<https://helda.helsinki.fi>

Return to Rodinia? Moderate to high palaeolatitude of the Sao Francisco/Congo craton at 920 Ma

Evans, D. A. D.

GEOLOGICAL SOCIETY PUBLISHING HOUSE
2016

Evans , D A D , Trindade , R I F , Catelani , E L , D'Agrella-Filho , M S , Heaman , L M ,
Oliveira , E P , Söderlund , U , Ernst , R E , Smirnov , A V & Salminen , J M 2016 , Return to
Rodinia? Moderate to high palaeolatitude of the Sao Francisco/Congo craton at 920 Ma . in
ZX Li , DAD Evans & JB Murphy (eds) , Supercontinent Cycles Through Earth History . vol.
424 , Geological Society Special Publication , vol. 424 , GEOLOGICAL SOCIETY
PUBLISHING HOUSE , Bath , pp. 167-190 . <https://doi.org/10.1144/SP424.1>

<http://hdl.handle.net/10138/329806>
<https://doi.org/10.1144/SP424.1>

unspecified
acceptedVersion

Downloaded from Helda, University of Helsinki institutional repository.

This is an electronic reprint of the original article.

This reprint may differ from the original in pagination and typographic detail.

Please cite the original version.

Return to Rodinia? Moderate to high palaeolatitude of the São Francisco/Congo craton at 920 Ma

Evans, D.A.D.(1), Trindade, R.I.F.(2), Catelani, E.L.(2,3), D'Agrella-Filho, M.S.(2), Heaman, L.M.(4), Oliveira, E.P.(5), Söderlund, U.(6), Ernst, R.E.(7), Smirnov, A.V.(8), Salminen, J.M.(9)

(1) Department of Geology & Geophysics, Yale University, New Haven CT 06520-8109, USA; david.evans@yale.edu

(2) Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, Rua do Matão, 1226, São Paulo, SP, 055080-090, Brazil

(3) current address: Octo Construções e Empreendimentos Ltda, Rua João Papaterra Limongi, 80 – Butantã - São Paulo – SP - CEP 05516-060 - Brazil

(4) Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, T6G 2E3, Canada

(5) Department of Geology and Natural Resources, Geosciences Institute, University of Campinas-UNICAMP, P.O. Box 6152, Campinas, 13083-970, Brazil

(6) Department of Geology, Lund University, Sölvegatan 12, SE 223 62 Lund, Sweden

(7) Department of Earth Sciences, Carleton University, Ottawa, Ontario, K1S 5B6, Canada

(8) Department of Geological and Mining Engineering and Sciences, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931, USA

(9) Department of Physics and Department of Geosciences and Geography, University of Helsinki, P.O. Box 64, Helsinki, 00014, Finland

revised submission to Geological Society of London Special Publication

ABSTRACT

Moderate to high palaeolatitudes recorded in mafic dykes, exposed along the coast of Bahia, Brazil, are partly responsible for some interpretations that the São Francisco/Congo craton was separate from the low-latitude Rodinia supercontinent at about 1050 Ma. We report new palaeomagnetic data that replicate the previous results. However, we obtain substantially younger U-Pb baddeleyite ages from five dykes previously thought to be 1.02–1.01 Ga according to the $^{40}\text{Ar}/^{39}\text{Ar}$ method. Specifically, the so-called "A-normal" remanence direction from Salvador is dated at 924.2 ± 3.8 Ma, within error of the age for the "C" remanence direction at 921.5 ± 4.3 Ma. An "A-normal" dyke at Ilhéus is dated at 926.1 ± 4.6 Ma, and two "A-normal" dykes at Olivença have indistinguishable ages with best estimate of emplacement at 918.2 ± 6.7 Ma. We

attribute the palaeomagnetic variance of the "A-normal" and "C" directions to lack of averaging of geomagnetic palaeosecular variation in some regions. Our results render previous $^{40}\text{Ar}/^{39}\text{Ar}$ ages from the dykes suspect, leaving late Mesoproterozoic palaeolatitudes of the São Francisco/Congo craton unconstrained. The combined "A-normal" palaeomagnetic pole from coastal Bahia places the São Francisco/Congo craton in moderate to high palaeolatitudes at ca. 920 Ma, allowing various possible positions of that block within Rodinia.

INTRODUCTION

Despite more than two decades of intense global research, the configuration of Neoproterozoic supercontinent Rodinia remains enigmatic. Following the first global synthesis by Hoffman (1991), most models include a central location for Laurentia, flanked by "East" Gondwana-Land cratons along its proto-Cordilleran margin and "West" Gondwana-Land cratons along its proto-Appalachian margin, and Siberia along its northern Canadian margin (e.g., Dalziel, 1997). Early palaeomagnetic syntheses supported this kind of reconstruction (Powell et al., 1993; D'Agrella-Filho et al., 1998; Weil et al., 1998). The Hoffman-style models imply major reorganization of the Laurentian connections following Rodinia breakup *en route* to the amalgamation of Gondwana-Land and ultimately Pangea, but entail relatively minor motions between each of the "East" and "West" Gondwana-Land cratonic groups through the same interval of time. In contrast, more recently acquired palaeomagnetic data (e.g., Wingate and Giddings, 2000; Wingate et al., 2002) pose challenges to these models and have led to alternatives that either question the existence of the supercontinent altogether (Meert and Torsvik, 2003), exclude certain cratons (Pisarevsky et al., 2003), shorten the lifespan of Rodinia considerably (Li et al., 2008), or generate a radically different long-lived reconstruction (Evans, 2009). Application of palaeomagnetic data to the problem requires not only a high reliability of the remanence directions, but also confidence in accurate dating of the rocks and their magnetic acquisitions.

One of the larger cratons in Meso-Neoproterozoic palaeogeography is the São Francisco (SF)/Congo craton, spanning eastern Brazil and formerly contiguous central Africa (Figure 1). The SF/Congo craton is surrounded by latest Proterozoic to Cambrian orogens that welded together the supercontinent Gondwana-Land. Prior to that orogenic activity, a substantial proportion of the craton's margins were passive (Trompette, 1994), established by rifting at ca. 920 Ma (Aracuaí and West Congolese; Tack et al., 2001), ca. 750 Ma (northern Damara and Lufilian; Hoffman and Halverson, 2008; Key et al., 2001), and poorly dated but likely mid-Neoproterozoic (Oubanguide; Poidevin, 2007). These rifted margins were created during the likely interval of Rodinia's breakup, and thus provide important conceptual impetus for including SF/Congo within the supercontinent. The interpretation of 1300-1000 Ma orogenic activity at the eastern margin of the SF/Congo craton (Kokonyangi et al., 2006; De Waele et al., 2009), during the nominal interval of Rodinia assembly, provides some further support for consideration of SF/Congo membership within the supercontinental landmass.

However, several recent studies have suggested that large regions of South America and central/southern Africa were absent from Rodinia. Kröner and Cordani (2003) based this argument on substantially different timing of orogeny and rifting among various regions such as Goiás, Mantiqueira, Borborema, Trans-Sahara, and Madagascar, relative to the expected Rodinian ages of assembly and breakup as noted above. The "Kibaran orogeny" of eastern SF/Congo could also represent mere arc-continent collisions (Johnson et al., 2005; De Waele et al., 2008) or largely thermal effects of intracratonic magmatism (Fernandez-Alonso et al., 2012), as opposed to continent-continent collisions. Independently, the interpretations of Cordani et al. (2003) and D'Agrella-Filho et al. (2004) have appealed to palaeomagnetic data from SF/Congo to substantiate a physical separation of the craton from others more plausibly connected to Rodinia. Namely, high palaeolatitudes for SF/Congo during the interval 1080-1010 Ma were contrasted with the low-latitude positions of Laurentia, Siberia, Australia, and Kalahari through those times.

The SF/Congo palaeomagnetic poles generating the high palaeolatitudes discussed above come from mafic dyke swarms in coastal Bahia, Brazil: Salvador, Ilhéus, Itaju do Colônia, and Olivença (Figures 1,2). As described in previous studies (e.g. D'Agrella-Filho et al., 1990, 2004), the dykes are composed of diabase, containing primary subophitic igneous textures and essentially unmetamorphosed aside from deuteric alteration within the interiors of some of the coarser-grained intrusions. Early palaeomagnetic (D'Agrella-Filho et al., 1990) and $^{40}\text{Ar}/^{39}\text{Ar}$ (Renne et al., 1990) studies on these dyke swarms generated a series of poles defining the 1080-1010 Ma apparent polar wander (APW) path for the SF/Congo craton: the Olivença "reversed" polarity pole at 1078 ± 18 Ma, the Ilhéus "normal" polarity pole at 1012 ± 24 Ma, and undated intermediate poles from Itaju do Colônia (dual polarity) and Olivença ("normal"). In the Southern Hemisphere, the convention is to refer to upward north-seeking directions as "normal" polarity and downward north-seeking directions as "reversed" polarity, despite the unknown absolute polarity sense due to incompleteness of APW paths backward from Phanerozoic into Precambrian time. We follow that convention herein.

The Bahia palaeomagnetic dataset was further substantiated by D'Agrella-Filho et al. (2004), on dykes from Salvador, including additional $^{40}\text{Ar}/^{39}\text{Ar}$ ages of ca. 1030-1000 Ma and two positive baked-contact tests on "reversed" polarity dykes into Palaeoproterozoic host rocks. An attempted baked-contact test on the "normal" polarity dyke at the "Meridian" locality was judged by the authors to be inconclusive. In addition to these poles, all given the code letter "A", results were reported from an undated group of dykes in the Valéria quarry (code letter "B") and three dykes exposed along the Salvador beaches with a southerly-downward characteristic remanence direction (code letter "C") that was associated with a preliminary U-Pb baddeleyite age of ca. 924 Ma (Heaman, 1991, abstract only). Note that the letter designations (A,B,C) refer only to characteristic remanence site-mean directions, not vector components within individual samples. The APW path derived from standard interpretation of these results is summarized in Figure 2.

The present study was motivated toward obtaining additional precise U-Pb ages from

the various Bahia dyke swarms, notably dykes carrying the “A” and “C” remanence directions, in order to test the validity of the $^{40}\text{Ar}/^{39}\text{Ar}$ ages, to refine the APW path for SF/Congo, and ultimately to test whether that craton could have been part of Rodinia.

METHODS

In order to determine which palaeomagnetic remanence directions would correspond with our new U-Pb ages, it was necessary to identify dykes in the field corresponding to the published poles. Because much of the previously published work (D'Agrella-Filho et al., 1990, 2004) derived from block samples collected prior to the availability of GPS technology, it was necessary for us to collect our palaeomagnetic samples from as many dykes as possible for complete coverage of the three coastal field areas: Salvador, Ilhéus, and Olivença. The sampling strategy was designed for verifying the existing published data rather than generating entirely new data, so only two cores were drilled in each dyke. Nonetheless, the cores were long enough to facilitate both alternating-field (AF) and thermal demagnetization procedures on sister specimens; this allowed for typically four estimates of the palaeomagnetic remanence directions at each site, and most samples were very stable to both AF and thermal demagnetization, yielding identical results from both methods. Thermal demagnetization was carried out in nitrogen-atmosphere ASC-Scientific magnetically shielded furnaces, and high-level AF demagnetization utilized a Molspin tumbler apparatus with self-reversing spin mechanism. Measurements were made on a 2G (now WSGI) cryogenic magnetometer with automated sample-changing system (Kirschvink et al., 2008) at Yale University, except for the baked-contact tests, which were measured with an AGICO JR6 spinner magnetometer at the Universidade de São Paulo. Vector components were isolated using principal component analysis (Kirschvink, 1980) and analyzed with Fisher (1953) statistics giving unit weight to each specimen to compute a site mean. Directional data were complemented by rock-magnetic data: magnetic hysteresis, using a Model 2900 Princeton Measurement Corporation Alternating Gradient Field Magnetometer, and thermomagnetic analyses, using an AGICO KLY-4S magnetic susceptibility meter

equipped with a high-temperature furnace and a cryostat.

Geochronologic samples for this study were collected during four excursions and by four different researchers; SAL2-90 and SAL5-90 were collected by T. Onstott (Princeton) in 1990, LH91-13 was collected by L.M. Heaman in 1991; OL4 and OL26 were collected by D. Evans, M. D'Agrella-Filho, and R. Trindade in 2006; and OLIV-3 was collected by E. Oliveira in 2009. Sample processing and U-Pb analyses were conducted at three laboratories denoted with the following abbreviations in Table 1: ROM – Royal Ontario Museum (Toronto), UofA – University of Alberta (Edmonton), and LIG – Laboratory for Isotope Geology at the Swedish Museum of Natural History (Stockholm). Baddeleyite extraction was accomplished using slightly different techniques over the duration of this study; samples processed at the Royal Ontario Museum were pulverized in a jaw crusher and Bico disc mill, heavy mineral concentrate obtained using a Wilfley table and final baddeleyite concentrate using standard magnetic (Frantz Isodynamic Separator) and density (heavy liquids) techniques. For samples collected since 2009, smaller hand samples were cut into slabs, pulverized using a tungsten-carbide puck mill (UofA), and baddeleyite concentration followed the Wilfley table procedure outlined by Söderlund and Johansson (2002).

In most of the samples, the baddeleyite crystals were minuscule (<20 microns in longest dimension) and were hand selected, washed in warm 4N HNO₃ for 1 hour, and cleaned by repeat rinses in Millipore H₂O and acetone. The selected grains were loaded into TFE Krogh-type dissolution vessels together with a measured amount of ²⁰⁵Pb/²³⁵U (²⁰⁵Pb/²³³⁻²³⁶U at LIG) tracer solution and a mixture of HF/HNO₃ (10:1), placed in an oven at 220°C for at least 36 hours, evaporated to dryness and converted to a chloride form by placing in the oven again overnight with 3.1N HCl. Uranium and lead were purified using anion exchange chromatography for fractions weighing >1 microgram (Heaman and Machado, 1992; French and Heaman, 2010). The isotopic composition of U and Pb were determined using a VG354 (ROM and UofA) and a Finnigan TRITON (LIG) thermal ionization mass spectrometer (TIMS) operating in single collector peak hopping mode. Typical in-run one sigma standard deviation measurement errors were

<0.5% for $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{238}\text{U}/^{235}\text{U}$. All isotopic data were corrected for mass discrimination, detector bias, spike contribution, blank (ROM: 5 pg Pb, 1 pg U; UofA: 1.0 pg Pb, 0.5 pg U; LIG: 0.6 pg Pb, 0.2 pg U) and initial common Pb (Stacey and Kramers, 1975). The total uncertainty for each analysis was determined by numerically propagating all known sources of error. All age calculations and plots were prepared using the Isoplot software of Ludwig (2003) with the ^{238}U and ^{235}U decay constants and $^{238}\text{U}/^{235}\text{U}$ value reported by Jaffey et al. (1971).

RESULTS: U-Pb GEOCHRONOLOGY

The U-Pb results for 11 baddeleyite fractions selected from 4 dyke samples are compiled in Table 1. The U-Pb results are presented in Figure 3. Two dyke samples were investigated from the Salvador area, informally known as the Meridian and Ondina dykes. Baddeleyite from two samples of the Meridian dyke (SAL2-90 and LH91-13) are less than 2% discordant and have $^{207}\text{Pb}/^{206}\text{Pb}$ dates that vary between 919.3 and 924.7 Ma, but overlap within analytical uncertainty (Figure 3a). The weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ date using all three analyses is 924.2 ± 3.8 Ma (MSWD=0.3) and is considered to be a good constraint for the emplacement age of this dyke.

The U-Pb results for three baddeleyite fractions from the Ondina dyke (SAL5-90) are displayed on a concordia plot in Figure 3b. Fractions 2 and 3 are concordant, that is they plot within error of the concordia curve and are <1% discordant. All three analyses have identical $^{207}\text{Pb}/^{206}\text{Pb}$ dates within analytical uncertainty and define a weighted average $^{207}\text{Pb}/^{206}\text{Pb}$ date of 921.5 ± 4.3 Ma (MSWD=0.02). This date is constrained primarily by the most precise analysis #2.

A tiny amount of minuscule baddeleyite (<15 crystals and fragments) was recovered from two dyke samples (OL4 and OL26) in the Olivença area. The total amount of radiogenic Pb in these analyses was very small (<30 pg) and the corresponding uncertainties are much larger than the results obtained from the Meridian and Ondina

dyke samples above. All five analyses are displayed on a concordia plot in Figure 3c, and the two analyses from sample OL26 are shown as yellow ellipses. All five analyses overlap the concordia curve within error, and the three most precise analyses (OL4-2, OL26-1 and OL26-2) yield a concordia age of 918.2 ± 5.7 Ma interpreted to be the best estimate for the emplacement age of these two dykes. The U-Pb age results for the four dyke samples from Salvador and Olivença are indistinguishable within analytical uncertainty.

The baddeleyite fractions of the OLIV-3 sample overlap and plot immediately below the concordia curve, with about 1.5% discordance (Figure 3d). All three analyses have identical $^{207}\text{Pb}/^{206}\text{Pb}$ dates within analytical uncertainty and define a weighted average $^{207}\text{Pb}/^{206}\text{Pb}$ date of 926.1 ± 4.6 Ma (MSWD=0.12).

RESULTS: ROCK MAGNETISM AND PALAEOMAGNETISM

Magnetic hysteresis loop parameters (coercivity, H_c ; coercivity of remanence, H_{cr} ; saturation remanence, M_{rs} ; and saturation magnetization, M_s) indicate the presence of a magnetic mineral phase with intermediate-to-high coercivity (Figure 4a,c,e). The M_{rs}/M_s and H_{cr}/H_c ratios suggest a pseudo-single domain (PSD) magnetic carrier in our samples (Day et al., 1977). Temperature dependence of low-field magnetic susceptibility, $\kappa(T)$, was measured from -192°C to $\sim 700^\circ\text{C}$ (in argon) followed by cooling back to room temperature. The thermomagnetic curves from all the samples are nearly reversible, revealing the presence of a single magnetic phase with a Curie temperature between $575\text{--}585^\circ\text{C}$ (Figure 4b,d,f), consistent with magnetite and/or low-Ti titanomagnetite as a magnetic carrier. A characteristic peak observed at -153°C , associated with the Verwey transition (Verwey, 1939) indicates that the magnetite is nearly stoichiometric. Overall, the results of our rock-magnetic analyses are consistent with the rock magnetic and microscopy data presented by D'Agrella-Filho et al. (1990, 2004).

Palaeomagnetic results are listed in Table 2, and representative demagnetization behaviors are illustrated in Figures 5, 7, and 8. Site mean directions from each locality are combined with site means from D'Agrella-Filho et al. (1990, 2004), even though we recognize that some of the same dykes have been analyzed both by us and by the previous studies. This is justified by the fact that measurements come from different laboratory demagnetization experiments and are thus independent, and also because the number of doubly analyzed sites is estimated to be small relative to the entire number of sites contributing to the grand mean palaeomagnetic pole. Among all datasets, only site-means derived from more than two samples and with Fisher (1953) a_{95} values less than 20° are included in the overall mean calculations.

Salvador

Along the beaches of Salvador city (Figure 5), four dykes were sampled (SA16,17,19,22). The site numbering system was intended to mimic that of D'Agrella Filho et al. (2004), and despite the lack of GPS coordinates from the earlier study, we are confident that all except SA19 do indeed correspond to the site numbers of the earlier study—based on the outcrop map in the unpublished Ph.D. thesis of M.S. D'Agrella-Filho (1992), as well as our palaeomagnetic results. Our site SA19 is located at the base of the breakwater wall almost directly north of the Farol da Barra, from a NNW-striking, 2 m-wide dyke with numerous previous drill holes from a magnetic anisotropy study (Raposo and Berquó, 2008). This site showed a scattered characteristic remanent magnetization (ChRM) directed West-Up, which could represent either an extreme outlier of the A-normal direction or the antipode of the B direction. Lacking unambiguous grouping with one of the known Bahia dyke ChRM directions, this result is not discussed further herein. The other three dykes from Salvador were collected at two localities. At the small “Ondina” cove, the N-striking, 13 m-wide dyke (SA22), bearing the new U-Pb baddeleyite age of 922 ± 4 Ma, is the same intrusion as that referred to by Heaman (1991). After removal of a low-coercivity overprint, this dyke exhibits the C remanence direction (Table 2, Figure 5), as earlier determined from the same site by D'Agrella-Filho et al. (2004). Unlike the vast majority of samples in this study, alternating-field demagnetization did not isolate the ChRM well at this site. At the

“Meridian” locality directly below the Ibis hotel, two dykes (SA16, SA17) carry opposite remanence polarities. The 1.5 m-wide, WNW-striking dyke (SA16), which is older, has the A-reversed direction that is verified by a positive baked-contact test into basement granulites by D’Agrella-Filho et al. (2004). The younger, 20-25 m-wide, NNW-striking dyke (SA17) has the A-normal direction and bears the new U-Pb baddeleyite age of 924 ± 4 Ma, reported above. Although the baked-contact test of this large dyke into Palaeoproterozoic basement rocks was judged by D’Agrella-Filho et al. (2004) to be inconclusive, we note that the presence of the A-reversed direction at SA16, merely tens of meters away in similar mafic lithology, suggests that the locality has not been magnetically overprinted since intrusion of the younger, larger SA17 dyke (i.e., the SA17 A-normal remanence is suggested to be primary). The intersection of these dykes is located within the storm surge zone, and heavy weather conditions (over three separate visits) unfortunately prevented us from sampling a complete baked-contact test between the two dykes, of opposite polarities, at the locality.

In summary for Salvador (Figure 6), we confirm that our new U-Pb ages correspond to both the C (Ondina, 922 ± 4 Ma) and A-normal (Meridian, 924 ± 4 Ma) remanence directions, which are both within error of the palaeomagnetic data reported for those same sites by D’Agrella-Filho et al. (2004). We filter the data to accept only those sites having three or more specimens contribute to the mean direction (Table 2); thereafter, none of the mean directions (An, Ar, C) contain enough sites to guarantee adequate time-averaging of the geomagnetic field. Another problem is that the An and Ar means, whether quality-filtered or not, differ from anti-parallelism at greater than 95% confidence level (McFadden and McElhinny, 1990). Therefore, although we calculate a two-polarity palaeomagnetic pole for the Salvador ‘A’ directions (Table 2), we prefer to combine data from the Salvador region with the other studied areas before making tectonic interpretations. Although D’Agrella-Filho et al. (2004) corrected for an inferred 2° of vertical-axis rotation for the Salvador region accompanying Atlantic-Ocean rifting, we do not employ such a correction herein because it does not significantly affect our combined mean directions that rely much more heavily on the more abundantly sampled southern outcrop areas.

Ilhéus

D'Agrella-Filho et al. (1990) found very stable, very tightly clustered data from two areas around the city of Ilhéus. We resampled the more southerly of those two areas, around a coastal promontory known as Pernambuco Hill (Figure 7), as well as an additional pair of dykes in a quarry SW of the city. Dykes are 0.5–12 m wide, and strike E to ENE.

Our data from Ilhéus show very high stability to both AF and thermal demagnetization, and tight clustering of ChRM directions to the NE and steeply upward, which reproduces the earlier work of D'Agrella-Filho et al. (1990) (Table 2). Our site IL1 is from a 12 m-thick E-striking dyke that yielded the U-Pb baddeleyite age of 926.1 ± 4.6 Ma, reported above.

We undertook a baked-contact test on the dated dyke, into isolated pod-like amphibolite lenses within the Palaeoproterozoic gneiss host-rock adjacent to its southern margin (Figure 7c). Samples of the host-rock were collected from within a few centimeters of the dyke margin, to distances as great as ~40m away. All host-rock samples yielded a ChRM direction that is slightly steeper than that of the dyke, but otherwise similar in its very stable demagnetization characteristics. We attribute the slight difference in directions to anisotropy in the amphibolite pods. The expected Palaeoproterozoic (ca. 2.0 Ga) host-rock direction is steeply down to the northeast (D'Agrella-Filho et al., 2004, 2011), and we did not find this direction in our baked-contact test at Pernambuco Hill. The results of this test, therefore, could be considered either negative or inconclusive. A primary age of remanence in the Ilhéus dykes would still be plausible if the overall density of dyke intrusion were great enough, or exposed crustal levels were deep enough, to remagnetize the entire outcrop area via magmatic heating. Lack of outcrop more than ~40m southward from the dated dyke also allows the possibility of additional dykes under cover, which could have contributed to the regional host-rock remagnetization.

Considering only the data from dykes (i.e., omitting baked-contacts), the mean of 27 sites (Figure 7d) is $D=058.4^\circ$, $I=-66.0^\circ$, $k=161$, $a_{95}=2.2^\circ$. The corresponding mean of

the 27 site-mean VGPs is at 31.8°S , 279.6°E , $K=71$, $A_{95}=3.3^{\circ}$. This mean is notable in its high degree of precision: the angular dispersion parameter (s) is calculated as 9.6° , anomalously low relative to comparable palaeolatitudes from either the time-averaged field of the last five million years, or typical Proterozoic data (Smirnov et al., 2011). We thus interpret the Ilhéus magnetizations as not averaging palaeosecular variation of the geomagnetic field at the time of remanence acquisition, so that this mean of VGPs in itself is regarded as merely a single VGP, not a time-averaged palaeomagnetic pole.

Olivença

Previous palaeomagnetic study of dykes exposed along the coast at Olivença (D'Agrella-Filho et al., 1990) documented a two-polarity ChRM directed either E-up (A-normal) or NW-down (A-reversed). The directions were found to be significantly not antiparallel. In addition, the A-reversed-magnetized dykes were mainly confined to a single section of coastline estimated to be 1-2 km in length, according to field notes from the original study. We resampled many of the Olivença dykes (Figure 8) in order to fix the location of the polarity transitions as well as tie the palaeomagnetic data to new U-Pb ages. Dykes range from 0.3 to 24 m wide, and strike ENE (the two remanence polarity groups have indistinguishable strike means). Palaeomagnetic data are listed in Table 2. As with Salvador and Ilhéus, we generally reproduce the ChRM data from the older study of D'Agrella-Filho et al. (1990). Combining high-quality data from that study as well as new sites analyzed herein, we compute the mean from 28 sites of "A-normal" ChRM directions at $D=082.7^{\circ}$, $I=-71.4^{\circ}$, $k=42$, $a_{95}=4.3^{\circ}$. The corresponding pole derived from the mean of the 28 VGPs is at 16.5°S , 286.7°E , $K=16$, $A_{95}=6.9^{\circ}$. For 10 "A-reversed" sites in the combined Olivença dataset, the ChRM mean is $D=301.9^{\circ}$, $I=61.9^{\circ}$, $k=42$, $a_{95}=7.5^{\circ}$, and the palaeomagnetic pole derived from VGPs is at 11.4°N , 282.6°E , $K=20$, $A_{95}=11.0^{\circ}$. These combined data are not antiparallel, as also determined by D'Agrella-Filho et al. (1990), which will be discussed further below.

A baked-contact test was performed at site OL3, a 28-cm-wide mafic dyke intruding amphibolite host rocks toward the southern end of the Olivença sampling profile. As with the test at Ilhéus, similar steeply upward ChRM directions are obtained from host

rocks as far as 6.5m away from the dyke (Figure 8c), much farther than typical for a simple conductive heating profile at shallow to moderate levels of emplacement. Lack of outcrop beyond 6.5m away allows the presence of additional dykes that could have contributed to regional remagnetization. A distant, isolated outcrop of amphibolite, ~90m away from the dyke (OL3x; Figure 8b, bottom row), yielded a southwest-shallow-up ChRM, very different from all other directions obtained in this study. We could perhaps consider this to indicate a positive result for the baked-contact test, but the following issues suggest caution. First, as noted above, the expected ca. 2.0 Ga host rock directions are steeply down to the northeast, substantially different from those observed in the isolated amphibolite outcrop. Second, in the earlier palaeomagnetic study of the region (D'Agrella-Filho et al., 1990), only one site gave a southwesterly and shallow direction (#70 in the Itaju do Colônia suite), and that site was located farthest south in the study area, closest to the northernmost Araçuaí orogenic front (Alkmim et al., 2006). It is possible that the isolated outcrop of amphibolite host rock retains a local hydrothermal record of Brasiliano (late Neoproterozoic) overprinting. Given these caveats, we must consider the Olivença baked-contact test as inconclusive.

Combined palaeomagnetic results

As noted above, site-mean palaeomagnetic data from Salvador and Ilhéus are each by themselves insufficient for statistical representation of the time-averaged Neoproterozoic geodynamo. Nonetheless, they may be combined with the more extensive Olivença dataset to produce a palaeomagnetic pole. Given that Ilhéus data, with their unusually high clustering of remanence directions and limited outcrop area, likely represent a single “snapshot” of the ca. 920-Ma geomagnetic field, we aggregate all of those data into a single mean direction with unit weight, equal to each of the quality-filtered sites from the two other regions (Table 2). The resulting means for the “normal” polarity An direction ($n=33$ sites, $D=086.5^\circ$, $I=-72.3^\circ$, $k=38$, $a_{95}=4.1^\circ$) and “reversed” polarity Ar direction ($n=13$ sites, $D=299.9^\circ$, $I=62.1^\circ$, $k=51$, $a_{95}=5.9^\circ$) “fails” the reversal test of McFadden and McElhinny (1990), in that directions are distinguishable from antiparallelism at >95% confidence (in fact, >99.9%). For this reason, and because we have only been able to separate and date baddeleyite from “normal”

polarity dykes, we calculate separate palaeomagnetic poles for each of the 'A' remanence polarities in coastal Bahia (Table 3). The An ("normal") pole derived from the mean of the 33 site-mean VGPs is at 14.3°S, 288.3°E, K=14.3, A₉₅=6.8°.

Although baked-contact tests on An remanence directions from the present study all proved to be inconclusive, D'Agrella-Filho et al. (2004) discuss the results of three baked-contact tests from Salvador. Two are presented as fully positive tests, with stable directions in both unbaked and baked host Palaeoproterozoic gneisses, the latter group aligned with remanence directions from Ar ("reversed") dykes at sites 8 and 16. These data demonstrate that the Ar direction is primary, dating from the time of dyke cooling immediately following intrusion. A third attempted baked-contact test by D'Agrella-Filho et al. (2004), on granulitic host rocks to the thick "Meridian" dyke with An ("normal") polarity, was judged to be inconclusive due to distant host rocks not yielding a stable direction. However, sites 16 and 17 are from the same beach cove; thus the magnetically stable, unbaked granulite samples pertinent to the test at site 16—although originally not considered as part of the test profile for site 17—are in fact integral to a positive baked contact test for that thicker dyke.

Both An and Ar remanence polarities, therefore, are arguably primary. Both poles are similar to Early Cambrian poles from the Congo craton (Meert et al., 1996), when viewed in a common Gondwana-Land reference frame (McElhinny et al., 2003), but the coastal Bahia study area entirely lacks any evidence for significant Cambrian (latest Brasiliano) structural or thermal disturbance (Renne et al., 1990). Our U-Pb ages now date the emplacement of An dykes as ca. 920 Ma, thus the Bahia coastal An pole (Table 3) is considered to be the most reliable palaeomagnetic result from the early Neoproterozoic SF/Congo craton. We calculate the dual-polarity combined mean of Bahia coastal An + Ar dykes, but we caution use of that pole without U-Pb dating of the Ar dykes. Inland from the coast, the Itaju do Colônia dykes have dual polarity with demonstrable antiparallelism, but these, too, remain undated.

DISCUSSION

Neoproterozoic large igneous province

This study reports new U-Pb baddeleyite ages for five diabase dykes from the coastal Bahia swarm(s) that vary between 926 and 918 Ma, the ages overlapping within analytical uncertainty. The short duration for emplacement of this magmatism (< 8 million years) appears to justify grouping all of the coastal Bahia dykes into a single large igneous province (LIP), for which we propose an emplacement age of 923.2 ± 2.6 Ma (weighted mean of our new dates; MSWD=1.6). The ages are significantly younger than previous $^{40}\text{Ar}/^{39}\text{Ar}$ biotite and plagioclase step-wise heating results from the same swarms (Renne et al., 1990; D'Agrella-Filho et al., 2004). Previous studies have shown that many of these dykes have disturbed K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ dates; in some cases younger dates are recorded that reflect a Neoproterozoic Brasiliano disturbance, for example some diabase plagioclase analyses that record dates of ca. 650 Ma (Renne et al., 1990), and in other cases older dates are recorded, likely a consequence of the presence of excess argon that appears pervasive in the region (summarized in D'Agrella-Filho et al., 2004).

Salvador, Ilhéus, and Olivença dykes have been considered to represent a radiating (Bahia) swarm converging on the eastern margin of the São Francisco craton (e.g., Ernst and Buchan, 1997). Our new geochronology supports this model, in which the various Bahia dyke swarms may converge toward an interpreted 920 Ma mantle plume center located near the northern apex of the Araçuaí-West Congo orogen (Fig. 1). On the other side of the cratonic “bridge” in a pre-Atlantic restoration, the Congo craton hosts the 920 Ma Gangila basalts and overlying Mayumbian rhyolites in the West Congo belt, which have geochemistry similar to continental flood magmas (Tack et al., 2001). Taken together, the ca. 920 Ma radiating swarm of the São Francisco craton, and coeval Mayumbian-Gangila magmatism of the Congo craton, delineate the minimum lateral extent of their LIP to more than 10,000 km². Machado et al. (1989) obtained a U-Pb zircon-baddeleyite combined age of 906 ± 2 Ma from a mafic body in the Espinhaço region, several hundred km to the southwest. Extensional granitoids

within the northern Araçuaí orogen are somewhat younger, dated by SHRIMP U-Pb on zircons at 875 ± 9 Ma (da Silva et al., 2008). Initial phases of sedimentation in the Macaúbas Group, within the Araçuaí orogen, appear to have begun at about this time (Pedrosa-Soares and Alkmim, 2011). Sedimentation within spoke-like aulacogens radiating from the Araçuaí-West Congo orogen also appears to be related to this regional extension (Alkmim and Martins-Neto, 2012); for example, the northern Paramirim aulacogen contains mafic magmatism dated by SHRIMP U-Pb on zircon at 854 ± 23 Ma (MSWD = 6.7; Danderfer et al., 2009).

Undated dykes in the Congo craton could also possibly be members of the 920 Ma LIP. Specifically, possible correlatives are swarms at Ebolowa (Cameroon), Sembe-Ouessou and Comba (Democratic Republic of Congo). A tree-like branching pattern for these dykes (extending over an area of 1200 km by 800 km), in the standard reconstruction of the Mesoproterozoic São Francisco and Congo cratons, is envisioned by Correa-Gomes and Oliveira (2000). However, precise dating is required before any conclusions can be drawn about swarm geometry in the Congo portion of the ca. 920 Ma LIP. D'Agrella-Filho et al. (1996) found a distinct palaeomagnetic remanence direction from unmetamorphosed dykes in Gabon, which if primary would indicate a significantly different age from the Bahia dykes investigated herein, and reinforce the possibility that more than one LIP event may be recorded by post-Palaeoproterozoic dykes in the western SF/Congo craton.

SF/Congo apparent polar wander path

Our U-Pb ages correspond to Bahia dykes carrying the “A-normal” and “C” palaeomagnetic remanence directions, from all three sampled regions (Salvador, Ilhéus, and Olivença). The discrepancy between A-normal and C directions corresponds to ca. 50° of arc distance between virtual geomagnetic poles (Figure 9), despite the indistinguishable U-Pb ages. The uncertainties on those ages could be stretched to their limits in an attempt to explain the palaeomagnetic discordance by rapid plate motions or true polar wander (see similar discussion in Swanson-Hysell et al., 2009), but we suggest that in this case the most parsimonious interpretation is that the “C”

direction represents a geomagnetic excursion sampled by three dykes (known thus far) in Salvador.

Similarly, time-averaging of the Proterozoic geomagnetic field can be questioned for the Ilhéus “A-normal” data. D’Agrella-Filho et al. (1990) discussed two alternative explanations for the exceptionally tight clustering of Ilhéus ChRM directions: either they record a mere “snapshot” of the Proterozoic geomagnetic field due to emplacement within a time span substantially less than a few thousand years, or ambient crustal temperatures at the time of emplacement were so high that the ChRMs were acquired over a protracted cooling period that tended to average palaeosecular variation of the field within each specimen’s range of iron oxide grain sizes. These models have opposing implications for tectonic reconstruction purposes; either the mean direction does not point to the Earth’s rotation axis at ca. 920 Ma, or it does. Given the conclusions from Salvador that suggest a large geomagnetic excursion recorded by the “C” direction, we suggest that the Ilhéus “A-normal” data represent another “snapshot” of the field that also does not coincide with the Earth’s rotation axis at that time. Whether these results imply that the ca. 920-Ma geomagnetic field was particularly prone to excursions, will be discussed further in relation to coeval data from other cratons, below. We note that both the Salvador “C” and Ilhéus “A-normal” virtual geomagnetic poles are displaced in approximately the same azimuth from the mean dual-polarity “A” pole from Salvador, and may indicate a palaeomeridian of preferred directions of the reversal-transitional field akin to that of the past few million years (Love, 2000; Hoffman and Singer, 2008).

Although several “A-reversed” dykes were sampled for geochronology, no baddeleyite has yet been recovered from those units. The asymmetry of A-normal and A-reversed directions from Olivença was ascribed to an age difference of 60-70 million years between those dykes (D’Agrella-Filho et al., 1990), consistent with the available $^{40}\text{Ar}/^{39}\text{Ar}$ data in the companion study (Renne et al., 1990). According to that model, the A-reversed dykes would have intruded as a narrow swarm centered on Olivença, and then tens of millions of years later, the A-normal dykes would have intruded neatly on

both sides of the older swarm but systematically avoided the zone of earlier emplacement. This could be plausible if “rift hardening” had occurred, by which the density of dyke intrusions in the central zone affected the material properties of the crust so as to preclude invasion by the younger dykes (see discussion of a variety of possible mechanisms, in Yamasaki and Stephenson, 2009). Alternatively, we suggest that the Olivença ChRM polarity profile could be equally well explained by a N-to-S or S-to-N propagation of magmatism encompassing two geomagnetic field reversals. In this model, the A-reversed and A-normal directions should be nearly equivalent in age, and dated to ca. 920 Ma by our U-Pb results from the southern A-normal zone. The asymmetry in Olivença “A” directions, then, would need to be explained by geomagnetic secular variation, for which compelling evidence exists in the Salvador and Ilhéus datasets as noted above.

Summary palaeomagnetic poles from Bahia are listed in Table 3. Our new results profoundly alter the Meso-Neoproterozoic database for the SF/Congo craton. If the U-Pb ages reported herein are to be used rather than the older $^{40}\text{Ar}/^{39}\text{Ar}$ data, then the A-normal directions correspond to ca. 920 Ma, and there is no longer any ca. 1010 Ma pole from SF/Congo. The A-reversed direction is either penecontemporaneous with A-normal (as suggested by the Itaju do Colônia dataset), or older, in which case the ca. 1080 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ age on Olivença A-reversed dykes (Renne et al., 1990) might still be relevant to that direction. The Salvador “C” direction, preserved in three dykes, was posited by D’Agrella-Filho et al. (2004) to represent the latitude and orientation of the SF/Congo craton at ca. 920 Ma; but herein we provide evidence that it merely represents a geomagnetic excursion, since it differs so greatly from the much more abundant A-normal direction of indistinguishable age. Only one other early Neoproterozoic pole exists from the SF/Congo craton; the Nyabikere pluton VGP (Meert et al., 1994) derives from one site with no tilt control. No other localities bear the same “anomalous” direction, which is interpreted to represent a thermal overprint dated by $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology at ca. 950 Ma. In the São Francisco reference frame, the Nyabikere VGP (Table 3) is similar to the 920-Ma poles refined herein (Figure 9).

Implications for Rodinia

The new ages and palaeomagnetic data reported herein carry important implications for Rodinia supercontinent reconstructions. Our discussion of possible pole/age comparisons relies on the global compilations of palaeomagnetic data by Li et al. (2008) and Evans (2009). In general, very few data exist for the ca. 920 Ma interval of relevance to our new results. The age of 920 Ma, in itself, may find a match in precisely coeval mafic dykes of the North China craton (Peng et al., 2011), although no palaeomagnetic data from the North China dykes are available to test that correlation. The Cuizhuang/Sanjiaotang sedimentary formations, also from North China, have a palaeomagnetic pole that was earlier estimated to be ca. 950 Ma (Zhang et al., 2006), but recent U-Pb geochronology demonstrates those formations to be Palaeoproterozoic in age (Su et al., 2012).

In Laurentia, granitic magmatism of ca. 950-930 Ma age is widespread in East Greenland (Watt and Thrane, 2001) and East Svalbard (Johansson et al., 2005), although the magmatism is accompanied by deformation and mafic dykes of that age have not yet been found; thus the tectonic character of magmatism is quite distinct from that of SF/Congo at the same age. No palaeomagnetic data are available from those granitic rocks. The so-called Grenville Loop of Laurentian apparent polar wander was long regarded as ca. 900 Ma in age, but more recent thermochronology indicates that the apex of the loop is ca. 1000 Ma (Warnock et al., 2000; Brown and McEnroe, 2012), too old for comparison with the present study. The Oaxaquia anorthosite palaeomagnetic pole (Ballard et al., 1989) has also been assigned an age of about 950 Ma, but the pole is not precisely dated, and the tectonic association of Oaxaquia in Rodinia is not straightforward.

The best palaeomagnetic comparisons that can be made to the Bahia coastal dykes are to be found within Baltica. Mafic dykes of similar age are found in southern Sweden, in the foreland to the Sveconorwegian orogen, and palaeomagnetic data are available from those units (Pisarevsky and Bylund, 2006; Elming et al., 2014). Early Neoproterozoic sedimentary rocks of the southern Urals also have yielded

palaeomagnetic data (Pavlov and Gallet, 2010) but the ages of those units are not well constrained.

Interestingly, the Sveconorwegian mafic palaeomagnetic record also indicates a swath of directions distributed over tens of degrees of arc length. The closest age matches in southern Sweden and Norway, as compared to 920 Ma for SF/Congo determined herein, are from the Blekinge-Dalarna dykes at 946–939 Ma (Elming et al., 2014), the Göteborg-Slussen dykes at 935 ± 3 Ma (Pisarevsky and Bylund, 2006), and the Hakefjorden intrusions at 916 ± 11 (Stearn and Piper, 1984; age from Scherstén et al., 2000). We follow Brown and McEnroe (2004), Pisarevsky and Bylund (2006), and Walderhaug et al. (2007) in assigning the Rogaland complex mean poles to an age significantly younger than that suite's U-Pb zircon determinations of ca. 930 Ma (Schärer et al., 1996), perhaps as young as ca. 900–870 Ma, due to slow regional cooling of that internal zone in the Sveconorwegian orogen (Walderhaug et al., 2007).

The Southern Swedish dykes (SSD; Table 3; Figure 10) key palaeomagnetic pole, at ca. 940 Ma, is bolstered by positive baked-contact tests (Elming et al., 2014). One older dyke at Karlshamn, dated by U-Pb at 954 ± 1 Ma, yields a distinct virtual geomagnetic pole that is considered by Pisarevsky and Bylund (2006) to record a geomagnetic excursion (Figure 10). Aside from that anomaly, the Baltica poles show a consistent pattern of migration, from low-moderate palaeolatitudes at 966–916 Ma, to high palaeolatitudes by ca. 900–870 Ma (Brown & McEnroe, 2004; Pisarevsky & Bylund, 2006; Walderhaug et al., 2007; Elming et al., 2014).

The most appropriate palaeomagnetic pole match between SF/Congo and Baltica is our new Bahia A-normal pole (BAn) at 920 Ma, and interpolation of the SSD and Hakefjorden poles dated at ca. 940 Ma and 916 ± 11 Ma, respectively (Table 3). These comparisons permit a direct test of the Rodinia reconstructions by Li et al. (2008) and Evans (2009). Figure 10 shows such tests, which fail (i.e., the Bahia dykes A-normal pole does not overlap the Baltica poles) in both cases; minor adjustments to the locations in each reconstruction could accommodate the new data, but other cratons'

positions would also need to be adjusted to make room for the modified location of SF/Congo.

Figure 11 shows a range of possible reconstructions of SF/Congo according to the 920-Ma palaeolatitude from the Bahia dykes A-normal pole, and exercising freedom of both palaeolongitude and absolute geomagnetic polarity. The figure also shows Baltica in its SSD-defined palaeolatitude and orientation, as well as Laurentia attached to Baltica in a “right-way-up” juxtaposition (Cawood and Pisarevsky, 2006). Despite many controversies surrounding Neoproterozoic supercontinent reconstructions, this “right-way-up” model of Laurentia and Baltica appears to be the most agreed upon (Piper 2007; Li et al., 2008; Evans, 2009), and indeed, it has the greatest scholarly longevity among the currently viable Neoproterozoic cratonic juxtapositions (first proposed by Ueno et al., 1975).

From Figure 11 it is seen that several possible positions of SF/Congo could merit its inclusion within a Rodinia landmass at 920 Ma. Each of those alternatives would make different predictions regarding the duration of the reconstruction. For example, positions (b) and (g) juxtapose the northeast margin of Congo with either cratonic Laurentia or Baltica, respectively. Since none of those margins contains a late Mesoproterozoic suture, the hypothesized juxtaposition should extend to pre-Rodinia times, perhaps as old as Palaeoproterozoic. Positions (c) and (f), however, juxtapose the Irumide margin of Congo with either Laurentia or Baltica. In those models, the Irumide orogeny would be a likely candidate for establishment of the juxtaposition at ca. 1020 Ma (De Waele et al., 2009); hence one would not expect geological or palaeomagnetic matches for pre-Rodinia times. Comprehensive exploration of all of these possibilities is beyond the scope of this paper.

The classical basis for a palaeomagnetic comparison between Laurentia and right-way-up Baltica is the superposition of the Grenville APW loop with its Sveconorwegian counterpart from Baltica (Ueno et al., 1975). As with the Sveconorwegian, much debate surrounds the timing and sense of rotation around the Grenville loop (e.g., Hyodo and

Dunlop, 1993; Weil et al., 1998), but the most recent data suggest its timing to be entirely older than the Sveconorwegian loop (Brown and McEnroe, 2012; Elming et al., 2014). If we are to accept a right-way-up reconstruction of Baltica against Laurentia during the assembly and tenure of Rodinia, then, we must accept a joint APW path with numerous parallel oscillations between 1000 and 900 Ma.

Many of the Grenville and Sveconorwegian palaeomagnetic data derive from high-grade crystalline rocks or plutons that may have cooled slowly through that interval of time. The palaeomagnetic record from more quickly cooled dykes in cratonic Baltica (Elming et al., 2014) and SF/Congo craton (this study) from the same time intervals may contribute substantially to the ambiguities presented by those APW loops. Our study may, therefore, provide a broader perspective toward the question of large palaeomagnetic variance in several intervals of Neoproterozoic time (most notably the Ediacaran Period), for which a variety of alternative explanations have been postulated: rapid plate tectonics (Meert et al., 1993), oscillatory true polar wander (Evans, 1998, 2003), or nonuniformitarian geodynamo (Abrajevitch and Van der Voo, 2010). Detailed palaeomagnetic study of precisely dated mafic dykes may hold the key to answering these issues.

ACKNOWLEDGMENTS

We thank Lely Evans for assistance in the field, and João Dalton de Souza (CPRM) for logistical support. Pete Hollings provided valuable comments on a draft version of the manuscript. DE was funded by the David & Lucile Packard Foundation. The U-Pb geochronology research at the University of Alberta was funded by an NSERC Discovery Grant to LMH. Other U-Pb ages were supported by the Industry-Academia-Government-Consortium project “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” (www.supercontinent.org). This is publication no. **XX** of that project.

REFERENCES

Abrajevitch, A. & Van der Voo, R., 2010. Incompatible Ediacaran paleomagnetic directions suggest an equatorial geomagnetic dipole hypothesis. *Earth and Planetary*

698 *Science Letters*, **293**, 164-170.
699
700 Alkmim, F.F. & Martins-Neto, M.A., 2012. Proterozoic first-order sedimentary
701 sequences of the São Francisco craton, eastern
702 Brazil. *Marine and Petroleum Geology*, **33**, 127-139.
703
704 Alkmim, F.F., Marshak, S., Pedrosa-Soares, A.C., Peres, G.G., Cruz, S., Whittington,
705 A., 2006. Kinematic evolution of the Araçuaí-West Congo orogen in Brazil and
706 Africa: Nutcracker tectonics during the Neoproterozoic assembly of Gondwana.
707 *Precambrian Research*, **149**, 43-64.
708
709 Ballard, M.A., Van der Voo, R., & Urrutia-Fucugauchi, J., 1989. Paleomagnetic results
710 from Grenvillian-aged rocks from Oaxaca, Mexico: Evidence for a displaced terrane.
711 *Precambrian Research*, **42**, 343-352.
712
713 Brown, L.L. & McEnroe, S.A., 2004. Palaeomagnetism of the Egersund-Ogna
714 anorthosite, Rogaland, Norway, and the position of Fennoscandia in the late
715 Proterozoic. *Geophysical Journal International*, **158**, 479-488.
716
717 Brown, L.L. & McEnroe, S.A., 2012. Paleomagnetism and magnetic mineralogy of
718 Grenville metamorphic and igneous rocks, Adirondack Highlands, USA. *Precambrian*
719 *Research*, **212-213**, 57-74.
720
721 Bylund, G. & Elming, S.-Å., 1992. The Dala dolerites, central Sweden, and their
722 palaeomagnetic signature. *GFF*, **114**, 143-153.
723
724 Cawood, P.A. & Pisarevsky, S.A., 2006. Was Baltica right-way-up or upside-down in
725 the Neoproterozoic? *Journal of the Geological Society, London*, **163**, 1-7.
726
727 Cordani, U.G., D'Agrella-Filho, M.S., Brito-Neves, B.B., & Trindade, R.I.F., 2003.
728 Tearing up Rodinia: the Neoproterozoic palaeogeography of South American cratonic
729 fragments. *Terra Nova*, **15**, 350-359.
730
731 Correa-Gomes, L.C. & Oliveira, E.P., 2000. Radiating 1.0 Ga mafic dyke swarms of
732 eastern Brazil and western Africa: Evidence of post-assembly extension in the Rodinia
733 supercontinent? *Gondwana Research*, **3**, 325-332.
734
735 D'Agrella-Filho, M.S., 1992. Paleomagnetismo de enxames de diques máficos
736 Proterozóicos e rochas do embasamento do cráton do São Francisco. PhD Thesis,
737 Departamento de Geofísica, IAG-USP, São Paulo, SP, Brasil, 201pp.
738
739 D'Agrella-Filho, M.S., Feybesse, J.L., Prian, J.P., Dupuis, D. & N'Dong, J.E., 1996.
740 Paleomagnetism of Precambrian rocks from Gabon, Congo craton, Africa. *Journal of*
741 *African Earth Sciences*, **22**, 65-80.
742
743 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., Pacca, I.I.G., Trindade, R.I.F., Teixeira, W., Raposo, M.I.B., & Onstott, T.C., 2004. Paleomagnetism and $^{40}\text{Ar}/^{39}\text{Ar}$ 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.

D'Agrella-Filho, M.S., Trindade, R.I.F., Siqueira, R., Ponte-Neto, C.F. & Pacca, I.G., 1998. Paleomagnetic constraints on the Rodinia supercontinent: Implications for its Neoproterozoic break-up and the formation of Gondwana. *International Geology Review*, **40**, 171-188.

D'Agrella-Filho, M.S., Trindade, R.I.F., Tohver, E., Janikian, L., Teixeira, W. & Hall, C., 2011. Paleomagnetism and $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology of the high-grade metamorphic rocks of the Jequié block, São Francisco Craton: Atlantica, Ur and beyond. *Precambrian Research*, **185**, 183-201.

Dalziel, I.W.D., 1997. Neoproterozoic-Paleozoic geography and tectonics: Review, hypothesis, environmental speculation. *Geological Society of America Bulletin*, **109**, 16-42.

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.

Day, R., Fuller, M. & Schmidt, V.A., 1977. Hysteresis properties of titanomagnetites: Grain size and compositional dependence. *Physics of the Earth and Planetary Interiors*, **13**, 260-267.

De Waele, B., Fitzsimons, I.C.W., Wingate, M.T.D., Tembo, F., Mapani, B. & Belousova, E.A., 2009. The geochronological framework of the Irumide Belt: A prolonged crustal history along the margin of the Bangweulu Craton. *American Journal of Science*, **309**, 132-187.

De Waele, B., Johnson, S.P. & Pisarevsky, S.A., 2008. Palaeoproterozoic to Neoproterozoic growth and evolution of the eastern Congo Craton: Its role in the Rodinia puzzle. *Precambrian Research*, **160**, 127-141.

Elming, S.-Å., Pisarevsky, S.A., Layer, P. & Bylund, G., 2014. A palaeomagnetic and $^{40}\text{Ar}/^{39}\text{Ar}$ study of mafic dykes in southern Sweden: A new Early Neoproterozoic key-pole for the Baltic Shield and implications for Sveconorwegian and Grenville loops. *Precambrian Research*, **244**, 192-206.

Ernst, R.E., and Buchan, K.L., 1997. Giant Radiating Dyke Swarms: Their use in

identifying pre-Mesozoic large igneous provinces and mantle plumes, *In* Mahoney, J. & Coffin, M. (eds.) *Large Igneous Provinces: Continental, Oceanic, and Planetary Volcanism*, *AGU Geophysical Monograph Series*, **100**, 297-333.

Evans D.A., 1998. True polar wander, a supercontinental legacy. *Earth and Planetary Science Letters*, **157**, 1-8.

Evans, D.A.D., 2003. True polar wander and supercontinents. *Tectonophysics*, **362**, 303-320.

Evans, D.A.D., 2009. The palaeomagnetically viable, long-lived and all-inclusive Rodinia supercontinent reconstruction. *In*: Murphy, J.B., Keppie, J.D. & Hynes, A., eds., *Ancient Orogens and Modern Analogues. Geological Society of London Special Publication*, **327**, 371-404.

Fernandez-Alonso, M., Cutten, H., De Waele, B., Tack, L., Tahon, A., Baudet, D. & Barritt, S.D., 2012. The Mesoproterozoic Karagwe-Ankole Belt (formerly the NE Kibara Belt): The result of prolonged extensional intracratonic basin development punctuated by two short-lived far-field compressional events. *Precambrian Research*, **216-219**, 63-86.

Fisher, R.A., 1953. Dispersion on a sphere. *Proceedings of the Royal Society of London, Series A*, **217**, 295-305.

French, J.E. & Heaman, L.M., 2010. Precise U-Pb dating of Paleoproterozoic mafic dyke swarms of the Dharwar Craton, India: Implications for the existence of the supercraton Sclavia. *Precambrian Research*, **183**, 416-441.

Heaman, L., 1991. U-Pb dating of giant radiating dyke swarms: potential for global correlation of mafic magmatic events. *In*: Extended Abstracts, International Symposium on Mafic Dykes, São Paulo, Brazil, p. 7-9.

Heaman, L.M. & Machado, N., 1992. Timing and origin of Midcontinent Rift alkaline magmatism, North America: Evidence from the Coldwell Complex. *Contributions to Mineralogy and Petrology*, **110**, 289-303.

Hellström, F.A., Johansson, Å. & Larson, S.Å., 2004. Age and emplacement of late Sveconorwegian monzogabbroic dykes, SWSweden. *Precambrian Research*, **128**, 39-55.

Hoffman, K.A. & Singer, B.S., 2008. Magnetic source separation in Earth's outer core. *Science*, **321**, 1800.

Hoffman, P.F., 1991. Did the breakout of Laurentia turn Gondwanaland inside-out? *Science*, **252**, 1409-1412.

- Hoffman, P. F. & Halverson, G. P. 2008. The Otavi Group of the Northern Platform and the Northern Margin Zone. In: Miller, R. McG. (ed.) The Geology of Namibia, Vol. 2. Geological Survey of Namibia, Windhoek, 13.69–13.136.
- Hyodo, H. & Dunlop, D.J., 1993. Effect of Anisotropy on the Paleomagnetic Contact Test for a Grenville Dike. *Journal of Geophysical Research*, **98**, 7997-8017.
- Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C. & Essling, A.M., 1971. Precision measurements of half-lives and specific activities of ^{235}U and ^{238}U . *Physics Review*, **C4**, 1889-1906.
- Johansson, Å., Gee, D.G., Larionov, A.N., Ohta, Y. & Tebenkov, A.M., 2005. Grenvillian and Caledonian evolution of eastern Svalbard – a tale of two orogenies. *Terra Nova*, **17**, 317-325.
- Johnson, S.P., Rivers, T. & De Waele, B., 2005. A review of the Mesoproterozoic to early Palaeozoic magmatic and tectonothermal history of south–central Africa: Implications for Rodinia and Gondwana. *Journal of the Geological Society of London*, **162**, 433-450.
- Key, R.M., Liyungu, A.K., Njamu, F.M., Somwe, V., Banda, J., Mosley, P.N. & Armstrong, R.A., 2001. The western arm of the Lufilian Arc in NW Zambia and its potential for copper mineralization. *Journal of African Earth Sciences*, **33**, 503-528.
- Kirschvink, J.L., 1980. The least-squares line and plane and the analysis of paleomagnetic data, *Geophysical Journal of the Royal Astronomical Society*, **62**, 699–718.
- Kirschvink, J.L., Kopp, R.E., Raub, T.D., Baumgartner, C.T. & Holt, J.W., 2008. Rapid, precise, and high-sensitivity acquisition of paleomagnetic and rock-magnetic data: Development of a low-noise automatic sample changing system for superconducting rock magnetometers. *Geochemistry Geophysics Geosystems*, **9**, doi:10.1029/2007GC001856
- Kokonyangi, J.W., Kampunzu, A.B., Armstrong, R., Yoshida, M., Okudaira, T., Arima, M. & Ngulube, D.A., 2006. The Mesoproterozoic Kibaride belt (Katanga, SE D.R. Congo). *Journal of African Earth Sciences*, **46**, 1-35.
- 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.
- 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., Lu, S., Natapov, 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.

Love, J.J., 2000. Statistical assessment of preferred transitional VGP longitudes based on paleomagnetic lava data. *Geophysical Journal International*, **140**, 211-221.

Ludwig, K.R., 2003. ISOPLOT: A plotting and regression program for radiogenic isotope data, version Ex/3.00. *Berkeley Geochronology Center Special Publication*, **4**, 73pp.

Machado, N., Schrank, A., Abreu, F.R., Knauer, L.G., and Almeida-Abreu, P.A., 1989. Resultados preliminares da geocronologia U-Pb na Serra do Espinhaço Meridional. Anais V Simpósio de Geologia de Minas Gerais, *Boletim da Sociedade Brasileira Geologia-Núcleo Minas Gerais*, **10**, 171-174.

McElhinny, M.W., Powell, C.McA., & Pisarevsky, S.A., 2003. Paleozoic terranes of eastern Australia and the drift history of Gondwana. *Tectonophysics*, **362**, 41-65.

McFadden, P.L., & McElhinny, M.W., 1990. Classification of the reversal test in palaeomagnetism. *Geophysical Journal International*, v. 103, p. 725-729.

Meert, J.G. & Torsvik, T.H., 2003. The making and unmaking of a supercontinent: Rodinia revisited. *Tectonophysics*, **375**, 261-288.

Meert, J.G., Van der Voo, R., Powell, C.McA., Li, Z.-X., McElhinny, M.W., Chen, Z. & Symons, D.T.A., 1993. A plate-tectonic speed limit? *Nature*, **363**, 216-217.

Meert, J.G., Hargraves, R.B., Van der Voo, R., Hall, C.M. & Halliday, A.N., 1994. Paleomagnetic and $^{40}\text{Ar}/^{39}\text{Ar}$ studies of late Kibaran intrusives in Burundi, East Africa: Implications for Late Proterozoic supercontinents. *Journal of Geology*, **102**, 621-637.

Patchett, P.J. & Bylund, 1977. Age of Grenville belt magnetization: Rb-Sr and palaeomagnetic evidence from Swedish dolerites. *Earth and Planetary Science Letters* **35**, 92-104.

Pavlov, V. & Gallet, Y., 2010. Variations in geomagnetic reversal frequency during the Earth's middle age. *Geochemistry Geophysics Geosystems*, **11**, doi: 10.1029/2009GC002583

Pedrosa-Soares, A.C. & Alkmim, F.F., 2011. How many rifting events preceded the development of the Araçuaí-West Congo orogen? *Geonomos*, **19**, 244-251.

Peng, P., Bleeker, W., Ernst, R.E., Söderlund, U. & McNicoll, V., 2011. U-Pb baddeleyite ages, distribution and geochemistry of 925 Ma mafic dykes and 900 Ma sills in the North China craton: Evidence for a Neoproterozoic mantle plume. *Lithos*, **127**, 210-221.

- Piper, J.D.A., 2007. The Neoproterozoic supercontinent Palaeopangaea. *Gondwana Research*, **12**, 202-227.
- Pisarevsky, S.A. & Bylund, G., 1998. Palaeomagnetism of a key section of the Protogine Zone, southern Sweden. *Geophysical Journal International*, **133**, 185-200.
- Pisarevsky, S.A. & Bylund, G., 2006. Palaeomagnetism of 935 Ma mafic dykes in southern Sweden and implications for the Sveconorwegian Loop. *Geophysical Journal International*, **166**, 1095-1104.
- Pisarevsky, S.A., Wingate, M.T.D., Powell, C.McA., Johnson, S., & Evans, D.A.D., 2003. Models of Rodinia assembly and fragmentation. In: Yoshida, M., Windley, B.F. & Dasgupta, S. (eds) *Proterozoic East Gondwana: Supercontinent Assembly and Breakup*. Geological Society, London, Special Publication, **206**, 35-55.
- Poidevin, J.-L., 2007. Stratigraphie isotopique du strontium et datation des formations carbonatées et glaciogéniques néoproterozoïques du Nord et de l'Ouest du craton du Congo. *Comptes Rendus Geoscience*, **339**, 259-273.
- Powell C.McA., Li Z.X., McElhinny M.W., Meert J.G. & Park J.K., 1993, Paleomagnetic constraints on timing of the Neoproterozoic breakup of Rodinia and the Cambrian formation of Gondwana, *Geology*, **21**, 889-892.
- Raposo, M.I.B., and Berquó, T.S., 2008. Tectonic fabric revealed by AARM of the Proterozoic mafic dike swarm in the Salvador city (Bahia State): São Francisco Craton, NE Brazil. *Physics of the Earth and Planetary Interiors*, **167**, 179-194.
- Renne, P.R., Onstott, T.C., D'Agrella-Filho, M.S., Pacca, I.G., & Teixeira, W., 1990. ⁴⁰Ar/³⁹Ar dating of 1.0-1.1 Ga magnetizations from the São Francisco and Kalahari cratons: tectonic implications for Pan-African and Brasiliano mobile belts. *Earth and Planetary Science Letters*, **101**, 349-366.
- Schärer, U., Wilmar, E. & Duchesne, J.-C., 1996. The short duration and anorogenic character of anorthosite magmatism: U-Pb dating of the Rogaland complex, Norway. *Earth and Planetary Science Letters*, **139**, 335-350.
- Scherstén, A., Årebäck, H., Cornell, D., Hoskin, P., Åberg, A. & Armstrong, R., 2000. Dating mafic-ultramafic intrusions by ion-microprobing contact-melt zircon: examples from SW Sweden. *Contributions to Mineralogy and Petrology*, **139**, 115-125.
- da Silva, L.C., Pedrosa-Soares, A.C., Teixeira, L.R. & Armstrong, R., 2008. Tonian rift-related, A-type continental plutonism in the Araçuaí Orogen, eastern Brazil: New evidence for the breakup stage of the São Francisco–Congo Paleocontinent. *Gondwana Research*, **13**, 527-537.
- Smirnov, A.V., Tarduno, J.A. & Evans, D.A.D., 2011. Evolving core conditions ca. 2

billion years ago detected by paleosecular variation. *Physics of the Earth and Planetary Interiors*, **187**, 225-231.

Söderlund, U. & Johansson, L., 2002. A simple way to extract baddeleyite (ZrO₂). *Geochem. Geophys. Geosyst.* **3** (2), 1–7.

Söderlund, U., Patchett, P.J., Vervoort, J.D. & Isachsen, C.E., 2004. The ¹⁷⁶Lu decay constant determined by Lu-Hf and U-Pb isotope systematics of Precambrian mafic intrusions. *Earth and Planetary Science Letters*, **219**, 311-324.

Söderlund, U., Isachsen, C.E., Bylund, G., Heaman, L.M., Patchett, P.J., Vervoort, J.D. & Andersson, U.B., 2005. U-Pb baddeleyite ages and Hf, Nd isotope chemistry constraining repeated mafic magmatism in the Fennoscandia Shield from 1.6 to 0.9 Ga. *Contributions to Mineralogy and Petrology*, **150**, 174-194.

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

Stearn, J.E.F. & Piper, J.D.A., 1984. Palaeomagnetism of the Sveconorwegian mobile belt of the Fennoscandian Shield. *Precambrian Research*, **23**, 201-246.

Su, W.-B., Li, H.-K., Xu, L., Jia, S.-H., Geng, J.-Z., Zhou, H.-Y., Wang, Z.-H. & Pu, H.-Y., 2012. Luoyu and Ruyang Group at the South Margin of the North China Craton (NCC) Should Belong in the Mesoproterozoic Changchengian System: Direct Constraints from the LA-MC-ICPMS U-Pb Age of the Tuffite in the Luoyukou Formation, Ruzhou, Henan, China. *Geological Survey and Research*, **35**(2), 96-108 [in Chinese with English abstract].

Swanson-Hysell, N.L., Maloof, A.C., Weiss, B.P. & Evans, D.A.D., 2009. No asymmetry in geomagnetic reversals recorded by 1.1-billion-year-old Keweenawan basalts. *Nature Geoscience*, **2**, 713-717.

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.

Trompette, R., 1994. Geology of Western Gondwana (2000–500 Ma). Pan-African-Brasiliano Aggregation of South America and Africa. Balkema, Rotterdam, 350 p.

Ueno, H., Irving, E. & McNutt, R.H., 1975. Paleomagnetism of the Whitestone anorthosite and diorite, the Grenville polar track, and relative motions of the Laurentian and Baltic Shields. *Canadian Journal of Earth Sciences*, **12**, 209-226.

Verwey, E.J.W., 1939. Electronic conduction of magnetite (Fe₃O₄) and its transition point at low-temperature. *Nature*, **44**, 327-328.

- Walderhaug, H.J., Torsvik, T.H., Eide, E.A., Sundvoll, B. & Bingen, B., 1999. Geochronology and palaeomagnetism of the Hunnedalen dykes, SW Norway: implications for the Sveconorwegian apparent polar wander loop. *Earth and Planetary Science Letters*, **169**, 71-83.
- Walderhaug, H.J., Torsvik, T.H. & Halvorsen, E., 2007. The Egersund dykes (SW Norway): a robust Early Ediacaran (Vendian) palaeomagnetic pole from Baltica. *Geophysical Journal International*, **168**, 935-948.
- Warnock, A.C., Kodama, K.P., & Zeitler, P.K., 2000. Using thermochronometry and low-temperature demagnetization to accurately date Precambrian paleomagnetic poles. *Journal of Geophysical Research*, **105**, 19435-19453.
- Watt, G.R. & Thrane, K., 2001. Early Neoproterozoic events in East Greenland. *Precambrian Research*, **110**, 165-184.
- Weil, A.B., Van der Voo, R., Mac Niocaill, C., & Meert, J.G., 1998. The Proterozoic supercontinent Rodinia: paleomagnetically derived reconstructions for 1100 to 800 Ma. *Earth and Planetary Science Letters*, **154**, 13-24.
- Wingate, M.T.D. & Giddings, J.W., 2000. Age and palaeomagnetism of the Mundine Well dyke swarm, Western Australia: Implications for an Australia-Laurentia connection at 755 Ma. *Precambrian Research*, **100**, 335-357.
- Wingate, M.T.D., Pisarevsky, S.A., & Evans, D.A.D., 2002. Rodinia connections between Australia and Laurentia: No SWEAT, no AUSWUS? *Terra Nova*, **14**, 121-128.
- Yamasaki, T. & Stephenson, R., 2009. Potential role of strain hardening in the cessation of rifting at constant tectonic force. *Journal of Geodynamics*, **47**, 47-62.
- Zhang, S., Li, Z.-X., & Wu, H., 2006. New Precambrian palaeomagnetic constraints on the position of the North China Block in Rodinia. *Precambrian Research*, **144**, 213-238.

FIGURE CAPTIONS

Figure 1. Regional tectonic map of the São Francisco(SF)/Congo craton after reconstruction of the South Atlantic Ocean, with Phanerozoic cover removed (modified from Alkmim et al., 2006; schematic dyke trends from Correa-Gomes and Oliveira, 2000). Inset, cratons of western Gondwana-Land: Kalah.=Kalahari, P=Paranapanema, RP=Rio de la Plata, SF=São Francisco.

Figure 2. Traditional representation of the paleomagnetic apparent polar wander path from Bahia mafic dykes, in present South American coordinates. Ages are $^{40}\text{Ar}/^{39}\text{Ar}$ determinations (Renne et al., 1990; D'Agrella-Filho et al., 2004) discussed in text. C-SF=Congo/São Francisco craton, IC = Itaju do Colônia, I = Ilhéus, O = Olivença, S=Salvador (with 'A' or 'C' subscripts). N = "normal" (upward remanence inclination), R = "reversed" (downward remanence inclination). Modified from D'Agrella-Filho et al., 2004.

Figure 3. Wetherill concordia plots of U-Pb baddeleyite data for Bahia diabase dykes. A) U-Pb baddeleyite results for two samples of the Meridian dyke, Salvador, B) U-Pb baddeleyite results for the Ondina dyke, Salvador, C) U-Pb baddeleyite results for two Olivença dykes (OL4 and OL26), and D) U-Pb baddeleyite results for the Pernambuco dyke, Ilhéus.

Figure 4. (a,c,e) Typical magnetic hysteresis loops after paramagnetic slope correction measured from Olivença (a), Ilhéus (c), and Salvador (e) dykes. Abbreviations are H_c , coercivity; H_{cr} , coercivity of remanence; M_{rs} , saturation remanence; M_s , saturation magnetization. (b,d,f) Typical low-field thermomagnetic curves ($\kappa(T)$) measured in argon from -192 °C to 700 °C from Olivença (b), Ilhéus (d), and Salvador (f) dykes.

Figure 5. Salvador palaeomagnetic data. Backdrop image from Google Earth™ shows sampling sites (with U-Pb ages reported herein), color-coded by the characteristic remanence direction (red=A component "normal", blue=A component "reversed", green=C component). On equal-area stereoplots, solid symbols represent lower hemisphere vectors, and open symbols represent upper hemisphere vectors. On orthogonal projection diagrams, solid symbols show projections onto the horizontal plane, and open symbols show projections onto the vertical plane.

Figure 6. Site-mean ChRM directions from Salvador (prior to quality filtering), grouped (a) according to D'Agrella-Filho et al. (2004); (b) according to this study, with new U-Pb ages indicated at sites with our independent confirmation of the previous palaeomagnetic directions; and (c) according to the geomagnetic interpretation of this study (square symbols show A_N site-mean directions reflected through the origin). Closed vs. open symbols indicate lower vs. upper hemisphere projections, respectively.

Figure 7. Ilhéus palaeomagnetic data. (a) Site location map with Google Earth™ background. (b) Representative demagnetization data from dykes, plotted as both

orthogonal projection diagrams and equal-area stereoplots. (c) Results of the baked-contact test into amphibolite pods within the Palaeoproterozoic basement gneiss. In the stereoplot, red symbols are from the dyke, whereas black symbols are from the amphibolites. (d) Equal-area stereoplot of site-means from this study (red) as compared with those of D'Agrella-Filho et al., 1990 (purple).

Figure 8. Olivença palaeomagnetic data. (a) Site location map with Google Earth™ background. (b) Representative demagnetization data from dykes, plotted as both orthogonal projection diagrams and equal-area stereoplots. (c) Results of the baked-contact test into amphibolite pods within the Palaeoproterozoic basement gneiss. In the stereoplot, red symbols are from the 28-cm-wide dyke, light blue and black symbols are from the amphibolites. (d) Equal-area stereoplot of site-means from this study, in the lower hemisphere (solid blue ovals, “reversed” polarity) and upper hemisphere (open red, “normal”).

Figure 9. Revised ages of early Neoproterozoic palaeomagnetic poles from the SF/Congo craton, in present South American coordinates (Tables 2 and 3). Star indicates the generalized location of sampling localities. Pole abbreviations match those in Table 3, plus the two virtual geomagnetic poles (VGPs) from Ilhéus (Ilh) and the Salvador ‘C’ component (SalC).

Figure 10. Palaeomagnetic tests of proposed Rodinia reconstructions at ca. 920 Ma, from (a) Li et al., 2008; and (b) Evans, 2009. Both panels show Baltica in present coordinates, with 30° grid lines. Pole abbreviations as in Table 3 and Figure 9.

Figure 11. Plausible (partial) Rodinia reconstructions including the SF/Congo craton, using the dual-polarity Bahia dykes pole from this study. Baltica and Laurentia are in the “right-way-up” relative configuration (Cawood and Pisarevsky, 2006) using the Euler parameters of Evans (2009), restored to the absolute frame according to the southern Swedish dykes mean pole (Elming et al., 2014). Grid lines are 30°, and absolute palaeolongitude is arbitrary. Possible positions of SF/Congo, labeled (a) through (h), are discussed in text.

n coastal Bahia, Brazil.

Sample									Model Ages (Ma)						%Disc
	²⁰⁶ Pb/ ²⁰⁴ Pb	²⁰⁶ Pb/ ²³⁸ U	1σ error	²⁰⁷ Pb/ ²³⁵ U	1σ error	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ error	ρ	²⁰⁶ Pb/ ²³⁸ U	1σ error	²⁰⁷ Pb/ ²³⁵ U	1σ error	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ error	
	1606	0.15274	0.00019	1.4715	0.0021	0.06988	0.00007	0.730	916.3	1.0	918.8	0.9	924.7	2.0	1.0
	427	0.15044	0.00028	1.4457	0.0061	0.06969	0.00027	0.401	903.5	1.6	908.1	2.5	919.3	7.9	1.8
	351	0.15116	0.00057	1.4535	0.0089	0.06974	0.00038	0.476	907.5	3.2	911.3	3.7	920.6	11.2	1.5
	660	0.14999	0.00028	1.4437	0.0069	0.06981	0.00030	0.477	900.9	1.6	907.3	2.9	922.8	8.7	2.5
	1560	0.15255	0.00017	1.4674	0.0022	0.06976	0.00008	0.694	915.3	0.9	917.1	0.9	921.4	2.3	0.7
	139	0.15277	0.00053	1.4713	0.0233	0.06985	0.00106	0.302	916.4	2.9	918.7	9.5	924.0	30.8	0.9
	320	0.15141	0.00170	1.4589	0.0172	0.06988	0.00033	0.892	908.8	11.5	913.5	8.5	924.9	9.6	1.6
	975	0.15198	0.00058	1.4660	0.0060	0.06996	0.00012	0.904	912.1	4.3	916.5	3.0	927.1	3.6	1.6
	950	0.15141	0.00045	1.4589	0.0047	0.06988	0.00010	0.892	908.8	3.1	913.5	2.5	924.9	3.0	1.7
	47	0.15018	0.00174	1.4694	0.0557	0.07096	0.00279	0.035	902.0	9.7	917.9	22.7	956.3	78.3	6.1
	92	0.15279	0.00133	1.4728	0.0364	0.06991	0.00161	0.370	916.6	7.4	919.3	14.9	925.7	46.5	1.1
	65	0.15028	0.00188	1.5346	0.0518	0.07406	0.00235	0.346	902.5	10.5	944.3	20.5	1043.1	62.6	14.4
	137	0.15361	0.00062	1.4811	0.0174	0.06993	0.00079	0.273	921.2	3.5	922.7	7.1	926.3	23.1	0.6
	76	0.15104	0.00123	1.4544	0.0357	0.06984	0.00166	0.264	906.8	6.9	911.7	14.7	923.6	48.1	2.0

mineral inclusions, frags - fragments

University of Alberta; LIG - analyses conducted at the Laboratory of Isotope Geology, Stockholm

5)

e

Table 2. Paleomagnetic data from Proterozoic dykes of coastal Bahia, Brazil

Site abbr.	Comp.	Lat.(°S)	Long.(°W)	w(m)	Strike/dip	n/N	GDec	GInc	k	α_{95}	Plat(N)	Plong(E)	Reference	U-Pb age (Ma)
<i>Salvador</i>														
1	C	12.83	38.34	20	005/?	10/?	178.8	59.6	---	12.4	-62.2	323.6	D'AF+04	
8	Ar	12.96	38.35	2	315/?	5/?	295.9	57.1	195	5.5	11.4	275.3	D'AF+04	
9	Ar	12.96	38.36	1.5	315/?	4/?	286.9	59.6	340	4.9	03.9	274.8	D'AF+04	
16	(Ar)	13.02	38.48			3/?	293.2	71.6	68	15.0	01.4	290.9 ^a	D'AF+04	
SA16	(Ar)	13.0159	38.4849	1.5	295/75E	2/2	302.8	68.7	708	9.4	08.5	290.0	<i>this study</i>	
16 comb.	Ar					5/?	297.4	70.5	120	7.0	04.3	290.5	<i>this study</i>	
17	(An)	13.02	38.48			6/?	086.8	-80.5	206	4.7	-13.3	302.5 ^a	D'AF+04	
SA17	(An)	13.0158	38.4847	20	330/90	4/4	142.1	-77.1	108	8.9	06.6	306.6 ^a	<i>this study</i>	
17 comb.	An					10/?	112.9	-80.4	96	5.0	-05.3	304.3 ^a	<i>this study</i>	924.2 ± 3.8
18	An	13.00	38.53	0.6	323/?	3/?	136.8	-64.6	1149	3.6	19.0	291.6 ^a	D'AF+04	
19	An	13.00	38.53	3.5	339/?	3/?	149.7	-65.0	73	14.5	24.2	299.3 ^a	D'AF+04	
SA19	(An)	13.0081	38.5325	2	325/70E	4/4	268.5	-74.1	26	18.5	-10.5	351.7 ^a	<i>this study</i>	
22	(C)	13.01	38.51			4/?	167.2	61.4	49	13.2	-58.4	339.7	D'AF+04	
SA22	(C)	13.0107	38.5147	13	350/73E	5/8	173.2	67.7	108	7.4	-52.0	328.5	<i>this study</i>	
22 comb.	C					9/?	170.2	64.9	71	6.2	-55.1	333.2	<i>this study</i>	921.5 ± 4.3
23	An	13.01	38.53	2	015/?	3/?	082.5	-83.5	224	8.2	-14.3	308.3 ^a	D'AF+04	
mean	An		<i>Salvador only</i>			4 ^b	133.3	-74.4	46	13.7	06.0	301.0 ^a	K=16.7, A ₉₅ =23.2°	
mean	Ar		<i>Salvador only</i>			3 ^b	293.0	62.5	114	11.6	06.7	280.0	K=65.9, A ₉₅ =15.3°	
mean	An+Ar		<i>Salvador only</i>			7 ^b	301.8	69.5	45	9.1	06.4	291.9	K=18.7, A ₉₅ =14.3°	
mean	C		<i>Salvador only</i>			2 ^b	174.9	62.3	299	14.5	-58.9	328.9	K=164.5, A ₉₅ =19.6°	
<i>Ilhéus</i>														
IL1	An	14.8077	39.0238	12	245/90	7/8	064.6	-58.1	198	4.3	-28.9	267.4 ^a	<i>this study</i>	926.1 ± 4.6
IL2	An	14.8061	39.0239	10	245/77N	4/4	055.9	-71.6	183	6.8	-30.7	289.0 ^a	<i>this study</i>	
IL3	An	14.8059	39.0241	10	230/undul.	4/4	046.0	-64.8	1353	2.5	-40.3	280.8 ^a	<i>this study</i>	
IL4	An	14.8055	39.0242	0.9	240/65N	4/4	044.6	-61.3	378	4.7	-42.9	276.0 ^a	<i>this study</i>	

Table 2. *Continued*

<u>Site abbr.</u>	<u>Comp.</u>	<u>Lat.(°S)</u>	<u>Long.(°W)</u>	<u>w(m)</u>	<u>Strike/dip</u>	<u>n/N</u>	<u>GDec</u>	<u>GInc</u>	<u>k</u>	<u>α95</u>	<u>Plat(N)</u>	<u>Plong(E)</u>	<u>Reference</u>	<u>U-Pb age (Ma)</u>
IL5	An	14.8054	39.0243	1.5	240/90	4/4	044.8	-60.6	1031	2.9	-43.1	274.8 ^a	<i>this study</i>	
IL6	An	14.8052	39.0245	7	248/90	4/4	048.4	-68.9	361	4.8	-36.5	286.4 ^a	<i>this study</i>	
IL7	An	14.8051	39.0253	2	250/72N	4/4	057.4	-63.4	467	4.3	-33.3	275.5 ^a	<i>this study</i>	
IL8	An	14.8050	39.0255	0.6	243/77N	4/4	072.9	-58.8	111	8.8	-22.4	268.1 ^a	<i>this study</i>	
IL9	An	14.8050	39.0255	0.7	230/90	4/4	062.1	-61.0	151	7.5	-30.5	271.4 ^a	<i>this study</i>	
IL11	An	14.8514	39.0407	4	230/undul.	4/4	042.4	-73.2	442	4.4	-29.9	274.9 ^a	<i>this study</i>	
IL12	An	14.8513	39.0407	3.5	240/undul.	4/4	062.3	-63.5	996	2.9	-34.3	277.4 ^a	<i>this study</i>	
52	An	14.81	39.02	10	280	4/4	065.6	-60.6	76	10.6	-27.9	270.5 ^a	D'AF+90	
53	An	14.81	39.02	3	270	3/3	045.4	-65.2	813	4.3	-40.3	281.6 ^a	D'AF+90	
54	An	14.81	39.02	8	260	3/3	042.3	-70.8	53	17.0	-38.1	291.6 ^a	D'AF+90	
55	An	14.81	39.02	1	260	3/3	053.3	-64.8	1371	3.3	-35.5	278.5 ^a	D'AF+90	
56	An	14.81	39.02	2	260	3/3	051.0	-65.6	84	13.5	-36.6	280.3 ^a	D'AF+90	
57	An	14.81	39.02	6	260	3/3	049.1	-65.4	211	8.4	-37.9	280.7 ^a	D'AF+90	
58	An	14.81	39.02	0.5	255	3/3	063.5	-63.5	293	7.2	-29.0	274.8 ^a	D'AF+90	
59	An	14.81	39.02	2	270	3/3	059.9	-60.9	99	12.4	-32.0	271.4 ^a	D'AF+90	
60	An	14.81	39.02	1.5	260	4/4	054.4	-64.2	99	9.2	-35.0	277.3 ^a	D'AF+90	
62	An	14.80	39.03	4	270	3/3	073.8	-70.2	775	4.4	-21.3	283.9 ^a	D'AF+90	
63	An	14.80	39.03	1	285	3/3	060.4	-71.4	514	5.4	-28.5	287.4 ^a	D'AF+90	
64	An	14.79	39.03	1.5	260	3/3	079.5	-73.2	225	8.2	-18.0	288.7 ^a	D'AF+90	
65	An	14.79	39.03	1.5	260	3/3	073.3	-66.5	1080	3.7	-21.9	278.2 ^a	D'AF+90	
66	An	14.79	39.03	4	230	3/3	058.2	-63.9	231	8.1	-32.5	276.0 ^a	D'AF+90	
68	An	14.78	39.10	?	?	3/3	065.0	-68.0	1512	3.1	-27.0	281.1 ^a	D'AF+90	
69	An	14.78	39.10	?	?	3/3	085.6	-71.7	91	13.0	-14.7	286.3 ^a	D'AF+90	
mean	An		<i>Ilhéus only</i>			27 ^b	058.4	-66.0	161	2.2	-31.8	279.6 ^a	K=71.3, A ₉₅ =3.3°	

Table 2. *Continued*

Site abbr.	Comp.	Lat.(°S)	Long.(°W)	w(m)	Strike/dip	n/N	GDec	GInc	k	$\alpha 95$	Plat(N)	Plong(E)	Reference	U-Pb age (Ma)
<i>Olivença</i>														
OL1	An	14.9582	39.0051	10	045	4/4	070.4	-60.6	262	5.7	-24.4	270.3 ^a	<i>this study</i>	ca. 920
OL2	(An)	14.9567	39.0067	>2	060	2/4	051.2	-53.6	67	31.1	-40.2	263.3 ^a	<i>this study</i>	
OL3	An	14.9551	39.0074	0.3	050	6/6	070.2	-71.1	497	3.0	-23.4	285.6 ^a	<i>this study</i>	
OL4	An	14.9529	39.0076	12	035	8/8	077.4	-59.8	146	4.6	-19.1	269.4 ^a	<i>this study</i>	
OL5	(An)	14.9526	39.0074	6	075	4/4	077.0	-58.4	15	24.2	-19.4	267.7 ^a	<i>this study</i>	
OL6	Ar	14.9517	39.0074	>2	070	4/4	327.3	54.9	38	15.0	30.9	290.1	<i>this study</i>	
OL7	(Ar)	14.9510	39.0075	3.5	040	4/4	321.7	60.4	16	23.4	23.5	290.5	<i>this study</i>	
OL8	(Ar)	14.9510	39.0075	0.4	070	2/4	295.0	58.1	41	40.0	09.0	275.3	<i>this study</i>	
OL9	Ar	14.9507	39.0077	2	060	4/4	268.5	56.1	70	11.1	-10.0	266.5	<i>this study</i>	
OL10	Ar	14.9503	39.0081	1.2	075	4/4	333.8	76.0	47	13.5	09.0	275.3	<i>this study</i>	
OL11	(Ar)	14.9482	39.0087	10	060	2/4	307.0	46.1	19	61.4	23.4	270.5	<i>this study</i>	
OL12	Ar	14.9477	39.0086	3.3	065	3/4	274.4	56.9	94	12.8	-05.6	268.3	<i>this study</i>	
OL13	(Ar?)	14.9471	39.0088	>2	080	4/4	290.7	26.2	10	30.2	15.7	250.4	<i>this study</i>	
OL14	(An)	14.9437	39.0108	40	060	2/4	099.7	-65.1	480	11.4	-04.5	278.7 ^a	<i>this study</i>	ca. 920
OL15	An	14.9321	39.0154	5	040	4/4	090.4	-77.0	157	7.4	-13.4	295.5 ^a	<i>this study</i>	
OL16	An	14.9312	39.0155	24	055	4/4	098.1	-75.2	520	4.0	-09.5	293.0 ^a	<i>this study</i>	
OL17	An	14.9308	39.0160	6	075	4/4	029.5	-70.1	112	8.7	-44.6	297.1 ^a	<i>this study</i>	
OL18	(Ar?)	14.9296	39.0165	6	080	2/4	323.5	49.6	34	44.1	32.6	283.5	<i>this study</i>	
OL19	(??)	14.9274	39.0171	>2	055	4/4	273.5	-47.0	46	13.6	10.0	204.3	<i>this study</i>	
OL20	---	14.9272	39.0171	>2	085	0/4	---	---	---	---	---	---	<i>this study</i>	
OL21	(??)	14.9268	39.0173	1.3	090	4/4	316.3	-59.1	12	27.5	44.5	189.1	<i>this study</i>	
OL22	An	14.9267	39.0174	1.8	060	4/4	107.9	-68.6	378	4.7	-01.1	285.0 ^a	<i>this study</i>	
OL23	An	14.9262	39.0176	7	075	4/4	085.6	-71.0	313	5.2	-14.7	285.2 ^a	<i>this study</i>	
OL24	---	14.9246	39.0181	>2	080	0/4	---	---	---	---	---	---	<i>this study</i>	
OL25	---	14.9240	39.0182	>2	060	0/4	---	---	---	---	---	---	<i>this study</i>	
OL26	An	14.9228	39.0185	>5	ENE?	4/4	100.9	-56.3	104	9.1	-00.5	269.2 ^a	<i>this study</i>	ca. 920
4	An	14.99	39.00	1	060	3/3	140.1	-73.8	449	5.8	08.6	302.0 ^a	D'AF+90	

Table 2. *Continued*

Site abbr.	Comp.	Lat.(°S)	Long.(°W)	w(m)	Strike/dip	n/N	GDec	GInc	k	α_{95}	Plat(N)	Plong(E)	Reference	U-Pb age (Ma)
6	An	14.98	39.00	20	080	3/3	129.1	-58.6	266	7.7	17.9	281.9 ^a	D'AF+90	
11	An	14.95	39.01	20	070	3/3	064.9	-64.1	541	5.3	-28.0	285.3 ^a	D'AF+90	
13	Ar	14.95	39.01	1.2	098	3/3	312.9	56.0	64	15.4	21.9	281.5	D'AF+90	
18b	Ar	14.95	39.01	?	?	4/4	292.6	51.8	28	17.6	10.1	268.7	D'AF+90	
22	Ar	14.95	39.01	0.8	080	3/3	299.3	65.1	79	13.9	07.6	284.2	D'AF+90	
23	Ar	14.95	39.01	15	085	3/3	314.4	63.2	86	13.4	17.4	288.8	D'AF+90	
24b	Ar	14.95	39.01	?	?	5/5	294.7	61.5	183	5.6	07.0	278.6	D'AF+90	
26	Ar	14.94	39.01	1.5	110	3/3	321.7	61.6	268	7.5	22.4	291.4	D'AF+90	
28	An	14.94	39.01	2	060	3/3	054.9	-67.4	146	10.2	-33.6	282.0 ^a	D'AF+90	
30	An	14.93	39.02	3.5	090	3/3	093.3	-74.2	270	7.5	-11.3	290.8 ^a	D'AF+90	
31	An	14.93	39.02	1.0	075	3/3	072.5	-69.5	458	5.7	-22.3	282.8 ^a	D'AF+90	
32	An	14.93	39.02	2.0	080	3/3	089.5	-71.9	172	9.4	-12.7	286.8 ^a	D'AF+90	
34	An	14.92	39.02	15	055	3/3	074.2	-76.6	64	15.4	-20.2	294.8 ^a	D'AF+90	
35	An	14.92	39.02	1.0	080	3/3	056.9	-70.6	3873	1.9	-30.9	286.7 ^a	D'AF+90	
37	An	14.92	39.02	0.6	095	4/4	026.7	-77.3	103	9.0	-22.2	296.6 ^a	D'AF+90	
39	An	14.91	39.02	2.0	065	3/3	195.9	-80.7	64	15.6	02.4	325.8 ^a	D'AF+90	
40	An	14.91	39.02	3.0	080	3/3	100.3	-72.2	500	5.5	-07.1	288.6 ^a	D'AF+90	
41	An	14.91	39.02	6.0	080	3/3	094.9	-69.7	610	4.9	-09.1	284.1 ^a	D'AF+90	
42	An	14.91	39.02	1.0	090	3/3	090.2	-73.0	254	7.7	-12.6	288.6 ^a	D'AF+90	
43	An	14.91	39.02	2.0	110	3/3	121.8	-60.4	1528	3.0	12.2	280.0 ^a	D'AF+90	
45	An	14.91	39.02	10	095	4/4	091.9	-65.6	128	8.1	-09.7	278.0 ^a	D'AF+90	
46	An	14.88	39.02	?	110	3/3	042.0	-75.6	162	9.7	-33.7	289.4 ^a	D'AF+90	
47	An	14.88	39.02	20	050	3/3	057.0	-50.2	415	6.0	-35.6	258.7 ^a	D'AF+90	
51	An	14.87	39.02	10	340	3/3	050.3	-67.2	913	4.0	-36.3	283.0 ^a	D'AF+90	
mean	An		<i>Olivença only</i>			28 ^b	082.7	-71.4	42	4.3	-16.5	286.7 ^a	K=16.4, A ₉₅ =6.9°	
mean	Ar		<i>Olivença only</i>			10 ^b	301.9	61.9	42	7.5	11.4	282.6	K=20.2, A ₉₅ =11.0°	
mean	An+Ar		<i>Olivença only</i>			38 ^b	276.0	69.9	31	4.3	-09.2	285.6	K=12.6, A ₉₅ =6.8°	

Table 2. *Continued*

<u>Site abbr.</u>	<u>Comp.</u>	<u>Lat.(°S)</u>	<u>Long.(°W)</u>	<u>w(m)</u>	<u>Strike/dip</u>	<u>n/N</u>	<u>GDec</u>	<u>GInc</u>	<u>k</u>	<u>α95</u>	<u>Plat(N)</u>	<u>Plong(E)</u>	<u>Pole statistics</u>
mean	An		<i>all areas combined</i>			59 ^b	071.9	-70.0	44	2.8	-22.3	284.6 ^a	K=17.2, A ₉₅ =4.6°
mean	An		<i>all areas comb., Ilhéus=1 site</i>			33 ^b	086.5	-72.3	38	4.1	-14.3	288.3 ^a	K=14.3, A ₉₅ =6.8°
mean	Ar		<i>all areas combined</i>			13 ^b	299.9	62.1	51	5.9	10.2	282.0	K=24.7, A ₉₅ =8.5°
mean	An+Ar		<i>all areas combined</i>			72 ^b	262.5	69.8	32	3.0	-16.5	284.1	K=12.9, A ₉₅ =4.8°
mean	An+Ar		<i>all areas comb., Ilhéus=1 site</i>			46 ^b	279.0	70.1	31	3.8	-07.3	286.4	K=12.5, A ₉₅ =6.2°

Notes: Comp. = ChRM component abbreviation as defined in text (parentheses indicate exclusion from means). w = dyke width. Strike/dip of dyke attitude in degrees. n/N = number of samples in mean direction/number analyzed. GDec, GInc = mean ChRM in geographic coordinates (degrees). k, α95 = Fisher's (1953) precision parameter, radius (°) of the 95% cone of confidence about the mean direction. Plat, Plong = virtual geomagnetic pole latitude, longitude. D'AF+90, 04 = site passing quality filtering herein, from D'Agrella-Filho et al. (1990, 2004). U-Pb ages are from this study.

^a Plat, Plong listed as antipole of the mean direction given in the table. ^b Number of sites contributing to the mean direction.

Table 3. Selected ca. 950-900 Ma paleomagnetic poles from SF/Congo and Baltica.

<u>Rock unit</u>	<u>Code</u>	<u>Age(Ma)</u>	<u>Method</u>	<u>Lat°N</u>	<u>Long°E</u>	<u>A₉₅(°)</u>	<u>1234567 Q</u>	<u>Paleomagnetic Reference</u>	<u>Geochronology Reference</u>
<i>São Francisco/Congo</i>									
Bahia coastal A-normal	BA-n	ca. 920	U-Pb	-14	288	7	1111100 5	<i>this study</i>	← <i>ibid.</i>
Bahia coastal A-reversed	BA-r	1080-920	Ar/Ar, U-Pb	10	282	6	0111100 4	<i>this study</i>	← <i>ibid.</i> , Renne et al., 1990
Bahia coastal A (2-polar.)	BA	920?	U-Pb	-07	286	6	1111110 6	<i>this study</i>	← <i>ibid.</i>
Itaju do Colônia	IC	ca. 920?	correl.	-08	291	10	0110110 4	D'Agrella-Filho et al., 1990	<i>this study</i>
Nyabikere pluton ^a	Nya	ca. 950?	Ar/Ar	-17	258	11	1010000 2	Meert et al., 1994	← <i>ibid.</i>
<i>Baltica</i>									
Rogaland complex	Rog	ca. 870	cooling	46	058	18	1111001 5	Walderhaug et al., 2007	← <i>ibid.</i>
Egersund-Ogna	EgO	ca. 900	cooling	42	020	9	1110001 4	Brown & McEnroe, 2004	← <i>ibid.</i>
Hakefjorden intrusions	Hak	916 ± 11	U-Pb	-05	069	4	1110001 4	Stearn & Piper, 1984	Scherstén et al., 2000
Southern Swedish dykes	SSD	946-935	U-Pb	01	061	7	1111111 7	Elming et al., 2014	← <i>ibid.</i>

Notes: correl. = correlation of undated rocks to others in the table with direct age constraints. Given the slight difference in pole position of the “reversed” Bahia-coastal dykes, it remains possible that it could have a substantially different age from the ca. 920 U-Pb dates on “normal” polarity dykes in the same region. The ⁴⁰Ar/³⁹Ar age on “reversed” dykes (Renne et al., 1990) is thus assumed as an approximate maximum constraint for that polarity.

^a Rotated to São Francisco reference frame using Euler parameters (46.8°, 329.4°, -55.9°) from McElhinny et al. (2003)

Evans et al. Fig.1

Evans et al. Fig.2

$^{206}\text{Pb}/^{238}\text{U}$

$^{207}\text{Pb}/^{235}\text{U}$

a. **b.** **c.** **d.** **e.** **f.**

Evans et al. **Figure 5**

Evans et al., Fig. 6

Evans et al. **Figure 9**

Evans et al., Fig. 10

Evans et al. **Figure 11**