Unravelling a Proterozoic basin history through detrital zircon geochronology: The case of the Espinhaço Supergroup, Minas Gerais, Brazil

Farid Chemale Jr. a,⁎, Ivo A. Dussin b, Fernando F. Alkmim d, Maximiliano Sousa Martins c, Gláucia Queiroga d, Richard Armstrong e, Marcelo N. Santos f

a IG-UnB, 70904-970, Brasília-DF, Brazil
b CPGEO/USP, São Paulo, SP, Brazil
c IGC-UFMG, Campus da Pampulha, Belo Horizonte, MG, Brazil
d DEGEO/EM/UFOP, Morro do Cruzeiro, 35400-000, Ouro Preto, MG, Brazil
e RSES, ANU, Canberra, Australia
f PFGCEO, UFRGS, Porto Alegre-RS, Brazil

ARTICLE INFO

Article history:
Received 30 March 2011
Received in revised form 2 July 2011
Accepted 24 August 2011
Available online 24 September 2011
Handling Editor: E. Tohver

Keywords:
U–Pb zircon geochronology
Espinhaço Basin
Stenian
São Francisco Craton
Rodinia

ABSTRACT

New U–Pb in situ zircon dating provides a new approach for the study of the Espinhaço Supergroup units exposed in the São Francisco Craton and Araçuaí Orogen. Located in Southern Espinhaço, Minas Gerais, the following two basins were formed in intraplate conditions: (i) the Lower Espinhaço Basin is marked by a volcano-sedimentary sequence with alluvial, fluvioglacial and eolian deposits that were formed from 1.68 Ga to 1.80 Ga; (ii) the overlying sequence, called the Upper Espinhaço Basin, is a rift-sag basin that presents basal diamond-bearing continental deposits (the Sopa–Brumadinho Formation) with a younger zircon peak at 1192 Ma, which is the maximum age for deposition of the upper units. The obtained U–Pb detrital zircon data of the studied units show age groupings related to the orogenic cycles of Jequié (Neoarchean) and Transamazonian (Paleoproterozoic), which are associated with the stability period from 1.8 Ga to 0.91 Ga in the São Francisco Craton, and record deposition during at least the three basalinal cycles. The Stenian–Tonian ages of the Upper Espinhaço Basin units (906 Ma to 1192 Ma) suggest a direct link with the evolution of the Rodinia Supercontinent and represent a marker for Mesoproterozoic to Early Neoproterozoic evolution in the São Francisco Craton and adjacent areas.

© 2011 International Association for Gondwana Research. Published by Elsevier B.V. All rights reserved.

1. Introduction

Studies performed in Phanerozoic intracratonic (and intracontinental) basins in the last decades show that basins in this category generally correspond to successor and poly-historic depositional sites; that is, they are filled by a series of unconformity-bounded units that record distinct subsidence pulses that are distributed over relatively long time periods (Sloss, 1963 and Klein, 1995). The literature also demonstrates the importance of these basins in recording (and revealing) events (even discrete ones) that involve their hosting plates. On the other hand, the study of Archean and Proterozoic basins has produced less revealing results, mainly due to the absence of fossils, the paucity of volcanogenic rocks, and the variable degrees of deformation or metamorphism affecting their fill units. However, this situation has changed significantly in recent years. Increasing use of the U–Pb SHRIMP and LA-ICPMS methods on detrital zircons is contributing to a better understanding of the timing and processes involved in the generation and evolution of Archean and Proterozoic basins.

In the present paper, we report the results obtained in a detailed geochronological investigation using U–Pb SHRIMP and LA-ICPMS methods on zircons extracted from metasedimentary and metavolcanic rocks of the Espinhaço Supergroup, a Proterozoic quartz-sandstone-dominated succession that is exposed along the homonymous mountain range in the State of Minas Gerais, eastern Brazil (Fig. 1A). The aim of this paper is to constrain the depositional ages of the Espinhaço Basin megasequences based on zircon dating of igneous and sedimentary rocks as well to understand the tectono-sedimentary evolution of the Espinhaço Basin in light of plate tectonic view during the Proterozoic.

2. Geological setting

The Espinhaço Supergroup comprises a package of metasandstones, metapelites and metaconglomerates with subordinate metavolcanic and carbonate rocks that is greater than 5000 m thick (Pflug, 1965; Dussin and Dussin, 1995; Uhlein et al., 1998; Martins-Neto, 2000 and Danderfer et al., 2009). The main area of occurrence
of the Supergroup is the São Francisco craton and its margins in eastern Brazil (Fig. 1A). In this portion of the Brazilian shield, the Espinhaço Supergroup is exposed in the Chapada Diamantina, a large plateau in the northern half of the craton, and in the Espinhaço mountain range, which is oriented roughly N–S and straddles over 1000 km in the craton’s interior and along its eastern margin (Fig. 1A). Famous for its diamond-bearing conglomerates, the Espinhaço Supergroup is portrayed by many authors as the fill sequence of an intracontinental rift-sag basin system that developed around 1.7 Ga in the continental mass that is presently represented by the São Francisco craton and its margins (Dussin and Dussin, 1995; Brito Neves et al., 1996; Uhlein et al., 1998; Martins-Neto, 2000). However, studies recently carried out in the craton’s interior (northern Espinhaço range and Chapada Diamantina) (Fig. 1A) suggest a more complex development history for the Espinhaço basin, including at least a second rifting phase dated at ca. 1.57 Ga (e.g., Danderfer et al., 2009).

The southern Espinhaço range is the morphological expression of the Neoproterozoic Araçuaí fold-thrust belt that fringes the São Francisco craton to the east and has been preserved during the Phanerozoic due to the differential erosion of its dominant lithology (quartzite). The Araçuaí belt corresponds to the external domain of the Araçuaí-West–Congo orogeny (640 to 490 Ma) that developed between the São Francisco and Congo cratons during the amalgamation of West Gondwana by the end of the Neoproterozoic (Alkmim et al., 2001, 2006 and Pedrosa-Soares et al., 2008). Affected by the folds and thrusts of the Neoproterozoic Brasiliano/PanAfrican orogen, the Espinhaço rocks that are exposed along the southern Espinhaço range exhibit conditions of metamorphic paragenesis of the lower greenschist facies (Dussin and Dussin, 1995; Uhlein et al., 1998). These metasedimentary rocks overlie an Archean/Paleoproterozoic basement, are cut by ca. 906±3 Ma mafic intrusives (Machado et al., 1989) and are unconformably overlain by the glaciogenic rifted margin succession of the Neoproterozoic (Tonian) Macaúbas Group (Dussin and Dussin, 1995; Uhlein et al., 1998) (Figs. 1A and 2).

In the type locality, the Espinhaço Supergroup is subdivided into two groups and nine formations (Pflug, 1965; Dussin and Dussin, 1995) or (according to a sequence-stratigraphy approach) into six unconformity-bounded units (tectonosequences) (Martins-Neto, 2000) (Fig. 2). The two basal formations of the Espinhaço Supergroup are Banderinha and São João da Chapada Fm. and are separated by angular unconformity (Fig. 2). These units are composed of alluvial sandstones, conglomerates and pelites and form a ca. 300-m-thick of two coarsening-upward sequences. K-rich alkaline volcanics and intrusives (Dussin and Dussin, 1995), locally known as hematite phyllite and comprised by sericite, hematite ± chloritoid ± quartz, intrude the Banderinha Fm. and the basal portion of São João da Chapada Formation. Zircons extracted from these K-rich alkaline volcanics by Machado et al. (1989) and Dussin and Dussin (1995) yielded U-Pb ages of 1715±2 Ma and 1710±12 Ma, respectively. The basal units of the Espinhaço Supergroup are herein interpreted as part of an intracontinental rift formed during the Statherian Period. Martins-Neto (2000) interpreted as records of the pre-rift and rift evolutionary stages of the Espinhaço basin (Fig. 2), which cannot be supported by the new geochronological data (see Discussion and conclusion section).

The Sopa–Brumadinho Fm. units overlie in angular unconformity the São João da Chapada lithologies as described by Santos et al. (unpublished data). The unconformity can be observed in the Serra da Miúda locality which separates different sandstones and also phyllites of the São João da Chapada Fm. from sandstones of the Sopa-Brumadinho Fm. The latter ones consist primarily of sandstones with plane-parallel stratification that pass vertically and laterally into pelites and diamonds-bearing conglomerates, which are well exposed in the Guinda and Sopa localities (Fig. 1A). In the locality of Extração, a 200 meter thick section of the Sopa–Brumadinho Fm. is exposed (Fig. 3), comprising from the bottom to the top: (i)
monomict conglomeratic quartzites with channelled and tabular cross-bending. (ii) diamond-bearing, basal polymict conglomerate with a greenish matrix of dacitic composition and pebbles of quartzite, ferruginous quartzite, banded iron formation and conglomerate. (iii) the intermediate section is composed by three main polymict conglomerate levels and two layers of quartzite, where the matrix of conglomerate is quartz-rich and pebble of quartzite, white quartz, ferruginous and fuchsite-bearing quartzites. (iv) upper section of fine to medium grained feldspathic quartzite with channelled and tabular cross-beding. The sedimentation of the Sopa–Brumadinho Fm. formed and fan delta, braid-plain and lacustrine depositional environment. 

Fig. 2. Stratigraphic chart for the Espinhaço Supergroup (modified after Dossin et al., 1990; Martins-Neto, 2000; Alkmim et al., 2006) with the sample location (*). a = after Machado et al., 1989; b = this work.

Fig. 3. Stratigraphic column of the Extraction Region (modified after Alvarenga, 1982). Detail of the meatconglomerate with greenisch matrix.
Onlapping the basement highs and packages of the previously mentioned units, the Galho do Miguel Formation consists of a ca. 2500-m-thick pile of aeolian and coastal quartz-arenites (Dussin and Dussin, 1995; Uhlein et al., 1998), which is interpreted as sag I sequence (Fig. 2). It shows a record of the first transgressive incursion and a substantial expansion of the Espinhaço basin and thereby marks the onset of the rift-sag transitional stage (Martins-Neto, 2000). The overlaying Conselheiro Mata Group, which is interpreted as sag sequence (Martins-Neto, 2000), comprises a ca. 900-m-thick marine succession of interbedded pelites and sandstones and contains lenses of carbonate rocks in the upper portion (Fig. 2).

3. Analytical procedures

Based on the quality of the outcrops and the large number of previous studies, we selected the type section of the Espinhaço Supergroup for our detailed geochronological investigation. This section is exposed in the central segment of the southern Espinhaço range near the town of Diamantina, Minas Gerais, in the localities of Guinda, Sopa and Extração (Fig. 1B).

For the purposes of our study, zircons were extracted from metasedimentary and metavolcanic rocks that are representative of all of the formations that are exposed in the southern Espinhaço range (Figs. 1 and 2). We also sampled the Duas Barras Formation, which comprises the basal quartz-sandstones of the Neoproterozoic Macaúbas Group that unconformably covers the Espinhaço Supergroup units of the Upper Espinhaço Basin in the study region. After heavy mineral separation, all zircons were mounted in circular epoxy 2.5-cm in diameter and were polished until zircons were revealed. Zircons were photographed in transmitted and reflected light, imaged using BSE (backscattered electron) and CL (cathodoluminescence), and dated using a laser ablation microprobe (New Wave UP213) coupled to a MC-ICP-MS (Neptune) at the isotope laboratories of universities of Brasilia and Rio Grande do Sul (Brazil) and with a SHRIMP RG at the Research School of Earth Sciences, Canberra, Australia (ANU). The U–Pb analytical procedures and data are shown in tables of the electronic supplementary material (U–Pb Analytical Procedures, U–Pb SHRIMP_Data.xls, U–Pb LA-MC-ICMS_Data.xls, and Sample Coordinates.xls).

Data reduction used the SQUID software (Ludwig, 2001) for the SHRIMP data and excel sheet for the LA-MC-ICPMS data developed in the Isotope Laboratory of the UFRGS. The Concordia diagram and histograms were prepared with Isoplot/Ex (Ludwig, 2003). For detrital zircon histogram we use those zircons data with discordance equal or lesser than 10%.

4. Results

The youngest ages that were obtained for the detrital zircons from the Bandeirinha and São João da Chapada Formations (the basal units of the Espinhaço Supergroup; Fig. 2), fall around 1704 to 1809 Ma. The Bandeirinha Fm. shows main peaks at 2089 Ma, 2180 Ma, 2451 Ma, 2711 Ma and 3271 Ma, whereas the São João da Chapada Fm. at 1711 Ma, 2134 Ma, 2701 Ma, 3151 Ma and 3336 Ma (Fig. 4).

High-temperature magmatic zircons from a body of K-rich alkaline silt (hematite-phyllite) that intrudes into basal section of the São João da Chapada metasandstones near Guinda (Fig. 1B) yield a concordant age of 1703 ± 12 Ma (Fig. 5). This is the minimum age of the basal units of the São João da Chapada Formation, Espinhaço Supergroup, so that we estimated that the upper part of the São João da Chapada Fm. deposited at a maximum of ca.1.68 Ga. The Bandeirinhas and São João da Chapada are part of the Statherin intracontinental rift as represented as Lower Espinhaço Basin (LE) in the Figs. 2 and 6.

Two samples from the diamond-bearing metaconglomerate of the Sopa Brumadinho Formation were collected in the Boa Vista Mine near the village of Extração (Fig. 1B); these are a greenish phyllitic matrix and a sandstone pebble (Fig. 3). The age spectra and zircon images obtained are shown in Fig. 7. Both samples have common age peaks at 2.722 Ma, 2.139 Ma and 1.748 Ma for pebble sample and 2675 Ma, 2142 and 1795 Ma for matrix sample, but ages that are
approximately 2.1 Ga (Rhyacian) are by far dominant. It is noteworthy that the youngest age group, which is obtained from zircons found in the matrix of the Sopa–Brumadinho conglomerate, falls within the interval between 1080±16 and 1240±20 Ma (with a peak at 1182 Ma; Fig. 7). Two other small peaks at 1341 and 1469 Ma can also be recognized in this sample. The youngest zircon population consists of magmatic zircons (volcanic origin) based in the alkali acid signature of the matrix and shape and inclusions of the zircons.

The samples collected in the Galho do Miguel Formation and the overlying units of the Conselheiro Mata Group yield age spectra that are similar to those of the Sopa–Brumadinho Formation (Fig. 6). However, the absence of ages younger than 1329 Ma in all these samples is remarkable; that is, the peak of the Stenian ages documented in the Sopa–Brumadinho conglomerate is not reproduced by the samples from the overlying Espinhaço units. The youngest ages that have been obtained for the detrital zircons of the Galho do Miguel Formation are 1862±16 Ma, whereas the youngest detrital zircons from the Santa Rita, Côrrego dos Borges, Côrrego Pereira and Rio Pardo formations (Conselheiro Mata Group) are dated at 1487±40 Ma, 1379±15 Ma, 1329±12 Ma and 1453±25 Ma, respectively. However, the main peaks in these marine sequences are dated at approximately 1.97 to 2.15 Ga. Archean ages of between 2531 Ma, 2705 Ma, 3032 Ma and 3348 Ma occur as subordinate peaks (Fig. 6).

The ages of zircons extracted from the Duas Barras Formation, the basal unit of the Neoproterozoic Macaúbas Group, show peaks at around 1094 Ma, 1219 Ma, 1554 Ma, 1901 Ma and 2021 Ma (Fig. 6). The youngest zircon is dated at 1079±16 Ma, but the maximum depositional age for the Macaúbas is younger than ca.910 Ma since this unit overlies the basic rocks dated at 906± Ma (Machado et al., 1989).

5. Discussion and conclusions

The new U–Pb ages from the detrital and magmatic zircons presented in the previous section brings to light a new chapter in the history of the Espinhaço basin. The rift-sag sequence, represented by the Sopa–Brumadinho and overlying formations, accumulated between 1192 Ma (age of youngest zircon peak) and 906 Ma (age of mafic dykes cutting the Espinhaço package, Machado et al., 1989). In other words, the Sopa–Brumadinho and younger units, which represent approximately 85% of the total thickness of the Espinhaço Supergroup that is exposed outside of the São Francisco craton, were deposited during the course of the Stenian period or Stenian and Tonian periods (by the end of the Mesoproterozoic and the beginning of the Neoproterozoic Era). These rocks were not deposited immediately after 1.75 Ga as previously thought (e.g., Dussin and Dussin, 1995; Brito Neves et al., 1996). Only the basal units (the Bandeirinha and São João da Chapada formations) are representative of the basin initiation stage in the period (Statherian). Thus, the unconformity that is recognized at the base of the Sopa–Brumadinho comprises a ca. 500 Ma hiatus. Indeed, the detrital zircons that formed between 1.8 to 1.68 Ga occur in the Lower Espinhaço Basin (LE in Fig. 6) and also in the fluvial and upper marine sections of Upper Espinhaço Basin as the Sopa–Brumadinho, Côrrego Bandeira, Côrrego Pereira and Rio Pardo Formations.

Our results also indicate that the only possible correlatives of the Sopa Brumadinho and younger formations in the craton’s interior are the middle and upper portions of the São Marcos and Chapada Diamantina groups (as described by Danderfer, 2009), exposed in the state of Bahia (Fig. 1A). The 1.57 Ga rift-related magmatic event and younger ages that were documented for the Chapada Diamantina and northern Espinhaço ranges (e.g: Babinski et al., 1993; Danderfer et al., 2009) is missing in the studied section; however, it is represented in the Upper Espinhaço Basin units (see ME column in Fig. 6 and U–Pb zircon data), as the detrital zircon ages in Santa Rita, Côrrego Bandeira, Côrrego Pereira and Rio Pardo Grande formations. Indeed, zircon population of the ages bracketing 1.4 to 1.6 Ga were found in the Sopa–Brumadinho metaglomerate and overlying units (Fig. 6). The provenance of these zircons would be from the Middle Espinhaço Basin units, which it is very well exposed in the Chapada Diamantina and Northern Espinhaço (Fig. 1A).

The obtained age spectra indicate that approximately 2.1-Ga-old Rhyacian rocks contribute to the majority of the southern Espinhaço basin zircons (Fig. 6). Whereas the 2.2-Ga to 1.9 Ga old zircons of Lower Espinhaço Basin have been deposited direct from the basement rocks, in the Upper Espinhaço Basin (1.19 to 0.91 Ga) transport of crystalline basement and recycling of Lower Espinhaço Basin sediments and igneous rocks is observed in the analyses of collected quartzite pebble in the sample PE-EX-34 A (Table 2 of U–Pb La-MC-
The higher sedimentation rate during the Permian–Carboniferous period of these intracratonic basins is result of major orogenic at border of Gondwana Supercontinent, when occurred the assembly of the Pangea.

It is also important that the units of the Upper Espinhaço Basin (0.91 to 1.19 Ga) may represent an extension of the passive margin sediments or foredeep basin that formed in an intraplate setting. As occurs in many intraplate basalts, the increase in the sedimentary thickness of the marine section (the Conselheiro Mata Group, Fig. 2) and the corresponding unit to north of the Setentrional Espinhaço (the Cabloco Formation units in the Chapada Diamantina) can be associated with the Grenvillian tectonism at margin or inside of the São Francisco–Congo Craton.

Mesoproterozoic Kibaran Orogenic System of central Africa developed between 1.4 and 0.95 Ga (from rifting to post collisional stage) situated in eastern part of the Congo Craton, with continental collision between 1250 and 1000 Ma (Kokonyangi et al., 2006; Batumike et al., 2007), could thus contribute to the increase of sedimentary rate in the Upper Espinhaço Intracratonic Basin, similar as described for the intracratonic basins in the Gondwana during the Permian and Carboniferous periods (e.g. Shaw et al., 1991; Milani and Ramos, 1998). The youngest zircons (formed between 1080 to 1242 Ma) may record the collision process at the margins or inside of the Congo Craton which occurred during the amalgamation of the Rodinia Supercontinent.

In the Tocantins Province, the structural province between the São Francisco and Amazon Craton, bimodal-volcanism and layered-intrusive complexes (Ferreira Filho et al., 2010) formed between 1.3 and 1.25 Ga (as early the rifting stage of the Central Goias Massif). The coeval intraplate magmatism of the Mesoproterozoic rifting may be also provide an alternative source for the significant number of zircons from the Sopa–Brumadinho Formation (formed between 1.3 and 1.25 Ga).

Further studies are recommended to understand the meaning of the new geochronological data of the Espinhaço Supergroup and their relationship to the assembling of the Rodinia Supercontinent.

Acknowledgements

This research is part of the project 'Tectonic Evolution and Stratigraphy of Southern Espinhaço, Minas Gerais, Brazil' supported by the PETROBRAS. We thank Fabrício Vieira dos Santos and Barbara Alcântara Lima for analytical assistance. This manuscript benefited from the comments of J. O. Santos and anonymous reviewer.

Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.gr.2011.08.016.

References

