University of São Paulo

Annual Symposium on Geology of Brazil and China

2019

The Paleoproterozoic record of the São Francisco Craton Paleocontinent and Late Paleoproterozoic to Neoproterozoic covers

Field Workshop

Brazil, 13-25 August, 2019

W. Teixeira (IGc-USP), F. Chemale Jr. (PPGEO-UNISINOS), E. P. Oliveira (IG-UNICAMP) (Organizers)

São Paulo, August - 2019

USP
University of São Paulo

Annual Symposium on Geology of Brazil and China

2019

FAPESP
FUNDAÇÃO DE AMPARO À PESQUISA DO ESTADO DE SÃO PAULO

CAPES

Institutional support:

GEOCIÊNCIAS USP

IG UnB 50 anos
IG | Instituto de Geociências

中国科学院
CHINESE ACADEMY OF SCIENCES

Field trip 1 – The Mineiro belt and the Quadrilátero Ferrífero, Southern São Francisco Craton

by

W. Teixeira, E. Oliveira, F. Alkmim, L. Seixas

Field workshop 1

Brazil, 13-18 August, 2019

1. Introduction

The field workshop on the Paleoproterozoic record of the São Francisco craton (SFC) has been designed to provide a view on the aspects of the Paleoproterozoic geology with emphasis on the Mineiro belt and the Minas Supergroup in Minas Gerais state, and thus afford the opportunity to discuss outcrop evidence for the issues such as: i) Significance of the Paleoproterozoic orogenic domains of the SFC; ii) Supercontinent assembly in the context of the Columbia Supercontinent; iii) Paleoproterozoic orogenic architecture as a transition between Archean tectonic styles; iv) Differential response of the Paleoproterozoic lithosphere to extensional tectonism.

The first part of field trip traverses the Paleoproterozoic orogenic domain of the southern portion of the SFC in Minas Gerais state, emphasizing its most representative rock assemblages, geochronological and geochemical constraints and tectonic features of the Mineiro belt. This part of the field workshop ends in the mining district of the Quadrilátero Ferrífero where it traverses the Minas Supergroup, which corresponds to the foreland domain of the Paleoproterozoic Mineiro belt.

After an introductory synthesis on the Archean and Paleoproterozoic orogenic domains, including aspects of the geology of the Quadrilátero Ferrífero of the southern portion of the São Francisco Craton, this field guide book presents the description of the outcrops that will be examined during the field trip.

2) The Archean and Paleoproterozoic record of São Francisco Craton: a summary

The Archean/Paleoproterozoic basement of the SFC is an extension of the much larger Congo craton of western-central Africa, encompassed by Neoproterozoic belts akin to the assembly of West Gondwana assembly (e.g., Trompette, 1994; Alkmim et al., 2001) (Figure 1). The SFC in eastern Brazil contains an Archean core and two segments of a Paleoproterozoic orogeny. The Archean core is almost entirely covered by Proterozoic and Phanerozoic sedimentary successions, which accumulated in two distinct basins: the São Francisco basin and the Paramirim aulacogen.

The Archean basement assemblages crop out in the southern and northern lobes (Barbosa and Sabaté, 2004; Oliveira et al., 2010; Teixeira et al., 2017a; Barbosa and Barbosa, 2017). Smaller exposures include a fault bounded block in the central portion of the Paramirim aulacogen in the northern portion of the craton, and stratigraphic windows in the interior and margins of the São Francisco basin. Different approaches, and consequently, different subdivision criteria have been used by authors working in the Archean terrains of the southern cratonic portion (e.g., Teixeira et al., 2017b; Simon et al., 2018). The southern exposure of the Archean rocks encompasses the Quadrilátero Ferrífero mining district and adjoining areas (e.g., Lana et al., 2013), where the ancient substratum has been traditionally subdivided into various metamorphic complexes and greenstone belts (e.g., Rio das Velhas Supergroup), largely overprinted by Paleoproterozoic episodes.

The Mineiro belt (Teixeira and Figueiredo, 1991; Teixeira et al., 2000; Alkmim and Teixeira, 2017), located in the southern end of the craton in the highlands of Minas Gerais, is composed of a large volume of granitic rocks and subordinate metavolcanic-sedimentary associations (Figure 2).The plutonic rocks characterize four distinct groups of subduction-related granitoids generated between 2.47 and 2.10 Ga with the individual segments distinguished by geophysical evidence (e.g., Noce et al., 2000; Ávila et al., 2010; 2014; Seixas et al., 2012; 2013; Teixeira et al., 2015; Barbosa et al., 2015, 2019; Moreira et al., 2018; Araujo et al., 2019). The associated supracrustal units comprise four volcano-sedimentary successions deposited in island arc settings during the same age interval of the granitoids according to the preliminary provenance studies and U-Pb dating in the associated amphibolite rocks (e.g., Teixeira et al., 2012; Ávila et al., 2010; 2012). The structural picture of the Mineiro belt is dominated by NE-trending oblique to strike-slip shear zones associated to a regionally penetrative SE-dipping foliation.

The Mineiro belt is one component of a Paleoproterozoic orogeny, termed as the Minas Orogen. This orogeny results from the collision between the Archean core of the SFC and Congo Craton that eventually led to consolidation of the São Francisco paleocontinent around 2.0 Ga (Teixeira et al., 2017b and references therein). In a broader sense, the Minas orogeny and its northern counterpart in the SFC have tectonic-geologic similarities with roughly coeval orogenic units in the North China Craton. The compelling evidence, including the LIP barcode match at the time suggests both cratons were close neighbors at late Paleoproterozoic times in Columbia, though the different reconstructions available.

The Paleoproterozoic overprint of the QF includes units like the metasedimentary successions attributed to the Minas Supergroup, as well as the underlaying Meso- to Neoarchean granite-gneissic basement and greenstone belt assemblage such as the ca. 2.78 Ga Rio das Velhas Supergroup (Dorr, 1969; Farina et al., 2016; Moreira et al., 2016; Teixeira et al., 2017a). The Minas Supergroup tracks the opening and closure of a basin comprises passive margin to syn-orogenic sediments, deposited in a passiave margin basins during the 2.58–2.42 Ga time interval., whereas the overlying sediments (Sabará Group) mark the inversion of the basin during the Minas accretionary orogeny around 2.10 Ga (Alkmim and Martins-Neto, 2012; Farina et al., 2014). The large-scale structures of the QF including basement domes and synclines containing the Paleoproterozoic units characterize a typical dome-and-keel architecture (Alkmim and Marshak, 1998), whose development included contractional deformation episodes that are penecontemporaneous to the final docking of the Mineiro belt against the foreland basin strata.

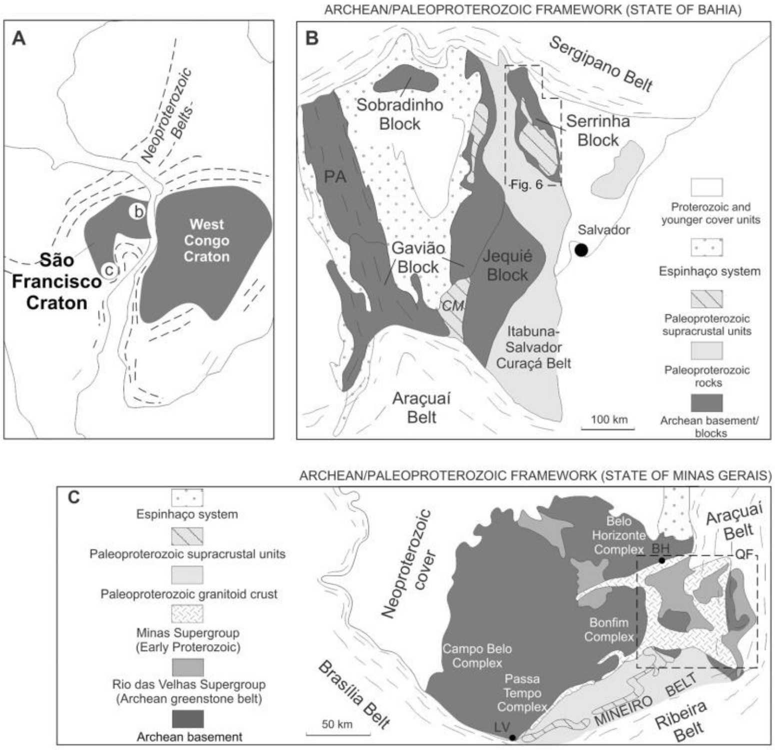

Figure 1 (Teixeira et al., 2017b): Tectonic sketch of the São Francisco craton and the adjoining West Congo craton, outlined by the Neoproterozoic marginal belts. Insets B and C show the geologic framework on the northern and southern portions of the craton, emphasizing the extent of the Archean basement and the adjoining Paleoproterozoic belts. Keys (b): PA Paramirim aulacogen, CM Contendas-Mirante supracrustal belt.

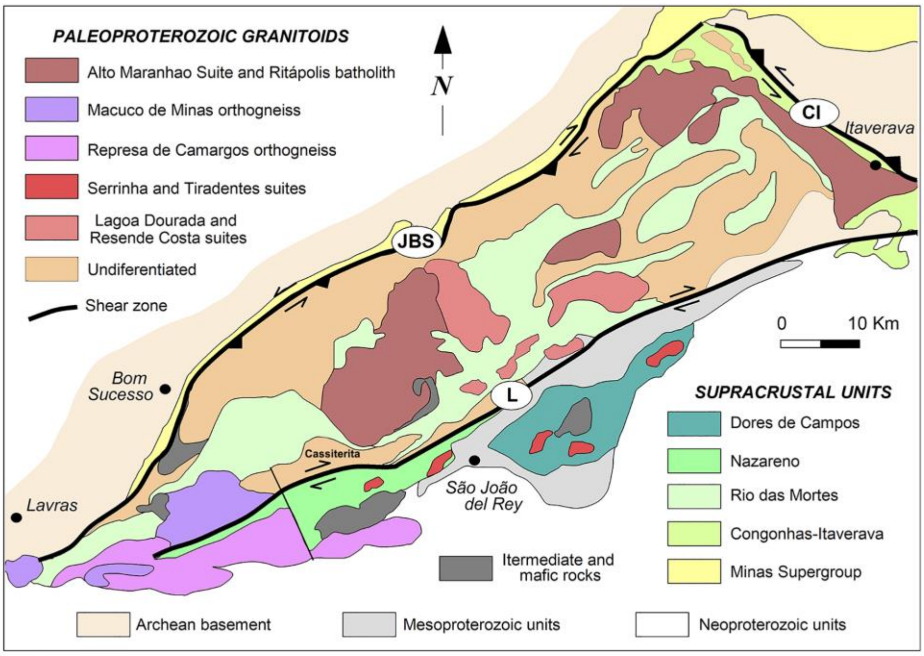

Figure 2: (Alkmim and Teixeira, 2017). Simplified geologic map of the Mineiro belt emphasizing the distribution of the main granitoid and supracrustal assemblages. Major shear zones: JBS Jeceaba Bom Sucesso, CI Congonhas Itaverava, L Lenheiro.

3. The Mineiro belt

Alkmim and Teixeira (2017) recently reassessed the lithological assemblages and tectonics of the Paleoproterozoic Mineiro belt, as well as those Paleoproterozoic units occurring in the adjoining mining district of the Quadrilátero Ferrífero - southern portion of the SFC. The highlights of this review are summarized below.

The Mineiro belt was previously defined by Teixeira and Figueiredo (1991) as the orogenic segment extensively affected by plutonism, metamorphism and deformation in the time interval of 2.2–1.9 Ga. However petrological., geochemical and geochronological studies performed in this region during the last 15 years have revealed that the Mineiro belt in reality encompasses a much complex geologic framework, given by distinct generations of granitoid and gneissic rocks in association with volcanic and sedimentary rocks emplaced and accumulated between the Siderian and Rhyacian periods (e.g., Rio das Mortes and Nazareno lithostratigraphic units). Occurrences of the Archean basement are very subordinate within the belt (e.g., Noce et al., 2000; Ávila et al., 2014; Barbosa et al., 2015, 2019; Seixas et al., 2012, 2013; Teixeira et al., 2015; Simon et al., 2018).

As presently portrayed in the literature, the NE-trending Mineiro belt occupies a ca. 180 km-long area located to southwest of the QF (Figures 1 and 2), bounded to the northwest and northeast by major shear zones referred to as the Jeceaba-Bom Sucesso and Congonhas-Itaverava lineaments, respectively. The Siderian and Rhyacian granitic rocks (dated between 2.47 and 2.10 Ga) are the most outstanding feature of the Mineiro belt. These bodies are grouped into plutons, suites or batholiths by various authors, showing in general calc-alkaline affinity. The available isotopic evidence suggests their formation in processes like oceanic slab subduction and magma underplating, coupled with variable amounts of continental crust assimilation from place to place.

The associated supracrustal assemblages characterize four distinct Paleoproterozoic informal units, namely: the Congonhas-Itaverava, Rio das Mortes, Nazareno and Dores de Campos, although other siliciclastic sequences were locally present (e.g., Ávila et al., 2010, 2014; Teixeira et al., 2015; Valladares et al., 2006; Alkmim and Teixeira, 2017). Dated between 2350 and 2100 Ma by means of zircon provenance studies and crystallization ages of coeval amphibolite rocks, the supracrustal units of the belt share as common traces a volcanosedimentary origin of arc-type settings. For instance, the extensive Rio das Mortes sequence occupies a large area along the portion of belt located between the Jeceaba-Bom Sucesso and Lenheiro lineaments (Figure 2). It encircles plutonic rocks of diverse ages, such as the Resende Costa and Cassiterita orthogneisses, whilst is intruded by the 2.15–2.10 Ga Ritápolis Batholith among other coeval plutons and pegmatite injections (Barbosa et al., 2015). This sequence comprises mainly phyllitic rocks in close association with gondites, as well as quartzites and tholeiitic amphibolites (originally basalts). Minor ultramafic rocks bodies are also present (Ávila et al. 2010). Detrital zircons from a phyllite of the succession indicate a major age mode (82 % of the population) between 2.30 and 2.49 Ga whereas Neoarchean ages constitute a minor component in the population. The youngest detrital grain, dated at 2.16 Ga, constraints the maximum depositional age of the sequence. Two amphibolites ascribed to this unit yielded U–Pb crystallization ages of 2231 and 2202 Ma respectively (Ávila et al., 2012).

The adjoining Nazareno sequence occurs to the south of the Lenheiro shear zone (Figure 2) and consists of abundant mafic and ultramafic rocks, including komatiites with spinifex textures, as well siliciclastic rocks and amphibolites. The latter rocks yield zircon U–Pb crystallization ages of 2223 and 2276 (Ávila et al., 2010). Detrital zircons recovered from two quartzites of the sequence display predominant Paleoproterozoic ages that are significantly older than the maximum depositional age of the Rio das Mortes sequence, suggesting major provenance probably from materials like the Serrinha and Resende Costa-Lagoa Dourada rocks.

Several of Late Paleoproterozoic plutons will be visited during a W-E transverse along the Mineiro belt:

1) the Cassiterita Orthogneiss (2.47-1.41 Ga) which represent the oldest arc-type plutonism so far found in the belt (Barbosa et al., 2019), as well as the adjoining 2.35-2.31 Ga Resende Costa Orthogneiss and the coeval Lagoa Dourada suite (Teixeira et al., 2015; Seixas et al., 2012); both occurring to the north of the Lenheiro shear zone. These two arcs oceanic and formed way from the Archean foreland (Barbosa et al., 2018)

2) the 2.23–2.20 Ga Serrinha suite, composed of plutonic and subvolcanic rocks, attributed to the Rhyacian Serrinha arc, occurring to the south of the Lenheiro shear zone. These rocks are coeval to the eastward Tiradentes suite (Ávila et al., 2010, 2014). The subvolcanic bodies of these two suites intrude the Nazareno metavolcanic-sequence.

3) the Ritápolis arc is exposed in the north of the Lenheiro Shear Zone, comprising orthogneisses of variable compositions and younger plutons with crystallisation ages between 2190 and 2100 Ma. The majority of these plutons intrude amphibolites from the Rio das Mortes metavolcanic-sedimentary sequence (Ávila et al., 2012).

4) The Alto Maranhão suite which age (2131 Ma; Seixas et al., 2013) allows a tentative correlation with the Ritapolis magmatism. Several plutons intruding the supracrustal assemblages in areas southwest of the Congonhas–Itaverava shear zone yield crystallization ages between 2.13 and 2.12 Ga matching the age of the Alto Maranhão suite (Barbosa et al., 2015).

Finally, two Paleoproterozoic metamorphic episodes have been recognized in the Mineiro belt rocks. The first episode (2.25–2.19 Ga) reached low-to medium-grade amphibolite facies conditions. It overprinted the metamafic-metaultramafic rocks of the Nazareno and Rio das Mortes metavolcano-sedimentary sequences and the country rocks. The second episode (2.13–2.10 Ga) reached greenschist to low-amphibolite facies and similarly overprinted the supracrustal rocks and orthogneisses, as well as some granitoid plutons (Ávila et al., 2014).

4. The Quadrilátero Ferrífero (QF) and the Minas Supergroup

The QF, located immediately to the northeast of the Mineiro belt, exposes, besides a complete section of the Archean granitic-greenstone terrane (Teixeira et al., 2017a and references therein), the Minas and Itacolomi sedimentary successions (Alkmim and Teixeira, 2017 and references therein) – Figure 2. Together, these sequences record a passive margin to post-orogenic basin evolution between the Siderian and Orosirian periods (Alkmim and Martins-Neto, 2012). Widely known for its large gold and iron deposits, the QF has been focus of systematic geologic (see Farina et al., 2016; Teixeira et al., 2017a).

This region hosting important iron and gold deposits is characterized by four long ridges underlain by quartzite and banded iron formation (Figure 3), where the Meso- to Neoarchean basement and distinct supracrustal sequences display a complex architecture of as a reflex of two superimposed orogens of Paleo- and Neoproterozoic ages. The structural panorama of the QF is characterized by an association of basement domes and synclines containing the supracrustal units, thereby defining a dome-and-keel geologic architecture (Marshak and Alkmim, 1998; Cutts et al., 2019). For instance, Archean basement occur in domes, showing tectonic contacts with the surrounding metasedimentary rocks akin to the Rio das Velhas and Minas supergroups. From a tectonic point of view, the QF region marks the foreland zone of the Siderian–Orosirian Minas orogen that encompasses the Mineiro belt and the substratum of the eastern reworked margin of the SFC. West-verging thrusting, folding, and strike-slip reactivation of preexistent structures occurred during the Neoproteozoic (580-560 Ma) Brasiliano event respectively (e.g., Dorr, 1969; Marshak and Alkmim, 1988; Farina et al., 2016; Teixeira et al., 2017a; Alkmim and Teixeira, 2017).

The Minas Supergroup, subdivided into five groups and eight formations (Figure 4) comprises a ca. 8000 m-thick succession of continental to marine sedimentary rocks (Dorr, 1969; Alkmim and Martins-Neto, 2012). The rocks of this unit were metamorphosed under greenschist to amphibolite facies conditions. Figure 4 presents the chrono-stratigraphic chart of the Minas Supergroup including the depositional environment interpretation and geochronological constraints (after Alkmim and Martins-Neto, 2012).

The maximum depositional ages of the basal Tamanduá and Moeda sandstones can be estimated at ca. 2.58 Ga, as indicated by the youngest detrital zircon concordant ages (Hartmann et al., 2006). Babinski et al. (1995) reported a Pb–Pb whole-rock isochron age of 2.42 Ga for a few limestone samples from the middle Gandarela Formation. These data indicate that the deposition of the QF guide layer, the Cauê Banded Iron Formation, occurred between 2.58 and 2.42 Ga, reproducing the same age interval of several very large Early Paleoproterozoic banded iron formation deposits around the world. In a similar manner, Cassino (2014) reported an age of 2.45 Ga for the youngest detrital zircon population from a quartzite lens found at the base of the Cauê Formation. Finally, provenance studies for the Piracicaba Group indicated major contribution from mixed Meso- to Neoarchean crustal sources given by the age clusters of 2.80 – 2.90 Ga, 3.21-3.27 Ga and 2.68 Ga (Mendes et al., 2014), in coherence with the local geologic framework.

The uppermost lithostratigraphic unit of the Minas Supergroup, the Sabará Group, is separated from the older and younger sequences by regional unconformities. It probably deposited after a hiatus of ca. 300 Ma given that the Sabará Turbidites contain detrital zircon population that gave an age as young as 2.12 Ga (Machado et al. 1996). Considering the geodynamic scenario with the adjoining Mineiro belt, the Minas Supergroup strata can be interpreted as passive margin to syn-orogenic sedimentary package, deposited during the 2.58–2.42 Ga interval and around 2.10 Ga, respectively. The Itacolomi Group (see Figures 4 and 5) comprises post-orogenic intermontane deposits, accumulated after 2.05 Ga (Machado et al., 1996; Hartmann et al., 2006). Its minimum depositional age is ca. 1.74 Ga which is the documented age of mafic intrusive magmatism in the QF.

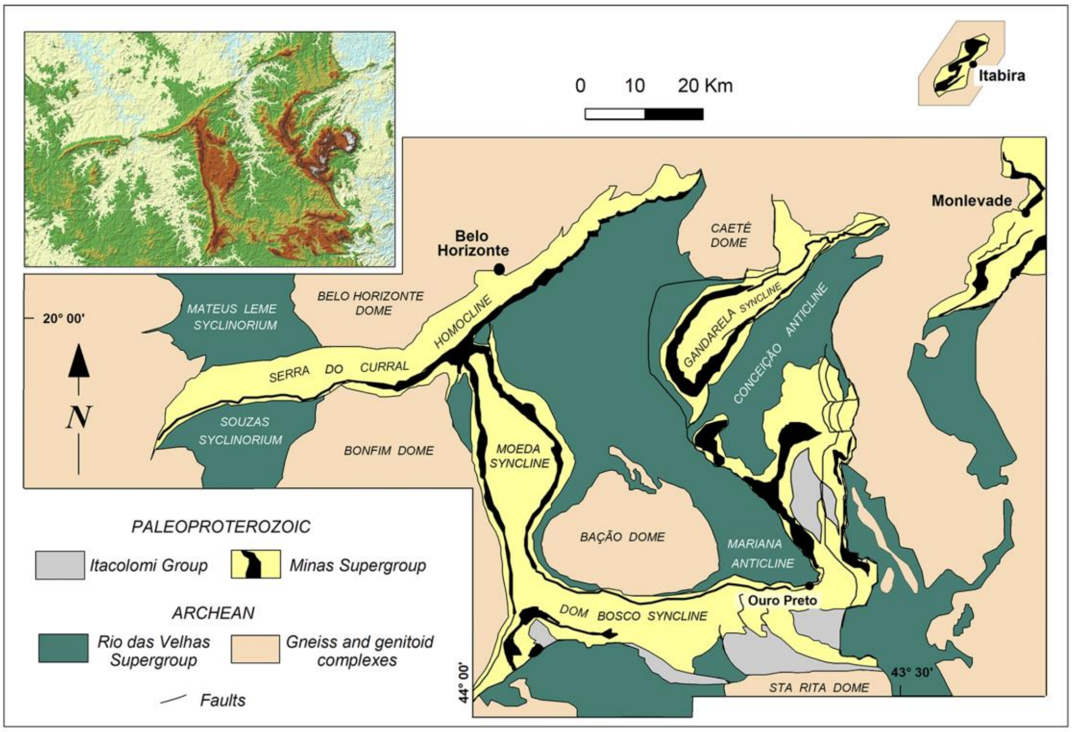

Figure 3: Digital elevation model and simplified geologic map of the Quadrilátero Ferrífero region, emphasizing the main lithological assemblages and the large scale structures (Alkmim e Teixeira, 2017)

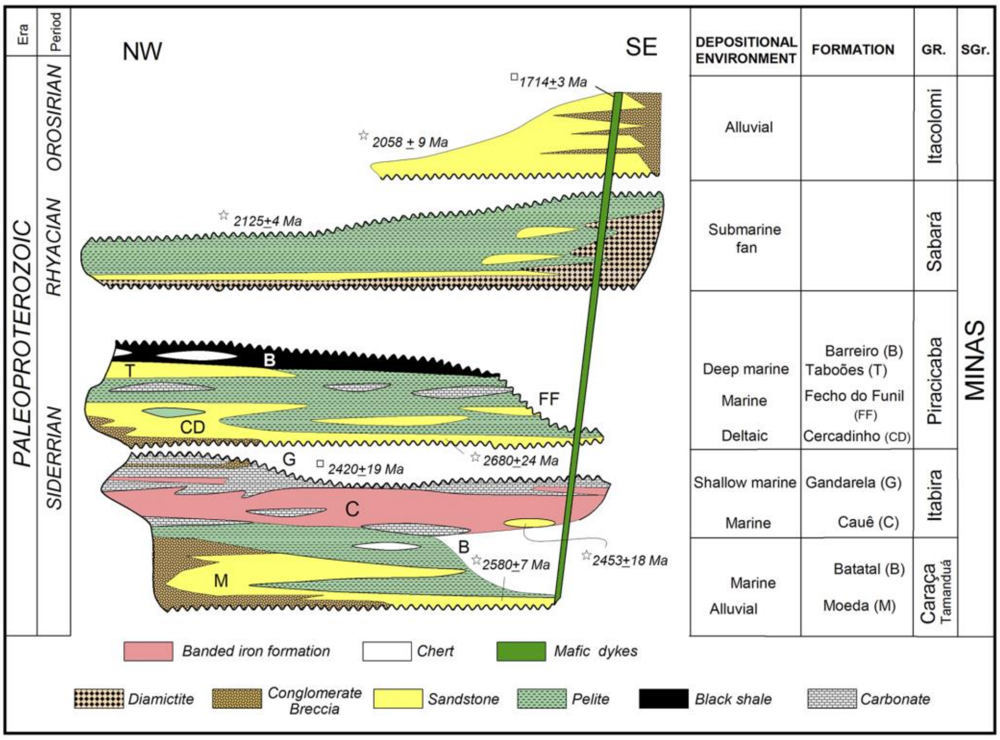

Figure 4: Stratigraphic chart for the Paleoproterozoic units of the Quadrilátero Ferrífero –QF (Alkmim and Teixeira, 2017). Numbers with stars indicate the youngest detrital zircon age; numbers with squares denote deposition or crystallization ages.

Day 01 (14 August) – Granitoid plutons and siliciclastic sequence of the Mineiro belt, (Saída de Lavras e volta para Lavras) (Overnights in Lavras: 13 and 14)

The stops planned for this day focus different granitoid plutons and the siliciclastic sequence of Serra do Ouro Grosso of Late Paleoproterozoic age. These outcrops belong to the western portion of the Mineiro belt, and are located in the vicinities of the Itutinga town and Camargos dam, ca. 70 km to the east from the Lavras town (overnight stay). See Figure 5 for a geologic perspective of the selected units to be visited.

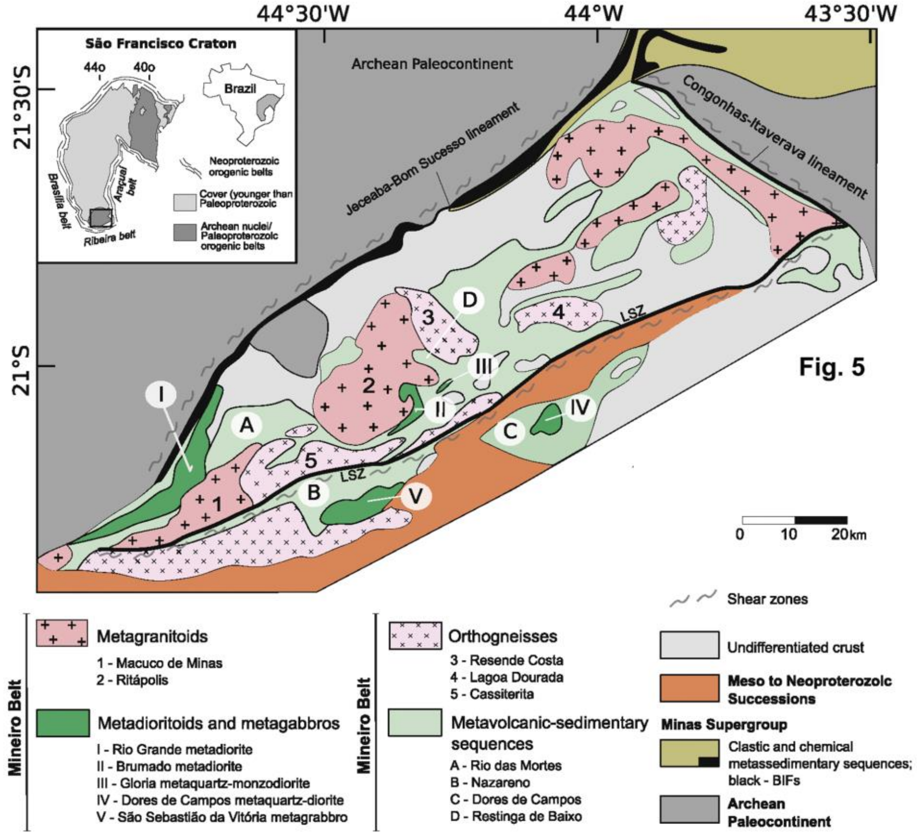

Figure 5: Geologic framework of the Mineiro belt located in the southern portion of the São Francisco Craton. Cardoso et al. (2019).

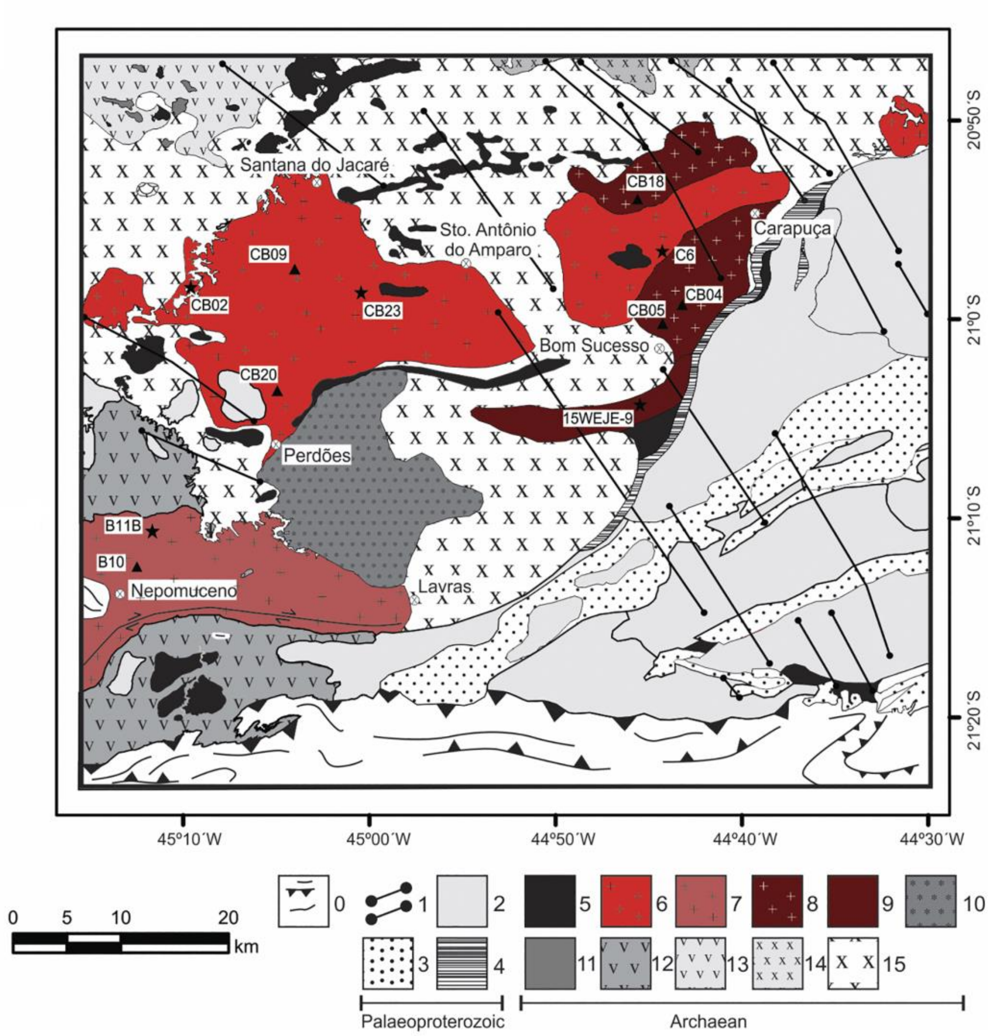

Figure 6: Geological outline of the southern portion of the São Francisco Craton (Moreno et al., 2017) showing the Neoarchean-aged Bom Sucesso pluton (in purple) to be visited in Stop 1 (close to the town of Bom Sucesso), which is transect by a NW-SW trending mafic dike swarm. Neoproterozoic belt: (0) Andrelândia-Carandaí sequences (1). Paleoproterozoic units: (1) Mafic dike swarms, (2) Diorite-granitoid crust, (3) Supracrustal sequences, (4) Minas supergroup (2.6-2.1 Ga). Archean units: (5) Ribeirão dos Motas meta-mafic-ultramafic unit, (6) Rio do Amparo pluton, (7) Lavras pluton, (8) **Bom Sucesso pluton**, (9) Porphyritic biotite orthogneiss, (10) Ribeirão Vermelho charnockite, (11) Sillimanite-quartzite, (12) Campos Gerais gneiss, (13) Candeias gneiss, (14) Claudio gneiss, (15) Fernão Dias gneiss. Sampling: black stars (U-Pb analysis), black triangles (Sm-Nd analysis) and black circles (U-Pb and Sm-Nd analysis).

Stop 1 – Itutinga Orthogneiss.

The hill exposes a scenery panorama of the western portion of the Mineiro belt, dominated by late Paleoproterozoic granitoid plutons and the adjoining Serra do Ouro Grosso quartzite. The outcrop is composed of a monzogranitic orthogneiss with a U-Pb zircon crystallization age of 2229 ± 12 Ma. This age is identical to the ages of the Serrinha and Tiradentes suites occurring to the east. The Itutinga pluton shows intrusive relationships with the Nazareno metavolcanic-sedimentary sequence and the country rocks given by the xenoliths of metamafic rocks and gneiss, respectively. The Nazareno amphibolites yielded U-Pb zircon ages of 2267 ± 14 Ma and 2223 ± 4 Ma. The orthogneiss presents a NE-SW trending foliation highlighted by preferential orientation of feldspar crystals and biotite aggregates, whilst showing isoclinal folding with axial planes. This pluton underwent a metamorphic overprint at ca. 2150 Ma that could be correlated to a regional (second generation) deformation/metamorphic phase of the Mineiro belt. Shear zones (mainly sinistral; NE-SW strike) characterized by a mylonitic foliation are common in the outcrop, and similarly transect nearby granitoid rocks. These shear zones could be tentatively related to a Neoproterozoic (Brasiliano aged) overprint affecting the southern fringe of the SFC in connection with the marginal evolution of the orogenic belts of West Gondwana.

Stop 2: Represa de Camargos Metagranite.

Geologic inferences indicate the Mineiro belt hosts distinct batholiths that are distinguished in terms of composition and ages (e.g., Represa de Camargos, Morro do Resende, Ritápolis, Macuco de Minas granitoids). This stop focuses on one of these plutons named Represa de Camargos (Fig. 5), occurring here as boulders.

The Represa de Camargos batholith occurs in the southern block of Lenheiros structure and has a large areal extent to the west of the 2.23–2.20 Ga Serrinha and Tiradentes suites and the adjoining Nazareno supracrustal sequence. It is intrusive into the Nazareno sequence and the Itutinga Orthogneiss, as given by coherent xenoliths of mafic gneiss and amphibolite rafts. Mafic enclaves are also present. This pluton comprises granitic to monzogranitic orthogneiss and metatonalite and associated granitic dykes. The selected outcrop shows pristine igneous texture, and may exhibit a slightly foliation or massive structure. U-Pb isotopic analyses are available for two rocks from the batholith. The first one regress to yield an upper intercept age of 2170 ± 36 Ma (MSWD = 2.4) and a lower intercept of ca. 500 Ma with a large error whereas the second one give an age of 2171 ± 24 Ma (MSWD = 1.2) with a lower intercept at ca. 730 Ma. The available Nd and Hf isotopic constraints can be explained by mechanisms like depleted melts that were variable contaminated by mixed pre-existent crust (Barbosa et al., 2015). According to these authors the Represa de Camargo pluton is part of an accretionary episode considering the evolution of the Mineiro belt dated between 2.17 and 2.15 Ga.

The geochemical data indicate that this group of rocks belong to the calc-alkaline series, are metaluminous to peraluminous and originally I-type. Based on chondrite and primitive mantle normalized diagram, among other geochemical evidences, these rocks (2.17–2.15 Ga) show mostly negative Eu anomalies, negative Ti, Nb, Sr and P, and some positive Pb anomalies. This Group is interpreted to have originated by partial melting of LREE enriched-MORB source with crustal contamination/assimilation in agreement with the isotopic evidences.

Stop 3: Interaction between the Represa de Camargos metagranite and the Itutinga Orthogneiss.

After a short walk we focus on a selected exposure of the eastern edge of the batholith in the vicinity of the Camargos Dam, where the metagranite locally crosscuts the country rock (weathered orthogneiss). The outcrop exhibits pegmatite injections and the regional NE-SW strike shear zones (Neoproterozoic?) as similar as the Itutinga Orthogneiss.

Stop 4: Serra de Ouro Grosso siliciclastic sequence

This outcrop belongs to a low greenschist facies succession composed of quartzite and conglomeratic quartzite. These rocks constitute an isolated body with approximately 200 m of thickness cropping out at the Serra do Ouro Grosso ridge. The overall structure is defined by a homocline of low-grade sedimentary rocks that lie on Paleoproterozoic migmatitic gneisses such as the nearby Itutinga Orthogneiss, as well as greenstone-like metavolcanic-sedimentary successions (Nazareno sequence) and metagranitoids.

First provenance studies in the green-mica quartzite from the main ridge indicated that the detrital zircon populations derived from erosion of sources as old as 2.5-2.8 Ga, with only one grain showing a Paleoproterozoic age (2245 ± 83 Ma) (Valladares et al., 2004). A more recent study (Teixeira et al., 2012) was conducted in a mylonitic quartzite located close to the Itutinga Orthogneiss. The zircon population indicated a young mode at 2172 ±17 Ma (6% from 91 grains), interpreted as the maximum depositional age. This value contrasts with the age of the Nazareno supracrustal sequence, given by the U-Pb dating of amphibolites (2223 and 2276 Ma). On the other hand, the maximum age of deposition of the Serra do Ouro Grosso sequence is consistent with the age of the nearby Represa de Camargos pluton. Combined with the mature composition of the sediments and the provenance studies we suggest a mixed derivation from Archean and Late Paleoproterozoic sources. In particular, a fast exhumation of this pluton, as the proximal source is apparent, from which the youngest detrital population derived. Recent structural studies suggest that Serra do Ouro Grosso sequence could be part of a Neoproterozoic framework.

Stop 5: Macuco de Minas metagranite

This metagranite constitutes a batholith that is bounded to the south by the Lenheiros shear zone, whilst intrusive into the Rio das Mortes sequence, given the xenoliths of amphibolitic rocks. Its rocks are medium- to coarse grained and may be porphyritic (fenocrystals of microcline). In general., the primary (relict) textures are superimposed by metamorphic features like foliation of the biotite due to the presence of shear zones. Quartz, microcline, albite and biotite are the main minerals. Allanite, zircon, titanite, monazite, thorite, thorogumite, ilmenite and apatite are the accessory minerals. Secondary minerals are: chlorite, epidote, zoisite and clinozoisite.

The available SHRIMP U-Pb ages for the Macuco de Minas rocks yielded roughly similar crystallization ages in the range 2126 ± 21 to 2095 ± 12 Ma. Neoarchean inherited zircons are also present in the Concordia plots, which is consistent with a crustal component in the magma genesis as also suggested by the negative $\varepsilon_{Hf(t)}$ and $\varepsilon_{Nd(t)}$ values (Barbosa et al., 2015). Potential candidates for the crustal contaminants should be the Archean continental crust of the SFC, as suggested by the isotopic constraints. From a tectonic perspective the compiled U-Pb data demonstrate the significant role of a recurrent plutonism in the 2.17-2.11 Ga time interval., representing the ultimate orogenic phase of the Mineiro belt. The geochemical data indicate that this particular plutonic rock belongs to the calc-alkaline series, are metaluminous to peraluminous and originally I-type. This group of rocks shows roughly REE pattern and negative Ti, Nb and P anomalies. This denotes a combination of magmatic process as fractional crystallization and contamination/assimilation from different crustal materials.

Stop 6 (depending of the time-schedule): Basement of the Southern São Francisco Craton.

This short stop will examine the geologic relations between the Neoarchean Lavras Orthogneiss and a slightly younger granitic aplite. Unpublished U-Pb dating will be discussed in the outcrop.

Day 02 (15 August) – Archean basement of the São Francisco Craton, the Bom Sucesso range and the granitoid plutons of the Mineiro belt
(Overnight in São João de Rei)

The stops planned for this day focus on the Neoarchean foreland (proto-São Francisco Craton) of the Paleoproterozoic Mineiro belt, including its northern tectonic bound highlighted by the Bom Sucesso supracrustal sequence. Different granitoid plutons of the Mineiro belt will be also visited on the way to the historical town of São João del Rey (overnight stay). See Figures 5 and 6 for a geologic perspective of the selected units to be visited.

Leave hotel in Lavras at 8:00 horas. Take road Ijaci-Bom Sucesso on the road junction to UFLA. Duration: 30 minutes.

Stop 1: Bom Sucesso metagranite.

A Neoarchean High-K metagranite crops out in the vicinity of the town of Bom Sucesso with an exposure of ca. 100 km^2. These plutons were studied in detail by Moreno et al. (2017), and the main results are presented below. The selected outcrop comprises several in-situ blocks, showing an equigranular rock with igneous texture and xenoliths. The Bom Sucesso body is intruded by meta-mafic dikes.

The Bom Sucesso granite consists of two facies: a gray-bluish homogeneous, medium-grained biotite syenogranite (Bom Sucesso I) and a porphyritic gray biotite monzogranite (Bom Sucesso II) that appears in the eastern part of the body. The Bom Sucesso I facies consists of medium-grained, rarely fine-grained, equigranular to inequigranular monzogranites to syenogranites, which are composed of alkali feldspar (mostly microcline) and subordinate perthite, quartz, plagioclase and biotite. The accessory assemblage consists of titanite, allanite, magmatic epidote included in biotite and plagioclase, zircon, apatite and Fe-Ti oxides. Plagioclase is commonly altered to sericite. The Bom Sucesso II facies consists of porphyritic monzogranites with coarse-grained alkali feldspar and plagioclase phenocrysts set in a medium-grained matrix of plagioclase, alkali feldspar, quartz and biotite. Small euhedral to subhedral plagioclase and quartz crystals can be found as inclusions in alkali feldspar. The accessory minerals are epidote, titanite, zircon, apatite and Fe-Ti oxides.

SHRIMP analyses for a highly porphyritic biotite orthogneiss (facies I) yielded a crystallization age of 2696 ± 6 Ma, whereas the inherited zircons gave weighted $^{207}Pb/^{206}Pb$ mean age of 2729 ± 5 Ma along with one zircon grain of ca. 2789 Ma. The latter age is similar to the TIMS U-Pb age of 2753 ± 11 Ma reported by Campos and Carneiro (2008) for a sample of the Bom Sucesso pluton in its southern border. These particular ages may be assigned to the country rock, given the crystallization age of the orthogneiss facies 1. The Sm-Nd data disclosed negative $\varepsilon_{Nd(t)}$ as low as -3.6.

The compositions of the Bom Sucesso granites generally straddle the boundary between magnesian and ferroan compositions, all of them plot in the compositional field of A-type rocks. It is slightly peraluminous with subordinate metaluminous composition. The highly porphyritic biotite granitoids from southern Bom Sucesso body reported by Campos and Carneiro (2008) show a clear different composition; they are strongly peraluminous and magnesian, high-silica granite. Chondrite normalized REE-patterns are enriched in LREE compared to HREE for the Bom Sucesso rocks, most samples showing a negative Eu anomaly.

Stop 2: Metadiabase dike.

The outcrop examines a peculiar dike which is intrusive into the Bom Sucesso metagranite. This dike belongs to a mafic swarm that strikes N20º-40ºE, composed of porphyritic and equigranular types. This swarm, occurring in the northwest region of the Bom Sucesso and Ibituruna ridges, crosscuts the Archean basement of the São Francisco Craton, but not the Bom Sucesso range which includes metasedimentary strata as young as 2.6 Ga according to provenance studies (Neri et al., 2013). No direct age is available for this swarm.

The metadiabase dykes have similar mineralogy, represented by plagioclase, amphibole, ilmenite, magnetite and apatite, and were subdivided into porphyritic and equigranular. The porphyritic metadiabase dykes are rare and may reach 7km in length. They present bytownite phenocrysts, which vary in size, shape and proportion. Tabular grains of labradorite predominate in the matrix. The equigranular metadiabase dykes are abundant, and exhibit fine to medium granulation and vary from isotropic to strongly foliated. The plagioclase corresponds to andesine and labradorite and was subdivided chemically into two groups. The first is more enriched in most elements, with slight REE fractionation and incipient negative Eu anomaly. The second group is more depleted in all elements and exhibits horizontalized ETR pattern. The porphyritic metadiabase and the metadiabase dykes are chemically similar and may be cogenetic, showing a tholeiitic composition.

Stop 3: BIF and phyllite; Bom Sucesso Range

The Bom Sucesso-Jeceaba lineament represents a NE-striking left-lateral shear zone, which affects the cratonic basement and the basal units of the Early Paleoproterozoic Minas Supergroup. In the Bom Sucesso region, this lineament hosts interlayered Archean ultramafic rocks and Early Paleoproterozoic metasedimentary strata, marking the tectonic boundary between the ancient foreland and the plutonic and metavolcanic-sedimentary rocks akin to the Mineiro belt. The metassedimentary strata (BIF, phyllite, quartzite, garnet-biotite schist) is correlative to the Minas Supergroup (2.6-2.1 Ga) occurring to the east in the Quadrilatero Ferrífero (QF), according the geologic correlations and detrital provenance study. The basal schist in the Bom Sucesso sequence yielded a maximum age of deposition of ca. 2603 Ma that matches that of the basal Caraça Group of the Minas Supergroup.

The Bom Sucesso BIF has predominant mineralogy formed by bands of iron oxide (maghemite) and amphibole; it is interlayered with discontinuous ferruginous dolomite lenses and it grades upwards to a ferruginous metapelitic layer at the top of the unit. The geochemical signature of the BIF is characterized by positive anomalies of Eu, Y and La, relative enrichment of heavy Rare Earth Elements (REE) and absence ofa negative Ce anomaly, analogous to the itabirites of the Itabira Group of the Minas Supergroup in the QF. The mineral assemblage of the other metasedimentary strata indicates contact metamorphism associated with alkaline metasomatism under sillimanite-alkali-feldspar facies, generated by the emplacement of the Tabuões Granite at ca. 2.0 Ga (e.g., Neri et al., 2013; Alkmim and Teixeira, 2017 and references therein).

Stop 4: Rio Grande Metadiorite

The Rio Grande metadiorite (Barbosa et al., 2015; Cardoso et al., 2019) presents an age similar to the nearby Macuco de Minas pluton, both occurring in the SW portion of the Mineiro belt. These two plutons are tectonically ascribed to the Rhyacian Ritápolis arc among other rock units occurring to the north of the Lenheiros structure (see Fig. 5). Notably, these two plutons show similar ages with the Alto Maranhão suite occurring in the eastern fringe of the Mineiro belt, which will be focused in the last day of the field trip.

The metadiorite consists of diorites, quartz-diorites, and tonalites composed of hornblende, plagioclase, and variable proportion of quartz. Mesocratic diorites and tonalites are concentrated in the southern region of the pluton, whereas hololeucocratic tonalites with higher quartz content occur in its northern portion. These rocks are crosscut in places by granitic dykes and pegmatites. Shear zones are also present (Cardoso et al., 2019). A metatonalite sample from the Rio Grande pluton yielded U-Pb ages from ± 24 to 2102 ± 33 Ma. The inherited zircon cores in one of the samples yielded a cluster in the Concordia at 2331 ± 9 Ma. The latter age suggests the presence of crustal components such as the Siderian Resende Costa Orthogneiss that occurs in the neighborhoods. Another zircon core from the Rio Grande sample gave a significantly older concordant age of 2785 ± 6 Ma. However, the slightly negative $\varepsilon_{Nd(2.1\ Ga)}$ values and low $^{87}Sr/^{86}Sr_{(2.1\ Ga)}$ ratios point out metasomatic-like derived magma. The Rio Grande pluton contains autoliths of hornblendite, ultramafite and metagabbro. From a chemical point of view these rocks show decrease in MgO, Fe_2O_3 total., and CaO contents with increasing SiO_2 that is consistent with fractional crystallisation. The calc-alkaline signature along with negative Nb, Ta, P and Ti anomalies suggest a magmatic arc setting.

Stop 5: Rio Grande pluton and its host rocks.

In this particular outcrop the geologic interaction between the country rocks and lithotypes of the Rio Grande pluton will be discussed. The metadiorite and tonalite rocks present igneous texture and entrain xenoliths (clynopyroxenite, hornblende gneiss and hornblendite) of the Rio das Mortes metavolcanic-sedimentary sequence. The hornblendite xenoliths are angular to round and can occur as lenses paralleling the Rio Grande metadiorite foliation. The hornblendite contains felsic veins of dioritic-tonalitic composition; at the contact of these lithotypes, we identified fine to medium-grained mesocratic hybrid rocks with a dioritic composition containing plagioclase and Mg-hornblende. The Clinopyroxenite crops out as in situ blocks and is spatially restricted (Cardoso et al., 2019).

U-Pb dating of the amphibolites gave crystallisation ages between 2231 ± 5 Ma and 2202 ± 11 Ma (Ávila et al., 2012. Barbosa et al., 2015). The Rio das Mortes supracrustal sequence partially encompasses the Rio Grande pluton; the metaultramafic rocks and amphibolites of this sequence predominate in the west and south, while phyllites and gondites are the main rocks in the east.

Day 03 (16 August) – Plutons of the Ritápolis Arc and the Serrinha and Tiradentes suites – Mineiro belt.

(overnight in São João del Rei)

The stops planned for this day focus on one of the largest Paleoproterozoic batholiths, namely Ritápolis (Fig. 5), among other plutons of the Ritápolis Arc (2.15-2.11 Ga). Additionally, the excursion traverses the plutonic and subvolcanic rocks akin to the Serrinha and Tiradentes suites that are tectonically associated to the evolution of the Serrinha oceanic arc at ca. 2.23- 2.21 Ga. See Figure 5 for a geologic perspective of the selected units to be visited.

Stop 1: Ritápolis metagranitoid and metabasic dike. Ritápolis Arc (Duração: 30 a 50 minutos).

The Ritapólis metagranitoid (2.15-2.12 Ga) occurs as a large batholith in the central part of the Mineiro belt in the northern block of the Lenheiros shear zone (Fig. 5). It is partially encompassed by the Rio das Mortes supracrustal sequence where the xenoliths of amphibolite and metasedimentary rocks determine the intrusive character of the batholith. The northeastern edge is in fault contact with the 2.35 Ga Resende Costa orthogneiss (Barbosa et al., 2015; Teixeira et al., 2015). The region hosts numerous Sn-Ta-Hf-Li bearing pegmatite bodies that are genetically and spatially related to the Ritápolis batholith.

The metagranitoid is composed of foliated leucogranites and tonalites that occur in different macroscopic facies (fine, medium, coarse grained) that usually show magmatic flow texture and xenoliths of distinct country rocks (Barbosa et al., 2015). The contact between the medium-grained equigranular facies and coarse-grained facies is cut by leucocratic pegmatite dikes. Amphibolite xenoliths are also common in the Ritápolis batholith. The available geochemical data indicate that the Ritápolis rocks are calc-alkaline, peraluminous to metaluminous (Teixeira et al., 2014; Barbosa et al. 2015 and references therein).

From an isotopic point of view, the Ritápolis rocks can reach highly negative $\varepsilon_{Nd(t)}$ values (−6.7 to −1.0), indicating a predominantly crustal component in their genesis, as similarly observed for the Rio Grande metadiorite (Cardoso et al., 2019). This is also in agreement with the predominantly negative $\varepsilon_{Hf(t)}$ signature of the metagranitoid, determining that assimilation of reworked zircons from heterogenous sources took place in the host magma. Therefore, the Ritápolis arc presents a crustal signature akin to an active continental margin setting

Stop 2: Brumado metadiorite. Ritápolis Arc. (Duração: 30-50 minutos).

The Brumado metadiorite crops out near the Ritápolis city with an estimated area of 30 km^2 (Fig. 5). Its northern and western border is in contact with the Ritápolis metagranitoid, and in the south and east with the Rio das Mortes metavolcanic-sedimentary sequence (Cardoso et al., 2019 and references therein). Pgmatites and granitic dikes correlative to the coeval Ritápolis metagranitoid are also present, whereas the Brumado pluton contains hornblendite autoliths and xenoliths from the Rio das Mortes sequence.

According to Cardoso et al. (2019) the Brumado pluton comprises diorites, quartz-diorites, and tonalites that are divided into three distinct facies. Two of them are equigranular and divided into medium-grained and medium- to fine-grained facies. The third facies is microporphyritic with 0.5 to 1.5mm-long plagioclase phenocrysts. The composition and facies are directly correlated: medium-grained facies concentrates diorites, quartz-diorites, and tonalites while in the medium to fine-grained facies the tonalitic terms predominate. The microporphyritic facies contains quartz-diorites and tonalites. Diorites and quartz-diorites present the highest concentration of amphibole and lowest of quartz compared with tonalites.

The age of the Brumado metadiorite is 2124 ± 6 Ma, whereas the available $\varepsilon_{Nd(2.1\ Ga)}$ and coupled $^{87}Sr/^{86}Sr_{(2.1\ Ga)}$ isotopic parameters suggest the important role of crustal components in the magma genesis. Its calc-alkaline signature along with negative Nb\\Ta, P, and Ti anomalies indicate an arc-type dioritic magmatism which is the youngest among other plutonic rocks (e.g., Rio Grande pluton) akin to the Ritápolis continental arc.

From the available geochemical data of the Brumado metadiorite, trace elements and REE contents show homogeneous behaviour. Brumado rocks contain higher values of Cr and Rb and lower Sr than the Rio Grande rocks. The magmatic differentiation is evidenced from depletion of MgO, FeO, and CaO with increasing SiO_2 in Harker diagrams; the slightly negative Eu anomaly suggests plagioclase, together with amphibole, controlled fractional crystallization of the Brumado metadiorite.

Stop 3: Cassiterita Orthogneiss. Cassiterita Arc.

The Cassiterita Orthogneiss was studied in detail by Barbosa et al. (2019). This is the oldest pluton so far found within the Mineiro belt. The Cassiterita pluton occupies ca. 300 km^2 in the western portion of the Mineiro belt southbounded by the ENE- to E-W-trending Lenheiro shear zone (Fig. 5). It is encircled by rocks of the Rio das Mortes sequence (Ávila et al., 2010). Some outcrops of the Cassiterita Orthogneiss exhibit an anastomosing foliation (~160/60) that dips to south and southwest (Vasconcelos, 2015), whereas local E-W millimetric- to metric-scale shear zones and mylonitization is present. Granitic dikes and pegmatites crosscut the Cassiterita rocks and are likely related to the nearby Ritápolis batholith.

The Cassiterita Orthogneiss yielded the oldest crystallization ages so far found in the Mineiro belt: 2468 ± 8 and 2414 ± 29 Ma. Zircon overgrowths are dated at 2024 ± 54 Ma, matching the timing of the regional metamorphic overprint in the Mineiro belt. The studied rocks exhibit low to medium grade metamorphism. They show peraluminous; high-Al_2O_3 geochemistry and tonalitic and granodioritic composition akin to TTG suites. The trace element patterns point that partial melting and fractional crystallization operated in the genesis. The positive $\varepsilon_{Nd(t)}$ values and coupled low $^{87}Sr/^{86}Sr_i$

isotopic signatures suggest a LREE and/or LILE LILE-enriched MORB mantle source. The zircon variable $\varepsilon_{Hf(t)}$ values indicate crustal assimilation operated during magma genesis.

From a tectonic point of view, the orogenic event represented by the Cassiterita arc is roughly coeval with the (chemical) sedimentary infill of the passive basin (Minas Supergroup), previously dated at ca. 2.42 Ga (Babinski et al., 1995). The age matches suggest a geodynamic link between the oceanic arc magmatism and penecontemporaneous basin infill in the continental margin.

Stop 4: Lajedo Orthogneiss. Serrinha Arc.

Lajedo granodiorite belong to a voluminous felsic-mafic plutonism, tectonically linked to Rhyacian magmatic evolution of the Serrinha Arc (2.23–2.20 Ga), Mineiro Belt (Ávila et al., 2010) – See Figure 2. The Lajedo granodiorite is located south of the Lenheiros shear zone and cuts the metamafic rocks of the Forro peridotite – pyroxenite and mafic and intermediate rocks of the Nazareno greenstone belt (see Figs. 2 and 5), as evidenced by amphibolite xenoliths from the latter unit (Teixeira et al., 2008). The Lajedo rocks are strongly foliated in the NEE/SWW direction and fine to medium-grained, and have granodioritic to tonalitic composition.

The Lajedo modal composition is consistent with granodioritic and tonalitic compositions. It indicates a predominantly peraluminous composition and calc-alkaline character. The crystallization age of the Lajedo granodiorite is 2208 ± 26 Ma. The Nd/Sr characteristics of the Fé and Lajedo plutons are consistent with mixtures of enriched mantle (EMI-type), DMM and crustal components during magma genesis in an arc setting with mafic protoliths during magma genesis. The selected outcrop exhibits a subvolcanic felsic dike from the Serrinha suite. From a petrographic point of view, the Lajedo orthogneiss presents quartz, plagioclase, biotite, microcline, epidote, whereas sphene, allanite, zircon, opaque minerals, white mica and chlorite are the accessory minerals. Plagioclase is usually clouded by epidote and white mica, as a result from low grade metamorphism. The texture is dominantly inequigranular xenoblastic.

Stop 5: Santo Antônio felsic-mafic rocks (Tiradentes Suite). Serrinha Arc (Duração: 60-90 minutos).

The Tiradentes Suite (Ávila et al. 2014) and the coeval Serrinha Suite (Ávila et al., 2010 comprise relatively small plutons intruding volcanosedimentary sequences in areas to the south of the Lenheiro shear zone (Fig. 2). The Tiradentes Suite which is focused in this stop includes well-preserved mafic andesites, dacites, granophyres and intrusive tonalites with primary texture, outcropping along a 500m x 10 km strip overlaid by Mesoproterozoic quartzites. The mafic andesites form extensive (weathered) exposures with local coeval dioritic dikes; the subvolcanic intrusions (stock and apophyses) represented by fine- to medium-grained equigranular tonalite bearing microgranular mafic andesite enclaves; the metric-scale dacitic-granophyric dikes and pegmatites crosscut the mafic andesites.

The samples of Tiradentes Suite vary from metaluminous to peraluminous like the Serrinha rocks; they are enriched in alkaline elements and follow the trondhjemitic differentiation trend. Most samples are compatible with low-Al_2O_3 trondhjemites. The high content of HREE, coupled with the observed incipient negative Eu anomaly and high Y values suggest the participation of hornblende and garnet in the partial melting. Ti, P, Nb and K negative anomalies and Ba and Zr positive ones are consistent with geochemical patterns of magmatic arcs.

Collectively, the Serrinha and the Tiradentes suite occurring to the east give crystallization ages between 2227 ± 22 and 2204 ± 11 Ma. They are composed mainly of sub-alkaline and calc-alkaline, metaluminous to peraluminous tonalites and granites. The Sm–Nd T_{DM} ages between 2.6 and 2.3 Ga and slighty positive to negative $\varepsilon_{Nd(t)}$ values attest the juvenile character of these two magmatic units as an intra-oceanic arc (Ávila et al., 2010, 2014).

Day 04 (17 August) – Resende Costa Orthogneiss and Lagoa Dourada suite, the Alto Maranhão suite and the Minas Supergroup (Quadrilátero Ferrífero) (Overnight in Belo Horizonte)

The last day of the field trip traverses two roughly coeval plutons, namely the Resende Costa and Lagoa Dourada (ca. 2.35 Ga), the Alto Maranhão suite (2.13 Ga), along a transverse in the eastern portion of the Mineiro belt. The Minas Supergroup (Serra da Moeda profile), located at adjoining Quadrilátero Ferrífero, will be visited at the end of this day.

Outcrops in the Mineiro belt:

Stop 1: Resende Costa Orthogneiss

The Resende Costa Orthogneiss (Teixeira et al., 2015) and associated rocks have an exposition of ca. 200 km^2 (see Figs 2 and 5), and crop out not far from the coeval Lagoa Dourada suite. This lithostratigraphic unit was studied in detail by Teixeira et al. (2015). The main aspects of this study are addressed below.

The Resende Costa Orthogneiss shows a tectonic contact (NW-SE trending brittle fault) with the Ritápolis batholith (215-2.12 Ga), and is encircled by the 2.23-2.20 Ga Rio das Mortes supracrustal sequence. Folded and unfolded granitic veins and aplites as well as pegmatites (up to 2.5m in width) crosscut the Resende Costa Orthogneiss. The field aspects indicate that the Resende Costa orthogneiss occurs as xenoliths in several nearby granitoid plutons, such as the Ritápolis batholith. The orthogneiss presents two co-magmatic mineralogical facies: a medium- to coarse-grained and locally a fine- to medium-grained facies. Typical outcrops have folded bands of tonalitic gneiss and amphibolite overprinted by two NW-trending deformational phases with high dipping foliation. The tonalitic gneiss is fine grained and shows alternate bands rich in quartz + plagioclase, and in biotite + hornblende + plagioclase, respectively. Both bands are composed of plagioclase, quartz, biotite, hornblende, epidote, zircon, allanite, apatite, sphene, opaque minerals, clinozoisite, zoisite, sericite and chlorite.

Detailed zircon U-Pb constraints and geochemical data of the Resende Costa Orthogneiss and coeval rocks unravel the Siderian history for the Mineiro belt in the time interval 2356 to 2311 Ma. Coupled Nd-Sr isotopic constraints indicate that the studied rocks probably derived from a short-lived, slightly depleted source subjected to minor crustal assimilation; therefore, pointing to an unequivocal juvenile crustal segment (>250 km^2) within the Mineiro belt framework. In particular, the negative and positive zircon $\varepsilon_{Hf(2.35Ga)}$ values point to a plausible mechanism of subducted material during the evolution, as similarly evidenced by the geochemical data (e.g., Dy/Dy* variations). The Resende Costa and the nearby Lagoa Dourada Suite (Seixas et al., 2014) represent a juvenile event that followed the origin of the Cassiterita Arc.

Stop 2: Lagoa Dourada suite

Geologic highlights by L. R. Seixas (guide leader)

This was the first ever juvenile Siderian granitoid suite described in the southern São Francisco craton. The finding brought light on whatever was known as a "plate tectonic shutdown" and or as a "magmatic lull period" on Earth's history (Partin et al., 2014; Pehrsson et al., 2014; Spencer et al., 2018 and references therein). The Lagoa Dourada suite (Seixas et al., 2012) is composed of metaluminous to slightly peraluminous, low-Mg#, low-K and high-Ca, biotite-hornblende to hornblende-biotite (± garnet-magnetite) tonalites and biotite trondhjemites, varying from ~62 to 73 wt.% SiO2. The trace element geochemistry is characterized by mildly depleted Nd isotope compositions [εNd(t) = +1.0 to +2.1], low large-ion-lithophile element (LILE, i.e., Rb, Ba, and including the highly incompatible Th) and heavy Rare Earth element (REE, Yb < 1.00 ppm) contents. The suite is also characterized by high Sr/Y ratios (≥41 up to 81), high $(La/Yb)_N$ ratios (≥12 up to 46), and positive Eu/Eu* anomalies. These data are consistent with the derivation of the suite from a tholeiitic metabasaltic source, which had a short crustal residence time prior to melting. The chemical diversity of the suite is attributed mainly to the fractional crystallization of hornblende and accessory minerals, coupled with plagioclase accumulation in the tonalitic parental melt. Emplacement of new batches of magma could explain samples which diverge from the proposed liquid line of descent of the suite (Seixas et al., 2012).

The Lagoa Dourada Suite has whole rock Sm-Nd analyses es for the Lagoa Dourada suite gave TDM ages between 2400 and 2500 Ma, which implies short crustal residence time, with significant positive εNd (2350 Ma) between +1.0 and +2.1 and εHf (2350 Ma) up to +5.6. The Lu-Hf TDM ages range between 2370 Ma and 2440 Ma, defining a depleted mantle source. Noticeably, Lu-Hf analyses of zircons from this suite yielded a crustal residence time as short as 15 - 20 Ma. The generally shorter crustal residence time of the Lagoa Dourada Suite suggests a relatively thinner and mafic crustal segment during the periods of magma emplacement. In contrast, the Resende Costa Suite has older Hf TDM ages in ca. 2350 Ma grains, ranging from 2400 Ma to 3400 Ma and one grain has εHf(t) as low as -9.0. However, whole rock εNd (2350 Ma) between +1.1 and+3.2 and the εHf (2350 Ma) of the spatially related Restinga de Baixo amphibolite (mostly between +4 and +7) suggests a juvenile signature (Moreira et al., 2018). The selected outcrop for the excursion is referred to LD3 site in Seixas et al. (2012, 20°52'00.0"S 44°02'58.1"W, see google maps reference). It is a ca. 60 × 60 m natural water-washed horizontal exposition of fresh rocks, with a well foliated biotite-hornblende tonalite (± magnetite, bring your hand magnet) intruded by at least three generations of dikes.

Stop 3: Alto Maranhão suite

A window on the processes acting upon the mantle wedge has been favored by the ongoing research over this sanukitoid-type tonalitic suite (Seixas et al., 2013; Moreira et al., 2018; Moreira et al., 2019a, 2019b). In fact, it was not until the early 90's the first high-precision U–Pb ID-TIMS zircon and Nd isotopic data were obtained and the ca. 2130 Ma age and a mantle origin were established for the Alto Maranhão batholith (Noce, 1995). Further on, we were able to considerably expand the areal expression of this suite (Seixas, 2000 and following field campaigns and laboratory work), and so, to present a comprehensive view of its broad diagnostic petrological features (Seixas et al., 2013). According to these authors, the plutons of the Alto Maranhão Suite occur to the south of the Congonhas Lineament (see Fig. 5), bordering the Archean crust of the Quadrilátero Ferrífero. It is mainly composed of biotite hornblende tonalites with a crystallization age of 2130 ± 2 Ma, cut by slightly younger granitic aplites and pegmatites. Its εNd(t) whole rock composition is zero on average. The suite resulted from the melting of the mantle wedge below a Palaeoproterozoic arc, which was previously metasomatised by TTG-like melts, similar to the sanukitoid genesis (Seixas et al., 2013, Moreira et al., 2018).

The outcrop selected for the excursion is a huge exposition of fresh rocks in an >150 × 150 m operating quarry placed in the Alto Maranhão village, southern from the famous historical city of Congonhas (20°33'11.7"S 43°50'25.0"W, see google maps reference). The site is referred to as T15 in the paper of Seixas et al. (2013). One of the fundamental features of this suite is the mingling between biotite-hornblende tonalite hosts and biotite-hornblende dioritic mafic magmatic enclaves with evidence for syn-magmatic diking and dismembering phenomena. However, the co-genetic link between these rocks and their roots in the metasomatised mantle are expressed by accessory minerals, like allanite, zircon and apatite.

Finally, it must be retained that collectively the Resende Costa-Lagoa Dourada-Alto Maranhão suite traverses in time the Siderian TTG to sanukitoid tectonic transition, bringing new challenges on the evolution of the continental crust during the magmatic lull (Moreira et al., 2018). The general increase of δ18O and decrease of εHf(t) values in zircon grains from these plutons argues for a continuous process of supracrustal reworking into the mantle and subsequent extraction of magmas. The hallmarks of this evolution are represented by recycling of oceanic crust, sediment contamination in magmas and continental growth during the Palaeoproterozoic (Moreira et al., 2019a, b).

Outcrops in the Quadrilátero Ferrífero:

Geologic highlights by F. F. Alkmim (guide leader)

Stop 4. Crest of the Moeda ridge

UTM 608.494/7757.840

This stop allows a scenic view of the landscape of western QF, which in many aspects is representative of the morphostructural picture of the whole province. Looking west and southwest, we see the low lands underlain by the Archean basement gneisses and granitoids (Bonfim Complex); looking south and northwest, two almost perpendicular ridges that expose quarztites and banded iron formation of the basal Minas Supergroup. The Archean gneisses and granitoids form the nucleus of a large dome, which is bounded on the east and north by the Moeda syncline and the Serra do Curral homocline, respectively. The NS-trending Moeda syncline interferes with the Serra do Curral homocline in a rather complex structure that will be discussed in the further in the field trip.

Besides the scenic view, the purpose of this stop is to provide an overview of the stratigraphy of the basal Minas Supergroup, i.e., the Moeda, Batatal and Cauê formations as exposed along the escarpment of the Moeda ridge.

The morphological expression of the three members of the Moeda Formation (Wallace, 1958; Dorr, 1969; Villaça, 1981) can be clearly observed in the escarpment south of this point. With a maximum thickness of 600m, they record the fill of a rift basin by alluvial and marine sandstones and pelites (Madeira et al. 2019). Unit 1, consisting of fluvial medium to fine-grained quartz-rich meta-sandstones with trough and tabular cross-bedding, makes up the steep slope above the basal contact with the basement. Unit II, composed of marine gray phyllites, occurs in the medium portion of the ridge, marked by the smooth surface covered by grass. The rugged surface in the upper portion of the escarpment corresponds to the Unit III, which is made up of medium- to coarse-grained quartz-rich meta-sandstones that records a transition from fluvio-deltaic to shallow marine deposits. The above lying Batatal Phyllite marks a new marine transgression and the opening of the Minas passive margin basin (Renger et al., 1995; Alkmim and Martins Neto, 2012; Madeira et al., 2019). The Batatal Formation is in turn covered by the Cauê Banded Iron Formation along crest of the ridge.

A large number of age determinations is available for the Moeda Formation (Machado et al., 1996; Hartmann et al., 2006; Martinez-Dopico et al., 2017). These data indicate that the initiation of the Minas basin took place between 2580 Ma, the age of the youngest zircon population of the Moeda Formation and 2420 Ma, the estimated age of carbonates of the Gandarela Formation that covers the three basal units of the Minas Supergroup (Babinski et al., 1995).

Stop 5. Basal section of the Moeda ridge

UTM 608.807/7756.478

The purpose of this stop is to examine the sheared contact between the Archean Mamona Granitoid (Carneiro 1992) and the quartzites of the Moeda Formation. The Mamona Granitoid, dated at 2721± 3 Ma (Machado et al., 1992) is composed of equal proportions of quartz, plagioclase, and microcline, containing smaller amounts of biotite and secondary white mica. Accessory minerals are zircon, apatite, opaque minerals surrounded by titanite, allanite, and fluorite (Jordt-Evangelista et al., 1993a). Away from the shear zone that marks the contact, the granitoid still preserves hypidiomorphic textures typical of igneous crystallization.

The Mamona granitoids in the southern half of the QF represents a late- to post-collisional high K granitic magmatism that took place between 2750 and 2680 Ma (Romano et al., 2013; Farina et al., 2015, 2016).

The shear zone along the contact between the granitoid and the quartzites is marked by a whole series of mylonitic rocks, including cm-thick phyllonite bands. The mylonitic foliation dips 50-60^o to ENE and displays a well-developed down-dip stretching lineation. A variety of small-scale asymmetric features indicates a systematic hanging-wall down motion along the shear zone.

According to Jordt-Evangelista et al. (1993a) the deformation of the granitoid was accompanied by strong hydrothermal alteration that causes intense sericitization and generation of the phyllonite bands we can observe in the outcrops. The main syn-kinematic reaction observed was the conversion of feldspars into quartz + white mica. Mass balance calculations carried out by Jordt-Evangelista (1993b) indicate Ca and Na depletion, combined with K and Mg enrichment along the shear zone.

Stop 6. Crest of the Moeda ridge

UTM 608.729/7758.341

The cuts on both sides of the road expose weathered itabirites, i.e., metamorphosed banded iron formation of the Cauê Formation. This unit, a classical Superior-type banded iron formation (Dorr, 1969; Klein and Ladeira, 2000; Rosière et al., 2008; Spier et al., 2007), marks the dominance of marine conditions in the Minas basin. Like the 2.45-2.30 Ga Siderian iron formations of many other Paleoproterozoic basins around the world, the Cauê Formation can be also considered the record of the initial stages of the Great Oxygenation Event.

The itabirites in this stop are silica and manganese rich. The preserved micro- and meso-bands of iron oxides consists essentially of hematite, with subordinate martite, magnetite, and goethite. Within these bands the hematite shows a strongly preferred orientation, thereby defining a layer-parallel foliation, which dips steeply towards east and southeast.

The 1515m-high Itabirito Peak stands out in the landscape to the east of this point. Located in the eastern limb of the Moeda syncline, the natural monument is the expression of a large body of hard hematite ore, surrounded by soft hematite ores that have been mined in the region since 1940.

Day 5 (18 August) – The Minas Supergroup and the São Francisco Basin (Quadrilátero Ferrífero)

(Overnight in Três Marias)

Geologic highlights by F. F. Alkmim (guide leader)

The stops planned for this morning focus on the stratigraphy of the upper Minas Supergroup and Itacolomi Group in the context of the Paleoproterozoic evolution in the Quadrilátero Ferrífero (QF). Around noon, we leave the QF and drive north along route BR-040. After crossing the city of Belo Horizonte, we travel on an area where Meso- to Neoarchean TTG-gneisses and granitoids of the Belo Horizonte Complex predominate. Near the town of the Sete Lagoas, we enter the intracratonic São Francisco basin, which occupies the NS-trending segment of the São Francisco Craton. Bounded by the Brasiliano orogenic belts, the São Francisco basin is currently portrayed as poly-phase successor depocenter filled by Paleo, Meso, and Neoproterozoic strata unconformably covered by Phanerozoic sedimentary and volcanic rocks (Martins-Neto and Alkmim 2001; Reis et al. 2017a, b).

<u>Quadrilátero Ferrífero:</u>

Stop 1. Natural outcrop located 1.2 km north of km 35 of Route BR 356.
UTM 613.918/7768.708

The natural outcrops in this locality expose a thick bed of lithic metaconglomerates with intercalations of pelites and metasandstones of the Sabará Group, the uppermost unit of the Minas Supergroup. The metaconglomerates are supported by clasts (pebbles and to boulder-sized) of phyllites, quartzites, vein-quartz and iron formation. The matriz is quarts and mica-rich. The bedding-parallel foliation is oriented at 050/60 and marked by flattened and stretched clasts, which also define a downdip lineation.

Besides conglomerates, the Sabará Group comprises an up to 3.5 km-thick sequence of turbidites and deep sea deposits, represented by metapelites, metadiamictites, conglomerates, and lithic sandstones, which unconformably overlies the older Minas units. They have been interpreted interpreted as a syn-orogenic "*flysch*" assemblage (Dorr, 1969; Barbosa, 1968; Renger et al., 1995; Reis, 2001), derived from sources that lay to the east and southeast of the QF. Geochronological determinations on zircons attest provenance from Paleoproterozoic and Archean sources and a maximum depositional age of ca. 2125 Ma. This age defines a hiatus of ca. 450 Ma in the Minas Supergroup succession.

Stop 2. Unpaved road cut located 2.7 km north of Km 32.5 of Route BR 356,

UTM 613.755/7769.103

The cross-bedded coarse-grained metasandstone exposed in this road cut marks the base of the Itacolomi Group, which also overlies unconformably all previous discussed units. The weathered metasandstones are poorly sorted quartz-rich and contain minor amounts of sericite, hematite and feldspar. Besides trough cross-bedding it exhibit in various parts of the outcrop soft-sediment deformation structures. Bedding dips 20^{o} to ENE and SE and is cut weakly developed foliation oriented at 087/55.

The Itacolomi Group is an up to 1.8 km-thick succession of sandstones, conglomerates and minor pelites, which represent alluvial-fan to braided fluvial deposits in transition to lacustrine or marine sediments (Alkmim, 1987). Separated from the underlying units by a regional unconformity, the occurrences of the group are concentrated in the southern half of the QF. Barbosa (1968) and Dorr (1969) interpreted the Itacolomi sediments as a "molasse deposit." Alkmim and Marshak (1998) suggest that the unit was deposited in small intermontane basins during the collapse phase of the Paleoproterozoic Transamazonian event.

Detrital zircons from the Itacolomi Group have yielded U-Pb ages around 2059 Ma (Machado et al., 1993, 1996), indicating that this unit is of the same age or, more likely, slightly younger than the Sabará Group, indeed significantly younger than other units of the Minas Supergoup.

São Francisco basin:

The type unit of the São Francisco basin is the Ediacaran Bambuí Group. This unit consists of alternating carbonate and pelitic rocks in lateral transition to diamictites and conglomerates caped by sandstone-dominated unit (Dardenne, 1978; Martins-Neto and Alkmim, 2001; Romeiro-Silva and Zálan 2005; Reis and Suss, 2016; Reis et al., 2017a, b; Uhlein et al., 2016, 2017). The basal Carrancas Formation, composed of conglomerates, breccias, sandstones and pelites, occur in form of discontinuous beds filling valleys carved in the basement along the southern border of the São Francisco basin (Vieira et al., 2007). Zircons extracted from the Carrancas Conglomerate yield a maximum deposition age of 1431±68 Ma (Rodrigues 2008).

A discontinuous layer of rhythmic calcilutites containing aragonite fans pseudomorphs and dated at dated at 740±22 Ma (Babinski et al. 2007), forms the base of the Sete Lagoas Formation, which is essentially a package of shallow water limestones and pelites, characterized by high organic matter content and positive $\delta^{13}C$ values (Vieira et al. 2007). The Sete Lagoas Formation is overlain by a succession of alternating siliciclastic and carbonate strata.

Except for the upper sandstones, all formations of the group seem to record the conversion of the São Francisco craton into a foreland basin induced and fed by the evolving Brasília orogenic belt that fringes the craton to the west (Chang et al., 1988; Martins-Neto and Alkmim, 2001; Alkmim and Martins-Neto, 2012; Reis et al., 2002, 2017a, b; Uhlein et al., 2016, 2017). The upper sandstones of the group (Três Marias Formation) was, however, sourced from both margins of the craton, recording, thus, the development of the Araçuaí orogen that bounds the craton to the east (Chiavegatto, 1992; Gomes, 1988; Chiavegatto and Dardenne 1997; Chiavegatto et al., 2003).

Many attempts to constrain the age of the Bambuí Group have been made in the last years (Rodrigues, 2008; Lima, 2011; Pimentel et al., 2011; Warren et al., 2014; Paula-Santos et al., 2015, 2017, 2018; Kuchenbecker et al., 2014; Uhlein et al., 2016, 2017). These data indicate maximum depositional ages of ca. 610 and 580 Ma for the Sete Lagoas and Três Marias Formations, which correspond to the basal and upper units of the group, respectively (Rodrigues, 2008; Pimentel et al., 2011).

Stop 3. Route BR-040, Km 470; Police station

UTM 574354/7846524

The base of the Ediacaran succession of the São Francisco basin in this locality comprises the Sete Lagoas Formation accumulated in a storm dominated carbonate ramp (Vieira et al., 2007). The type section of the unit exposed in this region includes pelites, calcilutites, calcarenites, and stromatolites that characterize two progradation sequences separated by retrogradational strata. The uppermost portion of the Sete Lagoas Formation crops out in this road cut, where it is in contact with the overlying Serra de Santa Helena Formation. The irregular shape of the contact surface results from dissolution of Sete Lagoas Limestone and collapse of the above lying Santa Helena slates.

The Sete Lagoas Formation comprises in this locality shallow water microbial boundstone (biolithite) made up of columnar stromatolites (Gymnosolenidae, Marchese, 1974). The up to 30 cm long and 7 cm wide columns show bifurcations and a convex-to-the-top internal lamination. The space between the columns is filled by black calcilutite, calcarenite or breccia. The intercalated calcarenites show cross lamination and hummocky cross-stratification, indicative of a high energy environment.

This outcrop is located in the outer edge of the Araçuaí foreland fold-thrust belt, where the basal detachment ramps up and becomes an emergent thrust. The limestone shows variable degree of deformation, whilst the pelites exhibit a conspicuous slate cleavage.

Stop 4. Inactive quarry, located at 4.2 km north of the town of Paraopeba

UTM 564.149/7871.229

The Lagoa do Jacaré Formation comprises a ca. 100m-thick coarsening-up sequence of pelites, calcarenites and calcirudites containing oolites, oncolites and stromatolites. Hercos et al. (2008) interpreted the Lagoa do Jacaré succession as shallow water deposits of a storm dominated carbonate ramp.

In this quarry, the Formation is made up of recrystallized oomicrite beds intercalated with calcilutites. The oomicrites correspond to cross-stratified calcarenites and calcirudites containing halfmoon ooids and imbricate clasts of composite ooids. The fine-grained intervals consist of siltites and fine grained sandstones, showing wavy laminations and wave ripples.

This outcrop is located outside of the Araçuaí orogenic front. Bambuí strata in this region, the central domain of the Sao Francisco craton, are not affected by tectonic deformation.

Stop 5. Little canyon in the Náutico Club, Três Marias

UTM 476.657/7983.071

Developed along WNW-trending joints, this little canyon exposed the typical lithofacies association of the Três Marias Formation, the youngest unit of the Bambuí Group. Siltites exhibiting soft-sediment deformation grade upwards into thick layers of fine grained sandstones with large-scale hummocky cross-stratification. The sandstones are quartz-rich and contain detrital mica and feldspar.

The Três Marias Formation covers an extensive area in the central São Francisco basin. The formation is made up of a 230m-thick shallowing upward sequence of marine tempestites that grade laterally into deltaic deposit and fluvial deposits. The dominant litotypes are gray-greenish arkoses, quartz and feldspar-rich sandstones, which contain layers and lenses of siltstones, as well as conglomerates and breccias of restrict occurrence (Chiavegatto, 1992).

References (Field workshop 1)

Alkmim F.F., 1987. Modelo deposicional para a seqüência de metassedimentos da Serra de Ouro Branco, Quadrilátero Ferrífero, Minas Gerais. Boletim Soc.Bras.Geol./Nucleo MG 6,47-68

Alkmim, F.F., Marshak, S., 1998. Transamazonian Orogeny in the Southern São Francisco Craton, Minas Gerais, Brazil: Evidence for Paleoproterozoic collision and collapse in the Quadrilátero Ferrífero. Precambrian Research 90, 29-58.

Alkmim, F.F., Teixeira, W., 2017. The Paleoproterozoic Mineiro belt and the Quadrilátero Ferrífero. M. Heilbron, F. Alkmim, U. G. Cordani (guest editors) In: The São Francisco Craton and its margins, Eastern Brazil. Regional Geology Review Series. Springer-Verlag, Chapter 5, pp. 71-94.

Ávila, C.A., 2000. Geologia, petrografia e geocronologia de corpos plutônicos Paleoproterozóicos da borda meridional do Cráton São Francisco, região de São João del Rei, Minas Gerais. Unpubl. Doctoral Thesis. Universidade Federal do Rio de Janeiro, Rio de Janeiro, 401 pp.

Ávila, C.A., Teixeira, W., Cordani, U.G., Moura, C.A.V., Pereira, R.M., 2010. Rhyacian (2.23–2.20 Ga) juvenile accretion in the southern São Francisco Craton, Brazil: Geochemical and isotopic evidence from the Serrinha magmatic suite, Mineiro belt. Journal of South American Earth Sciences, 29: 464–482.

Alkmim F.F., 1987. Modelo deposicional para a seqüência de metassedimentos da Serra de Ouro Branco, Quadrilátero Ferrífero, Minas Gerais. Boletim Soc.Bras.Geol./Nucleo MG 6,47-68

Alkmim, F.F., Marshak, S., 1998. Transamazonian Orogeny in the Southern São Francisco Craton, Minas Gerais, Brazil: Evidence for Paleoproterozoic collision and collapse in the Quadrilátero Ferrífero. Precambrian Research 90, 29-58.

Alkmim, F.F., Teixeira, W., 2017. The Paleoproterozoic Mineiro belt and the Quadrilátero Ferrífero. M. Heilbron, F. Alkmim, U. G. Cordani (guest editors) In: The São Francisco Craton and its margins, Eastern Brazil. Regional Geology Review Series. Springer-Verlag, Chapter 5, pp. 71-94.

Ávila, C.A., 2000. Geologia, petrografia e geocronologia de corpos plutônicos Paleoproterozóicos da borda meridional do Cráton São Francisco, região de São João del Rei, Minas Gerais. Unpubl. Doctoral Thesis. Universidade Federal do Rio de Janeiro, Rio de Janeiro, 401 pp.

Ávila, C.A., Teixeira, W., Cordani, U.G., Moura, C.A.V., Pereira, R.M., 2010. Rhyacian (2.23–2.20 Ga) juvenile accretion in the southern São Francisco Craton, Brazil: Geochemical and isotopic evidence from the Serrinha magmatic suite, Mineiro belt. Journal of South American Earth Sciences, 29: 464–482.

Ávila, C.A., Teixeira, W., Vasques, F.S.G., Dussin, I.A., Mendes, J.C., 2012. Geoquímica e idade U-Pb (LA-ICPMS) da crosta oceânica anfibolíticas riaciana do cinturão Mineiro, borda meridional do cráton São Francisco. In: 46° Congresso Brasileiro de Geologia, Santos, Anais.

Ávila, C.A., Teixeira, W., Bongiolo, E.M., Dussin, I.A., Vieira, T.A.T., 2014. Rhyacian evolution of subvolcanic and metasedimentary rocks of the Southern segment of the Mineiro belt, São Francisco Craton, Brazil. Precambrian Research, 243, 221–251.

Ávila, C.A., Guerra, F.G., Teixeira, W., Dussin, I.A., Silveira, V.L., Bongiolo, E.M., 2015. Petrografia, geoquímica e geocronologia do ortognaisse granodiorítico Ribeirão dos Mosquitos, região sul de Resende Costa, Minas Gerais. In: 14° Simpósio de Geologia do Sudeste, Campos do Jordão, Anais.

Babinski, M., Chemale, Jr. F., Van Schmus, W.R, 1995. The Pb/Pb age of the Minas supergroup carbonate rocks, Quadrilátero Ferrífero, Brazil. Precambrian Research 72, 235-245.

Barbosa, A.L.M. 1968. Contribuições recentes à geologia do Quadrilátero Ferrífero. Ed. Escola de Minas, Ouro Preto, 47pp.

Barbosa, N.S., Teixeira, W., Ávila, C.A., Montecinos, P.M., Bongiolo, E.M., 2015. 2.17-2.09 Ga crust forming episodes in the Mineiro belt, São Francisco craton, Brazil: U-Pb ages and geochemical constraints. Precambrian Research 270, 204-225.

Barbosa, N., Teixeira, W., Ávila, C.A., Montecinos, P.M., Bongiolo, E.M., Vasconcelos, F.F., 2019. U–Pb geochronology and coupled Hf–Nd–Sr isotopic–chemical constrains of the Cassiterita Orthogneiss (2.47–2.41 Ga) in the Mineiro belt, São Francisco Craton: geodynamic fingerprints beyond the Archean–Paleoproterozoic Transition. Precambrian Research, 326, 399-416.

Cardoso, C.D.; Ávila, C.A.; Neumann, R.; Oliveira, E.P.; Valeriano, C.M.; Dussin, I.A., 2019. A Rhyacian continental arc during the evolution of the Mineiro belt, Brazil: Constraints from the Rio Grande and Brumado metadiorites. Lithos 326-327: 246-264.

Carneiro, M.A., 1992. O Complexo Metamórfico Bonfim Setentrional (QuadriláteroFerrífero, Minas Gerais): Litoestratigrafia e evolução geológica de um segmento de crosta continental do Arqueano (Unpublished PhD thesis). University of São Paulo, São Paulo, 233pp.

Campos, J.C.S., Carneiro, M.A., 2008. Neoarchean and Paleoproterozoic granitoids marginal to the Jeceaba-Bom Sucesso lineament (SE border of the southern São Francisco craton): Genesis and tectonic evolution. Journal of South American Earth Sciences, 26, 463–484.

Dorr, J.V.N II, 1969. Physiographic, stratigraphic and structural development of the Quadrilátero Ferrífero, Minas Gerais, Brazil. U.S. Geological Survey Professional Paper 641-A, p.1-110

Farina, F., Albert, C., Lana, C., 2015. The Neoarchean transition between médium and High-K granitoids: clues from the Southern São Francisco Craton (Brazil). Precambrian Research 266, 375-394.

Farina, F.; Albert, C.; Martínez-Dopico, C.; Aguilar Gil, C.; Moreira, H.; Hippertt, J.P.; Cutts, K.; Alkmim, F.F.; Lana, C., 2016. The Archean-Paleoproterozoic evolution of the Quadrilátero Ferrífero (Brasil): Current models and open questions. Journal of South American Earth Sciences 68, 4-21

Gomes N. S., 1988. Contribuição à petrologia e a diagênese dos arenitos da Formação Três Marias, Bacia do São Francisco, Minas Gerais. In: SBG, Congresso Brasileiro de Geologia, 35, Belém, Anais, 2, 961-970.

Hartmann L.A., Endo I., Suita M.T.F., Santos J.O.S., Frantz J.C., Carneiro M.A., Naughton N.J., Barley M.E., 2006. Provenance and age delimitation of Quadrilátero Ferrífero sandstones based on zircon U–Pb isotopes. Journal of South American Earth Sciences 20, 273–285

Jordt-Evangelista, H., Alkmim, F.F. and Marshak, S., 1993a. Transformações mineralógicas e microestruturais do Granito Mamona (Complexo Metamórfico do Bonfim) na zona de cisalhamento do contato com o Supergrupo Minas, Quadrilátero Ferrífero, MG. IV

Simpósio Nacional de Estudos Tectônicos, SNET, Belo Horizonte. SBG/Núcleo MG, Bol.12, p. 106-111.

Jordt-Evangelista Carneiro, M.A. and Lindenberg, S.F., 1993b. Transformações químicas do Granito Mamona (Complexo Metamórfico do Bonfim) na zona de cisalhamento do contato com o Supergrupo Minas, Quadrilátero Ferrífero, MG. IV Simpósio nacional de Estudos Tectônicos, SNET, Belo Horizonte. SBG/Núcleo MG, Bol.12, p. 246-250.

Klein C., Ladeira E. A., 2000. Geochemistry and petrology of some Proterozoic banded iron formations of the Quadrilatero Ferrifero, Minas Gerais, Brazil. Economic Geology 95 (2), 405-427.

Machado, N., Noce, C.M., Ladeira, E.A., de Oliveira, O.A.B., 1992. U-Pb geochronology of the Archean magmatism and Proterozoic metamorphism in the Quadrilátero Ferrífero, southern São Francisco Craton, Brazil. Geol. Soc. Am. Bull. 104, 1221-1227.

Machado, N., Schrank, A., Noce, C.M., Gauthier, G., 1996. Ages of detrital zircon from Archean-Paleoproterozoic sequences: Implications for Greenstone Belt setting ans evolution of a Transamazonian foreland basin in Quadrilátero Ferrífero, southeast Brazil. Earth and Planetary Science Letters 141, 259-276.

Madeira, M. R., 2018. Evolução sedimentar e história deformacional da Formação Moeda ao longo da junção entre o Sinclinal da Moeda e o Homoclinal da Serra do Curral., Quadrilátero Ferrífero, MG. MScThesis, Departamento de Geologia, Universidade Federal de Ouro Preto, Ouro Preto, 162p.

Marchese, H.G., 1974. Estromatolitos Gyminosolenida en el bordo oriental de Minas Gerais, Brasil. Revista Brasileira de Geociências 4(4), 257-271.

Martínez Dopico C. I., Lana C., Moreira H. S., Cassino L. F., Alkmim F. F., 2017. U-Pb ages and Hf-isotope data of detrital zircons from the late Neoarchean-Paleoproterozoic Minas Basin, SE Brazil. Precambrian Research, 291, 143-161.

Moreira, H., Seixas L., Storey, C., Fowler, M., Lasalle, S., Stevenson, R., Lana, C., 2018. Evolution of Siderian juvenile crust to Rhyacian high Ba-Sr magmatism in the Mineiro Belt, southern São Francisco Craton. Geoscience Frontiers 9, 977−995.

Moreira, H., Storey, C., Fowler, M., Seixas, L., Dunlop, J., 2019a. Latest TTG to sanukitoid transition: implications for the evolution of the continental crust during the magmatic lull. Geochemistry Group Research in Progress, GGRiP meeting 2019, The Geological Society and Mineralogical Society, Portsmouth, UK, Programme-Abstract-Volume, p. 26.

Moreira, H., Storey, C., Fowler, M., Seixas L., 2019b. Earth’s secular magmatic evolution through time: insights from trace element analyses in accessory phases.

Goldschmidt2019, Barcelona, Spain. Geochemical Society and European Association of Geochemistry, Abstract.

Moreno J.A., Baldim M.R., Semprich J., Oliveira E.P., Verma S.K., Teixeira W., 2017. Geochronological and geochemical evidences for extension-related Neoarchean granitoids in the southern São Francisco Craton, Brasil. Precambrian Research, 294, 322-343.

Neri, M.E.N.V.; Rosière, C.A., Lana, C.C., 2013. Supergrupo Minas na Serra de Bom Sucesso, extremo sudoeste do Quadrilátero Ferrífero – MG: petrografia, geoquímica e isótopos de U-Pb. Geologia USP, Série Científica 13, 117-202.

Noce, C. M., 1995. Geocronologia dos Eventos Magmáticos, Sedimentares e Metamórficos na Região do Quadrilátero Ferrífero, Minas Gerais. PhD Thesis. Universidade de São Paulo.

Partin, C. A., Bekker, A., Sylvester, P. J., Wodickad, N., Stern, R. A., Chacko, T., Heaman, L.M., 2014. Filling in the juvenile magmatic gap: Evidence for uninterrupted Paleoproterozoic plate tectonics. Earth and Planetary Science Letters 388, 123–133.

Pehrsson, S. J., Buchan, K. L., Eglington, B. M., Berman, R. M., Rainbird, R. H., 2014. Did plate tectonics shutdown in the Palaeoproterozoic? A view from the Siderian geologic record. Gondwana Research 26, 803−815.

Renger, F. E., Noce, C.M., Romano, A.W., Machado, N., 1995. Evolução sedimentar do Supergrupo Minas: 500 Ma de registro geológico no Quadrilátero Ferrífero, Minas Gerais, Brasil. Geonomos 2(1), 1-11.

Romano, R., Lana, C., Alkmim, F.F., Stevens, G.S., Armstrong, R., 2013. Stabilization of the southern portion of the São Francisco Craton, SE Brazil, through a long-lived period of potassic magmatism. Precambrian Research 224, 143-159.

Rosière C. A., Spier C. A., Rios F. J., Suckau V. E., 2008. The itabirites from the Quadrilátero Ferrífero and related high-grade ores: An overview. Reviews in Economic Geology, 15, 223-254.

Seixas, L. A. R., 2000. Pétrologie de la suite TTG de la bordure nord du batholite d'Alto Maranhão et du pluton Congonhas, Minas Gerais, Brésil. Ph.D. thesis, Université de Paris-Sud, Orsay.

Seixas, L.A.R., David, J., Stevenson, R., 2012. Geochemistry, Nd isotopes and U–Pb geochronology of a 2350 Ma TTG suite, Minas Gerais, Brazil: implications for the crustal evolution of the southern São Francisco craton. Precambrian Research, 196, 61–80.

Seixas, L. A. R., Bardintzeff, J-M., Stevenson, R., Bonin, B., 2013. Petrology of the High-Mg tonalites and dioritic enclaves of the ca. 2130 Ma Alto Maranhão suite: Evidence for a major juvenile crustal addition event during the Rhyacian orogenesis, Mineiro Belt, southeast Brazil. Precambrian Research 238C, 18–41.

Silveira, V.S.L, Ávila C.A., Neumann R., Neves C.V.S., Capistrano, F.M., 2019. Mineralogia, Petrografia e Geoquímica de Diques de Metadiabásio equigranular e porfirítico da região de Bom Sucesso, Estado de Minas Gerais, Brasil. Anuário do Instituto de Geociências, 42 (1): 656-671.

Spencer, C. J., Murphy J. B., Kirkland C. L., Liu, Y., Mitchell, R. N., 2018. A Palaeoproterozoic tectono-magmatic lull as a potential trigger for the supercontinent cycle. *Nature Geoscience* **11**, 97–101.

Spier C. A., Oliveira S. M. B., Sial A. N., Rios F. J. 2007. Geochemistry and genesis of the banded iron formations of the Cauê Formation, Quadrilátero Ferrífero, Minas Gerais, Brazil. Precambrian Research 152, 170-206.

Teixeira, W., Ávila, C.A., Nunes, L.C., 2008. Nd–Sr isotopic geochemistry and U–Pb geochronology of Fé granitic gneiss and Lajedo granodiorite: implications for Paleoproterozoic evolution of the Mineiro belt, southern São Francisco Craton. Geologia USP Série Científica 8, 53–73.

Teixeira, W., Ávila, C.A., Bongiolo, E.M., Hollanda, M.H.B., Barbosa, N.S., 2014. Age and tectonic significance of the Ritápolis batholith, Mineiro belt (Southern São Francisco Craton): U-Pb LA-ICPMS, Nd isotopes and geochemical evidence. In: 9th South American Symposium on Isotope Geology, p. 2014.

Teixeira, W., Ávila, C.A., Dussin, I.A., Neto, A.C., Bongiolo, E.M., Santos, J.O., Barbosa, N.S., 2015. A juvenile accretion episode (2.35–2.32 Ga) in the Mineiro belt and its role to the Minas accretionary orogeny: Zircon U–Pb–Hf and geochemical evidences. Precambrian Research, 256, 148–169.

Vasconcelos, F.F., 2015. Evolução geológica, metamorfismo e metassomatismo da região ao redor da Mina de Volta Grande, Nazareno, Estado de Minas Gerais. Dissertação (Mestrado). Rio de Janeiro, Instituto de Geociências, Universidade Federal do Rio de Janeiro.

Villaça, J.N., 1981. Alguns aspectos sedimentares da Formação Moeda. Boletim da Sociedade Brasileira de Geologia, Núcleo Minas Gerais, Belo Horizonte, v.2, p. 93-137.

Wallace, R.M., 1958. The Moeda Formation. Boletim da Sociedade Brasileira de Geologia, 7-2, 59-60.