ELECTRONIC SUPPLEMENTARY MATERIAL-ESM for article

Strong continentality and effective moisture drove unforeseen vegetation dynamics since the last interglacial at inland Mediterranean areas: the Villarquemado sequence in NE Iberia

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1. Geochemical data

The geochemical dataset, elemental composition derived from XRF analysis, magnetic susceptibility (MS), total organic carbon (TOC), total inorganic carbon (TIC), and total sulfur (TS), are available in separate files.

2. Palynological sequence results extended version

In total, 15 pollen zones (with subzones) have been established following main taxa and group dynamics. VIL-15 corresponds to the end of MIS 6 and the transition to MIS 5e at the bottom of the record and VIL-6 to VIL-1, on the top, to the already published Lateglacial and Holocene data (Aranbarri et al., 2014)

Pollen zones

- VIL-15 (131.3-127 ka BP: end of MIS 6 and transition period to MIS 5e). Woody taxa in this zone record ca. 40% progressively declining towards the top of VIL-15 (Fig. 4). *Juniperus* is the main arboreal Woody component determining thus the group dynamics. Mesophytes are also relevant reaching percentages of ca. 8-10%. Both deciduous and evergreen *Quercus* are already present, as well as isolated, low values of *Abies,* Oleaceae or *Pistacia* and *Cedrus* pollen grains. *Pinus* completes the principal tree taxa record with an average abundance of ca. 10%. Regarding the herbaceous component, Poaceae dominate with values reaching 50% and Steppe taxa fluctuate increasing towards the top. *Artemisia* percentage rarely exceeds 15% while the indicators of local moisture (aquatics and ferns) are less than 10%. Hygrophytes such as present very abrupt changes, both in terms of abundance change and time duration.

- VIL-14 to VIL-11 (127-70 ka BP: MIS 5). *Juniperus, Quercus* and the Mediterranean taxa (mainly Oleaceae), dominate the Woody vegetation during MIS 5 in Villarquemado sequence (Fig. 4). Steppe taxa evolution evidences an opposite trend to that of Woody communities despite *Artemisia*, Cichorioideae or Chenopodiaceae do not converge at all times. Both hygrophytes (Cyperaceae and Typhaceae) and aquatic plants (*Myriophyllum*) reveal changing environments with constant and abrupt variations.

VIL-14 (127-112 ka BP: MIS 5e). We observe similar fluctuating dynamics of the Woody communities inclusive of *Juniperus, Quercus*, Mediterranean elements and the local indicators of moisture while Steppe taxa and Poaceae progressively decrease, Mesophytes develop and Hygrophytes alternate Cyperaceae-Typhaceae dominance. We identify four subzones within VIL-14 that broadly correspond to interglacial MIS 5e:

Subzone 14D (127-126 ka BP). It is evidenced an abrupt drop in *Juniperus* and Woody taxa and a decrease in Mesophytes and the Mediterranean component, including the disappearance of some taxa such as *Pistacia* (Fig. 4). Similarly, the local moisture group decreases significantly while steppe (mainly Chenopodiaceae) and Poaceae dominate the palynological spectra during ca. two millennia. Cyperaceae reach one of the highest developments of the record.

Subzone 14C (126-122.5 ka BP). Woody taxa return to similar values of those of the basal part of the sequence (Fig. 4), while *Artemisia* increases and, counterintuitively, steppe taxa and Poaceae decrease and Cichorioideae virtually disappear. Cyperaceae and Typhaceae (hygrophytes) drop and, on the contrary, aquatics (led by *Myriophyllum*) and the local moisture group increase.

Subzone 14B (122.5-116 ka BP). In spite of a first peak of both junipers and Mediterranean components, an intense decrease of Woody taxa is recorded marked too by drops in both *Quercus* types. Also mesophytes evolution evidences a change towards lower values at the end of this subzone. Steppe taxa interrupt the decreasing trend, Poaceae don't exceed 15-20% but *Artemisia* maintains percentages at around 30% despite fluctuating. Typhaceae clearly substitute Cyperaceae around the basin. Isolated pollen grains of *Cedrus* are recorded again (Fig. 4).

Subzone 14A (116-112 ka BP). *Abies* develops in this subzone reaching its highest value of the whole record (4%). *Juniperus*, mesophytes and the Mediterranean taxa also increase while Cichoriodeae and Chenopodiaceae almost disappear (Fig. 4). Cyperaceae led the hygrophytic vegetation.

VIL-13 (112-109 ka BP: MIS 5d). An interruption in the presence of thermophilous taxa such as Oleaceae and *Pistacia* is recorded in this zone. Simultaneously, *Abies* decreases and the arrival of *Cedrus* pollen grains reach the maximum of the record (Fig. 4). Steppe taxa reaches a peak towards the top of this zone while Poaceae and *Artemisia* remain with similar abundances to the previous zone. Cyperaceae drops again and Typhaceae expands.

VIL-12 (109-93 ka BP: MIS 5c). Maximum values of both Oleaceae and *Pistacia* curves are recorded in this zone, next to fluctuating *Juniperus*, Mesophytes and the Woody communities (Fig. 4), while the Steppe taxa follow an opposite trend. Typhaceae and *Myriophyllum* show important development with fluctuations. Four subzones can be distinguished:

Subzone 12D (109-107 ka BP). Lower values of junipers and Mesophytes contrast with the highest proportion of Oleaceae during the whole MIS 5 (mainly 4%). Both Cichorioideae and Chenopodiaceae expand while *Artemisia* drops. Local moisture indicators increase despite *Myriophyllu*m is absent.

Subzone 12C (107-102.5 ka BP). A strong decrease in steppe taxa and *Pinus* content concurs with the expansion of *Juniperus*, Mesophytes, Mediterranean taxa and *Artemisia*, as well as *Myriophyllum* (Fig. 4).

Subzone 12B (102.5-97.5 ka BP). Woody communities and junipers experience a strong decrease while both Mesophytes and Mediterranean groups trend to reduce their presence, as well as *Artemisia*. On the contrary, steppe taxa develop with a peak at the end of this subzone.

Subzone 12A (97.5-93 ka BP). The recovery of Woody taxa is evidenced by mainly junipers and mesophytes and new increases of Oleaceae and *Pistacia*. As usually in VIL sequence, the steppe-like communities record opposite values in comparison with forest and shrub components (Fig. 4). Cyperaceae, Typhaceae and *Myriophyllum* show a complex pattern of coeval fluctuations.

Sterile level (93-87 ka BP: MIS 5b). A low pollen preservation level of ca. 6 ka precludes any inference on vegetation dynamics between VIL-12 and VIL-11 pollen zones. Following our chronological model, this moment broadly corresponds to MIS 5b stadial and it is showed in the pollen diagram with a white band which, despite the lack of pollen, evidences a very different state of vegetation at the onset and termination of this phase (Fig. 4).

VIL-11 (87-70 ka BP: end of MIS 5b and MIS5a). A new development of the Mediterranean component and lower values of Woody taxa and *Juniperus,* which disappear at the end of this zone, characterize the last interstadial of MIS 5. It is worth mentioning the continuous presence of *Cedrus* pollen and the absence of *Pistacia* that never recovers until the Holocene (Fig. 4). Both steppe and local moisture indicators fluctuate with alternating trends. Three subzones can be identified for this period:

Subzone 11C (87-80 ka BP). Intense fluctuations are recorded in all coniferous taxa (*Pinus, Juniperus*, and with much lower proportion, the presence of *Abies* and *Cedrus*), as well as in Mesophytes. Poaceae expands with similar values to those of the base of VIL while, for the first time since the beginning of the record, *Artemisia*, Cichorioideae and Chenopodiaceae show the same trend.

Subzone 11B (80-72 ka BP). Despite lower values of Woody taxa caused by the *Juniperus* drop, Mesophytes develop again reaching proportions ca. 12-15%. The Mediterranean group also shows important values but decreasing towards the top of this zone. Abrupt peaks are recorded in steppe, aquatics, local moisture taxa and the Cyperaceae-Typhaceae tandem, revealing a changing complex basin reinforced by the *Artemisia* development.

Subzone 11A (72-71 ka BP). An abrupt drop is observed in *Juniperus,* Mesophytes, Mediterranean taxa, *Artemisia* and *Myriophyllum*, despite Steppe taxa don't increase significantly. On the contrary, *Pinus* increases and began its hegemony in the arboreal component during the rest of the sequence.

- VIL-10 (71- 57.5 ka BP: MIS 4). We evidenced the last occurrences of Mediterranean taxa, both *Quercus* types, the practical disappearance of junipers and fluctuating aquatics and hygrophytes evolution, indicating an intense change in the vegetation record (Fig. 4). Two subzones characterize this period which would correspond to MIS 4:

Subzone 10B (71-65 ka BP). The highest value of *Myriophyllum* of the whole sequence is recorded in this phase. Deciduous *Quercus* also shows a local maximum. Oleaceae disappears completely as well as *Abies*, while *Juniperus* and *Artemisia* present timid values.

Subzone 10A (65-57.5 ka BP). One of the most paramount changes occur in this zone as the Woody vegetation abundance recedes to values similar to those of the top of the sequence while *Myriophyllum* and *Artemisia* also disappear. Poaceae and Cichorioideae on the one hand and Typhaceae and Cyperaceae on the other, expanded with opposite fluctuating trends.

- VIL-9, VIL-8 and sterile levels (57.5-31 ka BP: MIS 3). These zones reveal an open landscape steppe communities expand and we evidenced the lowest values of Woody taxa. Besides, intense fluctuations and abrupt peaks of the hydrological indicators are recorded (Fig. 4). The local moisture group records the lowest proportions of the sequence and two long periods of low pollen preservation are observed in a time window which broadly corresponds to MIS 3.

VIL-9 (57.5-50 ka BP). This zone reflects a grassland landscape through the increasing abundance of steppe communities, Poaceae and the declining Woody taxa. Both hygrophytes and aquatics present a small expansion

Sterile level (50-43 ka BP). A new phase of low pollen preservation is recorded during ca. 7 ka. Contrarily to the sterile period observed during MIS 5, similar values of most taxa characterize the beginning and the end of this palynological silence.

VIL-8 (43-37 ka BP). A complex scenario of intense fluctuations is recorded in this zone, when a first peak of *Pinus* rapidly drops while a return of few proportions of *Juniperus* and some Mesophytes is shown. Coevally, an intense decrease of Poaceae and a development of *Artemisia* reaching similar values than during interstadials of MIS 5 are also observed. Steppe taxa peak at the end of this zone reaching one of the highest proportions of the whole record but decreasing abruptly.

Sterile level (37-31 ka BP). The top sterile level included in MIS 3 has a similar duration than the others observed in the sequence (ca. 6 ka) and we suggest that it is recorded between two different scenarios because it begins after an increase in *Betula* and a drop of steppe taxa but it ends with an opposite trend.

- VIL 7 and sterile level (31-16 ka BP: end of MIS 3 and MIS 2). Intense fluctuations of main taxa and groups characterize this period which includes the uppermost sterile level of the VIL palynological sequence (Fig. 4). The lowest Mesophyte and highest steppe taxa abundances are recorded in this zone, which however show variability determined by the Woody taxa, Hygrophytes and local moisture proportions changes.

Subzone 7B (31-25.5 ka BP). Woody taxa reveal their minimum abundances while the steppe group, led by Chenopodiaceae, hold their maximum values of the whole record. *Betula* is still present but disappears at the end of this subzone (Fig. 4). Typhaceae dominates the hydrological basin despite *Myriophyllum* is also recorded with intense fluctuations.

Subzone 7A (25.5-22 ka BP). An abrupt drop of steppe communities and the development of *Juniperus* mark the difference of this subzone. Cyperaceae substitute Typhaceae and Myriophyllum almost disappears. Both *Pinus* and Woody taxa recover.

Sterile level (22-16 ka BP: LGM and Mystery Interval). The upper most sterile level of the VIL record broadly corresponds to the LGM and precludes a new development of Poaceae, while steppe taxa decline to never reach again similar abundances of those of previous zones, reflecting a very different scenario from any time before.

- VIL 6 (16-11.7 ka BP: Lateglacial, beginning of MIS 1). We observe intense fluctuations of the dominant *Pinus* communities coexisting with few proportions of *Juniperus,* with abrupt changes in the Cyperaceae abundance (Fig. 4).

- VIL 5 to VIL 1 (11.7-1.6 ka BP: Holocene). A progressive expansion of Woody vegetation is detected at the Holocene onset while there is a slow increase in both Mesophytes and Mediterranean communities which record their maximum values at ca. 7 ka BP (Aranbarri et al., 2014). Evergreen *Quercus, Pistacia* and Oleaceae record the highest proportions of the whole sequence. *Artemisia* is still present, Poaceae and the open land communities decline concurrently and Typhaceae dominates the hygrophytes while *Myriophyllum* is always present but with low values (Fig. 4).

3. Pollen types included in each palynological group:

Functional groupings

Woody: *Acer, Alnus, Arbutus unedo, Betula, Buxus, Carpinus, Castanea, Cedrus, Cistaceae, Corylus, Ephedra, Ericaceae, Evergreen Quercus, Fagus, Fraxinus, Genista, Hedera helix, Helianthemum, Ilex aquifolium, Juglans, Juniperus, Lamiaceae,* Marcescent *Quercus, Myrica, Myrtus, Oleaceae, Picea, Pistacia, Populus, Rhamnus, Ribes, Rosaceae, Salix, Sambucus, Tamarix, Taxus, Thymelaea, Tilia, Ulmus, Viburnum.*

Pinus pollen type, despite being a clear woody element, is not included in the group as it has been considered and discussed at all times as an stand-alone taxon.

Herbs: Apiaceae, *Aristolochia, Artemisia, Asphodelus*, Asteroidae, Berberidaceae, Boraginaceae, Brassicaceae, Campanulaceae, *Cannabis-Humulus,* Carduaceae, Caryophyllaceae, *Centaurea*, Cerealia, Chenopodiaceae, Cichorioidae, *Colchicum*, Convolvulaceae, *Corydalis*, Crassulaceae, *Crocus*, Dipsacaceae, Epilobium, Euphorbiaceae, Fabaceae, *Filipendula*, Fumariaceae, *Gentiana*, Geraniaceae, Iridaceae, Liliaceae, *Linum, Lotus,* Lygeum.spartum, Malvaceae, *Mentha*.t, Onagraceae, Orobanche, *Papaver*, Plantago, Plumbaginaceae, Poaceae, Polygonaceae, *Potentilla*, Primulaceae, Ranunculaceae, Resedaceae, Rubiaceae, *Rumex, Sanguisorba*, Saxifragaceae, Scrophulariaceae, *Trifolium*, Urticaceae, Valerianaceae, Violaceae.

Ferns: *Asplenium, Botrychium, Equisetum, Polypodium, Pteris, Selaginella*, Spora monolete, Spora monolete ornamentada, Spora trilete, Spora trilete ornamentada.

Hydrophytes: *Alisma, Callitriche, Isoetes, Lemna, Myriophillum, Nuphar, Nymphaea, Potamogeton.*

Hygrophytes: Cyperaceae, *Juncus, Ledum palustre, Lythrum, Pedicularis, Ranunculus, Sparganium, Stratiotes, Thalictrum*, Typhaceae, *Utricularia*.

Bioclimatic and community groupings

Mesophytes: *Acer, Alnus, Betula, Carpinus, Castanea, Corylus, Fagus, Fraxinus, Juglans,* Marcescent *Quercus, Populus, Salix, Tilia, Ulmus.*

Mediterranean: *Arbutus, Buxus*, Cistaceae, Evergreen *Quercus*, *Helianthemum, Myrtus*, Oleaceae, *Pistacia, Rhamnus, Thymelaea, Viburnum*.

Steppe: Amaranthaceae/ Chenopodiaceae, Cichorioideae, Ephedra.

Local Moisture: *Alisma, Asplenium, Botrychium, Callitriche*, Cyperaceae, *Equisetum, Isoetes, Juncus, Ledum palustre, Lemna, Lythrum, Myriophyllum, Nuphar, Nymphaea, Pedicularis, Polypodium, Potamogeton, Pteris, Ranunculus, Selaginella, Sparganium,* Spora monolete, Spora monolete ornamented, Spora trilete, Spora trilete ornamented*, Stratiotes, Thalictrum, Typhaceae, Utricularia.*

3. Full Palynological diagrams

In the following figures we include all present taxa abundances above 2%.

ESM- Figure 1.Villarquemado trees and shrubs abundaces (%).

ESM-Figure 2. Villarquemado herbs (a) abundaces (%).

ESM-Figure 3. Villarquemado herbs (b) abundaces (%).

ESM-Figure 4. Villarquemado aquatics abundaces (%).

Figure 1. VILLARQUEMADO TREES AND SHRUBS

Villarquemado (1050 m asl)

Analysts: Eduardo García-Prieto Fronce, Josu Aranbarri Erkiaga, Penélope González-Sampériz, Graciela Gil-Romera, Fátima Franco Múgica, Antonia Andrade Olalla.

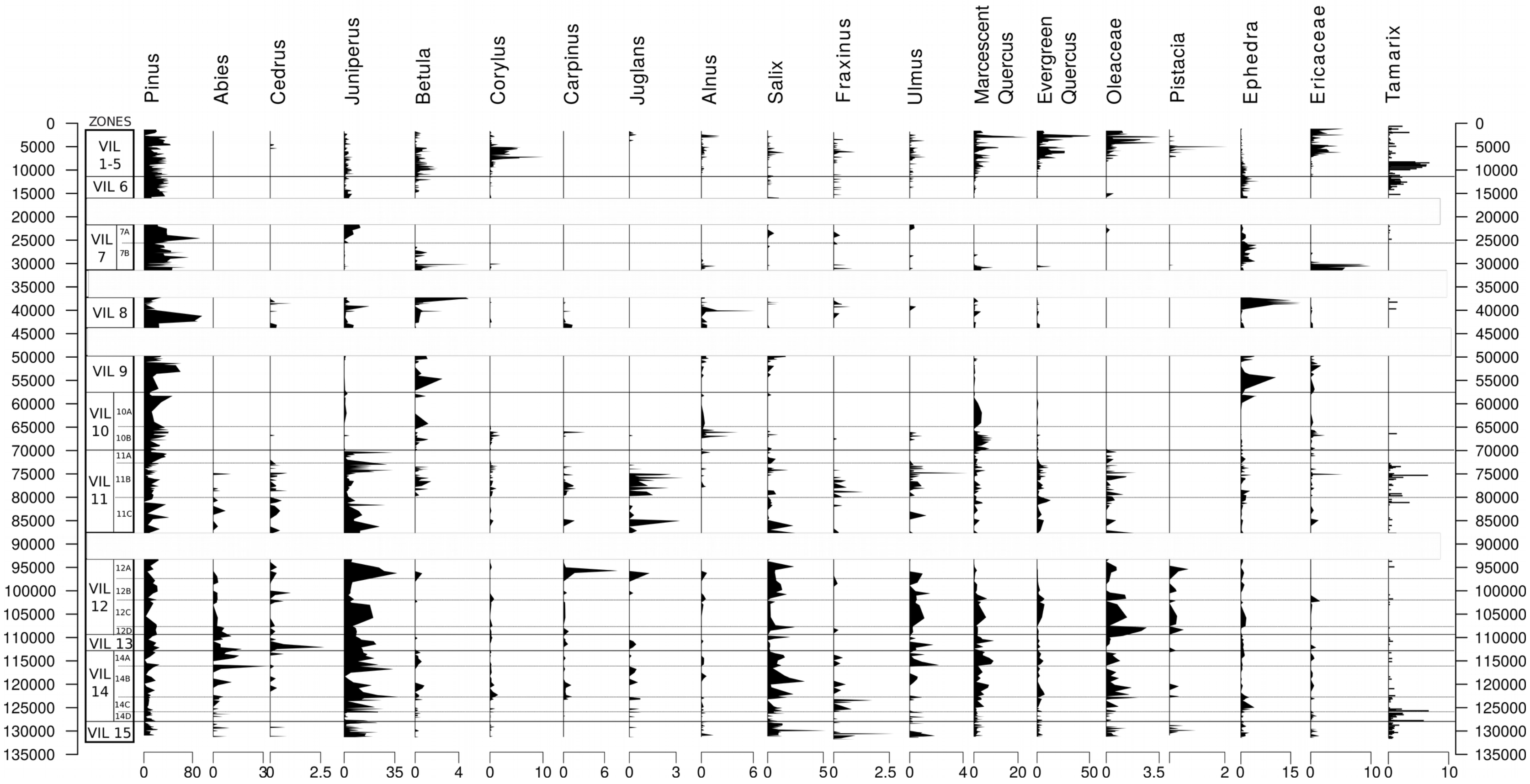

Figure 2. VILLARQUEMADO HERBS-A

Villarquemado (1050 m asl)

Analysts: Eduardo García-Prieto Fronce, Josu Aranbarri Erkiaga, Penélope González-Sampériz, Graciela Gil-Romera, Fátima Franco Múgica, Antonia Andrade Olalla.

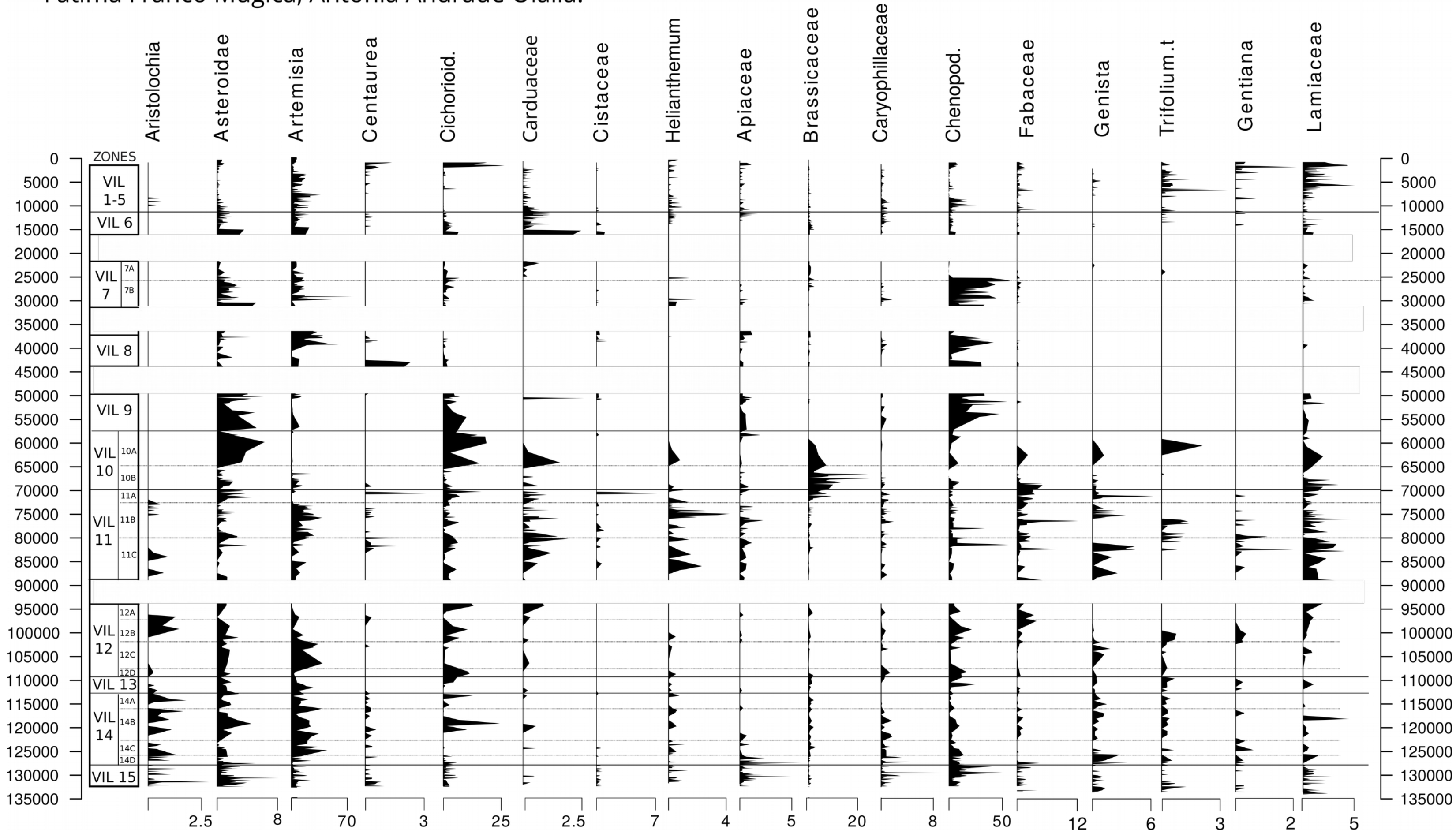

Figure 3. VILLARQUEMADO HERBS-B

Villarquemado (1050 m asl)

Analysts: Eduardo García-Prieto Fronce, Josu Aranbarri Erkiaga, Penélope González-Sampériz, Graciela Gil-Romera, Fátima Franco Múgica, Antonia Andrade Olalla.

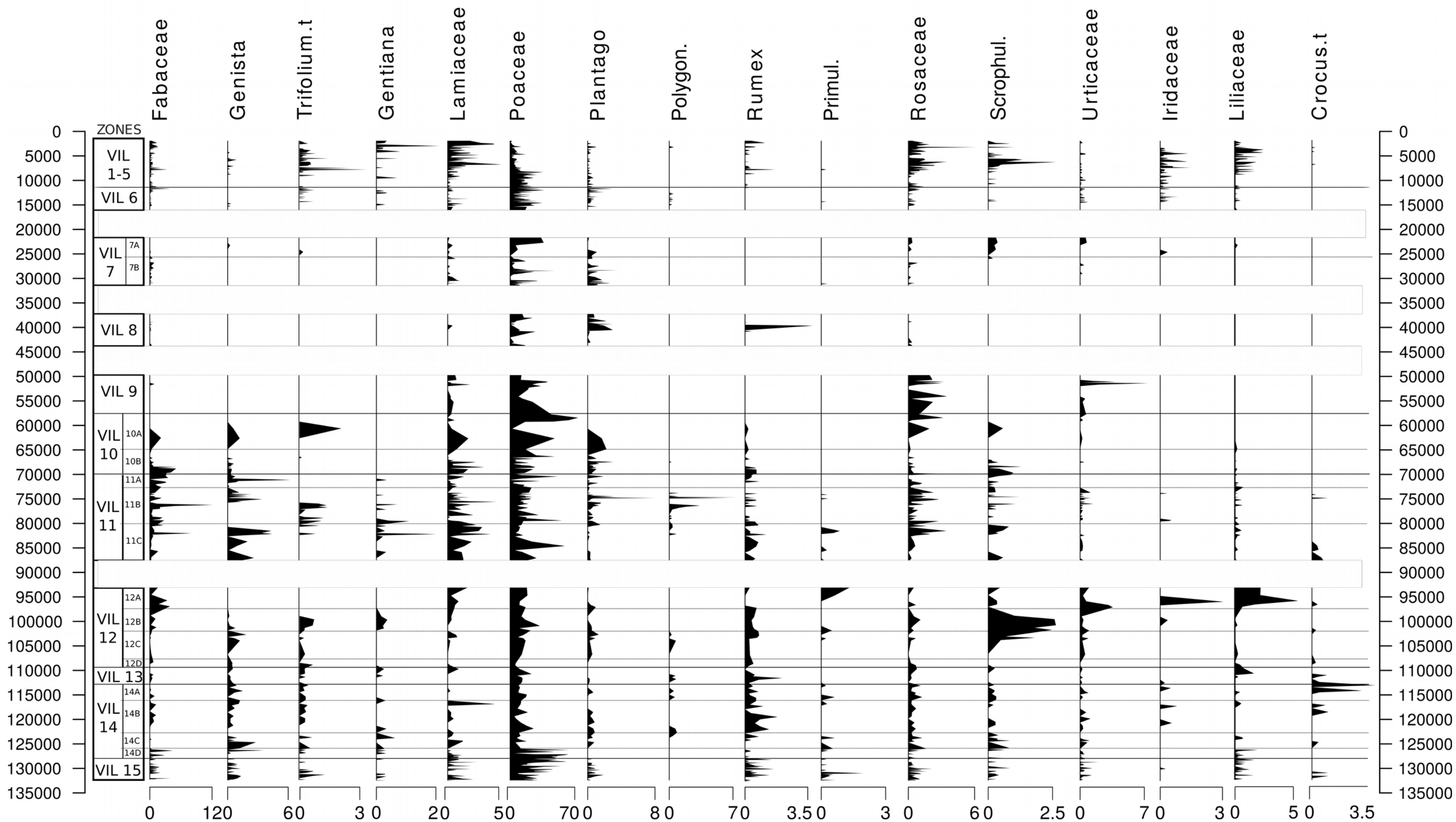

Figure 4. VILLARQUEMADO AQUATICS

Villarquemado (1050 m asl)

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