U-Pb baddeleyite dating of the Pará de Minas dyke swarm in the São Francisco craton (Brazil) – three generations in a single swarm

Julia Cederberg

Dissertations in Geology at Lund University,
Master's thesis, no 364
(45 hp/ECTS credits)

Department of Geology
Lund University
2013

U-Pb baddeleyite dating of the Pará de Minas dyke swarm in the São Francisco craton (Brazil) - three generations in a single swarm

Master´s Thesis

Julia Cederberg

Department of Geology
Lund University

2013

Contents

1 Introduction **5**
2. Geological setting **5**
2.1 Regional geology 5
2.2 Adjacent cratons to SFC during supercontinent events 6
2.3 Mafic dyke swarms in SFC 6
2.4 The Pará de Minas swarm 7
3. Local geology and sample sites **8**
3.1 MG-3 *(S 20° 51.882′/W 45° 12.650′)* and MG-8 *(S 20° 53.980′/W 45° 08.247′)* *8*
3.2 MG-4 *(S 19° 42.129′/W 44° 52.779′)* *8*
3.3 MG-5 *(S 20° 22.367′/W 44° 22.118′)* *9*
3.3 MG- 6 *(S 20° 39.048′/W 44° 44.136′)* and MG-7 *(S 20° 42.355′/W 44° 46.724′)* *9*
4. Petrography **10**
4.1 MG-3 10
4.2 MG-4 10
4.3 MG-5 10
4.4 MG-7 11
4.5 MG-8 11
5. Analytical protocols for dating with the U-Pb baddeleyite method **11**
5.1 TIMS Geochronology 11
6. Results **12**
7. Discussion **14**
7.1 U-Pb data of investigated dykes 14
7.2 New and previous ages of mafic dykes in the São Francisco craton 15
7.3. LIP barcode for a combined SFC and Congo Craton 15
7.4. Comparison with other Archaean blocks 16
7.4.1 The 1790 Ma generation 16
7.4.2 The 1690 Ma generation 17
7.4.3. The 766 Ma generation 17
7.5 Three generations of dykes in a single swarm 18
7.6 Potential Reconstruction 19
8. Conclusion **21**
9. Acknowledgements **21**
10. References **22**

U-Pb baddeleyite dating of the Pará de Minas dyke swarm in the São Francisco craton (Brazil) - three generations in a single swarm

JULIA CEDERBERG

Cederberg, J., 2013: U-Pb baddeleyite dating of the Pará de Minas dyke swarm in the São Francisco craton (Brazil) - three generations in a single swarm. Examensarbete i geologi vid Lunds Universitet, Nr. 364, 26 pp. 45 points.

Abstract: The São Francisco craton in Brazil, South America, host a significant number of mafic intrusions and dyke swarms, but their ages and tectonic significance are poorly constrained. This study presents U-Pb baddeleyite (ID-TIMS) data that demonstrate the occurrence of three dyke generations of the NW-trending Pará de Minas swarm, dated at 1790 Ma (1788 ± 3 Ma, 1792 ± 16 Ma, 1785 ± 5), 1690 Ma (1687 ± 8 Ma, 1691 ± 5 Ma) and 766 ± 36 Ma. All the sampled dolerites have undergone the imprint of low grade metamorphism, presumably related to Braziliano Pan-African compressional tectonics.

The São Francisco and Congo Craton were connected as a single crustal block that lasted from about 2.05 Ga until ca. 130 Ma, when Africa separated from South America. The new U-Pb ages have implications for positioning the São Francisco craton - Congo cratonic block in the configuration of Rodinia and Columbia supercontinents. Based on temporal constraints, the Uruguayan dykes (1790 ± 5 Ma) in the southern Rio de la Plata craton, the Ilhas sill (1793 ± 1 Ma) in the northern part and the Pedra Preta dolerite sill (1795 ± 2 Ma) near the Venezuelan border in the Amazonian craton, the Tomashgorod dykes (1789 ± 3) in Sarmatian, the Hart dolerites (1790 ± 4) in the Northern Australia craton and the Taihand-Lavliang dyke swarm (ca. 1.78Ga) in the North China craton allow all these cratons to have been potential “neighboring” blocks to the São Francisco craton- Congo craton at 1790 Ma. The 1690 Ma age is relatively rare for global record making this age relatively unique. The Byraiy swarm (1707 ± 32) in the Siberian craton and the Pelly Bay dyke swarm (1692 ± 2) in northern Laurentia are two possible candidates. The 766 Ma age may be connected to the Niquelândia complex (ca.790 Ma) in Goias state, the Mundine Well swarm (755 ± 3) in the Western Australia and the dykes in the Mt. Rogers (757 ± 5) in southeastern Laurentia.

Keywords: Baddeleyite, U-Pb, São Francisco craton, Brazil, Pará de Minas swarm

Julia Cederberg, Department of Earth and Ecosystem Sciences, Division of Geology, Lund University,
Sölvegatan 12, SE-223 62 Lund, Sweden. E-mail: julia@ibb.se

U-Pb baddeleyit datering av Pará de Minas diabassvärmen i São Francisco kratonen (Brasilien) - tre generationer i en diabassvärm

JULIA CEDERBERG

Cederberg, J., 2013: U-Pb baddeleyit datering av Pará de Minas diabassvärmen i São Francisco kratonen (Brasilien) - tre generationer i en diabassvärm. *Examensarbete i geologi vid Lunds universitet*, Nr.364, 26 sid. 45 högskolepoäng (hp)

Sammanfattning: São Francisco kratonen i Brasilien, Syd Amerika, innehåller ett antal signifikanta mafiska intrusioner och diabasgångar men deras ålder och tektoniska betydelse är oklar. Denna studie presenterar åldersdata (U-Pb metoden på mineralet baddeleyit) som visar att den NV-riktade Pará de Minas svärmen, består av tre generation av diabasgångar, åldersbestämda till 1790 Ma (1788 ± 3 Ma, 1792 ± 16 Ma, 1785 ± 5), 1690 Ma (1687 ± 8 Ma, 1691 ± 5 Ma) och 766 ± 36Ma. Diabaserna visade påverkan av låggradig metamorfos.

De nya åldrarna har betydelse för hur São Francisco kratonen var beläget i förhållande till andra kratoner under superkontinenthändelser då Rodinia och Columbia existerade. Potientiella matchningar med SFC vid 1790 Ma utgörs av de Uruguyanska diabasgångarna (1790 ± 5 Ma) i södra Rio de la Plata kratonen, Ilhas sill (1793 ± 1 Ma) i norra delen i Amasonas kratonen och Pedra Preat sill (1795 ± 2 Ma) nära den Venezulianska gränsen i Amasonas kratonen, Tomashgorod diabasgångarna (1789 ± 3) i Sarmatian, Hart diabasgångarna (1790 ± 4) i norra Australien och Taihand-Lavliang svärmen (ca. 1.78Ga) i norra China. Åldern 1690 Ma är relativt ovanlig i ett globalt perspektiv. Möjliga kandidater är Byraiy svärmen (1707 ± 32) i Siberia kratonen och Pelly Bay diabassvärmen (1692 ± 2) i norra Laurentia. Åldern 766 Ma kan kopplas till Niqulandia komplexet (ca.790 Ma) i staten Goias, Mundine Well svärmen (755 ± 3) i västra Australien och diabasgångarna i Mt. Rogers (757 ± 5) i Laurentia.

Keywords: Baddeleyite, U-Pb, São Francisco craton, Brazil, Pará de Minas swarm

Julia Cederberg, Department of Earth and Ecosystem Sciences, Division of Geology, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden. E-mail: julia@ibb.se

1 Introduction

A key question in planet Earth's geological history concerns the position of continents through time and, in particular, at those times when all or most of the continental blocks were positioned in supercontinent arrangements. Earth is today made up of approximately 35 main pieces of Archaean crust that today are dispersed around the globe (Bleeker, 2003). There are reasons to believe that all these blocks were originally amalgamated into a single supercontinent, Superia (or Kenorland), or a few supercratons. Throughout Earth's history it has been recurrent supercontinents existing in cycles of approximately 500 Ma, e.g Columbia (1.8-1.5 Ga), Rodinia (1.1-0.6 Ga) and Pangea (0.3-0.2 Ga) (e.g. Evans, 2009; Zhang et al., 2012). Mafic dyke swarms play an important role since they may manifest the products of break up or attempted break up of supercontinents. They are emplaced typically either parallel to continental margins or radiate out from a magmatic center (i.e. focal point) into the interior parts of a craton (e.g. Ernst & Buchan, 1997). In the latter case, dykes are commonly considered linked to the arrival of a mantle plume into areas of thinned lithosphere, i.e. a voluminous amount of hot material rising through the mantle in plume-like bodies. Major mafic dykes, sill complexes and basaltic volcanic provinces of short duration pulses (termed Large Igneous Provinces (LIPs) are useful geological markers in the reconstructions of supercontinents (e.g. Wingate & Gidding, 2000) and their positions prior to breakup (e.g. Corrêa Gomes & Oliveira, 2000, Ernst et al., 2013).

Precise radiometric ages of these rocks can be arranged in a "time column", a so-called LIP barcode that characterizes each "puzzle piece". Each bar in a column represents a single LIP event and the LIP barcode column of different blocks can be compared. Multiple age matches suggest the blocks were "next neighbors" during the period matches are identified whereas no matches indicate crustal bocks were far apart. It is well accepted that the São Francisco craton (SFC) and the Congo craton (CC) were connected from ca. ≥2.0 Ga until the opening of the South Atlantic at about 130 Ma (D'Agrella-Filho et al., 1996; Feybesse et al., 1998). As such, the combined SFC and CC represents together a relative large 'puzzle piece' in palaeocontinental reconstructions. Yet its position in the supercontinents Columbia and Rodinia is poorly known (e.g., Meert, 2012; Zhang et al. 2012). Mafic dyke swarms of various age and trends are widespread in the SFC (Corrêa Gomes & Oliveira, 2000) but their ages and tectonic significance are poorly constrained.

The Pará de Minas swarm has a SW-NE trend and extends throughout most of the SFC. Previous attempts to date dykes of this swarm are uncertain and have to some extent given conflicting results (Silva et al., 1995; Chaves, 2001). This study provides precise datings of a number of dykes of the Pará de Minas swarm using U-Pb geochronology on baddeleyite ($ZrO2$). The objective of this study is to extend the "LIP barcode" for the combined SFC-CC block during the Palaeoproterozoic. By comparing these barcodes with corresponding data from other blocks it will contribute to better constrain SFC-CC in supercontinent configurations.

2. Geological setting

2.1 Regional geology

Large volumes of Archaean crust are preserved in South America (35%) in various crustal blocks together with juvenile rocks (54%) that accreted during the Palaeoproterozoic (mainly from 2.2 to 1.9 Ga). The craton has been completed through the addition of Meso- to Neoproterozoic material (10%), together with a small fraction (1%) of Phanerozoic igneous rocks (Sato & Siga Jr., 2000).

The SFC is located in the northeastern portion of Brazil (Fig. 1) within the state of Minas Gerais and Bahia. The craton is surrounded by Neoproterozoic mobil belts, i.e. the Araçuai, Brasilia, Riacho do Portal, Rio Preto and the Sergipano belts. The Araçuai belt is located along the east and southeast edges of the SFC (Almeida, 1977, Fig. 1). The basement of the Araçuai orogen consists of Archaean to Mesoproterozoic units including the rift-sag Espinhaço Supergroup and the related anorogenic Borrachudos suits (Uhlein et al., 1998; Martins-Neto, 2000; Noce et al., 2007). The Brasilia belt is located in the western margin of the SFC, and comprises a thick Meso-Neoproterozoic sedimentary/metasedimentary pile (e.g Arai Paranoá, Araxá, Canastra, Vazante and Bambuí group). The rocks are mostly unformed and unmetamorphosed throughout most of the craton but become increasingly deformed and metamorphosed westwards, reaching amphibolite to granulite facies conditions in the central part of the belt (Dardenne, 2000; Pimentel et al., 2000; Piuzana et al., 2003).

The SFC basement is dominated by Archaean to Palaeoproterozoic high-grade (magmatic, granulite) gneisses and granite-greenstone belts (Rio Capim, Rio Itapicuru, Mundo Novo, Contendas-Mirante, Umburanas and Rio das Velhas) with local spinifex-textured komatiites occurring in most of the southern part of Minas Gerais state (Teixeira et al., 2000) and in the Umburanas region in the north (Cunha & Fróes, 1994). These rocks are covered by Meso- to Neoproterozoic sedimentary rocks of the Espinhaço Supergroup and the São Francisco Supergroup (Danderfer et al., 2009). The basal formation in the southern Espinhaço Supergroup is an extensive intracontinental rift sedimentary sequence which is located on both the west and eastern border of the SFC, some 600 km apart from each other. In Minas Gerias the oldest Espinhaço Basin is formed 1.68 Ga-1.80 Ga (Chemale Jr. et al., 2012).

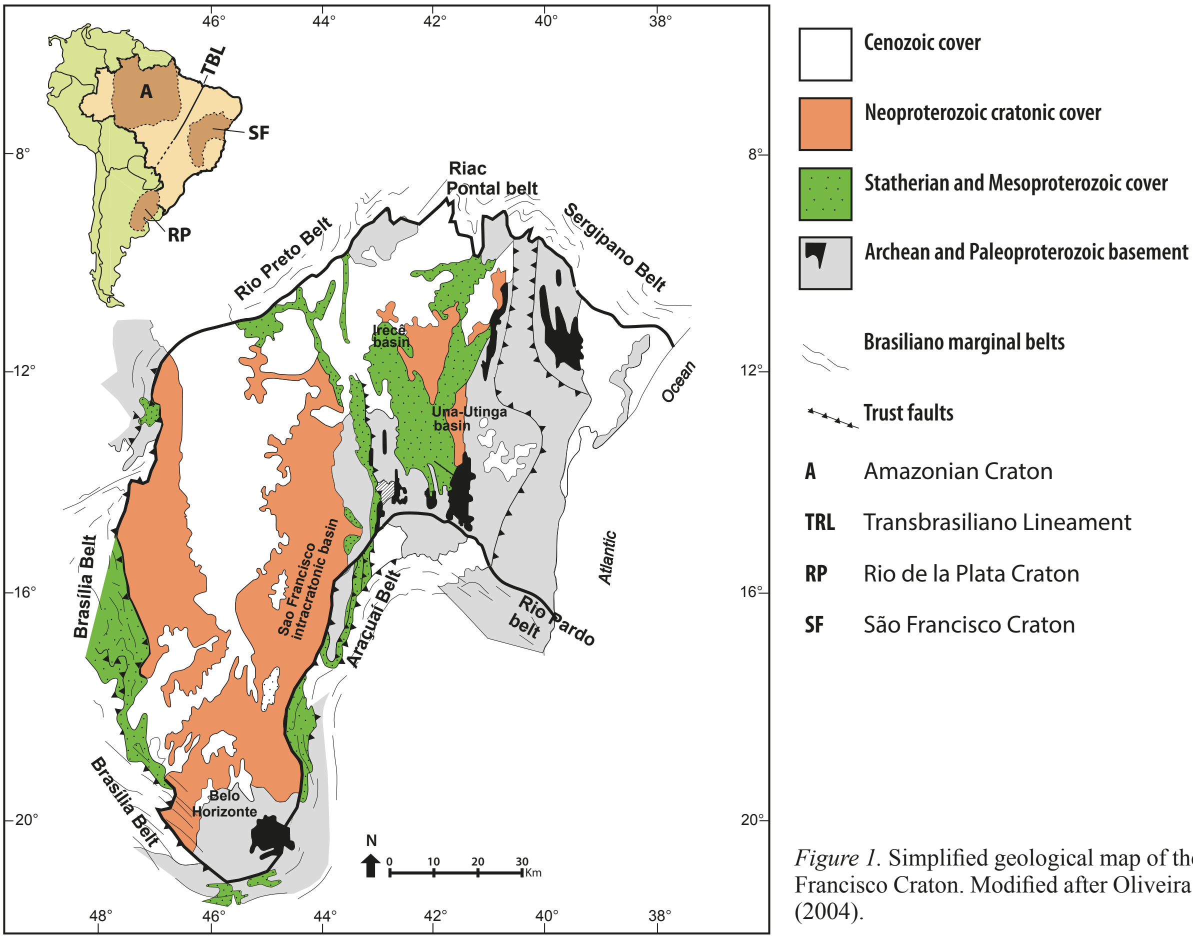

Figure 1. Simplified geological map of the São Francisco Craton. Modified after Oliveira et al. (2004).

2.2 Adjacent cratons to SFC during supercontinent events

All cratonic blocks of South America have been involved in the assembly and breakup of larger continental blocks (supercontinents), such as Columbia in the Palaeo- to Mesoproterozoic (e.g., Condie, 2002), Rodinia in the Mesoproterozoic (e.g., Cordiani et al., 2000) and West Gondwana, in the Neoproterozoic to Phanerozoic (e.g., Unrug, 1996). The South American platform is composed of three major cratons, Amazonian, São Francisco and Rio de la Plata (e.g Hoffman, 1991; Unrug, 1996; Fuck et al., 2008) and some smaller cratons, e.g. the Rio Apa craton. The Amazonian is the largest block and is located northwest of SFC (Fig. 1). The Amazonian craton and the eastern portion of the South American Platform are separated by the Transbrasiliano lineament (Fig. 1). It is a 3000 km long intra-continental deformational strike slip system, and it extends discontinuously from Paraguay, across the Tocantins Province and the Phanerozoic Paraná and Parnaíba basins, into Ceará in Brazil (Feng et al., 2004). The Archaean–Palaeoproterozoic Rio de la Plata craton is located south of SFC and is exposed over a relatively large area in Uruguay, eastern Argentina, and southernmost Brazil (Fig. 1). Its geological evolution is poorly known because of great geological complexity and paucity of data (e.g Gaucher et al., 2008).

The CC is located in the central and southern Africa and extends from Congo into the Angola region. It is generally accepted that the SFC and the CC were joined at about 2.05 Ga and remained together until the ca. 130 Ma breakup of Africa from South America (D´Agrella-Filho et al., 1996; Freybesse et al., 1998). The combined SFC-CC positions in the supercontinents Columbia and Rodinia are poorly known but are represented as a large ‘puzzle piece’ in palaeocontinental reconstruction (e.g. Li et al., 2008).

2.3 Mafic dyke swarms in SFC

SFC is intruded by a number of mafic dyke swarms with different trend directions and age (fig. 2). The dyke swarms are briefly described in this section whereas the studied swarm, the Pará de Minas swarm, is presented in more detail in section 2.4.

The Lavras swarm in the southernmost region of SFC is the oldest swarm (2658 ± 44 Ma, Sm-Nd). It comprises NW-SE trending noritic dykes traceable for up to 30 km with the thickest dykes being up to ca. 100 metre in width (Pinese, 1997).

The NNW- and NE- trending Paraopeba swarm is made up of metadiabase and amphibolite dykes. The dykes are associated with NNW- and NE- trending transcurrent shear zones, hence implying a contemporaneous and genetic relationship between dyking and shearing. The dykes are tholeiitic and located in the southern part of SFC. The dykes dimensions range from hundreds of meters in length to 5 km and 2 to 10 metres in width. Rb-Sr whole-rock isochron dating indicated an intrusive age of 2189 ± 45 Ma and are classified as tholeiitic basalt (Chaves, 2001). Due to the associated shear zones the dykes are illustrated as oval shaped circles (Fig. 2).

In the very northern part of Minas Gerais state, dykes of the NW- trending Januária swarm do not cut the Neoproterozoic cover, whereas further south the dykes cut through the Espinhaço supergroup. The Januária swarm has been dated with K-Ar to 1.1-1.4 Ga (Parenti Couto et al., 1983 discussed in Chaves & Correia Neves, 2005).

The Formiga swarm consists of NE-trending tholeiite dykes, located throughout the Minas Gerais state. The dykes have a length up to 400 km and individual dykes are up to 100 m in width. The dykes are postdated by Neoproterozoic cover (Chaves, 2001). Previous age determinations have given ages of 906 ± 2 Ma (U-Pb, Machado et al., 1989) and 984 ± 100 Ma (Sm-Nd whole-rock isochron, Chaves, 2001). Some of the dykes are porphyritic with plagioclase phenocrysts. Close to the SFC border the dykes appear as metadolerites, metamorphosed under greenschists facies condition. The dykes were presumably metamorphosed during the Neoprotherozoic Brasiliano Pan-African thrusting event (Chaves, 2001).

The Transminas swarm has a predominantly NNW trend. The swarm is located along the eastern border of SFC and cuts the Neoproterozoic and older rocks of the Araçuaí belt. The largest dykes are traceable for 600 km and have a width of ca. 50 metre. K-Ar dating has given dates between 220 and 170 Ma (Dussin, 1994 discussed in Chaves & Correia Neves, 2005). The Transminas swarm was emplaced in response to the development of an extensive zone of mantle melting and led to the first stage of fragmentation of Gondwanaland (Carvalho, 1983)

The Santos-Rio de Janeiro (Serra do Mar) swarm is located in the southern part of, and along, the southern border of SFC. Dykes of this NE- trending swarm reach up to 100 km in length and have a width up to ca 100 meter. Ar-Ar and K-Ar dates fall in the 120-130 Ma age span (Turner et al., 1994; Silva et al., 1995; Pinese, 1997). This swarm, together with the Florianópolis dyke swarm (NNE-trending) in southern Brazil, may be linked to a Cretaceous triple junction located near the Angolan and Namibian coastline (Carvalho, 1983) and are linked with the Paraná-Etendeka LIP (Ernst & Buchan 1997).

The NW and NE trending Arraial do Cabo swarm is represented by two groups of basalt and andesite bodies and intruded approximately 55 Ma ago (Bennio et al., 2003). The Arraial do Cabo swarm may be connected to extension-related melting of incompatible element of a depleted mantle. This would indicate the beginning of the transition from subcontinental to suboceanic sources during the Brazil-Africa separation (Bennio et al., 2003).

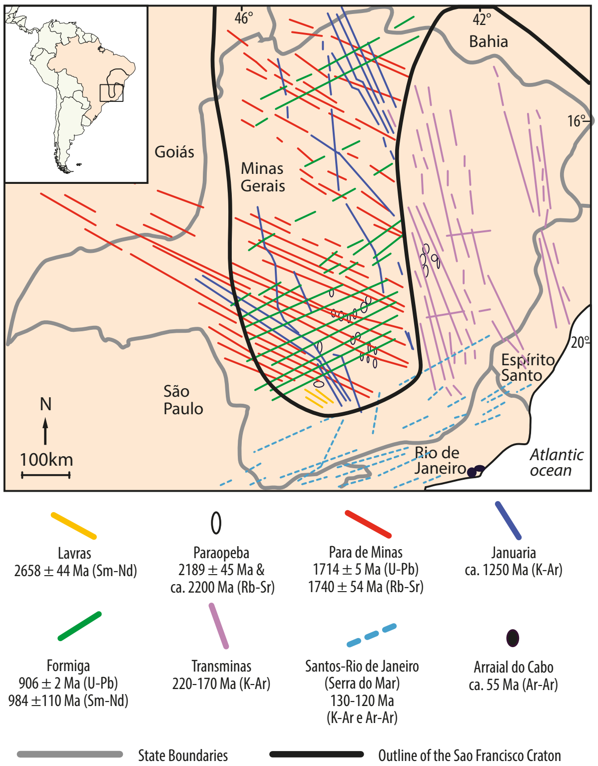

Figure 2. The mafic dyke swarms of southern Brazil. The map is modified after Chaves and Correia Neves (2005), incorporating previous dating of the Pará de Minas swarm by Silva et al. (1995) and Chaves (2001).

2.4 The Pará de Minas swarm

The Pará de Minas swarm is a giant tholeiitic dyke swarm trending across the southern part of SFC with dominating basaltic to andesitic compositions. These NW-trending dykes are up to 100 metre in width and the swarm is traceable for at least 1400 km, extending from the Minas Gerais state in the south, through the southwestern part of the Bahia state and ending west of the Transbrasiliano lineament (Borges & Drews, 2001). The dykes are parallel throughout the SFC (Fig. 2) into the Neoproterozoic Braziliano Pan-African orogeny. In Minas Gerais state the dykes cut the 1.68-1.80 Ga basal sequence of the Espinhaço Supergroup (Chaves & Correia Neves, 2005). About 80-90% of the dykes are overlain by Neoproterozoic rocks, but some cut the Neoproterozoic rocks indicating that more than one generation of dykes occur in the Pará de Minas swarm. In the southernmost SFC, the dykes are better exposed and typically display a subophitic texture. Some dykes are porphyritic, with plagioclase phenocrysts up to 10 cm across. Closer to the SFC margin the dykes are affected by metamorphism under greenschist facies condition presumably related to Brasiliano overthrusting during the Neoproterozoic (Chaves, 2001).

Anisotropy of magnetic susceptibility (AMS) data recorded by Raposo et al. (2004) indicate that dykes of the Pará de Minas swarm have a NW to SE subhorizontal magma flow. For normal and intermediate AMS fabric, 70 % of the the K_{max} inclination is between 0 and 25°. The dyke walls contain contact fractures, as indicated by centimetric magma branches with horn shapes, point to magma flow from NW to SE. This implies that magmas were fed from a source further to the northwest (Chaves, 2001).

Six dykes of the Pará de Minas swarm have previously been dated with the Rb-Sr whole-rock isochron method, yielding an age of 1740 ± 54 Ma (discussed in Chaves & Correia Neves, 2005). One dyke (the Ibirité Gabbro) of the Pará de Minas swarm was dated with U-Pb on baddeleyite yielding an upper intercept age of 1714 ± 5 Ma (Silva, 1995).

3. Local geology and sample sites

Eight dykes were sampled in Minas Gerais state for U-Pb geochronology, petrographic studies and geochemistry. Six samples (MG-3 - MG-8), relevant for the study, are shown on the maps at the sample sites. The mean trend of the dykes is 40° NW and the dykes are exposed at the surface mainly as weathered boulders, with the exception for one dyke (MG-5), which can be seen as an outcrop. No contact between dykes and host rocks could be seen at any of the sample sites. Samples were hence taken from boulders assumed to be derived from near the center of the dykes.

3.1 MG-3 *(S 20° 51.882´/W 45° 12.650´)* and MG-8 *(S 20° 53.980´/W 45° 08.247´)*

Both MG-3 and MG-8 are located in the Fernão Dias gneiss (Fig. 3), a gray medium-grained gneiss and characterized by leucocratic bands (quartz and feldspar) and melanocratic bands (hypersthene, hornblende and biotite) (Carneiro et al., 2006). MG-3 is a fine to medium-grained light grey dolerite. This sample is taken from a ca. 15 metre wide dyke that can be observed approximately 50 metres along strike. Sample MG-8 is gray, fine to medium grained dolerite. Only a couple of boulders were found at the sampling site and therefore the width of the dyke is uncertain.

In the north part of the map, the Fernão Dias gneiss is overlain by the slightly younger Candeias gneiss (a greenish, medium to coarse grained gneiss sequence). The Ribeirão dos Motas suite (a deformed and metamorphosed ultramafic-mafic body) and the Sillimanite Quartzite (foliated quartzitic rocks, classified as sillimanite schist or sillimanite-quartzite) overlay the gneisses (Carneiro et al., 2006).

Faults with a dextral shear component can be identified throughout the map area as indicated in Figure 3. One of the faults is located only ca. 1 km north of the MG-8 sample site. All bedrock and faults were crosscut by the Pará de Minas NW-trending mafic dyke systems.

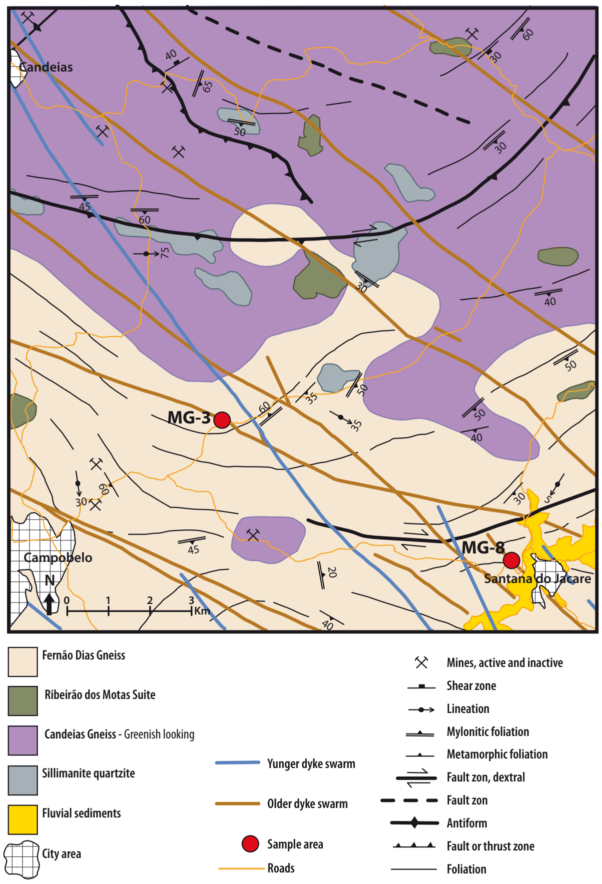

Figure 3. Sample area for MG-3 and MG-8. Modified from Carneiro et al. (2006).

3.2 MG-4 *(S 19° 42.129´/W 44° 52.779´)*

In Figure 4, MG-4 is located within metavolcanic rocks - and metasedimentary of the Rio das Velhas Supergroup (Romano, 2007). Sample MG-4 is a dark grey (slightly greenish), fine-grained, ca. 15 metre wide dolerite with light green plagioclase phenocrysts of varying sizes, of which some are up to 3 cm. The phenocrysts are mostly rounded though some elongated shapes occur.

The metavolcanic rocks- and metasedimentary overlay the Divinopolis complex (banded gneiss). In the northern part of the map the Sete Lagoas Formation (dolomite) and the Serra de Santa Helena Formation (pelite) overlay the Metavolcanic rocks- and metasedimentary. The Metaultamafic-metamafic unit can be seen both diagonal and as a "wave" turning east. The Dentro unit (granitoid) is slightly elongated. There are a number of faults especially in the metaultramfic-metamafic unit (Romano, 2007).

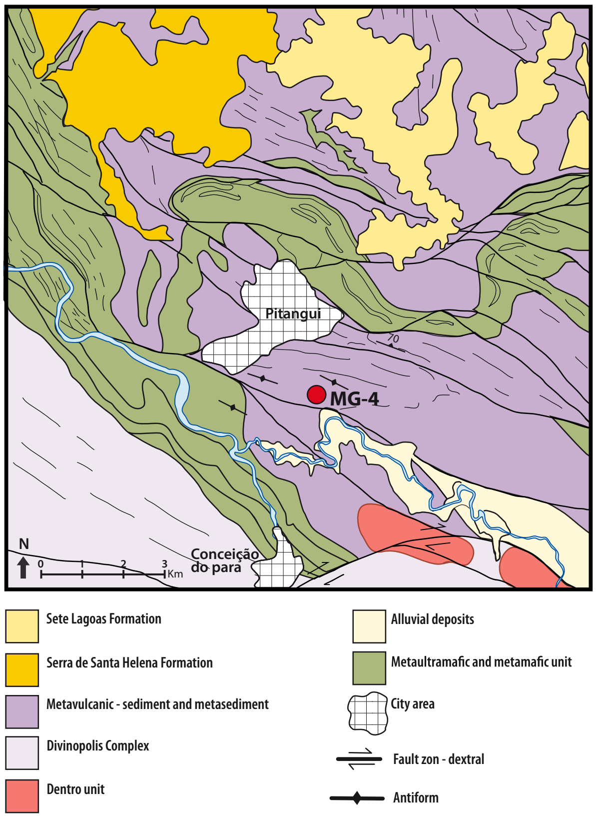

Figure 4. The sample site for MG-4. Modified map from Romano (2007).

3.3 MG-5 *(S 20° 22.367´/W 44° 22.118´)*

Figure 5 shows the location for the MG-5 sample site. The basement to the dyke is composed of various types of high-grade metamorphic rocks, and comprises a number of metamorphic complexes (Teixeira., 1996, 2000). The bedrock in the area was formed during the Mesoarchaean and is related to several tectono-metamorphic events, in particular the Rio Velhas event (Carneiro, 1992 discussed in Carneiro, 1998). This event, besides reworking the sialic crust, generated the Rio das Velhas Supergroup basal unit (greenstone belt-type sequences).

The Itaguara Layered Sequence (SAI) forms a NE-SW belt between Itaguara and Crucilandia. SAI encompasses a sequence of deformed and metamorphosed ultramafic-mafic rock intrusive into the Neoarchaean sialic crust. Its igneous layering is still preserved (Goulart, 2006, discussed in Goulart, 2008).

Both dextral and sinistral transpressive faults are abundant in the northwest and western part of the map. All bedrock lithologies are intruded by both mafic and granitic dykes. The NE-trending granitic dykes seem to follow the general fault direction. The MG-5 dyke is a grey, medium grained dolerite. The sample is collected from a ca. 100 metre wide dyke that cuts the NE- granitic dykes. The MG-5 dyke can be seen as both weathered boulders and in fresh outcrops. The outcrop exhibits abundant fractures with a 70° N direction, i.e. semi-parallel to the dyke.

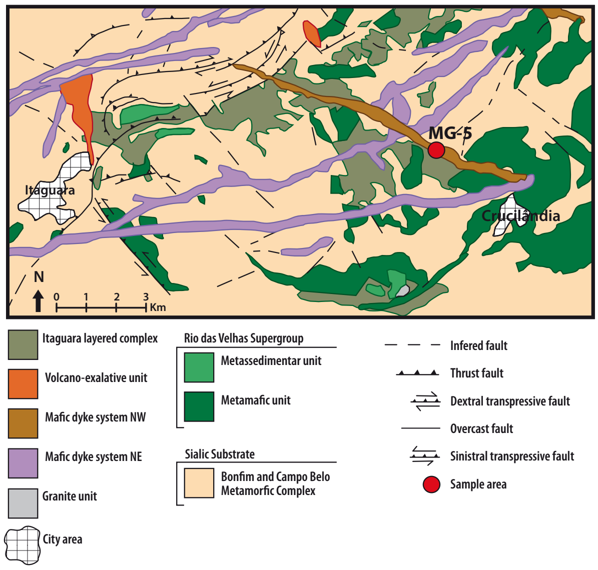

Figure 5. The sample suite for MG-5. The map is modified from Goulart (2006).

3.3 MG- 6 *(S 20° 39.048´/W 44° 44.136´)* and MG-7 *(S 20° 42.355´/W 44° 46.724´)*

In Figure 6, MG- 6 and MG-7 are located in the Cláudio Gneiss (grey, medium grained gneiss). The Claudio gneiss is overlain by the slightly younger Ribeirão dos Motas suite (a deformed and metamorphosed ultrama-

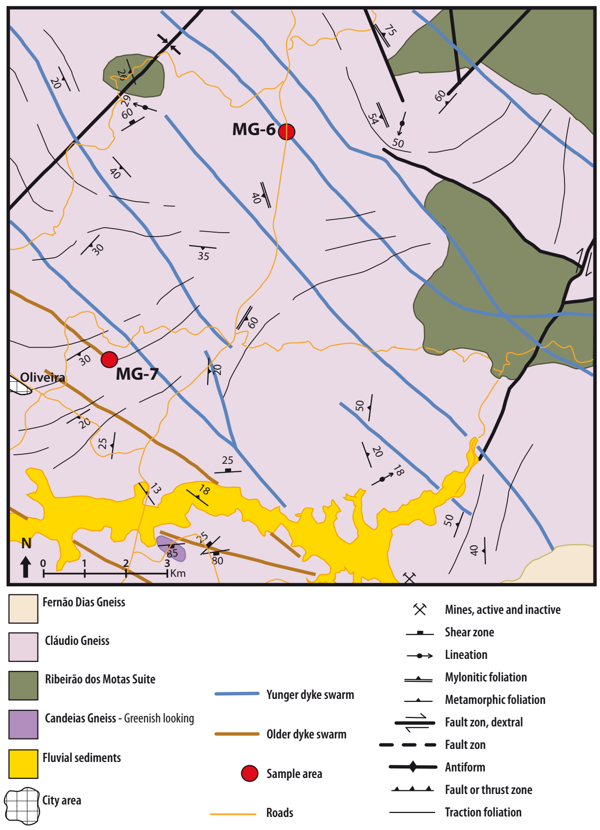

Figure 6. The sample suite for MG-6 and MG-7. The map is modified from Carneiro et al. (2006).

fic-mafic rock) and the Candeias gneiss (a greenish, medium to coarse grained gneiss sequence) (Carneiro et al., 2006). The Ribeirão dos Motas suite has been affected by faults. All bedrocks and faults are crusscut by the Pará de Minas mafic dyke system.

MG-6 is a grey, pale greenish medium-grained granular dolerite. The sample is taken from a ca. 15-20 metre wide dyke. The MG-7 sample is a dark grey, fine-grained dolerite with few plagioclase phenocrysts about 1-1.5 cm in size. The dyke is approximately 10 metres in width.

4. Petrography

Thin sections have been made for all sample sites (MG-3 to MG-8) with the exception of sample MG-6 and studied in the petrographic microscope (Fig. 7 to 11). Observed pyroxene is assumed to be clinopyroxene but has to be confirmed by mineral chemistry analysis.

4.1 MG-3

MG-3 is a medium grained dolerite. The main minerals consist of plagioclase, pyroxene and small amount of olivine where the two former minerals were formed coeval. Accessory minerals are quartz, apatite, amphibole and opaque minerals. Small amounts of olivine and apatite can be seen as inclusions in pyroxene. Some of the pyroxene crystals display compositional zoning. Granophyric texture (intergrowths of quartz and alkali feldspar) is seen in contact to, or around, plagioclase. Myrmekite texture (intergrowth between quartz and plagioclase) occur occasionally. Many of the grains (especially plagioclase) are slightly altered.

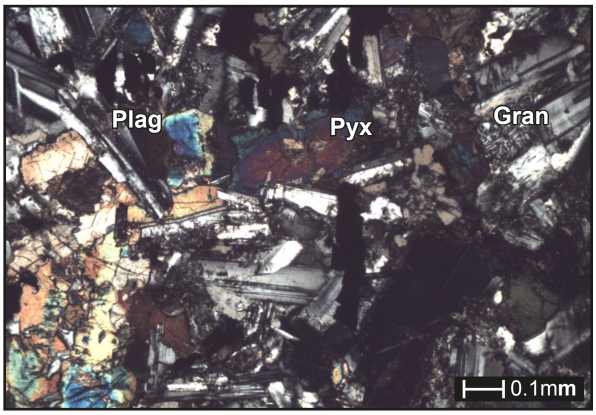

Figure 7a. An overview of mineral content in Mg-3.

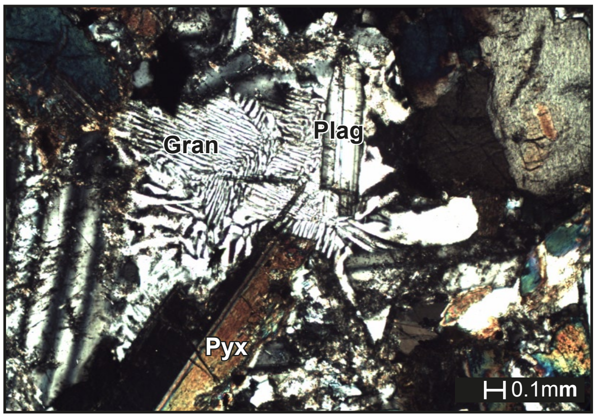

Figure 7b. Granophric texture in contact to plagioclase.

4.2 MG-4

MG-4 is a coarse grained dolerite with ophitic texture and a groundmass of pyroxene and plagioclase. Accessory minerals are actinolite, tremolite, zoisite, apatite, quartz, biotite, chlorite, epidote and opaque minerals. Both chloritization (replacement of mafic mineral to chlorite) and saussuritization (plagioclase replacement to epidote) can be seen. Some of the biotite grains are red. Many of the grains are extremely altered. Some of the plagioclase grains are pseudomorphed by the alteration.

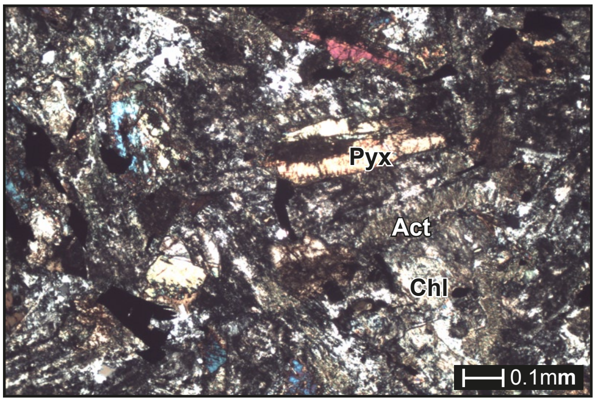

Figure 8. An overview of mineral content in Mg-4.

4.3 MG-5

MG-5 is coarse-grained dolerite and has an ophitic texture. The groundmass consists of plagioclase and pyroxene. Accessory minerals are biotite, actinolite, tremolite, zoisite, apatite and opaque grains. Some of the pyroxenes show inclusions of opaque minerals whereas others have recrystallized into actinolite, tremolite and occur as corona around the opaque minerals. Some of the biotite grains are red. Relic oxidized olivine are observed and have formed magnetite and a greenish unknown mineral. Many of the grains are very to extremely altered.

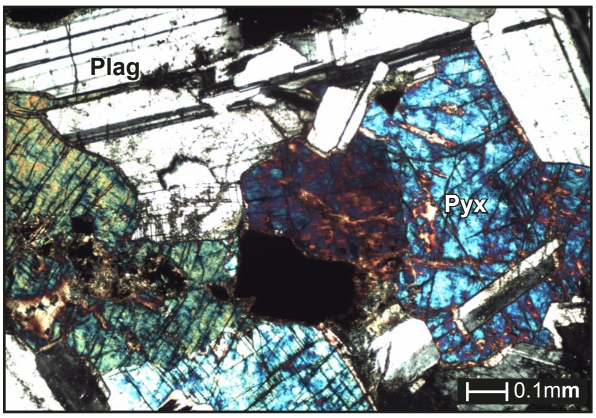

Figure 9a. An overview of mineral content in Mg-5.

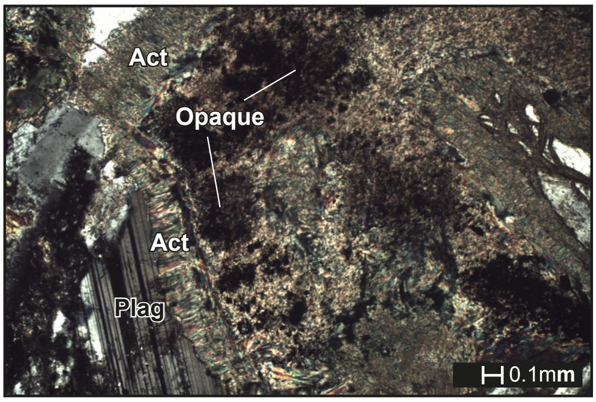

Figure 9b. Inclutions of opaque minerals in a pyroxene that have altered into actinolite and tremolite and occur as a corona around the opaque minerals.

4.4 MG-7

MG-7 is a medium grained dolerite with ophitic texture. The groundmass consists of pyroxene, mica and chlorite. Accessory minerals are apatite, quartz, biotite, actinolite, tremolite, and opaque minerals. The plagioclase is extremely altered and most of the crystals can only be seen as pseudomorphs consisting of mica. Chloritization, replacement of mafic mineral to chlorite is observed. Some of the biotite grains are red.

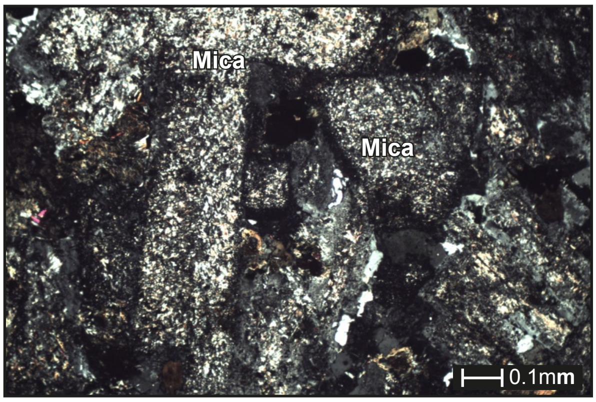

Figure 10. An overview of mineral content in Mg-7. Most plagioclase crystals can be seen as pseudomorphs consisting of mica.

4.5 MG-8

MG-8 is a medium grained dolorite with subophitc texture. The main minerals are plagioclase and pyroxene. Accessory minerals are quartz, apatite, feldspar, actinolite, tremolite, and opaque minerals. Some of the pyroxene grains show inclusions of opaque minerals and some of the grains have altered into actinolite and tremolite which occurs as corona around the opaque minerals. Pyroxene and feldspar are slightly too severely altered.

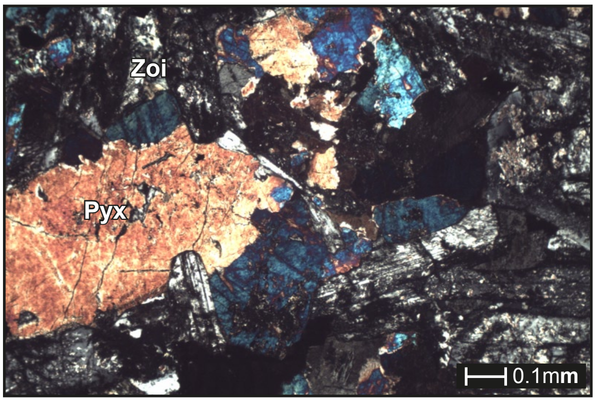

Figure 11. An overview of mineral content in Mg-8.

5. Analytical protocols for dating with the U-Pb baddeleyite method

Samples for geochronology and thin sections were collected in the southern area of Minas Gerais state during 2012 and prepared for analysis at the Department of Geology at Lund University. Mass spectrometric analyses were performed at the Laboratory of Isotope Geology (LIG) at the Natural History Museum of Stockholm.

5.1 TIMS Geochronology

Approximately 200 to 350 g material of each sample was crushed by hand using a sledgehammer to smaller, cm-sized, pieces and subsequently milled in ca. 50 g portions to finer material using a mill tray. Baddeleyite crystals were then separated on a Wilfley table following the technique of Söderlund and Johansson (2002). The magnetic minerals were removed using a magnetic pen wrapped into plastic to prevent sample contamination. The best baddeleyite crystals were hand-picked under a microscope, and transferred to a Petri dish using a hand-made pipett. Baddeleyite was identified in sample MG-3, MG-4, MG-5, MG-6, MG-7 and MG-8, whereas no baddeleyite grains were found in sample MG-1 and MG-2.

The baddeleyite grains have similar morphologies, dominated by pale- to medium dark brown thin blades or needles typically 40-60 µm in longest dimension. In most samples a portion of the crystals display a frosty appearance that presumably indicates alteration from baddeleyite to zircon in the presence of silica. The baddeleyite yield after separation varied strongly between samples. MG-3 and MG-6 gave the largest and also the most abundant grains whereas lesser and smaller grains were recovered from MG-8 and MG-4, especially MG-8 was problematic for extracting a sufficient amount of grains.

The baddeleyite grains of highest quality were transferred with a pipette to Teflon capsules, each comprising 8 to 15 grains except one fraction of MG-8 (comprising a single large grain). The crystals were then repeatedly washed with ultra-clean 7N HNO_3 and

H2O. 8-10 drops of HNO_3 and 8-10 drops of H_2O were added and the Teflon capsules were put on hot plate (to ca. 100º C) for ca. 20 min. The reason for the repeated washing procedure is to successively dilute the amount of blank Pb in the liquid and from loosely bound Pb on crystal surfaces. The crystals were then finally washed 3-4 times with nitric acid and H_2O. After the final washing, each fraction was spiked using a $^{236-233}U$- ^{205}Pb tracer solution. Ten drops of conc. HF and one drop of nitric acid were added. The capsules were placed in an oven for two days (200º C) in order to dissolve the sample and obtain complete homogenization of U and Pb from both the sample and tracer solution.

The dissolved samples were then taken to the Museum of Natural History in Stockholm where the capsules were placed on a hot plate for 45 min (95° C) to evaporate to complete dryness. Ten drops of 6N HCl were then added into each capsule, which was then placed on a hot plate (95° C) for ca. 15 minutes. A drop of 0.25 N H_3PO_4 was added and the samples were evaporated again on a hot plate (95° C) for ca 45 min. The evaporated sample was re-dissolved in 2 µl Si-gel and immediately loaded onto out-gased Rhenium filaments in 2-3 small portions using a micro pipette. The sample drop was evaporated at low current (1A), before gradually increasing the current through the filament in small step up to ca 2.4 A or until a string of white smoke from phosphorus was visible and sample crust become whitish. After a small increase of the current the filament started to glow and the filaments were ready to assemblage in the mass spectrometer ion source.

Mass spectrometry analysis takes place under exceptionally high vacuum in order to avoid collisions between air molecules and sample elements. At the instant baddeleyite is formed, the amount of initial Pb is very low and sometimes almost negligible compared to the amount of radiogenic Pb produced by decay of U and Th over time. Pb was analyzed at a filament temperature of ca. 1160-1210° C and U subsequently over the temperature range 1260-1310° C.

The intensities of U and Pb isotopes were measured on a TIMS Finnigan Triton mass spectrometer. 208Pb, 207Pb, 206Pb and 205Pb were recorded using Faraday collectors in static mode or in dynamic (peak-switching) mode using a Secondary Electron Multipiler (SEM), the latter for small samples. For the large samples, the $^{206}Pb/^{204}Pb$ ratio was used for common lead correction with 207Pb and 204Pb measured in dynamic collector mode using the SEM by switching between these masses. A "in-house" program, based on the algorithms of Ludwig (2003), were used for data reduction written in an Office Excel spreadsheet (by Per-Olof Persson, Stockholm).

The total procedural blank for the chemical separation was estimated as 1 pg for Pb and 0.1 pg for U. Mass fractionation is 0.1% per mass unit for Pb, determined by replicate analyses of NBS standards SRM 981 and SRM 983. The global Pb evolution model of Stacey and Kramers (1975) were taken for initial Pb. The Pb blank isotopic composition is 206Pb/204Pb = 18.5, $^{207}Pb/^{204}Pb$ = 15.6 and $^{208}Pb/^{204}Pb$ = 38.5. The decay constants are those recommended by Steiger and Jäger (1977); ^{238}U (1.55125×10−11 a-1), ^{235}U (9.8485×10−10 a-1) and the isotopic composition of U 238U/235U= 137.88. Uncertainties in U-Pb dates are reported at the 2 sigma level.

6. Results

U–Pb TIMS data are listed in Table 1 and plotted in Concordia diagrams in Figure 12. Baddeleyite grains in the dolerite samples are dominated by pale- to medium dark brown thin blades and blade fragments. In all samples, except MG-8, the baddeleyite grains exhibit a frosty appearance that presumably indicates rim alteration from baddeleyite to zircon in the presence of silica.

Data from MG-3 plot slightly discordant (0-3 %) though the most imprecise analysis is concordant within error. Regression yields an upper intercept at 1788 ± 3 Ma when using a forced lower intercept at 0 ± 100 Ma. This regression yields an acceptable mean square weighted deviation (MSWD) of 0.6.

The two fractions analyzed of MG-4 are less than 2-4% discordant and yield upper and lower intercepts of 1687 ± 8 Ma and 203 ± 130 Ma, respectively, with an MSWD value of 1.4.

The three baddeleyite fractions of sample MG-5 are as much as 5 to 9% discordant. The discordance is presumably a result from complex Pb-loss and reaction from baddeleyite into a polycrystalline zircon rim after magmatic crystallization. Unforced regression yields an upper intercept of 1792 ± 16 Ma and a lower intercept age of 559 ± 260 Ma (MSWD = 1.0).

Four fractions analyzed of MG-6 are also moderately discordant (2-6 %) but show scatter beyond analytical uncertainties as indicated by a MSWD value of 7.1. This scatter provides an imprecise upper intercept of 1785 ± 67 Ma and a lower intercept at 405 ± 67 Ma.

The three fractions for MG-7 basically overlap. Using a forced lower intercept of 0 ± 100 Ma yields an upper intercept age of 1690 ± 6 Ma with a slightly elevated MSWD value of 2.1.

Due to the low abundance of baddeleyite in sample MG-8, only three fractions were analyzed in which fraction A comprises a single large crystal. Fraction B and C was loaded with 15 crystals each. The three analyses plot concordant within error and yield a concordia age of 765 ± 37 Ma and gives a MSWD value of 1.05. The weighted mean in $^{207}Pb/^{206}Pb$ ages at 766 ± 36 Ma is preferred (MSWD value of 1.05) as the best age estimate for this sample.

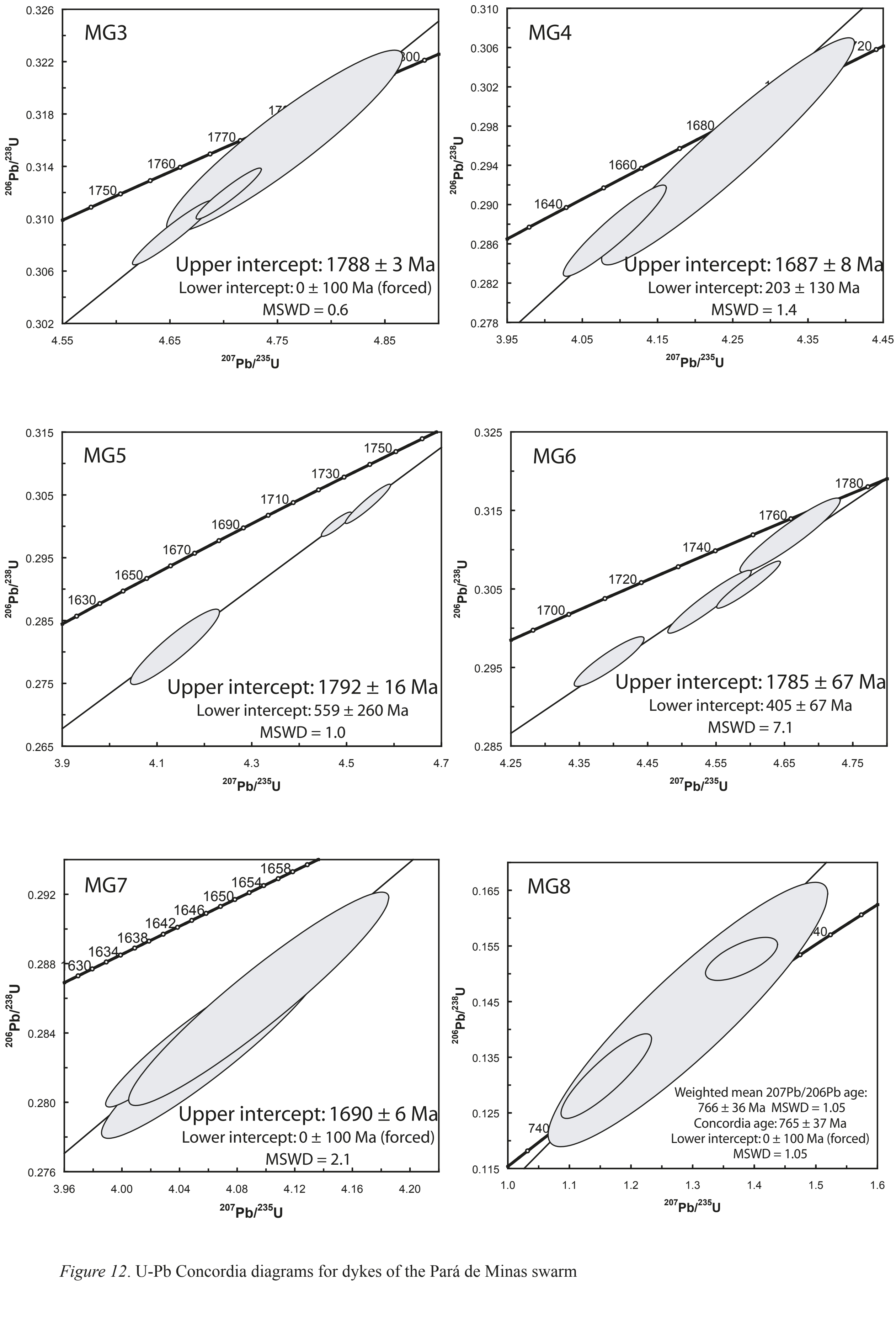

Figure 12. U-Pb Concordia diagrams for dykes of the Pará de Minas swarm

Table 1 U-Pb data

Table 1. U-Pb TIMS data

Analysis no. (number of grains)	U/ Th	Pbc/ Pbtot[1)]	^{206}Pb/ ^{204}Pb	^{207}Pb/ ^{235}U	± 2s % err	^{206}Pb/ ^{238}U	± 2s % err	^{207}Pb/ ^{235}U	^{206}Pb/ ^{238}U	^{207}Pb/ ^{206}Pb	± 2s	Concord- ance
			raw[2)]	[corr][3)]				[age, Ma]				
MG-3												
Bd-1 (9 grains)	12,0	0,046	1421,1	4,6521	0,66	0,30889	0,65	1758,7	1735,2	1786,6	3,7	0,971
Bd-2 (7 grains)	15,4	0,279	198,1	4,7560	1,89	0,31590	1,81	1777,2	1769,7	1786,0	12,7	0,991
Bd-3 (8 grains)	9,1	0,032	2045,1	4,7038	0,53	0,31189	0,51	1767,9	1750,0	1789,2	3,0	0,978
MG-5												
Bd-1 (8 grains)	20,4	0,044	1444,1	4,4771	0,58	0,30032	0,53	1726,7	1692,9	1768,0	4,6	0,958
Bd-2 (6 grains)	20,0	0,224	263,4	4,1364	1,85	0,28072	1,75	1661,5	1595,0	1746,7	13,2	0,913
Bd-3 (7 grains)	14,8	0,055	1198,4	4,5438	0,86	0,30355	0,84	1739,0	1708,9	1775,4	4,8	0,963
MG-6												
Bd-1 (7 grains)	26,6	0,074	860,0	4,3924	0,95	0,29568	0,88	1710,9	1669,9	1761,5	7,2	0,948
Bd-2 (4 grains)	58,4	0,085	792,2	4,6566	1,29	0,31183	1,24	1759,5	1749,7	1771,1	8,3	0,988
Bd-3 (8 grains)	37,7	0,078	853,8	4,5391	1,10	0,30332	1,08	1738,2	1707,8	1775,0	6,2	0,962
Bd-4 (8 grains)	28,1	0,046	1437,0	4,5962	0,83	0,30550	0,80	1748,6	1718,5	1784,7	4,8	0,963
MG-7												
Bd-1 (9 grains)	0,5	0,046	972,8	4,0397	1,04	0,28321	1,02	1642,2	1607,5	1687,0	6,0	0,953
Bd-2 (6 grains)	10,9	0,220	262,4	4,0629	1,56	0,28310	1,51	1646,9	1607,0	1698,2	9,9	0,946
Bd-3 (5 grains)	15,7	0,174	364,2	4,0471	1,81	0,28264	1,77	1643,7	1604,6	1694,0	10,8	0,947
MG-4												
Bd-1 (7 grains)	7,6	0,170	349,9	4,0920	1,37	0,28729	1,32	1652,7	1628,0	1684,3	8,9	0,967
Bd-2 (6 grains)	4,5	0,611	58,4	4,1804	2,44	0,31722	1,21	1670,2	1776,1	1539,5	38,8	1,154
Bd-3 (4 grains)	0,6	0,212	213,6	4,2425	3,23	0,29540	3,21	1682,3	1668,5	1699,6	18,1	0,982
MG-8												
Bd-1 (1 grains)	2,1	0,899	80,6	1,2915	14,35	0,14263	13,65	841,9	859,5	795,9	125,2	1,080
Bd-2 (15 grains)	10,8	0,463	137,7	1,1587	5,19	0,13152	4,73	781,4	796,5	738,2	52,9	1,079
Bd-3 (15 grains)	0,6	0,438	80,6	1,3783	3,47	0,15266	2,07	879,7	915,8	789,9	54,6	1,159

1) Pbc = common Pb; Pbtot = total Pb (radiogenic + blank + initial).

2) measured ratio, corrected for fractionation and spike.

3) isotopic ratios corrected for fractionation (0.1% per amu for Pb), spike contribution, blank (1 pg Pb and <1 pg U), and initial common Pb. Initial common Pb corrected with isotopic compositions from the model of Stacey and Kramers (1975) at the age of the sample.

7. Discussion

7.1 U-Pb data of investigated dykes

Baddeleyite in mafic intrusions can confidently be linked to crystallization of mafic magmas since baddeleyite readily reacts with free silica to form polycrystalline zircon during melting processes or metamorphism (Heaman and LeCheminant, 1993; Söderlund et al., 2013). In fresh dolerite, baddeleyite generally yields concordant to nearly concordant U-Pb dates whereas altered or weakly metamorphosed samples typically give discordant data sets, caused by mixing of baddeleyite and secondary zircon (rather than Pb-loss). Accordingly, fresh samples are preferentially dated by ID-TIMS to obtain precise emplacement ages, typically yielding age uncertainties of ±0.1-0.5 % (2s).

Both MG-3 and MG-4 plot only slightly discordant yielding U-Pb ages of 1788 ± 3 Ma and 1687 ± 8 Ma. The lower intercept for MG-5 (559 ± 260 Ma) might be linked to the Brasiliano Pan-African Orogeny that resulted in the amalgamation of Gondwana at approximately 600 Ma ago.

Both the MG-4 and MG-7 dykes (1690 Ma generation) are porphyritic with phenocrysts made up of greenish plagioclase. This may be a characteristic feature for this generation since all other samples that were sampled for geochronology lack feldspar phenocrysts. It was also noted by Chaves (2001) and discussed in Chaves & Correia Neves (2005) that some Pará de Minas dykes are porphyritic with plagioclase phenocrysts up to 10 cm across.

All the sampled dolerites have undergone low grade metamorphism. From thin section studies, all samples, except MG-3, have mineralogies indicating they were in transition to or in the lower greenschist facies. This can be seen by the minerals detected in the thin sections of the samples consisting of typical greenschist minerals e.g actinolite, tremolite, zoisite, apatite, biotite, chlorite and epidote. According to Chaves (2001), and as discussed in Chaves and Correia Neves (2005), the dykes close to the borders of the SFC in the Pará de Minas swarm are affected by metamorphism under greenschist facies condition presumably related to the Brasiliano Pan-African overthrusting during the Neoproterozoic (ca.630-570 Ma).

An alternative explanation is that their secondary minerals were formed during slow cooling of the dolerites in the presence of a relatively Si-rich fluid. In this study the imprint of metamorphism in the studied dykes seems equally strong throughout the sampling area indicating that a metamorphic event also affected the interior of the SFC. Surprisingly the 1690 Ma generation (MG-4 and MG-7) is the most metamorphosed samples whereas the 1790 Ma generation (MG-3 and MG-5) is better preserved. Notably, MG-8 (ca.766 Ma) is also altered although to a lesser degree than MG-4 and MG-7. It is not clearcut to explain differences in degree of metamorphic imprint between samples, and further more systematic studies must be conducted before concluding if the observed difference is real or fortuitous. No correlation between scatter in the concordia diagrams and grade of metamorphism in the thin sections can be found. For instance, MG-3, MG-4 and MG-8 plot all concordant or near-concordant but still show different ages and grade of metamorphism.

7.2 New and previous ages of mafic dykes in the São Francisco craton

The new U-Pb dating in this study demonstrates that the Pará de Minas swarm consists of at least three intermixed swarms with different emplacement ages of 1785-1792 Ma (MG3, MG5, MG6), 1687-1691 Ma (MG4, MG7) and a significantly younger generation of approximately 766 Ma (MG-8).

Some portion of the NW-SE trending Pará de Minas swarm extends outside the SFC border to the NW and intrude rocks of the Neoproterozoic Braziliano Pan-African orogeny. On the basis of the new U-Pb dates, one alternative is that dykes of the Para de Minas swarm outside SFC belong to the ca. 766 Ma swarm, then inferring that the Brasiliano Pan-Africa event west of SFC took place earlier than suggested previously. The possibility that the MG-8 generation continues and connects to the Niqulândia complex outside the SFC is discussed in section 7.4.3. Another alternative is that a further (fourth) generation of dykes even younger than ca. 766 Ma, that yet is to be found, continues into the Neoproterozoic Braziliano Pan-African orogeny. The latter alternative is to some extent supported by the greenschist facies imprint of the MG-8 dyke (Fig. 11), providing this imprint was a result of Brasiliano Pan-African metamorphism.

In the Minas Gerais State, many dykes cut the 1.68-1.8 Ga basal sequence of southern Espinhaço Supergroup and 80-90% of the dykes are overlain by Neoproterozoic rocks of the Bambui Group (Chaves, 2001; Chaves and Correia Neves, 2005). The dykes cutting the Espinhaço sediments must belong to either the 1690 Ma or the 766 Ma swarms.

Until now, the age of the Pará de Minas swarm has previously been dated at 1714 ± 5 Ma obtained for the Ibirite Gabbro, assuming dykes of the swarm are genetically related to the gabbro intrusion (Silva et al., 1995). The question is if the 1714 ± 5 Ma age represents a fourth generation of the Pará de Minas swarm or if it belongs to the 1690 Ma or the 1790 Ma generations. In the dating by Silva et al. (1995) the upper intercept is constrained by two fractions only. The two-point regression comprise one fraction being two percent discordant whereas the other fraction being approximately 99 percent discordant. Silva et al. (1995) reported that the grains in the strongly discordant fraction were severely frosted, probably due to incipient formation of secondary zircon by metamorphism. This means that the age of the sample is entirely controlled by a single analysis, i.e. the older 1702 Ma fraction (cf. Silva et al., 1995).

A later attempt to date the Pará de Minas swarm was performed by Chaves (2001) and presented in Chaves & Neves (2005, figure 6 and table 2). In that study six dykes were dated with Rb-Sr isochron whole-rock, which defined an age of 1740 ± 54 Ma with a MSWD value at 1.3. If significant, it means that in contrast to the present study all the dykes sampled by Chaves (2001) must have been of the same generation. Though possible it would be a fortuitous coincidence, considering sampling of six dykes in this study revealed three separate generations of dykes in the Pará de Minas swarm.

7.3. LIP barcode for a combined SFC and Congo Craton

It has been generally accepted that the SFC and CC were part of the same crustal block that lasted from about 2.05 Ga until the ca. 130 Ma breakup of Africa from South America (D´Agrella-Filho et al., 1996; Feybesse et al., 1998). Both the SFC and the CC consist of Archaean to Palaeoproterozoic high-grade gneisses and granite-greenstone supracrustal terrains. They are overlain by Mesoproterozoic to Neoproterozoic sediments. The Neoproterozoic belts surround the two cratons and define their borders. Mafic magmatism is widespread in both the SFC and CC and regional events of mafic magmatism can hence be expected to be found on both cratons. However, there are not many dyke swarms identified or yet properly dated from either the SFC and the CC.

Figure 13 shows events of mafic magmatism in the SFC and CC. The oldest match is represented by the 1790 Ma generation of the Pará de Minas swarm, with a possible connection to the Chela Group in the Angola shield present in the southwestern portion of the CC. The Chela group is a ca. 1814-1810 Ma sub-volcanic acid body including dykes (Pereira et al., 2011).

No similar intrusions in the CC have been identified and properly dated that potentially could match the 1690 Ma generation of the Pará de Minas swarm. Considering the general view that SFC and the CC were "next neighbours" from 2.05 Ga to 130 Ma, all dyke generations of the Pará de Minas swarm should occur on both blocks.

The only match during the Mesoproterozoic is the matching between Curaçá and Chapada dykes from the northern SFC (Oliveira et al., 2012; Silveira et al., 2012). and the Humpata event in the Angolan portion of the CC (Ernst et al., 2013) at 1505 Ma.

The extensive Umkondo event in southern Africa is dated with baddeleyite yielding consisted ages between 1112 and 1108 Ma (Hanson et al., 2004) and may be connected to the Januária swarm in the SFC (Fig 2). The Januária swarm has been dated to ca. 1.1 (K-Ar) and may represent a further westerly extension of the Umkundo event (discussed in Chaves & Neves, 2005).

In SFC, Bahia state, the Salvador (924-921 Ma), Ilheus (926 Ma) and Olivença (920-930 Ma) dyke swarms is located on the eastern border of the SFC (Heaman, 1991; Evens et al., 2010; Oliveira et al., 2012). A similar age is found in the CC for the Gangila (920 Ma) basalt, associated with the bimodal Mayumbian volcanism in the West Congo belt (Tack et al., 2001) and correlated with the Bahia dykes in Ernst and Buchan (1997). The 920 Ma event is believed to manifest attempted break up between the SFC and CC (Alkmim et al., 2006).

No direct link between the SFC and CC at 766 Ma has yet been identified.

7.4. Comparison with other Archaean blocks

The three generations 1785-1792 Ma, 1687-1691 Ma and 766 Ma may play an important role for reconstructing the Rodina and Columbia supercontinents. Many positional candidates for the neighbour cratons can be observed for the three generations and will be discussed in the following text.

7.4.1 The 1790 Ma generation

The new 1790 Ma age has a number of direct matches with magmatism on other crustal blocks. In the Rio de la Plata craton (southeastern Brazil), the ENE trending Uruguayan dyke swarm (UDS) has been dated by U-Pb on baddeleyite at 1790 ± 5 Ma and palaeomagnetically studied (Halls et al., 1999; Teixeira et al., 2012). The

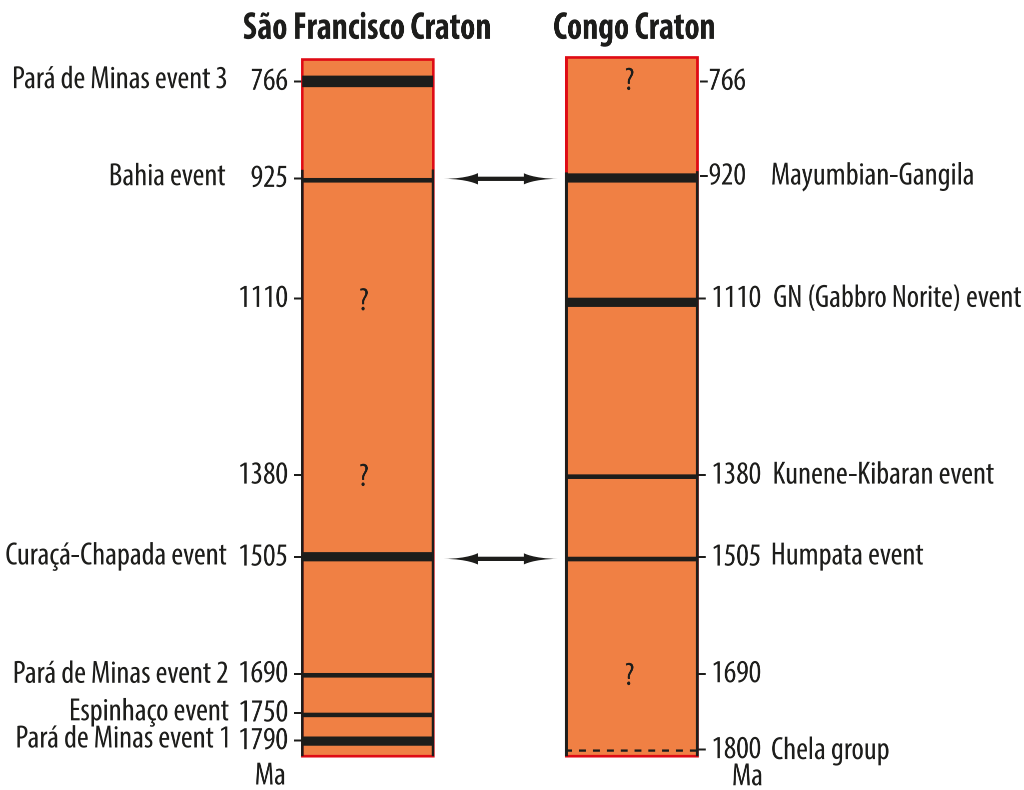

Figure 13. The LIP barcode comparison SFC and CC. The thickness of the black bars shows the uncertainty in the ages and the dashed line indicates the estimated age of the Chela Group.

UDS swarm is about 100 km wide and almost 250 km long and is located in the southern part of the craton.

The Amazonian craton in northwestern Brazil is one of the largest Meso- to Neo-proterozoic "puzzle piece" on Earth, but its magmatic events have been poorly dated. Both the Ilhas sill (1793 ± 1 Ma, Reis et al., 2012) in the northern part of the Amazonian craton and the Pedra Preta dolerite sill (1795 ± 2 Ma, Reis et al., 2012) near the Venezuelan border are coeval with the Pará de Minas swarm. The swarms in Amazonia have both been dated with zircon and baddeleyite (U-Pb TIMS), being coeval with the widespread 1790 Ma Avanavero LIP (Reis et al., 2012). Other units connected to the Avanavero event comprise the Crepori dolerite in Guapore in the southern part of the Amazonian craton (1780 ± 7 Ma), the Quarenta Ilhas dolerite (1780 ± 3 Ma) and the Cipo dolorite (1778 ± 12 Ma) in the Northeastern part of the Amazonia craton (Santos et al., 2002). On the basis of geochronology only, both the Rio de la Plata craton and the Amazonian cratons may thus have been adjacent to SFC at ca. 1790 Ma, though not necessarily in their present-day positions relative to SFC. However there is a Palaeomagnetic comparison between the Rio de la Plata craton and the Amazonian craton at 1790 Ma (Teixeira et al., 2012) and therefore a possible connection to SFC.

Three major tectonic elements comprise the east European craton; the Sarmatian block, Volgo-Uralia and Fennoscandia (e.g. Bogdanova et al., 2008). The NNW-trending Tomashgorod dyke in the northwestern Ukrainian shield was dated yielding a precise U-Pb baddelyite age of 1789 ± 3 Ma (Bogdanova et al., 2012), hence a direct match with the 1790 Ma dyke generation of the Pará de Minas swarm.

The Hart dolerite rocks in the northern Australia craton consists of a series of massive sills, up to 1800 metre thick and less of dykes. The Hart intrusions are exposed all along the southeastern and southwestern margins of the Speewah and Kimberley Basins. The intrusion of sills seems very much controlled by lithology, with siltstone beds being the preferred host. One dolerite sill was dated with the SHRIMP U-Pb zircon method and gave an age of 1790 ± 4 Ma (discussed in Li, 2000).

The Taihang-Lvliang dyke Swarm (TLS) consists of NNW-SSE-trending dykes evenly distributed throughout the central Northern China Craton (NCC) with subordinate NE-SW and E-W trending dykes. The TLS dykes are up to 60 km long and up to 100 metre in width. One of the dykes has been dated with baddeleyite TIMS at 1789 ± 28 Ma (Peng et al., 2006), and many more dolerites have yielded similar (1.78 Ga) U-Pb zircon and baddeleyite ages (Peng, 2005, 2006). The Taihand-Lavliang dyke swarm has been suggested to have a connection with the Xiong'er triple-junction rift, in which the Xiong'er volcanic province is proposed to be the extrusive counterpart of this swarm. It resulted in significant extension, uplift and magmatic accretion of the NCC, and is comparable with Phanerozoic LIPs in style. A plume tectonic model has been suggested for this event in NCC (Peng, 2010).

The 1790 Ma magmatism is globally distributed and therefore it is difficult to deduce which of these cratons the SFC was connected to at 1790 Ma. Additional and more detailed palaeomagnetic investigations as well as other geological considerations have to be accounted for in order to make robust reconstructions.

7.4.2 The 1690 Ma generation

Potential age matches to the 1.69 Ga dykes of the Pará de Mina swarm mafic intrusions are relatively rare. One of two possible candidates is the Byraiy swarm in Siberian craton. The NW trending Byraiy swarm in the SE part of the Siberian craton is dated at 1707 ± 32 Ma on zircon (Gur'yanov et al., 2011). The swarm is more than 80 km in length and dykes of this swarm cut a slightly older A-type granite swarm dated at 1716-1721 Ma (discussed in Gur'yanov et al., 2011). Both the Byraiy mafic dykes and the granite dykes correspond to the final stage of Paleoproterozoic magmatism in the 750 km long Ulkan-Bilyakchan rift system in southeastern Siberian Craton (Larin et al. 1997). The swarm has been linked to attempted break-up along an E-W rift arm and possible successful breakup along a N-S rift arm, along the eastern margin of the Aldan terrine. These rifts may represent arms of a triple junction rift system converging to a magmatic center (Gur'yanov et al., 2011).

The other candidate is the major E-W trending Pelly Bay dyke swarm in northern Laurentia. One dyke of this swarm was dated at 1692 ± 2 Ma (U-Pb on baddeleyite) (Bleeker et al., 2010). The dykes of the Pelly bay are fresh, many dykes are more than 50 metre in width (Bleeker et al., 2010).

Both the Pelly Bay swarm and Byraiy swarm are coeval with the 1690 Ma dyke generation of the Para de Minas swarm. However, SE Siberia and Laurentia is unlikely to have been near the SFC at this time.

7.4.3. The 766 Ma generation

The youngest generation of the Pará de Minas swarm, 766 ± 36 Ma age is within error and coeval with one of the world´s largest mafic-ultramafic plutonic complex, the Niquelândia complex in Brazil. The Niquelândia complex is about 350 km long and divided into three tectonically separated fragments, Barro Alto, Niquelândia and Cana Brava. The complex is parallel to the Maranhão thrust belt, a major tectonic boundary formed by tectonic activity between Amazonia and SFC during the Brasiliano Pan-African event at ca. 630-570 Ma (Feininger et al., 1991). All the fragments were tilted and uplifted above the thrust zone during the Brasiliano Pan-African event, the lowermost levels being exposed in the east. The complex is divided in a lower sequence (upper amphibolites, olivine-gabbros and anorthosites) and an upper sequence (mainly gabbro, norite, dunites and harzburgites), separated by a hydrous zone (biotite- and amphibole-bearing gabbro) (Girardi et al., 1986). It has long been debated if the upper and lower sequences are of the same age. Wherein the upper sequence of the complex has indicated a crystallization age of about 1.25 Ga (Pimentel et al., 2004, 2006; Ferreira Filho et al., 2010) and affected by metamorphism at 833 ± 21 Ma (Correia et al., 2007), the lower sequence crystallized at 797 ± 10 Ma (Pimentel et al., 2006). According to Correia et al. (2012), the 1.25 Ga age is not the real age for the upper sequence because similar ages (1.25 Ga) have been recorded from correlative units at the roof of the Barro Alto and Cana Brava Complexes.

New SHRIMP U-Pb dating of zircon shows that both the upper and lower sequence of the Niquelândia complex has an age at 781 ± 4 Ma (Correia et al., 2012). According to Pimentel et al. (2006) and Ferreira Filho et al. (2010) the youngest zircon ages may be an artifact of later closure of the system due to slow cooling or to a later heating episode, hence the age is possibly close to 790 Ma.

The youngest generation of dykes dated in the Pará de Minas swarm is here constrained at 766 ± 36 Ma, i.e. within uncertainty of the 790 Ma age of the Niquelândia complex. The Niquelândia complex west of SFC is located some 800 km from SFC in Goiás state. According to Borges & Drews (2001), the Pará de Minas swarm ends at the Transbrasiliano lineament. The lineament lay on the west side of the Niquelândia complex i.e. the Pará de Minas swarm, may be connected to the Niquelândia complex. If the Transbrasiliano lineament would have been east of the Niquelândia complex the youngest generation of the Pará de Minas swarm would not have been able to be connected but instead have been cut off at the lineament. However, it is uncertain if the youngest generation crosscuts the area of the Niquelândia complex.

Laurentia is surrounded by Neoproterozic to Cambrian rift/breakup margins (Bond et al., 1984), and should therefore have occupied a relatively central position in Rodinia, whereas the position for Western Australia is much more uncertain. Nevertheless, the two cratons (Laurentia and Western Australia) have been suggested to be amalgamated since ca. 1080-1050 Ma until progressive breakup of Rodinia started ca. 780-715 Ma (e.g. Hoffman, 1991; Moores, 1991; Brookfield, 1993). The younger generation of dykes of the Parà de Minas swarm now dated at 766 ± 36 Ma (MG-8) may represent an initial stage of break-up, or attempted, break-up.

The multiple-generations of dykes of the swarm signal that younger dykes utilized pre-existing crustal zones of weakness as they were emplaced in the crust. Tectonostratigraphic analysis proposes that the breakup between Australia and Laurentia did not occur until 560 Ma (Veevers et al., 1997). The NNE- trending Mundine Well swarm in western Australia is made up of a small number of sub-parallel dykes. The dykes are ca. 50 km apart and are less than 30 metre wide with a length of ca. 200 km. The Mundine Well dykes have been dated to 755 ± 3 Ma (Wingate & Giddings, 2000). A gabbro dyke in the Mt. Rogers area, located in the eastern part of Laurentia (Appalachian mountains) has yielded an age of 757 ± 5 Ma, dated with zircon using both SHRIMP and ID-TIMS (Aleinikoff et al., 1995; Tollo et al., 2012). Further south in the Roan Mounting area, the so-called Bakersville dykes and correlated dykes are widespread in basement inliers along the Appalachian mountains (Goldberg et al., 1986; Ernst et al., 2008). They have been dated with the SHRIMP zircon technique at 759 ± 7 Ma (Aleinikoff, 1995; Tollo et al., 2012). The Mundines Well and Mt. Rogers swarms emphasizes the exact age match of these two craton marginal LIPs at 755 Ma. The age of MG-8 has a very close match with the two swarms.

Units with an age of ca. 755 Ma are also found in the south China block (bimodal magmatism) and the Katangan magmatism in the Lufilian arc on the west side of the Kalahari craton, ca. 765-735 Ma The position of South China and the Kalahari cratons at ca 766 Ma remains uncertain (Key et al., 2001; Ernst et al. 2008). The Manson swarm (867 ± 16 Ma) in western Africa craton (WAC) (Kouyate et al., 2013) is significantly older in age and is not considered a probable match with the Para de Minas swarm.

It is difficult to deduce which of these cratons the 766 Ma generation is linked to since the SFC position during this time is far from resolved and many dykes remain to be dated. The most probable age matches are those in Laurentia and western Australia, but the 766 Ma generation should also be present in the CC.

7.5 Three generations of dykes in a single swarm

According to Jourdan et al. (2006), the direction of younger dykes in swarms with multiple dyke generations may sometimes be controlled by crustal weaknesses linked to the oldest dyke generation. Thus the trend of the ca. 766 Ma dyke generation may not correspond to an extensional lithospheric stress direction perpendicular to the swarm. However, the fact that dykes traceable outside the SFC proper do not deviate from the regular NE-SW direction does not support such hypothesis, if assuming these belong to the youngest generation. Chaves (2001) showed that at least one of the generations of the Pará de Minas swarm has a NW to SE subhorizonal magma flow but the age of the dykes investigated was unconstrained.

7.6 Potential Reconstruction

Several proposed reconstructions have been put forward for the supercontinent Columbia (1.8-1.5 Ga) and a few have been constrained focusing on the distribution of 1790 Ma magmatism that may stem from a single LIP event. At 1790 Ma Columbia had finished its assembly and the 1790 Ma LIP event hence occurred shortly after Columbia became stable (Rogers & Santos, 2002; Zhao et al., 2004).

The reconstruction of Zhang et al. (2012) accounts for all valid 1790 Ma LIP cratons including associated dykes (and their trends) and sills, discussed in this paper. In the reconstruction the dyke swarms are radiating outward in the Avanavero and Ukrainian shields and this radiating pattern can be traced from an inferred origin shown with red star in Figure 14 (Whitney, 2013). At this time (ca. 1790 Ma) the LIP center (magmatic center) was located at near-equatorial latitudes (Whitney, 2013). The TSL dykes in the Xiongér province in NCC are not compatible with this reconstruction, however, since they are placed at a suspected subduction zone in the Zhang et al. (2012) reconstruction (fig. 14). The Hart dolerite sill system could be linked to the NCC or simply been fed from the same magmatic center as the other dyke swarms (Whitney, 2013). The SFC-CC and the Rio de la Plata craton are not included in this reconstruction due to the lack of reliable palaeomagnetic data from the 1.8-1.3 Ga interval (Zhang et al., 2012). The 1790 Ma age in the Pará de Minas swarm may suggest that this swarm might have been part of a radiating dyke system.

Figure 15 shows a reconstruction shortly before break-up of Columbia proposed by Rogers and Santosh (2002), in Meert (2002). In this reconstruction the NCC

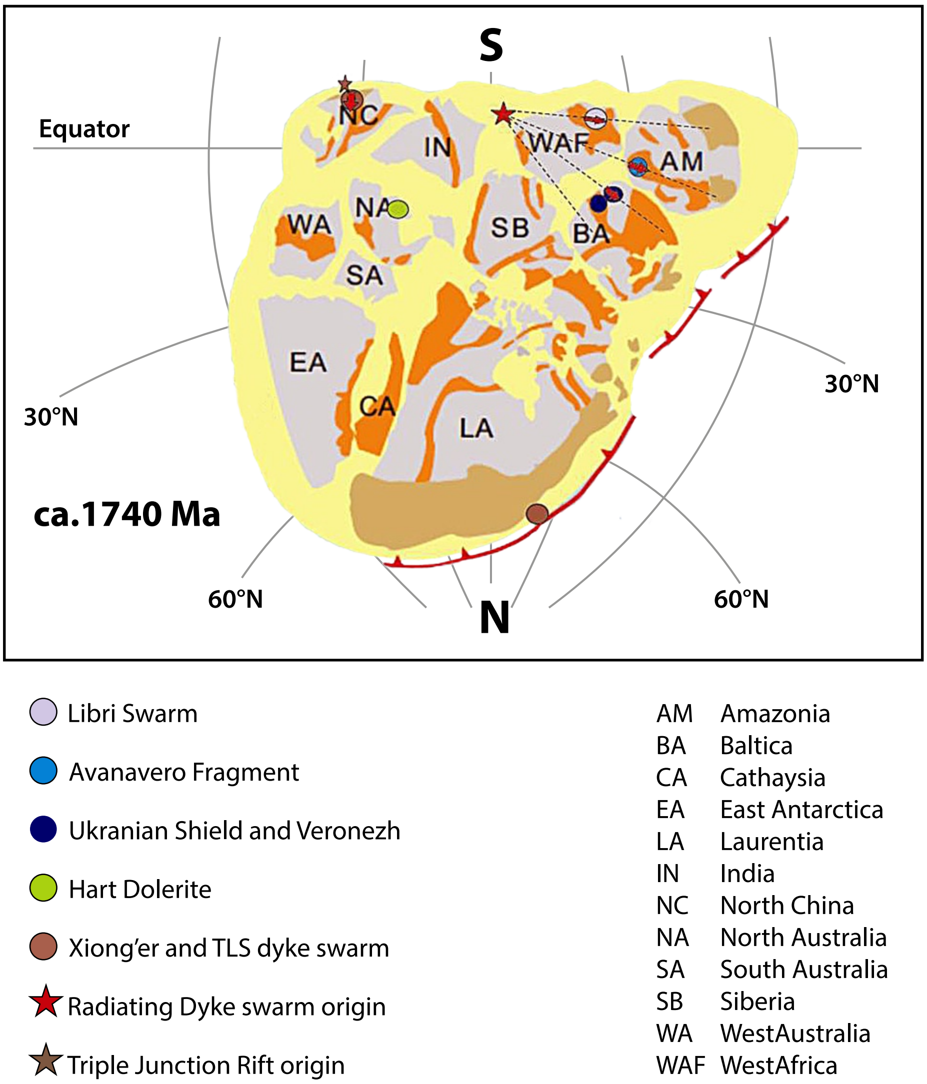

Figure 14. Reconstruction of the cratons at 1740 Ma with the 1790 Ma LIP including the dyke trend directions. The figure is modified after Whitney (2013).

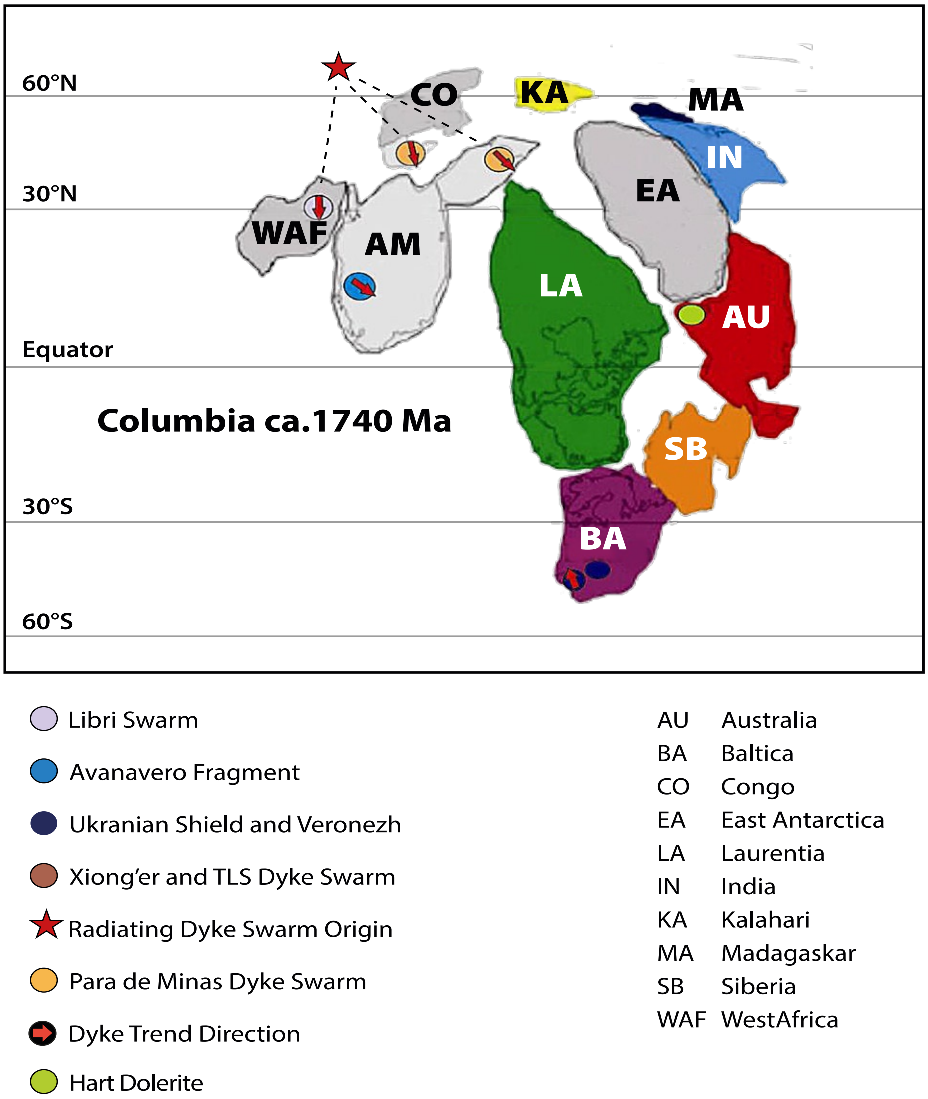

Figure 15. Reconstruction of the cratons at 1740 Ma with the 1790 Ma LIP including the dyke trend directions. The figure is modified after Whitney (2013).

has been left out but shows a possible position for the SFC-CC block. Baltica is located at a distance too far away from the other cratons. In the remaining cratons the dyke swarms (1790 Ma) have trends that agree with a radiating pattern, inferring a single or at least a dominating single magmatic center. All the issues of this reconstruction (NCC position and the fact that Baltica lie too far away from the radiating pattern) make the Zhang model more likely (Whitney, 2013). If the dyke trend direction should be pulled out so that they eventually would meet, the magmatic center was located west of SFC-CC (Fig 14)

Most reconstructions consider the supercontinent Rodinia to exist from ca. 1 Ga to 750 Ma, and involve amalgamation of the largest continental blocks such as Laurentia, Baltica and Amazonia. SFC and CC have been suggested to be separate from Rodinia to form a single craton of their own during this period (Kröner & Cordani, 2003; Cordani et al., 2003). Evans (2009) consolidated data of many cratons in his configuration of Rodinia. Reliable palaeomagnetic data from the aggregated CC and SFC are sparse but grouping of poles from dykes in both SFC and CC have been used to incorporate their positions in a Rodinia supercontinent. These data suggest a high-latitude position with a not long-lived Rodinia connection with Laurentia (Weil et al., 1998; Pisarevsky et al., 2003; Cordani et al., 2003). A problem to reconstruct the position of SFC and CC in Rodinia is that the dykes that have been used to palaeomagnetism have only been dated by the Ar-Ar method (Maier et al., 2007; Deblond et al., 2001). This makes the age of the dykes not so reliable and also the position of the SFC and CC in relation to Laurentia could be wrong. There are two possible super-positions (or

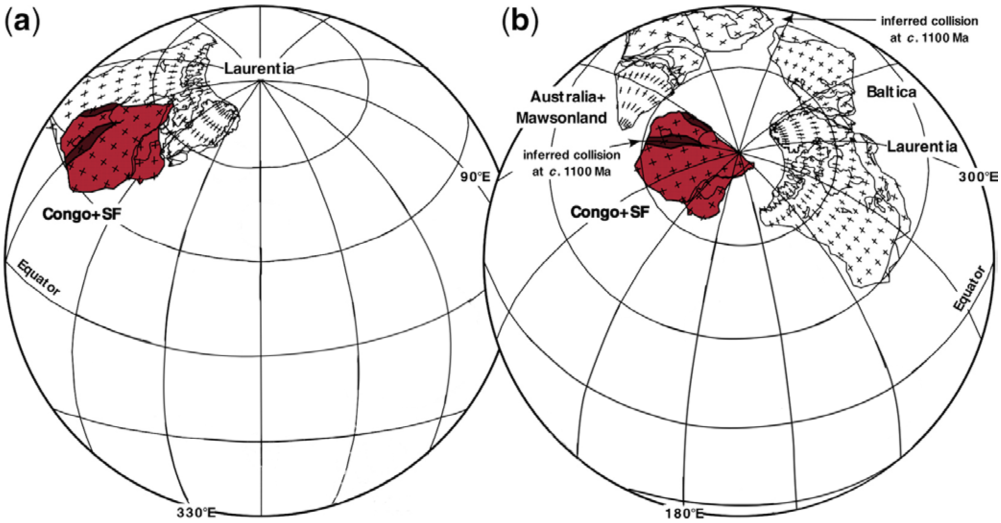

Figure 16. The Congo-São Francisco craton position during the interval ca. 1370-750 Ma, (a) generates a complete overlap between the two cratons while (b) produce the ANDACONDA juxtaposition. The figure is modified after Evans (2009).

polarity options) that could fit the SFC-CC block's position relative to Laurentia. The first polarity option results in a substantial overlap of the SFC-CC and Laurentia blocks which infers that this reconstruction, even if paleomagnetically accurate, is physically impossible (Fig. 16a). The second polarity option is that SFC-CC and Laurentia produces a juxtaposition of Arctic North America (Fig 16b) with CONgo at its DAmaride –Lufilian (Orogenic belt in Zambia) margin (ANACONDA). The 766 Ma dyke generation of the Pará de Minas swarm is a close age match with the Mt. Rogers dyke (755 Ma) and the Bakersville dykes (759 Ma), both located in eastern Laurentia, implying that the SFC-CC block remained in close vicinity with Laurentia until break-up of Rodinia (Evans, 2009).

.

8. Conclusion

- The Pará de Minas swarm has previously been interpreted as one generation of dykes, but with these new data the swarm must consist of at least three generations, 1790 Ma (1788 ± 3 Ma, 1792 ± 16 Ma, 1785 ± 5),1690 Ma (1687 ± 8 Ma, 1691 ± 5 Ma) and 766 ± 36Ma.
- All the sampled dolerites have undergone a low grade of metamorphism. All samples, except MG-3, are in transition to or in the lower greenschist facies. No correlation between crystallization age, scatter of U-Pb isotopic analyses or grade of metamorphism is obvious.
- The 1790 Ma age is coeval with the Uruguayan dykes in the southern Rio de la Plata craton, the Avanavero event of the Amazonian craton, the Tomashgorod dykes in Sarmatia, the Hart dolerites in the Northern Australia craton, and the Taihand-Lavliang dyke swarm in the North China craton. This high number of age matches makes it difficult to use this dyke generation for paleoreconstructions until robust paleomagnetic investigations have been conducted.
- The 1690 Ma age is relatively rare in the global record. Two possible candidates are the Byraiy swarm in the Siberian craton and the Pelly Bay dyke swarm in northern Laurentia.
- The 766 Ma age can be temporally be connected to the Niquelândia complex in Goiás state, the Mundine Well swarm in the Western Australia craton and the Mt. Rogers dykes in eastern Laurentia.

9. Acknowledgements

I would like to thank my supervisor Ulf Söderlund for his great devotion, reviewing of my thesis and all help he has given me throughout this time. Thanks to my co-supervisors Elson Paiva de Oliveira and Richard Ernst for your kind advises and guidance. Thanks to Eduardo Miranda da Silveira for translating Portuguese's texts to English. Last but not least I want to thank my family and friends for all love, support and help you given me though this time.

This study is funded by, and intergrated into, an industrial-academic project that was launched 2009. The project will try to reconstruct supercontinents back to 2.7 Ga using LIP record. The project will make it possible for implications for mineral deposit targeting, hydrocarbon resource exploration and earth system evolution (supercontinent.org).

10. References

Aleinikoff, J.N., Zartman, R.E., Walter, M., Rankin, D.W., Lyttle, P.T. & Burton, W.C., 1995: U-Pb ages of metarhyolites of the Catoctin and Mount Rogers formations, Central and Southern Appalachians, evidence for two pulses of Iapetan rifting. *American Journal Science 295*, 428-434.

Alkmim, F.F., Marshak, S., Pedrosa-Soares, A.C., Peres, G.G., Cruz, S.C.P. & Whittington, A., 2006: Kinematic evolution of the Araçuaí-West Congo in Brazil and Africa: Nutcracker tectonics during the Neoproterozoic assembly of Gondwana. *Precambrian Research 149*, 43-64.

Almeida, F.F.M., 1977: O Cráton di São Francisco. *Revista de Geociências 7*, 349-364.

Bennio, L., Brotzu, P., D´Antonio, M., Faraud, G., Gomes, C.B., Marzoli, A., Melluso, L., Morbidelli, L., Morra, V., Rapaille, C. & Ruberti, E., 2003: The tholeiitic dyke swarm of the Arraial do Cabo peninsula (SE Brazil): 39 Ar/40Ar ages, petrogenesis, and regional significance. J*ournal of South American Earth Sciences 16,* 163-176.

Bleeker, W., 2003: The late Archean record: a puzzle in ca. 35 pieces. *Lithos 71*, 99-134.

Bleeker, W., Hamilton, M., Ryan, J. & Ernst, R., 2010: Pelly Bay dykes: A new magmatic event for northern Laurentia at 1692 Ma. Unpublished. Reconstruction of Supercontinents Back To 2.7 Ga Using The Large Igneous Province (LIP) Record: With Implications For Mineral Deposit Targeting, Hydrocarbon Resource Exploration, and Earth System Evolution. Toronto.

Bogdanova, S.V., Bingen, B., Gorbatschev, R., Kheraskova, T.N., Kozlov, V.I., Puchkov, V.N. & Volozh, Yu. A., 2008: The East European Craton (Baltica) before and during the assembly of Rodinia. *Precambrian Research 160*, 23-45.

Bogdanova, V.S., Gintov, B.O., Kurlovich, M.D., Lubnina, V.N., Nilsson, M.K.M., Orlyuk, I.M., Pashkevich, K.I., Shumlyanskyy, V.L. & Starostenko, I.V., 2012: Late Palaeoproterozoic mafic dyking in the Ukrainian Shield of Volgo-Sarmatia caused by rotation during the assembly of supercontinent Columbia (Nuna). *Lithos*. In Press. Doi:org/10.1016/j.lithos.2012.11.002

Bond, G.C., Nickeson, P.A. & Kominz, M.A., 1984: Breakup of a supercontinent between 625 Ma and 555 Ma: new evidence and implications for continental histories: *Earth and Planetary Science Letters 70*, 325-345.

Borges, A.J. & Drews, M.G.P., 2001: Caracteristicas magmetometricas da Bacia do Sao Francisco em Minas Gerais. In: Pinto, C.P., Martins-Neto, M.A (Eds), Bacia do Sao Francisco –Geologia e Recursos Naturais. SBG-Minas Gerais, 55-66.

Brookfield, M.E., 1993: Neoproterozoic Laurentia-Australia fit. *Geology 21*, 683-686.

Carvalho, H., 1983: Notice explicative preliminaire sur la geologie de l´Angola. Revista Garcia da Orta: Série Geológica, *Lisboa 6*, 15-30.

Carneiro M.A., Teixeira, W., Carvalho, Jr. I.M. & Fernandes, R.A., 1998: Ensialic tectonic setting of the Archean Rio das Velhas Greenstone Belts: Nd and Pb isotopic evidence from the Bonfim Metamorphic complex, Quadrilátero Ferrífero, Brazil. *Revista Brasileira de Geociências 28*, 189-200.

Carneiro M.A, Endo I., Nalini Jr. H.A, Sales J.C.C., Goulart L.E.A., Silva E.F., Pereira A.A., Tavares T.D., Jiamelaro F, Carneiro J.M., Mariano L.C., Prado G.E.A., Urbano E.P.C., Santos C., Miguel F.P., 2006: Folhas Campo Belo e Oliveira (1:100.000). Convênio CPRM/UFO.

Carneiro M.A., 1992: O Complexo Metamórfico Bonfim Setentrional (Quadrilátero Ferrífero, Minas Gerais): Litoestratigrafia e Evolução Geológica de um Segmento de Crosta Continental do Arqueano. Tese de Doutoramento, Instituto de Geociências, Universidade de São Paulo, 233.

Chaves, A. O., 2001: Enxames de diques maficos do setor sul do Craton do Sao Francisco (MG, Brasil), PhD thesis, IGC-USP, Sao Paulo, 1-154.

Chaves, A.O. & Correia Neves, J.M., 2005: Radiometric ages, aeromagnetic expression, and geology of mafic dykes from southern Brazil and implications for African-South American correlations. *Journal of South American Earth Sciences 19*, 387-397.

Chemale Jr. F., Dussin, A.I., Alkmim, F.F., Martins, S.M., Gláucia Queiroga, G., Armstrong, R. & Santos, N.M.,2012:Unravelling a Proterozoic basin history through detrital zircon geochronology: The case of the Espinhaço Supergroup, Minas Gerais, Brazil. *Gondwana Research 22*, 200–206.

Condie, K.C., 2002: Breakup of a Paleoproterzoic Supercontinent. *Godwana Research 5*, 41-43.

Corrêa Gomes L.C. & Oliveira E.P., 2000: Radiating 1.0 Ga mafic dyke swarms of Eastern Brazil and Western Africa: Evidence of post-assembly extension in the Rodinia Supercontinent? *Gondwana Research 3*, 325–332.

Correia, C.T., Girardi, V.A.V., Basei, M.A.S. & Nutman, A., 2007: Cryogenian U–Pb (Shrimp I) zircon ages of anorthosites from the upper sequences of Niquelandia and Barro Alto Complexes, Central Brasil. *Revista Brasileira de Geociências 37*, 70–75.

Correia, C.T., Sinigoi. S., Girardi, V.A.V., Mazzucchelli, M., Tassinari, G.C.C., Giovanardi. T., 2012. The growth of large mafic intrusions: Comparing Niquelândia and Ivrea igneous complexes. *Lithos 155*, 167–182.

Cordiani, U.G., Sato, K., Texixeira, W., TassinRI, C.C.G. & Basei, M.A.S. 2000: CRUSTAL Evolution of the South American Platform. In: Crdani, U.G., Miliani, E.J., Thomaz Filho, A., Campos, D.A. (Eds.), *Tectonic Evolution of south America, Rio de Janeiro, Brazil, 31st*. International Geological Congress, pp.19-40.

Cordiani, U.G., D´Agrella-Filho, M.S., Brito-Neves, B.B. & Trindade, R.I.F., 2003: Tearing up Rodinia: the Neoproterozoic paleogeography of South American cratonic fragments. *Terra Nova 15*, 350-359.

Cunha, J.C. & Fróes, R.J.B., 1994: Komatiitos com texure ”spinifex” do Greenstone Belt de Umburanas, Bahia. Salvador, CBPM. 29p. (série Arquivos Abertos 7).

D'Agrella-Filho, M.S., Pacca, I.G., Renne, P.R., Onstott, T. C.&Teixeira, W., 1990: Paleomagnetism of Middle Proterozoic (1.01 to 1.08 Ga) mafic dykes in southeastern Bahia State–São Francisco Craton, Brazil. *Earth and Planetary Science Letters 101*, 332–348.

D'Agrella Filho, M.S., Feybesse, J.L, Prian, J.P., Dupuis, D. & N'Dong, J.E., 1996: Paleomagnetism of Precambrian rocks from Gabon, Congo craton, Africa. *Journal of African Earth Sciences 22,* 65-80.

D'Agrella-Filho, M.S., Pacca, I.I.G., Trindade, R.I.F., Teixeira, W., Raposo, M.I.B. & Onstott, T.C., 2004: Paleomagnetism and 40Ar/39Ar ages of mafic dikes from Salvador (Brazil): new constraints on the São Francisco craton APW path between 1080 and 1010 Ma. *Precambrian Research 132*, 55–77.

Danderfer A., De Waele, B., Pedreira, A.J., Nalini H.A., 2009. New geochronological constraints on the geological evolution of Espinhaço basin within the São Francisco Craton- Brazil. *Precambrian Research 170*, 116-128.

Dardenne, M.A., 2000: The Brasília fold belt. *Tectonic Evolution of South America*, 231-263.

Deblond, A., Punzalan, L.E., Boven, A. & Tack, L., 2001: The Malagarazi Supergroup of southeast Burundi and its correlative Bukoba Supergroup of northwest Tanzania: neo- and Mesoproterozoic chron- ostratigraphic constraints from Ar – Ar ages on mafic intrusive rocks. *Journal of African Earth Sciences 32*, 435 – 449.

Dussin, T.M., 1994: Associations volcano-Plutoniques de I´Espihaço Meridonal (SE-Bresil), These de Doctorant, Univ. D´Orleans, France, 177pp.

Ernst, E.R., Bleeker, W., Söderlund, U. & Kerr, C.A., 2013: Large Igneous Provinces and supercontinents: Toward completing the plate tectonic revolution. *Lithos 230*, 103-118.

Ernst, R.E., Wingate, M.T.D., Buchan, K.L. & Li, Z.X., 2008: Global record of 1600–700 Ma large igneous provinces (LIPs): implications for the reconstruction of the proposed Nuna (Columbia) and Rodinia supercontinents. *Precambrian Research 160*, 159–178.

Ernst, E.R. & Buchan, L.K., 1997: Giant Radiating Swarms: Their Use in Identifying Pre-Mesozoic Large Igneous Provinces and Mantle Plumes. In: Mahoney, J.J. & Coffin, F.M. (eds.), Large Igneous Provinces: Continental, Oceanic, and Planetary Flood Volcanism. *Geophysical Monograph Series 100*, 297-333.

Evans, D.A.D., 2009: The palaeomagnetically viable, long-lived and all-inclusive Rodinia supercontinent reconstruction. Geological Society, London, *Special Publicaions 327*, 271-404.

Evans, D.A.D., Heaman, L., Trindade, R.I.F., D'Agrella-Filho, M.S., Smimov, A.V. & Catelani, E.L., 2010. Precise U-Pb Baddeleyite Ages From Neoproterozoic Mafic Dykes in Bahia; Brazil, and their Paleomagnetic/Paleogeographic Implications, AGU Brazil Abstract, GP31E-07, American Geophysical Union, Joint Assembly, Meeting of the Americas, Iguassu Falls, August 2010.

Feng, M., Assumpção, M. & Van der Lee, S., 2004: Group-velocity tomography and litospheric S-velocity structure of the South American continent. *Physic of the Earth and Planetary Interiors 147*, 315-331.

Feininger, T., Dantas, J.J., Girardi, V.A.V., 1991: Gravity interpretation and possible regional significance of the Niquelândia layered basic–ultrabasic complex, Goiàs, Brasil. *Journal of South American Earth Sciences 4*, 343–350.

Ferreira Filho, C.S., Pimentel, M.M., Maria de Araujo, S. & Laux, J.H., 2010: Layered intrusions and volcanic sequences in Central Brazil: geological and geochronological constraints for Mesoproterozoic (1.25 Ga) and Neoproterozoic (0.79 Ga) igneous associations. *Precambrian Research 183*, 617-634.

Feybesse, J.L., Johan, V., Triboulet, C., Guerrot, C., Mayaga Mikolo, F., Bouchot, V. & N'dong, J.E., 1998: The West Central African belt: a model of 2.5-2.0 Ga accretion and two-phase orogenic evolution. *Precambrian Research 87*, 161-216.

Fuck, R.A., Brito Neves, B.B. & Schobbenhaus, C., 2008: Rodinia descendants in South America. *Precambrian Research 160*, 108-126.

Gaucher, C., Finney, C.S., Poiré, G.D., Valencia, A.V., Grove, M., Blanco, G., Pamoukaghlián, K. & Peral, G.L., 2008: Detrital zircon ages of Neoproterozoic sedimentary successions in Uruguay and Argentina: Insights into the geological evolution of the Río de la Plata Craton. *Precambrian research 167,* 150-170.

Girardi, V.A.V., Rivalenti, G. & Sinigoi, S., 1986: The petrogenesis of Niquelandia layered basic–ultrabasic complex, central Goias, Brasil. *Journal of Petrology 27*, 715–744.

Goldberg, S.A, Butler, J.R. & Fullagar, P.D., 1986: The Bakersville dike swarm: geochronology and progenesis of late Proterozoic basaltic magmatism in the southern Appalachian Blue Ridge. *American Journal of Science 286,* 403-430.

Goulart, A.E.L. & Carneiro, A.M., 2008: General characteristics and lithogeochemistry of the itaguara layered (ultramafic-mafic) sequence, southern São Francisco creton. *Geochimica Brasiliensis 22*, 045-072.

Goulart,. L.E.A., 2006: O Complexo Acamadado Itaguara Rio-Manso. Dissertação de Mestrado. Departamento de Geologia da Escola de Minas, Universidade Federal de Ouro Preto, Ouro Preto, 1-178 .

Gur'yanov, A.V., Didenko, N.A., Perestoronin, N.A., Ernst, E.R., Hamilton, A.M. & Peskov, Yu.A., 2011: Ca. 1700 Ma Byraiy dyke swarm, south eastern Siberia: link with Ulkan-Bilyakchan rift system, and potential ocean-opening to the east. Unpublished. Reconstruction of Supercontinents Back To 2.7 Ga Using The Large Igneous Province (LIP) Record: With Implications For Mineral Deposit Targeting, Hydrocarbon Resource Exploration, and Earth System Evolution. Toronto.

Halls, H.C., Campal, N., Davis, D.W. & Bossi, J., 1999: Magnetic studies and U-Pb geochronology of the Uruguayan dyke swarm, Rio de la Plata craton, Uruguay: pelomagnetic and economic implications. *Jounral of South American Earth Sciences 14*, 349-361.

Hanson, R.E., Crowley, J.L., Bowring, S.A., Ramezani, J., Gose, W.A., Dalziel, I.W.D., Pancake, J.A., Seidel, E.K., Blenkinsop, T.G. & Mukwakwami, J., 2004: Coeval Large-Scale Magmatism in the Kalahari and Laurentian Cratons During Rodinia Assembly. *Science 304*, 1126-1129.

Heaman, L.M., 1991: U/Pb dating of giant radianting dyke swarms:potential for global correlation of mafic magmatic events. International Symposium of mafic dykes. Extended abstracts, são Paulo, Brazil, 7-9.

Heaman, L.M. & LeCheminant, A.N., 1993: Paragenesis and U-Pb systematics of baddeleyite (ZrO2). *Chemical Geology 110*, 95-126.

Hoffman, P.F., 1991: Did the breakout of Laurentia turn Gondwanaland insideout? Sience 253, 1409-1411.

Jourdan, F., Féraud, G., Bertrand, H., Watkeys, K.M., Kampumzu, B.A. & Le Gall, B., 2006: Basment control on dyke distribution in Large Igneous Provinces: Case study of the Karoo triple junction. *Earth and Planetary Science 241*, 307-322.

Key, R.M., Liyugu, A.K., Njamu, F.M., Somwe, V., Banda, J., Mosley, P.N. & Armstrong, R.A., 2001: The weatern Arm of the Lufilian Arc in Zambia and its potential for copper mineralization. *Journal of African Earth Scences 33*, 503-528.

Kouyaté, D., Söderlund, U., Youbi, N., Ernst, R., Hafid, A., Ikenne, M., Soulaimani, A., Bertrand, H., El Janati, M. & Chaham, R.K., 2013: U–Pb baddeleyite and zircon ages of 2040 Ma, 1650 Ma and 885 Ma on dolerites in the West African Craton (Anti-Atlas inliers): Possible links to break-up of Precambrian supercontinents. *Lithos*. In Press. Doi.org/10.1016/j.lithos.2012.04.028

Kröner., A. & Cordani., U.G., 2003. African, southern Indian and South American cratons were not part of the Rodinia supercontinent:evidence from field relationships and geochronology. *Tectonophysics 375*, 325-352.

Larin, A.M., Amelin, Yn.V., Neymark, L.A. & Krymsky, R.Sh., 1997: The origin of the 1.73-1.70 Ga Anorogenic Ulkan Volcano-Plutonic complex, Siberian platform, Russian: inferences from Geochronological, Geochemical and Nd-Sr-Pb: Isotopic Data. *Annales de Academia Brasiliana Ciencas 69*, 295-312.

Li, Z.X., Bogdanova, S.V., Collins, A.S., Davidson, A., De Waele, B., Ernst, R.E., Fitzsimons, I.C.W., Fuck, R.A., Gladkochub, D.P., Jacobs, J., Karlstrom, K.E., Lul, S., Natapovm, L.M., Pease, V., Pisarevsky, S.A., Thrane, K. & Vernikovsky, V., 2008: Assembly, configuration, and break-up history of Rodinia: A synthesis. *Precambrian Research 160*, 179-210.

Li, Z.X., 2000: Palaeomagnetic evidence for unification of the North and West Australian craton by ca. 1.7 Ga: new results from the Kimberley Basin of northwestern Australia. *Geophysics Journal International 142*, 173-180.

Ludwig, K.R., 2003: User's manual for Isoplot 3.00: A geochronological toolkit for Microsoft Excel. Berkeley Geochronology Center, *Special Publication 4*, 1-71.

Machado, N., Schrank, A., Abreu, F.R., Knauer, L.G., Almeida Abreu, P.A., 1989: Resultados preliminaries da geocronologia U-Pb na Serra do Espihaço Meridional, Anais V Simposio Geologia de MG e I Simposio Geologia Brasilia, SBG 10, 171-174.

Maier, W.D., Peltonen, P. & Livesey, T., 2007: The age of the Kabanga North and Kapalagulu intrusions, western Tanzania: a reconnaissance study. *Economic Geology 102,* 147-154.

Martins-Neto, A.M., 2000: Tectonics and sedimentation in a Paleo/mesoproterozoic rift-sag basin (Espinhaço basin, southeastern Brazil). Precambrian Research 103, 147-173.

Meert, J.G., 2002: Paleomagnetic evidence for a Paleo-Mesoproterozoic supercontinent, Columbia. *Gondwana Research 5*, 207-215.

Meert, J.G., 2012: What's in a name? Columbia (Paleopangaea/Nuna) supercontinent. *Gondwana Research issue 21*, 987-993.

Moores, E.M., 1991: Southwest U.S.-East Antarctic (SWEAT) connection: a hypothesis. *Geology 19*, 425-428.

Noce, C.M., Pedrosa-Soares, A.C., da Silva, L.C., Armstrong, R. & Piuzana, D., 2007: Evolution of polycyclic basement complexes in the Araçuaí Orogen, based on U-Pb SHRIMP data: Implications for Brazil-Africa links in Paleoproterozoic time. *Precambrian Research 159*, 60-78.

Oliveira, E.P., Windley, B.F. and McNaughton, N., Pimentel, M. & Fletcher, I.R., 2004: Contrasting copper and chromium metallogenic evolution of terranes in the Palaeoproterozoic Itabuna-Salvador-Curaçá Orogen, São Francisco Craton, Brazil: new zircon (SHRIMP) and Sm-Nd (model) ages and their significance for orogen-parallel escape tectonics. P*recambrian Research 128,* 143-165.

Oliveira, P. E., Silveira, M.E., Söderlund, U., Ernst, E.R., 2012. U–Pb ages and geochemistry of mafic dyke swarms from the Uauá Block, São Francisco Craton, Brazil: LIPs remnants relevant for Late Archaean break-up of a supercraton. *Lithos*. In Press. Doi: 10:1016/j.lithos.2012.05.025

Parenti Couto, J.G., Texixeira, W. & Cordani, U.G., 1983: Considerações sobre as principais épocas de fraturamento do Craton do São Francisco, com base em datações K-Ar em rochas básicas, Anais II Simpósio Geologia MG, Belo Horizonte 1983, 38-49.

Peng, P., Zhai, M.-G.,Zhang, H.-F. & Guo, J.-H., 2005: Geochronological constraints on the Palaeoproterozoic evolution of the North China Craton: SHRIMP zircon ages of different types of mafic dikes. International Geology Review 47, 492-508.

Peng, P., Zhai, M.-G. & Guo, J.-H. 2006: 1.80 – 1.75 Ga mafic dyke swarms in the central North China craton: implications for a plume-related break-up event. In: Hanski, E., Mertanen, S., Ramo,T.& Vuollo, J. (eds) *Dyke Swarms – Time Markers of Crustal Evolution.* Taylor & Francis, London, 99-112.

Peng, P., 2010: Reconstruction and interpretation of the giant mafic dyke swarms: a case study of 1.78 Ga magmatism in the North China Craton. *Geological Society, London, Special Publication 338,* 163-178.

Pereira, E., Tassinari, C.G., Rodrigues, J.F. & Van-Dúnen, M.V., 2011: New data on the deposition age of the volcano-sedimentary Chela Group and its Eburnean basement: implications to post-Eburnean crustal evolution of the SW of Angola. *Comunicações Geológicas do LNEG 98*, 27-40.

Pimentel, M.M., Fuck, R.A. & Gioia, S.M.C.L., 2000: The Neoproterozoic Goiás Magmatic Arc, Central Brazil: A review and new Sm-Nd data. *Revista Brasileira de Geociências 30*, 35-39.

Pinese, J.P.P., 1997: Geologia Geoquímica isotrpica e aspectos petrológicos dos diques máficos pré-cambrianos da região de Lavras (MG), porção sul do Cráton do São Francisco, PhD de Janeiro, 31 IGC, 195-229.

Pimentel, M.M., Ferreira Filho, C.F., & Amstrong, R.A., 2004: Shrimp U–Pb and Sm–Nd ages of the Niquelandia Layered Complex: Meso (1,25 Ga) and Neoproterozoic (0,79 Ga) extensional events in Central Brasil. *Precambrian Research 132*, 132–135.

Pilmentel, M.M., Ferreira Filho, C.F. & Armele, A., 2006: Neoproterozoic age of the Niquelandia complex, Central Brasil: further ID-TIMS and Sm–Nd isotopic evidence. *Journal of South American Earth Sciences 21*, 228–238.

Pisarevsky, S.A., Wingate, M.T.D. & Harris, L.B., 2003: Late Mesoproterozoic (c.1.2 Ga) palaeomagnetism of the Albany-Fraser orogen: no pre-Rodinia Australia-Laurentia connetion. *Geophysical Journal International 155*, F6-F11.

Piuzana, D., Pimentel, M.M., Fuck, R.A., Armstrong, R., 2003. Neoproterozoic granulite facies metamorphism and coeval granitic magmatism in the Brasilia belt, Central Brazil: Regional implications of new SHRIMP U-Pb and Sm-Nd data. *Precambrian Research 125*, 245-273.

Romano, W.A., 2007: Folha Pará de Minas (1:100.000). CPRM.

Rogers, W.J.J. & Santosh., M., 2002. Configuration of Columbia, a Mesoproterozoic supercontinent. *Gondwana Research 5*, 5-22.

Raposo, M.I.B., Caves, A.O., Lojkasek-Lima, P., D´agrella-Filho, M.S. & Teixeira, W., 2004: Magnetic fabric and rock magnetism of Proterozoic dike swarm from the southern Sao Francisco craton, Minas Gerais state, Brazil. *Tectonophsics 378*, 43-63.

Reis, J.N., Teixeira, W., Mike A. Hamilton, A.M., Bispo-Santos, F., Almeida, E.M. & D'Agrella-Filho, S.M., 2012: Avanavero mafic magmatism, a late Paleoproterozoic lip in the Guiana Shield, Amazonian Craton: U–Pb ID-TIMS baddeleyite, geochemical and paleomagnetic evidence. *Lithos*. In Press. Doi: org/10.1016/j.lithos.2012.10.014

Stacey, J.S. & Kramers, J.D., 1975: Approximation of Terrestrial lead isotope evolution by a two-stage model. *Earth and Planetary Science Letter 26,* 207–221.

Santos, J.O.S., Hartmann, L.A., McNughton, N.J. & Fletcher, I.R., 2002: Timing of mafic magmatism in the Tapajós Province (Brazil) and implciations for the evolution of the Amazon craton: Evidence from baddeleyite and zircon U-Pb SHRIMP geochronology. *Journal of South America Earth Sciences 15*, 409-429.

Sato, K. & Siga Jr. O., 2000: Evidence of the superproduction of the continental crust during Paleoproterozoic in south American platform: Implications regarding the interpretative value of the Sm-Nd model ages. *Revista Brasileira de Geociências 30*, 126-129.

Silva, A.M., Chemale Jr, F., Kuyumjian, R.M. & Heamann, L., 1995: Mafic dike swarms of Quadrilatero Ferrifero and southern Espinhaço, Minas Gerais, Brazil. *Revista Brasileira de Geociências 25*, 124-137.

Silveira, M.E., Söderlund, U., Oliveira, P.E., Ernst, E.R & Leal, B.A., 2012: First precise U–Pb baddeleyite ages of 1500 Ma mafic dykes from the São Francisco Craton, Brazil, and tectonic implications. *Lithos*. In Press. Doi: 10.1016/j.lithos.2012.06.004

Steiger, R.H. & Jäger, E., 1977: Subcommision on Geochronology. Convention on the use of decay constants in geo- and cosmochronology. *Earth and Planetary Science Letter 36*, 359–362.

Söderlund, U., Ibanez-Mejia, M., El Bahat, A., Ernst, E.R., Ikenne, M., Soulaimani, A., Youbi, N., Cousens, B., El Janati, M. & Hafid, A., 2013: Reply to Comment on "U–Pb baddeleyite ages and geochemistry of dolerite dykes in the Bas-Drâa inlier of the Anti-Atlas of Morocco: Newly identified 1380 Ma event in the West African Craton" by André Michard and Dominique Gasquet. *Lithos*. In Press. Doi.org/10.1016/j.lithos.2013.04.003

Söderlund, U. & Johansson, L., 2002. A simple way to extract baddeleyite (ZrO2). *Technical brief 3*, 1-7.

Tack, L., Wingate, M.T.D., Liégeois, J.-P., Fernandez-Alonso, M. & Deblond, A., 2001: Early Neoproterozoic magmatism (1000-910 Ma) of the Zadinian and Mayumbian Groups (Bas-Congo): Onset of Rodinia rifting at the western edge of the Congo craton. *Precambrian Research 110*, 277-306.

Teixeira W., Carneiro M.A., Noce C.M., Machado N., Sato K. & Taylor P.N., 1996: Pb, Sr and Nd Isotope Constrains on the Archean Evolution of Gneissic-granitoid Complexes in the Southern São Francisco Cráton, Brazil. *Precambrian Research 78,*151-164.

Teixeira, W., Sabaté, P., J., Noce, C.M. & Carneiro, M.A., 2000: Archean and Paleoproterozoic Tectonic Eolution of the São Francisco Craton. In: Cordani, U.G., Milani, E.J., Thomaz-Filho, A., Campos, D.A. (eds), *Tectonic Evolution of South America.* 31st International Geological Congress, Rio de Janeiro, 101-137.

Teixeira, W., D'Agrella-Filho, S.M., Hamilton, A.M., Ernst, E.R., Girardi, V.A.V., Mazzucchelli, M. & Bettencourt, S.J., 2012: U–Pb (ID-TIMS) baddeleyite ages and paleomagnetism of 1.79 and 1.59 Ga tholeiitic dyke swarms, and position of the Rio de la Plata Craton within the Columbia supercontinent. *Lithos.* In Press. Doi.org/10.1016/j.lithos.2012.09.006

Tollo, R.P., Aleinikoff, J.N., Mundil, R., Southworth, C.S., Cosca, M.A., Rankin, D.W., Rubin, A.E., Kentner, A.E., Parendo, C.A. & Ray, M.S., 2012: Igneous activity, metamorphism, and deformation in the Mount Rogers area of SW Virginia and NW North Carolina: A geologic record of Precambrian tectonic evolution of the southern Blue Ridge Province. In: Eppes, M.C. & Bartholomew, M.J. (eds), *From the Blue Ridge to the Coastal Plain: Field Excursions in the Southeastern United States*: Geological Society of America Field Guide 29, 1-66.

Turner, S., Regelous, M., Kelly., Hawkesworth, C. & Mantovani, M., 1994: Magmatism and continental break-up in the South Atlantic: high precision Ar-Ar geochronology. *Earth and Planetary Science Letters 20*, 67-72.

Uhlein, A., Ytompette, R.R. & Egydio-Silva, M., 1998: Proterozoic rifting and closure, Se border of the São Francisco Craton, Brazil. *Journal of south American Earth Sciences 11*, 191-203.

Unrug, R., 1996: The assembly of Godwanaland. *Episodes 19*, 11-20.

Veevers, J.J., Walter, M.R. & Scheibner, E., 1997: Neoproterozoic tectonics of Australia-Antarctica and Laurentia and the 560 Ma birth of the Pacific Ocean reflect the 400 m.y. P*angean Supercycle Journal Geology 107*, 225-242.

Weil, A.B., Van Der Voo, R., Mac Niocaill, C & Meert, J.G., 1998: The Proterozoic supercontinent Rodinia: Paleomagnetically devied reconstructions for 110-800Ma. *Earth and Planetary Science Letters 154*, 13-24.

Wingate, D.T.M. & Giddings, W.J., 2000: Age and paleomagnetism of the Mundine Well dyke swarm, Western Australia: implications for an Australia-Laurentia connection at 755 Ma. *Precambrian Research 100*, 335-357.

Whitney, K., 2013: Digitization and Reconstruction of the 1790 Ma LIP event, and its Economic Potential. Unpublished report for course ERTH 4909, instructor R. Ernst, Carleton University, Ottawa, Canada, 20 p.

Zhang, S., Li, Z.X., Evans, D.A.D., Wu, H., Li, H. & Dong, J., 2012. Pre-Rhodinia supercontinent Nuna shaping up: a global synthesis with new plaeomagnetic results from North China. *Earth and Planetary Science Letters 353-354*, 145 – 155.

Zhao, G., Sun, M., Wilde, S.A. & Li, S., 2004: A Paleo-Mesoproterozoic supercontinent: assembly growth and breakup. *Earth-Science Reviews 67*, 91-123.

Tidigare skrifter i serien ”Examensarbeten i Geologi vid Lunds universitet”:

314. Eliasson, Isabelle Timms, 2012: Arsenik: förekomst, miljö och hälsoeffekter. (15 hp)
315. Badawy, Ahmed Salah, 2012: Sequence stratigraphy, palynology and biostratigraphy across the Ordovician-Silurian boundary in the Röstånga-1 core, southern Sweden. (45 hp)
316. Knut, Anna, 2012: Resistivitets- och IP-mätningar på Flishultsdeponin för lokalisering av grundvattenytor. (15 hp)
317. Nylén, Fredrik, 2012: Förädling av ballastmaterial med hydrocyklon, ett fungerande alternativ? (15 hp)
318. Younes, Hani, 2012: Carbon isotope chemostratigraphy of the Late Silurian Lau Event, Gotland, Sweden. (45 hp)
319. Weibull, David, 2012: Subsurface geological setting in the Skagerrak area – suitability for storage of carbon dioxide. (15 hp)
320. Petersson, Albin, 2012: Förutsättningar för geoenergi till idrottsanläggningar i Kallerstad, Linköpings kommun: En förstudie. (15 hp)
321. Axbom, Jonna, 2012: Klimatets och människans inverkan på tallens etablering på sydsvenska mossar under de senaste århundradena – en dendrokronologisk och torvstratigrafisk analys av tre småländska mossar. (15 hp)
322. Kumar, Pardeep, 2012: Palynological investigation of coal-bearing deposits of the Thar Coal Field Sindh, Pakistan. (45 hp)
323. Gabrielsson, Johan, 2012: Havsisen i arktiska bassängen – nutid och framtid i ett globalt uppvärmningsperspektiv. (15 hp)
324. Lundgren, Linda, 2012: Variation in rock quality between metamorphic domains in the lower levels of the Eastern Segment, Sveconorwegian Province. (45 hp)
325. Härling, Jesper, 2012: The fossil wonders of the Silurian Eramosa Lagerstätte of Canada: the jawed polychaete faunas. (15 hp)
326. Qvarnström, Martin, 2012: An interpretation of oncoid mass-occurrence during the Late Silurian Lau Event, Gotland, Sweden. (15 hp)
327. Ulmius, Jan, 2013: P-T evolution of paragneisses and amphibolites from Romeleåsen, Scania, southernmost Sweden. (45 hp)
328. Hultin Eriksson, Elin, 2013: Resistivitetsmätningar för avgränsning av lakvattenplym från Kejsarkullens deponis infiltrationsområde. (15 hp)
329. Mozafari Amiri, Nasim, 2013: Field relations, petrography and 40Ar/39Ar cooling ages of hornblende in a part of the eclogite-bearing domain, Sveconorwegian Orogen. (45 hp)
330. Saeed, Muhammad, 2013: Sedimentology and palynofacies analysis of Jurassic rocks Eriksdal, Skåne, Sweden. (45 hp)
331. Khan, Mansoor, 2013: Relation between sediment flux variation and land use patterns along the Swedish Baltic Sea coast. (45 hp)
332. Bernhardson, Martin, 2013: Ice advance-retreat sediment successions along the Logata River, Taymyr Peninsula, Arctic Siberia. (45 hp)
333. Shrestha, Rajendra, 2013: Optically Stimulated Luminescence (OSL) dating of aeolian sediments of Skåne, south Sweden. (45 hp)
334. Fullerton, Wayne, 2013: The Kalgoorlie Gold: A review of factors of formation for a giant gold deposit. (15 hp)
335. Hansson, Anton, 2013: A dendroclimatic study at Store Mosse, South Sweden – climatic and hydrologic impacts on recent Scots Pine (*Pinus sylvestris*) growth dynamics. (45 hp)
336. Nilsson, Lawrence, 2013: The alteration mineralogy of Svartliden, Sweden. (30 hp)
337. Bou-Rabee, Donna, 2013: Investigations of a stalactite from Al Hota cave in Oman and its implications for palaeoclimatic reconstructions. (45 hp)
338. Florén, Sara, 2013: Geologisk guide till Söderåsen – 17 geologiskt intressanta platser att besöka. (15 hp)
339. Kullberg, Sara, 2013: Asbestkontamination av dricksvatten och associerade risker. (15 hp)
340. Kihlén, Robin, 2013: Geofysiska resistivitetsmätingar i Sjöcrona Park, Helsingborg, undersökning av områdets geologiska egenskaper samt 3D modellering i GeoScene3D. (15 hp)
341. Linders, Wictor, 2013: Geofysiska IP-undersökningar och 3D-modellering av

geofysiska samt geotekniska resultat i GeoScene3D, Sjöcrona Park, Helsingborg, Sverige. (15 hp)

342. Sidenmark, Jessica, 2013: A reconnaissance study of Rävliden VHMS-deposit, northern Sweden. (15 hp)
343. Adamsson, Linda, 2013: Peat stratigraphical study of hydrological conditions at Stass Mosse, southern Sweden, and the relation to Holocene bog-pine growth. (45 hp)
344. Gunterberg, Linnéa, 2013: Oil occurrences in crystalline basement rocks, southern Norway – comparison with deeply weathered basement rocks in southern Sweden. (15 hp)
345. Peterffy, Olof, 2013: Evidence of epibenthic microbial mats in Early Jurassic (Sinemurian) tidal deposits, Kulla Gunnarstorp, southern Sweden. (15 hp)
346. Sigeman, Hanna, 2013: Early life and its implications for astrobiology – a case study from Bitter Springs Chert, Australia. (15 hp)
347. Glommé, Alexandra, 2013: Texturella studier och analyser av baddeleyitomvandlingar i zirkon, exempel från sydöstra Ghana. (15 hp)
348. Brådenmark, Niklas, 2013: Alunskiffer på Öland – stratigrafi, utbredning, mäktigheter samt kemiska och fysikaliska egenskaper. (15 hp)
349. Jalnefur Andersson, Evelina, 2013: En MIFO fas 1-inventering av fyra potentiellt förorenade områden i Jönköpings län. (15 hp)
350. Eklöv Pettersson, Anna, 2013: Monazit i Obbhult-komplexet: en pilotstudie. (15 hp)
351. Acevedo Suez, Fernando, 2013: The reliability of the first generation infrared refractometers. (15 hp)
352. Murase, Takemi, 2013: Närkes alunskiffer – utbredning, beskaffenhet och oljeinnehåll. (15 hp)
353. Sjöstedt, Tony, 2013: Geoenergi – utvärdering baserad på ekonomiska och drifttekniska resultat av ett passivt geoenergisystem med värmeuttag ur berg i bostadsrättsföreningen Mandolinen i Lund. (15 hp)
354. Sigfúsdóttir, Thorbjörg, 2013: A sedimentological and stratigraphical study of Veiki moraine in northernmost Sweden. (45 hp)
355. Månsson, Anna, 2013: Hydrogeologisk kartering av Hultan, Sjöbo kommun. (15 hp)
356. Larsson, Emilie, 2013: Identifying the Cretaceous–Paleogene boundary in North Dakota, USA, using portable XRF. (15 hp)
357. Anagnostakis, Stavros, 2013: Upper Cretaceous coprolites from the Münster Basin (northwestern Germany) – a glimpse into the diet of extinct animals. (45 hp)
358. Olsson, Andreas, 2013: Monazite in metasediments from Stensjöstrand: A pilot study. (15 hp)
359. Westman, Malin, 2013: Betydelsen av raka borrhål för större geoenergisystem. (15 hp)
360. Åkesson, Christine, 2013: Pollen analytical and landscape reconstruction study at Lake Storsjön, southern Sweden, over the last 2000 years. (45 hp)
361. Andolfsson, Thomas, 2013: Analyses of thermal conductivity from mineral composition and analyses by use of Thermal Conductivity Scanner: A study of thermal properties in Scanian rock types. (45 hp)
362. Engström, Simon, 2013: Vad kan inneslutningar i zirkon berätta om Varbergscharnockiten, SV Sverige. (15 hp)
363. Jönsson, Ellen, 2013: Bevarat maginnehåll hos mosasaurier. (15 hp)
364. Cederberg, Julia, 2013: U-Pb baddeleyite dating of the Pará de Minas dyke swarm in the São Francisco craton (Brazil) – three generations in a single swarm. (45 hp)

LUNDS UNIVERSITET

Geologiska institutionen
Lunds universitet
Sölvegatan 12, 223 62 Lund