the nut." Furthermore, anatomical details of the fossil samara indicate an affinity with Polygalaceae, including "a spongy mesocarp and a prominent palisade layer of the outer seed coat." (Pigg et al., 2008). Some attributes of Paleosecuridaca are more similar to those of other genera of Polygalaceae, and in one feature, the presence of two seeds of unequal size in a single locus, it differs from extant members of this family (Pigg et al., 2008). On the basis of the detailed morphlogical, structural and anatomical similarities of these fossil samaras with those of Securidaca, and of extant Polygalaceae, we consider them crown members of Polygalaceae, and use them to calibrate its crown node."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Suriana inordinata

Calibration at a glance	crown Surianaceae (Fabales), min 48.5 Ma
ID number (NFos)	210

Fossil identity

Full taxon name	**†Suriana inordinata Kruse**
Organs	Silicified wood
Specimens	Type: No. B-2868 of the Paleobotanical Collection of the University of Cincinnati
Locality	Hays' Ranch, Eden Valley, east of Farson, Wyoming
Formation	Green River Formation
Country	USA

Reference (description)

Kruse H. 1954. Some Eocene dicotyledonous Woods from Eden Valley, Wyoming. Ohio Journal of Science 54: 243–268.

Fossil age

Safe minimum age	**48.5 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Green River Formation was deposited between ca. 53.5 Ma and 48.5 Ma, based on 40Ar-39Ar (Smith et al. 2003)

Reference (age)

Smith ME. 2003. 40Ar/39 Ar geochronology of the Eocene Green River Formation, Wyoming. Geological Society of America Bulletin: 549–565.

Fossil relationships

Node calibrated	**crown Surianaceae (Fabales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Kruse 1954 (OhioJSci): "Wood of Suriana maritima L. was compared with the fossil. The radial sections were remarkably similar, i.e., both showed a preponderance of square cells in the rays with walls thickened in the corners. Other sections showed a few differences as follows: (1) Ripple marks are indistinctly defined in the modern wood, but definitely absent in the specimen. (2) Wood fiber walls are thinner in the specimen than they are in the modern wood. Ripple marks are not of much diagnostic value, especially when all other characteristics fit very closely. Perhaps they are the result of environment and thus would not be present consistently throughout even such a small group as a species. Fiber wall thickness can vary considerably within a genus. The specific epithet suggests the lack of storied structure which is present in the only modern species of Suriana." Accepted by Friis et al. (2011).

Reference (relationships)

Kruse H. 1954. Some Eocene dicotyledonous Woods from Eden Valley, Wyoming. Ohio Journal of Science 54: 243–268.

†*Archaefagacea futabensis*

Calibration at a glance	stem Fagales, min 86.3 Ma
ID number (NFos)	215

Fossil identity

Full taxon name	**†Archaefagacea futabensis Takahashi, Friis, Herendeen et Crane**
Organs	Flower, fruit, pollen
Specimens	PP3687, Field Museum Palaeobotanical Collection
Locality	Kitba River, Kamikitaba
Formation	Ashizawa Formation (Asamigawa Member), Futaba Group
Country	Japan

Reference (description)

Takahashi M, Friis EM, Herendeen PS, Crane PR. 2008. Fossil Flowers of Fagales from the Kamikitaba Locality (Early Coniacian; Late Cretaceous) of Northeastern Japan. International Journal of Plant Sciences 169: 899–907.

Fossil age

Safe minimum age	**86.3 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Coniacian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Magallón et al (2015): "The age of the plant-bearing sediments in the Asamigawa Member corresponds to the early Coniacian (Takahashi et al., 2008; Friis et al., 2011)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Fagales**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al (2015) conclude: "The morphological and structural attributes of flowers, pollen and seeds of Archaefagacea futabensis indicate an affinity with Fagales, in particular with Fagaceae or Nothofagaceae, but not with the core Fagles. We here consider that this fossil may have been a Fagaceae stem relative, a Nothofagaceae stem relative, or a Fagales crown or stem relative. Hence, we use it to calibrate the Fagales stem node."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Caryanthus sp.

Calibration at a glance	stem Myricaceae+Juglandaceae, min 83.6 Ma
ID number (NFos)	216

Fossil identity

Full taxon name	**†Caryanthus sp.**
Organs	Flowers, fruits and associated anthers
Specimens	Specimens: PP45095, PP44593, PP44604, PP45098, PP45243
Locality	Approximately 9.5 km southeast of Roberta, Georgia, USA, at the south pit of the Atlanta Sand and Supply Company at Gaillard, Crawford County, Georgia, USA
Formation	Gaillard Formation (Buffalo Creek Member, Allon Flora)
Country	USA

Reference (description)

Sims HJ, Herendeen PS, Lupia R, Christopher RA, Crane PR. 1999. Fossil flowers with Normapolles pollen from the Upper Cretaceous of southeastern North America. Review of Palaeobotany and Palynology 106: 131–151.

Fossil age

Safe minimum age	**83.6 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Santonian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Sims et al 1999 (RevPalPal): "Palynological analyses indicate that the Gaillard Formation is of late Santonian age (Christopher, 1979, unpubl. data), although in earlier studies it has been cited as lower Campanian based on a less precise understanding of the biostratigraphy (Herendeen et al., 1995; Crane and Herendeen, 1996; Keller et al., 1996; Magallo´n- Puebla et al., 1996; Konopka et al., 1997). The recent reinterpretation of the age of the Allon locality was based on the presence of terrestrial palynomorphs considered to be biostratigraphically equivalent to marine units that are assigned to the upper Santonian on the basis of calcareous nannofossils [i.e., equivalent to the lower part of calcareous nannofossil Zone CC17, which Burkett (1996) considers to be late Santonian] (Christopher in Sims et al., 1998)."

Reference (age)

Sims HJ, Herendeen PS, Lupia R, Christopher RA, Crane PR. 1999. Fossil flowers with Normapolles pollen from the Upper Cretaceous of southeastern North America. Review of Palaeobotany and Palynology 106: 131–151.

Fossil relationships

Node calibrated	**stem Myricaceae+Juglandaceae**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al (2015): "Flowers, fruits and associated anthers found in the Allon locality of Georgia, USA were assigned by Sims et al. (1999) to the genus Caryanthus, described from the slightly younger Åsen locality in Sweden by Friis (1983). The flowers from Allon are described by Sims et al. (1999) as being “small and epigynous. The perianth apparently consisted of six free imbrticate tepals possibly in two whorls. The flowers were bisexual or pistillate with well-developed staminodes. The androecium apparently consisted of six stamens placed in a single *whorl, opposite the tepals. The gynoecium consists of an inferior ovary and a single style." (Sims et al., 1999). Pollen grains on the apex of flowers and fruits corresponds to the Normapolles polen taxon Pseudoplicapollis endocuspis. They are oblate to peroblate, with three very short colpi (Sims et al., 1999). Sims et al. (1999) considered that the flowers, fruits and isolated stamens are very similar to Caryanthus knoblochii, from the Åsen locality (Friis, 1983). The pollen of Caryanthus, and some aspects of its floral structure, are very similar to extant Rhoiptelea (Rhoipteleaceae). However, a different ovary position (superior in Rhoiptelea, inferior in Caryanthus) is an important difference between the two (Sims et al., 1999). Friis (1983) considered that Caryanthus shared features with Juglandaceae, specifically with the extant Pterocarya, or with Rhoiptelea in some aspects of floral structure. We here consider that among core Fagales, Caryanthus was more closely related to Rhoipteleaceae, Myricaceae and Juglandaceae, and use the Caryanthus fossils from the Allon locality to calibrate the stem node of the clade that includes these three families. In addition to Caryanthus, an unnamed flower from Allon also shows similarities with Juglandaceae/Myricaceae (Sims et al., 1999)."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Normapolles pollen

Calibration at a glance: stem Normapolles group, min 93.9 Ma
ID number (NFos): 218

Fossil identity

Full taxon name: **†Normapolles pollen**
Organs: Pollen
Specimens: from bore Ln-1, depth 47.80 m [Pacltová 1977]
Locality: Bohemia
Formation: Peruc Formation
Country: Czech Republic

Reference (first description)

Pacltová B. 1966. Pollen grains of angiosperms in the Cenomanian Peruc Formation in Bohemia. Palaeobotanist 15: 52-54.

Reference (latest description)

Pacltová B. 1977. Cretaceous angiosperms of Bohemia: Central Europe. Botanical Review 43: 128–142.

Fossil age

Safe minimum age: **93.9 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Cenomanian
Reference time scale: ICS (v2017/02)
Age quality score: 2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Dispersed pollen grains of the Normapolles complex (Pflug, 1953) from Formations representing fresh and brackish-water environments of Bohemia, corresponding to the middle Cenomanian (Pacltová, 1966)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated: **stem Normapolles group**
Node assignment score: 2 / intuitive or unspecified (trusted source)
Reconciliation score: 3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Pollen grains assigned to the Normapolles complex are distinctly oblate, triangular in shape, with protruding, complex aperture regions, and a tectate, slightly sculptured pollen wall (Friis et al., 2003). More than 80 diferent Normapolles genera have been recognized (Friis et al., 2003). Stratigraphically, Normapolles occur in the pollen spectrum as traces only in the middle and upper Cenomanian (Pacltová, 1971, 1977, 1978; in Pacltová 1981), but in the Turonian they are represented in the spectrum of marine sediments in frequencies that vary from 3 to 6 % depending on facies. The first representatives of this morphological group display a simple structure of pores; but during a short interval they become more complicated. Such are the first representatives of the first Normapolles specimens discovered in the Peruc Formation (Pacltová, 1977). They persisted until the early Eocene (Góczán et al., 1967), and had their maximal abundance, diversity and geographical *distribution during the Santonian-Campanian. During the late 80 Cretaceous, they constituted a floristic realm termed the Normapolles province, which occupied western Siberia, Europe and North America. Based exclusively on the morphology of the dipersed polen grains, establishing the systematic affinity of Normapolles was uncertain, but relationships with Fagales were proposed (e.g. Góczán et al., 1967; Skarby, 1968; Wolfe, 1973; in Friis et al., 2006). The fagalean affinity of Normapolles became very strongly supported by the finding of different types of flowers, from at least three Late Cretaceous localities, with in situ Normapolles pollen grains. These flowers have been assigned to six different genera from three geographical regions, i.e., Manningia and Antiquocarya from the Åsen locality in Scania, Sweden (Friis, 1983); Caryanthus also from Åsen, and from the Allon locality in Georgia, USA (Friis, 1983; Sims et al., 1999); Bedellia, from Allon (Sims et al., 1999); and Normanthus and Endressianthus, from localities in the Beira region in Portugal (Schönenberger et al., 2001; Friis et al., 2003). More specifically, the flowers with in situ Normapolles pollen show similarities with Juglandaceae/Myricaceae (i.e., Manningia, Antiquocarya and Caryanthus; Friis 1983; Sims et al., 1999), or with Betulaceae (Bedellia, Normanthus and Endressianthus; Sims et al., 1999; Schönenberger et al., 2001; Friis et al., 2003). Flowers and polen of Fagaceae and Nothofagaceae (and of the fossils Protofagaceae allonensis, Antiquacupula sulcata and Archaefagaceae futabensis) are structurally different from those in core Fagales. On the basis of their general inflorescence structure, floral organisation, and pollen features Friis et al. (2006) considered that the Normapolles complex comprises a heterogeneous, non-monophyletic group of plants representing different fagalean lineages within or close to the clade comprising extant Betulaceae, Casuarinaceae, Ticodendraceae, Myricaceae, Rhoipteleaceae and Juglandaceae (core Fagales). Based on inflorescence, flower and pollen character distribution, Normapolles pollen could have evolved independently in different lineages of core Fagales, or on the branch subtending this clade. Hence, we use Normapolles pollen to calibrate the stem node of core Fagales." (In PROTEUS, we refer to this clade as 'Normapolles group'.)*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Protofagacea allonensis

Calibration at a glance	stem Fagales, min 83.6 Ma
ID number (NFos)	1

Fossil identity

Full taxon name	**†Protofagacea allonensis Herendeen, Crane and Drinnan**
Organs	Inflorescences, bisexual flowers, pollen in situ, fruits and cupules
Specimens	PP43913
Locality	Allon Quarry; Approximately 9.5 km southeast of Roberta, Georgia, at the south pit of the Atlanta Sand and Supply Company at Gaillard, Crawford County, Georgia (Knoxville Quadrangle, lat. 32°37'47"N, long. 83°59'10"W).
Formation	Buffalo Creek Member of the Gaillard Formation
Country	USA

Reference (description)

Herendeen PS, Crane PR, Drinnan AN. 1995. Fagaceous flowers, fruits and cupules from the Campanian (Late Cretaceous) of Central Georgia, USA. International Journal of Plant Sciences 156: 93–116.

Fossil age

Safe minimum age	**83.6 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Santonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Sauquet et al 2012 (SystBiol): "Palynology (Herendeen et al. 1995; but also see Burnett 1996)"

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**stem Fagales**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Sauquet et al 2012 (SystBiol): "Stem Fagales: in the original description, the authors suggested an affinity to Fagaceae sensu lato, which is Fagaceae + Nothofagus, but acknowledged that clarification of relationships between Fagaceae and Nothofagus is required"

Reference (relationships)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

†Bedellia pusilla

Calibration at a glance stem Betulaceae (Fagales), min 83.6 Ma
ID number (NFos) 211

Fossil identity

Full taxon name	**†Bedellia pusilla Sims, Herendeen, Lupia, Christopher & Crane**
Organs	Flowers, anthers and pollen
Specimens	PP45100 Field Museum Paleobotanical Collection
Locality	Gaillard, Georgia
Formation	Gaillard Formation (Buffalo Creek Member)
Country	USA

Reference (description)

Sims HJ, Herendeen PS, Lupia R, Christopher RA, Crane PR. 1999. Fossil flowers with Normapolles pollen from the Upper Cretaceous of southeastern North America. Review of Palaeobotany and Palynology 106: 131–151.

Fossil age

Safe minimum age	**83.6 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Santonian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Sims et al 1999 (RevPalPal): "Palynological analyses indicate that the Gaillard Formation is of late Santonian age (Christopher, 1979, unpubl. data), although in earlier studies it has been cited as lower Campanian based on a less precise understanding of the biostratigraphy (Herendeen et al., 1995; Crane and Herendeen, 1996; Keller et al., 1996; Magallo´n- Puebla et al., 1996; Konopka et al., 1997). The recent reinterpretation of the age of the Allon locality was based on the presence of terrestrial palynomorphs considered to be biostratigraphically equivalent to marine units that are assigned to the upper Santonian on the basis of calcareous nannofossils [i.e., equivalent to the lower part of calcareous nannofossil Zone CC17, which Burkett (1996) considers to be late Santonian] (Christopher in Sims et al., 1998)."

Reference (age)

Sims HJ, Herendeen PS, Lupia R, Christopher RA, Crane PR. 1999. Fossil flowers with Normapolles pollen from the Upper Cretaceous of southeastern North America. Review of Palaeobotany and Palynology 106: 131–151.

Fossil relationships

Node calibrated	**stem Betulaceae (Fagales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fossil taxon Bedellia is established on the basis of two flowers, one anther cluster, and one isolated anther. Sims et al. (1999) describe Bedellia as "actinomorphic flowers that appear to be staminate and unisexual (no ovary is apparent). Tepals are free and imbricate, and each is apically acute. The androecium is interpreted as having ten stamens, but their position regarding the tepals is uncertain. An ovary is not apparent, and Bedellia was thus interpreted as being unisexual." (Sims et al., 1999). Pollen on the specimens of Bedellia is referable to the Normapolles type. Pollen grains are triaperturate (or rarely quadriporate), and are oblate *in shape with a triangular to subtriangular equatorial outline and straight to slightly convex sides. Sims et al. (1999) considered that Bedellia is similar in several respects to the extant Alnus (Betulaceae) "including the possession of staminate flowers that have prominent tepals and lack vestigial carpels. The triporate pollen grains are also similar to those of Betulaceae in the characteristic finely rugulate to granulate tectum in which the granules are often arranged on short ridges. The presence of weakly developed arci also suggests a close relationship to Alnus, which is unique in having this feature among extant Betulaceae. Pentamerous flowers also occur in some species of Alnus, although in those taxa there are only five tepals and five stamens, which differs from the ten tepals and ten stamens seen in Bedellia." Following the similarities with Betulaceae discussed by Sims et al. (1999), we consider that Bedellia was a stem representative of Betulaceae, and use it to calibrate the stem node of this family."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Palaeocarpinus dakotensis

Calibration at a glance	crown Betulaceae (Fagales), min 56 Ma
ID number (NFos)	212

Fossil identity

Full taxon name	**†Palaeocarpinus dakotensis Manchester, Pigg, & Crane**
Organs	Infructescences
Specimens	Holotype: PP34080, Field Museum, Chicago
Locality	Near Almont, Morton County, North Dakota
Formation	Almont and Beicegel Creek floras, Sentinel Butte Formation
Country	USA

Reference (description)

Manchester SR, Pigg K, Crane PR. 2004. Palaeocarpinus dakotaensis sp. nov. (Betulaceae: Coryloideae) and associated staminate catkins, pollen and leaves from the Paleocene of North Dakota. International Journal of Plant Sciences 165: 1135–1148.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Manchester et al 2004 (IJPS): "The species treated here is known only from two localities in North Dakota: Almont and Beicegel Creek. Both of these localities are within the Sentinel Butte Formation, which is considered to be Late Paleocene (Tiffanian) based on mammal correlations (Kihm and Hartman 1991)." (see also Sauquet et al 2012, who proposed a slightly older minimum age constraint of 59.8 Ma)

Reference (age)

Manchester SR, Pigg K, Crane PR. 2004. Palaeocarpinus dakotaensis sp. nov. (Betulaceae: Coryloideae) and associated staminate catkins, pollen and leaves from the Paleocene of North Dakota. International Journal of Plant Sciences 165: 1135–1148.

Fossil relationships

Node calibrated	**crown Betulaceae (Fagales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Sauquet et al 2012 (SystBiol): "Crown Betulaceae, on the assumption that it is more closely related to Coryloideae (represented here by Carpinus) than Betuloideae: Bracteate fruits; nuts subtended by an involucre of 2 equal to subequal bracts, nutlets flattened in the plane of the bracts with ribs on both faces; perigone with simple hairs (Crane 1981)"

Reference (relationships)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times

using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

†Gymnostoma antiquum

Calibration at a glance	stem Casuarinaceae (Fagales), min 56 Ma
ID number (NFos)	213

Fossil identity

Full taxon name	**†Gymnostoma antiquum Scriven & R.S. Hill**
Organs	Branch with infructescence
Specimens	LB 271/LB 272, Department of Plant Science, University of Tasmania
Locality	Lake Bungarby, New South Wales
Formation	
Country	Australia

Reference (description)

Scriven LJ, Hill RS. 1995. Macrofossil Casuarinaceae: their identification and the oldest macrofossil record, Gymnostoma antiquum sp. nov., from the Late Paleocene of New South Wales, Australia. Australian Systematic Botany 8: 1035–1053.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Thanetian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Sauquet et al 2012 (SystBiol): "Thanetian: Late Paleocene Upper Lygistepollenites balmei Zone of Stover and Partridge (1973)" (min age originally proposed as 55.8 in Sauquet et al., but revised according to the 2017 GTS)

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**stem Casuarinaceae (Fagales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Sauquet et al 2012 (SystBiol): "Large articles, one to two stomatal rows, large fruit size, rounded tooth sinuses"

Reference (relationships)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

†Castaneoidea puryearensis

Calibration at a glance	crown Fagaceae (Fagales), min 37.8 Ma
ID number (NFos)	353

Fossil identity

Full taxon name	**†Castaneoidea puryearensis Crepet & Daghlian**
Organs	Inflorescences and flowers
Specimens	Holotype-University of Connecticut Paleobotanical Collection P36 (Fig. 27, 28)
Locality	Laird Brick Company Pit, Puryear, western Tennesee
Formation	Claiborne Formation
Country	USA

Reference (description)

Crepet WL, Daghlian CP. 1980. Castaneoid inflorescences from the Middle Eocene of Tennessee and the diagnostic value of pollen (at the subfamily level) in Fagaceae. American Journal of Botany 67: 739–757.

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Bartonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Sauquet et al 2012 (SystBiol) on +Castanopsoidea columbiana (in Appendix S2): "Oldest Claiborne beds are in calcaraeous nannoplankton zone NP12, and youngest are in zone NP17 but also within the Bartonian marine stage (e.g., Dockery 1998). Using GTS 2004, base of NP12 is 52.3 Ma (+/- about 0.2 Ma) and end of Bartonian is 37.2 +/- 0.1 Ma." Here, we have revised the absolute age using the ICS v2017/02 geologic time scale.

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**crown Fagaceae (Fagales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The reproductive structures assigned to Castaneoidea puryearensis are dichasia composed of three florets, subtended by bracts up to 1 mm in length, and are arranged helically on the inflorescence axis. The inflorescences possibly abscised before anthesis. Floral envelopes are connate, and apparently had six lobes. Trichomes appear to be short, probably unicellular hairs. There were up to ten stamens in each floret. Stamens have small, more or less elliptical anthers, and contain well-preserved pollen. Pollen is prolate; with exine sculpture consisting of variously anastomosing ridges; and tectate with a minutely perforate tectum (Crepet & Daghlian, 1980). Other detailed features of pollen are available, Crepet & Daghlian (1980) considered it in all respects to be identical to that in modern Castaneoideae. Crepet & Daghlian (1980) considered these fossils to be *“most 81 closely related to the subfamily Castaneoideae of the Fagaceae. They have general inflorescence morphology, flowers borne in bract subtended dichasia, connate lobed floral envelopes with at least five lobes, stamen number and trichomes in common with the Fagaceae .... The affinities of the fossil may be further traced to the subfamly Castaneoideae." These authors conducted a detailed examination of exine characters in Fagaceae, and concluded that exine ornamentation alone is a good diagnostic feature allowing discrimination among the three subfamilies. They indicated that "The diagnostic value of pollen exine ornamentation, size and shape within the Fagaceae has already been demonstrated. The pollen of the fossil is indistinguishable in every respect from the pollen of the modern Castaneoideae ... and on this basis alone the fossils could be reliably assigned to that subfamily. However, there are additional diagnostic features that also indicate the castaneoid nature of these fossils." (Crepet & Daghlian, 1980). These fossils are clearly related to Castaneoideae, and could be members of the stem lineage, or of the crown group of this subfamily. They are here used to calibrate the crown node of family Fagaceae."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Castanopsoidea columbiana

Calibration at a glance	crown Quercoideae (Fagaceae, Fagales), min 37.8 Ma
ID number (NFos)	2

Fossil identity

Full taxon name	**†Castanopsoidea columbiana Crepet & Nixon**
Organs	Pistillate inflorescences, fruits, with in situ pollen
Specimens	UCPC B627
Locality	Buchanan, Tennessee
Formation	Claiborne Formation
Country	USA

Reference (description)

Crepet WL, Nixon KC. 1989. Earliest megafossil evidence of Fagaceae: phylogenetic and biogeographic implications. American Journal of Botany 76: 842–855.

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Bartonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Sauquet et al 2012 (SystBiol): "Claiborne Fm. ranges from late early to late middle Eocene; floras isolated and not placed stratigraphically. Oldest Claiborne beds are in calcaraeous nannoplankton zone NP12, and youngest are in zone NP17 but also within the Bartonian marine stage (e.g., Dockery 1998). Using GTS 2004, base of NP12 is 52.3 Ma (+/- about 0.2 Ma) and end of Bartonian is 37.2 +/- 0.1 Ma."

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**crown Quercoideae (Fagaceae, Fagales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	4 / morphological and molecular trees compared

Node justification

Sauquet et al 2012 (SystBiol): "Stem node of [Castanea + Lithocarpus + Chrysolepis + Quercus] clade; in the original description (Crepet and Nixon 1989), the authors assign the fossil anywhere on the stem or within the crown of a "Castaneoideae" clade composed of [Castanea + Lithocarpus + Chrysolepis (+ Castanopsis unsampled here)]"

Reference (relationships)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

†Polyptera manningii

Calibration at a glance	crown Juglandaceae (Fagales), min 64.4 Ma
ID number (NFos)	217

Fossil identity

Full taxon name	**†Polyptera manningii Manchester & Dilcher**
Organs	Fruits associated with infructescences, pollen and compound leaves
Specimens	USNM267205
Locality	sec. 14, T. 16 N., R. 105 W., southwest of Antelope Butte, Wyoming (USGS loc. 8821; Brown, 1962); Montana
Formation	Fort Union Formation
Country	USA

Reference (first description)

Manchester SR, Dilcher DL. 1982. Pterocaryoid fruits (Juglandaceae) in the Paleogene of North America and their evolutionary and biogeographic significance. American Journal of Botany 69: 275–286.

Reference (latest description)

Manchester SR, Dilcher DL. 1997. Reproductive and vegetative morphology of Polyptera (Juglandaceae) from the Paleocene of Wyoming and Montana. American Journal of Botany 84: 649–663.

Fossil age

Safe minimum age	**64.4 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Sauquet et al 2012 (SystBiol): "40Ar-39Ar dates (Belt et al. 2004). Mammals not well associated with the plants. One of the localities, Mexican Hat, is from the Lebo Member of the Fort Union Fm, which has Ar-Ar dated ashes (Belt et al. 2004). Wilf et al. (2006) averaged the Ar-Ar dates ("Ash I" and "Ash III" of Belt et al.) for an estimate of 64.4 Ma for Mexican Hat, which is a good date for P. manningii. Error of +/0.5 Ma is conservative."

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**crown Juglandaceae (Fagales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Sauquet et al 2012 (SystBiol): "Stem (safe) or crown (risky) Juglandoideae; this fossil was found to be sister to a clade of Carya + Cyclocarya + Juglans in all analyses of Manos et al. (2007); however, this clade does not exist in our tree, because we find Platycarya to be sister to Carya; the safe interpretation is that the fossil could be a stem relative of the whole [Carya + Platycarya + Cyclocarya + Juglans] clade; the risky interpretation is that the fossil is more closely related to Carya OR [Cyclocarya + Juglans] than any other genus of Juglandaceae and therefore lies in the crown group of Juglandoideae"

Reference (relationships)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

†Nothofagidites senectus

Calibration at a glance	stem Nothofagaceae (Fagales), min 83.5 Ma
ID number (NFos)	352

Fossil identity

Full taxon name	**†Nothofagidites senectus Dettmann & Playford**
Organs	Pollen
Specimens	Preparation FI19/ 9, 36·9 114·9, GSV 61898.
Locality	Victoria, F.B.H. Flaxmans No. 1 well, 4479-96 ft (core 5), Bass and Gippsland Basins
Formation	
Country	Australia

Reference (description)

Dettmann ME, Playford G. 1968. Taxonomy of some Cretaceous spores and pollen grains from Eastern Australia. Proceedings of the Royal Society of Victoria 81: 69–93.

Fossil age

Safe minimum age	**83.5 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Santonian-Campanian
Reference time scale	Gradstein et al (2004)
Age quality score	4 / revised (stratigraphic)

Age justification

Sauquet et al 2012 (SystBiol): "Palynostratigraphy, cross-correlated to the marine record: N. senectus zone; Beginning of the Campanian. This is the indicator species for this pollen zone; it is reasonable to take this pollen type back to the start of the Campanian (in theory it must have arisen some time later, but this is so small as to be undetectable); correlated with the marine record; McGlone et al. (1996) placed this in the Piripauan (=Santonian) in NZ, but Ian Raine (pers. comm.) says that there is no sign of it before the Campanian." Note that this should have been revised to 83.6 Ma using the ICS v2017/02 geologic time scale, however the difference is arguably insignificant.

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**stem Nothofagaceae (Fagales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Sauquet et al 2012 (SystBiol): "Stem node of Nothofagus: Apomorphy of papillose, stephanocolpate pollen"

Reference (relationships)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

†Chrysobalanus lacustris

Calibration at a glance	crown Chrysobalanaceae (Malpighiales), min 48.5 Ma
ID number (NFos)	219

Fossil identity

Full taxon name	**†Chrysobalanus lacustris Brown**
Organs	Leaf
Specimens	Plate 72, Figure 8 [specimen number not provided in original description]
Locality	Between Carr and Brush Creeks, 30 miles northwest of De Beque, Colorado Green River Flora
Formation	Green River Formation
Country	USA

Reference (description)

Brown RW. 1929. Additions to the flora of the Green River formation. U.S. Geological Survey Professional Paper 154: 279–292.

Fossil age

Safe minimum age	**48.5 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Green River Formation was deposited between ca. 53.5 Ma and 48.5 Ma, based on 40Ar-39Ar (Smith et al. 2003)

Reference (age)

Smith ME. 2003. 40Ar/39 Ar geochronology of the Eocene Green River Formation, Wyoming. Geological Society of America Bulletin: 549–565.

Fossil relationships

Node calibrated	**crown Chrysobalanaceae (Malpighiales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Brown 1929 (USGeolSurveyProfPaper): "The leaves of the living Ohrysobalanus icaco·, of the extreme southern United States, are in general somewhat larger than this specimen."

Reference (relationships)

Brown RW. 1929. Additions to the flora of the Green River formation. U.S. Geological Survey Professional Paper 154: 279–292.

†*Pachydermites diederixi*

Calibration at a glance	crown Clusiaceae (Malpighiales), min 41.2 Ma
ID number (NFos)	220

Fossil identity

Full taxon name	**†Pachydermites diederixi Germeraad, Hopping & Muller**
Organs	Pollen
Specimens	Holotype: Slide TC-161
Locality	well Ughelli-3, 5200 ft.
Formation	
Country	Nigeria

Reference (description)

Germeraad JH, Hopping CA, Muller J. 1968. Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology 6: 189–348.

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Germeraad et al 1968 (RevPalPal): "In Nigeria there is clear evidence of first appearance in the Middle Eocene, but in the Caribbean area the first appearance is much later and can be fairly accurately dated as Early Miocene." (see also Muller 1981)

Reference (age)

Germeraad JH, Hopping CA, Muller J. 1968. Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology 6: 189–348.

Fossil relationships

Node calibrated	**crown Clusiaceae (Malpighiales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Germeraad et al 1968 (RevPalPal): "Identical with the pollen of Symphonia globulifera (Guttiferae, Plate X, 3). As far as known this pollen type does not occur in other genera and the identification has a very high degree of probability."

Reference (relationships)

Germeraad JH, Hopping CA, Muller J. 1968. Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology 6: 189–348.

†Paleoclusia chevalieri

Calibration at a glance	stem Clusiaceae (Malpighiales), min 86.3 Ma
ID number (NFos)	221

Fossil identity

Full taxon name	**†Paleoclusia chevalieri Crepet & Nixon**
Organs	Flower
Specimens	CUPC 1192 L.H. Bailey Hortorium, Cornell University
Locality	Old Crossman Clay Pit, Sayreville, New Jersey
Formation	Raritan Formation
Country	USA

Reference (description)

Crepet WL, Nixon KC. 1998. Fossil Clusiaceae from the Late Cretaceous (Turonian) of New Jersey and implications regarding the history of bee pollination. American Journal of Botany 85: 1122–1133.

Fossil age

Safe minimum age	**86.3 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Coniacian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Massoni et al 2015 on +Jerseyanthus calycanthoides: "These fossils were collected from the South Amboy Fire Clay Member of the Raritan Formation at the Old Crossman clay pit in Sayreville, New Jersey, USA (Crepet et al., 2005). This unit was first studied palynologically by Groot et al. (1961), who considered it Turonian based on preliminary studies on European sequences, and subsequently by Doyle (1969b), Wolfe and Pakiser (1971), Doyle and Robbins (1977), and Christopher (1979). Building on the palynological zonation of the Potomac Group by Brenner (1963), to which Doyle (1969a) added Zone III (uppermost Potomac) and Zone IV (lower Raritan), Sirkin (1974) assigned South Amboy palynofloras to a new Zone V. This unit was renamed the Complexiopollis exigua - Santalacites minor Zone by Christopher (1979) and redefined by Christopher et al. (1999) as the lowest of three subzones of the Sohlipollis Taxon Range Zone. Wolfe and Pakiser (1971) and Sirkin (1974) considered the South Amboy late Cenomanian, not much younger than underlying Woodbridge Clay Member (Zone IV), but Doyle (1969b) and Doyle and Robbins (1977) argued that it is no older than middle Turonian, based on the presence of Normapolles genera that appear at that level in Europe (Góczán et al., 1967). Doyle and Robbins (1977) and Christopher (1979) allowed that it was "possibly Coniacian," but Crepet and Nixon (1994) and Crepet et al. (2005) accepted a late Turonian age. By contrast, Clarke et al. (2011) suggested a minimum age of the Santonian-Campanian boundary, 82.8 Ma. However, correlations by Christopher et al. (1999) and Christopher and Prowell (2010) with better-dated rocks in South Carolina imply that the Crossman locality is not this young; they correlate the C. exigua - S. minor Zone with calcareous nannofossil zones CC13 and CC14, which extend from late Turonian through Coniacian (Burnett, 1998; Ogg and Hinnov, 2012). We therefore believe there is enough evidence to consider that Jerseyanthus was at least of Coniacian age, which translates into a conservative minimum age of 85.8 Ma, the Coniacian-Santonian boundary (86.3 ±0.5 Ma; Ogg and Hinnov, 2012)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated **stem Clusiaceae (Malpighiales)**

Node assignment score 5 / phylogenetic analysis

Reconciliation score 5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Ruhfel et al 2013 (IJPS): "The extinct Paleoclusia was placed as a member of stem group Clusiaceae s.s. or within crown group Clusiaceae s.s. as sister to one of its two major subclades."

Reference (relationships)

Ruhfel BR, Stevens PF, Davis CC. 2013. Combined morphological and molecular phylogeny of the clusioid clade (Malpighiales) and the placement of the ancient rosid macrofossil Paleoclusia. International Journal of Plant Sciences 174: 910–936.

†Ctenolophonidites costatus

Calibration at a glance	stem Ctenolophonaceae (Malpighiales), min 66 Ma
ID number (NFos)	222

Fossil identity

Full taxon name	**†Ctenolophonidites costatus (van Hoeken-Klinkenberg) van Hoeken-Klinkenberg**
Organs	Pollen
Specimens	NKC 16, NS 21 (Department of Geology, University of Calabar, Nigeria) (from Edet & Nyong 1994)
Locality	Locality L.6 42 km, Nkporo Shale on the Calabar Flank, Nigeria
Formation	Nkporo Shales
Country	Nigeria

Reference (first description)

van Hoeken-Klinkenberg P. 1964. A palynological investigation of some Upper Cretaceous sediments in Nigeria. Pollen et Spores 6: 209–231.

Reference (latest description)

Van Hoeken-Klinkenberg PMJ. 1966. Maastrichtian, Palaeocene and Eocene pollen and spores from Nigeria. Leidse Geol. Meded., 38: 37-48.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Edet & Nyong 1994 (RevPalPal): "Detailed palynological examination of the Nkporo Shales based on the occurrence of both miospores and organic-walled microplankton, mainly dinoflagellate cysts, has been carried out for the first time. The recovered palynofloral assemblage essentially displays the typical characteristics of the Senonian Palmae province comprising a majority of the Campanian-Maastrichtian elements recorded from tropical-subtropical regions of South America, Africa and India. Based on the data, a late Campanian-Maastrichtian age range is established for the Nkporo Shales succession on the Calabar Flank."

Reference (age)

Edet JJ, Nyong EE. 1994. Palynostratigraphy of Nkporo Shale exposures (late Campanian-Maastrichtian) on the Calabar Flank, SE Nigeria. Review of Palaeobotany and Palynology 80: 131–147.

Fossil relationships

Node calibrated	**stem Ctenolophonaceae (Malpighiales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

van Hoeken-Klinkenberg 1966 (LeidseGeolMeded): "Stephanocolpate pollengrains with endexinous thickenings between the furrows. Thickenings fusing at the poles, forming an irregular ringlike pattern, as in recent Ctenolophonaceae."

Reference (relationships)

Van Hoeken-Klinkenberg PMJ. 1966. Maastrichtian, Palaeocene and Eocene pollen and spores from Nigeria. Leidse Geol. Meded., 38: 37-48.

†Hippomaneoidea warmanensis

Calibration at a glance	crown Euphorbioideae (Euphorbiaceae, Malpighiales), min 37.8 Ma
ID number (NFos)	223

Fossil identity

Full taxon name	**†Hippomaneoidea warmanensis Crepet & Daghlian**
Organs	Inflorescences, pollen
Specimens	W55 University of Connecticut Paleobotanical Collection
Locality	Warman mine of the H. C. Spinks Clay Company in Henry County, Tennessee
Formation	Claiborne Formation
Country	USA

Reference (description)

Crepet WL, Daghlian CP. 1982. Euphorbioid inflorescences from the Middle Eocene Claiborne Formation. American Journal of Botany 69: 258–266.

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Bartonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Sauquet et al 2012 (SystBiol) on +Castanopsoidea columbiana (in Appendix S2): "Oldest Claiborne beds are in calcaraeous nannoplankton zone NP12, and youngest are in zone NP17 but also within the Bartonian marine stage (e.g., Dockery 1998). Using GTS 2004, base of NP12 is 52.3 Ma (+/- about 0.2 Ma) and end of Bartonian is 37.2 +/- 0.1 Ma." Here, we have revised the absolute age using the ICS v2017/02 geologic time scale.

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**crown Euphorbioideae (Euphorbiaceae, Malpighiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The reproductive structures assigned to Hippomaneoidea warmanensis are described as “Inflorescences are spikes of sometimes branched, bract-subtended cymules of up to 5 cm in length. Bracts are ovate and cupped and the cymules are composed of at least three diminuitive florets. Pollen is preserved within the anthers and is tricolporate, prolate and has notably lalongate pores. Exine stratification is tectate columellate with a relatively thick tectum and short columellae.” (Crepet & Daghlian, 1982). 91 Crepet & Daghlian (1982) indicate that the combination of floral and palynological features of this fossil can be found only in Euphorbiaceae. Furthermore, they indicate that the features of the fossil inflorescences are consistent with those that are diagnostic of inflorescences of the subfamily and the fossil inflorescence compares very closely with those of a complex of extant genera within the Hippomaneae (Bentham, 1880). Regarding the fossil pollen, Crepet &

Daghlian (1982) indicate that "Pollen similar to that of the fossil inflorescences (i.e., tricolporate, oblate to prolate) is common in the Euphorbiaceae (Punt, 1962; Webster, 1975). Furthermore, fossil pollen fits well within the subfamily Euphorbioideae (pollen of the Euphorbioideae is tricolporate, often marginate, with a reticulate, more often perforate tectum; Webster, 1975) and within the "Hippomaneae configuration" and "Hippomaneae type" of Punt (i.e., tricolporate, circular to three-lobed in polar view, pore short or narrow and elongate, colpi narrow often with a margo, tectate with distinct columellae). More detailed comparisons at the generic level emphasize the similarities between the inflorescences of the Hippomaneae and the fossil inflorescence." All of the major features of the fossil inflorescences are shared by the inflorescences of one or more genera of the Hippomaneae (Crepet & Daghlian, 1982). These authors find noteworthy that inflorescences of such a modern aspect existed in the Middle Eocene, as Hippomaneae is derived within Euphorbiaceae."
Contrary to Magallón et al 2015 (NewPhytol), who used this fossil to constrain the stem node of Euphorbioideae, we here constrain the crown node of Euphorbioideae on the assumption that it belongs to the total group of tribe Hippomaneae (which is nested in Euphorbioideae: e.g., see Wurdack et al 2005).

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Humiriaceoxylon ocuensis

Calibration at a glance	crown Humiriaceae (Malpighiales), min 33.9 Ma
ID number (NFos)	224

Fossil identity

Full taxon name	**†Humiriaceoxylon ocuensis Herrera, Manchester, Velez-Juarbe & Jaramillo**
Organs	Wood
Specimens	USNM 312574
Locality	Ocú, Azuero Peninsual; locality UF 606 (lat. 7 55.476 N, long. 80 47.959 W)
Formation	
Country	Panama

Reference (description)

Herrera F, Manchester SR, Vélez-Juarbe J, Jaramillo C. 2014. Phytogeographic history of the Humiriaceae (part 2). International Journal of Plant Sciences 175: 828–840.

Fossil age

Safe minimum age	**33.9 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Eocene
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Herrera et al 2014 (IJPS): "Fossil invertebrates from the siltstones indicate a late Eocene age for these sediments (A. Hendy, personal communication). Recent mapping of the north-central part of the Azuero Peninsula suggests that sediments exposed near the town of Ocu´ and surrounding areas belong to the late Eocene–late Oligocene Tonosi Formation (Buchs et al. 2011). Based on our observations near Ocu´ and the recent geological mapping, we tentatively consider the fossil wood of Stern and Eyde (1963) to be Late Eocene (ca. 37.2–33.9 Ma) in age."

Reference (age)

Herrera F, Manchester SR, Vélez-Juarbe J, Jaramillo C. 2014. Phytogeographic history of the Humiriaceae (part 2). International Journal of Plant Sciences 175: 828–840.

Fossil relationships

Node calibrated	**crown Humiriaceae (Malpighiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Herrera et al 2014 (IJPS): "Based on our overview of the extant wood in the family, we place the Ocú material in a new fossil genus for wood with anatomy corresponding to Humiriaceae including vessel-ray pits with distinct borders."

Reference (relationships)

Herrera F, Manchester SR, Vélez-Juarbe J, Jaramillo C. 2014. Phytogeographic history of the Humiriaceae (part 2). International Journal of Plant Sciences 175: 828–840.

†Eoglandulosa warmanensis

Calibration at a glance	stem Malpighiaceae (Malpighiales), min 37.8 Ma
ID number (NFos)	226

Fossil identity

Full taxon name	**†Eoglandulosa warmanensis Taylor & Crepet**
Organs	Flower with pollen
Specimens	W243a, b, Univ. of Connecticut Paleobotanical Collection (UCPC)
Locality	Warman clay pit, Como, Tennessee, on Route 57 on the border of Henry and Weakley Counties
Formation	Claiborne Formation
Country	USA

Reference (description)

Taylor DW, Crepet WL. 1987. Fossil floral evidence of Malpighiaceae and an early plant-pollinator relationship. American Journal of Botany 74: 274.

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Bartonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Sauquet et al 2012 (SystBiol) on +Castanopsoidea columbiana (in Appendix S2): "Oldest Claiborne beds are in calcaraeous nannoplankton zone NP12, and youngest are in zone NP17 but also within the Bartonian marine stage (e.g., Dockery 1998). Using GTS 2004, base of NP12 is 52.3 Ma (+/- about 0.2 Ma) and end of Bartonian is 37.2 +/- 0.1 Ma." Here, we have revised the absolute age using the ICS v2017/02 geologic time scale.

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**stem Malpighiaceae (Malpighiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Magallón et al (2015): "The flowers of Eoglandulosa warmanensis are considered as the earliest megafossil evidence of Malpighiaceae (Taylor & Crepet, 1987). The flower "has paired glands on the five sepals, clawed petals and tricolporate pollen with reticulate ornamentation and an unusual infratectal wall structure of anastomosing elements. The fossil is similar in wall structure to some extant species of Malpighiaceae." (Taylor & Crepet, 1987). Taylor & Crepet (1987) indicate that the fossil has a mixture of ancestral characters, like floral morphology and pollen's tricolporate aperture configuration and ornamentation; and derived characters, for example, the pollen wall structure. Given this character combination, Eoglandulosa could have been a stem representative or a crown member of Malpighiaceae. We use this fossil to calibrate the stem node of this family."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Tetrapterys harpyiarum

Calibration at a glance	crown Malpighioideae (Malpighiaceae, Malpighiales), min 27.82 Ma
ID number (NFos)	225

Fossil identity

Full taxon name	**†Tetrapterys harpyiarum Unger emend. Hably & Manchester**
Organs	Fruits with four wings
Specimens	Lectotype: 77.248 from Unger, 1850a, Plate 29(8), Graz, Landesmuseum Joanneum
Locality	Budapest–Nagybatony-Ujlak brickyard, Budapest–Vorosvari Street, Eger-Kiseged, Eger-Vecsey valley (Hungary); Sagor, Sotzka, Novi Dol (Slovenia)
Formation	Tard Clay Formation
Country	Hungary

Reference (description)

Hably L, Manchester SR. 2000. Fruits of Tetrapterys (Malpighiaceae) from the Oligocene of Hungary and Slovenia. Review of Palaeobotany and Palynology 111: 93–101.

Fossil age

Safe minimum age	**27.82 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Oligocene (Rupelian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Hably & Manchester 2000 (RevPalPal): "In Hungary specimens of Tetrapterys harpyiarum have been collected from two areas separated by 130 km: Obuda (Nagybatony-Ujlak brickyard; and Vorosvari Street H-16 drilling) in Budapest, as well as Kiseged hill and Vecsey valley near Eger. In both areas the fossils occur in the Tard Clay Formation in sediments containing nannoplankton indicating zone NP 23, which is correlated with the lower Oligocene (Nagymarosy and Baldi-Beke, 1988)."

Reference (age)

Hably L, Manchester SR. 2000. Fruits of Tetrapterys (Malpighiaceae) from the Oligocene of Hungary and Slovenia. Review of Palaeobotany and Palynology 111: 93–101.

Fossil relationships

Node calibrated	**crown Malpighioideae (Malpighiaceae, Malpighiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fruits T. harpyiarum fruits are bilaterally symmetrical, consisting of a globose nut surrounded by four elongate wings with parallel venation that spread in a common plane. They are described as "Usually the fruits are bisymmetrical, with a larger and slightly smaller wing on each side of the plane of symmetry. In addition, a minor wing, or crest, runs in a plane that bissects the fruit body in the plane of bisymmetry. The wings have parallel venation. The midvein is no more pronounced than the others. The venation is not looped or reticulate and there is not a well-marked marginal vein." (Hably & Manchester, 2000). The fossil fruits are reported as being similar to those of the extant tropical American genus Tetrapterys (Hably & Manchester, 2000). We use these fruits to calibrate the stem node of Tetrapterys."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Phyllanthus sp.

Calibration at a glance	crown Phyllanthoideae (Phyllanthaceae, Malpighiales), min 33.9 Ma
ID number (NFos)	227

Fossil identity

Full taxon name	**†Phyllanthus sp. Zakinslaja**
Organs	Pollen
Specimens	Figs. 10-12 [specimen numbers not provided]
Locality	Site 368
Formation	
Country	Cape Verde

Reference (description)

Zaklinskaya ED. 1978. Palylonogy of the Paleogene Clay from DSDP Site 368, Cape Verde Rise. Deep Sea Drilling Project (U.S. Government Printing Office) 41: 933-937

Fossil age

Safe minimum age	**33.9 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Eocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Zaklinskaya 1978 (DSDPUS): "It is evident that the exact age of the flora cannot be determined by studying only one sample. Nevertheless, the Paleogene (likely Eocene) age of the palynocomplex is beyond doubt."

Reference (age)

Zaklinskaya ED. 1978. Palylonogy of the Paleogene Clay from DSDP Site 368, Cape Verde Rise. Deep Sea Drilling Project (U.S. Government Printing Office) 41: 933-937

Fossil relationships

Node calibrated	**crown Phyllanthoideae (Phyllanthaceae, Malpighiales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Justification not provided in original description

Reference (relationships)

Zaklinskaya ED. 1978. Palylonogy of the Paleogene Clay from DSDP Site 368, Cape Verde Rise. Deep Sea Drilling Project (U.S. Government Printing Office) 41: 933-937

†Rhizophora sp.

Calibration at a glance	stem Rhizophora (Rhizophoraceae, Malpighiales), min 33.9 Ma
ID number (NFos)	357

Fossil identity

Full taxon name	**†Rhizophora sp. Graham**
Organs	Pollen
Specimens	Fig. 61. Rhizophora, 4-1, K-24
Locality	Alcalde Diaz (Penoncito)
Formation	Gatuncillo Formation
Country	Panama

Reference (description)

Graham A. 1985. Studies in Neotropical Paleobotany. IV. The Eocene Communities of Panama. Annals of the Missouri Botanical Garden 72: 504–534.

Fossil age

Safe minimum age	**33.9 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Eocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Pollen grains of Rhizophora from Late Eocene sediments of the Caribbean area (Germeraad, et al., 1968); from the Gatuncillo Formation, Panama, dated as Middle to Late Eocene (Graham, 1985); and from the Cadell Formation, Texas, USA, dated as Priabonian (Late Eocene; Elsik & Yancey, 2000)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Rhizophora (Rhizophoraceae, Malpighiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The polen of Rhizophora from Gatuncillo, Panama is "prolate to prolate-spheroidal; tricolpate, colpi narrow, straight, 14-16 µm, apices acute, equatorially arranged, meridionally elongated, equidistant, costae colpi c. 3 µm, pores elongated equatorially (colpi transversalis), 1 µm by 4 µm, constricted at mid-point of colpus, inner margin entire; tectate-per- forate, wall thick (2-3 µm); finely reticulate; 19- 21 µm by 22-24 µm." (Graham, 1985). Elsik & Yancely (2000) indicate that the the polen grains from the Caddel Fromation, Texas, closely match those of Rhizophora. Based on the distictive appearance of Rhizophora polen, and onthe simultaneous appearance of these type of polen grains in different localities from the (Middle) Late Eocene, we calibrate the stem node of the genus Rhizophora."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree

documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Zonocostites ramonae

Calibration at a glance: crown Rhizophoraceae (Malpighiales), min 33.9 Ma
ID number (NFos): 228

Fossil identity

Full taxon name: **†Zonocostites ramonae Germeraad, Hopping & Muller**
Organs: Pollen
Specimens: Holotype: Slide TC-164,
Locality: well CO-77, 3600 ft., Trinidad
Formation:
Country: Trinidad

Reference (description)

Germeraad JH, Hopping CA, Muller J. 1968. Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology 6: 189–348.

Fossil age

Safe minimum age: **33.9 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Late Eocene
Reference time scale: ICS (v2017/02)
Age quality score: 2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Pollen grains of Rhizophora from Late Eocene sediments of the Caribbean area (Germeraad, et al., 1968); from the Gatuncillo Formation, Panama, dated as Middle to Late Eocene (Graham, 1985); and from the Cadell Formation, Texas, USA, dated as Priabonian (Late Eocene; Elsik & Yancey, 2000)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated: **crown Rhizophoraceae (Malpighiales)**
Node assignment score: 2 / intuitive or unspecified (trusted source)
Reconciliation score: 3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The pollen grains assigned to Rhizophora from the Caribbbean area are of the Zonocostites ramonae type. A single grain is known, which is "radially symmetrical, isopolar, spherical. Tricolporate, colpi ectexinous, medium long, straight with pointed ends, slightly costate, endexinous apertures equatorially elongated to almost fused, distinctly costate, in polar view slightly vestibulate. Endexine < 0.5 μ(m) thick; columellae < 0.5 μ(m) thick and high; tectum < 0.5 μ(m) thick, densely perforate, coarser on poles and finer to almost psilate on equatorial belt, perforations < 0.5 μ(m) wide." (Germeraad et al., 1968). Germeraad et al. (1968) indicate that the pollen of Rhizophora is distinctive and "cannot be confused with pollen from other taxa"."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Populus tidwelli

Calibration at a glance	crown Salicoideae (Salicaceae, Malpighiales), min 48.5 Ma
ID number (NFos)	229

Fossil identity

Full taxon name	**†Populus tidwelli Manchester, Judd & Handley**
Organs	Leaves and twig
Specimens	Holotype: UCMP 398135
Locality	Roan Creek near Douglas Pass, Colorado
Formation	Green River Formation (Parachute Creek Member)
Country	USA

Reference (description)

Manchester SR, Judd WS, Handley B. 2006. Foliage and Fruits of Early Poplars (Salicaceae: Populus) from the Eocene of Utah, Colorado, and Wyoming. International Journal of Plant Sciences 167: 897–908.

Fossil age

Safe minimum age	**48.5 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Green River Formation was deposited between ca. 53.5 Ma and 48.5 Ma, based on 40Ar-39Ar (Smith et al. 2003)

Reference (age)

Smith ME. 2003. 40Ar/39 Ar geochronology of the Eocene Green River Formation, Wyoming. Geological Society of America Bulletin: 549–565.

Fossil relationships

Node calibrated	**crown Salicoideae (Salicaceae, Malpighiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fossils assigned to Populus tidwellii are described as follows: "… leaves have a lanceolate to elliptical rather than deltoid outline and a strongly ascending basal pair of secondary veins. The fruits of P. tidwellii so far recovered do not show seeds inside, but they have dispersed hairy seeds that are likely candidates for having been produced by these fruits. The infructescence with capsules corresponding morphologically to those of Populus in attachment to the twig of this foliage type. The fruiting specimen of P. tidwellii suggest that pseudoracemes (i.e., raceme-like cymes) may have characterized stem lineages within the Populus + Salix clade. On the other hand, the lack of true racemes in P. tidwellii may indicate that it (like Pseudosalix) is an early divergent member of the stem lineage (of the Populus + Salix clade). Fruits of P. tidwellii show a structure at the top of the pedicel that may represent a scar (resulting from a deciduous calyx, as in Pseudosalix) or a reduced calyx, as in extant species of Populus." (Manchester et al., 2006). Manchester et al. (2006) considered that although the leaves of P. tidwellii are distinctive in their prominent basal pair of secondary veins, their placement in Populus is consistent with fruit and calyx morphology. However, this fossil is also similar to Pseudosalix in having a branched terminal inflorescence. Manchester et al. (2006) interpreted P. tidwellii as either a member of the Populus clade or, like Pseudosalix, an early divergent member of the clade containing Populus and Salix that is characterized by the Populus-type capsule (Manchester et al., 2006). We accept the latter interpretation, and use P. tidwellii to calibrate *the stem node of the clade that includes Populus and Salix."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Populus wilmattae

Calibration at a glance stem Populus (Salicaceae, Malpighiales), min 48.5 Ma
ID number (NFos) 356

Fossil identity

Full taxon name **†Populus wilmattae Cockrell**
Organs Leaves, infructescences and fruits
Specimens The specimen is housed in the paleobotanical collection of Brigham Young University (BYU 3003).
Locality approximately five miles south of Bonanza, UT (I.U. Geol. loc. 15751)
Formation Parachute Creek Member of the Green River Formation
Country USA

Reference (description)

Manchester SR, Dilcher DL, Tidwell WD. 1986. Interconnected reproductive and vegetative remains of Populus (Salicaceae) from the Middle Eocene Green River Formation, Northeastern Utah. American Journal of Botany 73: 156–160.

Fossil age

Safe minimum age **48.5 Ma**
Absolute age source radioisotopic
Age quality score 5 / revised (radioisotopic)

Age justification

Green River Formation was deposited between ca. 53.5 Ma and 48.5 Ma, based on 40Ar-39Ar (Smith et al. 2003)

Reference (age)

Smith ME. 2003. 40Ar/39 Ar geochronology of the Eocene Green River Formation, Wyoming. Geological Society of America Bulletin: 549–565.

Fossil relationships

Node calibrated **stem Populus (Salicaceae, Malpighiales)**
Node assignment score 2 / intuitive or unspecified (trusted source)
Reconciliation score 3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The characters that indicate the affinity of these fossils with Populus are deltoid leaves with salicoid glandular teeth and long petioles, together with racemose infructescences bearing valvate capsules with distinct floral disks, and seeds with an attached hairy placenta (Manchester et al., 1986). Manchester et al. (1986) indicate that Populus wilmattae is most similar to P. mexicana, the single living species of section Abaso. “The leaves of these two species share several features that do not occur in other modem Populus species, such as percurrent tertiary venation and the continuation of teeth along the flanks of the apical tip of the leaf. The scar subtending each capsule indicates that the floral disks were caducous, as in P. mexicana, rather than persistent as in most other sections. However, the capsules of P. wilmattae appear to be tri-valvate in contrast to those 89 of P. mexicana which are predominantly bi-valvate. The tri-valvate condition of the fossil is common in other extant sections of Populus and migth be a primitive character.” (Manchester et al., 1986). We agree with Manchester et al. (1986) in that P. wilmattae is an extinct species most closely related to extant P. mexicana. Hence, we use this fossil to calibrate the stem node of Populus."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Eucryphia falcata

Calibration at a glance	crown Cunoniaceae (Oxalidales), min 56 Ma
ID number (NFos)	230

Fossil identity

Full taxon name	**†Eucryphia falcata R Hill**
Organs	Leaves
Specimens	Holotype: LB-025, stored in the Department of Plant Science, University of Tasmania
Locality	Lake Bungarby, NSW (36" 09' S, 149" 08' E).
Formation	
Country	Australia

Reference (description)

Hill RS. 1991. Leaves of Eucryphia (Eucryphiaceae) from Tertiary Sediments in South-eastern Australia. Australian Systematic Botany 4: 481-497.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Hill 1991 (AustSystBot): "The palynoflora has been assigned by Taylor ec al. (1990) to the Upper Lygistepollenites balmei Zone of Stover and Partridge (1973), which encompasses the Late Palaeocene."

Reference (age)

Hill RS. 1991. Leaves of Eucryphia (Eucryphiaceae) from Tertiary Sediments in South-eastern Australia. Australian Systematic Botany 4: 481-497.

Fossil relationships

Node calibrated	**crown Cunoniaceae (Oxalidales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Hill 1991 (AustSystBot): "The Late Palaeocene specimens from Lake Bungarby are the oldest assignable to Euc,yphia. The collection consists of five compressions, four of which are complete or nearly complete leaves or leaflets (e.g. Figs 20, 21). The cuticularmorphology of all these specimens is identicaJ, with paracytic or brachyparacytic subsidiary cell arrangements (Fig. 22) and peltiform extensions present on the abaxial surface (Fig. 23), with a groove clearly present on the inner cuticular surface (Fig. 22). The peltiform extensions are not well preserved but, based on observation with both the light microscope (LM) (Figs 24, 25) and SEM, it is concluded that they are much Jess substantial in form and overlap less than in any of the living evergreen species. Trichome bases are present on both the abaxial and adaxial surface over the veins (Figs 23, 24). The venation pattern of these leaves is difficult to determine in detail as the leaves are thick and have not left a clear impression in the sediment. However, some detail was observed on the surface of two leaves which suggests a brochidodromous or semicraspedodromous venation pattern, depending on whether or not serrations are present. These cuticular and venation characters confirm that the specimens can be assigned to Euc,yphia."

Reference (relationships)

Hill RS. 1991. Leaves of Eucryphia (Eucryphiaceae) from Tertiary Sediments in South-eastern Australia. Australian Systematic Botany 4: 481-497.

†Lacinipetalum spectabilum

Calibration at a glance	stem Schizomerieae (Cunoniaceae, Oxalidales), min 63.49 Ma
ID number (NFos)	362

Fossil identity

Full taxon name	**†Lacinipetalum spectabilum Jud, Gandolfo, Iglesias & Wilf**
Organs	Flowers with pollen
Specimens	Holotype designated here. MPEF-Pb 8423 (Fig. 2A), from Palacio de los Loros-2 (PL-2), Chubut Province, Argentina; upper Salamanca Formation, Chron C28n, early Danian (early Palaeocene). Repository. Museo Paleontológico Egidio Feruglio.
Locality	Palacio de los Loros-2 (PL-2), Chubut Province
Formation	Upper Salamanca Formation
Country	Argentina

Reference (description)

Jud NA, Gandolfo MA, Iglesias A, Wilf P. 2018. Fossil flowers from the early Palaeocene of Patagonia, Argentina, with affinity to Schizomerieae (Cunoniaceae). Annals of Botany: 431–442.

Fossil age

Safe minimum age	**63.49 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Jud et al 2018 (AnnBot): "Most of the flowers (107 specimens) were collected from the Palacio de los Loros-2 (PL-2) site in the Salamanca Formation; this site is correlated to geomagnetic polarity Chron C28n (Clyde et al., 2014; Comer et al., 2015), which spans 64.67–63.49 Ma (Gradstein et al., 2012). The PL-2 site yields a parautochthonous assemblage of leaves and reproductive structures preserved in a grey shale interpreted as a tidally influenced channel-fill (Iglesias et al., 2007; Comer et al., 2015). Four specimens were collected from the Palacio de los Loros-5 (PL-5) locality, which is slightly more coarse-grained than PL-2 and nearly 1 km away, but also interpreted as a tidally influenced channel-fill deposit from Chron C28n (Iglesias et al., 2007; Comer et al., 2015). Two specimens came from the fluvio-volanic Las Flores locality (LF), which is in the late Danian Peñas Coloradas Formation. The LF locality is correlated to Chron C27n (Clyde et al., 2014; Comer et al., 2015), which spans 62.52–62.22 Ma (Gradstein et al., 2012), and the fossils are preserved in reddish, fissile mud that is wedged between cross-bedded sets of poorly sorted, cross-bedded sandstone. The LF locality is interpreted as a fluvial channel-fill deposit (Comer et al., 2015). "

Reference (age)

Jud NA, Gandolfo MA, Iglesias A, Wilf P. 2018. Fossil flowers from the early Palaeocene of Patagonia, Argentina, with affinity to Schizomerieae (Cunoniaceae). Annals of Botany: 431–442.

Fossil relationships

Node calibrated	**stem Schizomerieae (Cunoniaceae, Oxalidales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

A total evidence phylogenetic analysis based on a small morphological and molecular dataset supports this fossil taxon as sister to Schizomerieae. Although this result is entirely conditional on the a priori assignment of the fossil to a subclade of Cunoniaceae (with a single outgroup of Schizomerieae sampled), this placement is also supported by *an extensive discussion of morphological characters in a modern phylogenetic framework.*

Reference (relationships)

Jud NA, Gandolfo MA, Iglesias A, Wilf P. 2018. Fossil flowers from the early Palaeocene of Patagonia, Argentina, with affinity to Schizomerieae (Cunoniaceae). Annals of Botany: 431–442.

†Platydiscus peltatus

Calibration at a glance	stem Cunoniaceae (Oxalidales), min 80.7 Ma
ID number (NFos)	76

Fossil identity

Full taxon name	**†Platydiscus peltatus Schönenberger & Friis**
Organs	Flower
Specimens	Holotype: S107143 (sample GI 32116)
Locality	Höganäs AB quarry at Asen near Axeltorp, Scania, Fluviatile-lacustrine sequence
Formation	
Country	Sweden

Reference (description)

Schönenberger J, Friis EM, Matthews ML, Endress PK 2001 Cunoniaceae in the Cretaceous of Europe: Evidence from fossil flowers. Annals of Botany 88: 423-437.

Fossil age

Safe minimum age	**80.7 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Campanian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Flowers assigned to Platydiscus peltatus Schönenberger, Friis, Matthews & Endress, from the Höganäs AB's kaolin quarry, Åsen locality, Scania, Sweden (Schönenberger et al., 2001), considered to be of late Santonian to early Campanian age (Schönenberger et al., 2001; Friis et al., 2011)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Cunoniaceae (Oxalidales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Magallón & Castillo 2009 (AmJBot): "The flowers of Platydiscus peltatus are described as being "small, bisexual, actinomorphic, tetramerous with broadly attached valvate sepals; they have narrowly attached petals; eight stamens in two whorls; a massive, lobed nectary; a semiinferior, syncarpous gynoecium with axile placentation; numerous ovules; separate styles; and peltate, probably secretory, trichomes." (Schönenberger, et al., 2001). Schönenberger et al. (2001) considered that the combination of small, bisexual, actinomorphic, tetramerous flowers with broadly attached, valvate sepals, narrowly attached petals, eight stamens, a massive nectary, a syncarpous gynoecium with axile placentation, and separate styles, found in the fossil flowers, is known from two families among modern eudicots, namely the Cunoniaceae (Oxalidales) and Anisophylleaceae (Cucurbitales). However, these authors found greater support for an affinity with Cunoniaceae, given the structure of the gynoecium (inferior and completely united at the overy level in Ansiophylleaceae); the numer of ovules per carpel (only one in Ansiphylleaceae); and the presence of involute placentas (apparently absent in Anisophylleaceae). However, the *combination of features observed in the fossil is not found in an extant geus of Cunoniaceae. We agree with the assignment of Platydiscus to Cunoniaceae by Schönenberger et al. (2001), and consider that it could have been an extinct crown member or a stem representative of the family. We use it to calibrate the stem node of Cunoniaceae."*

Reference (relationships)

Magallón S, Castillo A. 2009. Angiosperm diversification through time. American Journal of Botany 96: 349–365.

†Sloanea ungeri

Calibration at a glance crown Elaeocarpaceae (Oxalidales), min 61.6 Ma
ID number (NFos) 231

Fossil identity

Full taxon name **†Sloanea ungeri (Heer) Manchester & Z. Kvacek**
Organs Fruits
Specimens Lectotype: BMv11326
Locality Atanikerdluk
Formation Upper Atanikerdluk Formation
Country Greenland

Reference (description)

Manchester SR, Kvaček Z. 2009. Fruits of Sloanea (Elaeocarpaceae) in the Paleogene of North America and Greenland. International Journal of Plant Sciences 170: 941–950.

Fossil age

Safe minimum age **61.6 Ma**
Absolute age source stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age Danian
Reference time scale ICS (v2017/02)
Age quality score 3 / unrevised (recent source >= 2000)

Age justification

Manchester & Kvacek 2009 (IJPS): "The Atanikerdluk flora of Greenland, from which the type specimen was collected, is considered Early Paleocene (late Danian) on the basis of correlations using dinoflagellates, mollusks, and foraminifera (Golovneva 2000)." Note that the oldest North American specimens reported by Manchester & Kvacek 2009 (e.g., Table 1) would allow an equally old (or optentially slightly older: Puercan) age constraint.

Reference (age)

Manchester SR, Kvaček Z. 2009. Fruits of Sloanea (Elaeocarpaceae) in the Paleogene of North America and Greenland. International Journal of Plant Sciences 170: 941–950.

Fossil relationships

Node calibrated **crown Elaeocarpaceae (Oxalidales)**
Node assignment score 3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score 3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fruits of Sloanea ungeri are characterized “by spiny ornamentation, spreading capsular valves, and long unscarred pedicels. The complete pedicel on one specimen measures 7 cm in length below a fruit that is only 2.5 cm long. Counterpart impressions of the same fruit show the distinct morphology of inner and outer surfaces of the capsule valves. The inner surface is smooth and concave with a median longitudinal keel (septum), while the outer surface is convex and covered with spines. The spines are straight, stiff, unbranched, and densely spaced over the surface of the fruit . The length of these spines, 4–8 mm, varies among different specimens. The prominent disk at the base of the fruits represents the attachment area of numerous stamens at the flowering stage. In well-preserved specimens, the surface of the disk as impressed in the sediment shows a punctate surface indicative of the scars made by the original stamen filaments of the flower.” (Manchester & Kvaček, 2009). Manchester & Kvaček (2009) consider that the fossil fruits correspond closely with the fruits of *extant Sloanea "in the shape and number of valves, the prominent staminal disk persistent in fruit, a pedicel that may be longer than the fruit it bears, and the stout style seen in immature unopened fruits. … The staminal disk, which persists at the base of the fruit even after the stamens have been shed, is one of the distinguishing features for the family." Based on the detailed morphological and structural similarities between the fossil fruits and extant Solanea, we use these fossils to calibrate the crown node of Elaeocarpaceae."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Aphananthe cretacea*

Calibration at a glance	crown Cannabaceae (Rosales), min 66 Ma
ID number (NFos)	232

Fossil identity

Full taxon name	**†Aphananthe cretacea Knobloch & Mai**
Organs	Endocarp
Specimens	Holotype: MMG (9245)
Locality	Walbeck, graue Tone
Formation	
Country	Germany

Reference (description)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Friis et al 2011 (book): "The sediments [...] were deopsited in a deltaic or near-shore environment and are dated as Late maastrichtian in age based on palynological studies (Knobloch & Mai, 1986)."

Reference (age)

Friis EM, Crane PR, Pedersen KR. 2011. Early flowers and angiosperm evolution. Cambridge University Press.

Fossil relationships

Node calibrated	**crown Cannabaceae (Rosales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fossil endocarps from Walbeck and Eisleben show morphological features that link them with the extant genera Aphanthe and Gironniera (Knobloch & Mai, 1986). Knobloch & Mai (1986) considered these genera to belong to Ulmaceae, but they are now have been recognized as members of Cannabaceae (e.g., Stevens, 2013). Friis et al. 78 (2011) accept the assignment of these fossil endocarps to the extant genera. Based on this assignment, we use them to calibrate the crown node of Cannabaceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Morus poolensis

Calibration at a glance	crown Moraceae (Rosales), min 47.8 Ma
ID number (NFos)	233

Fossil identity

Full taxon name	**†Morus poolensis Chandler**
Organs	Endocarp and seed
Specimens	Holotype: V.43269
Locality	Bournemouth Freshwater Beds, Sandbanks (National Grid Reference 30/052886)
Formation	
Country	UK

Reference (description)

Chandler MEJ. 1963. The Lower Tertiary floras of Southern England. III. Flora of the Bournemouth Beds; the Boscombe, and the Highcliff Sands. London: British Museum (Natural History).

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Eocene (Ypresian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

We assume the presence of Morus endocarps near the base of the Eocene, based on Fig. 18.2 of Collinson 1989 (article). The oldest records may not correspond to +Morus poolensis (only species that we could track, said to be of Bartonian age in the original description by Chandler 1963a).

Reference (age)

Collinson M. 1989. The fossil history of the Moraceae, Urticaceae (including Cecropiaceae), and Cannabaceae. In: Crane PR, Blackmore S, eds. Evolution, systematics, and fossil history of the Hamamelidae 2. 319–339.

Fossil relationships

Node calibrated	**crown Moraceae (Rosales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Chandler 1963a (book): "The relationship is unquestionably with Morus as indicated by every detail of structure. It differs clearly from M. nigra in its more circular outline (M. nigra is oval) and in the smaller size of the interlocking cells of the locule lining (M. nigra cells 0.1 mm. in diameter). A typical endocarp of M. nigra measured 3.5 by 2.5 mm." Collinson 1989 also agrees with this assessment.

Reference (relationships)

Chandler MEJ. 1963. The Lower Tertiary floras of Southern England. III. Flora of the Bournemouth Beds; the Boscombe, and the Highcliff Sands. London: British Museum (Natural History).

†*Coahuilanthus belindae*

Calibration at a glance	stem Rhamnaceae (Rosales), min 72.1 Ma
ID number (NFos)	234

Fossil identity

Full taxon name	**†Coahuilanthus belindae Calvillo-Canadell & Cevallos-Ferriz**
Organs	Flower
Specimens	Holotype: catalog no. IGM-PB 2573 (Paleontological Collection of the Instituto de Geolog ́ıa, UNAM)
Locality	El Almacigo, General Cepeda County, Coahuila, Mexico, 25 31 N, 101 19 W
Formation	Cerro del Pueblo Formation
Country	Mexico

Reference (description)

Calvillo-Canadell L, Cevallos-Ferriz SRS. 2007. Reproductive structures of Rhamnaceae from the Cerro del Pueblo (Late Cretaceous, Coahuila) and Coatzingo (Oligocene, Puebla) Formations, Mexico. American Journal of Botany 94: 1658–1669.

Fossil age

Safe minimum age	**72.1 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Campanian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Calvillo-Canadell & Cevallos-Ferriz 2007 (AmJBot): "a late Campanian age has been suggested for the Cerro del Pueblo Formation based on physical geology and the presence of E. ponderosa Römer (Boyd, 1959; Murray et al., 1962; McBride et al., 1974; Vega-Vera and Perrilliat, 1990; Kirkland et al., 2000)."

Reference (age)

Calvillo-Canadell L, Cevallos-Ferriz SRS. 2007. Reproductive structures of Rhamnaceae from the Cerro del Pueblo (Late Cretaceous, Coahuila) and Coatzingo (Oligocene, Puebla) Formations, Mexico. American Journal of Botany 94: 1658–1669.

Fossil relationships

Node calibrated	**stem Rhamnaceae (Rosales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Calvillo-Canadell & Cevallos-Ferriz 2007 (AmJBot): "The floral morphology of Coahuilanthus belindae is consistent with Rhamneae (e.g., Rhamnus and Sageretia) (Figs. 40, 41) and Zizypheae (e.g., Berchemia) (Fig. 44). Floral cup structure and parts of the perianth are very much like those of Rhamnus and Berchemia. For example, they share five acute, triangular, slightly keeled sepals lacking a thickening on the adaxial surface, and an acute campanulate floral cup. Coahuilanthus belindae shares with Sageretia a nectariferous ring with an irregular crenate margin (Brizicky, 1964). Nevertheless, they differ in other floral characters like the conspicuously keeled petals in Zyzypheae, obovate petals in Sageretia and Berchemia, or flat and bilobed petals in Rhamnus; these differences support the recognition of a new taxon."

Reference (relationships)

Calvillo-Canadell L, Cevallos-Ferriz SRS. 2007. Reproductive structures of Rhamnaceae from the Cerro del Pueblo (Late Cretaceous, Coahuila) and Coatzingo (Oligocene, Puebla) Formations, Mexico. American Journal of Botany 94: 1658–1669.

†Solanites pusilus

Calibration at a glance	crown Rhamnaceae (Rosales), min 37.8 Ma
ID number (NFos)	235

Fossil identity

Full taxon name	**†Solanites pusilus Berry**
Organs	Flower
Specimens	Syntypes: USNM-222831, USNM-222832, USNM-39950
Locality	Holly Springs sand, Grable pit (common), Henry County, Tenn.; La Grange (one specimen), Fayette County, Tenn.
Formation	Claiborne Formation
Country	USA

Reference (first description)

Berry EW. 1930. Revision of the Lower Eocene Wilcox flora of the southeastern States. United States Geological Survey Professional Paper 156: 1–196.

Reference (latest description)

Millan M, Crepet W. 2014. The Fossil Record of the Solanaceae Revisited and Revised---The Fossil Record of Rhamnaceae Enhanced. The Botanical Review 80: 73–106.

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Bartonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Sauquet et al 2012 (SystBiol) on +Castanopsoidea columbiana (in Appendix S2): "Oldest Claiborne beds are in calcaraeous nannoplankton zone NP12, and youngest are in zone NP17 but also within the Bartonian marine stage (e.g., Dockery 1998). Using GTS 2004, base of NP12 is 52.3 Ma (+/- about 0.2 Ma) and end of Bartonian is 37.2 +/- 0.1 Ma." Here, we have revised the absolute age using the ICS v2017/02 geologic time scale.

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**crown Rhamnaceae (Rosales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	2 / morphological tree only

Node justification

Millan & Crepet 2014 (BotRev): "The combination of characters present in this taxon: small pentamerous flowers with cupulate hypanthium ending in a thick presumably nectariferous rim, triangular sepals with a prominent midvein or keel, thin clawed cucullate petals alternating with the sepals, and stamens opposite to the petals is not found in the Solanaceae or even in the Asteridae, but in the Rhamnaceae, a family that is today classified with the Order Rosales in the Rosid clade (APG, 1998, 2003). The gross morphology of genera such 102 M. Millan, W. Crepet *as Colubrina, Scutia or Ziziphus (Fig. 4g–i) is very similar to that of S. pusillus. The pollen morphology of the fossil is also consistent with Rhamnaceae: tricolporate pollen with rugulate to striate-rugulate exine is present in Ziziphus (Nasri-Ayachi & Nabli, 1995), Paliurus (Schirarend, 1996), Hovenia (Zhang & Chen, 1992), and Sageretia (Perveen & Qaiser, 2005); but not in Rhamnus, Frungula (Punt et al., 2003), or Colubrina (Zhang & Chen, 1992). The phylogenetic analysis conducted in this study yielded two trees, one with S. pusillus as sister to Condalia and as sister to Krugiodendron in the other, well nested in Tribe Rhamneae (Fig. 9). However S. pusillus has a few characters that distinguish it from its putative closer relatives, for example its pubescence, a character not present in Krugiodendron or in Condalia (Medan et al., 2004). Pubescence is not a common feature among Rhamnaceae but it can be found in other genera such as Adolphia, Discaria, Kentrorhamnus, Retanilla, or Trevoa (Medan & Aagesen, 1995). Only with more detailed studies, can the position of S. pusillus within the Rhamnaceae be more confidently established. However, the recognition of S. pusillus as a member of the Rhamnaceae is a significant step towards a better understanding of the fossil history of that family. The abundance of specimens of this taxon (Table 3), the good degree of preservation and the previous observations made on this taxon (i.e. Crepet, 1974, 1979, 1984) allow for a more thorough study of the biology of this taxon, study that will be presented in a separate paper. Suffice to say that S. pusillus is a bona fide member of the Rhamnaceae and therefore not a member of the Solanaceae as was originally suggested (Berry, 1930)."*

Reference (relationships)

Millan M, Crepet W. 2014. The Fossil Record of the Solanaceae Revisited and Revised---The Fossil Record of Rhamnaceae Enhanced. The Botanical Review 80: 73–106.

†Prunus wutuensis

Calibration at a glance	stem Amygdaloideae (Rosaceae, Rosales), min 47.8 Ma
ID number (NFos)	236

Fossil identity

Full taxon name	**†Prunus wutuensis Li, Smith, Liu, Awasthi, Yang, Wang & Li**
Organs	Endocarps
Specimens	Holotype: (IBCAS) No. 2009E002
Locality	Wutu Coal Mine, Shandong Province
Formation	Wutu formation
Country	China

Reference (description)

Li Y, Smith T, Liu C-J, Awasthi N, Yang J, Wang Y-F, Li C-S. 2011. Endocarps of Prunus (Rosaceae: Prunoideae) from the early Eocene of Wutu, Shandong Province, China. TAXON 60: 555–564.

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Eocene (Ypresian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Li et al 2011 (Taxon): "This important fossil locality, which also yielded seeds of Nuphar (Nymphaeaceae) (Chen & al., 2004), is mainly known for its mammal fauna that has allowed to assign an early Eocene age to the Wutu Formation (Tong & Wang, 1998)."

Reference (age)

Li Y, Smith T, Liu C-J, Awasthi N, Yang J, Wang Y-F, Li C-S. 2011. Endocarps of Prunus (Rosaceae: Prunoideae) from the early Eocene of Wutu, Shandong Province, China. TAXON 60: 555–564.

Fossil relationships

Node calibrated	**stem Amygdaloideae (Rosaceae, Rosales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Li et al 2011 (Taxon): "The fruits of Prunus wutuensis are described as “unilocular, singleseeded drupes. Endocarps are flattened, elliptical or ovoid in lateral view, bilaterally symmetrical, 8.5–12.0 mm (average 10.4 mm) long, 7.0–11.5 mm (average 9.0 mm) wide, and 2.5–3.0 mm thick in the compressions. Each of them possesses a broad ventral keel, a round and obtuse apex, as well as a round base. Endocarp outer surface is smooth. Laterally compressed endocarps are flat. Apically or basally compressed endocarps show two distinct ridges along the suture. The endocarp sometimes dehisces into two equal halves along the suture. Endocarp inner surface is smooth or with radial striation. Locule casts are broad ovoid in lateral view, smooth or striated, with acute apex, and acute or round base, 7.3–9.3 mm long, 5.5–8.6 mm wide. A curved canal originally hosting the ventral vascular bundle approaches the apex of the endocarp. The endocarp wall consists of successive layers of sclereids and is compressed, with a thickness of 1.0–1.5 mm (average 1.4 mm) along the suture and 0.4–0.6 mm in the rest. The endocarp wall at the ventral suture has the same thickness as that at the dorsal suture. The secondary walls of sclereids are composed of *parallel layers." (Li et al., 2011). Li et al. (2011) consider that features of Prunus wutuensis that indicate an affinity with the extant genus Prunus are "unilocular, singleseeded drupes; elliptical or ovate shape; development of a ventral keel; a curved vascular bundle canal approaching the apex; and sclereids in the endocarp wall." These authors consider that the fossil endocarps are similar to those of P. avium and P. yedoensis in particular morphological and anatomical characters. Based on these similarities, we consider that Prunus wutuensis belong to crown group Rosaceae, and use them to calibrate this node." Here, we less conservatively use this fossil to calibrate the stem node of Amygdaloideae, on the assumption that this fossil is more closely related to Prunus than members of other subfamilies of Rosaceae.*

Reference (relationships)

Li Y, Smith T, Liu C-J, Awasthi N, Yang J, Wang Y-F, Li C-S. 2011. Endocarps of Prunus (Rosaceae: Prunoideae) from the early Eocene of Wutu, Shandong Province, China. TAXON 60: 555–564.

†*Cedrelospermum nervosum*

Calibration at a glance: crown Ulmaceae (Rosales), min 48.5 Ma

ID number (NFos): 237

Fossil identity

Full taxon name: **†Cedrelospermum nervosum (Newberry) Manchester**

Organs: Leaves, flowers, fruits

Specimens: Specimens with attached leaves and fruits: IU7043, IU7041, IU7044, IU7347, and USNM 38590. Specimens with attached flowers: IU7042 and USNM 414096.

Locality: Localities: IU 15751, 15753, 15754,15755,15883,15884,15885, USGS 8773, near Watson, Uintah County, Utah; UCMP-PA 106, IU 15727, 18001 from Wardell Ranch, Rio Blanco County, Colorado, and USGS 8642 on Carr Creek, Garfield County, Colorado

Formation: Parachute Creek Member, Green River Formation

Country: USA

Reference (description)

Manchester SR. 1989. Attached reproductive and vegetative remains of the extinct American-European genus Cedrelospermum (Ulmaceae) from the early Tertiary of Utah and Colorado, USA. Amer. J. Bot. 76: 256-276.

Fossil age

Safe minimum age: **48.5 Ma**

Absolute age source: radioisotopic

Age quality score: 5 / revised (radioisotopic)

Age justification

Green River Formation was deposited between ca. 53.5 Ma and 48.5 Ma, based on 40Ar-39Ar (Smith et al. 2003)

Reference (age)

Smith ME. 2003. 40Ar/39 Ar geochronology of the Eocene Green River Formation, Wyoming. Geological Society of America Bulletin: 549–565.

Fossil relationships

Node calibrated: **crown Ulmaceae (Rosales)**

Node assignment score: 2 / intuitive or unspecified (trusted source)

Reconciliation score: 1 / pre-molecular era (before 1990)

Node justification

Manchester (1989) considers the fossil firmly belong within the Ulmoideae

Reference (relationships)

Manchester SR. 1989. Attached reproductive and vegetative remains of the extinct American-European genus Cedrelospermum (Ulmaceae) from the early Tertiary of Utah and Colorado, USA. Amer. J. Bot. 76: 256-276.

†Caryophylloflora paleogenica

Calibration at a glance	stem Alsineae+Caryophylleae+Sperguleae+Sagineae+Sclerantheae (Caryophyllaceae, Ca
ID number (NFos)	263

Fossil identity

Full taxon name	**†Caryophylloflora paleogenica G. J. Jord. & Macphail**
Organs	Inflorescence
Specimens	Holotype: Specimen LA218, School of Plant Science, University of Tasmania
Locality	Locharbour tin mine in northeastern Tasmania (40 56 16 S, 148 0 34 E)
Formation	
Country	Australia

Reference (description)

Jordan GJ, Macphail MK. 2003. A Middle-Late Eocene Inflorescence of Caryophyllaceae from Tasmania, Australia. American Journal of Botany 90: 761–768.

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Jordan & Macphail 2003 (AmJBot): "The sediments are part of extensive mid-Cretaceous-early Neogene freshwater deposits in the region (Baillie, 1989). The associated palynoflora falls in the Lower Nothofagidites asperus zone of Stover and Partridge (1973), implying a Middle or possibly Late Eocene age."

Reference (age)

Jordan GJ, Macphail MK. 2003. A Middle-Late Eocene Inflorescence of Caryophyllaceae from Tasmania, Australia. American Journal of Botany 90: 761–768.

Fossil relationships

Node calibrated	**stem Alsineae+Caryophylleae+Sperguleae+Sagineae+Sclerantheae (Caryophyllaceae,**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Jordan & Macphail 2003 (AmJBot): "The analyses of the power to correctly classify fossils suggest that, given the characters available on the fossil, the approach used here would place only members of higher Caryophyllaceae within that clade. Combined with the additional numbers of steps required to place the fossil outside the clade, this makes the placement of C. paleogenica as a member of higher Caryophyllaceae (Fig. 2) convincing, in spite of extensive homoplasy. These interpretations assume that the fossil is a member of the order. However, the combination of periporate pollen, cymose inflorescence, fused calyx, and pentamerous flowers, with five stamens opposite the sepals and five alternate, makes placement in other groups unlikely."

Reference (relationships)

Jordan GJ, Macphail MK. 2003. A Middle-Late Eocene Inflorescence of Caryophyllaceae from Tasmania, Australia. American Journal of Botany 90: 761–768.

†Coahuilacarpon phytolaccoides

Calibration at a glance	stem Phytolacca (Phytolaccaceae, Caryophyllales), min 72.1 Ma
ID number (NFos)	264

Fossil identity

Full taxon name	**†Coahuilacarpon phytolaccoides Cevallos-Ferriz et al.**
Organs	Infructescences, fruits and seeds
Specimens	Holotype: IGM-PB 124 (Coleccion Nacional de Paleontologia, Instituto de Geologia, UNAM)
Locality	Agua de Mula, La Rosa, Rincón Colorado and Rancho Altamira
Formation	Cerro del Pueblo Formation
Country	Mexico

Reference (description)

Cevallos-Ferriz SRS, Estrada-Ruiz E, Pérez-Hernández BR. 2008. Phytolaccaceae Infructescence from Cerro del Pueblo Formation, Upper Cretaceous (Late Campanian), Coahuila, Mexico. American Journal of Botany 95: 77–83.

Fossil age

Safe minimum age	**72.1 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Campanian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Cevallos-Ferriz et al 2008 (AmJBot): "The presence of the ammonite Sphenodiscus sp. and the bivalve Inoceramus vanuxemi Meek and Hayden suggests a late Campanian age for the formation (Kirkland et al., 2000), which allows correlation with the Baculites reesidae and B. jenseni biozones of the Western Interior of North America. Furthermore, the presence of Sphenodiscus sp. and I . vanuxemi in marine facies suggests that age may be restricted to a time interval between 72.3 and 71.3 Ma (Kirkland et al., 2000). This interpretation is supported by magnetostratigraphic data recovered from the sediments of Cerro del Pueblo Formation in which the magnetocronozones 32n.3r – 32n.2n are recognized, and these can be correlated with the same biozones of the Western Interior of North America."

Reference (age)

Cevallos-Ferriz SRS, Estrada-Ruiz E, Pérez-Hernández BR. 2008. Phytolaccaceae Infructescence from Cerro del Pueblo Formation, Upper Cretaceous (Late Campanian), Coahuila, Mexico. American Journal of Botany 95: 77–83.

Fossil relationships

Node calibrated	**stem Phytolacca (Phytolaccaceae, Caryophyllales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Coahuilacarpon phytolaccoides is described as having “numerous fruits united to an axis that runs through the center of the inflorescence (similarly to the fruits of Phytolacca), forming a spike. The fossil infructescences have apical fruits somewhat smaller than the basal ones, suggesting that they represent an indeterminate inflorescence, as in Phytolacca (Rohwer, 1993). The helical carpotaxy typical of Phytolacca is also found in C. phytolaccoides. On the other hand, the number of seeds per fruit in the different species of Phytolacca is *variable (Cronquist, 1981). For example, P. octandra L. has 7 – 8 seeds per berry, though eight is relatively usual. In contrast, C. phytolaccoides always had six seeds per berry, with no variation among the more than 130 infructescences studied. Further similarity is found in the seed coat surface, though deficiently preserved. While the seed coat of C. phytolaccoides is glabrous, it has striations similar to the ornamentations formed in Phytolacca when its seeds dry (Rohwer, 1993)." (Cevallos-Ferriz et al., 2008). Cevallos- Ferriz et al. (2008) conducted anatomical studies and described in detail the integumentary anatomy of the seeds. They found that in both extant Phytolacca and the fossil fruits, the 37 external zone of the outer integument is represented by a palisade of thick-walled cells. Another important characteristic of the seeds of Phytolaccaceae (and Caryophyllales) is the presence of a curved embryo (Kajale, 1954), and its presence allowed the comparison of the fossil material with the available literature on mature seeds of Phytolacca (Cevallos-Ferriz et al., 2008). Cevallos-Ferriz et al. (2008) detected some differences between Coahuilacarpon phytolaccoides and Phytolacca, for example, pendulous versus axilar placentation, respectively, but these authors considered that shared characters between them are more numerous and of greater significance. Cevallos-Ferriz et al. (2008) considered that the fossil berry is morphologically and anatomically similar to Caryophyllales, and in particularly to Phytolaccaceae, and that attributes of Coahuilacarpon phytolaccoides clearly support a relationship with particular species of Phytolacca. Based on the similarity at morphological and anatomical level between the fossil and Phytolaccaceae, and particular species of Phytolacca, we consodered it to be closely related to this genus. We would have used it to calibrate the crown node of Phytolaccaceae, but in our phylogenetic tree, as well as in independent analyses (Stevens, 2013), Phytolaccaceae is paraphyletic. In our tree, the two species assigned to Phytolaccaceae are respectively more closely related to Sarcobataceae and Nyctaginaceae. Thus, we used Coahuilacarpon phytolaccoides to calibrate the crown node of the least inclusive clade that includes the two species assigned to Phytolaccaceae."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Polygonocarpum johnsonii

Calibration at a glance	stem Polygonaceae (Caryophyllales), min 66 Ma
ID number (NFos)	265

Fossil identity

Full taxon name	**†Polygonocarpum johnsonii Manchester & Oleary**
Organs	Winged fruit
Specimens	Holotype. DMNH 16608
Locality	Slope County, North Dakota, DMNH locality 2087
Formation	
Country	USA

Reference (description)

Manchester SR, O'Leary EL. 2010. Phylogenetic distribution and identification of fin-winged fruits. Botanical Review 76: 1–82.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Manchester & O'Leary 2010 (BotRev): "We recognize a new species of polygonaceous fruit from the late Cretaceous (Maastrichtian) of southwestern North Dakota" (additional details not provided)

Reference (age)

Manchester SR, O'Leary EL. 2010. Phylogenetic distribution and identification of fin-winged fruits. Botanical Review 76: 1–82.

Fossil relationships

Node calibrated	**stem Polygonaceae (Caryophyllales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Polygonocarpum johnsonii is described as “an elliptical to nearly circular samara, 6.5–9.5 mm high, 6.5– 8.2 mm wide, with emarginate apex and base. Two (possibly 3?) lateral wings spreading from the central axis. Achene fusiform, pedicel and style unknown. Wings supplied with very fine fusiform-reticulate venation radiating from the central axis with a high vein density of 6 per mm. Fimbrial vein lacking, but with an arched longitudinal intramarginal vein (well inset from the wing margin) in each wing running parallel to the edge of the achene about 1 mm beyond the achene margin.” (Manchester & O'Leary, 2010). Manchester & O'Leary (2010) considered this fruit to be a member of Polygonaceae on the basis of the fine fusiform-reticulate venation over the wings, combined with the lack of fimbrial vein and presence of deeply inset intramarginal veins. A similar set of features are present in extant Pteropyrum and Rheum. In the survey of extant fruits, this type of very fine, fusiform-reticulate venation was observed in very few other families, including Dioscoreaceae and Nyctaginaceae. However, such venation, in combination with the deeply inset intramarginal vein, is known only in Polygonaceae. Similar fruits assigned to P. curtisii Manchester & O'Leary are also reported from the Maastrichtian of southwestern North

Dakota (Manchester & O'Leary, 2010). Fruits similar to both species are also known from Paleocene localities (e.g., Crane et al., 1990). Based on the detailed similarities and combination of features between the fossil fruits and extant members of Polygonaceae noted by Manchester & O'Leary (2010), we consider these fruits to be at least related to this family, and use them to calibrate its stem node."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Cranwellia edmontonensis

Calibration at a glance	stem Santalales, min 63 Ma
ID number (NFos)	270

Fossil identity

Full taxon name	**†Cranwellia edmontonensis Srivastava**
Organs	Pollen
Specimens	Holotype: Sc 1-14/1; 48/125.2 ; Plate XI, Fig. 9
Locality	Upper Edmonton Beds above the Kneehills Tuffin the Scollard area, Alberta
Formation	Edmonton Formation
Country	Canada

Reference (description)

Srivastava SK. 1966. Upper Cretaceous microflora (Maastrichtian) from Scollard, Alberta, Canada. Pollen and Spores 8: 497-552.

Fossil age

Safe minimum age	**63 Ma**
Absolute age source	radioisotopic
Age quality score	2 / unrevised (old source < 2000)

Age justification

Srivastava 1966 (PollSpores): "The transition from Lower-Middle Edmonton to Upper Edmonton at the Knechills Tuff, shows marked break both in the JiU10logy· and in the saurian fauna with the introduction of Triceratops, Tyrannosaurus, Ankylosaurus and Thescelosaurus (STERNBERG, 1947). Difrerences in the macroflora have also been shown by BELL (1949) with the introduction of Carpolithus ceratops KNOWLTON and Fraxiinus lcii BERRY. On the basis of potassium-argon dating method, RITCHIE (I9fl0) assigned an age to the Kneehills Tuff of 70 million years (plus or minus two million years). FOLINSBEE, BAADSGAARD and LIPSON (1961) 1·e-assessed the age of the }{neehills Tuff at 6G million years by the potassium-argon method. SHAPJQULL.m (1963) determined the age of the Ardley Coal Seam of the Red Deer River valley as 63 million years. Thus the span of lhe time of the deposition of the Upper Edmonton Member is dated circa 67 to 63 million years. BELL (1949) has correlated the upper part of the Edmonton Formation with the Lance Formation in Montana (U.S.A.) which is upper Maestrichtian in age."

Reference (age)

Srivastava SK. 1966. Upper Cretaceous microflora (Maastrichtian) from Scollard, Alberta, Canada. Pollen and Spores 8: 497-552.

Fossil relationships

Node calibrated	**stem Santalales**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Aquilapollenites was established for pollen grains “characterised by two to four wing-like projections extending from a broadly subrectangular body” (Rouse, 1957). Subsequently, about other 12 genera were described based on dispersed pollen with similar distinctive apertural and equatorial projections. Collectivelly, these genera are included in the form group Triprojectacites established by Mtchedloshvili (1961). Triprojectacites-Aquilapollenites pollen has been reported from many Late Cretaceous floras from high-latitude areas of the Northern Hemisphere in Greenland, North America and Asia. The abundance and diversity of such *grains define the so-called Aquilapollenites Province (Friis et al., 2011). The affinity of Triprojectacites-Aquilapollenites with Santalales is based on general similarity, and it may contain members of different plant groups, e.g., Fagaceae, Proteaceae, Betulaceae and Myricaceae (Herngreen et al., 1996). Friis et al. (2011) consider that until more information about the plants that produced the pollen is available, the affinity of the Aquilapollenites polen grains should be considered as uncertain. We here consider that at least some of the pollen grains included in the Triprojectacites- Aquilapollenites complex belong to Santalales, and use them to calibrate the Santalales stem node." Friis et al. (2011) explicitly mention Cranwellia in this context.*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Cranwellia sachalinensis

Calibration at a glance: stem Santalales, min 80.7 Ma
ID number (NFos): 337

Fossil identity

Full taxon name: **†Cranwellia sachalinensis Markevich**
Organs: Pollen
Specimens: Holotype - BPI of the DVNC AS of the USSR, preparation 548a / 1
Locality: Western Sakhalin, north of the village Megachi
Formation: (Layers with gilyak flora)
Country: Russia

Reference (description)

Markevich V. 1986. НОВЫЙ ВИД ПЫЛЬЦЫ ЛОРАНТОВЫХ В ВЕРХНЕ МЕЛУ САХАЛИНА [A new species of Loranthaceae pollen in the Upper Cretaceous of Sakhalin]. Paleontologicheskii Zhurnal 4: 118–121.

Fossil age

Safe minimum age: **80.7 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Early Campanian
Reference time scale: Ogg & Hinnov (2012)
Age quality score: 2 / unrevised (old source < 2000)

Age justification

Markevich 1986 (PalZhu): "Santonian-lower Campanian"

Reference (age)

Markevich V. 1986. НОВЫЙ ВИД ПЫЛЬЦЫ ЛОРАНТОВЫХ В ВЕРХНЕ МЕЛУ САХАЛИНА [A new species of Loranthaceae pollen in the Upper Cretaceous of Sakhalin]. Paleontologicheskii Zhurnal 4: 118–121.

Fossil relationships

Node calibrated: **stem Santalales**
Node assignment score: 2 / intuitive or unspecified (trusted source)
Reconciliation score: 3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Aquilapollenites was established for pollen grains “characterised by two to four wing-like projections extending from a broadly subrectangular body” (Rouse, 1957). Subsequently, about other 12 genera were described based on dispersed pollen with similar distinctive apertural and equatorial projections. Collectivelly, these genera are included in the form group Triprojectacites established by Mtchedloshvili (1961). Triprojectacites-Aquilapollenites pollen has been reported from many Late Cretaceous floras from high-latitude areas of the Northern Hemisphere in Greenland, North America and Asia. The abundance and diversity of such grains define the so-called Aquilapollenites Province (Friis et al., 2011). The affinity of Triprojectacites-Aquilapollenites with Santalales is based on general similarity, and it may contain members of different plant groups, e.g., Fagaceae, Proteaceae, Betulaceae and Myricaceae (Herngreen et al., 1996). Friis et al. (2011) consider that until more information about the plants that produced the pollen is available, the affinity of the Aquilapollenites polen grains should be considered as uncertain. We here consider that at least some of the pollen grains included in the Triprojectacites-Aquilapollenites complex belong to Santalales, and use them to calibrate the Santalales stem node." Friis et al. (2011) explicitly mention Cranwellia in this context.

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Anacolosidites meyeorum

Calibration at a glance	stem Olacaceae (Santalales), min 66 Ma
ID number (NFos)	271

Fossil identity

Full taxon name	**†Anacolosidites meyeorum Chmura**
Organs	Pollen
Specimens	Holotype: Plate 33-AE18; L8.9, + 8.2
Locality	Localities: 4, 5, 6, 8, 9, 10 (in Chmura 1973), San Joaquin Valley, California
Formation	Moreno Formation
Country	USA

Reference (description)

Chmura CA. 1973. Upper Cretaceous (Campanian-Maastrichtian) angiosperm pollen from the western San Joaquin Valley, California, U.S.A. Palaeontographica Abteilung B 141: 89–171.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Stratigraphy. All of the localities are Maastrichtian in age, with the possible upper Campanian ? locality 5 (but see Chmura for uncertainty in this age).

Reference (age)

Chmura CA. 1973. Upper Cretaceous (Campanian-Maastrichtian) angiosperm pollen from the western San Joaquin Valley, California, U.S.A. Palaeontographica Abteilung B 141: 89–171.

Fossil relationships

Node calibrated	**stem Olacaceae (Santalales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Chmura 1973 (PalAbtB): "Fossil pollen grains referable to the genus Anqcolosidites have characters like those of pollen of the three extant genera Anacolosa, Cathedra, and Ptychopetalum, all of which are members of the family Olacaceae."
Anacolosa and Cathedra now belong to family Aptandraceae, while Ptychopetalum remains in Olacaceae. The two families are sister groups in our phylogeny and hence have the same stem node.

Reference (relationships)

Chmura CA. 1973. Upper Cretaceous (Campanian-Maastrichtian) angiosperm pollen from the western San Joaquin Valley, California, U.S.A. Palaeontographica Abteilung B 141: 89–171.

†Schoepfia republicensis

Calibration at a glance	crown Schoepfiaceae (Santalales), min 48 Ma
ID number (NFos)	272

Fossil identity

Full taxon name	**†Schoepfia republicensis (LaMotte) Wolfe and Wehr**
Organs	Leaf
Specimens	Hypotypes. USNM 32683; UW 39194.
Locality	Locality 8428, Republic, NE Washington
Formation	Klondike Mountain Formation
Country	USA

Reference (description)

Wolfe JA, Wehr WC. 1987. Middle Eocene dicotyledonous plants from Republic, northeastern Washington. United States Geological Survey Bulletin 1597: 1–25.

Fossil age

Safe minimum age	**48 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Wolfe & Wehr 1987 (USGeolSurveyBull): "Radiometric ages from the Klondike Mountain Formation range from 42.3 ±2.0 to 50.3 ±1.7 m.y. (Pearson and Obradovich, 1977). The three samples dated are from flows, and all samples came from the same stratigraphic position about 300 m above the plant-bearing unit in the Torada graben. Two of the samples had three analyses each; these analyses produced an average apparent age of 48.1 ± 1.8 m.y. for one sample and 49.4 ± 1.6 m.y. for the second sample. The third sample, on which two analyses were made, produced an average apparent age of 42.4 ±1.8 m.y. The two older apparent ages are in close agreement and are accepted as the upper age limit for the Republic flora. Because the Sanpoil Volcanics are 51-52 m.y. old and are unconformable beneath the Klondike Mountain, the Republic flora is probably closer in age to 48-49 m.y. than to 51-52 m.y."

Reference (age)

Wolfe JA, Wehr WC. 1987. Middle Eocene dicotyledonous plants from Republic, northeastern Washington. United States Geological Survey Bulletin 1597: 1–25.

Fossil relationships

Node calibrated	**crown Schoepfiaceae (Santalales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Wolfe & Wehr 1987 (USGeolSurveyBull): "A tendency for acrodromous secondary veins and tertiary veins oriented perpendicular to the midrib is evidenced in Olacaceae, particularly in Anacalosa and even more pronounced in Schoepfia. One critical character is the decurrency of the lamina to form an alate petiole; two pairs of veins one weak pair and the most basal pair of secondary veins depart from the midrib along the petiole and extend along the wing to flare out in the lamina. This characteristic architecture is totally lacking in Cornus but is found in Schoepfia."

Reference (relationships)

Wolfe JA, Wehr WC. 1987. Middle Eocene dicotyledonous plants from Republic, northeastern Washington. United States Geological Survey Bulletin 1597: 1–25.

†Hironoia fusiformis

Calibration at a glance	crown Cornales, min 86.3 Ma
ID number (NFos)	267

Fossil identity

Full taxon name	**†Hironoia fusiformis Takahashi, Crane & Manchester**
Organs	Fruits
Specimens	Holotype: NSM-PP 12015. Department of Geology and Paleontology, National Science Museum (NSM-PP), Tokyo
Locality	Kamitikaba locality 37°12 N, 140°57 E
Formation	Ashizawa Formation (Asamigawa Member)
Country	Japan

Reference (description)

Takahashi M, Crane PR, Manchester SR. 2002. Hironoia fusiformis gen. et sp. nov.; a cornalean fruit from the Kamikitaba locality (Upper Cretaceous, Lower Coniacian) in northeastern Japan. Journal of Plant Research 115: 463–473.

Fossil age

Safe minimum age	**86.3 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Coniacian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Takahashi et al 2002 (JPlRes): "The Futaba Group is a fluvial to shallow marine sedimentary succession that occurs in the southern Abukuma Belt in northeast Japan close to the Pacific Coast of Honshu (Ando et al. 1995). In the north it unconformably overlies the Early Cretaceous Abukuma granite, while in the south it rests unconformably on the shales of the Permian Takakurayama Group. It is overlain by Tertiary sediments (Ando 1997). Based on the occurrence of Lower Coniacian ammonites and inoceramids, the age of the Futaba Group is thought to range from Early Coniacian to Early Santonian. The age of the plant-bearing sediments in the Asamigawa Member is probably Early Coniacian (ca. 89 million years B.P., Gradstein et al. 1995)."

Reference (age)

Takahashi M, Crane PR, Manchester SR. 2002. Hironoia fusiformis gen. et sp. nov.; a cornalean fruit from the Kamikitaba locality (Upper Cretaceous, Lower Coniacian) in northeastern Japan. Journal of Plant Research 115: 463–473.

Fossil relationships

Node calibrated	**crown Cornales**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fruits of Hironia fusiformis "developed from an epigynous ovary with three to four locules. Each locule bears one seed and has a distinctive dorsal germination valve." (Takahashi et al., 2003). Takahashi et al. (2003) considered that these features, together with the adnate calyx, indicate an affinity to extant Cornales, and particularly to Cornaceae sensu lato. Specifically, they indicate that the cornalean affinities of Hironoia *fusiformis are indicated by the presence of an epigynous perianth and pulvinate disk, a sclerenchymatous endocarp, one pendulous seed per locule, and locules opening by dorsal valves from the apex (Takahashi et al., 2003). Takahashi et al (2003) indicate that Hironia fusiformis is similar to the fossil genus Amersinia, interpreted as being closely related to the extant Davidia and Camptotheca (Nyssaceae). Based on the detailed similarities of Hironia fusiformis with members of Cornaceae s.l. (Takahasi et al., 2003), we here consider it to be related to Cornaceae or Nyssaceae, and use it to calibrate the stem node of the clade that includes these two families." Given current uncertainty in relationships among families of Cornales, including the possibility that Cornaceae and Nyssaceae are no longer sister clades, we hereby convert this assignment into a safer crown Cornales constraint.*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Cornus hyperborea

Calibration at a glance	crown Cornaceae (Cornales), min 56 Ma
ID number (NFos)	266

Fossil identity

Full taxon name	**†Cornus hyperborea Heer**
Organs	Leaves
Specimens	USNM 43719; PU 20117
Locality	Bear Den Member at loc. 14051a (USGS loc. 8540). Camels Butte Member at loc. 14066d, North Dakota
Formation	Golden Valley Formation
Country	USA

Reference (description)

Hickey LJ. 1977. Stratigraphy and paleobotany of the Golden Valley Formation (Early Tertiary) of western North Dakota. Geological Society of America Memoir 150: 1–181.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Stratigraphy (Hickey 1977)

Reference (age)

Hickey LJ. 1977. Stratigraphy and paleobotany of the Golden Valley Formation (Early Tertiary) of western North Dakota. Geological Society of America Memoir 150: 1–181.

Fossil relationships

Node calibrated	**crown Cornaceae (Cornales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Manchester 1999 (AMBG): "Leaves are readily identified to the genus (sensu lato) because of the smoothly curving acrodromous secondaries, thin, widely spaced, percurrent tertiary veins, and entire margin, but discrimination of subgenera or sections requires reproductive material."

Reference (relationships)

Manchester SR. 1999. Biogeographical relationships of North American Tertiary floras. Annals of the Missouri Botanical Garden 86: 472–522.

†*Hydrangea antica*

Calibration at a glance	crown Hydrangeaceae (Cornales), min 56 Ma
ID number (NFos)	268

Fossil identity

Full taxon name	**†Hydrangea antica Brown**
Organs	Leaf
Specimens	Plate 41, figs. 3,5 [numbers not provided in original description]
Locality	SW14 sec. 5, T. 45 N., R. 97 W., near Ilo Post Office, WY (locality 4661)
Formation	Fort Union formation (lower)
Country	USA

Reference (description)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Extensively reviewed by Brown 1962, concluding: "In particular, the Fort Union of the northern areas, having been the subject of so much dispute and because the type section is not typical, has been redefined as follows and is thus virtually synonymous with Paleocene series in that region"

Reference (age)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

Fossil relationships

Node calibrated	**crown Hydrangeaceae (Cornales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Justification not provided in original publication

Reference (relationships)

Brown RW 1962. Paleocene flora of the Rocky Mountains and Great Plains. Geological Survey Professional Paper 375: 1-119.

†Beckettia samuelis

Calibration at a glance: stem Nyssaceae (Cornales), min 66 Ma
ID number (NFos): 269

Fossil identity

Full taxon name: **†Beckettia samuelis Knobloch & Mai**
Organs: Fruits and seeds
Specimens: Holotype: NKM (8512)
Locality: Eisleben, graue Tone
Formation:
Country: Germany

Reference (description)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil age

Safe minimum age: **66 Ma**
Absolute age source: stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age: Maastrichtian
Reference time scale: ICS (v2017/02)
Age quality score: 2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "The Walbeck and Eisleben localities correspond to the Maastrichtian (Knobloch & Mai, 1986)"

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated: **stem Nyssaceae (Cornales)**
Node assignment score: 2 / intuitive or unspecified (trusted source)
Reconciliation score: 1 / pre-molecular era (before 1990)

Node justification

Magallón et al 2015 (NewPhytol): "Endocarps of mastixioids (Nyssaceae) are distinctive, and those closely related to Mastixia can be distinguished from those of Nyssa due to "more pronounced dorsal infolds, resulting in locules that are U-shaped in cross section, and the germination valves extend the entire length of the endocarp, rather than being confined to the apical end." (Manchester, 1999). The mastixioid genera reported by Knobloch & Mai (1986) differ
in size, surface sculpture and presence or absence of gum/resin cavities (Manchester, 1999). Endocarps assigned to Mastixia are known from different localities in North America, for example, from the Nut Beds of the Clarno Formation, Oregon, USA, of Middle Eocene age (Manchester, 1994). We here consider the mastixiod endocarps from the Maastrichtian of Germany to be stem lineage or crown group members of Nyssaceae, and use them to calibrate the stem node of this family."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Actinocalyx bohrii

Calibration at a glance	crown Ericales, min 80.7 Ma
ID number (NFos)	285

Fossil identity

Full taxon name	**†Actinocalyx bohrii E.M. Friis**
Organs	Flowers
Specimens	Holotype: SEM-2961, Plate I, 1 (sample GI32107).
Locality	Höganäs AB kaolin quarry at the Asen locality in the Kristianstad Basin, Scania (56 9 N, 14 30 E)
Formation	
Country	Sweden

Reference (description)

Friis EM. 1985. Actinocalyx gen. nov., sympetalous angiosperm flowers from the upper cretaceous of southern Sweden. Review of Palaeobotany and Palynology 45: 171–183.

Fossil age

Safe minimum age	**80.7 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Campanian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Friis 1985 (RevPalPal): "The plant-bearing sequence is dated as Upper Santonian or Lower Campanian."

Reference (age)

Friis EM. 1985. Actinocalyx gen. nov., sympetalous angiosperm flowers from the upper cretaceous of southern Sweden. Review of Palaeobotany and Palynology 45: 171–183.

Fossil relationships

Node calibrated	**crown Ericales**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al (2015): "On the basis of comparison of the fossil with extant flowers, Friis (1985) found close relationship to some members of the Ericales (Clethraceae, Ericaceae, Epacridaceae, Cyrillaceae), and in particular, with Diapensiaceae, considering floral structure and organization. However, there are some differences between Actinocalyx and Diapensiaceae, namely in the type of anthers." However, phylogenetic relationships in Ericales still remain uncertain and partly unresolved. The families to which this fossil was originally compared do not form a clade and their MRCA is a large clade nested three nodes up from the crown node of the entire order. For these reasons, and awaiting formal phylogenetic analyses, we think a reasonably safe approach for the time being is to use this fossil to calibrate the crown node of Ericales.

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Paleoenkianthus sayrevillensis

Calibration at a glance	crown Ericales, min 86.3 Ma
ID number (NFos)	288

Fossil identity

Full taxon name	**†Paleoenkianthus sayrevillensis Nixon & Crepet**
Organs	Flower
Specimens	Holotype: CUPC-1100 (Cornell University Paleobotanical Collection)
Locality	Old Crossman Clay Pit in Sayreville, New Jersey
Formation	Lower Raritan (Magothy) Formation, South Amboy Fire Clay
Country	USA

Reference (description)

Nixon KC, Crepet WL. 1993. Late Cretaceous fossil flowers of Ericalean affinity. American Journal of Botany 80: 616–623.

Fossil age

Safe minimum age	**86.3 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Coniacian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Massoni et al 2015 on +Jerseyanthus calycanthoides: "These fossils were collected from the South Amboy Fire Clay Member of the Raritan Formation at the Old Crossman clay pit in Sayreville, New Jersey, USA (Crepet et al., 2005). This unit was first studied palynologically by Groot et al. (1961), who considered it Turonian based on preliminary studies on European sequences, and subsequently by Doyle (1969b), Wolfe and Pakiser (1971), Doyle and Robbins (1977), and Christopher (1979). Building on the palynological zonation of the Potomac Group by Brenner (1963), to which Doyle (1969a) added Zone III (uppermost Potomac) and Zone IV (lower Raritan), Sirkin (1974) assigned South Amboy palynofloras to a new Zone V. This unit was renamed the Complexiopollis exigua - Santalacites minor Zone by Christopher (1979) and redefined by Christopher et al. (1999) as the lowest of three subzones of the Sohlipollis Taxon Range Zone. Wolfe and Pakiser (1971) and Sirkin (1974) considered the South Amboy late Cenomanian, not much younger than underlying Woodbridge Clay Member (Zone IV), but Doyle (1969b) and Doyle and Robbins (1977) argued that it is no older than middle Turonian, based on the presence of Normapolles genera that appear at that level in Europe (Góczán et al., 1967). Doyle and Robbins (1977) and Christopher (1979) allowed that it was "possibly Coniacian," but Crepet and Nixon (1994) and Crepet et al. (2005) accepted a late Turonian age. By contrast, Clarke et al. (2011) suggested a minimum age of the Santonian-Campanian boundary, 82.8 Ma. However, correlations by Christopher et al. (1999) and Christopher and Prowell (2010) with better-dated rocks in South Carolina imply that the Crossman locality is not this young; they correlate the C. exigua - S. minor Zone with calcareous nannofossil zones CC13 and CC14, which extend from late Turonian through Coniacian (Burnett, 1998; Ogg and Hinnov, 2012). We therefore believe there is enough evidence to consider that Jerseyanthus was at least of Coniacian age, which translates into a conservative minimum age of 85.8 Ma, the Coniacian-Santonian boundary (86.3 ±0.5 Ma; Ogg and Hinnov, 2012)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated **crown Ericales**

Node assignment score 1 / intuitive or unspecified

Reconciliation score 3 / molecular tree only

Node justification

Magallón et al (2015) noted: "Nixon & Crepet (1993) considered that “the character suite observed in Paleoenkianthus sayrevillensis is a mosaic of characters found in modern families of Ericales, and particularly Ericaceae."" However, phylogenetic relationships in Ericales were not well understood at the time of the orignial publication and till remain uncertain and partly unresolved. For these reasons, and awaiting formal phylogenetic analyses, we think a reasonably safe approach for the time being is to use this fossil to calibrate the crown node of Ericales.

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Paradinandra suecica

Calibration at a glance	crown Ericales, min 80.7 Ma
ID number (NFos)	286

Fossil identity

Full taxon name	**†Paradinandra suecica Schönenberger & Friis**
Organs	Flowers
Specimens	Holotype: S106194-01 (sample Asen 2), microtome sections S106194-02–53 (Swedish Museum of Natural History)
Locality	Höganäs AB kaolin quarry at the Asen locality in the Kristianstad Basin, Scania (56 9 N, 14 30 E), Fluviatile-lacustrine sequence
Formation	
Country	Sweden

Reference (description)

Schönenberger J, Friis EM. 2001. Fossil flowers of ericalean affinity from the Late Cretaceous of Southern Sweden. American Journal of Botany 88: 467–480.

Fossil age

Safe minimum age	**80.7 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Campanian
Reference time scale	Ogg & Hinnov (2012)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Magallón et al 2015 (NewPhytol): "considered to be of late Santonian to early Campanian age (Schönenberger & Friis, 2001; Friis et al., 2011)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**crown Ericales**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al (2015): "Schönenberger & Friis (2001) considered that Paradinandra suecica is most similar to the Adinadra group within “Ternstroemiaceae” (now in Pentaphyllacaceae), but it also resembles members of Theaceae and Actinidiaceae. These authors found that the fossil taxon is neither identical to any one genus of these families nor to any of the previously described ericalean taxa from the Cretaceous. They considered that the fossil flower probably represents a separate, now extinct lineage within the Ericales, most likely among “Ternstroemiaceae”, Theaceae and core Ericales." However, phylogenetic relationships in Ericales were not well understood at the time of the orignial publication and till remain uncertain and partly unresolved. The three families to which this fossil was originally compared do not form a clade and their MRCA is a very large clade nested only two nodes up from the crown node of the entire order. For these reasons, and awaiting formal phylogenetic analyses, we think a reasonably safe approach for the time being is to use this fossil to calibrate the crown node of Ericales.

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Pentapetalum trifasciculandricus

Calibration at a glance	crown Ericales, min 86.3 Ma
ID number (NFos)	287

Fossil identity

Full taxon name	**†Pentapetalum trifasciculandricus Martínez-Millán, Crepet and Nixon**
Organs	Flower
Specimens	Holotype: part CUPC579 and counterpart CUPC591 (L. H. Bailey Hortorium Paleobotany Collection, Department of Plant Biology, Cornell University)
Locality	Old Crossman Clay Pit locality, New Jersey
Formation	Raritan formation
Country	USA

Reference (description)

Martínez-Millán M, Crepet WL, Nixon KC. 2009. Pentapetalum trifasciculandricus gen. et sp. nov., a thealean fossil flower from the Raritan Formation, New Jersey, USA (Turonian, Late Cretaceous). American Journal of Botany 96: 933–949.

Fossil age

Safe minimum age	**86.3 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Coniacian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Massoni et al 2015 on +Jerseyanthus calycanthoides: "These fossils were collected from the South Amboy Fire Clay Member of the Raritan Formation at the Old Crossman clay pit in Sayreville, New Jersey, USA (Crepet et al., 2005). This unit was first studied palynologically by Groot et al. (1961), who considered it Turonian based on preliminary studies on European sequences, and subsequently by Doyle (1969b), Wolfe and Pakiser (1971), Doyle and Robbins (1977), and Christopher (1979). Building on the palynological zonation of the Potomac Group by Brenner (1963), to which Doyle (1969a) added Zone III (uppermost Potomac) and Zone IV (lower Raritan), Sirkin (1974) assigned South Amboy palynofloras to a new Zone V. This unit was renamed the Complexiopollis exigua - Santalacites minor Zone by Christopher (1979) and redefined by Christopher et al. (1999) as the lowest of three subzones of the Sohlipollis Taxon Range Zone. Wolfe and Pakiser (1971) and Sirkin (1974) considered the South Amboy late Cenomanian, not much younger than underlying Woodbridge Clay Member (Zone IV), but Doyle (1969b) and Doyle and Robbins (1977) argued that it is no older than middle Turonian, based on the presence of Normapolles genera that appear at that level in Europe (Góczán et al., 1967). Doyle and Robbins (1977) and Christopher (1979) allowed that it was "possibly Coniacian," but Crepet and Nixon (1994) and Crepet et al. (2005) accepted a late Turonian age. By contrast, Clarke et al. (2011) suggested a minimum age of the Santonian-Campanian boundary, 82.8 Ma. However, correlations by Christopher et al. (1999) and Christopher and Prowell (2010) with better-dated rocks in South Carolina imply that the Crossman locality is not this young; they correlate the C. exigua - S. minor Zone with calcareous nannofossil zones CC13 and CC14, which extend from late Turonian through Coniacian (Burnett, 1998; Ogg and Hinnov, 2012). We therefore believe there is enough evidence to consider that Jerseyanthus was at least of Coniacian age, which translates into a conservative minimum age of 85.8 Ma, the Coniacian-Santonian boundary (86.3 ±0.5 Ma; Ogg and Hinnov, 2012)."

Reference (age)

Massoni J, Doyle J, Sauquet H. 2015. Fossil calibration of Magnoliidae, an ancient lineage of angiosperms. Palaeontologia Electronica: 18.1.2FC.

Fossil relationships

Node calibrated	**crown Ericales**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Magallón et al 2015 (NewPhytol): "Pentapetalum trifasciculandricus is described as "actinomorphic pentamerous flowers with quincuncial calyx, imbricate corolla, numerous stamens of markedly different heights, and a superior tricarpellate ovary..." (Martínez-Millán et al., 2009). Martínez-Millán et al. (2009) considered that the flowers of Pentapetalum trifasciculandricus are morphologically consistent with those of the traditionally-defined Theaceae s.l . and of members of the order Theales (e.g., Cronquist, 1981). These authors found especiall similarities between the fossil flowers and those of Stewartia (Theaceae), namely "the stamen height that varies laterally, the slight adnation of stamen bases to petals, the quincuncial aestivation of the calyx and the imbricate aestivation of the corolla. The ovaries of Stewartia and Pentapetalum have a broad base and taper toward the styles in a teardrop shape, with the rest of the floral parts attached to the receptacle at the same level of the gynoecium. Inside the ovary, the ovules of Pentapetalum and Stewartia are globose in shape and several per locule." (Martínez-Millán et al., 2009). However, Pentapetalum trifasciculandricus has free styles and a tricarpellar gynoecium, which differ form the condition in Stewartia (Martínez-Millán et al., 2009). Martínez-Millán et al. (2009) conducted phylogenetic analyses using different combinations of molecular and morphological data, and a broad representation of lineages of Ericales, to ellucidate the phylogenetic positon of Pentapetalum trifasciculandricus. Although the morphological attributes of the fossil flowers suggest an affinity mostly with Stewartia (Theaceae), and with members of the traditional Theales (Tenstroemiaceae and Pentaphylacaceae), the phylogenetic analyses indicate different relationships. In all analyses, Pentapetalum trifasciculandricus forms part of a "basal" polytomy that involves the major lineages of Ericales. Thus, there is a conflict between the position that we would have assigned to the fossil based only on morphological similarity (close to Theaceae- Pentaphyllacaceae), and that derived from the result of phylogenetic analyses. For consistency with other assignments, we will follow the explicit phylogenetic results, and use Pentapetalum trifasciculandricus to calibrate the crown node of Ericales."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Parasaurauia allonensis*

Calibration at a glance crown Actinidiaceae (Ericales), min 83.6 Ma
ID number (NFos) 273

Fossil identity

Full taxon name	**†Parasaurauia allonensis Keller, Herendeen et Crane**
Organs	Flowers
Specimens	Holotype: PP44612 (Department of Geology, The Field Museum, PP)
Locality	allon quarry, South pit of the Atlanta Sand and Supply Company in Gaillard, Georgia (Knoxville Quadrangle, 32 37'47"N, 83 59' 1O"W)
Formation	Gaillard Formation (Buffalo Creek Member, Allon Flora)
Country	USA

Reference (description)

Keller JA, Herendeen PS, Crane PR. 1996. Fossil flowers and fruits of the Actinidiaceae from the Campanian (Late Cretaceous) of Georgia. American Journal of Botany 83: 528–541.

Fossil age

Safe minimum age	**83.6 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Santonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Magallón et al 2015 (NewPhytol): "Flowers and fruits assigned to Parasaurauia allonensis Keller, Herendeen & Crane, from the the Allon locality, Buffalo Creek Member, Gaillard Formation, Georgia, USA (Keller et al., 1996), corresponding to the late Santonian (Friis et al., 2011)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**crown Actinidiaceae (Ericales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	4 / morphological and molecular trees compared

Node justification

Magallón et al 2015 (NewPhytol): "The flowers of Parasaurauia allonensis “are exquisitely preserved as charcoal, have five imbricate, quincuncially arranged sepals and petals. The androecium consists of ten stamens with anthers that are deeply sagittate proximally. The gynoecium is tricarpellate, syncarpous, and has three free styles that emerge from an apical depression in the ovary. The fruit is trilocular and contains numerous ovules on intruded axile placentae. The structire of the mature fruit is unknown.” (Keller et al., 1996). Keller et al. (1996) considered that this fossil has characters that suggest a relationship with Ericales, in particular to Actinidiaceae, because of the free petals, open corolla, and anthers lacking spurs. “Within Actinidiaceae, Parasaurauia allonensis is most similar to Saurauia, differing only in the number of stamens (ten in the fossil vs. 15 to numerous in Saurauia) and perhaps the apparent alternation or large and small stamens in the fossil. Like Parasaurauia allonensis, Saurauia also has free styles with an adaxial longitudinal groove, simple stigmas and 3-5 carpels. Although Parasaurauia allonensis is most *comparable to the Actinidiaceae, and Saurauia in particular, it is not identical to the flowers of any extant genus in the Actinidiaceae or any other ericalean family" (Keller et al., 1996). A morphology-based phylogenetic analysis found that Parasaurauia allonensis is nested within Actinidiaceae, as sister to Actinidia and Saurauia (Keller et al., 1996). Based on this phylogenetic result, this fossil is considered to be a crwon group member of Actinidiaceae, and is used to calibrate the crown group of this family." Accepted by Martinez-Millan (2010).*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Austrodiospyros cryptostoma

Calibration at a glance	crown Ebenaceae (Ericales), min 33.9 Ma
ID number (NFos)	274

Fossil identity

Full taxon name	**†Austrodiospyros cryptostoma Basinger & Christophel**
Organs	Flowers and leaves
Specimens	Holotype: UAPC-A340 (University of Adelaide Paleobotanical Collection)
Locality	Alcoa of Australia open-cut coal mine about 4km NW of Anglesea, Victoria (38 24S, 144 8.3E)
Formation	Demons Bluff Formation
Country	Australia

Reference (description)

Basinger JF, Christophel DC. 1985. Fossil flowers and leaves of the Ebenaceae from the Eocene of southern Australia. Canadian Journal of Botany 63: 1825–1843.

Fossil age

Safe minimum age	**33.9 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Eocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Basinger & Christophel 1985 (CanJBot): "The contact between the Eastern View Fornlation and the overlying Demons Bluff Formation, a predominantly fine-grained, burrowed sediment, is considered possibly gradational (Abele et al. 1976). At the Anglesea site, the boundary is placed at the top of the highest coal seam in the sequence. The fossiliferous clay lenses, then, which occur in sands that overlie the coal at the Anglesea open cut, are probably part of the base of the Demons Bluff Formation. The palynoflora of these lenses (including the following diagnostic species: Triorites magnificus, Proteacidites pachypolus, P. leightenii, P. recavns, P. adenanthoides, P. crassus, Santalumidites cainozoicus, and the dinoflagellate Saeptodinium tasmaniensis) represents the middle Nothofagidites asperus zone, indicating a Late Eocene age and that a hiatus may be present at the top of the coal (A. D. Partridge, personal communication). The fossil flowers occur in a clay lens 5 m above the top of the coal seam."

Reference (age)

Basinger JF, Christophel DC. 1985. Fossil flowers and leaves of the Ebenaceae from the Eocene of southern Australia. Canadian Journal of Botany 63: 1825–1843.

Fossil relationships

Node calibrated	**crown Ebenaceae (Ericales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Basinger & Christophel 1985 (CanJBot): "Flowers are tubular, less than 10 mm long, and about 5 mm wide. Four sepals are connate forming a cup-shaped calyx. Four petals are fused in their basal third and alternate with sepals. Flowers are all unisexual and staminate. Stamens are epipetalous and consistently 16 in number, arranged in 8 radial pairs. Pollen is subprolate, tricolporate, and about 32 pm in diameter. The exine is smooth to slightly scabrate.

A rudimentary ovary occurs in some flowers. Sepals usually have a somewhat textureless abaxial cuticle with actinocytic stomata. Some sepals, however, have frill-like cuticular thickenings over some abaxial epidermal cells and some subsidiary cells with pronounced papillae overarching guard cells. One of the more common leaf types found associated with the flowers is characterized by the same peculiar cuticular thickenings and overarching papillae on subsidiary cells that occur on sepals. This cuticular similarity indicates that flowers and leaves represent a single taxon. Leaves are highly variable in size and shape but are consistently entire margined, with pinnate, brochidodromous venation. The suite of features characterizing the flowers is unique to the Ebenaceae. Flowers of many extant species of Diospyros (Ebenaceae) closely resemble the fossil flowers. Fossil leaves, too, are typical of leaves of extant Diospyros. Both flowers and leaves are considered conspecific and have been assigned the name Austrodiospyros cryptostoma gen. et sp. nov."

Reference (relationships)

Basinger JF, Christophel DC. 1985. Fossil flowers and leaves of the Ebenaceae from the Eocene of southern Australia. Canadian Journal of Botany 63: 1825–1843.

†Leucothoe praecox

Calibration at a glance: crown Vaccinioideae (Ericaceae, Ericales), min 66 Ma
ID number (NFos): 275

Fossil identity

Full taxon name	**†Leucothoe praecox Knobloch & Mai**
Organs	Fruits and seeds
Specimens	Holotype: NKM (8517)
Locality	Eisleben, graue Tone
Formation	
Country	Germany

Reference (description)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Knobloch & Mai 1986 (Praha): "Die Pollenflora aus den basalen dunklen Tonen ist als "Eislebener Bild" definiert worden und wird neuerdings (W. Krutzsch, mündl. Mitteil.) ins höhere Maastricht gestellt. Die Früchte- und Samellflora entstammt einem grauen, kohligen Ton, der unmittelbar über den Auslaugungsresten des Zechsteins liegt oder Auslaugungsschlotten ausfüllt."

Reference (age)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil relationships

Node calibrated	**crown Vaccinioideae (Ericaceae, Ericales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Knobloch & Mai 1986 (Praha): "Von der Art wurden etwa ein Dutzend Kapselfrüchte gefunden, die sich durch ihre Kleinheit und die glatten Kelchzipfel deutlich von den eozänen Funden der Gattung Leucothoe D. DON unterscheiden (MAI - WALTHER 1985). Sie weisen ebenfalls auf die Sektion Eubotrys (Nun.) GRAY hin und zeigen durch die enganliegenden Zipfel des glockigen Kelches auch Merkmale der Gattung Pieris D. DON. Das erdgeschichtlich frühe Vorkommen von Resten der Andromedeae in Europa unterstreicht deren Bedeutung in der primären laurophyllen Vegetation unseres Kontinentes."

Reference (relationships)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

†Visnea minima

Calibration at a glance	stem Pentaphylacaceae (Ericales), min 66 Ma
ID number (NFos)	276

Fossil identity

Full taxon name	**†Visnea minima Knobloch & Mai**
Organs	Seeds
Specimens	Holotype: MMG (9262)
Locality	Walbeck, graue Tone
Formation	
Country	Germany

Reference (description)

Knobloch E, Mai DH. 1986. Monographie der Früchte und Samen in der Kreide von Mitteleuropa. Rozpravy ústredního ústavu geologichénho. Praha 47: 1-219.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Fruits assigned to Visnea minima Knobloch & Mai, and to Pentaphylax protogaea Knobloch & Mai, from Walbeck, Germany, corresponding to the Maastrichtian (Knobloch & Mai, 1986)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Pentaphylacaceae (Ericales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fruits of both species contain seeds. The fruits are capsules with five valves borne on a persistent five-parted calyx. Characters of the fossils indicate a close relationship to Pentaphylacaceae, but Knobloch & Mai (1986) noted that many of the characters of the fossils also occur in other ericalean families (Friis et al., 2011). Knobloch & Mai (1986) additionally describe species belonging to extinct genera of potential affinities with Pentaphyllacaceae. Visnea minima and Pentaphyllax protogaea could be crown group members or stem lineage representatives of Pentaphyllacaceae. They are here used to calibrate the stem node of Pentaphyllacaceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Gilisenium hueberi

Calibration at a glance	crown Polemoniaceae (Ericales), min 48.5 Ma
ID number (NFos)	277

Fossil identity

Full taxon name	**†Gilisenium hueberi Lott, Manchester & Dilcher**
Organs	Whole plant, incl. leaves and fruits
Specimens	Holotype: USNM 414369 (U.S. National Museum of Natural History, Smithsonian Institution)
Locality	Along route 45, north of Watson, Uintah County, Utah
Formation	Green River Formation, Parachute Creek Member
Country	USA

Reference (description)

Lott TA, Manchester SR, Dilcher DL. 1998. A unique and complete polemoniaceous plant from the middle Eocene of Utah, USA. Review of Palaeobotany and Palynology 104: 39–49.

Fossil age

Safe minimum age	**48.5 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Green River Formation was deposited between ca. 53.5 Ma and 48.5 Ma, based on 40Ar-39Ar (Smith et al. 2003). (Martinez-Millan 2010 did not revise this and cited Middle Eocene instead.)

Reference (age)

Smith ME. 2003. 40Ar/39 Ar geochronology of the Eocene Green River Formation, Wyoming. Geological Society of America Bulletin: 549–565.

Fossil relationships

Node calibrated	**crown Polemoniaceae (Ericales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Gilisenium hueberi is a well-preserved, complete herbaceous plant "consisting of taproot, stems, leaves, and fruits. The full length from roots to apex is only 20.3 cm indicating that the species was an herb or shrub of low stature. The presence of fruits indicates that it is a mature plant ..." (Lot et al., 1998). Lott et al. (1998) considered that Gilisenium is related to Polemoniaceae, and particularly with Gilia, on the basis of herbaceous habit, a woody taproot, leaves 1–3-pinnate, inflorescence paniculate, bracts linear, calyx five-lobed, and fruits with persistent calyx. The characters of the fossil do not occur collectively in a single modern species but are scattered among different extant species of Gilia (Lott et al., 1998). Based on the detailed similarities between the fossil plant and species of Gilia, we use the former to calibrate the crown node of Polemoniaceae." Also accepted by Martinez-Millan 2010 (BotRev).

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†unnamed Roridulaceae

Calibration at a glance	crown Roridulaceae (Ericales), min 33.9 Ma
ID number (NFos)	278

Fossil identity

Full taxon name	**†unnamed Roridulaceae Sadowski et al.**
Organs	Leaves
Specimens	GZG.BST.27310 and GZG.BST.27311 (Christel and Hans Werner Hoffeins collection, Hamburg)
Locality	Jantarny Mine, Kaliningrad, Blue Earth layer
Formation	Baltic amber
Country	Russia

Reference (description)

Sadowski E-M, Seyfullah LJ, Sadowski F, Fleischmann A, Behling H, Schmidt AR. 2015. Carnivorous leaves from Baltic amber. Proceedings of the National Academy of Sciences 112: 190–195.

Fossil age

Safe minimum age	**33.9 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Priabonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Sadowski et al 2015 (PNAS): "The leaf inclusions were discovered in an amber piece that derives from Jantarny mine near Kaliningrad (Russia). Amber in this locality is mined in the “Blue Earth” layer, which is Priabonian in age (late Eocene, 35 million years minimum age) (13, 14)."

Reference (age)

Sadowski E-M, Seyfullah LJ, Sadowski F, Fleischmann A, Behling H, Schmidt AR. 2015. Carnivorous leaves from Baltic amber. Proceedings of the National Academy of Sciences 112: 190–195.

Fossil relationships

Node calibrated	**crown Roridulaceae (Ericales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Sadowski et al 2015 (PNAS): "As in extant Roridula, the fossil leaves possess two types of plant trichomes, including unicellular hairs and five size classes of multicellular stalked glands (or tentacles) with an apical pore. The apices of the narrow and perfectly tapered fossil leaves end in a single tentacle, as in both modern Roridula species. The glandular hairs of the fossils are restricted to the leaf margins and to the abaxial lamina, as in extant Roridula gorgonias."

Reference (relationships)

Sadowski E-M, Seyfullah LJ, Sadowski F, Fleischmann A, Behling H, Schmidt AR. 2015. Carnivorous leaves from Baltic amber. Proceedings of the National Academy of Sciences 112: 190–195.

†Chrysophyllum tertiarum

Calibration at a glance	crown Sapotaceae (Ericales), min 56 Ma
ID number (NFos)	279

Fossil identity

Full taxon name	**†Chrysophyllum tertiarum Mehrota**
Organs	Leaf
Specimens	Holotype: Specimen no. BSIP 38094 (Birbal Sahni Institute of Palaeobotany, Lucknow)
Locality	Nangwalbibra near Williamnagar, East Garo Hills District, Meghalaya
Formation	Tura Formation
Country	India

Reference (description)

Mehrotra, R. C. 2000. Study of plant megafossils from the Tura Formation of Nangwalbibra, Garo Hills, Meghalaya, India. The Palaeobotanist 49(2): 255–237.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Mehrotra 2000 (Paleobotanist): "the general stratigraphic sequence noticed in the area is given below in Fig. 2. As evident from this figure the Tura Formation is considered as Upper Palaeocene in age (Saxena er at., 1996; Mehrotra ef at., 1998)."

Reference (age)

Mehrotra, R. C. 2000. Study of plant megafossils from the Tura Formation of Nangwalbibra, Garo Hills, Meghalaya, India. The Palaeobotanist 49(2): 255–237.

Fossil relationships

Node calibrated	**crown Sapotaceae (Ericales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Martinez-Millan 2010 (BotRev) did not provide a detailed justification, but presumably relied on Mehrotra 2000 (Paleobotanist): "The diagnostic characters of the fossil are: elliptic shape, rounded base, entire margin, eucamptodromous venation, moderate to wide acute angle of divergence of secondary veins, stout primary vein and presence of intersecondary veins. These features indicate the affinities of the fossil leaf with that of Chrysophyllum Linnaeus of Sapotaceae. Its identification up to specific level is not possible due to absence of well preserved tertiaries in the present fossi I leaf. However. the only species available for comparison, C. cainilO, shows close resemblance with the fossil."

Reference (relationships)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

†Rehderodendron stonei

Calibration at a glance	stem Styracaceae (Ericales), min 47.8 Ma
ID number (NFos)	280

Fossil identity

Full taxon name	**†Rehderodendron stonei (Reid et Chandler) Mai**
Organs	Endocarps
Specimens	BM v30451, BM v30347
Locality	Herne Bay, England
Formation	London Clay Flora
Country	UK

Reference (description)

Reid EM, Chandler MEJ. 1933. The London Clay flora. British Museum (Natural History), London, UK.

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Ypresian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Chandler 1961a (book) clearly places the London Clay Flora in the Ypresian, an age that has apparently not been challenged since.

Reference (age)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Fossil relationships

Node calibrated	**stem Styracaceae (Ericales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The genus corresponds to well preserved fruits from the Tertiary of Europe, including the Early Eocene London Clay of England (Mai, 1970), the Miocene of Germany (Mai, 1970), the Pliocene of Germany and Italy (Geissert and Gregor, 1981; Martinetto, 1998, in Manchester et al., 2009), and the Upper Pliocene of Romania (Mai & Petrescu, 1983, in Manchester et al., 2009). The fruits of Rehderodendron stonei could 43 correspond to crown group or stem lineage Styracaceae, and use it to calibrate the stem node of this family."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Styrax transversa

Calibration at a glance	crown Styracaceae (Ericales), min 48.5 Ma
ID number (NFos)	281

Fossil identity

Full taxon name	**†Styrax transversa MacGinitie**
Organs	Leaf
Specimens	Holotype: PA20643
Locality	Wardell Ranch (loc. PA106), Colorado,
Formation	Parachute Creek Member, Green River Formation
Country	USA

Reference (description)

MacGinitie 1969. The Eocene Green River flora of northwestern Colorado and northeastern Utah. Univ. Calif. Publ. Geo. Sci. 83: 1-140

Fossil age

Safe minimum age	**48.5 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Green River Formation was deposited between ca. 53.5 Ma and 48.5 Ma, based on 40Ar-39Ar (Smith et al. 2003)

Reference (age)

Smith ME. 2003. 40Ar/39 Ar geochronology of the Eocene Green River Formation, Wyoming. Geological Society of America Bulletin: 549–565.

Fossil relationships

Node calibrated	**crown Styracaceae (Ericales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

MacGinitie 1969 (UCPublGeoSci): "The fossil leaves are characterized by dentate margins, low angle of the secondaries, and tertiary venation aligned perpendicular to the midrib. They are closely similar to the leaves of the living Styrax agrostis G. Don now native to Indo-China, and they show strong similarities to several other species of Styrax: S. americana Lambert from the southern Appalachians and S. philadelphoides Perkins and S. faberi Perkins from southern and central China."

Reference (relationships)

MacGinitie 1969. The Eocene Green River flora of northwestern Colorado and northeastern Utah. Univ. Calif. Publ. Geo. Sci. 83: 1-140

†*Symplocos grimsleyi*

Calibration at a glance	crown Symplocaceae (Ericales), min 47.8 Ma
ID number (NFos)	282

Fossil identity

Full taxon name	**†Symplocos grimsleyi Tiffney**
Organs	Endocarp
Specimens	Type specimen: USNM #495852 (National Museum of Natural History, Smithsonian Institution)
Locality	Fisher/Sullivan site, unnamed tributary of Muddy Creek in eastem Stafford County Virginia (77'22'02" W, 38' 17'06" N); "Bed B"
Formation	Potapaco Member, Nanjemoy Formation
Country	USA

Reference (description)

Tiffney B H. 1999. Fossil fruit and seed flora from the Early Eocene Fisher/Sullivan Site. Pages 139–159 in RE Weems & GJ Grimsley (eds.), Early Eocene vertebrates and plants from the Fisher/Sullivan Site (Nanjemoy Formation) Stafford County, Virginia. Virginia Division of Mineral Resources Publication.

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Ypresian
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Martinez-Millan 2010 (BotRev): "Early Ypresian, Early Eocene"

Reference (age)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

Fossil relationships

Node calibrated	**crown Symplocaceae (Ericales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Accepted by Martinez-Millan 2010 (BotRev)

Reference (relationships)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

†Psilatricolporites crassus

Calibration at a glance	crown Tetrameristaceae (Ericales), min 23.03 Ma
ID number (NFos)	283

Fossil identity

Full taxon name	**†Psilatricolporites crassus van der Hammen & Wymstra**
Organs	Pollen
Specimens	Holotype: slide Monty 47a, loc. 107.2 X 36.5 (mier. Po 40)
Locality	Pollen zone EF of the Montgomery mine, Mackenzie, Maracaibo Basin (Riecito Maché)
Formation	
Country	Guyana

Reference (first description)

Van der Hammen T, Wymstra TA. 1964. A palynological study on the tertiary and Upper Cretaceous of British Guiana. Leidse Geologische Mededelingen 30: 183–241.

Reference (latest description)

Germeraad JH, Hopping CA, Muller J. 1968. Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology 6: 189–348.

Fossil age

Safe minimum age	**23.03 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Oligocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Van der Hammen & Wymstra 1964 (LeidseGeolMeded): "It will be clear that we may at any rate safely assign an "Oligocène to Lower Miocene" age to zones E and F."

Reference (age)

Van der Hammen T, Wymstra TA. 1964. A palynological study on the tertiary and Upper Cretaceous of British Guiana. Leidse Geologische Mededelingen 30: 183–241.

Fossil relationships

Node calibrated	**crown Tetrameristaceae (Ericales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Germeraad et al 1968 (RevPalPal): "Recently LANGENHEIM et al. (1967) have described a fossil pollen closely resembling that of Pelliciera rhizophorae (Theaceae) from the Oligo-Miocene of Chiapas (Mexico). The resemblance to some variations of Psilatricolporites crassus is striking indeed and the possibility that this monotypic mangrove genus had formerly a much wider range is worth further investigation."

Reference (relationships)

Germeraad JH, Hopping CA, Muller J. 1968. Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology 6: 189–348.

†Andrewsiocarpon henryense

Calibration at a glance	crown Theaceae (Ericales), min 37.8 Ma
ID number (NFos)	284

Fossil identity

Full taxon name	**†Andrewsiocarpon henryense Grote et Dilcher**
Organs	Seed/fruit
Specimens	Holotype is specimen IU15815- 459 (Indiana University Paleobotany Collection)
Locality	Lamkin clay pit, Graves County, Kentucky (IU loc.15815)
Formation	Claiborne Formation
Country	USA

Reference (description)

Grote PJ, Dilcher DL. 1989. Investigations of Angiosperms from the Eocene of North America: A New Genus of Theaceae Based on Fruit and Seed Remains. Botanical Gazette 150: 190-206

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Bartonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Sauquet et al 2012 (SystBiol) on +Castanopsoidea columbiana (in Appendix S2): "Oldest Claiborne beds are in calcaraeous nannoplankton zone NP12, and youngest are in zone NP17 but also within the Bartonian marine stage (e.g., Dockery 1998). Using GTS 2004, base of NP12 is 52.3 Ma (+/- about 0.2 Ma) and end of Bartonian is 37.2 +/- 0.1 Ma." Here, we have revised the absolute age using the ICS v2017/02 geologic time scale.

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**crown Theaceae (Ericales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Accepted by Martinez-Millan 2010 (BotRev).
Grote & Dilcher 1989 (BotGaz): "Andrewsiocarpon is a locllicidally dehiscent five-valved cap- sule with persistent imbricate sepals, a large central columella, and five two-seeded locules. Detailed mor- phological and anatomical analyses of the fossil genus and comparison with fruits and seeds of many extant genera provide evidence that allows placement into the subfamily Camellioideae of the Theaceae but not within any modern genus. Andrewsiocarpon shares characters with several modern genera in this subfamily, but appears most similar to Franklinia"

Reference (relationships)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

†Carpites ulmiformis

Calibration at a glance	stem Apiaceae (Apiales), min 66 Ma
ID number (NFos)	313

Fossil identity

Full taxon name	**†Carpites ulmiformis Dorf**
Organs	Fruit
Specimens	Holotype: USNM 40260. Other specimens: USNM 455147, USNM 455149, DMNH 20484
Locality	U. S. Geol. Survey Locality 1479. Near Buck Creek corrals, Converse County, Wyoming
Formation	Lance Formation
Country	USA

Reference (description)

Dorf E. 1942. Upper Cretaceous floras of the Rocky Mountain Region. II. Flora of the Lance Formation at its type locality, Niobrara County, Wyoming. Carnegie Inst. Wash. Contrib. Palaeont. 508: 79–159.

Fossil age

Safe minimum age	**66 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Maastrichtian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Stratigraphy (Dorf 1942)

Reference (age)

Dorf E. 1942. Upper Cretaceous floras of the Rocky Mountain Region. II. Flora of the Lance Formation at its type locality, Niobrara County, Wyoming. Carnegie Inst. Wash. Contrib. Palaeont. 508: 79–159.

Fossil relationships

Node calibrated	**stem Apiaceae (Apiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Manchester & Oleary 2010 (BotRev): "Compressed fruits of Carpites ulmiformis Dorf (1942) from the Late Cretaceous (Maastrichtian) of Wyoming and Montana are likely to represent Apicaceae. They have an obovate–elliptical fruit body with a pair of prominent lateral wings and clearly show a persistent epigynous perianth of several equal tepals fused basally into a short tube that arises the top of the fruit (Fig. 20f, g). A prominent fimbrial vein outlines each wing (Fig. 20f–k), but venation fanning across the wing from the obovate central body is fine and inconspicuous. The fruit body is traversed by a straight median longitudinal vein and four additional longitudinal veins symmetrically placed on either side of the median vein. The outline of the fruit is cordate apically and rounded to cuneate basally. These disseminules resemble the"

Reference (relationships)

Manchester SR, O'Leary EL. 2010. Phylogenetic distribution and identification of fin-winged fruits. Botanical Review 76: 1–82.

†Umbelliferospermum latahense

Calibration at a glance stem Apiaceae (Apiales), min 41.2 Ma
ID number (NFos) 312

Fossil identity

Full taxon name	**†Umbelliferospermum latahense Berry**
Organs	Fruit
Specimens	Plate 64, Figures 10-12 [specimen numbers not provided in original description]
Locality	Brickyard at Spokane (Washington)
Formation	Latah Formation
Country	USA

Reference (description)

Berry E. 1929. A revision of the flora of the Latah Formation. United States Geological Survey Professional Paper 154: 225–264.

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Fruit assigned to Umbelliferospermum latahense from the Middle Eocene of Washington, USA (Berry, 1929; in Manchester & O'Leary, 2010)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**stem Apiaceae (Apiales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Umbelliferospermum latahense are described as dispersed mericarps with paired veinless wing an apically positioned persistent perianth (Manchester & O'Leary, 2010). These authors consider that the fossil displays characters diagnostic of the family. We tentatively accept Umbelliferospermum latahense as a stem representative or crown
member of Apiaceae, and use it to calibrate its stem node."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Paleopanax oregonensis

Calibration at a glance	crown Aralioideae (Araliaceae, Apiales), min 41.2 Ma
ID number (NFos)	314

Fossil identity

Full taxon name	**†Paleopanax oregonensis Manchester**
Organs	Endocarp
Specimens	Holotype: OMSI Pb810. Paratypes: OMSIPM779, PM014.
Locality	Face 3, Clarno Nut Beds
Formation	Nut Beds Flora, Clarno Formation
Country	USA

Reference (description)

Manchester SR. 1994. Fruits and Seeds of the Middle Eocene Nut Beds Hora, Clarno Formation, Oregon. Paleontographica Americana 58: 1-205

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Summarized by Sauquet et al 2012 (SystBiol) on Castanopsis crepetii: "40Ar–39Ar weighted mean age of 43.8 ± 0.3 Ma, and Bridgerian mammal fossils (Manchester 1994)" Here, we conservatively used the equivalent stratigraphic age (but this will be revised in future versions of this dataset).

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**crown Aralioideae (Araliaceae, Apiales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fruit of Paleopanax oregonensis is described as “wide-elliptical in face view, bicarpellate, bilaterally symmetrical, dorsiventrally compressed, with an epigynous perianth bulge; base flat or somewhat cordate, apex rounded; length 4.5-5.6 mm, width 5.4-6.6 mm, estimated thickness 1-2 mm; carpels D-shaped in face view, with two to three arched longitudinal grooves, adjoined ventrally at the central fruit axis by their straight margins, outer margins convex, smooth; pedicel >2.0 mm long, >0.3 mm thick; two styles arising parallel to each other from the apex, 2.0-3.0 mm long, recurving distally.” (Manchester, 1994). Manchester (1994) considered that this fossil fruit is similar to those of Apiaceae and Araliaceae in having an epigynous perianth, as many styles as carpels and schizocarp morphology. The the apical bulge in the perianth region may be interpreted as a nectary disk, as is characteristic of Apiales. Manchester (1994) indicated that paired thin mericarps are characteristic of Apiaceae, and of some Araliaceae; but that specialized carpophores as those in Apiaceae are not *developed in the fossil. The fossil is particularly similar to those of the extant genus Pseudopanax. The fossil Paleopanax differs in having two distinct styles (Manchester, 1994). Considering the similarities between Paleopanax and fruits of Pseudopanax, we consider that the fossil was an extinct member of crown group Araliaceae, and use it to date the crown node of the family." Here, we less conservatively use this fossil to constrain the crown node of Aralioideae (the clade that includes Pseudopanax), on the assumption that is is more closely related to Pseudopanax than any member of Hydrocotyloideae. Accepted by Martinez-Millan 2010 (BotRev) as a*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Toricellia bonensii

Calibration at a glance	crown Torricelliaceae (Apiales), min 56 Ma
ID number (NFos)	315

Fossil identity

Full taxon name	**†Toricellia bonensii (Manchester) Manchester**
Organs	Fruit
Specimens	Holotype: UF 9288
Locality	Almont (North Dakota), Oregon [not type]
Formation	
Country	USA

Reference (first description)

Manchester SR. 1994. Fruits and Seeds of the Middle Eocene Nut Beds Hora, Clarno Formation, Oregon. Paleontographica Americana 58: 1-205

Reference (latest description)

Manchester SR. 1999. Biogeographical relationships of North American Tertiary floras. Annals of the Missouri Botanical Garden 86: 472–522.

Fossil age

Safe minimum age	**56 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Paleocene
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Manchester et al 2009 (JSystEvol): "Fossil endocarps of Toricellia are known from the Eocene of Oregon and Washington, USA (Manchester, 1999), as well as from the Eocene of Messel, Germany and the Miocene of Oberdorf, Austria (Meller, 2006). The oldest known occurrence is from the Paleocene of Almont, North Dakota, USA, based on the single specimen illustrated here (Figs. 53–55)."

Reference (age)

Manchester SR, Chen ZD, Lu AM, Uemura K. 2009. Eastern Asian endemic seed plant genera and their paleogeographic history throughout the Northern Hemisphere. Journal of Systematics and Evolution 47: 1–42.

Fossil relationships

Node calibrated	**crown Torricelliaceae (Apiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fruits of the extant Torricellia have "endocarps of three chambers: a small central chamber containing a seed, and two large lateral chambers that are empty; there is no central vascular strand, and the endocarp wall and septa are composed of isodiametric sclereids (Manchester, 1999; Meller, 2006)." (Manchester et al., 2009). Manchester et al. (2009) indicate that endocarps of Torricellia are known from Eocene and Miocene sediments of Europe, but the oldest known occurrence of the genus is from the Paleocene Almont locality. Based on the detailed structural similarity between the fossil fruits and those of the extant genus, we use the former to calibrate the crown node of Torricelliaceae."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Ilex hercynica

Calibration at a glance	stem Aquifoliaceae (Aquifoliales), min 61.6 Ma
ID number (NFos)	316

Fossil identity

Full taxon name	**†Ilex hercynica Mai**
Organs	Seed
Specimens	Holotypus: Taf. LXII. Fig . 20 - Bhrg . Walkmühlo/Jkckon von Gonna (177 - 195 m) (tiefes Palaozan) - Zen tralsammlung ZUl Berlín (Slg. 1\1,u, Nr. 6004).
Locality	Gonna
Formation	
Country	Germany

Reference (first description)

Mai DH. 1970. Subtropische Elemente im europäischen Tertiär I. Die Gattungen Gironniera, Sarcococca, Illicium, Evodia, Ilex, Mastixia, Alangium, Symplocos und Rehderodendron. Paläontologische Abhandlungen Abt. B 3: 441–503, pls. 58–69.

Reference (latest description)

Mai D. 1987. Neue Früchte und Samen aus päleozänen Ablagerungen Mitteleuropas. Feddes Repertorium 98: 197–229.

Fossil age

Safe minimum age	**61.6 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Paleocene (Danian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Martinez-Millan 2010 (BotRev): "Early Paleocene"

Reference (age)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

Fossil relationships

Node calibrated	**stem Aquifoliaceae (Aquifoliales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The seeds of Ilex hercynica were accepted by Martínez-Millán (2010) as reliable fossils of Aquifoliaceae. Older fruits from the Maastrichtian (I. antiqua, Knobloch & Mai, 1986) were considered in need of revision. Conservatively, we follow Martínez-Millán's (2010) acceptance of I. hercynica as the oldest fossil remain of Aquifoliaceae. As Ilex is the single genus in the family, we considered the fossil belonged to the stem lineage of the family, and use it to calibrate Aquifoliaceae's stem node."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Raiguenrayun cura

Calibration at a glance	crown Asteraceae (Asterales), min 47.46 Ma
ID number (NFos)	317

Fossil identity

Full taxon name	**†Raiguenrayun cura Barreda, Katinas, Passalia & Palazzesi**
Organs	Capitulescence with attached pollen
Specimens	Specimen MLG 1156 (Museo del Lago Gutierrez Dr. Rosendo Pascual de Geologıa y Paleontologıa)
Locality	Rio Pichileufu fossil-bearing strata, near the Estancia Don Hipolito locality (41 09'26.06''S, 70 49'57.11''W), Rıo Negro Province
Formation	Huitrera Formation
Country	Argentina

Reference (description)

Barreda VD, Palazzesi L, Katinas L, Crisci J V, Tellería MC, Bremer K, Passala MG, Bechis F, Corsolini R. 2012. An extinct Eocene taxon of the daisy family (Asteraceae): evolutionary, ecological and biogeographical implications. Annals of Botany 109: 127–134.

Fossil age

Safe minimum age	**47.46 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Barreda et al 2012 (AnnBot): "The age of the Rıo Pichileufu flora-bearing strata is well constrained (Middle Eocene 47.46+0.05 Ma) based on 40Ar/39Ar dating of sanidine phenocrysts from stratigraphically related tuffs (Wilf et al., 2005)."

Reference (age)

Barreda VD, Palazzesi L, Katinas L, Crisci J V, Tellería MC, Bremer K, Passala MG, Bechis F, Corsolini R. 2012. An extinct Eocene taxon of the daisy family (Asteraceae): evolutionary, ecological and biogeographical implications. Annals of Botany 109: 127–134.

Fossil relationships

Node calibrated	**crown Asteraceae (Asterales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Here, we take a slightly less conservative approach than Magallón et al (2015) and propose to follow Barreda et al. (2012) in their explicit hypothesis (Fig. 6) that this fossil is nested in crown Asteraceae, based on a combination of characters and the apomorphic spiny pollen of the associated Mutisiapollis telleriae pollen grains.

Reference (relationships)

Barreda VD, Palazzesi L, Katinas L, Crisci J V, Tellería MC, Bremer K, Passala MG, Bechis F, Corsolini R. 2012. An extinct Eocene taxon of the daisy family (Asteraceae): evolutionary, ecological and biogeographical implications. Annals of Botany 109: 127–134.

†Tubulifloridites lilliei type A

Calibration at a glance	stem Asteraceae (Asterales), min 72.1 Ma
ID number (NFos)	328

Fossil identity

Full taxon name	**†Tubulifloridites lilliei type A Barreda et al**
Organs	Pollen
Specimens	Specimens on slide BAPal. ex CIRGEO Palin 963b: N42(4), L36(0), P57(1)
Locality	James Ross and Vega islands
Formation	Snow Hill Island and López de Bertodano Formations
Country	Antarctica

Reference (description)

Barreda VD, Palazzesi L, Tellería MC, Olivero EB, Raine JI, Forest F. 2015. Early evolution of the angiosperm clade Asteraceae in the Cretaceous of Antarctica. Proceedings of the National Academy of Sciences 112: 10989–10994.

Fossil age

Safe minimum age	**72.1 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Campanian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Barreda et al 2015 (PNAS): "In the studied section near Santa Marta Cove, James Ross Island, the outcrops of the Snow Hill Island Formation are included in the Gamma Member. This member consists of a lower sandstone-dominated package with lenticular coquinas, approximately 120 m thick, and an upper mudstone-dominated package, approximately 50 m thick (Fig. S1A). Both packages represent the transgressive system tract of the NG Sequence, with proximal, sandstone-dominated shore–face deposits at the base, followed by prodelta mudstones interbedded with sandy tempestites at the top (7). The lower package of the Gamma Member bears important fossil vertebrates, including a partial skeleton of the ankylosaur Antarctopelta oliveroi (30) and the ornithopod Trinisauras antamartaensis (31). Ammonites are scarce, but the basal conglomerate bears a reworked ammonite fauna, including diagnostic mid Campanian taxa, such as Baculites subanceps, Metaplacenticeras subtilistriatum, and Hoplitoplacenticeras sp., and several horizons, including the kossmaticeratid Neograhamites primus, which defines the mid–Campanian Ammonite Assemblage 8-1 (7). The studied samples in this package were recovered within the Ammonite Assemblage 8.1 Neograhamites primus, and include samples D8-1, D10-8, D11-1, D12-8, and D13-3b (Fig. S1A). The upper mudstone-dominated package of the Gamma Member is more fossiliferous and bears, in stratigraphic order, the Ammonite Assemblage 8-2 Neogramites cf kiliani, late Campanian, and the Ammonite Assemblage 9 Neograhamites–Gunnarites, latest Campanian–early Maastrichtian. The studied samples 14S-4d, Hy-20, and Hy were recovered within the Ammonite Assemblage 8-2, and the sample 14S within the Ammonite Assemblage 9 (7) (Fig. S1A)."

Reference (age)

Barreda VD, Palazzesi L, Tellería MC, Olivero EB, Raine JI, Forest F. 2015. Early evolution of the angiosperm clade Asteraceae in the Cretaceous of Antarctica. Proceedings of the National Academy of Sciences 112: 10989–10994.

Fossil relationships

Node calibrated **stem Asteraceae (Asterales)**

Node assignment score 5 / phylogenetic analysis

Reconciliation score 5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Barreda et al 2015 (PNAS): "Using an apomorphy-based method [in the sense of Sauquet et al. (10)] as a first attempt at comparing the Antarctic fossils (T. lilliei type A) and the pollen produced by extant eudicots (all supported by a single morphological synapomorphy: triaperturate pollen), we found strong morphological similarities between T. lilliei type A and some members of Asterales (Supporting Data and Figs. S2A and S3C). We explored further the phylogenetic placement of T. lilliei type A within Asterales in a parsimonious framework by using a matrix of pollen morphological characters (Supporting Data, List of Characters and Character State Definitions Used to Compile a Matrix Used as Input in Parsimony Analyses Aimed at Placing the Fossil Taxa and Table S1) and a phylogenetic tree of Asterales as backbone constraint (Fig. 2). After conducting a sensitivity analysis (see SI Materials and Methods, Estimation of Divergence Times) we found one position suitable for calibration based on the single most-parsimonious tree (188 steps). This single most-parsimonious tree places T. lilliei type A within Dasyphyllum of the Barnadesioideae (Fig. 2), the earliest diverging subfamily of the Asteraceae; the fossil possesses most of the derived morphological character states of the Dasyphyllum pollen (Figs. 3 and 4 and Fig. S3 A, B, D, and E). We also explored other scenarios, assuming T. lilliei type A was either an extinct stem relative of Asteraceae or more closely related to other members of the Asterales (Fig. S5 and Table S2). Here, we discuss the age of the origin of the daisy family considering T. lilliei type A as a crown group member (i.e., nested within Dasyphyllum)."

Reference (relationships)

Barreda VD, Palazzesi L, Tellería MC, Olivero EB, Raine JI, Forest F. 2015. Early evolution of the angiosperm clade Asteraceae in the Cretaceous of Antarctica. Proceedings of the National Academy of Sciences 112: 10989–10994.

†*Campanula palaeopyramidalis*

Calibration at a glance	crown Campanuloideae (Campanulaceae, Asterales), min 5.333 Ma
ID number (NFos)	318

Fossil identity

Full taxon name	**†Campanula palaeopyramidalis Łańcucka-Środoniowa**
Organs	Seeds
Specimens	Nowy Sacz I, sample No. 278 (Paleobotanic Museum, Institute of Botany, Polish Academy of Sciences
Locality	Nowy Sącz Basin, West Carpathians
Formation	
Country	Poland

Reference (description)

Łańcucka-Środoniowa M. 1977. New herbs described from the Tertiary of Poland. Acta Palaeobotanica 18: 37–44.

Fossil age

Safe minimum age	**5.333 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Miocene
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Łańcucka-Środoniowa 1977 (ActaPalaeobot): "The seed-and-fruit flora obtained with the help of bores (cf. Oszczypko & Stuchlik 1972) from the Miocene deposits of the Nowy Sącz Basin contains many herbs, [...]"

Reference (age)

Łańcucka-Środoniowa M. 1977. New herbs described from the Tertiary of Poland. Acta Palaeobotanica 18: 37–44.

Fossil relationships

Node calibrated	**crown Campanuloideae (Campanulaceae, Asterales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The seeds of Campanula palaeopyramidalis were described as "Seeds measuring 1.25-1.5 x 0.5-0.7 mm, longitudinally cylindrical in shape, somewhat narrowed and rounded at base, horizontally truncated at top and a little damaged, which shows a relatively great thickness of the seed testa. ... All the tree specimens have irregular longitudinally cylindrical in shape. The external surface of the seeds is covered by a network composed of large polygonal cells, distinctly elongated in a direction parallel to the seed height in some places and shorter, almost equilateral in other places. The walls of these cells are clear-cut and relatively high, and the spaces enclosed within them are lightgrey in colour and subtly opalescent." (Łańcucka-Środoniowa, 1977). Łańcucka-Środoniowa (1977) considered that morphologically similar seeds are produced by Campanula, but noted that most of the species of this living genus "have almost smooth and only gently longitudinally ridged seeds, which is not visible but under the microscope", and that the fossil seeds are broader than the extant ones. Nevertheless, Łańcucka-Środoniowa (1977) considered that the strong similarity of the fossil seeds with those of a rare type in Campanulaceae, exemplified by C. pyramidalis, justify the erection of a new species for the fossil seeds. An additional seed of Campanula was reported for the same deposits. Martínez- Millán (2010) accepts both species as reliable *reports of Campanulaceae. We consider that this fossil was closely related to Campanula, and use it to calibrate the Campanulaceae crown node."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Poluspissusites ramus

Calibration at a glance: crown Goodeniaceae (Asterales), min 23.03 Ma
ID number (NFos): 319

Fossil identity

Full taxon name	**†Poluspissusites ramus Pocknall**
Organs	Pollen
Specimens	Holotype: L9368, single mount SM2150; coord. 13.8 x 108.9; England Finder reading O40(1)
Locality	Waikoikoi Creek, Koi flat Road, Southland
Formation	Pomahaka Estuarine Bed
Country	New Zealand

Reference (description)

Pocknall DT. 1982. Palynology of late Oligocene Pomahaka Estuarine Bed sediments, Waikoikoi, Southland, New Zealand, New Zealand Journal of Botany, 20:3, 263-287

Fossil age

Safe minimum age	**23.03 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Oligocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Pocknall 1982 (NewZealandJBot): "Wood (1956) mapped the district naming the deposit the Pomahaka Estuarine Bed and correlating it with the Chatton Marine Formation of Duntroonian (late OIlgocene) age."

Reference (age)

Pocknall DT. 1982. Palynology of late Oligocene Pomahaka Estuarine Bed sediments, Waikoikoi, Southland, New Zealand, New Zealand Journal of Botany, 20:3, 263-287

Fossil relationships

Node calibrated	**crown Goodeniaceae (Asterales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Pocknall 1982 (NewZealandJBot): "Clearly related to the Goodeniaceae in which the following genera have pollen with similar characteristics: Goodenia. Seaevola. Se/liera. and Vel/eia. The family is centred in Australia with only a few species of Seaevola and Selliera radieans more widespread. It is not possible to make a closer identification although Scaevola ealendulaeea (Duigan 1961; plate 17, fig. 13) looks broadly similar."

Reference (relationships)

Pocknall DT. 1982. Palynology of late Oligocene Pomahaka Estuarine Bed sediments, Waikoikoi, Southland, New Zealand, New Zealand Journal of Botany, 20:3, 263-287

†Menyanthes cf. trifoliata

Calibration at a glance	crown Menyanthaceae (Asterales), min 5.333 Ma
ID number (NFos)	320

Fossil identity

Full taxon name	**†Menyanthes cf. trifoliata**
Organs	Seed
Specimens	Nowy Sacz I, sample No. 301 (Paleobotanic Museum, Institute of Botany, Polish Academy of Sciences)
Locality	Nowy Sącz Basin, West Carpathians
Formation	
Country	Poland

Reference (description)

Łańcucka-Środoniowa M. 1979. Macroscopical plant remains from the freshwater Miocene of the Nowy Sącz Basin (West Carpathians, Poland). Acta Palaeobotanica 20: 3–117.

Fossil age

Safe minimum age	**5.333 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Miocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Łańcucka-Środoniowa 1979 (ActaPalaeobot): "In the light of the recently expressed opinions on the stratigraphy of the Miocene formations of the N owy SlI!CZ Basin, based on the results of geological and palynological studies (Oszczypko & Stuchlik 1972; Oszast & Stuchlik 1977), the deposits discussed here belong to two periods of the Miocene:"

Reference (age)

Łańcucka-Środoniowa M. 1979. Macroscopical plant remains from the freshwater Miocene of the Nowy Sącz Basin (West Carpathians, Poland). Acta Palaeobotanica 20: 3–117.

Fossil relationships

Node calibrated	**crown Menyanthaceae (Asterales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Łańcucka-Środoniowa 1979 (ActaPalaeobot): "There is no doubt that this specimen belongs to the genus Menyanthes. Its size agree with the most frequently occurring dimensions of the seeds of M. cf. trifoliata L., known from the Miocene (Truchanowicz6wna 1964, 1967). There being only one specimen preserved, no anatomical examination has been carried out. This determination has been confirmed by Dr J. Truchanowicz6wna, who examined seeds from several Miocene localities of Poland and Germany using the biometrical method." Accepted by Martinez-Millan 2010 (BotRev).

Reference (relationships)

Łańcucka-Środoniowa M. 1979. Macroscopical plant remains from the freshwater Miocene of the Nowy Sącz Basin

(West Carpathians, Poland). Acta Palaeobotanica 20: 3–117.

†Diervilla echinata

Calibration at a glance	crown Diervilloideae (Caprifoliaceae, Dipsacales), min 27.82 Ma
ID number (NFos)	322

Fossil identity

Full taxon name	**†Diervilla echinata Piel**
Organs	Pollen
Specimens	Holotype: Alexandria Ferry Clay, Channel 4, slide no. 1 (94.3 x 6.1)
Locality	Fraser River, British Columbia
Formation	
Country	Canada

Reference (description)

Piel KM. 1971. Palynology of Oligocene sediments from central British Columbia. Canadian Journal of Botany 49: 1885–1920.

Fossil age

Safe minimum age	**27.82 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Oligocene (Rupelian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Piel 1971 (CanJBot): "The age of the Alexandria-Narcosli sediments Present Vegetation and Climate is Late Early Oligocene, based on titanothere The vegetation in the study area is classified as teeth bedded with the lignites at the Narcosli the Cariboo Aspen - Lodgepole Pine - Douglas Creek exposure."

Reference (age)

Piel KM. 1971. Palynology of Oligocene sediments from central British Columbia. Canadian Journal of Botany 49: 1885–1920.

Fossil relationships

Node calibrated	**crown Diervilloideae (Caprifoliaceae, Dipsacales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Martinez-Millan 2010 (BotRev) did not provide a detailed justification, but presumably relied on Piel 1971 (CanJBot): "Pollen very similar to Diervilla echinata is found in the modern Diervilla japonica: less similar modern pollen are those of D. lonicera, Lonicera java, and Lonicera sernpervirens. Sato (1963) refers pollen similar to D. echinata to the genus Lonicera."

Reference (relationships)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

†Diplodipelta reniptera

Calibration at a glance	crown Linnaeoideae (Caprifoliaceae, Dipsacales), min 34.07 Ma
ID number (NFos)	323

Fossil identity

Full taxon name	**†Diplodipelta reniptera (Becker) Manchester et Donoghue**
Organs	Fruit
Specimens	Holotype UM 33621, paratype UM 33622 from Ruby flora, Montana (University of Michigan, Ann Arbor)
Locality	Ruby Creek, Montana
Formation	Ruby flora
Country	USA

Reference (first description)

Becker, HF. 1961. Oligocene plants from the Upper Ruby River Basin, South-Western Montana. The Geological Society of America Memoir 82. Waverly Press, New York.

Reference (latest description)

Manchester SR, Donoghue MJ. 1995. Winged Fruits of Linnaeeae (Caprifoliaceae) in the Tertiary of Western North America: Diplodipelta gen. nov. International Journal of Plant Sciences 156: 709–722.

Fossil age

Safe minimum age	**34.07 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

40Ar/39Ar radioisotopic date (34.07 ± 0.10 Ma) from Evanhoff et al. (2001) (see also Manchester 2001), based on the additional specimens collected from Florissant (see Manchester & Donoghue 1995)

Reference (age)

Evanhoff E, McIntosh W, Murphey P. 2001. Stratigraphic summary and 40Ar/39Ar geochronology of the Florissant Formation, Colorado. Proceedings of the Denver Museum of Nature & Science 4: 1–16.

Fossil relationships

Node calibrated	**crown Linnaeoideae (Caprifoliaceae, Dipsacales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	4 / morphological and molecular trees compared

Node justification

Martinez-Millan 2010 (BotRev): "Bell and Donoghue (2005) have also evaluated the available fossil record of the Dipsacales when searching for suitable calibration points for their molecular age estimation analysis and found that Diplodipelta is the oldest most reliable fossil of this group. Diplodipelta places the Dipsacales in the Late Eocene (Table 7; Fig. 7) and although it was not placed in phylogenetic analysis as a terminal, enough synapomorphies were found to confidently place it as sister of Dipelta (Manchester & Donoghue, 1995). ^^^^^^-"

Reference (relationships)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

†Patrinia paleosibirica

Calibration at a glance	crown Valerianoideae (Caprifoliaceae, Dipsacales), min 5.333 Ma
ID number (NFos)	321

Fossil identity

Full taxon name	**†Patrinia paleosibirica Dorofeev**
Organs	Fruit
Specimens	Nowy Sacz I, sample No. 303 (Paleobotanic Museum, Institute of Botany, Polish Academy of Sciences
Locality	Nowy Sącz Basin, West Carpathians
Formation	
Country	Poland

Reference (description)

Łańcucka-Środoniowa M. 1979. Macroscopical plant remains from the freshwater Miocene of the Nowy Sącz Basin (West Carpathians, Poland). Acta Palaeobotanica 20: 3–117.

Fossil age

Safe minimum age	**5.333 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Miocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Łańcucka-Środoniowa 1979 (ActaPalaeobot): "In the light of the recently expressed opinions on the stratigraphy of the Miocene formations of the N owy SlI!CZ Basin, based on the results of geological and palynological studies (Oszczypko & Stuchlik 1972; Oszast & Stuchlik 1977), the deposits discussed here belong to two periods of the Miocene:"

Reference (age)

Łańcucka-Środoniowa M. 1979. Macroscopical plant remains from the freshwater Miocene of the Nowy Sącz Basin (West Carpathians, Poland). Acta Palaeobotanica 20: 3–117.

Fossil relationships

Node calibrated	**crown Valerianoideae (Caprifoliaceae, Dipsacales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fruit of Patrinia paleosibirica is described as "regularly oval in shape, acute at the base, somewhat rounded at the top. It is markedly flattened but was slightly convex in the dorsal side and concave on the ventral. Across the middle of the dorsal side a thin vascular bundle runs from the top of the fruit, brown in colour, which has burst and been destroyed, are seen on the ventral side. The fruit surface is smooth and dull, with fine punctation formed by polygonal cells." (Łańcucka-Środoniowa, 1979). Patrinia paleosibirica was first described by Dorofeev (1962) from Pliocene sediments, who compared the fossils with the extant P. sibirica. The specimens from Poland fall within the range of variation of P. paleosibirica. However, their wings, characteristic of the genus Patrinia, which sometimes occur on fossil specimens in the form of thick nerves converging at the base of the peduncle, are not preserved on this specimen (ŁańcuckaŚrodoniowa, 1979). We consider these fruits to be *related to the extant Patrinia, and use them to calibrate the crown node of Valerianaceae."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Lithospermum dakotense

Calibration at a glance	crown Boraginaceae (Boraginales), min 5.333 Ma
ID number (NFos)	289

Fossil identity

Full taxon name	**†Lithospermum dakotense Gabel**
Organs	Fruit
Specimens	Holotype: M. L. Gabel MG 17.7 (BHSC 14,912), housed at the Black Hills State College Herbarium
Locality	site MG 17, Ash Hollow, Bennett, South Dakota
Formation	Ash Hollow Formation
Country	USA

Reference (description)

Gabel ML. 1987. A Fossil Lithospermum (Boraginaceae) from the Tertiary of South Dakota. American Journal of Botany 74: 1690–1693.

Fossil age

Safe minimum age	**5.333 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Late Miocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Stratigraphy

Reference (age)

Gabel ML. 1987. A Fossil Lithospermum (Boraginaceae) from the Tertiary of South Dakota. American Journal of Botany 74: 1690–1693.

Fossil relationships

Node calibrated	**crown Boraginaceae (Boraginales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Gabel 1987 (AmJBot): "Nutlet characteristics of the Boraginaceae are frequently available in de- scriptions, or used in keys to modem taxa. It is possible, based upon comparisons to extant nutlets of the Boraginaceae, to determine that the fossil specimens are clearly of the genus Lithospermum. Characteristics such as size, shape, texture, angle of attachment, basal at- tachment, presence and development of the keel, and the nature of the basal scar (Johnston, 1952, 1954) all support this conclusion".
Accepted by Martinez-Millan (2010)

Reference (relationships)

Gabel ML. 1987. A Fossil Lithospermum (Boraginaceae) from the Tertiary of South Dakota. American Journal of Botany 74: 1690–1693.

†Cordia platanifolia

Calibration at a glance	crown Cordiaceae (Boraginales), min 23.03 Ma
ID number (NFos)	290

Fossil identity

Full taxon name	**†Cordia platanifolia (Ward) Chelebayeva**
Organs	Leaf
Specimens	Plate XL, Fig. 1 (Ward 1887)
Locality	Seven Mile Creek, Montana, Sparganium bed [type]; Kamchatka
Formation	
Country	Russia

Reference (first description)

Ward L. 1887. Types of the Laramie Flora. United States Geological Survey Bulletin 37: 1–354.

Reference (latest description)

Chelebayeva A. 1984. Rod Cordia (Boraginaceae) v Paleogene Kamchatki i sopredel'nykh territoriy [The genus Cordia (Boraginaceae) from the Paleogene of Kamchatka and adjacent territories]. Botanicheskii Zhurnal 69: 605–615.

Fossil age

Safe minimum age	**23.03 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Paleogene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Based on age provided in Table 12 of Martinez-Millan 2010 (BotRev)

Reference (age)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

Fossil relationships

Node calibrated	**crown Cordiaceae (Boraginales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	3 / molecular tree only

Node justification

Accepted by Martinez-Millan (2010)

Reference (relationships)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

†Ehretia clausentia

Calibration at a glance	crown Ehretiaceae (Boraginales), min 47.8 Ma
ID number (NFos)	291

Fossil identity

Full taxon name	**†Ehretia clausentia Chandler**
Organs	Fruit
Specimens	Holotype. V.34569.
Locality	Nursling, Southampton (additional specimens from Upper Fish Tooth Bed, Bognor, Beetle Bed, and Lower Aldwick Beds)
Formation	London Clay Flora
Country	UK

Reference (first description)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Reference (latest description)

Chandler MEJ. 1964. The Lower Tertiary floras of southern England. IV. A summary and survey of findings in the light of recent botanical observations. London: British Museum (Natural History).

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Ypresian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Chandler 1961a (book) clearly places the London Clay Flora in the Ypresian, an age that has apparently not been challenged since.

Reference (age)

Chandler MEJ. 1961. The Lower Tertiary floras of southern England. I. Paleocene Floras. London Clay Flora (Supplement). Text and Atlas. London: British Museum (Natural History).

Fossil relationships

Node calibrated	**crown Ehretiaceae (Boraginales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Accepted by Martinez-Millan 2010 (BotRev). In the original description, Chandler 1961a (book) wrote: "The pyrenes closely resemble those of the living Ehretia acuminata in the ornamentation of the dorsal surface, but they are somewhat smaller (E. acuminata, 2-5 to 3 by 2-25 to 2-5 mm.)."

Reference (relationships)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

†Eucommia eocenica

Calibration at a glance	stem Eucommiaceae (Garryales), min 37.8 Ma
ID number (NFos)	339

Fossil identity

Full taxon name	**†Eucommia eocenica (Berry) Brown**
Organs	Fruits
Specimens	USNM 39849
Locality	LaGrange, TN
Formation	Claiborne Formation
Country	USA

Reference (first description)

Berry EW. 1930. Revision of the Lower Eocene Wilcox flora of the southeastern States. United States Geological Survey Professional Paper 156: 1–196.

Reference (latest description)

Call VB, Dilcher DL. 1997. The fossil record of Eucommia (Eucommiaceae) in North America. American Journal of Botany 84: 798–814.

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Bartonian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

See Sauquet et al 2012 (SystBiol) on +Castanopsoidea columbiana (in Appendix S2): "Oldest Claiborne beds are in calcaraeous nannoplankton zone NP12, and youngest are in zone NP17 but also within the Bartonian marine stage (e.g., Dockery 1998). Using GTS 2004, base of NP12 is 52.3 Ma (+/- about 0.2 Ma) and end of Bartonian is 37.2 +/- 0.1 Ma." Here, we have revised the absolute age using the ICS v2017/02 geologic time scale.

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**stem Eucommiaceae (Garryales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Magallón et al 2015 (NewPhytol): "The fruits of extant Eucommia ulmoides and of fossil species of Eucommia are distinctive. E. eocenica is described as "asymmetrical, stipitate, bicarpellate samaras composed of a flattened ovate nutlet surrounded by an ovate narrow wing. The expanded basal articulation observed on stipes of E. ulmoides samaras and on fossil samaras from other floras is not preserved on any E. eocenica specimens. The two carpels are fused along their ventral margins nearly to the apex. The free carpel apices form a small asymmetrical cleft lined by the ventral stigmatic surfaces of the respective carpels. ... Unequal development of the two carpels in these fruits *produced an asymmetric singleseeded samara whose expanded fertile carpel comprises the majority of the samara." (Call and Dilcher, 1997). The fruits of E. ulmoides are characterized by a network of latex filaments that are also present in the fossils. Call & Dilcher (1997) indicate that " the ... network of latex filaments in the fossil samaras consist of two distinct components. The most conpisuous and innermost is an ovate net of longitudinally oriented, loosely anastomosing fascicles of unbranched latex filaments that surrounds the seed. The second and outermost component consists of a relatively uniform fabric of closely spaced latex filaments and small-diameter filament fascicles oriented transversely with respect to the long axis of the samara and the anastomosing coarser fascicles of the first component.". Based on detailed morphological and structural similarities between the fossil samaras and those of Eucommia ulmoides, we consider the fossils to be stem lineage members of Eucommia, and use them to calibrate the stem node of the monotypic Eucommiaceae."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Eucommia montana

Calibration at a glance: stem Eucommiaceae (Garryales), min 47.8 Ma
ID number (NFos): 292

Fossil identity

Full taxon name	**†Eucommia montana Brown**
Organs	Fruit
Specimens	UWBM 77562 (Holotype: USNM 42330)
Locality	Republic, Ferry Co., WA
Formation	Klondike Mountain Formation
Country	USA

Reference (first description)

Brown RW. 1940. New species and changes of name in some American fossil floras. Journal of the Washington Academy of Sciences 30: 344–356.

Reference (latest description)

Call VB, Dilcher DL. 1997. The fossil record of Eucommia (Eucommiaceae) in North America. American Journal of Botany 84: 798–814.

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Eocene (Ypresian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Both Call & Dilcher 1997 (AmJBot) and Martinez-Millan 2010 (BotRev) cite "Late early Eocene" for the age of the Republic, WA records of this taxon (presumably the oldest recorded so far).

Reference (age)

Call VB, Dilcher DL. 1997. The fossil record of Eucommia (Eucommiaceae) in North America. American Journal of Botany 84: 798–814.

Fossil relationships

Node calibrated	**stem Eucommiaceae (Garryales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Accepted by Martinez-Millan (2010).
Call & Dilcher (1997): "Autofluorescent elastic latex filaments bearing capitate termini are preserved in nearly all of the remains and provide conclusive evidence of their affinity to Eucommia. (...) Wehr (1995) figured an incomplete Eucommia montana fruit from the late early Eocene Klondike Mountain Formation at Republic, Washington. Polymerized latex threads preserved in this fruit and in two fruits and associated leaves from the "Coldwater Beds" of the Kamloops Group in southern British Columbia confirm the identification of Eucommia in the Republic and Quilchena floras."

Reference (relationships)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

†Garrya axelrodi

Calibration at a glance	crown Garryaceae (Garryales), min 11.63 Ma
ID number (NFos)	293

Fossil identity

Full taxon name	**†Garrya axelrodi Wolfe**
Organs	Leaf
Specimens	Holotype: USNM 41935; Paratype: USNM 41936, UCMP 8627 (counterpart)
Locality	Stewart Spring, Cedar Mountains, Nevada
Formation	Stewart Spring Flora
Country	USA

Reference (description)

Wolfe JA. 1964. The Miocene floras from Fingerrock Wash Southwestern Nevada. U.S. Geological Survey Professional Paper 454–N: N1–N36

Fossil age

Safe minimum age	**11.63 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Serravalian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Barstovian according to Table 4 of Wolfe 1964 (USGSProffPaper): overlaps Langhian and Serravalian according to http://www.stratigraphy.org/bak/geowhen/stages/Barstovian.html

Reference (age)

Wolfe JA. 1964. The Miocene floras from Fingerrock Wash Southwestern Nevada. U.S. Geological Survey Professional Paper 454–N: N1–N36

Fossil relationships

Node calibrated	**crown Garryaceae (Garryales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Wolfe 1964 (USGSProffPaper): "The undulatory forking secondaries and the irregular series of marginal loops indicate that these fossils are referrable to Garrya. The closest extant species to G. axelrodi is G. elliptica Dougl. from, northern and central California. The primary difference between leaves of the two species is in shape in G. axelrodi the length to width ratio is 2:1 but in G. elliptica the ratio is typically 1.5:1. Axelrod (1944c, p. 204) noted that Garrya elliptica leaves are entire, rather than revolute or undulate, in the more mesic parts of this species' range, and only entire-margined leaves of G. axelrodi are known."
Accepted by Martinez-Millan (2010).

Reference (relationships)

Wolfe JA. 1964. The Miocene floras from Fingerrock Wash Southwestern Nevada. U.S. Geological Survey Professional Paper 454–N: N1–N36

†*Apocynospermum coloradensis*

Calibration at a glance	crown Apocynaceae (Gentianales), min 48.5 Ma
ID number (NFos)	294

Fossil identity

Full taxon name	**†Apocynospermum coloradensis Brown**
Organs	Seeds
Specimens	Holotype: USNM 42829A
Locality	Wardell Ranch (loc. PA106), Colorado
Formation	Parachute Creek Member, Green River Formation
Country	USA

Reference (first description)

Brown RW. 1929. Additions to the flora of the Green River formation. U.S. Geological Survey Professional Paper 154: 279–292.

Reference (latest description)

Brown RW. 1934. The recognizable species of the Green River Flora. U.S. Geological Survey Professional Paper 185–C.

Fossil age

Safe minimum age	**48.5 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Green River Formation was deposited between ca. 53.5 Ma and 48.5 Ma, based on 40Ar-39Ar (Smith et al. 2003). (Martinez-Millan 2010 did not revise this and cited Late Eocene instead.)

Reference (age)

Smith ME. 2003. 40Ar/39 Ar geochronology of the Eocene Green River Formation, Wyoming. Geological Society of America Bulletin: 549–565.

Fossil relationships

Node calibrated	**crown Apocynaceae (Gentianales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Brown 1929 (USGeolSurveyProfPaper): "This specimen is similar to numerous species described by Heel' 51 and others as Cypselites or Bidentites of the Compositae. The probability however, is that most of these fOrIns, as shown recently by Reid and Chandler,52 belong either to the Apocynaceae or to the Asclepiadaceae."

Reference (relationships)

Brown RW. 1929. Additions to the flora of the Green River formation. U.S. Geological Survey Professional Paper 154: 279–292.

†*Voyrioseminites magnus*

Calibration at a glance	crown Gentianaceae (Gentianales), min 33.9 Ma
ID number (NFos)	296

Fossil identity

Full taxon name	**†Voyrioseminites magnus**
Organs	Seed
Specimens	
Locality	about 10 miles west of Kuala Lumpur
Formation	
Country	Malaysia

Reference (description)

Trivedi BS, Chaturvedi SK. 1972. Voyrioseminites magnus gen. nov. et sp. nov. a fossil seed from Tertiary coal of Malaya. Geophytology 1: 161–164.

Fossil age

Safe minimum age	**33.9 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Eocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Unspecified

Reference (age)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

Fossil relationships

Node calibrated	**crown Gentianaceae (Gentianales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Accepted by Martinez-Millan (2010)

Reference (relationships)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

†Emmenopterys dilcheri

Calibration at a glance	crown Ixoroideae (Rubiaceae, Gentianales), min 41.2 Ma
ID number (NFos)	297

Fossil identity

Full taxon name	**†Emmenopterys dilcheri Manchester**
Organs	Fruits
Specimens	Holotype: OMSI PM197
Locality	Nut Beds locality (UF loc. 225) 44°56'36' N 120°25'34" W, at Wheeler County, Oregon
Formation	Nut Beds Flora, Clarno Formation
Country	USA

Reference (description)

Manchester SR. 1994. Fruits and Seeds of the Middle Eocene Nut Beds Hora, Clarno Formation, Oregon. Paleontographica Americana 58: 1-205

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Summarized by Sauquet et al 2012 (SystBiol) on Castanopsis crepetii: "40Ar–39Ar weighted mean age of 43.8 ± 0.3 Ma, and Bridgerian mammal fossils (Manchester 1994)" Here, we conservatively used the equivalent stratigraphic age (but this will be revised in future versions of this dataset).

Reference (age)

Sauquet H, Ho SYW, Gandolfo MA, Jordan GJ, Wilf P, Cantrill DJ, Bayly MJ, Bromham L, Brown GK, Carpenter RJ, Lee DM, Murphy DJ, Sniderman JMK, Udovicic F. 2012. Testing the impact of calibration on molecular divergence times using a fossil-rich group: the case of Nothofagus (Fagales). Systematic Biology 61: 289–313.

Fossil relationships

Node calibrated	**crown Ixoroideae (Rubiaceae, Gentianales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Emmenopterys dilcheri is described by Manchester (1994) as infructescences, fruits and seeds. The seeds, as seen in transverse and longitudinal section show a distinctive seed coat of large reticulately thickened cells. Manchester (1994) considered that Emmenopteris dilcheri "conforms to the Rubiaceae in the cymose infructescence, inferior ovary, bilocular fruit, axile placentation and endocarps with transversely arranged fibers. Capsular fruits occur in several tribes of the family 47 (Schumann, 1897). Reticulately thickened, or "pitted" seed coats are characteristic of the subfamily Cinchonoideae (Bremekamp, 1966), and are considered to be plesiomorphic in the Rubiaceae because they also occur in Loganiaceae (Bremer and Struwe, 1992)." Manchester (1994) considered that this fossil could be placed within tribe Cinchoneae (sensu Schumann, 1897) on the basis of pedicellate, elongate, thin-walled, septicidal capsules, with numerous tiny winged seeds (Standley and Williams, 1975). The fossil most closely resembles extant Emmenopterys, to which it is assigned. Emmenopterys dilcheri *compares well with extant E. henryi, a deciduous tree endemic to the mixed mesophytic forest of China, in the relatively inconspicuous persistent perianth, and in features of the seed including elongate wing shape and reticulate thickening of the seed coat cells (Manchester, 1994). Based on the close similarity of the fossil with Emmenopterys, and the structural features that conform to Rubiaceae, we consider that this fossil was a crown group member of Rubiaceae, and use it to calibrate the crown node of this family." Accepted by Martinez-Millan 2010 (BotRev)*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Icacinanthium tainiaphorum*

Calibration at a glance	crown Icacinaceae (Icacinales), min 47.8 Ma
ID number (NFos)	329

Fossil identity

Full taxon name	**†Icacinanthium tainiaphorum Del Rio & De Franceschi**
Organs	Flowers with in situ pollen
Specimens	Holotype: Deposited in the collection of Palaeobotany of MNHN (MNHN.F.44051.)
Locality	Le Quesnoy, Oise
Formation	"argiles à lignites du Soissonais" Formation
Country	France

Reference (description)

Del Rio C, Haevermans T, De Franceschi D. 2017. First record of an Icacinaceae Miers fossil flower from le Quesnoy (Ypresian, France) amber. Scientific Reports 7: 1–8.

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Ypresian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Del Rio et al 2017 (SR): "The fossil resin remains were collected from 1997 to 2000 from the Le Quesnoy (Houdancourt, Oise, France) lignitic clay sediments which belong to the ≪ argiles à lignites du Soissonais ≫ Formation. These sediments are dated to the Ypresian (±56 Ma) according to mammal biochronology (MP7) and palynological studies24, 42. This corresponds to the Sparnacian facies of the lower Ypresian (lower Eocene)."

Reference (age)

Del Rio C, Haevermans T, De Franceschi D. 2017. First record of an Icacinaceae Miers fossil flower from le Quesnoy (Ypresian, France) amber. Scientific Reports 7: 1–8.

Fossil relationships

Node calibrated	**crown Icacinaceae (Icacinales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Fossil well nested in the crown group of the modern Icacinaceae (as recently recircumscribed)

Reference (relationships)

Del Rio C, Haevermans T, De Franceschi D. 2017. First record of an Icacinaceae Miers fossil flower from le Quesnoy (Ypresian, France) amber. Scientific Reports 7: 1–8.

†Acanthus rugatus

Calibration at a glance	crown Acanthoideae (Acanthaceae, Lamiales), min 27.82 Ma
ID number (NFos)	301

Fossil identity

Full taxon name	**†Acanthus rugatus Reid and Chandler**
Organs	Seed
Specimens	Holotype: V.17612
Locality	Bembridge beds, Isle of Wright, Gurnard Bay and Thorness Bay, England
Formation	Bembridge Flora
Country	UK

Reference (description)

Reid EM, Chandler MEJ. 1926. Catalogue of Cainozoic plants in the Department of Geology. The Bembridge Flora. Catalogue of Cainozoic Plants in the Department of Geology, British Museum.

Fossil age

Safe minimum age	**27.82 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Oligocene (Rupelian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Stratigraphy

Reference (age)

Reid EM, Chandler MEJ. 1926. Catalogue of Cainozoic plants in the Department of Geology. The Bembridge Flora. Catalogue of Cainozoic Plants in the Department of Geology, British Museum.

Fossil relationships

Node calibrated	**crown Acanthoideae (Acanthaceae, Lamiales)**
Node assignment score	4 / apomorphy-based (apomorphies listed and tested)
Reconciliation score	3 / molecular tree only

Node justification

Tripp & McDade 2014 (SystBiol): "Monophyly of Acanthus cannot be rejected by molecular data (McDade et al. 2005); plants produce seeds with distinctly rugose surface sculpturing (Tomlinson 1986) exactly like that of this fossil; thus, fossil used to constrain the MRCA of the lineage containing Acanthus sennii. Ranked "4" because (Reid and Chandler 1926) report provide an image of a macrofossil (seed) that we deem reliably assigned to Acanthus; not ranked "5" because seed sculpturing has not been exhaustively surveyed across tribe Acantheae."

Reference (relationships)

Tripp EA, McDade LA. 2014. A rich fossil record yields calibrated phylogeny for acanthaceae (Lamiales) and evidence for marked biases in timing and directionality of intercontinental disjunctions. Systematic Biology 63: 660–684.

†unnamed cf. *Avicennia*

Calibration at a glance	stem Avicennioideae (Acanthaceae, Lamiales), min 37.8 Ma
ID number (NFos)	300

Fossil identity

Full taxon name	**†unnamed cf. Avicennia Cavagnetto & Anadón**
Organs	Pollen
Specimens	[neither specimen numbers nor illustrations provided in original description]
Locality	Pontils-Santa Coloma de Queralt section (P-1 to P-88)
Formation	Collbas Formation
Country	Spain

Reference (description)

Cavagnetto C, Anadón P. 1996. Preliminary palynological data on floristic and climatic changes during the Middle Eocene-Early Oligocene of the eastern Ebro Basin, northeast Spain. Review of Palaeobotany and Palynology 92: 281–305.

Fossil age

Safe minimum age	**37.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Bartonian
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Cavagnetto & Anadón 1996 (RevPalPal): "The uppermost part of the Pontils Group consists of paludine limestones (Bosc d'en Borr/ts Formation; Fig. 2) that contain fossil mammals (Anad6n et al., 1983) and charophytes (Anad6n and Feist, 1981; Anad6n et al., 1992/1993), both indicating an early Bartonian age for this unit."

Reference (age)

Cavagnetto C, Anadón P. 1996. Preliminary palynological data on floristic and climatic changes during the Middle Eocene-Early Oligocene of the eastern Ebro Basin, northeast Spain. Review of Palaeobotany and Palynology 92: 281–305.

Fossil relationships

Node calibrated	**stem Avicennioideae (Acanthaceae, Lamiales)**
Node assignment score	3 / apomorphy-based (apomorphies unlisted or untested)
Reconciliation score	3 / molecular tree only

Node justification

Tripp & McDade 2014 (SystBiol): "Avicennia are monophyletic (Schwarzbach and McDade 2002) and share unique pollen features: spheroidal and tricolporate with longitudinally elongated ora and reticulate surface ornamentation with broad muri and small lumina (Borg and Schonenburger 2011); these fossils share these traits and were used to constrain the MRCA of the three sampled spp. of Avicennia."

Reference (relationships)

Tripp EA, McDade LA. 2014. A rich fossil record yields calibrated phylogeny for acanthaceae (Lamiales) and evidence for marked biases in timing and directionality of intercontinental disjunctions. Systematic Biology 63: 660–684.

†*Catalpa sp.*

Calibration at a glance: stem Catalpa (Bignoniaceae, Lamiales), min 38.4 Ma
ID number (NFos): 303

Fossil identity

Full taxon name: **†Catalpa sp.**
Organs: Seeds
Specimens: UF26394
Locality: 44°56.2’N., 120°25.07’W., about 3 km north-northeast of Hancock Field Station, John Day Fossil Beds National Monument, Oregon
Formation: John Day Formation, Whitecap Knoll flora
Country: USA

Reference (description)

Manchester SR. 2000. Late Eocene fossil plants of the John Day Formation, Wheeler County, Oregon. Oregon Geology 62: 51-63.

Fossil age

Safe minimum age: **38.4 Ma**
Absolute age source: radioisotopic
Age quality score: 5 / revised (radioisotopic)

Age justification

Manchester 2000 (OregonGeol): "The fossil-bearing shale is above the member A ignimbrite, dated 39.17 ± 0.15 Ma, and below a tuff dated 38.4 ± 0.7 Ma and is considered to be about 38.8 Ma."

Reference (age)

Manchester SR. 2000. Late Eocene fossil plants of the John Day Formation, Wheeler County, Oregon. Oregon Geology 62: 51-63.

Fossil relationships

Node calibrated: **stem Catalpa (Bignoniaceae, Lamiales)**
Node assignment score: 2 / intuitive or unspecified (trusted source)
Reconciliation score: 3 / molecular tree only

Node justification

Manchester 2000 (OregonGeol): "Catalpa is recognized by a single seed (Figure 8L), which is bilaterally symmetrical with a straight, straplike wing on either side of the central body and with a tuft of hairs at the distal margin of each wing. Catalpa seeds are also present at two assemblages of the Bridge Creek flora (Meyer and Manchester, 1997)."

Reference (relationships)

Manchester SR. 2000. Late Eocene fossil plants of the John Day Formation, Wheeler County, Oregon. Oregon Geology 62: 51-63.

†Golden Grove Byblidaceae parataxon

Calibration at a glance	crown Byblidaceae (Lamiales), min 41.2 Ma
ID number (NFos)	304

Fossil identity

Full taxon name	**†Golden Grove Byblidaceae parataxon Conran & Christophel**
Organs	Seed
Specimens	Fig. 1A, Golden Grove Byblidaceae seed Molenaar s.n. (ADU, destroyed; represented by the photograph) (specimen number not provided in original description due to accidental destruction)
Locality	East Yatala Sand Pit, Golden Grove, South Australia (138°439300E, 34°479100S)
Formation	Golden Grove clays
Country	Australia

Reference (description)

Conran JG, Christophel DC. 2004. A Fossil Byblidaceae Seed from Eocene South Australia. International Journal of Plant Sciences 165: 691–694.

Fossil age

Safe minimum age	**41.2 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Eocene (Lutetian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	3 / unrevised (recent source >= 2000)

Age justification

Conran & Christophel 2004 (IJPS): "The lens was dated palynologically as Middle Eocene (Alley 1987), with the original environment considered to be similar to a modern complex notophyll vine forest (Christophel and Greenwood 1987)."

Reference (age)

Conran JG, Christophel DC. 2004. A Fossil Byblidaceae Seed from Eocene South Australia. International Journal of Plant Sciences 165: 691–694.

Fossil relationships

Node calibrated	**crown Byblidaceae (Lamiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "The fossil is a mummified seed 0.7 mm long and 0.45 mm wide, described as being “elliptical, black, ends rounded, micropylar end slightly more acute. Testal cells 7–9 along the long axis and 4–6 across; cells 90–140 μm long and 80–120 μm wide (mean 110 x 90 μm). Testa reticulately honeycombed; longitudinal ridges minutely denticulate-crenulate; transverse ridges shallow. Periclinal walls deeply concave; anticlinal wall ridges verrucate.” (Conran & Christophel, 2004). Conran & Christophel (2004) considered that “The combination of deep reticulately honeycombed cells and the verrucate anticlinal walls places the seed close to extant taxa in the Byblis liniflora Salisb. complex.”. The seed was not formally assigned to a taxon, because the specimen was lost, and the description was made on the basis of photographs (Conran & Christophel, 2004). Based on the similarities with species of Byblis, we tentatively consider that this fossil was a member of crown group Byblidaceae, *and use it to calibrate the crown group of this family."*

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Ajuginucula smithii*

Calibration at a glance	stem Ajugoideae (Lamiaceae, Lamiales), min 27.82 Ma
ID number (NFos)	305

Fossil identity

Full taxon name	**†Ajuginucula smithii Reid et Chandler**
Organs	Fruit
Specimens	Holotype: V.17608
Locality	Bembridge beds, Isle of Wright, Gurnard Bay and Thorness Bay
Formation	Bembridge Flora
Country	UK

Reference (description)

Reid EM, Chandler MEJ. 1926. Catalogue of Cainozoic plants in the Department of Geology. The Bembridge Flora. Catalogue of Cainozoic Plants in the Department of Geology, British Museum.

Fossil age

Safe minimum age	**27.82 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Oligocene (Rupelian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Stratigraphy

Reference (age)

Reid EM, Chandler MEJ. 1926. Catalogue of Cainozoic plants in the Department of Geology. The Bembridge Flora. Catalogue of Cainozoic Plants in the Department of Geology, British Museum.

Fossil relationships

Node calibrated	**stem Ajugoideae (Lamiaceae, Lamiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Accepted by Martinez-Millan 2010 (BotRev). Reid & Chandler 1926 (book): "The nutlet is comparable in size with those of Teucrium, many of which are not more than i mm. long ; but its form is more graceful than those of any species of Teucrium, in which the nutlets are all rounded below, not narrowed as is the fossil. The nutlets of Cymaria are also similar in size, and those of C. elongata are not unlike in shape, but are yet more narrowed at the base than the fossil. In neither genus does the sculpture of the nutlets closely resemble that of Ajuginucula. In Teucrium the seeds are either much more .finely dr much more coarsely pitted than in the fossil, and in all species the arrangement of pits is less uniform. In Cymaria the pits are still coarser, there being only 5 or 6 in the width of the nut, and these are elongate longitudinally below like the large pits of Ajuga. Whilst therefore the general characters are those of Ajugoideae, no genus shows all its characters, so that we have been obliged to give a new generic name."

Reference (relationships)

Martínez-Millán M. 2010. Fossil record and age of the Asteridae. Botanical Review 76: 83–135.

†Melissa parva

Calibration at a glance	crown Nepetoideae (Lamiaceae, Lamiales), min 27.82 Ma
ID number (NFos)	306

Fossil identity

Full taxon name	**†Melissa parva Reid et Chandler**
Organs	Fruit
Specimens	Holotype: V.17607
Locality	Bembridge beds, Isle of Wright, Gurnard Bay and Thorness Bay
Formation	Bembridge Flora
Country	UK

Reference (description)

Reid EM, Chandler MEJ. 1926. Catalogue of Cainozoic plants in the Department of Geology. The Bembridge Flora. Catalogue of Cainozoic Plants in the Department of Geology, British Museum.

Fossil age

Safe minimum age	**27.82 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Oligocene (Rupelian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Stratigraphy

Reference (age)

Reid EM, Chandler MEJ. 1926. Catalogue of Cainozoic plants in the Department of Geology. The Bembridge Flora. Catalogue of Cainozoic Plants in the Department of Geology, British Museum.

Fossil relationships

Node calibrated	**crown Nepetoideae (Lamiaceae, Lamiales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

*Reid & Chandler 1926 (book): "The actual nut with carbonised pericarp is preserved. Its structure is almost identical with that of M. officinalis Linn. The only differences are the smaller size {M. officinalis length i'5 to 2 mm. ; breadth 0*75 to 0*9 mm.), blunter base, more clumsy oblong form and less well-defined cellstructure of the surface ; the cells of M. officinalis are identical in character but larger, and they have more conspicuous walls." Accepted by Martinez-Millan 2010 (BotRev).*

Reference (relationships)

Reid EM, Chandler MEJ. 1926. Catalogue of Cainozoic plants in the Department of Geology. The Bembridge Flora. Catalogue of Cainozoic Plants in the Department of Geology, British Museum.

†Fraxinus rupinarum

Calibration at a glance	crown Oleaceae (Lamiales), min 27.82 Ma
ID number (NFos)	307

Fossil identity

Full taxon name	**†Fraxinus rupinarum Becker**
Organs	Fruit and leaf
Specimens	Holoytpes. UM 33625, 33626
Locality	Upper Ruby River Basin, Montana
Formation	Metzel Ranch flora
Country	USA

Reference (description)

Becker, HF. 1961. Oligocene plants from the Upper Ruby River Basin, South-Western Montana. The Geological Society of America Memoir 82. Waverly Press, New York.

Fossil age

Safe minimum age	**27.82 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Rupelian
Reference time scale	ICS (v2017/02)
Age quality score	4 / revised (stratigraphic)

Age justification

Lielke 2012 (PhD): "Becker (1960 & 1961) based his original age assignments on correlations with allied fossil floras now considered late Eocene/early Oligocene, rather than late Oligocene/early Miocene, in age (Meyer & Manchester, 1997; Meyer, 2003) and on associated Chadronian mammal fossils, then considered Oligocene, and now correlated with the late Eocene (Prothero, 1985, 1994 & 1995). Based on these revised ages and new field observations, the Ruby laminated shales and similar Paleogene sediments to the north and northeast are reassigned to the top of the Climbing Arrow Member of probable early Oligocene age, although a latest Eocene age cannot be ruled out. Based on these age revisions, the Metzel Ranch and Ruby floras are reinterpreted as a transitional phase of vegetation close to the E/O boundary."

Reference (age)

Lielke KJ. 2012. The climatic, biotic and tectonic evolution of the Paleogene Renova formation of Southwestern Montana. PhD Thesis, University of Montana, U.S.A.

Fossil relationships

Node calibrated	**crown Oleaceae (Lamiales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Becker 1961 (book): "This species is represented by numerous samaras and one leaflet with counterpart which is clearly a long-petioluled terminal blade of the compound leaf. The samaras vary slightly in size and degree of preservation. Although reminiscent of Fraxinus coulteri Dorf (1936), their composite dimensions are somewhat smaller; the samaras are apically acute, and the midvein of the wing is absent. Because of the presence of identifiable leaflets, it seems appropriate to consider the samaras conspecific, even if slight differences exist which are similar to those in other named samaras. The leaflet and the samaras show characters akin to those of the living

Fraxinus americana L. (PI. 28, figs. 6a, b, c), but the leaflet also resembles those of F. pennsylvanica var. lanceolata (Borkhausen) Sargent, which grows in the entire Rocky Mountain region from Texas through Montana to Saskatchewan."

Reference (relationships)

Becker, HF. 1961. Oligocene plants from the Upper Ruby River Basin, South-Western Montana. The Geological Society of America Memoir 82. Waverly Press, New York.

†Paulownia inopinata

Calibration at a glance	stem Paulowniaceae (Lamiales), min 11.63 Ma
ID number (NFos)	341

Fossil identity

Full taxon name	**†Paulownia inopinata Butzmann & Fischer**
Organs	Fruit valves
Specimens	Holotype: Fruit No. 1 pictured as Figure 1; housed in the Naturmuseum Augsburg, Inv. No. 97-119/1494
Locality	Sand pit HUBER close to Unterwohlbach, R 66180, L 66580, Gemeinde Hohenkammer, Kreis Freising
Formation	
Country	Germany

Reference (description)

Butzmann R, Fischer T. 1997. Description of the fossil fruit Paulownia inopinata nov. sp. from the Middle Miocene of Unterwohlbach (Bavaria) and other possible occurrences of the genus in the Tertiary. Documenta Naturae 115: 1–13.

Fossil age

Safe minimum age	**11.63 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Middle Miocene (Serravallian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Butzmann & Fischer 1997 (DocNat): "Marl horizon (limno-fluviatile facies) belonging to the Middle Miocene, Obere SiiBwassermolasse, Sarmatium, mittlere DEHM'sche Serie, Phytozone OSM 3b2"

Reference (age)

Butzmann R, Fischer T. 1997. Description of the fossil fruit Paulownia inopinata nov. sp. from the Middle Miocene of Unterwohlbach (Bavaria) and other possible occurrences of the genus in the Tertiary. Documenta Naturae 115: 1–13.

Fossil relationships

Node calibrated	**stem Paulowniaceae (Lamiales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Butzmann & Fischer (1997; in Manchester et al., 2009) described distinctive fruit valves of Paulownia in middle Miocene sediments of Bavaria. Other even more tentative reports of Paulownia seeds and wood from younger sediments are also mentioned by Manchester et al. (2009). We here tentatively accept this report, and because Paulowniaceae includes only the genus Paulownia, we use the fossils to calibrate the stem node of this family."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†Trapella weylandi

Calibration at a glance	crown Pedaliaceae (Lamiales), min 2.58 Ma
ID number (NFos)	308

Fossil identity

Full taxon name	**†Trapella weylandi (Thomson et Grebe) Tralau**
Organs	Fruit
Specimens	Type: Figured in Grebe 1955, pi. XXXIV, f. 14. The original specimen in Thomson's collection is lost [Tralau 1964 (BotNot)]
Locality	Swisterberg /Weilerswist
Formation	
Country	Germany

Reference (first description)

Grebe H. 1955. Die Mikro- and Megaflora der pliozänen Ton- und Tongyttjalinse in den Kieseloolithschichten vom Swisterberg/Weilerswist (Blall Sechtem) und die Altersstellung der Ablagerung im Tertiär der Niederrheinischen Bucht. Geologisches Jahrbuch 70.

Reference (latest description)

Tralau H. 1964. The genus Trapella Olivier in the Tertiary of Europe. Botaniska Notiser 117: 119–123.

Fossil age

Safe minimum age	**2.58 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Pliocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Trapella cf. antennifera (Léveillé) Glück (Tralau, 1965) and Trapella weylandi (Thompson & Grebe) Tralau (Tralau, 1964), from Swisterberg, Germany, corresponding to the Pliocene (Martínez-Millán, 2010)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**crown Pedaliaceae (Lamiales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "Martínez-Millán (2010) considered that the species of Trapella from the Pliocene of Germany can be reliably related to Pedaliaceae. We consider these fossils as members of the crown group of Pedaliaceae, and use them to calibrate the crown group of this family."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

†*Calystegiapollis microechinatus*

Calibration at a glance	crown Convolvulaceae (Solanales), min 47.8 Ma
ID number (NFos)	310

Fossil identity

Full taxon name	**†Calystegiapollis microechinatus Salard-Cheboldaeff**
Organs	Pollen
Specimens	
Locality	
Formation	
Country	Cameroon

Reference (description)

Salard-Cheboldaeff M. 1975. Quelques grains de pollen peripores Tertiaires du Cameroun. Rev. Micropaleontol. 17: 182–190.

Fossil age

Safe minimum age	**47.8 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Early Eocene (Ypresian assumed)
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Reference (age)

Muller J. 1981. Fossil pollen records of extant angiosperms. Botanical Review 47: 1-142.

Fossil relationships

Node calibrated	**crown Convolvulaceae (Solanales)**
Node assignment score	1 / intuitive or unspecified
Reconciliation score	1 / pre-molecular era (before 1990)

Node justification

Muller 1981 (BotRev): "Calystegiapollis microechinatus, a periporate type described by Salard- Cheboldaeff (1975a) from the lower Eocene of Cameroon, appears comparable with the pollen of Merremia tridentata and M. medium (cf. Ferguson et al., 1977)"

Reference (relationships)

Muller J. 1981. Fossil pollen records of extant angiosperms. Botanical Review 47: 1-142.

†Physalis infinemundi

Calibration at a glance	crown Solanaceae (Solanales), min 52.22 Ma
ID number (NFos)	327

Fossil identity

Full taxon name	**†Physalis infinemundi Wilf, Carvalho, Gandolfo, Cúneo**
Organs	Fruits
Specimens	MPEF-Pb 6434a,b
Locality	quarry LH13, Laguna del Hunco in Chubut, Patagonia
Formation	Huitrera Formation
Country	Argentina

Reference (description)

Wilf P, Carvalho MR, Gandolfo MA, Cúneo NRC. 2017. Eocene lantern fruits from Gondwanan Patagonia and the early origins of Solanaceae. Science 355: 71-75.

Fossil age

Safe minimum age	**52.22 Ma**
Absolute age source	radioisotopic
Age quality score	5 / revised (radioisotopic)

Age justification

Wilf et al 2017 (Science): "The minimum age of the fossils is 52.22 ± 0.22 Ma, based on three 40Ar-39Ar dates from closely associated tuffs and two paleomagnetic reversals from the local stratigraphic section (16, 20)."

Reference (age)

Wilf P, Carvalho MR, Gandolfo MA, Cúneo NRC. 2017. Eocene lantern fruits from Gondwanan Patagonia and the early origins of Solanaceae. Science 355: 71-75.

Fossil relationships

Node calibrated	**crown Solanaceae (Solanales)**
Node assignment score	5 / phylogenetic analysis
Reconciliation score	5 / combined morphological and molecular analysis (total evidence or backbone)

Node justification

Wilf et al 2017 (Science): "Both the MP and ML results (Fig. 2 and fig. S1) support the fossils' affinity with Physalinae and Physalis. The newly identified species is placed in Physalinae with strong support in both MP and ML analyses and at a basal polytomy of (MP, weak support) or within (ML, strong support) the crown of core Physalis. Both the MP and ML topologies are generally consistent with and reproduced most major clades from (10), with robust support of the critical Physalinae clade. However, each tree recovered the closely related (10) Iochrominae and Deprea as collapsed into a single clade that also included Nicandra, which has Deprea-like calyx morphology but is not closely related to that genus. Nevertheless, the overall agreement of the MP and ML tree topologies with (10) is notable in light of the limitations of the analysis. Notably, no species fromoutside Physalinae were misplaced among Physalinae, and no Physalinae species were misplaced into other clades. Considering the unknown additional organs of this extinct species, the incomplete knowledge of calyx morphology in extant Solanaceae, and problematic resolution among extant basal species of Physalinae (13, 25), we suggest that the newly identified species can be used, conservatively, to constrain the divergence of Physalinae to a minimum of 52.2 Ma." Here, we more conservatively use this fossil to constrain the crown node of Solanaceae.

Reference (relationships)

Wilf P, Carvalho MR, Gandolfo MA, Cúneo NRC. 2017. Eocene lantern fruits from Gondwanan Patagonia and the early origins of Solanaceae. Science 355: 71-75.

†Solanispermum reniforme

Calibration at a glance	crown Solanaceae (Solanales), min 33.9 Ma
ID number (NFos)	311

Fossil identity

Full taxon name	**†Solanispermum reniforme Chandler**
Organs	Seed
Specimens	V.40891, V.40893, V.40894, V.40897, V. 40895, V.42091
Locality	Lower Bagshot, Dorset (var.?); Bournemouth Freshwater Beds, Sandbanks and Branksome Dene, Dorset; Lignite above Boscombe Sands, Southbourne (Auversian?), Hampshire; Cliff End Beds, Mudeford (Auversian?), Hampshire
Formation	Lower Bagshot beds
Country	UK

Reference (first description)

Chandler MEJ. 1962. The Lower Tertiary floras of Southern England. II. Flora of the Pipe-Clay Series of Dorset (Lower Bagshot). London: British Museum (Natural History).

Reference (latest description)

Chandler MEJ. 1962. The Lower Tertiary floras of Southern England. II. Flora of the Pipe-Clay Series of Dorset (Lower Bagshot). London: British Museum (Natural History).

Fossil age

Safe minimum age	**33.9 Ma**
Absolute age source	stratigraphic (upper limit of oldest stratigraphic age)
Oldest stratigraphic age	Eocene
Reference time scale	ICS (v2017/02)
Age quality score	2 / unrevised (old source < 2000)

Age justification

Magallón et al 2015 (NewPhytol): "Seeds assigned to Solanispermum reniforme Chandler, and to Solanum arnense Chadler from the Lower Bagshot, UK (Chandler, 1962), corresponding to the Eocene (Martínez-Millán, 2010)."

Reference (age)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.

Fossil relationships

Node calibrated	**crown Solanaceae (Solanales)**
Node assignment score	2 / intuitive or unspecified (trusted source)
Reconciliation score	3 / molecular tree only

Node justification

Magallón et al 2015 (NewPhytol): "In her examination of the fossil record of Asterids, Martínez-Millán (2010) considered that the known fossil record of Solanaceae is mostly unreliable, but that the seeds of Solanispermum reniforme and Solanum arnense “show some solanaceous characters and could potentially belong to this family” (Martínez-Millán, 2010). Based on this apprisal, we consider that these seeds could belong to crown group or stem lineage Solanaceae, and use them to calibrate the Solanaceae stem node."

Reference (relationships)

Magallón S, Gómez-Acevedo S, Sánchez-Reyes LL, Hernández-Hernández T. 2015. A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. New Phytologist 207: 437–453.