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Abstract: The Quadrilátero Ferrífero is a metallogenic district (Au, Fe, Mn) located at the southernmost end of the São Francisco craton in eastern Brazil. In this region, a supracrustal assemblage composed of Archean greenstone and overlying Neoarchean-Paleoproterozoic sedimentary rocks occur in elongated keels bordering domal bodies of Archean gneisses and granites. The tectonomagmatic evolution of the Quadrilátero Ferrífero began in the Paleoarchean with the formation of continental crust between 3500 and 3200 Ma. Although this crust is today poorly preserved, its existence is attested to by the occurrence of detrital zircons in the supracrustal rocks. Most of the Quadrilátero crystalline basement, which is composed of banded gneisses intruded by leucogranitic dikes and weakly foliated granites, formed during three major magmatic events: Rio das Velhas I (2920-2850 Ma), Rio das Velhas II (2800-2760 Ma) and Mamona (2760-2680 Ma). The Rio das Velhas II and Mamona events represent a subduction-collision cycle, likely marking the action of a modern-style plate tectonic regime in the Quadrilàtero Ferrífero region. Granitic rocks emplaced during the Rio das velhas I and II events formed by mixing between a magma generated by partial melting of metamafic rocks with an end member derived by recycling gneissic rocks of older continental crust. After deformation and regional metamorphism at ca. 2770 Ma, a change in the composition of the granitic magmas occurred and large volumes of high-K granitoids were generated.
The ca. 6000 m-thick Minas Supergroup tracks the operation of a Wilson cycle in the Paleoproterozoic between 2600 and 2000 Ma. The basal sequence involves continental to marine sediments deposited in a passive margin basin and contain as a marker bed the Lake Superior-type Cauê Banded Iron Formation. The overlying sediments of the Sabará Group mark the inversion of the basin during the Rhyacian Minas accretionary orogeny. This orogeny, resulting from the collision between the nuclei of the present-day São Francisco and Congo cratons, generated the fold-and thrust belt structure of the Quadrilátero Ferrífero. Afterwards, the post-collisional orogenic collapse resulted in the deposition of the Itacolomi Group and in the genesis of the dome-and-keel structure.
In this paper, we review current knowledge about the 1500 Ma long-lasting tectonomagmatic and structural evolution of the Quadrilátero Ferrífero identifying the most compelling open questions and future challenges.

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The Archean-Paleoproterozoic evolution of the Quadrilátero Ferrífero (Brasil): current models and open questions

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Abstract

The Quadrilátero Ferrífero is a metallogenic district (Au, Fe, Mn) located at the southernmost end of the São Francisco craton in eastern Brazil. In this region, a supracrustal assemblage composed of Archean greenstone and overlying Neoarchean-Paleoproterozoic sedimentary rocks occur in elongated keels bordering domal bodies of Archean gneisses and granites. The tectonomagmatic evolution of the Quadrilátero Ferrífero began in the Paleoarchean with the formation of continental crust between 3500 and 3200 Ma. Although this crust is today poorly preserved, its existence is attested to by the occurrence of detrital zircons in the supracrustal rocks. Most of the Quadrilátero crystalline basement, which is composed of banded gneisses intruded by leucogranitic dikes and weakly foliated granites, formed during three major magmatic events: Rio das Velhas I (2920-2850 Ma), Rio das Velhas II (2800-2760 Ma) and Mamona (2760-2680 Ma). The Rio das Velhas II and Mamona events represent a subduction-collision cycle, likely marking the action of a modern-style plate tectonic regime in the Quadrilàtero Ferrífero region. Granitic rocks emplaced during the Rio das velhas I and II events formed by mixing between a magma generated by partial melting of metamafic rocks with an end member derived by recycling gneissic rocks of older continental crust. After deformation

and regional metamorphism at ca. 2770 Ma, a change in the composition of the granitic magmas occurred and large volumes of high-K granitoids were generated.

The ca. 6000 m-thick Minas Supergroup tracks the operation of a Wilson cycle in the Paleoproterozoic between 2600 and 2000 Ma. The basal sequence involves continental to marine sediments deposited in a passive margin basin and contain as a marker bed the Lake Superior-type Cauê Banded Iron Formation. The overlying sediments of the Sabará Group mark the inversion of the basin during the Rhyacian Minas accretionary orogeny. This orogeny, resulting from the collision between the nuclei of the present-day São Francisco and Congo cratons, generated the fold-and thrust belt structure of the Quadrilátero Ferrífero. Afterwards, the post-collisional orogenic collapse resulted in the deposition of the Itacolomi Group and in the genesis of the dome-and-keel structure.

In this paper, we review current knowledge about the 1500 Ma long-lasting tectonomagmatic and structural evolution of the Quadrilátero Ferrífero identifying the most compelling open questions and future challenges.

1. Introduction

In the mid-twentieth century, the ca. 7000 km^2 portion of the Brazilian highlands south of the city of Belo Horizonte (Fig. 1) became well-known under the name of Quadrilátero Ferrífero ("Iron Quadrangle"). This region, which has been an important mining site since the XVIII century, represents the most intensively studied region of Brazil. Its valuable iron and gold deposits together with its puzzling geological complexity have attracted the attention of many scientists over the last century. The goal of the present paper is to provide an up-to-date state of the art on the geology of the Archean crystalline basement and Archean-Paleoproterozoic metasedimentary sequences forming the Quadrilátero Ferrífero. This review, focussed on the Archean and Paleoproterozoic evolution of this portion of the southern São Francisco craton, is not aiming to be exhaustive. Some important topics will not be addressed (e.g. the origin of ore deposits) while others will be only briefly presented (e.g. the structural evolution). The goal of this contribution is to discuss the present-day petrologic and geodynamic models proposed for the Quadrilátero, drawing attention to the main open problems and limitations in an attempt to highlight future challenges and favourable research directions.

2. Historical background and geographic boundaries

In the sixteenth century, the discovery of large gold and silver deposits in the Spanish colonial possessions in South America (e.g. the Potosí silver deposits in Bolivia) triggered the Portuguese empire to embark in the exploration of inland Brazil seeking precious metals. From 1545, the Portuguese colonial government organized and financed many expeditions as well as encouraging private expeditions (i.e. the “bandeiras”) that were mostly organized by adventurers from the São Paulo region (the Captaincy of São Vicente). For ca. 100 years the hunt for payable precious metals proved futile and only in 1646 the first discovery of small alluvial gold deposit in Brazil was made in the southern state of Paraná (Figueiredo, 2011; Fig. 2). In 1693, the first gold placer deposit was found in southeastern Brazil (state of Minas Gerais), close to the city of Ouro Preto (“black gold” in Portuguese). The discovery of many rich gold deposits in the region that is today known as the Quadrilátero Ferrífero, revitalized Brazil’s economy, which had been stagnating since the decline of the sugar plantations (Costa et al., 2003). Gold discovery caused such a stir that, by the end of the century a considerable proportion of Sao Paulo’s, Rio de Janeiro’s and the northern province of Bahia’s population had rushed to the site of the discovery. More significantly, as news of the discovery spread to the mother country, thousands of Portuguese adventurers moved to Brazil at the turn of the eighteenth century: the first great gold rush had begun. Between 1693 and 1720, the population of the gold-rich province grew exponentially; i.e. in that period, about 400000

Portuguese and 500000 slaves had relocated to southeastern Brazil to mine gold. Such was the growth that half Brazil's entire population was residing in Minas Gerais in 1725. Gold production increased as the eighteenth century advanced, peaking around mid-century and then, due to the rudimental mining technique implemented (e.g. mostly panning and sluicing in shallow water stream) slowly declined but continuing into the nineteenth century (Costa et al., 2003).

By the beginning of the nineteenth century, many European explorers and naturalists carried out geographic and geological studies in the gold-bearing province (Fig.2; Machado, 2009). In 1810, the mineralogist and geologist Baron Wilhelm Ludwig von Eschwege arrived to Brazil entrusted by the king Dom João VI to study the ores and the mining activity with the goal of implementing new mining techniques to increase gold production. The baron, defined by Derby (1906), "the founder of Brazilian Geology" made a significant step forward in the description and understanding of the geology of the Quadrilátero Ferrífero. Eschwege published various books (e.g. *Jornal do Brasil, 1811-1817*; *Pluto brasiliensis* (1833)) in which he outlined the main geological features of the Precambrian terranes of central Brazil proposing a stratigraphic subdivision according to Werner's Neptunism theory. Moreover, the baron also produced the first cross-section from Rio de Janeiro to Vila Rica (the old name of Ouro Preto). The work of Eschwege was influential and guided many other foreign naturalists that visited Brazil in the eighteenth century such as Peter Claussen (1805-1852), Aimé Pissis (1812-1889) and the geologist and mining engineer Virgil von Helmreichen (1802-1855) who produced the first geological maps of the region surrounding the city of Ouro Preto (Machado, 2009).

In the early twentieth century, the gold-rich region around Ouro Preto returned to the spotlight because of its iron and manganese deposits. One century after Eschwege arrived in Brazil, the American geologist Derby published a work titled "The iron ores of Brazil" that attracted the interest of the mining community to the iron and manganese deposits of Minas

Gerais. In the mid-twentieth century, an agreement was set between the Brazilian National Department of Mineral Production (DNPM) and the U.S. Geological Survey to undergo the first detailed geological study of the region where the main iron and manganese deposits were located (Machado, 2009). This agreement and the two decades of work that followed marked the most important step forward in the understanding of the geology of the Quadrilátero Ferrífero. The outcome of this joint project was a set of 42 geological maps in the 1:25.000 scale followed by a stratigraphic column and a report written by the head of the team, John Van N. Dorr II, in which the main geological features of the studied region were defined. Dorr and collaborators used the term Quadrilátero Ferrífero in 1952 (Machado, 2009) to give credit to the abundance of high-grade iron ore deposits in the region. These authors defined the geographic boundaries of the Quadrilátero producing a detailed 1:150.000 geological map. Oddly, as shown in figure 1, the "iron quadrangle" of Dorr and collaborators is not a quadrangle but rather a complex polygon, including the Itabira mining district. The reason for the use of the term Quadrilátero proposed by Dorr is historical. In fact, the term was introduced in 1923 by the Brazilian geologist Luis Flores de Moraes Rego in a paper titled "As jazidas de ferro do centro de Minas Gerais" (i.e. "The iron ores of central Minas Gerais") to define the four-sided area comprised between the cities of Belo Horizonte, Santa Bárbara, Congonhas and Mariana (Machado, 2009). Clear geographic features do not delimit the Quadrilátero Ferrífero as defined and mapped by Dorr and collaborators and thus, the term has been used loosely to describe the geology of areas that are not part of the original map of the Quadrilátero. As shown in Figure 1, we will also extend the limits of the Quadrilátero Ferrífero to include the Bonfim and the Belo Horizonte domes in their entirety.

3. Main geological features

The São Francisco craton in eastern Brazil is one of the major and probably the best-exposed shield area forming the South American platform. The craton is subdivided into four Archaean blocks bounded by major ca. 2100 Ma old sutures zones (Teixeira and Figuereido, 1991; Barbosa and Sabaté, 2004) and surrounded by Neoproterozic orogenic belts (e.g. the Araçuaí and Brasilia belts; Pedrosa-Soares, 2001; Pimentel et al., 2011). The northern part of the craton comprises four crustal segments intensively affected by the Rhyacian-Orosirian orogenic event (Barbosa and Sabaté, 2004): the Gavião, Jequié, Serrinha and Itabuna-Salvador-Curaçá blocks (Fig. 1). The basement of the southern São Francisco craton, probably representing an extension of the Gavião block (Alkmim and Noce, 2006; Lana et al., 2013) comprises various granitoid-gneiss complexes (i.e. Campo Belo, Passa Tempo, Bonfim, Belo Horizonte, Bação, Caeté) partially covered by Archean and Paleoproterozoic supracrustal sequences. The Quadrilátero Ferrífero mining district, occupying the eastern part of the Southern São Francisco Craton, is fringed by the Ediacaran-Cambrian Araçuaí belt (Pedrosa-Soares et al., 2001) to the east and by the Paleoproterozoic Mineiro Belt (Teixeira and Figueiredo, 1991) to the south (Fig. 1). The district exhibits NNW-verging folds and thrusts and has a metamorphic overprint at about 2100-2000 Ma, which was originally known as the "Minas diastrophism" (e.g., Cordani et al., 1980). The distinctive structural architecture of the Quadrilátero is its dome-and keel geometry, in which belts of low-grade Paleoproterozoic supracrustal rocks surround medium to high-grade granitoid-gneiss Archean complexes (Marshak et al., 1997). The Quadrilátero Ferrífero can be subdivided into four Archean to Paleoproterozoic lithostratigraphic units:

(i) Archean metamorphic complexes composed of gneisses, migmatites, and granitoids;

(ii) the Archean Rio das Velhas Supergroup, formed by greenstone and low- to medium-grade metasedimentary units;

(iii) the Paleoproterozoic Minas Supergroup, consisting of low- to medium-grade metasedimentary rocks;

(iv) the Paleoproterozoic Itacolomi Group composed of metasandstones and conglomerates.

In addition, the Quadrilátero Ferrífero includes small granite bodies and pegmatite veins locally cutting the youngest strata of the Minas Supergroup as well as different generations of mafic dikes showing contrasting metamorphic grade, composition and trending direction. A stratigraphic section of the Quadrilátero Ferrífero is presented in Figure 3 and the different lithostratigraphic units are described in the following sections.

4. The Archean metamorphic complexes

4.1. Field relationships and petrography

In the field, the rocks of the basement can be subdivided into three main groups:

i) fine-grained banded orthogneisses intruded by (ii) and (iii)

ii) leucogranites and aplitic/pegmatitic veins and dikes;

iii) medium- to coarse-grained, mostly weakly foliated granites (*sensu lato*).

The gneisses are characterised by the alternation between leucocratic and mesocratic, or more rarely, melanocratic bands, varying in width from 2 mm to up to 10 cm defining a penetrative amphibolite-facies foliation (Fig. 4). The mesocratic bands are rich in plagioclase and biotite and display lepido-nematoblastic textures, whereas the leucocratic ones, containing predominantly plagioclase, quartz and minor microcline, show granoblastic textures (Lana et al., 2013). Alkali-feldspars are generally interstitial, but occasionally form cm-scale phenocrysts. Locally, the gneisses exhibit a variety of migmatitic structures (Farina et al., 2015). The gneisses are intruded by multiple, meter- to cm-scale leucogranitic sheets sub-parallel to the gneissosity as well as by crosscutting younger felsic and/or pegmatitic dikes (Lana et al., 2013). Felsic bodies oriented sub-parallel to the banding (i.e. leucogranitic sheets) have width ranging from few centimetres to ca. 60 cm and may be either foliated or massive. A younger generation of leucogranitic, pegmatitic and aplitic dikes that crosscut both the gneissic banding and the leucogranitic sheets have widths reaching a maximum of about 2 meters. These dikes are only occasionally slightly folded or boudinaged, but in general appear little stretched, nor shortened.

Granitic rocks form texturally and compositionally composite batholiths (e.g. the Mamona batholith, Fig. 1) as well as relatively small-scale domains and stocks intruded in or closely associated with the banded gneisses (Farina et al., 2015). Although typically weakly foliated, granitoids may also locally develop prolate L>S fabric. The granitic rocks are medium- to coarse-grained and exhibit either equigranular or porphyritic textures ranging in composition from tonalite to syenogranite. Based on the ferromagnesian minerals contained, three rock types are recognised: biotite-bearing granodiorites and granites, two-mica granites and biotite- and amphibole-bearing tonalites and granodiorites. The first group represents the most abundant granite-type while muscovite- and amphibole-bearing granitoids are rare, mostly cropping out in the Bonfim complex. The relationship between banded gneisses and granitoids is observable in some key outcrops in the Baçao and Bonfim complexes. The intrusion of granites into banded gneisses produces different features. From gneiss- to granite-dominated outcrops, we observe: i) dikes of medium-grained granites cutting both the gneissic banding and the leucogranite sheets; ii) complex intermingled gneiss-granite structures; iii) meter- to decametre-scale domains of granites intruding the banded gneisses; iv) xenoliths of banded gneisses hosted within granites (Fig. 4).

4.2. Geochemistry: medium- and high-K granitoids

Whole rock major and trace element data for granites and gneisses in the Quadrilátero Ferrífero is scarce, with different contributions generally investigating the compositional variability of individual complexes without attempting any regional-scale correlation (Carneiro et al., 1992; Noce et al., 1997). An exception to this approach is represented by the work of Farina et al. (2015) in which a large database of chemical compositions for the granites and gneisses of the Bação, Bonfim and Belo Horizonte complexes was produced. In figures 5, 6 and 7, we plotted the major and trace element composition of gneisses and granitoids from the Bação, Bonfim, Belo Horizonte and Caeté complexes as well as the composition of dacites from the Rio das Velhas greenstone belt. A complete dataset of whole rock compositions is presented in the Electronic supplement (Table A).

Gneisses, granitoids and leucogranites of the Quadrilátero Ferrífero are silica-rich (i.e. ca. 70% of samples have silica content higher than 72 wt.%) and all major element oxides are broadly negatively correlated with SiO_2 (Fig. 6), except K_2O that displays positive correlation.

In the normative feldspar classification diagram for granitoids (An–Ab–Or, O´Connor, 1965), most of the gneisses and granites plot either in the trondhjemite or in the granite fields (Fig. 5), with only the biotite- and hornblende-bearing Samambaia pluton described by Carneiro (1992) plotting in the field of tonalities. The An–Ab–Or diagram reflects the existence of two main groups of rocks exhibiting different potassium over sodium contents. The two groups can be distinguished in the K_2O vs. SiO_2 diagram where most of the trondjemites of figure 5 plot in the medium-K field defined by Gill (1981) while granitic rocks plot in the high-K field (Fig. 6). The occurrence of medium- and high-K gneisses and granitic rocks in the basement of the Quadrilátero Ferrífero is evident when the K_2O/Na_2O of the rocks is plotted in a frequency histogram (Fig. 6). The distribution is bimodal showing well-defined peaks at 0.4-0.6 and 1.2-1.6 K_2O/Na_2O. Systematic compositional differences exist between medium- and high-K rocks. Medium-K gneisses and granitoids have higher Al_2O_3, Na_2O, CaO and Sr as well as lower silica and Rb than high-K rocks (Fig. 6). In addition, medium-K granitoids have relatively high contents in light Rare Earth Element (LREE) and low heavy Rare Earth Element contents (HREE), resulting in steep REE patterns (La/Yb up to 70) while high-K rocks exhibit less fractionated REE patterns with HREE contents that are significantly higher than those of medium-K rocks (Fig. 7). The two rock types display different Eu anomalies with no Eu anomaly or slightly negative in the medium-K rocks and a well pronounced Eu anomaly for high-K granitoids and gneisses. Overall, medium-K_2O rocks share similar chemical features with rocks of the Archean tonalite-trondhjemite-granodiorite (TTG) series, whilst high-K granitoids are similar to high-silica I-type granites. The latter plotting consistently in the field of biotite- and two-mica granites recently defined by Laurent et al. (2014) for late-Archean granites (Farina et al., 2015).

Finally, leucogranitic sheets and dikes, representing ca. 10% of the bulk crystalline basement exposed in the Quadrilátero Ferrífero, display characteristic low to very low MgO + Fe_2O_{3tot} contents (0.2-1.1 wt.%) and scattered major element composition with K_2O ranging from 3.8 to 8.9 wt.% and silica between 71 and 76 wt.% (Fig. 6). In the SiO_2 vs. Al_2O_3 diagram, they generate a quasi-linear negative trend and for equivalent silica contents they are slightly enriched in Al_2O_3 and depleted in MgO and Fe_2O_{3tot} than both granites and gneisses (Fig. 6). The leucogranitic rocks exhibit Eu anomalies varying from slightly negative to strongly positive (Eu/Eu*= 0.9-2.8), low REE contents and flat REE patterns resulting in low La/Yb ratios (Fig 7).

4.3. Geochronology

A review of published U–Pb ages from the basement of the Quadrilátero Ferrífero (Table B in the Data Repository) allowed the identification of four main magmatic events (Farina et al., 2015; Lana et al., 2013; Romano et al., 2013). These periods of magmatic activity, described as the Santa Bárbara (SB), Rio das Velhas I (RVI), Rio das Velhas II (RVII) and Mamona, embody a significant part of the protracted tectonomagmatic Archean history of the Quadrilátero Ferrífero, spanning from 3220 to 2680 Ma. The first magmatic pulse, poorly preserved in the north-south elongated Santa Bárbara complex (Fig. 1), ranges from 3220 to 3200 Ma, with these rocks representing the only Paleoarchean crust identified in the Quadrilátero Ferrífero so far. Most of the gneisses in the Quadrilátero Ferrífero formed during the following periods of magma production, the Rio das Velhas I and II events (Lana et al. 2013). The Rio das Velhas I period, which originally had an interval of between 2930 and 2900 Ma, has been recently expanded down to 2850 Ma by Farina et al. (2015). Similarly, new geochronological data, of Farina et al. (2015) redefine the time of the Rio das Velhas II period to between 2800 and 2760 Ma. It is worth noting that, two weakly deformed plutons intruded the orthogneisses during the Rio das Velhas II event at about 2770 Ma (i.e. the Caeté and Samambaia plutons, Machado et al., 1992). The age of these granites suggest that the youngest Archean regional metamorphic event in the Quadrilátero Ferrífero occurred in the early Neoarchean, during the Rio das Velhas II event. The occurrence of this metamorphic event is supported by the observation that many magmatic zircon grains from the banded gneisses of the Rio das Velhas I period are overgrown by metamorphic rims yielding Rio das Velhas II ages (Lana et al., 2013). Just after the regional metamorphic event, the basement complexes underwent a new period of widespread magmatism between 2750 and 2680 Ma (Romano et al., 2013) referred to as the Mamona event by Farina et al. (2015). During this event, granites were emplaced as large batholiths and small leucogranitic veins and dikes into the pre-existing deformed crust. Finally, a volumetrically minor event of granite production accounting for less than 1% of the continental crust in the Quadrilátero occurred at ca. 2612 Ma (Romano et al., 2013).

Two leucogranitic-pegmatitic dikes analysed by Machado et al. (1992) in the southern part of the Bação complex have yielded Paleoproterozoic U-Pb monazite ages (i.e. 2130 and 2122 Ma, Table E Data Repository). One of the dike is intrusive into the banded gneisses while the other intruded along the schistosity of the greenstone belt, a few meters away from the shear zone marking the contact between the supracrustal rocks and the basement. These ages match with the crystallization age of the Alto Maranhão suite (Noce et al., 1998; Seixas et al., 2013); a tonalitic-dioritic batholith, located on the southern edge of the Quadrilátero Ferrífero, formed during the Rhyacian orogenesis of the South American platform (Seixas et al., 2013). Paleoproterozoic U-Pb ages were also obtained from metamorphic titanites and monazites from amphibolitic dikes (ca. 2050 Ma) and gneisses (2080-1950 Ma) in the Bação, Bonfim and Belo Horizonte complexes (Machado et al., 1992; Noce et al., 1998; Aguilar Gil et al., 2015).

5. The Rio das Velhas Supergroup

5.1. Stratigraphy

The metavolcanic and metasedimentary rocks of the Rio das Velhas Supergroup (Dorr, 1969) form a typical Archean greenstone belt sequence characterized by the association between mafic and ultramafic rocks (komatiite–basalt), evolved volcanic (dacites) and volcaniclastic rocks and immature clastic sediments (Zucchetti et al., 2000; Noce et al., 2005). These rocks are metamorphosed at greenschist to lower amphibolite-facies conditions and are commonly affected by hydrothermal alteration (Ladeira et al. 1983; Zucchetti et al., 2000). Many different stratigraphic subdivision were proposed for the Rio das Velhas Supergroup (Baltazar and Zucchetti, 2007 and references therein). A first level of classification was introduced by Dorr (1969), which subdivided the greenstone belt into the Nova Lima and Maquiné groups, the former occurring at the base of the sequence and hosting the major gold deposits of the Quadrilátero Ferrífero (Fig. 3). Recently, Baltazar and Zucchetti (2007), following the approach of Eriksson et al. (1994) subdivided the Nova Lima Group into six sedimentary lithofacies associations forming four sedimentary cycles. From bottom to top these are: (i) mafic-ultramafic volcanic; (ii) volcano-chemical-sedimentary; (iii) clastic-chemical-sedimentary, (iv) volcaniclastic; (v) re-sedimented and (vi) coastal. The basal lithofacies of the Nova Lima Group is made of mafic and ultramafic lavas (Fig. 9) intercalated with minor intrusions of gabbro, anorthosite and peridotite as well as with banded iron formation, ferruginous cherts, chemical carbonaceous sediments and rare felsic volcaniclastic rocks. The ultramafic lavas are massive and pillowed komatiites characterized by spinifex textures (Schorscher, 1978; Sichel, 1983), with layers of cumulus olivine/intercumulus orthopyroxene and a level of lahar-type breccia (Baltazar and Zucchetti, 2007). This event of mafic volcanism was followed by submarine deposition of pelites, graywackes and quartzites with intercalation of banded iron formation, dolomites, marls, carbonate-rich pelites (hosting the world-class Morro Velho gold deposit; Lobato et al., 2001) and conglomerates (i.e. lithofacies ii and iii). Volcaniclastic and resedimented volcaniclastic rocks as well as minor lava flows of dacitic composition and turbiditic graywakes form the overlying lithofacies (iv and v). It is worth noting that the minor dacitic lava flows have a TTG signature, exhibiting high Na_2O and Al_2O_3 contents (Fig. 6) and strongly fractionated Rare Earth Element patterns that are consistent with partial melting of basaltic rocks at depths where garnet is stable as a residual phase (Da Silva et al., 2000). Finally, the lithofacies at the top of the sequence (i.e. vi) is formed by sandstones with herringbone cross-bedding, ripple marks and large-scale cross-bedding. This lithofacies is restricted to a small area northwest of the Bação Complex and was probably deposited in shallow marine environment.

Overlying the Nova Lima Group, the Maquiné Group represents a 2000 m thick clastic association comprising conglomerates (Fig. 9) and sandstones that was described by Dorr (1969) as a flysch to molasse-type sequence, consisting of a coarsening upward succession of sandstones getting more quartz rich and conglomeratic toward the top. The Maquiné Group was divided into two formations: the basal Palmital (O'Rourke, 1957) and the upper Casa Forte (Gair, 1962). The Palmital Formation was deposited in a marine environment as proximal turbidites while the Casa Forte Formation is interpreted as a non-marine alluvial fan – braided river deposit. The contact between the Nova Lima Group and the overlying sandstones and conglomerates of the Maquiné Group is either gradational or locally unconformable and marked by fault zones (Dorr, 1969). The lack of a clear discordance between the Palmital

Formation and the top of the Nova Lima Group as well as the marine environment of deposition for the Palmital Formation led Baltazar and Zucchetti (2007) to associate this formation to the coastal association defined in the Nova Lima Group.

5.2. Geochronology

U-Pb ages of detrital zircon grains from the Rio das Velhas greenstone belt were determined by Machado et al. (1992, 1996), Noce et al. (2005) and Hartmann et al. (2006) using different analytical techniques such as SHRIMP, LA-ICP-MS and ID-TIMS (Table C in the Data Repository). Eight of the nine samples analysed are greywackes from the Nova Lima group while only five zircon grains were analysed for one sample collected by Machado et al. (1996) from the Maquiné Group. Three volcaniclastic graywackes from the Nova Lima Group yielded maximum deposition ages of 2792±11, 2773±7 and 2751±9 Ma, indicating ca. 40 Ma of felsic volcanism in the Quadrilátero Ferrífero (Machado et al., 1992, 1996; Noce et al., 2005). The occurrence of a Neoarchean felsic volcanic event is supported by a zircon $^{207}Pb/^{206}Pb$ crystallization age of 2772±6 Ma determined by Machado et al. (1992) for a dacitic flow intercalated within the sequence of mafic- to ultramafic volcanic rocks in the greenstone belt. Detrital zircons from two sandstones from the top of the Nova Lima Group dated by SHRIMP by Hartmann et al. (2006) gave a maximum depositional age of 2749±7 Ma.

U-Pb age data from detrital zircon grains in the Nova Lima Group are plotted in the frequency diagram of figure 10. In this diagram, ages that are more than 10% discordant were excluded together with spot analyses with Th/U < 0.1 as such low ratios are typical of high-grade metamorphic zircon (e.g. Rubatto et al., 2001). Detrital zircon grains from the volcaniclastic graywackes of the Nova Lima Group define a polymodal age spectrum with ages ranging from 2700 to 3450 Ma. The occurrence of a large number of detrital zircon grains suggests that these rocks were not formed in an intra-oceanic arc environment, but more likely in an intracontinental or continental-margin tectonic setting (Noce et al., 2005). A comparison of the detrital zircons age spectra of the Nova Lima Group with the ages of the main magmatic events defined by Lana et al. (2013), Romano et al., (2013) and Farina et al. (2015), leads to the following conclusions:

- The main magmatic event preserved in the metasedimentary rock record is the 2800-2760 Ma Rio Das Velhas II event,
- The second highest frequency peak is at ca. 2860 Ma matching the youngest limit of the Rio Das Velhas I event (2920-2860 Ma).
- There is a peak at ca. 3200 Ma matching the age of the Santa Bárbara event.
- The ca. 3000 Ma peak suggest an event of continental crust production that took place between the Rio Das Velhas I and Santa Bárbara magmatic events.
- Small peaks at ca. 3450 and 3550 Ma were found by Noce et al (2005) and Machado et al. (1996), respectively. The age of these peaks do not match with any of the magmatic event preserved in the basement, suggesting the existence of a pre-3200 Ma (older than the Santa Bárbara event) continental crust.

The limited available U–Pb age data for the Maquiné Group suggest that a continental block ranging in age from 3260 to 2877 Ma was the main source for the sandstones and conglomerates of this group (e.g., Machado et al., 1996). A recent study has associated this sedimentary sequence with the genesis of an inferred arc formed during the Rio das Velhas II event (Lana et al., 2013). Moreira et al. (subm.) produced geochronological U-Pb data of ca. 1500 zircon grains from different units of the Maquiné Group. The new data indicate that the main source of the basin are rocks formed between 2760 and 2800 Ma (i.e. Rio das Velhas II event) and that the maximum depositional age for the Casa Forte Formation is 2730 Ma. Thus, suggesting that the basin closed after the Mamona magmatic event.

Finally, Schrank and Machado (1996a and b) dated monazite grains from the Nova Lima and upper Maquiné Groups obtaining Paleoproterozoic metamorphic ages spanning between 2080 Ma to 1989 Ma (Table E, Data Repository). These data are consistent with the ages obtained for metamorphic monazite and titanite grains from the basement (Noce et al., 1998; Aguilar et al., 2015) as well as with U-Pb zircon magmatic ages from two leucocratic dikes analysed by Machado et al. (1992) in the southern part of the Bação complex.

6. The Minas Supergroup

6.1. Main stratigraphic features

The Paleoproterozoic Minas Supergroup (Dorr, 1969; Renger et al., 1995) is a ca. 6000 m-thick package of clastic and chemical rocks lying unconformably on the Archean greenstone belt (Fig. 3). According to Alkmim and Martins-Neto (2012), the Minas Supergroup can be subdivided in two sequences separated by a regional unconformity. The basal sequence, involving continental to marine sediments (Dorr, 1969; Renger et al., 1995) represents the development stage of a passive margin basin. The overlying sequence, consisting of the turbidites of the Sabará Group was interpreted as a submarine fan deposit marking the inversion of the passive margin (Machado et al., 1996; Alkmim and Marshak, 1998; reis et al., 2002).

The basal continental to marine sedimentary sequence has been further subdivided into:

- A ca. 600 m-thick package of gold-uranium-bearing alluvial to marine sandstones, conglomerates and subordinate offshore pelites comprising the Tamanduá and Caraça groups (Simmons and Maxwell, 1961, Dorr, 1969). These rocks represent the rift and transitional phases of the passive margin development (Renger et al., 1995; Alkmim and Marshak, 1998);

- A 400 m-thick package of marine sediments that includes banded iron formations and carbonates of the Itabira Group (Dorr, 1969), recording the thermal subsidence stage of the continental passive margin (Alkmim and Marshak, 1998);
- A ca. 450 m-thick pile of deltaic to shallow marine to deep water sediments (Piracicaba Group, Renger et al., 1995), consisting mainly of siliciclastic rocks with minor carbonates.

In the next sections, we discuss the main stratigraphic and geochronological features of each group. A summary of ages for the Minas Supergroup is presented as Supplementary material (Table D).

6.2. Tamanduá and Caraça Groups

The beginning of the rifting stage is recorded by the deposition of the Tamanduá Group and by the overlying basal unit of the Caraça Group: the Moeda Formation (Dorr, 1969). The Tamanduá Group (Simmons and Maxwell, 1961; Dorr, 1969) comprises mostly quartzites and quartz-phyllites -also referred as Cambotas Quartzite- and minor phyllitic and dolomitic itabirites at the top. The unit crops out in small and discontinuous areas, lying in contact with the Maquiné Group through an erosional unconformity (Dorr, 1969). The Caraça Group (Dorr, 1959) showing great lateral extension in relation to its average thickness, encompasses quartzites, metaconglomerates (Moeda Formation) and phyllites (Batatal Formation) that overlie with angular and erosional discordance the Archean greenstone belt and conformably underlie the chemical sediments of the Itabira Group. The Moeda Formation comprises mostly quartzites. Subordinate pyritiferous and locally auriferous metaconglomerates, crop out predominantly in the northern half of the Quadrilátero Ferrífero (Dorr, 1969; Vilaça, 1981; Renger et al., 1988; Koglin et al. 2012). The average thickness of the formation is ca. 300 m, locally reaching up to 1000 m. This sequence represents a braided river system locally alternated with deltaic to beach deposits as well as with thin deposits formed during marine transgression events (Vilaça, 1981; Canuto, 2010). The Moeda Formation exhibits significant mineralogical and grain size lateral variation. In several localities, the basal conglomerates exhibit lenticular shaped pebbles and cobbles of phyllites probably from the Nova Lima Group as well as rounded quartz and quartzite cobbles (Dorr, 1969; Koglin et al., 2012). Some of the basal fluvial metaconglomerates exhibit heavy mineral layers of detrital pyrite with economic gold concentrations (Renger et al., 1988). The Caraça cycle ends with the deposition of the Batatal Formation (Maxwell, 1968, Dorr, 1969) that conformably overlies the Moeda Formation. The contact between the two formations is commonly sharp, but locally the units can also be intergradational (Wallace, 1965). The Batatal formation consists of bluish-grey phyllites with minor metacherts, iron-formation and graphitic phyllites (Simmons, 1968) cropping out in the western and central areas of the Serra do Curral where it shows a thickness ranging from 30 to 200 meters (Dorr, 1969). The sedimentation of the Batatal Formation reflects the gradation from a marine to a coastal marine environment (Moraes, 1985), recording the transition from the rift-opening to the passive margin stage (Alkmim and Marshak, 1998).

Zircon U–Pb detrital age data for the quartzites of the Caraça and Tamanduá sediments show two main age populations: 2.85-2.90 and 2.68-2.75 Ga (Machado et al., 1996; Hartmann et al., 2006; Koglin et al., 2014; Fig. 11). The age of these population peaks matches with the Rio das Velhas I and Mamona events for the genesis of the gneisses and granites of the basement. The youngest concordant zircon detrital age for a quartzite sample of the Tamanduá Group indicates a maximum age of sedimentation of 2676 ± 23 Ma (Koglin et al., 2014). The deposition age for the Moeda Formation is a matter of debate. A maximum depositional age as young as 2580 ± 7 Ma was proposed by Hartmann et al. (2006) based on U-Pb SHRIMP data from a zircon grain derived from a quartzite at the top of the Serra de Moeda. This depositional age is slightly younger than the deposition ages determined by Machado et al.

(1996) for three quartzites collected near the city of Ouro Preto, south of the Serra do Gandarela and in western flank of the Serra de Moeda (2606 ± 47 Ma, 2649 ± 16 Ma and 2651 ±33 Ma, respectively). Recently, U-Pb analyses carried out on zircons grains from the southernmost tip of the Serra de Gandarela led Koglin et al. (2014) to suggest a maximum depositional age for the upper part of the Moeda Formation of 2623 ± 14 Ma. In addition, Koglin et al. (2014) determined the Lu–Hf isotope composition of detrital zircon grains from metaconglomerates of the Moeda Formation (Fig.12). The zircon grains show mainly subchondritic initial ε_{Hf} and large ε_{Hf} variations for all the population peaks.

6.3. Itabira Group

The sedimentation of the Caraça shallow-water pelites (Batatal Formation) is interdigitated with rocks formed during a major marine transgression recording a period of iron-rich chemical sedimentation known as the Itabira Group (Dorr, 1969). This event led to the accumulation of more than 350 m-thick Lake Superior-type banded-iron deposit –the Cauê Formation-, and to the subsequent deposition of ca. 600 m of the stromatolite-rich carbonates of the Gandarela Formation (Fig. 3; Dorr, 1969; Babinski et al., 1995; Machado et al., 1996). The Cauê Formation (Dorr, 1969; Klein and Ladeira, 2000) or Cauê *Itabirite* –as metamorphosed rocks of the banded iron-formations are known in Brazil (the term itabirite was introduced by Eschwege in 1822) - is nowadays the economically most important unit of the Quadrilátero Ferrífero, hosting world-class hematite-rich iron ore deposits producing more than 180 Mt per year (Rosière et al., 2008). Four compositionally different lithofacies of the metamorphosed iron formations occur: siliceous, dolomitic, amphibolitic and magnetitic itabirites (Fig. 9). Rosière et al. (2008) reviewed the main features of the iron ores in the Quadrilátero Ferrífero, presenting the petrogenetic and metallogenic models proposed for the origin of these rocks. The youngest unit of the Itabira Group is the Gandarela Formation (Dorr, 1969; Babinski et al. 1993). This formation is predominantly composed of dolomites, limestones, carbonaceous phyllites and dolomitic iron-rich formation in which stromatolitic structures are preserved (Souza and Müller, 1984). This formation crops out in the Serra de Moeda, in the central part of the Serra do Curral and in the Gandarela syncline where it reaches its maximum thickness (750 meters, Dorr 1969). Its basal contact with the Caûe Formation consists of a transitional zone (up to ten meters thick) in which the dolostone is associated with the dolomitic itabirite. Babinski et al. (1995) provided an isochron Pb-Pb age of 2419± 19 Ma for a stromatolithic limestone from an intermediate member of the formation sampled from the Gandarela syncline. This age, due to the preservation of organic structures and the absence of deformation in the rocks of the Ganderela Formation, is considered to represent the sedimentation age of the carbonates.

The depositional age of the Cauê Formation can be bracketed between 2580 and 2420 Ma; i.e. between the maximum deposition age of the underlying Moeda Formation (Machado et al., 1996; Hartmann et al., 1996) and the age of the overlying Gandarela Formation (Babinski et al., 1995). Recently U–Pb dating of zircon grains from a metavolcanic layer sampled within the Itabira iron formation led Cabral et al. (2012) to propose a considerably earlier (2650 Ma) deposition age for this unit (Fig. 11). The interpretation of this age is controversial, since it contradicts most of the data produced so far for the underlying Caraça Group. Recently, LA-ICP-MS U-Pb dating of detrital zircon grains from a quartzite lens hosted within the Cauê Formation showed a quasi-unimodal distribution with a peak at 2795 Ma (Cassino et al., 2014). The youngest concordant zircon grain in this lens yielded an age of 2453 ± 18 Ma.

6.4. Piracicaba Group

The carbonates of the Gandarela Formation are in contact with deep-seated marine sandstones and pelites of the Piracicaba Group (Dorr et al., 1957; Dorr, 1969). This group is composed of ca. 1300 m-thick metasediments consisting of quartz-rich sandstones that gradually fines and thins upward to mudstone and graphitic mudstone. The Piracicaba Group is subdivided into four formations that are known as the Cercadinho, Fêcho do Funil, Taboões and Barreiro formations (Fig. 3). The lowest sequence (i.e. Cercadinho Formation) comprises coarse to fine grained hematite-rich quartzites, quartzites, silvery sheen phyllites, Fe-rich phyllites as well as dolomites (Simmons, 1968; Dorr, 1969). A conglomerate containing pebbles derived from the underlying Cauê and Gandarela Formations, from which the Cercadinho Formation is separated by an erosional unconformity, marks the base of the Piracicaba Group. Detrital zircon grains from quartzites and poorly sorted conglomeratic quartzites at the base of the Cercadinho Formation, in the western part of Serra do Curral, show an Archean contribution during the initial stages of deposition of the Piracicaba Group (Mendes et al., 2014). The detrital zircon ages from these samples range between 2750 and 2900 Ma with two distinguishable peaks at 2793 Ma and 2859 Ma (Fig. 11), which correspond to the Rio das Velhas II and Rio das Velhas I events. The deposition age for the Piracicaba Group is still poorly constrained between 2420 Ma (i.e. the age of the Gandarela Formation; Babinski et al., 1995) and ca. 2100 Ma (Babinski et al., 1993). The minimum age for the Piracicaba Group (2100 Ma) was obtained by Babinski et al. (1993), by dating deformed dolomitic carbonates from the Fecho do Funil Formation. This Pb/Pb isochron age is interpreted as the metamorphic age of the rock, thus defining the minimum age of deposition for the carbonates.

6.5. Sabará Group

The Sabará Group is the youngest and thickest unit of the Minas Supergroup (Fig. 3), comprising up to 3.5 km-thick pile of coarsening upwards sequences of metapelites, greywackes, lithic conglomerates, and diamictites (Fig. 9; Dorr 1969; Barbosa 1979; Renger et al. 1994; Reis et al., 2002). This formation is interpreted as representing a turbiditic, submarine fan deposit formed during the inversion of the Minas Supergroup passive margin (Alkmim and

Martins-Neto, 2012). The unit is well exposed and can be mapped continuously for more than 60 km along the Serra do Curral (Fig. 1).

Detrital zircon ages obtained by Machado et al. (1996) for a greywacke from the Serra do Curral suggest a distinctive age distribution pattern showing a few Proterozoic ages spreading between 2100 and 2500 Ma and a well-defined peak at 2850-2900 Ma (Fig. 11). The U-Pb age distribution of detrital zircon grains in this sample is remarkably different from the age distribution of zircon grains from a felsic schist belonging to the Sabará Group, collected close to Ouro Preto. The schist, analysed by Hartmann et al. (2006) by SHRIMP, shows no Proterozoic ages and two Archean peaks at 2720 and 2900 Ma (Fig. 11). Although, Hartmann et al., (2006), reported no Proterozoic ages, a Rhyacian maximum age of deposition for the Sabará Group is confirmed by two zircon ID-TIMS U-Pb ages yielding 2125±4 Ma (Machado et al. 1992) and 2131±5 Ma (Machado et al., 1996). These Rhyacian ages match well with the ages obtained by Noce et al. (1998) and Seixas et al. (2013) from the Alto Maranhão suite (*ca*. 2130 Ma) and associated granitoids of the Mineiro Belt (2100-2200 Ma) that bounds the Quadrilátero Ferrífero to the south. In addition, the deposition of the Sabará turbidites marks a major change in the source of Minas sediments. Paleogeographic studies (Dorr, 1969; Renger et al., 1995; Machado et al., 1996) indicate that during the genesis of the passive margin the Archean sources were located to the north. On the other hand, a non-cratonic source, located to the south and southeast, is suggested to account for the occurrence of 2100 Ma old granitoid clasts and zircons in the conglomerates of the Sabará Group (Alkmim and Martins-Neto, 2012). The turbiditic pelites, greywackes, lithic conglomerates and diamictites of the Sabará Group were interpreted as representing syn-orogenic sediments (Dorr, 1969; Renger et al., 1995; Reis et al., 2002) shed from a colliding magmatic arc and spread over an evolving foreland basin onto the São Francisco craton margin during the Rhyacian orogeny (Alkmim and Marshak, 1998; Alkmim and Martins-Neto, 2012).

7. The Itacolomi Group

The Itacolomi Group (Dorr, 1969), the youngest unit in the Quadrilátero Ferrífero supracrustal sequence, comprises an up to 2 km-thick section of medium- to coarse-grained quartz metasandstones (Fig. 9), metaconglomerates and minor phyllites separated from the underlying Minas Supergroup by regional unconformity (Dorr, 1969; Alkmim and Martins-Neto, 2012). The occurrence of a major erosional event at the base of the unit is manifested by the polymictic nature of the metaconglomerates, in which pebbles of quartzite, itabirite and granitic rocks were recognized (Dorr, 1969). The group has a restricted areal distribution, limited to the southernmost region of the Quadrilátero Ferrífero south of Ouro Preto (Fig. 1). These rocks preserve primary sedimentary structures such as ripple marks and cross bedding and exhibit abrupt lateral changes of sedimentary facies. These features suggest that the Itacolomi Group represents interfingering marine and continental deposits. The only studies of sedimentary provenance that used U–Pb dating of detrital zircons for the Itacolomi Group are those published by Machado et al. (1996) and more recently, Hartmann et al. (2006). A summary of zircon U-Pb ages in the Itacolomi Group is presented as Supplementary material (Table D). The two datasets show significant differences that are difficult to reconcile, as the datasets are hardly comparable. Machado et al. (1996) determined by laser ablation the U-Pb age of many detrital grains, however the age uncertainties are variable and typically large (1σ = 15-200 Ma) and the degree of concordance is not provided, therefore casting doubt about the reliability of these ages. On the other hand, Hartmann et al. (2006) used a more accurate technique (SHRIMP) and provided information about the degree of concordancy as well as on accuracy and precision. However, the database of Hartmann et al. (2006) is very limited and likely not representative as these authors analysed only seven concordant zircons. Hartmann et al. (2006) determined a maximum depositional age of 2143±16 Ma for the Itacolomi Group in its type locality, while Machado et al. (1996) determined depositional ages that are ca. 100 Ma younger (i.e. 2039±42 Ma and 2059±58 Ma; Fig. 11). Another difference between the two datasets is that Machado et al. (1996) found many grains yielding $^{207}Pb/^{206}Pb$ ages in the range 2200-2500 Ma (Fig.11) which are not found by Hartmann et al. (2006). Finally, in contrast to what is observed for the underlying Sabará Group, only a subset of zircon grains from the sandstone and conglomerates of the Itacolomi Group yielded Archean ages. The large percentage of Rhyacian detrital zircons (i.e. between 2300 and 2050 Ma) in the conglomerates of the Itacolomi basins support a non-cratonic source (Machado et al., 1996; Alkmim and Marshak, 1998) suggesting that most of the sediments were derived from terrains generated during the Rhyacian orogeny. The source was probably located to the south and southeast, with the Alto Maranhão Suite (ca. 2130 Ma, Seixas, et al., 2013), Juiz de Fora (2041±7 Ma and 2137±19, Noce et al., 2007) and Mantiqueira complexes (2119 ±16 to 2084±13 Ma, Noce et al., 2007) being the most suitable candidates. The Itacolomi Group is interpreted as an intermontane molasse deposit developed along the margin of the Archean nucleus of the São Francisco craton during the collapse phase of the Rhyacian orogeny (Marshak et al., 1992; Alkmim and Marshak, 1998; Alkmim and Martins-Neto, 2012).

8. Mafic and intermediate dikes

Mafic and intermediate intrusives occur as meter-scale blocks, boudins and lenses hosted within the gneisses as well as dikes crosscutting granites and supracrustal rocks. Carneiro (1992) and Carneiro et al. (1998) defined four groups of mafic-intermediate amphibolites in the Bonfim complex, based on field relationships, orientation as well as on textural and compositional data. Two swarms of dikes crosscut the basement and gave Neoarchean Sm-Nd model ages (Carneiro et al., 1998) whereas the other two groups are younger as indicated by the fact that they crosscut Paleoproterozoic metasediments and exhibit well-preserved sub-volcanic textures. Indeed, Silva et al. (1995) dated baddeleyite crystals extracted from a gabbro crosscutting the Sabará Group in the northern part of the Quadrilátero Ferrífero obtaining a crystallization age of 1714 Ma. In the Belo Horizonte complex, unmetamorphosed tholeiitic dikes crosscutting the basement and the Supracrustal sequences yielded K/Ar feldspar ages of ca. 1000 Ma (Chavez et al., 1997). These dikes will not be described any further as this late evolution of the Quadrilátero is beyond the scope of this review.

The oldest population of amphibolites in the Quadrilátero is composed of mafic and intermediate boudins intruding the felsic basement. These bodies that intruded as dikes, were later rotated into parallelism with the banding in the enclosing gneisses and disrupted during ductile deformation of the basement. These boudins or lenses (hereafter "rafts") are fine- to medium-grained, with textures varying from nematoblastic to granoblastic and geochemical affinity of within-plate tholeiite basalts. Recently, one of these rafts from the Bação complex was dated by zircon U-Pb geochronology by Lana et al. (2013) yielding a well-defined Concordia age of 2778 ± 8 Ma. Titanite U-Pb ages from the same mafic raft yield Paleoproterozoic (ca. 2.1) ages suggesting resetting of the basement in the southern Quadrilátero during the Rhyacian (Aguilar et al., 2015). Farina et al. (2015) dated a dike crosscutting the ca. 2770 Ma old Samambaia tonalite in the Bonfim dome. Zircon grains from this rock gave a weighted mean $^{207}Pb/^{206}Pb$ age of 2719 ± 14 Ma, with this age matching well with the age of mafic dikes in the Uauá block in the northern São Francisco craton (Oliveira et al., 2103). These geochronological data seem to confirm the occurrence of two Neoarchean systems of dikes. The first swarm that emplaced at ca. 2780 Ma was successively metamorphosed and deformed together with the hosting gneisses. The second population of dikes crosscuts granitoids formed during the 2760-2680 Ma Mamona event. These dike systems are useful relative time markers allowing bracketing of the metamorphism and deformation between 2780 Ma and 2720 Ma. The tectonic significance of these Archean dikes is currently unknown as no systematic geochemical and isotopic studies were performed in the region.

9. Main structures and structural evolution

The Quadrilátero Ferrífero experienced a polyphase tectonic history that produced complex regional patterns of rock deformation (e.g., Dorr 1969; Drake and Morgan 1980; Endo 1997; Alkmim and Marshak 1998; Chemale et al 1994; Chauvet et al. 1994). This complexity, together with the lack of absolute ages dating the tectonic structures, gave rise to different and in many cases conflicting interpretations for the deformation history of the Quadrilátero. Three main sets of structures characterise the Quadrilátero Ferrífero. From the oldest to the youngest, these are:

- Northwest-verging and north–northeast-trending regional-scale folds and thrusts generating large asymmetric folds (the Gandarela syncline, Conceição anticline, Itabira synclinorium) and the steeply dipping to overturned Serra do Curral homocline (e.g., Pomerene, 1964; Dorr, 1969; Pires, 1979; Marshak et al., 1992; Alkmim & Marshak, 1998; Fig. 1).
- Extensional structures related to the formation of a typical dome-and-keel province; in which troughs of deformed and metamorphosed Paleoproterozoic supracrustal rocks surround domes of Archean basement (e.g., Belo Horizonte, Caeté, Bação complexes; Chemale et al., 1991, 1994; Alkmim & Marshak, 1998).
- West verging thrust folds reactivating and overprinting pre-existent structures in the region east of a north-trending line that follows the west edge of the Moeda syncline (Fig.1; Chemale et al., 1994).

According to Alkmim and Marshak (1998), these structures correspond to three kinematic phases that affect the rocks of both the Rio das Velhas and Minas Supergroups. The maximum age of formation of the oldest structures is constrained by the deposition age of the top of the Minas Supergroup: the Sabará group. This 3.5 km-thick flysch sequence that has a maximum deposition age of 2130 Ma (Machado et al., 1996) is involved in northwest-verging folding. This age constraint led Alkmim and Marshak (1998) to interpret the northwest-verging folds and thrusts as a fold and thrust belt formed shortly after the deposition of the Sabará Group in the foreland of a Rhyacian collisional orogeny. This event, however, did not generate a strong foliation.

The second structures relate to the formation of the dome-and-keel geometry of the Quadrilátero. The contacts between granitic-gneissic complexes and the Supracrustal sequences are tectonic, marked by thrusts and/or normal faults, and by ductile shear zones showing variable sense of displacement (Hippertt et al., 1992; Machado et al., 1996; Alkmim & Marshak, 1998). For instance, the enveloping shear zones of the Bonfim and Belo Horizonte domes show normal sense kinematic indicators (Hippertt et al., 1992), while the shear sense observed in the contact zone of the Bação and Caeté domes varies between reverse, reverse-oblique and strike-slip (Marshak and Alkmim, 1989; Hippertt, 1994; Endo, 1997). Kinematic indicators in supracrustal rocks clearly indicate supracrustal-side-down displacement (Marshak et al., 1997) supporting an extensional event (Hippertt et al., 1992). Metamorphic aureoles in the supracrustal rocks at the contact with the domes have different thickness (Pomerene, 1964; Herz, 1978; Carneriro, 1992; Jordt-Evangelista et al., 1992; Marshak et al., 1992, 1996). The dome-border shear zones and their related metamorphic aureoles overprint the foliation of Archean gneisses as well as the early regional lower greenschist-facies metamorphism and the foliation, folds and faults in the supracrustal sequence. This evidence indicates that the doming event post-dated the northwest-verging thrust and associated syncline folds (Marshak et al., 1992; Alkmim and Marshak, 1998). Syn-shear garnets formed in a dome-border shear zone in rock of the Minas Supergroup gave a Sm–Nd age of 2095 ± 65 Ma (Marshak et al., 1997). This age, that is consistent with titanite and monazite U–Pb metamorphic ages obtained in the basement (Machado et al., 1992; Schrank and Machado, 1996a, b; Aguilar et al., 2015), suggests that dome emplacement occurred during the extensional collapse of the Rhyacian orogen.

Finally, the collisional and extensional structures described were overprinted and reactivated by a series of west-verging thrust faults and associated structures, attributed to the Neoproterozoic Brasiliano event (630 to 490 Ma; e.g., Endo and Fonseca, 1992; Chemale et al., 1994; Alkmim and Marshak, 1998). West-verging structures including penetrative east-southeast-dipping schistosity, north-trending folds and a north–south-trending crenulation lineation are observed east of a north-trending line that follows the west edge of the Moeda syncline and cuts northwards across the Serra do Curral (i.e. the Brasiliano front). West of this front, the Brasiliano tectonism generates northeast-trending dextral strike-slip shear zones (Alkmim and Marshak, 1998).

10- Discussion: models and open problems

In this section we discuss the evolution of the Quadrilátero Ferrífero from the genesis of the continental crust in the Paleoarchean to the Orosirian Period. In addition, we present a series of unresolved questions relative to the genesis and evolution of the Quadrilátero Ferrífero.

10.1. Building up the continental crust: the Paleo- to Mesoarchean rock record

The oldest preserved rocks in the Quadrilátero Ferrífero are banded gneisses from the Santa Bárbara complex that formed at the Paleo-Mesoarchean boundary (i.e. 3200 Ma, Lana et al., 2013). Unfortunately, very little study has been conducted on these rocks so that the Paleo-Mesoarchean rock record of the Quadrilátero Ferrífero remains enigmatic. The occurrence of these gneisses in the region provide various lines of evidence for the generation of a considerable volume of continental crust during the Paleoarchean and Late Mesoarchean

(Lana et al., 2013). Firstly, zircon grains yielding 3000–3400 Ma ages occur as inherited components in a limited number of gneisses dated by Lana et al. (2013) and represent a significant subset in the detrital spectra of the greenstone belt succession and the Minas Supergroup (Figs. 10 and 11). In particular, minor peaks at ca. 3200 Ma occur in the Tamanduá, Caraça, Itabira and Piracicaba Groups (Fig. 11) as well as in the greenstone belt in both the Nova Lima (Fig. 10) and Maquiné groups (Moreira et al., 2015). Secondly, Sm–Nd model ages for Neoarchean gneisses and granites in the Bonfim complex resulted in ages of up to 3300 Ma (Teixeira et al., 1996). Finally, most of the detrital zircon grains from the Moeda Formation have subchondritic initial ε_{Hf} values (Fig. 12) resulting in calculated depleted mantle model ages varying from 3200 to 3600 Ma (Koglin et al., 2014). These model ages are in good agreement with those calculated by Albert et al. (2015) for magmatic zircon crystals in gneisses and granitoids from the Bonfim complex. Taken together these geochronological and isotopic data advocate for the existence of a large segment of Paleoarchean continental crust in the Quadrilátero Ferrífero. This crust was probably reworked and eroded during the subsequent epidodes of magmatic and tectonic activity.

Recently, Farina et al. (2015) compared the composition of gneisses and granitoids from the Quadrilátero Ferrífero with TTGs from other cratons and experimental melts produced by fluid-absent melting of tonalites. Medium-K rocks are significantly more silica- and K_2O-rich and less Na_2O- and Al_2O_3-rich than typical TTGs (Fig. 6) and show intermediate compositions between TTGs and experimental melt obtained through fluid-absent partial melting of TTG sources such those used as starting material by Watkins et al. (2007). Based on whole-rock chemical arguments, Farina et al. (2015) suggested that medium-K banded gneisses and granitoids formed by mixing between a TTG-like melt produced by partial melting of basaltic oceanic crust and a melt derived by reworking of the continental crust. The occurrence of a recycled crustal component in the genesis of the medium-K rocks formed during the Rio Das Velhas I and II magmatic events is supported by the negative ε_{Hf} composition displayed by both detrital zircons in the Moeda Formation (Koglin et al., 2014) and magmatic zircon crystals in gneisses and granitoids (Albert et al., 2015). A subset of detrital zircon in the Moeda Formation (< 10% of the grains) and magmatic zircon from a few gneisses sampled in the Bação complex show superchondritic Hf isotopic compositions suggesting that juvenile crust was also formed during the Meso- and Neoarchean Rio das Velhas I and II magmatic events (Koglin et al., 2014; Albert et al., 2015).

10.2. The record of plate tectonics: the Meso-Neoarchean

Two significant changes occurred in the Quadrilátero Ferrífero during the early Neoarchean, between ca. 2800 and 2700 Ma. Firstly, high-K granites similar to post-Archean high-silica I-type granites were produced, largely replacing medium-K granitoids and gneisses; the latter showing chemical affinity similar to TTGs and representing the volumetrically dominant rocks produced during the Rio das Velhas I and II events (ca. 2920-2760 Ma). Secondly, mature sedimentary sequences emerged and were deposited in the Rio das Velhas greenstone belt forming the 2000 m-thick association of conglomerates and sandstones of the Maquiné Group. We argue that a model involving subduction of oceanic crust and subsequent continental collision between two continental blocks account for these two major changes explaining coherently most of the Neoarchean evolution of the Quadrilátero Ferrífero. The model that is illustrated in figure 13 has been proposed to explain the late-Archean geodynamic evolution of many other terranes worldwide (e.g., Percival et al., 2006; Laurent et al.; 2014).

In the Quadrilátero, medium-K rocks were produced during the Rio das Velhas I and II events (2920-2850 and 2800-2760 Ma). These rocks have chemical composition suggesting mixing between magmas derived by partial melting of an oceanic crust and magmas derived by crustal reworking. These compositions can be generated by significant interaction between melts derived by melting a subducting oceanic slab and an upper plate formed by a Meso-

Paleoarchean continental nucleus. In this scenario, clastic sediments from the upper-plate eroded and deposited in a back arc basin (i.e the Maquiné Group) and volcanic rocks with TTG-affinity erupted forming dacitic flows in the greenstone belt.

The granitoids formed during the Rio das Velhas II event were readily deformed and metamorphosed between 2780 and 2730 Ma as indicated by the age of the earliest granites emplaced in the Bação, Bonfim and Belo Horizonte complexes (Machado et al., 1992, Romano et al., 2013, Farina et al., 2015). During these ca. 50 Ma of metamorphism the medium-K granitoids were deformed and transformed into banded gneisses and leucogranitic sheets and mafic/intermediate dikes were emplaced and rotated into parallelism with the banding in the gneisses. The pressure and temperature conditions attained during the metamorphic event are not constrained, but the occurrence of migmatites suggest that the basement reached locally granulite-facies conditions (Alkmim and Marshak, 1998). We suggest that this high-grade metamorphic event records the collision between two continental blocks. During crustal thickening, fertile metasedimentary rocks were buried. Then, thermal relaxation and extension following lithospheric delamination triggered the upwelling of the asthenosphere heating up the continental crust and inducing partial melting. High-K granites and crosscutting mantle-derived dikes form in this syn- to late-collisional geodynamic environment. Based on whole-rock chemical arguments, Farina et al. (2015) suggested that high-K granites in the Quadrilátero were produced by low degree of melting of metasedimentary sources deposited during the Rio das Velhas II event. In this scenario, the transition between medium-K and high-K granitoids reflects a change in the sources undergoing melting.

It is worth noting that during the Neoarchean, the northern (i.e. the Belo Horizonte complex) and southern (the Bação and Bonfim complexes) portions of the Quadrilátero Ferrífero experienced different magmatic evolutions. In the southern portion, medium-K granitoids emplaced for ca. 20 Ma (2790-2770 Ma) after the metamorphic peak and were then replaced by high-K monzogranite and syenogranite with composition of late Archean biotite and two-mica granites (Farina et al., 2015). This rather sharp compositional change was not recorded in the Belo Horizonte complex where the ca. 2750-2720 Ma massive granitic batholiths (Pequi and Florestal, Fig. 1) have TTG-affinity. In the Belo Horizonte complex, minor bodies of high-K granites (e.g. the Santa Luzia granite) were only emplaced at ca. 2700 Ma (Noce et al., 1997).

The emplacement of high-K granites during the Mamona magmatic event marks the stabilization of the southern São Francisco craton. This probably occurred because the emplacement of high-K magmas at shallow level in the crust concentrated heat-producing elements (e.g. K, Th, U) in the upper crust, leaving the middle crust thermally stable (e.g., Sandiford and McLaren, 2002). In addition, partial melting of the continental crust left the lower crust dry (refractory) and therefore more resistant to future episodes of partial melting (Romano et al., 2013).

10.3. Evolution of the Minas Basin

The rocks of the Minas Supergroup represents a passive-margin to syn-orogenic sedimentary package tracking the operation of a Wilson cycle between ca. 2.6 and 2.0 Ga (Alkmim and Marshak, 1998). The development of the Minas passive margin took place in the time interval between approximately 2600 and 2400 Ma (i.e. between the deposition of the Moeda and Gandarela formations; Babinski et al., 1995; Koglin et al., 2014) along the borders of the São Francisco and Congo cratons. The clastic metasedimentary rocks, forming the lowest part of the Minas Supergroup (the Tamanduá and Caraça groups), were deposited during the early subsidence of the precursor passive margin basin. The intermediate Itabira Group that is composed of the Cauê Banded Iron Formation, hosting the valuable iron ore deposits of the Quadrilátero Ferrífero, and of the limestones of the Gandarela Formations, mark the thermally subsiding stage of the Minas Basin (Alkmim and Martins-Neto, 2012). Finally, clastic immature and flysch-like metasedimentary rocks of the uppermost Sabará Group, marks the inversion of the basin representing syn-orogenic sediments shed from a colliding magmatic arc (Dorr 1969; Barbosa 1979; Renger et al. 1995). The Sabará Group contains detrital zircon grains as young as 2125 ± 4 Ma (Machado et al., 1992); i.e. 300 Ma younger than the age of the underlying units of the Minas Supergroup. This marks a significant change in both the depositional setting and sediment source compared to the older Minas units that mainly derived from Archean material. The Sabará turbidites are a submarine fan deposit interpreted as having formed either as a syn-orogenic deposit scraped off from an active magmatic arc (Hartmann et al. 2006) or as a foreland basin (Machado et al., 1996).

10.4. The Minas accretionary orogeny

The regional setting of the Quadrilátero Ferrífero is dominated by two set of structures: i) northwest-verging and north–northeast-trending regional-scale folds and thrusts with associated low- to medium-grade metamorphism affecting the supracrustal rocks and ii) gneiss-granitic domes surrounded by elongate keels of polydeformed supracrustal rocks (i.e dome-and-keel structure). These structures formed in the Paleoproterozoic as indicated by the depositional age of the Sabará Group (2125 Ma; Machado et al., 1996), which is involved in the folding and thrusting, as well as by the age of the dome-related metamorphic contact aureole (ca. 2095 Ma; Marshak et al., 1997). The fold-and thrust belt formed in the Paleoproterozoic during the collision between the nuclei of the present-day São Francisco and Congo cratons (Alkmim and Martins-Neto, 2012). In the southern portion of the São Francisco craton, the continental collision between these two plates generated the Mineiro Belt and the adjoining Mantiqueira and Juiz de Fora complexes (Teixera et al., 2015). The Mineiro Belt, bordering the Quadrilátero Ferrífero to the south, is a km-wide corridor of polydeformed Archean gneisses and greenstone belt remnants intruded by 2350–2000 Ma granitoids (Seixas et al., 2012). This belt was generated through successive accretion of oceanic and continental arcs that were active during the Paleoproterozoic and then final collision with the São Francisco craton, representing the foreland of the belt (Teixeira et al., 1996; Alkmim and Marshak, 1998; Ávila et al., 2010). This event is recorded in the basement by monazite and titanite crystals yielding 2100-1950 Ma U-Pb metamorphic ages (Machado et al., 1992; Schrank and Machado, 1996a, b; Aguilar et al., in prep). The tectonomagmatic event affecting the southern São Francisco craton, usually referred to as the Transamazonian event (e.g., Machado et al., 1996), has been named by Teixeira et al. (2015) the Minas accretionary orogeny.

In the Orosirian, after the formation of the fold-and thrust belt the Quadrilátero underwent orogenic collapse, resulting in the deposition of the alluvial sandstones, conglomerates and pelites of the Itacolomi Group and development of the dome-and-keel structure (Alkmim and Marshak, 1998). The large percentage of Rhyacian detrital zircons (i.e. between 2300 and 2050 Ma) in the conglomerates of the Itacolomi basins support a non-cratonic source (Machado et al., 1996; Alkmim and Marshak, 1998) suggesting that most of the sediments were derived from terrains generated during the Minas accretionary orogeny.

At a regional scale, the Minas accretionary orogeny correlates with the tectonic-magmatic events recognized in the Eastern Bahia belt in the northern portion of the São Francisco craton (Teixeira et al., 2015). These events seem to reflect the assembly of a supercontinent during the Orosirian period, the Atlantica supercontinent (Rogers, 1996), followed by Columbia (Rogers and Santosh, 2004; Zhao et al., 2004), whose reconstructions, though not fully accomplished, have progressed significantly in the last few years.

10.5. Questions for future research

Recently, new geochronological data helped improve our understanding of the ca. 1.5 Ga of evolution of the Quadrilátero Ferrífero (Lana et al., 2013, Romano et al., 2013, Mendes et al., 2014; Farina et al; 2015). However, many open questions remain to be solved. The list of queries that follows is not aimed to be exhaustive, but we hope it could serve as a guide for future studies.

- What are the metamorphic conditions attained by the basement during the Neoarchean metamorphic event? Did the basement undergoes extensive partial melting between 2780 and 2730 Ma?
- During the Neoarchean Mamona event, TTG-like granitoids emplaced in the Belo Horizonte complex while high-K granites were generated in the Bação and Bonfim complexes. Why magmas with different chemical affinity formed at the same time in the northern and southern portion of the Quadrilátero Ferrífero? Moreover, what is the chemical composition of gneisses and granitoids in the Santa Bárbara and Caeté complexes?
- Metaluminous Mg- Fe- and K-rich monzodiorite and granodiorites forming the sanukitoid series are regarded as markers of Archean subduction (Martin et al., 2009) and typify the late Archean evolution of many cratons (e.g. Laurent et al., 2014). Magmatic rocks with sanukitoid affinity were not described in the Quadrilátero Ferrífero. How does the proposed model of Neoarchean subduction-collision for the Quadrilátero account for the lack of sanukitoids?
- What is the age and tectonic significance of the different mafic-intermediate dike swarms crosscutting the basement and the supracrustal sequences? In particular, what is the chemical composition of the two populations of Neoarchean dikes and what do they tell us about the geodynamic evolution of the Quadrilátero Ferrífero?
- What is the age and tectonic significance of the unconformity bounded Piracicaba Group, whose depositional age is still poorly constrained?
- Why are the U-Pb depositional age and age distribution obtained by Machado et al. (1996) and Hartmann et al., (2006) for the rocks of the Sabará Groups so different (Fig.

11)? Does this discrepancy reflect the fact that the samples were collected from different localities and/or different stratigraphic positions? Ultimately, what is the depositional age and age distribution of the turbidites of the Sabará Group?

- Monazite and titanites grains from the basement gave Rhyacian U-Pb ages, while no metamorphic zircon crystals/overgrowths yielded non-Archean ages. What are the metamorphic conditions attained by the basement during the Minas orogeny? What is the geographic extent of the Rhyacian metamorphic overprint? Why no magmatism was produced in the Quadrilátero Ferrífero during the continental collision between the proto São Francisco and Congo cratons?

FIGURES

Figure 1. Geological map of the Quadrilátero Ferrífero modified after Alkmim and Marshak (1998). Batholith and pluton abbreviations: F- Florestal, M- Mamona, P- Pequi, Sa- Samambaia; SN- Souza-Noschese. Inset: tectonic sketch of the São Francisco craton showing the location of the bordering Brasiliano orogenic belts as well as of the Paleoproterozoic Mineiro Belt

Figure 2. Timeline showing the main historical events and geological discoveries in Brazil from the first colonization until today.

Figure 3. Stratigraphic column of the supracrustal sequences in Quadrilátero Ferrífero. Modified after Dorr (1969) and Alkmim and Marshak (1998).

Figure 4. Field photographs of the basement. (a) Leucogranitic sheets and dikes hosted within a banded gneiss, Bação Complex. (b) Banded gneiss hosting cm-scale leucogranitic sheets following the gneissosity, Bação Complex. (c) Leucogranitic sheets in a gneiss crosscut by a late fine-grained leucocratic dike. (d) meter-scale xenolith of banded gneiss hosted within medium-granite granites, Bação Complex. (e) Coarse-grained granodiorite, Mamona batholith, Bonfim Complex. (f) Contact between biotite-rich and plagioclase–quartz–biotite granites crosscut by a leucogranitic dike, Belo Horizonte complex.

Figure 5. Normative An-Ab-Or triangle (O´Connor, 1965) showing the composition of gneisses, granites and leucogranites as well as the composition of Rio das Velhas dacites. The field for Archean TTGs is from Moyen and Martin, (2012). Data are from Gomes (1985), Carneiro et al. (1992), Noce et al. (1997), Da Silva et al. (2000) and Farina et al. (2015).

Figure 6. Harker diagrams for the igneous rocks of the Quadrilátero Ferrífero: (a) SiO_2 vs. Al_2O_3, (b) SiO_2 vs. K_2O. Grey dots are TTGs from Moyen, 2011. In (c)**,** histogram showing the frequency of K_2O/Na_2O values exhibited by the rocks of the Quadrilátero Ferrífero. The bin width used is 0.2. The height of the bars represents the number of samples having the corresponding K_2O/Na_2O value.

Figure 7. Average chondrite-normalized REE patterns for high-K granites and medium-K gneisses and granitoids. The trace element pattern for high-K granites is obtained averaging the composition of eleven samples, patterns for medium-K gneisses and granitoids are from fifteen and sixteen samples, respectively. Data are from Farina et al. (2015). The field of TTGs is drawn using the composition of high- medium- and low-pressure TTGs (Moyen, 2011). Normalization values are from McDonough and Sun (1995).

Figure 8. Timeline showing $^{207}Pb/^{206}Pb$ zircon ages for intrusive and volcanic rocks of the Quadrilátero Ferrífero. Circles, squares, diamonds and triangles indicate the Bação, Bonfim,

Belo Horizonte and Santa Bárbara complexes, respectively. White and dark grey symbols are for high and medium-K rocks, respectively. In black, mafic and intermediate dikes and metamorphic zircon ages. The vertical light grey fields indicate the different magmatic events: SB- Santa Barbara RdV I- Rio das Velhas I; RdV II- Rio das Velhas II; Mam- Mamona. Data are from Romano et al., 2013; Lana et al., 2013; Machado and Carneiro, 1992; Machado et al., 1992; Noce et al., 1998; Noce et al., 1997; Chemale et al., 1993; Noce et al., 2005.

Figure 9. Field photographs of the supracrustal rocks. (a) Komatiite showing spinifex structure, basal portion of the Nova Lima Group;. (b) Metabasalt with deformed pillow structure, basal portion of the Nova Lima Group; (c) Polymictic conglomerate of the Maquiné group containing stretched clasts. (d) Cauê Itabirite showing the typical intercalation of hematatite and quartz-rich bands; (e) Conglomerate of the Sabará Group containing clasts of quartzite, gneisses, granites and banded iron formation embedded in a chlorite-rich matrix; (f) Quartz metasandstone of the Itacolomi Group showing crossbedding. Crossbedding sets are marked by concentration of heavy minerals, especially iron oxides. The pens in (b), (c), (d) and (e) are 14 cm long.

Figure 10. Frequency histogram showing the age distribution of detrital zircon grains in the rocks of the Rio das Velhas Supergroup. The probability curve is produced considering 109 U–Pb analyses from Machado et al., 1992; Machado et al., 1996; Noce et al., 2005; Hartmann et al., 2006. Maximum discordance accepted 10%. Analyses with Th/U<0.1 were excluded. Vertical bands mark the age of the main magmatic events in the basement.

Figure 11. Frequency histogram for the Minas Supergroup. Histograms and Probability Density plots for the available U-Pb zircon ages of the Minas Supergroup and Itacolomi Group. Age display software (Sircombe, 2004) was used to build the graphs and evaluate the data. All

weighted zircon data was 95% concordant (excepting data from Machado et al. 1996) and treated as sigma-1 errors.

Figure 12. Results of U–Pb and Lu–Hf spot analyses of detrital zircon from the metaconglomerates and quartzites of the Moeda Formation presented in a $\varepsilon_{Hf(t)}$ versus $^{207}Pb/^{206}Pb$ age diagram. Data are from Koglin et al. (2014). Vertical grey bars mark the main magmatic-metamorphic events in the Quadrilátero Ferrífero. Crustal evolution trends are determined using a $^{176}Lu/^{177}Hf$ of 0.0113 for the average continental crust.

Figure 13. Sketch of the geodynamic evolution of the Quadrilátero Ferrífero during the Rio Das Velhas I, Rio Das Velhas II and Mamona periods. In the 2920-2850 Ma cartoon, we tentatively propose that the continental crust formed by multiple accretion of island-arcs. During the Rio das Velhas II period, the subduction of an oceanic crust under a continental block led to the formation of medium-K granitoids by mixing between two components: melts derived by partial melting of the mafic oceanic crust and melts derived by recycling of older continental crust. During this event, volcanic rocks erupted above the ultramafic-mafic sequence of the Nova Lima Group and mantle-derived magmas intruded the basement. Finally, during the Mamona event, two continental blocks collided. Slivers of metasediments were buried and started melting producing high-K granites and clastic sediments were deposited forming the Maquiné Group. Modified and adapted from Laurent, 2012.

Supplementary material:

Table A- Major and trace element composition of igneus rocks from the Quadrilátero Ferrífero. Data are from: Gomes, 1985; Carneiro, 1992; Noce et al., 1997; Da Silva et al., 2000; Farina et al., 2015.

Table B. Summary of U-Pb zircon ages for the basement of the Quadrilátero Ferrífero. Data are from: Machado and Carneiro, 1992; Machado et al., 1992; Chemale et al., 1993; Noce et al., 1997; Noce et al., 1998; Romano et al., 2013; Lana et al., 2013; Farina et al., 2015.

Table C. Summary of U-Pb zircon ages for the Rio Das velhas Greenstobe Belt. Data are from: Machado et al., 1992; Machado et al., 1996; Noce et al., 2005; Hartmann et al., 2006.

Table D. Summary of detrital, magmatic and metamorphic ages for the Minas Supergroup**.** Data are from: Machado et al., 1992; Babinski et al., 1995; Machado et al., 1996; Brueckner et al., 2000; Hartmann et al., 2006; Cabral et al., 2012; Koglin et al., 2014; Cassino, 2014; Mendes et al., 2014.

Table E. Summary of magmatic and metamorphic Rhyacian ages in the Quadrilátero Ferrífero. Data are from: Belo de Oliveira and Teixeira, 1990; Machado et al., 1992; Babinski et al., 1995; Schrank & Machado, 1996a; Schrank and Machado, 1996b; Marshak et al., 1997; Noce et al., 1998.

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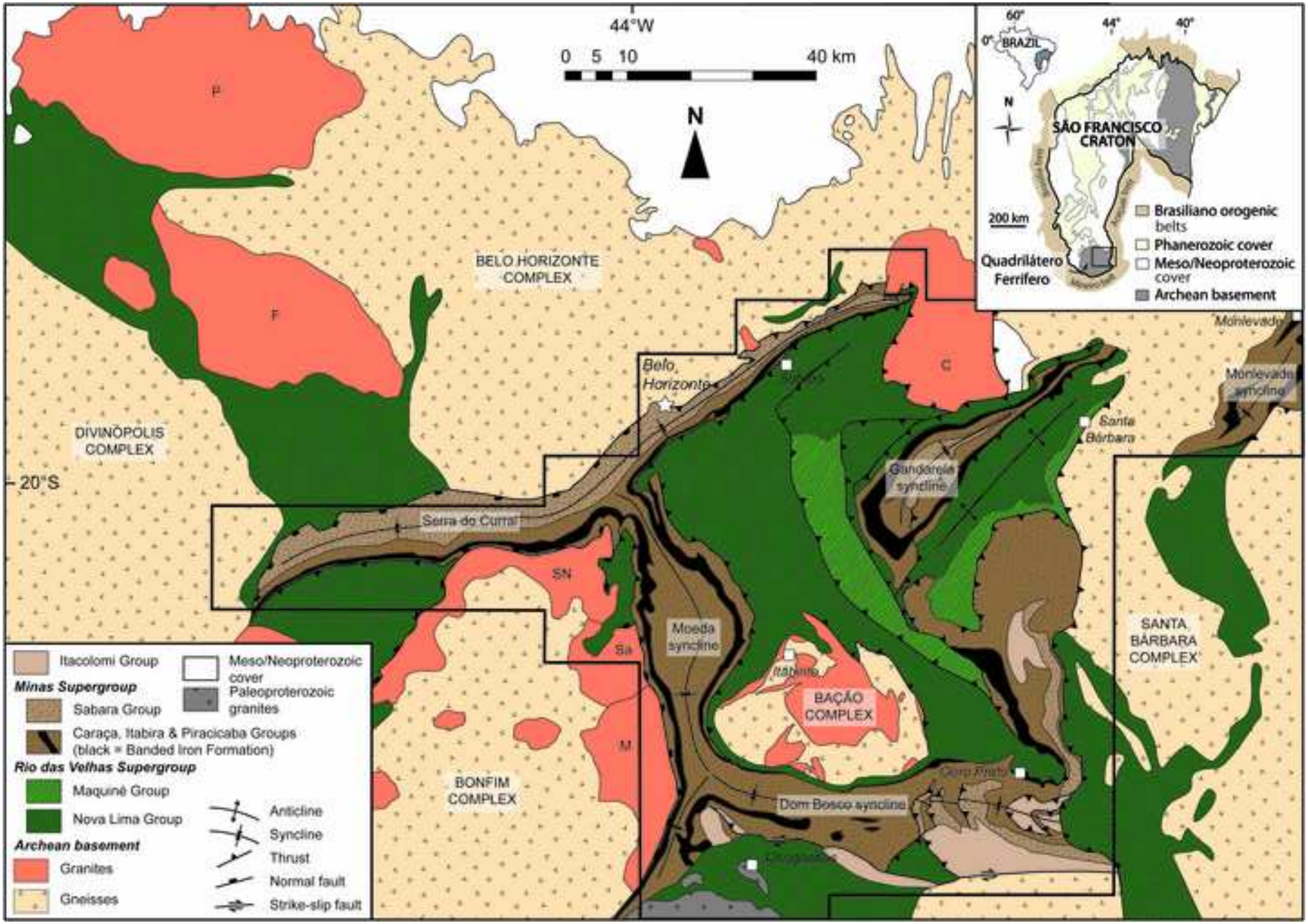

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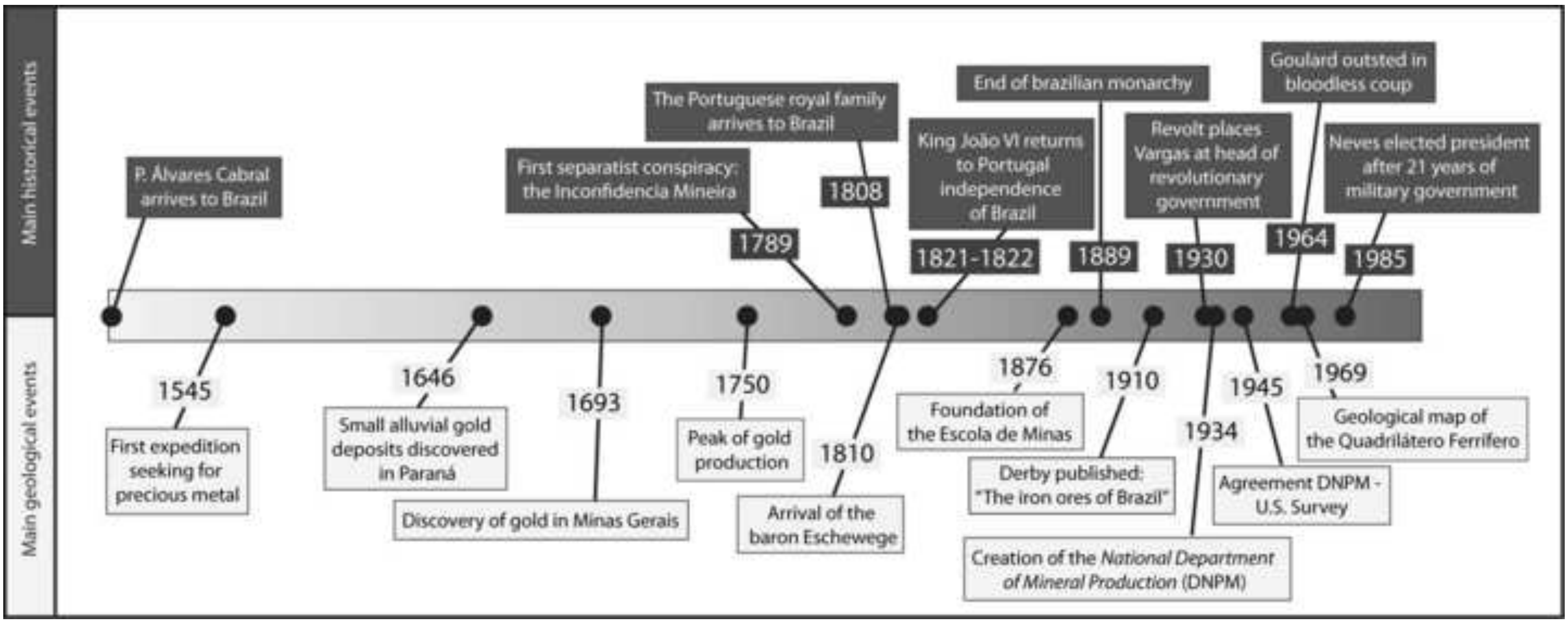

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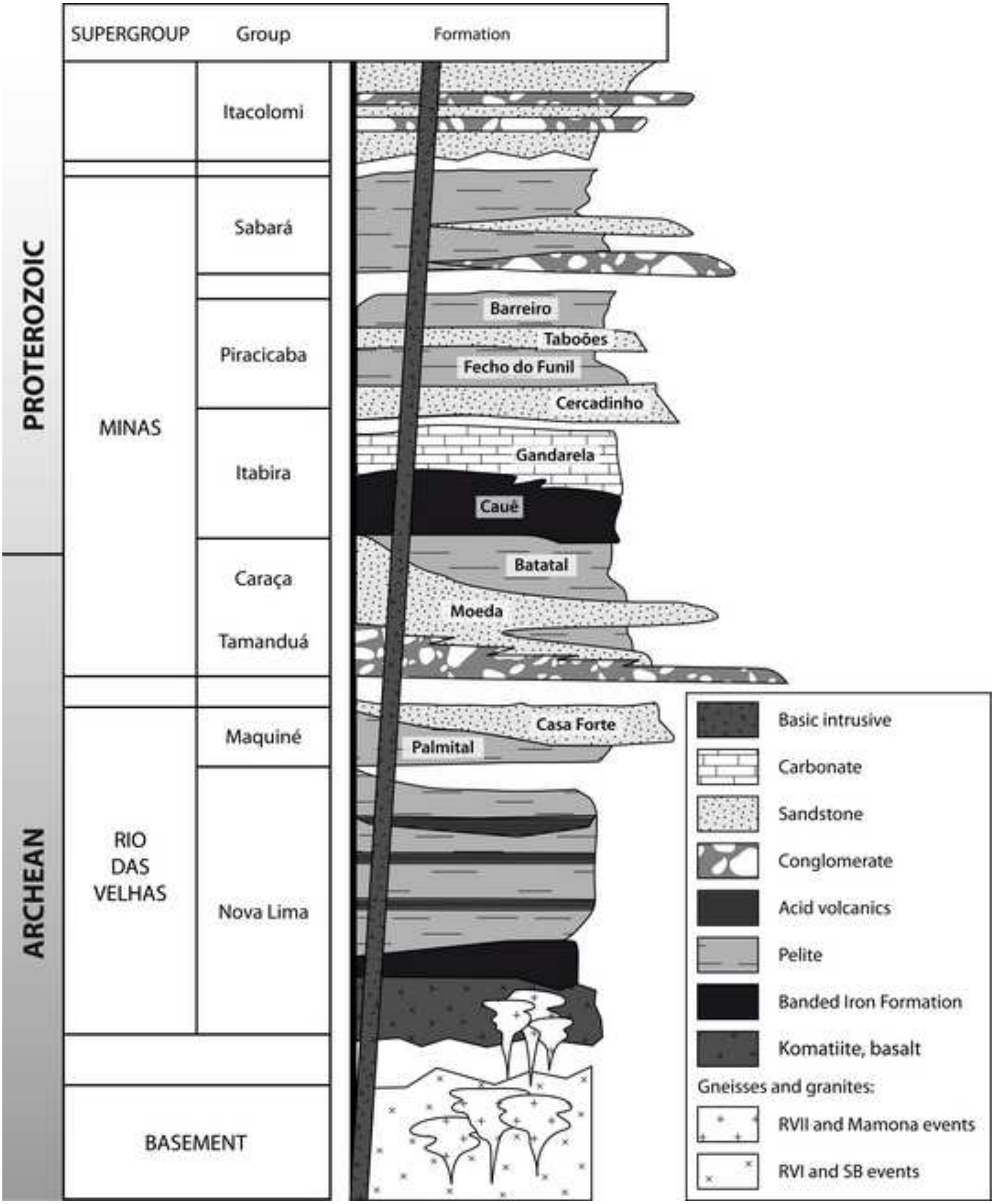

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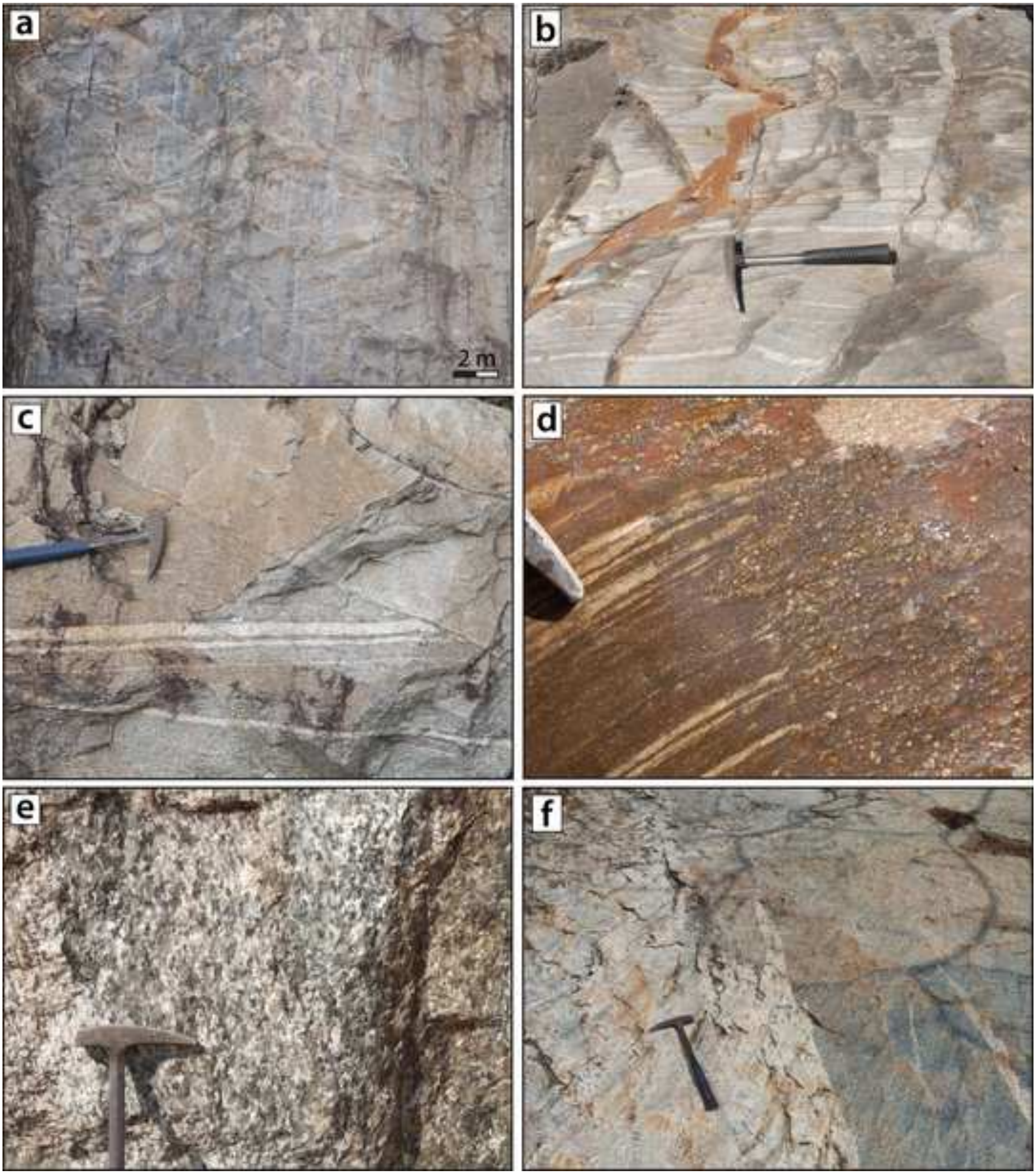

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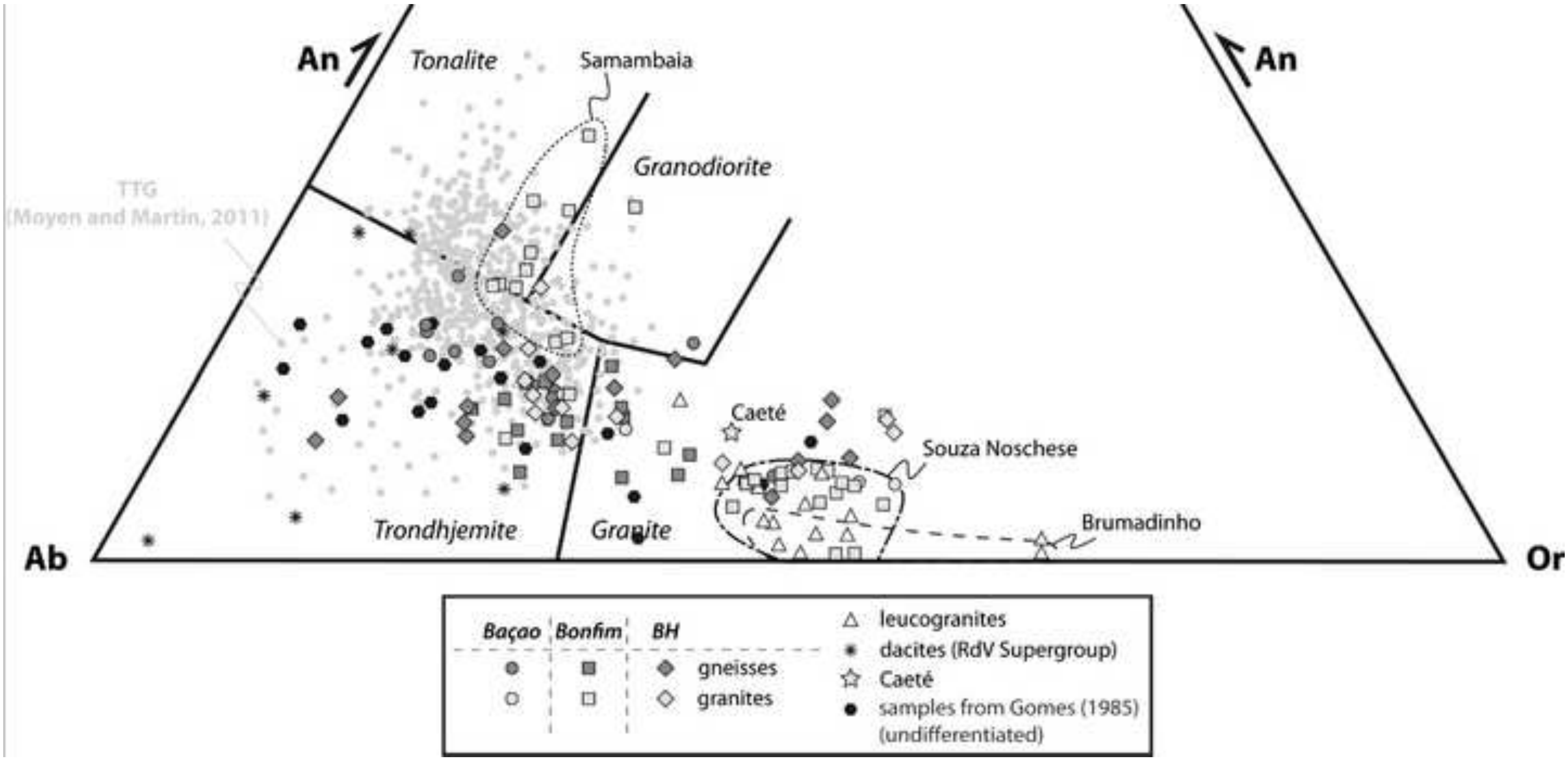

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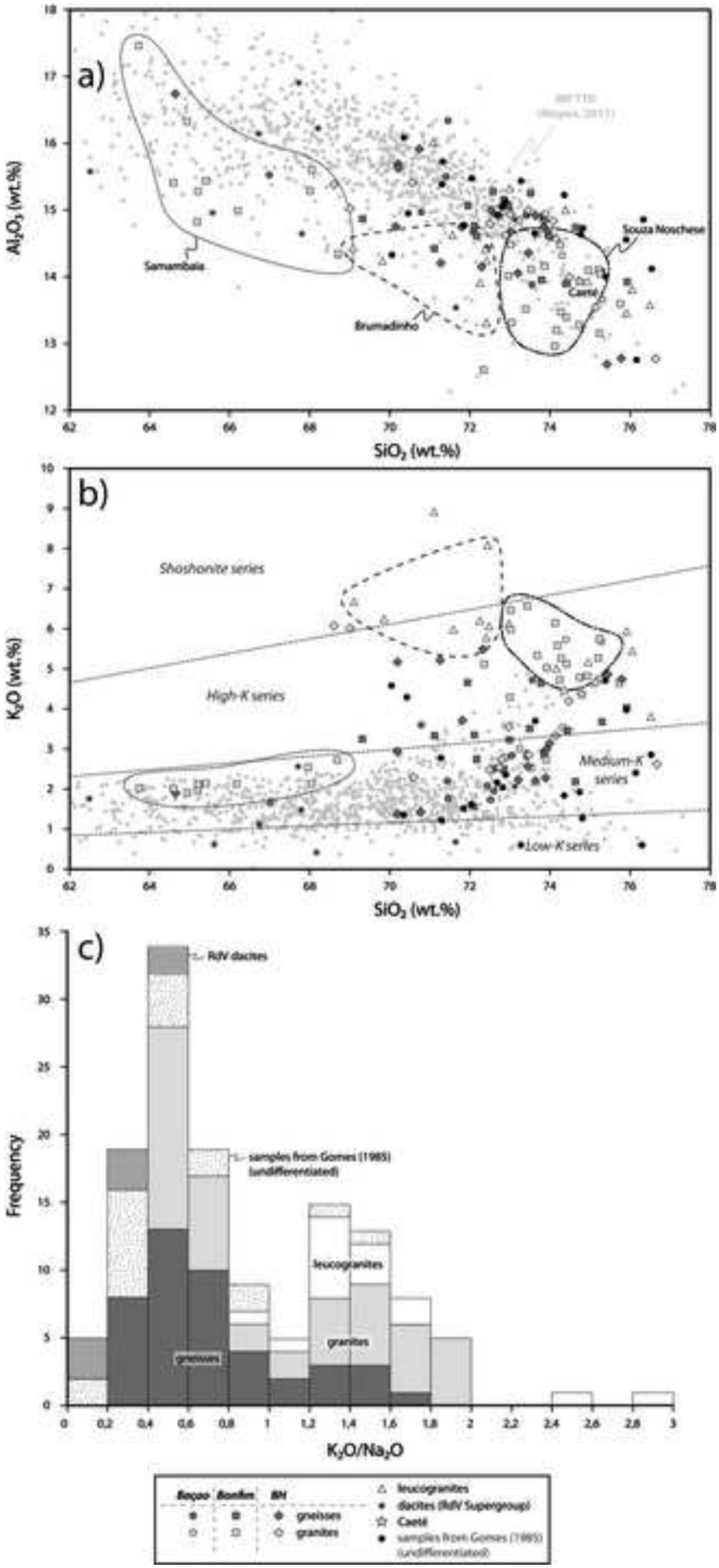

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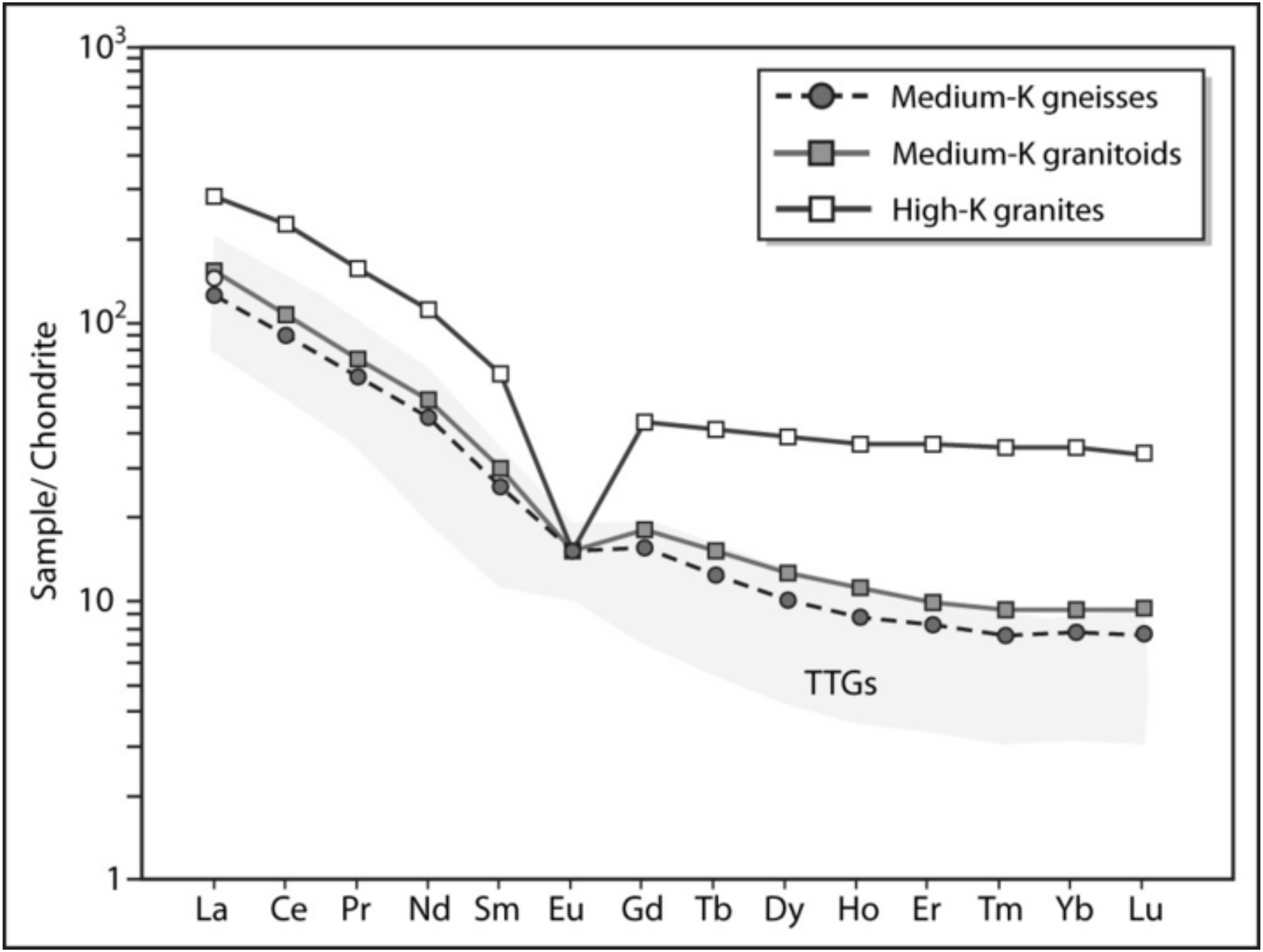

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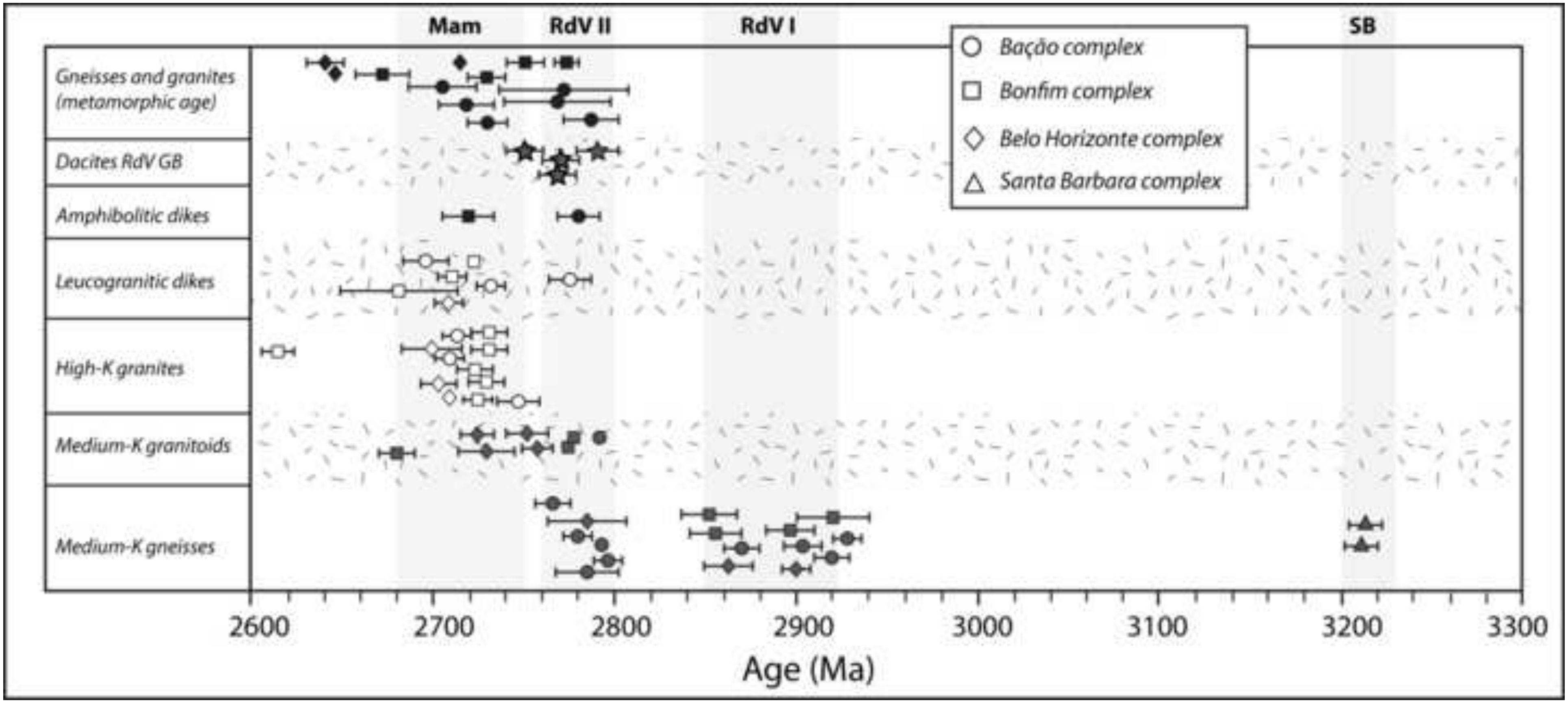

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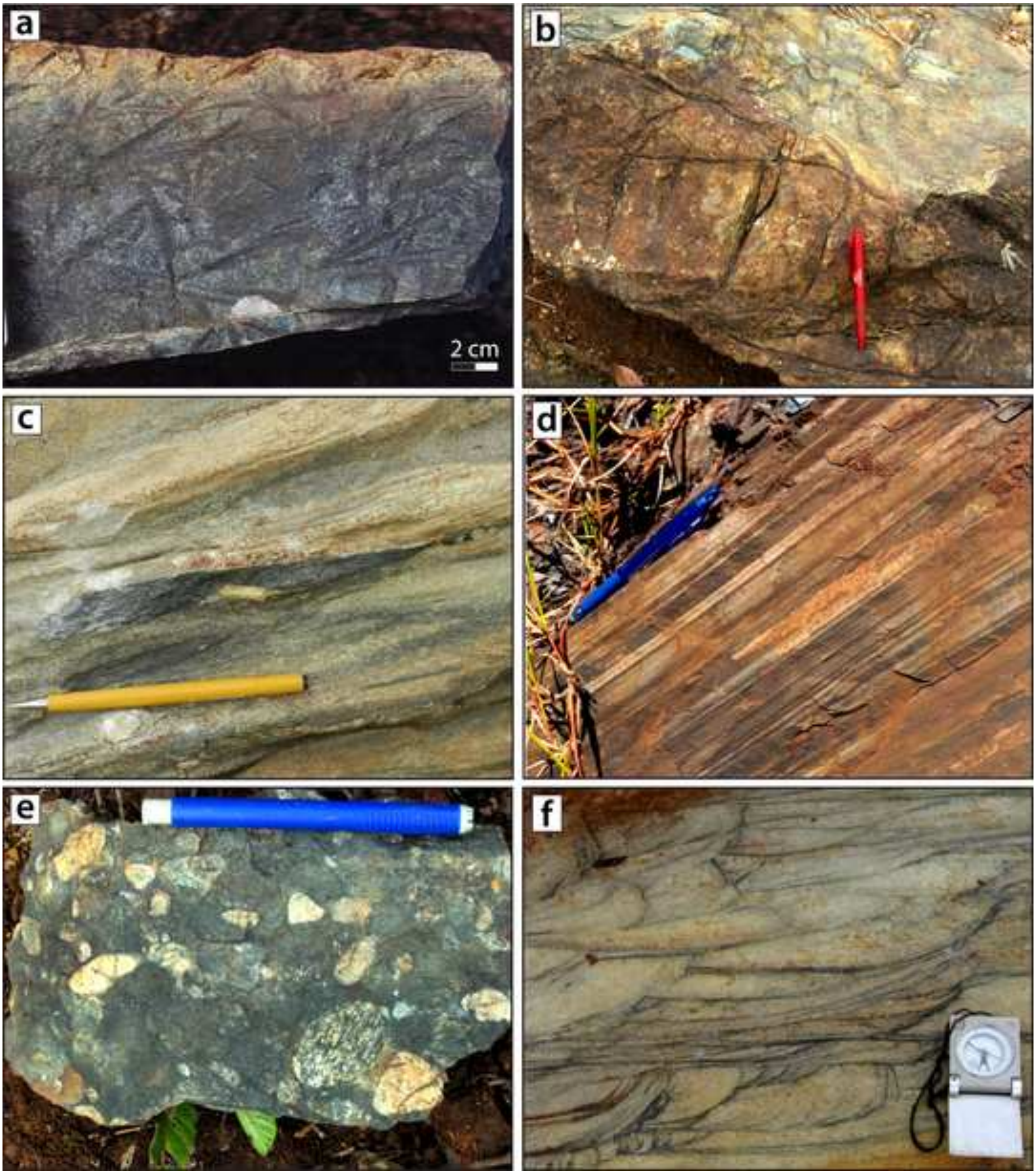

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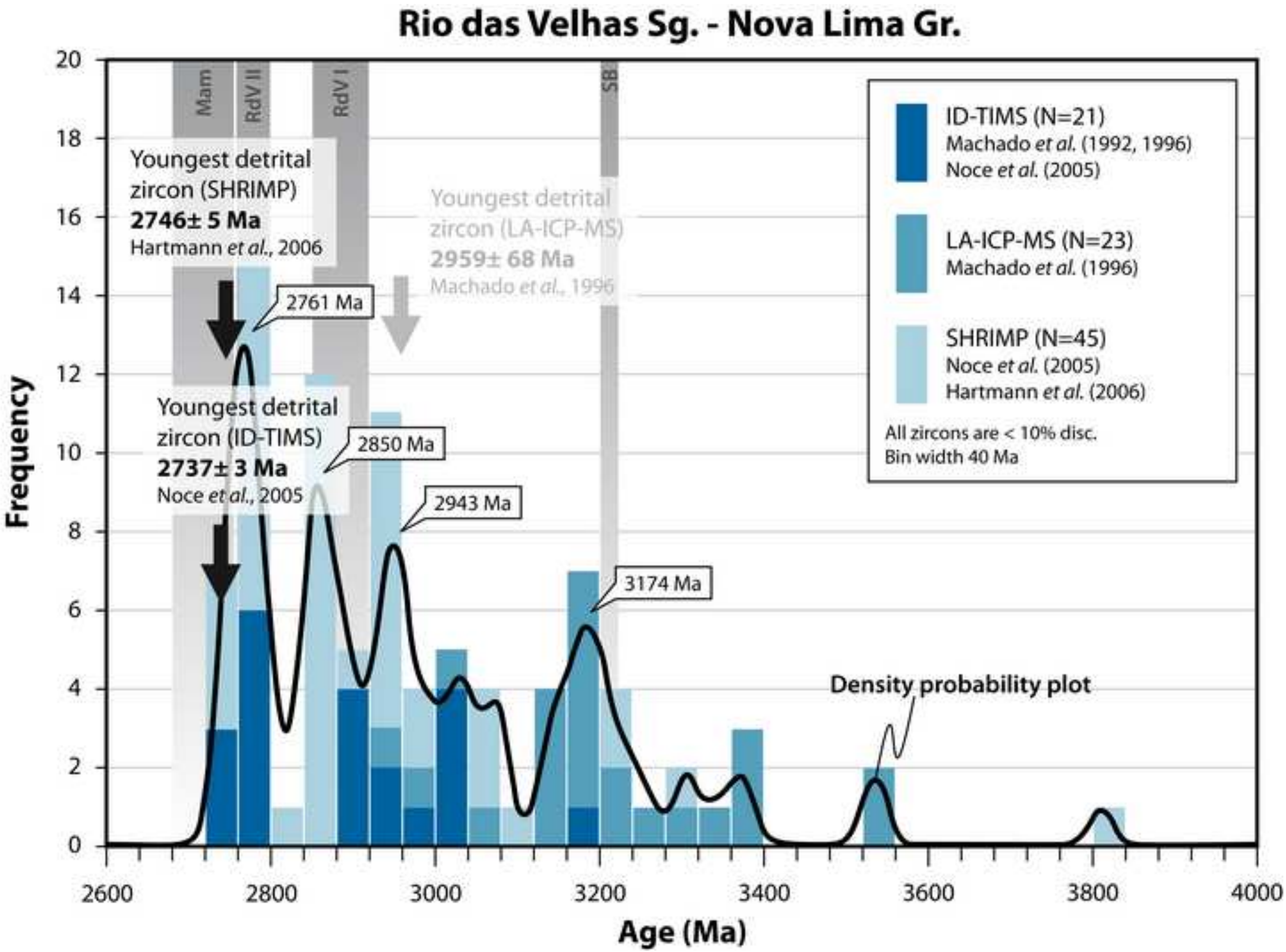

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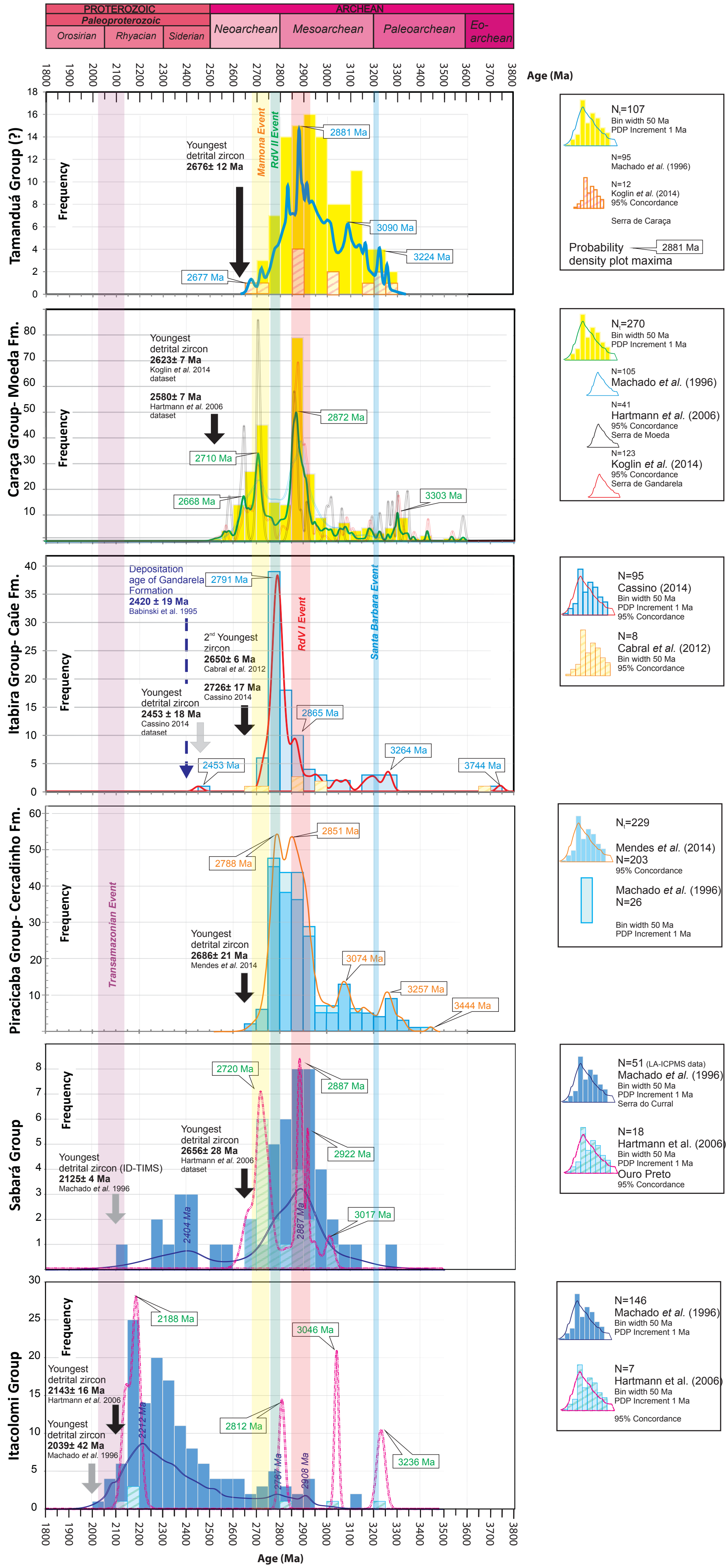

PROTEROZOIC
Paleoproterozoic
Orosirian
Rhyacian
Siderian
ARCHEAN
Neoarchean
Mesoarchean
Paleoarchean
Eo-archean
Age (Ma)
Tamanduá Group (?)
Frequency
Youngest detrital zircon 2676± 12 Ma
Mamona Event
RdV II Event
2881 Ma
3090 Ma
3224 Ma
2677 Ma
N=107
Bin width 50 Ma
PDP Increment 1 Ma
N=95
Machado et al. (1996)
N=12
Koglin et al. (2014)
95% Concordance
Serra de Caraça
Probability density plot maxima
2881 Ma
Caraça Group- Moeda Fm.
Youngest detrital zircon 2623± 7 Ma
Koglin et al. 2014 dataset
2580± 7 Ma
Hartmann et al. 2006 dataset
2872 Ma
2710 Ma
2668 Ma
3303 Ma
N=270
N=105
Machado et al. (1996)
N=41
Hartmann et al. (2006)
95% Concordance
Serra de Moeda
N=123
Koglin et al. (2014)
95% Concordance
Serra de Gandarela
Itabira Group- Cauê Fm.
Depositation age of Gandarela Formation
2420 ± 19 Ma
Babinski et al. 1995
2791 Ma
2nd Youngest zircon 2650± 6 Ma
Cabral et al. 2012
2726± 17 Ma
Cassino 2014
Youngest detrital zircon 2453 ± 18 Ma
Cassino 2014 dataset
RdV I Event
Santa Barbara Event
2865 Ma
3264 Ma
2453 Ma
3744 Ma
N=95
Cassino (2014)
Bin width 50 Ma
PDP Increment 1 Ma
95% Concordance
N=8
Cabral et al. (2012)
Bin width 50 Ma
95% Concordance
Piracicaba Group- Cercadinho Fm.
Transamazonian Event
2851 Ma
2788 Ma
Youngest detrital zircon 2686± 21 Ma
Mendes et al. 2014
3074 Ma
3257 Ma
3444 Ma
N=229
Mendes et al. (2014)
N=203
95% Concordance
Machado et al. (1996)
N=26
Bin width 50 Ma
PDP Increment 1 Ma
Sabará Group
2720 Ma
2887 Ma
Youngest detrital zircon 2656± 28 Ma
Hartmann et al. 2006 dataset
2922 Ma
Youngest detrital zircon (ID-TIMS) 2125± 4 Ma
Machado et al. 1996
2404 Ma
3017 Ma
N=51 (LA-ICPMS data)
Machado et al. (1996)
Bin width 50 Ma
PDP Increment 1 Ma
Serra do Curral
N=18
Hartmann et al. (2006)
Bin width 50 Ma
PDP Increment 1 Ma
Ouro Preto
95% Concordance
Itacolomi Group
2188 Ma
3046 Ma
Youngest detrital zircon 2143± 16 Ma
Hartmann et al. 2006
2212 Ma
Youngest detrital zircon 2039± 42 Ma
Machado et al. 1996
2812 Ma
2787 Ma
2908 Ma
3236 Ma
N=146
Machado et al. (1996)
Bin width 50 Ma
PDP Increment 1 Ma
N=7
Hartmann et al. (2006)
Bin width 50 Ma
PDP Increment 1 Ma
95% Concordance

Figure 12
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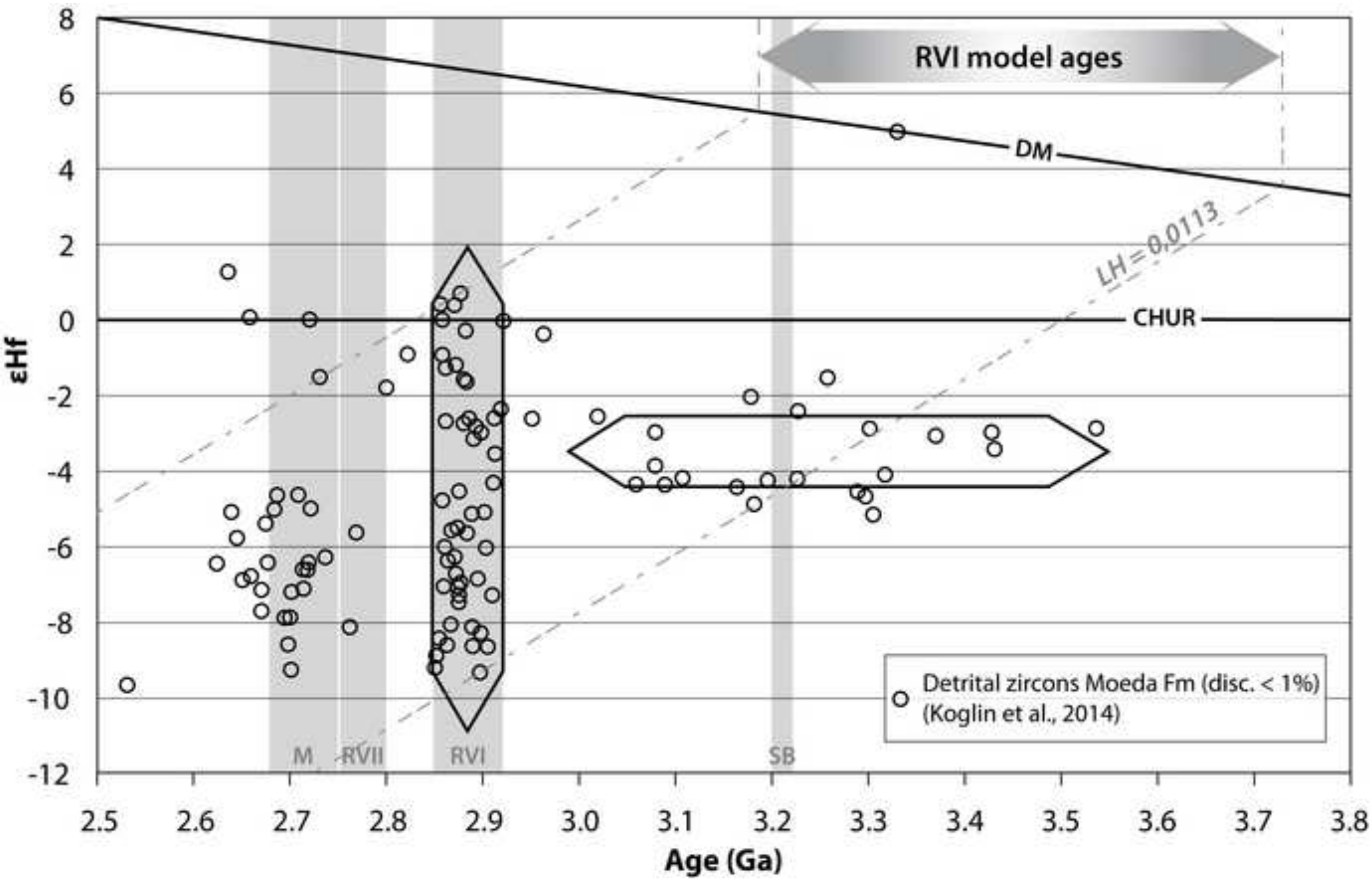

Figure 13

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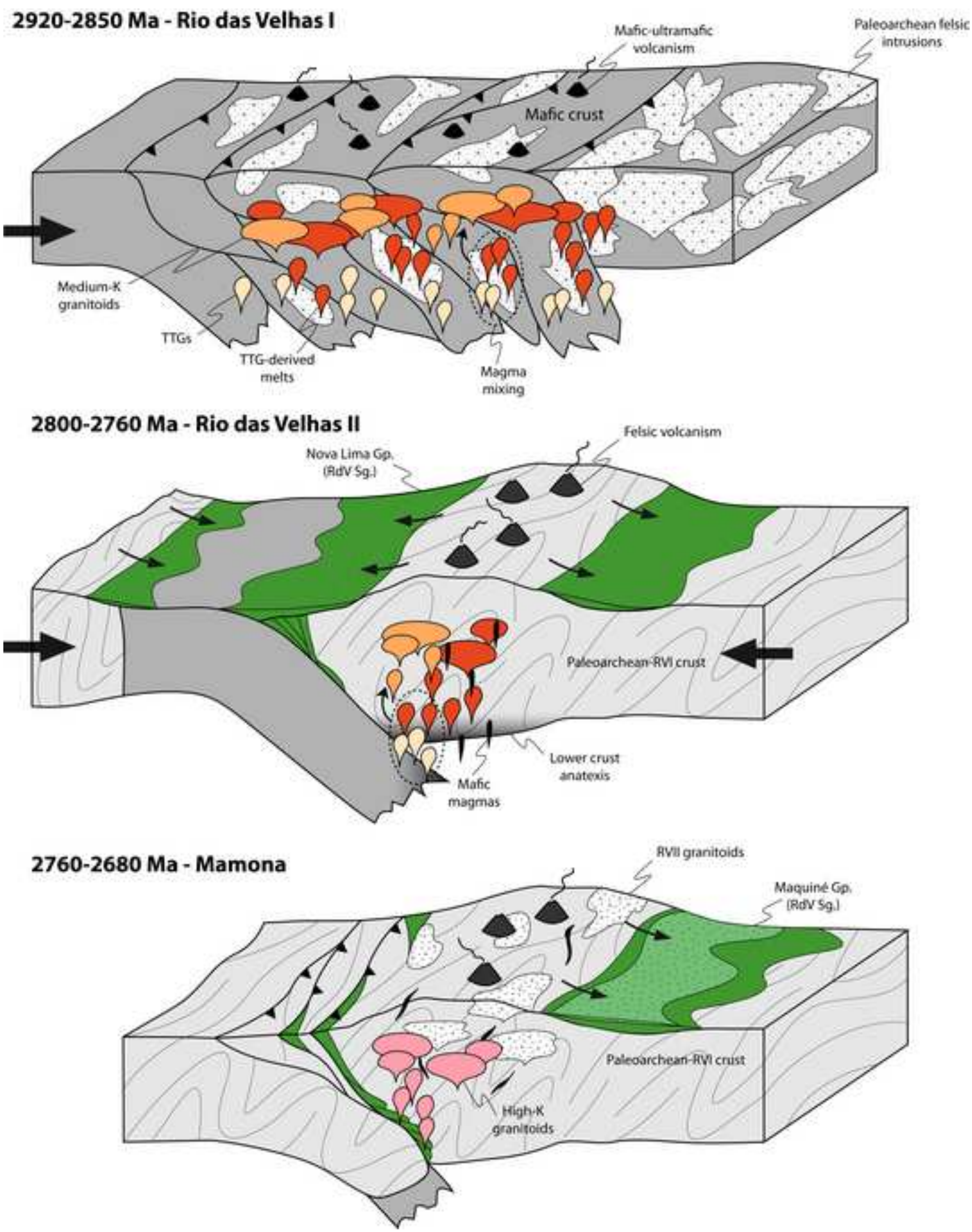

Supplementary material

Table A: Major and trace element composition of igneus rocks from the Quadrilátero Ferrífero

Sample	FQ1	FQ2	FQ3	FQ4	FQ5	FQ6	FQ7	FQ8	FQ10
Dome/Group	Baç	Baç	Baç	Baç	Baç	Baç	Baç	Baç	Baç
Field group	Granite	Gneiss	Leucogr.	Gneiss	Granite	Gneiss	Granite	Gneiss	Gneiss
Reference	1	1	1	1	1	1	1	1	1
SiO_2	74.41	72.44	71.09	73.41	74.31	70.79	75.29	73.56	72.59
TiO_2	0.21	0.50	0.04	0.22	0.17	0.49	0.08	0.36	0.31
Al_2O_3	13.90	14.43	16.00	14.93	14.32	14.99	13.66	13.90	14.97
$Fe_2O_{3\ tot}$	1.51	2.75	0.42	1.54	1.59	3.14	0.90	2.23	2.01
MnO	0.01	0.03	0.03	0.03	0.02	0.03	0.01	0.05	0.03
MgO	0.21	1.01	0.04	0.44	0.30	0.78	0.15	0.47	0.64
CaO	0.92	2.14	0.36	1.84	1.44	2.45	0.90	1.03	2.38
Na_2O	3.00	4.49	3.03	4.63	4.27	3.58	3.30	3.56	5.02
K_2O	5.74	2.09	8.93	2.89	3.54	3.61	5.67	4.73	1.95
P_2O_5	0.08	0.13	0.04	0.07	0.04	0.15	0.03	0.11	0.09
LOI	0.6	0.9	0.32	0.85	0.75	1.05	0.42	0.69	0.67
K_2O/Na_2O	1.92	0.46	2.94	0.62	0.83	1.01	1.72	1.33	0.39
Sc	5.1	9.2	4.4	5.8	5.8	7.0	3.9	7.0	4.4
V	16.0	51.8	13.0	24.6	16.1	38.8	12.4	25.8	26.5
Cr	8.8	8.5	8.0	10.4	14.3	23.2	10.6	21.4	18.6
Co	81.3	53.1	60.6	71.8	88.9	57.9	76.6	48.2	59.2
Ni	4.5	6.1	5.0	7.2	7.7	9.7	4.8	7.6	9.0
Cu	8.2	15.2	5.1	10.7	14.7	36.2	5.8	5.9	11.3
Zn	44.0	56.3	14.6	64.4	45.3	67.7	33.7	63.1	55.3
Rb	211	63	267	93	100	152	212	343	76
Sr	70	240	98	375	126	154	60	59	414
Y	7.8	42.3	4.7	7.8	22.6	24.5	39.7	58.7	8.8
Zr	112	216	13	127	127	311	86	178	156
Nb	10.9	15.0	6.2	5.5	18.9	21.1	11.4	24.7	6.3
Mo	0.7	0.3	0.3	0.4	0.6	1.6	0.5	0.9	0.3
Cs	9.5	4.4	7.3	3.9	2.7	6.2	15.2	17.3	6.7
Ba	442	596	418	696	776	940	424	296	537
La	24.02	24.41	2.87	14.11	38.90	66.77	19.33	42.32	35.03
Ce	55.14	49.73	4.65	33.86	78.85	152.24	43.44	93.58	59.75
Pr	6.50	5.90	0.39	2.79	8.28	14.56	4.58	10.96	6.00
Nd	22.69	24.17	1.22	9.76	29.04	52.01	16.04	42.56	20.06
Sm	4.49	5.84	0.38	1.87	6.03	8.39	4.29	10.04	3.30
Eu	0.60	1.38	0.37	0.58	1.08	1.55	0.61	0.43	0.82
Gd	2.58	6.69	0.42	1.66	5.12	5.97	5.03	10.21	2.57
Tb	0.35	1.12	0.09	0.29	0.79	0.85	0.99	1.76	0.34
Dy	1.54	7.57	0.69	1.50	4.52	4.66	6.72	10.63	1.69
Ho	0.27	1.54	0.16	0.31	0.94	0.87	1.44	2.13	0.32
Er	0.72	4.66	0.67	0.74	2.29	2.48	4.07	6.05	0.86
Tm	0.11	0.71	0.13	0.13	0.36	0.33	0.62	0.92	0.13
Yb	0.77	4.66	1.01	0.81	2.32	2.19	3.84	6.23	0.79
Lu	0.13	0.74	0.17	0.12	0.32	0.35	0.52	0.87	0.12
Hf	3.49	6.35	0.57	3.69	4.28	8.38	3.85	5.78	4.44
Ta	1.52	1.73	2.28	1.05	1.54	1.55	1.76	3.04	1.44
Pb	48.9	12.4	47.1	29.3	35.3	31.8	66.1	35.0	21.0
Th	15.5	7.5	1.0	5.9	18.2	20.3	15.2	35.9	9.6
U	3.3	2.1	3.0	1.5	2.8	2.7	3.9	11.1	2.6

Abbreviations: Baç - Bação complex; Bo- Bonfim complex; Ca- Caeté complex; BH- Belo Horizonte complex; RdV- Rio das Velhas greenstone