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Neoproterozoic geochronology and palaeogeography of the Seychelles microcontinent: the India link

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Abstract

The geology of the Seychelles Islands in the Indian Ocean is dominated by granitoid rocks and to a lesser extent by basaltic dykes. A U–Pb zircon age from the Takamaka dolerite dyke (Mahé Island) gives an intrusion age of 750.2 ± 2.5 Ma. The dyke age is considerably older than previous age estimates and suggests that some of the Mahé dolerite dykes are almost coeval with the granitoid rocks. The Mahé dykes show variable degrees of magnetic overprinting, but the proposed oldest magnetization, component A (Decl. = 001.4°, Incl. = +49.7° and $\alpha_{95} = 11.2$; palaeomagnetic pole: Lat. = 54.8°N and Long. = 057.6°E), is identified as a high unblocking component in most dykes, and compares favorably with palaeomagnetic data from the Mahé granitoids. A new Seychelles–India fit (Euler pole: Lat. = 25.8°, Long. = 330° and rotation angle = 28°) produces a good match of palaeomagnetic poles from ca. 750 Ma magmatic rocks in the Seychelles and NW India (Malani), and places these regions only 600 km apart. Together with Madagascar, this tectonic trio formed an outboard continental terrane of the Rodinia supercontinent during the Neoproterozoic (ca. 750 Ma). The position of the Seychelles at this time marks the incipient formation of a microcontinent because there is no evidence for older continental crust than the 750–755 Ma granitoid rocks. The Seychelles formed at 30°N and most likely as part of an Andean-type arc along the western margin of the former Rodinia supercontinent.

Keywords: Geochronology; Palaeogeography; Palaeomagnetism; Rodinia; Seychelles

1. Introduction

The interpretation of the Seychelles (Fig. 1) as a continental fragment left behind during Gondwanaland (Pangea) break-up was recognized by both Wegener (1924) and Du Toit (1937). Our interest in the Seychelles and other continental components such as Madagascar and India relates to current efforts that attempt to refine a more precise fit of Rodinia–Gondwana–Pangea components and to develop an increased understand-

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ing of the details of both assembly and break-up of supercontinents.

Madagascar, the Seychelles and India have formed a tectonic trio, at least since the assembly of Gondwanaland in Late Precambrian times (ca. 550 Ma; Meert and Van der Voo, 1997). This trio remained coupled until the mid-Cretaceous (ca. 85 Ma) when Madagascar separated from the Seychelles and India, followed by break-up of the Seychelles from India close to the Cretaceous–Tertiary (K–T) boundary (Storey et al., 1995; Plummer and Belle, 1995; Torsvik et al., 1998). The pre-Gondwanan history for Madagascar–Seychelles–India is less constrained, but recent Rodinia reconstruction maps tentatively place Madagascar and India next to East Antarctica (Dalziel, 1992, 1997; Torsvik et al., 1996). The palaeogeography of the Seychelles during the Neoproterozoic has not yet been addressed, and is the main scope of this paper.

2. Geology

The geology of the Seychelles is dominated by granitoids, of which four types have been distinguished (Fig. 1), including northern, grey, pink and porphyritic varieties (Baker, 1963). These granitoids yield Rb–Sr ages of 570–713 Ma (reviewed in Suwa et al., 1994), but the majority of recent U–Pb zircon data yield intrusion ages between 748 and 764 Ma (Stephens et al., 1997; Tucker et al., 2001). The youngest Seychelles igneous rocks include syenites, alkaline granites and trachytic tuffs in an early Tertiary alkaline ring complex (63.2 ± 1 Ma, Rb–Sr; Dickin et al., 1986). The young alkaline magmatism, exposed on Silhouette and North Island (Fig. 1), has been linked to the Reunion hotspot (Fig. 1), which may have been instrumental in the separation of India and the Seychelles beginning at a time near the K–T boundary (Devey and Stephens, 1992; Plum-

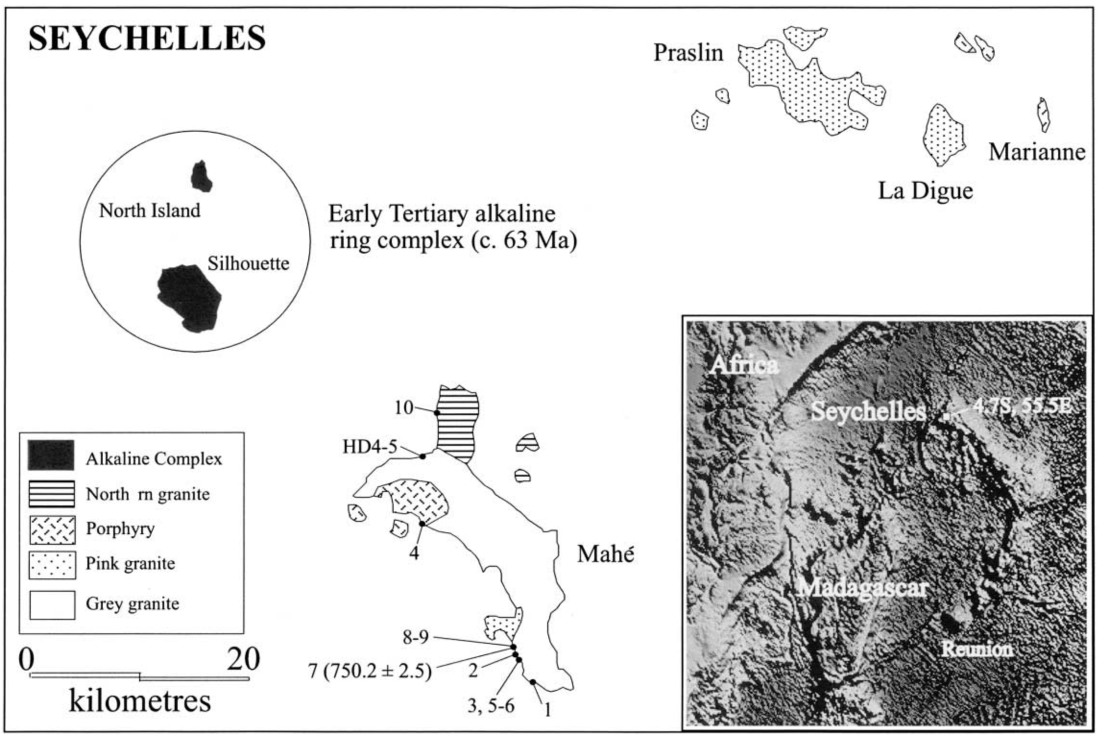

Fig. 1. Geological map of the Island of Mahé and adjacent islands (Seychelles). Numbers one to ten denote sampling sites. Dyke sites HD 4–5 are those of Hargraves and Duncan (1990). U–Pb zircon age from Takamaka dyke (750.2 ± 2.5 Ma, site 7) is from this study (Fig. 2; Table 1). Inset gives the location of the Seychelles in the Indian Ocean with sea-floor topography (after Smith and Sandwell, 1997).

mer and Belle, 1995). We note that the granitoid rocks of the Seychelles are completely undeformed and unmetamorphosed.

Basaltic dykes are also present throughout the Seychelles Islands. Age information is more sparse than for the granitoid rocks, but both Late Precambrian and K–T dykes have been reported (Hargraves and Duncan, 1990; Dickin et al., 1986). Dolerite dykes from Mahé Island are the main focus of the present account, and we present geochronological and palaeomagnetic data that we consider are important to the age and palaeoposition of the Seychelles microcontinent during its initial formation in the Neoproterozoic.

3. Sampling details

Basaltic dykes, up to 80 m thick, but typically 0.5–2 m in width, are present throughout the Seychelles. Most dykes are near-vertical (75–90°) with strikes of 290–340°, averaging ca. 320°C. Petrographically the dykes range from fresh olivine dolerites to altered assemblages of amphibole (hornblende and/or actinolite), chlorite, epidote and white mica. Hargraves and Duncan (1990) reported palaeomagnetic results from two dykes in north Mahé (Fig. 1, sites HD 4 and 5). Based on whole-rock K–Ar and staircase-like ^{40}Ar–^{39}Ar spectra (no valid plateau age), they argued for a crystallization age of ca. 620 Ma.

We avoided sampling of the most hydrothermally altered dykes and focused our studies in southwest Mahé (sites 1–3, 5–6 and 7–8) where the dykes appear fresher in outcrop. Sites 7 and 8 are from the same dyke system in southwesterly Mahé (Takamaka beach) sampled in two different locations. Palaeomagnetic and petrological studies of granites from Mahé have been carried out previously by Suwa et al. (1994); for comparison we have acquired palaeomagnetic data for the 'Gray' granite (site 9) close to sites 7 and 8 and the 'Northern' granite. The 'Northern' granite at site 10 (Fig. 1) has been dated at 755 ± 1 Ma (U–Pb zircon; Stephens et al., 1997).

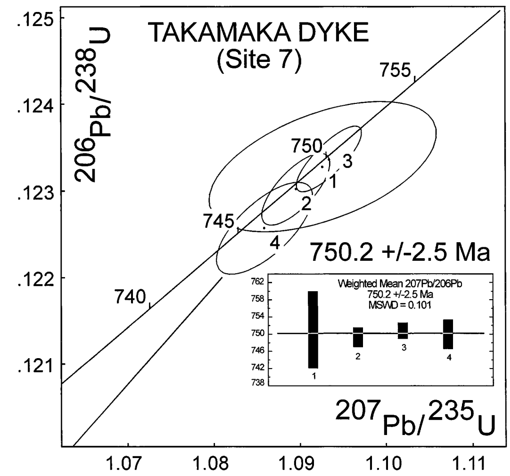

Fig. 2. Concordia diagram showing isotope dilution analyses of zircons (analyses 1–4) from the Takamata dyke (site 7, Fig. 1). All analyses are concordant and define a weighted mean ^{207}Pb–^{206}Pb age of 750 ± 2.5 Ma (95% confidence).

4. U–Pb isotope data

From the Takamaka dyke (Fig. 1, sites 7 and 8), we recovered zircons from the coarse-grained granophyre in the dyke center (dyke width 10 m). Zircons were extracted using standard density and magnetic methods. The zircons are optically clear, colorless and skeletal, like the type expected from a granophyric gabbro. All grains were air abraded (Krogh, 1982), and common Pb components were removed by cleaning in warm 4 N HNO_3, water and distilled acetone. Uranium and Pb isotopic ratios were measured on a VG Sector 54 TIMS at the Washington University, St Louis, MO. Four U–Pb isotope dilution analyses give concordant ages with a weighted mean of 750.2 ± 2.5 Ma (Fig. 2, Table 1). This age is considerably older than the 620 Ma ^{40}Ar–^{39}Ar age cited by Hargraves and Duncan (1990), and suggests that some of the Mahé dolerite dykes are almost coeval with the Mahé granitoids (the majority of ages for the latter are between 750 and 755 Ma; Tucker et al., 2001). Since the sampled dykes in western and southwestern Mahé (Fig. 1) strike ca. 320°, are between 1 and 20 m in width and have similar geochemical signatures (Ashwal, unpublished data), it is reasonable to assume that all the studied dykes are of similar age (i.e. ca. 750 Ma).

Table 1
U–Pb isotope dilution analyses, Takamaka dolerite

Fractions			Concentrations			Atomic ratios					Age (Ma)
No.	Properties[a]	Wt. (μg)[b]	Pb rad (ppm)[b]	U (ppm)[b]	Pb com (pg)[c]	Th–U[d]	^{206}Pb–^{204}Pb[e]	^{207}Pb–^{206}Pb[f]	^{207}Pb–^{235}U[f]	^{206}Pb–^{238}U[f]	^{207}Pb–^{206}U[g]
LA-97M-28A Takamaka dolerite											
1	2 gr, cl, c, sk, pr	6	9.73	72.1	4.7	0.657	750.7	0.06429 ± 27	1.0927 ± 54	0.12328 ± 31	751.0 ± 8.9
2	2 gr, cl, c, sk, pr	9	21.8	163	2.3	0.627	5022	0.06423 ± 7	1.0896 ± 16	0.12302 ± 17	749.3 ± 2.2
3	4 gr, cl, c, sk, pr	12	11.9	88.3	3.2	0.633	2550	0.06428 ± 5	1.0934 ± 16	0.12337 ± 15	750.8 ± 1.8
4	3 gr, cl, c, sk, pr	10	11.1	83.2	1.2	0.641	5204	0.06425 ± 10	1.0859 ± 23	0.12257 ± 22	749.9 ± 3.3

[a] The first column denotes the number of the analysis. The cardinal number in the second column indicates the number of zircon grains analysed (e.g. 2 gr = 2 grains); all grains were selected from non-paramagnetic separates at 0° tilt at full magnetic field in Frantz magnetic separator; c = colorless; cl = clear; sk = skeletal; pr = prismatic. All zircon grains were abraded following Krogh (1982).

[b] Concentrations are known to ~30% for sample weights of about 20 μg and ~50% for samples ≤5 μg.

[c] Corrected for 0.0215 mole fraction common-Pb in the ^{205}Pb–^{235}U spike.

[d] Calculated Th–U ratio assuming that all ^{208}Pb in excess of blank, common-Pb, and spike is radiogenic (λ $^{232}Th = 4.9475 \times 10^{-11}$ yr^{-1}).

[e] Measured, uncorrected ratio.

[f] Ratio corrected for fractionation, spike, blank, and initial common-Pb (at the determined age from Stacey and Kramers, 1975). Pb fractionation correction = 0.094%/amu (±0.025% 1σ); U fractionation correction = 0.111%/amu (±0.02% 1σ). U blank = 0.2 pg; Pb blank ≤ 10 pg. Absolute uncertainties (1σ) in the Pb–U and ^{207}Pb–^{206}Pb ratios calculated following Ludwig (1980).

[g] This column lists the ^{207}Pb–^{206}Pb age (±1σ absolute). U and Pb half-lives and isotopic abundance ratios from Jaffey et al. (1971).

5. Palaeomagnetic results

The natural remanent magnetization (NRM) of the samples was measured with a JR5A magnetometer at the Geological Survey of Norway (NGU). Stability of NRM was tested by both thermal (MMTD60 furnace) and alternating field (AF) demagnetization (two-axis tumbler; built at NGU). Characteristic remanence components (ChRc) were calculated with the least-square regression analysis implemented in the SIAPD computer program (http://www.ngu.no/geophysics). Thermomagnetic analysis (TMA) was carried out on a horizontal translation balance built at NGU.

We have identified three characteristic remanence components (A–C) in the Mahé dykes (Fig. 3; Table 2): component A is characterized by northerly declinations with positive inclinations (Fig. 3a), component B has E–W declinations with shallow inclinations (dual-polarity) and component C shows NE declinations with negative inclinations (Fig. 3b). Except for site 6, components B and C are low unblocking temperature or field strength (LB) components. Component interplay is commonly observed at the sample level. As an example, site 1 samples reveal LB C-components, typically demagnetized in the 200–540°C range, or in AF fields of ca. 9 mT, and high-unblocking temperature or field strength (HB) A-components (Fig. 4a). Sites 2 and 3 samples are almost single-component, but directionally similar to HB components from site 1 (Fig. 3a). Sites 7 and 8 samples (U–Pb dated at 750 Ma; Fig. 2, Table 1) could also be essentially single-component (component A) with discrete unblocking above 530–500°C (Fig. 4b), but many samples from these latter sites yield LB components with shallow inclinations and westerly declinations (component B, see later). Component B is also identified at sites 4 and 6, but with opposite polarity compared with those of sites 7 and 8 (see Fig. 3b).

The interplay of components A and B is illustrated in data from site 8 (Fig. 5). This site embraces a profile through two merging dykes at the Takamaka beach. The central part of the larger dyke (Fig. 5b) shows essentially a single A-component, but samples along the dyke margin show strong influence of the B-component (Fig. 5c). In Fig. 5c the westerly and shallowly inclined B-component is identified in the 2–10 mT range, while the northerly directed A-component is well identified above 50 mT. The B-component typically constitutes 80% of the total NRM. Overall,

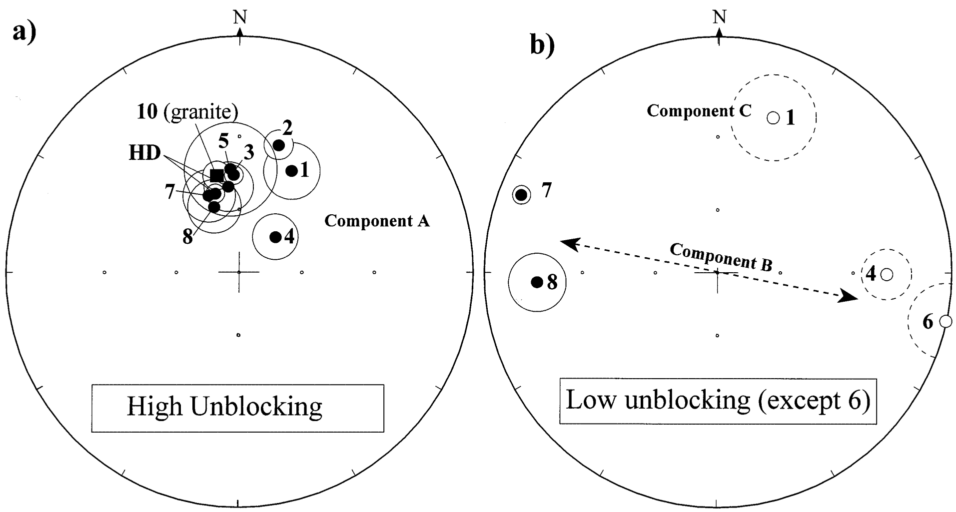

Fig. 3. Site-mean directions with α_{95} confidence circles (Table 2). (HD = dike site means of Hargraves and Duncan (1990): (a) A-components which all are high unblocking components; and (b) B- and C-components, all low unblocking except site 6. Closed (open) symbols represent positive (negative) inclinations.

Table 2
Palaeomagnetic results from Mahé Island and dyke data from Hargraves and Duncan (1990)

Site	Rock	Age ± 2σ (Ma)	Decl.	Incl.	α_{95}	N	Component
1	Dyke		019.7	−20.1	13.8	13	C (LB)
			027.5	+38.2	11.1	6	A (HB)
2	Dyke		017.2	+30.9	5.4	11	A (HB)
3	Dyke		356.8	+45.0	3.9	6	A (HB)
4	Dyke		090.5	−18.4	8.1	6	B (LB)
			045.5	+65.6	10.6	4	A (HB)
5	Dyke		355.2	+42.8	19.0	4	A (HB)
6	Dyke		101.9	−0.2	9.2	9	B (HB)
7	Dyke		291.5	+5.9	2.5	6	B (LB)
		750 ± 3.0	338.4	+51.4	11.4	6	A (HB)
8	Dyke		266.8	+15.2	9.0	4	B (LB)
		750 ± 3.0	340.9	+56.4	12.0	9	A (HB)
10	Granite	755 ± 1[a]	347.0	+44.2	5.9	13	A (HB)
H4[b]	Dyke		343.1	+51.4	4.1	6	A (HB)
H5[b]	Dyke		352.9	+49.7	10.6	6	A (HB)

Decl./Incl. = declination/inclination; N = number of samples; α_{95} = 95% confidence circle; component = components A–C (cf text); LB = low-unblocking; HB = high-unblocking. Ages are U–Pb zircon ages.

[a] Stephens et al. (1997), sites 7 and 8 are from the Takamaka dyke swarm.

[b] Hargraves and Duncan (1990).

granite samples from sites 8 and 9 show inconsistent ChRc at site level and the directional behavior is rather erratic; in Fig. 5a, however, we notice that the contact granite yields a B-component that is similar to the LB component identified for dyke margin samples (compare Fig. 5a and c). It is likely that post-intrusion fluids along the dyke–granite interface have caused partial overprinting of the magnetic signature in dyke samples while completely resetting presumed older components in the less magnetically stable and coarse-grained granite samples. Also, the NRM intensity profile through site 8 displays disturbed behavior with NRM maxima along the margins of the thinner dyke and an asymmetry in the intensity pattern across the wider dyke (Fig. 5a). An undisturbed, primary cooling system should be characterized by maximum NRM intensity and susceptibility in the central parts of a dyke owing to grain size contrasts.

Gray granite samples from southwest Mahé (sites 8 and 9) did not provide a coherent directional within-site signature, but the granite site from north Mahé (site 10) shows exemplary single-component magnetizations, with northerly declinations and positive inclinations (Fig. 6a). The northern granite site mean direction is similar to the A-component from the dykes (Fig. 3a).

Maximum unblocking temperatures of 570–580°C indicate magnetite or titanium-poor titanomagnetite as the prime remanence carrier for all dyke samples; TMA yields Curie temperatures of ca. 580°C (Fig. 6b). TMA curves are either almost reversible or may show minor magneto-mineralogical phase changes attendant upon increased (10–20%) saturation magnetization during cooling. TMA and the thermal unblocking spectra for granite samples suggest pure magnetite as the main remanence carrier (Fig. 6b).

6. Interpretation

Based on the experimental blocking temperature contrasts, we infer that the A-component is the oldest remanence and linked to the 750.2 ± 2.5 Ma Takamaka dyke age (Fig. 2; Table 1). The A-components are similar to HB components reported from two dykes in north Mahé (Hargraves and Duncan 1990; Figs. 1 and 3a). A certain spread in the site-mean/dyke directions might be attributed to the effects of younger low-temperature hydrothermal alteration and/or minor component overlap with B- and C-components. Component A dyke magnetization also matches granite site 10 (755 ± 1 Ma; Stephens et al., 1997) as well as granitoid palaeomagnetic data reported by Suwa et al. (1994). Hence, dolerite dykes (750 Ma) and granitoid rocks (mostly 750–755 Ma) appear broadly coeval on both isotopic and palaeomagnetic grounds. We cannot, however, exclude the possibility that both granitoid rocks and dolerites were totally re-magnetized at a younger time; this might not have affected the U–Pb system due to the high retentivity of radiogenic Pb. Evidence for younger remagnetization of the dykes carrying the A-component is clearly evident, mostly identified as B-components (sites 4, 6–8), and is commonly found along dyke margins. This suggests the possible involvement of low-temperature 'remagnetization fluids' along the dyke–granite interface. The B-component is probably thermochemical in origin; the age of this event is as yet uncertain (see later), but if deemed reliable, existing Rb–Sr ages (Suwa et al., 1994) from granites and ^{40}Ar–^{39}Ar ages from dykes in north Mahé (Hargraves and Duncan, 1990) may suggest a weak Pan-African influence. We stress nevertheless that the Mahé granites and dykes we sampled are completely unmetamorphosed, and only hydrothermal alteration and sporadic fracturing along dyke margins were observed. Component C might be Tertiary in age, but this conclusion, based on one low unblocking site observation is premature.

7. Comparison with India and the Rodinia supercontinent

Palaeomagnetic poles from the Seychelles dykes and granitoids (Table 3) are shown in Fig. 7a together with a pole from the Malani Rhyolite (Klootwijk, 1975) in NW India and a suggested East Gondwanaland apparent polar wander path (APWP; Powell et al., 1993). In previous studies of the Seychelles dykes and granitoids (Hargraves and Duncan, 1990; Suwa et al., 1994), palaeomagnetic data (similar to our A-components) were rotated back to Madagascar, and then back to Africa placing the Seychelles adjacent to Somalia in a 'traditional' Late Precambrian Gondwanaland reconstruction. This exercise was motivated by the then-existing age data and an apparent match between the Seychelles poles and the Late Precambrian Namibian Nama Group pole (N1 poles of Kröner et al., 1980). However, the palaeomagnetic reliability of the Nama Group is suspect (Meert et al., 1997); furthermore, the intrusion ages of the Seychelles granitoid rocks (ca. 750–755 Ma) and dykes (ca. 750 Ma) are considerably older than previously assumed. New U–Pb

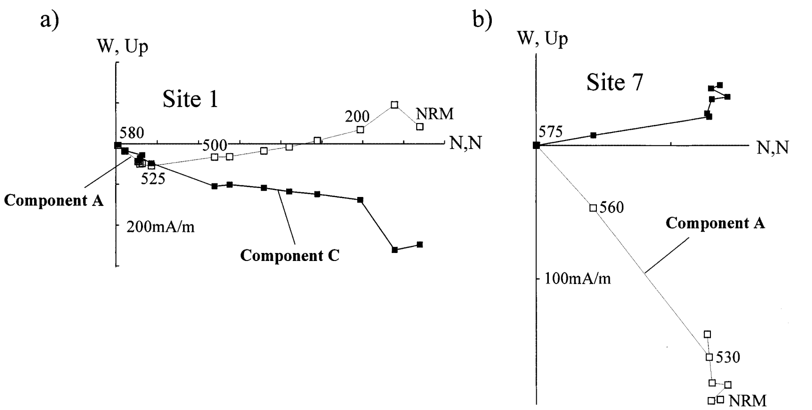

Fig. 4. Thermal demagnetisation results of dyke samples from: (a) site 1; and (b) site 7. Central parts of the Takamaka dyke dated to 750 ± 2.5 Ma. In Zijderveld diagrams closed (open) symbols represent points in the horizontal (vertical) plane. NRM = Natural Remanent Magnetisation. Numbers are temperature in °C.

Table 3
Summary of Palaeomagnetic data from Mahé (Seychelles). Mean geographic location for pole calculation is Lat. = 4.7°S, Long. = 55.5°E

Rock type	Decl.	Incl.	α_{95}	*N*	Pole		dp/dm	Pole IND		Ref.
					Lat.	Long.		Lat.	Long.	
Dykes	005.3	+49.1	14.5	7						Component A, this study
	001.4	+49.7	11.2	9	54.8	057.6	9.9/14.9	79.8	78.6	Component A, this study; Hargraves and Duncan (1990)
	277.8	+10.1	15.9	4	−7.3	151.3	8.1/16.1	−9.8	159.9	Component B, This study
Granites	348.0	+48.7	2.0	121*	54.0	038.2	1.7/2.6	76.6	23.0	Suwa et al. (1994)

N = number of sites (* = samples); Pole = Palaeomagnetic pole; Pole IND = Palaeomagnetic pole in Indian co-ordinates (Euler fit: Lat. = 25.8°, Long. = 330° and rotation angle = 28°); Lat. = Latitude, Long. = Longitude, dp/dm = semi-axes of the cone of 95% confidence about the pole; see Table 2 and text for further details.

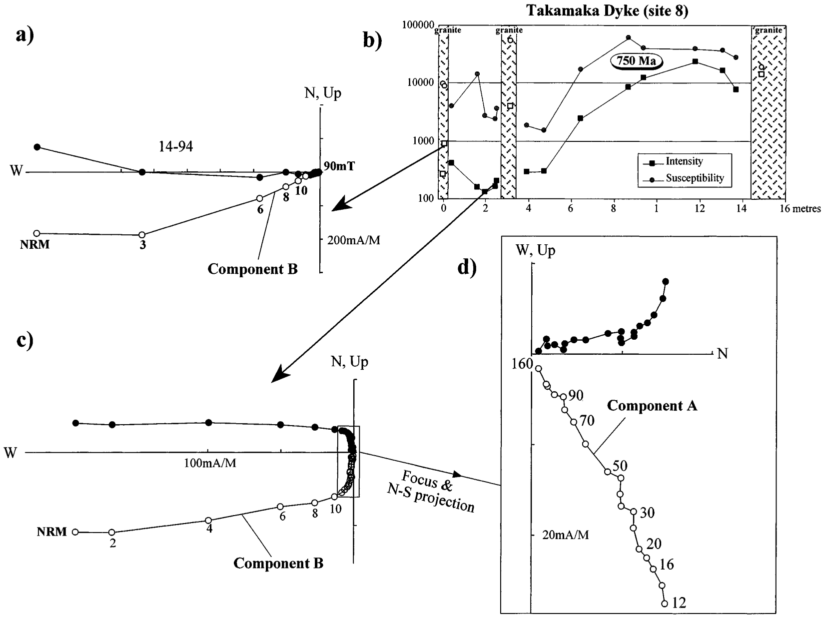

Fig. 5. Alternating field demagnetization of: (a) contact granite sample; and (c and d) Takamaka dyke sample at site 8. (b) NRM intensity (mA/M) and bulk susceptibility (10^{-6} SI units) profile. (d) Expanded central part of (c) using a N–S projection plane.

ages clearly demonstrate that the Seychelles granitoids (Stephens et al., 1997; Tucker et al., 2001) and dykes (this study) pre-date Gondwanaland assembly. We address this issue directly via a comparison with India and the Rodinia supercontinent.

An age of 730 ± 10 Ma (recalculated Rb–Sr whole rock age of Crawford and Compston, 1970) is commonly quoted for the Malani rhyolites. The palaeomagnetic stability of these rhyolites is superb (Klootwijk, 1975; own work in progress), but one should notice that Rb–Sr ages vary from 779 to 680 Ma (reviewed in Rathore et al., 1999). If we accept an approximately similar magnetization age for the Malani and the Seychelles data, the palaeomagnetic poles are fully matched (Fig. 7a) with an Euler pole of Lat. = 25.8°N and Long. = 330°E, and a rotation angle of 28°. This produces a tight Seychelles–India fit (Fig. 7a) with the Seychelles (Mahé Island) located approximately 600 km SW of the Malani Igneous Province, and 300 km NNW of Madagascar (Madagascar–India fit as in Dalziel, 1992; Torsvik et al., 1996; Euler Lat. = 20.9°, Long. = 26.3° and rotation angle = 57.9°). This fit implies that ca. 750 Ma magmatism in northern Madagascar (Tucker et al., 1999), the Seychelles and Malani, now widely separated by ca. 5000 km, was originally spatially concentrated.

Whereas we have confidence that the Seychelles (component A) and Malani palaeomagnetic data have an age of ± 750 Ma, the palaeomagnetic age of the B-component is less certain. Magmatic rocks in the Seychelles and NW India are undeformed and unmetamorphosed while those in northern Madagascar include highly deformed gneisses metamorphosed to amphibolite/granulite grade (Tucker et al., 1999). Penetrative Pan-African magnetic resetting in northern Madagascar is reflected by complete remagnetization of 715–754 Ma granites; palaeomagnetic poles are similar to those from Late Neoproterozoic poles from Central Madagascar (Meert et al., personal communication) which plot near the Vendian–early Palaeozoic segment of the East Gondwanan APWP (using the Madagascar–India fit as in Fig. 7a). With the Seychelles–India fit outlined above, our B-component does not converge toward the Vendian–early Palaeozoic segment of the East Gondwanan APWP; hence, this may not imply a

Pan-African influence. It is possible, however, to use a different Seychelles–India fit that places both the A- and B-components on the Neoproterozoic–early Palaeozoic APWP in Fig. 7a, but this will place the Seychelles unrealistically far away from both India and Madagascar, and would suggest no spatial relationship between this continental trio (even at Gondwanan ca. 550 Ma times). If the B-component is Pan-African, an alternative is to use an entirely different fit for component B. This, however, would imply that the Seychelles microcontinent underwent some rotation relative to India after its formation at 750 Ma, but prior to remanence acquisition of the B-component.

During the early Neoproterozoic, it has been suggested that most continents formed part of the Rodinia supercontinent (e.g. Dalziel, 1991, 1992; Hoffman, 1991; Torsvik et al., 1996; Weil et al., 1998). Rodinia configurations hinge on the continuity of ca. 1.2–1.0 Ga orogens (Sveconorwegian–Grenvillian–Kibaran) and to some extent on palaeomagnetic data (reviewed in Torsvik et al., 1996; Weil et al., 1998). Fig. 7b illustrates the apparent match of East Gondwanaland, Baltica and Laurentia APWPs at ca. 750 Ma using the continent fits as shown in Fig. 8. We have also superimposed the Malani (NW India) and the Seychelles poles, and, by implication, these poles fall on the oldest segment of the East Gondwanan APWP since the Malani pole was used as an input pole in this APWP (Powell et al., 1993).

Parts of Rodinia (East Gondwanaland, including the presumed India–Seychelles–Madagascar bond) survived internal fragmentation until the Mesozoic (mid-Jurassic). Other parts broke up in the Neoproterozoic, with the initial break-up estimated to have taken place after 750–725 Ma, when East Gondwanaland (including Australia–Antarctica–India–Seychelles–Madagascar) rifted off the western margin of Laurentia (Powell et al., 1993; Torsvik et al., 1996; Fig. 8). The early break-up history is illustrated in Fig. 7b and suggests that East Gondwanaland separated from Laurentia and Baltica sometime after 750–720 Ma (diverging APWPs), while the two latter continents separated at a later stage (ca. 600 Ma)

8. Conclusions

U–Pb isotope data from the Takamaka dolerite dyke (Mahé Island, the Seychelles) testify to an intrusion age of 750.2 ± 2.5 Ma. This is significantly older than previous age estimates, and the dyke age is comparable with the Seychelles granitoid rocks, mainly 750–755 Ma (Stephens et al., 1997; Tucker et al., 2001). The Mahé dykes have suffered magnetic overprinting, and three magnetization components have been identified. The assumed oldest, component A, is seen as an HB component in most dykes and has earlier been reported from both dykes and granitoid rocks

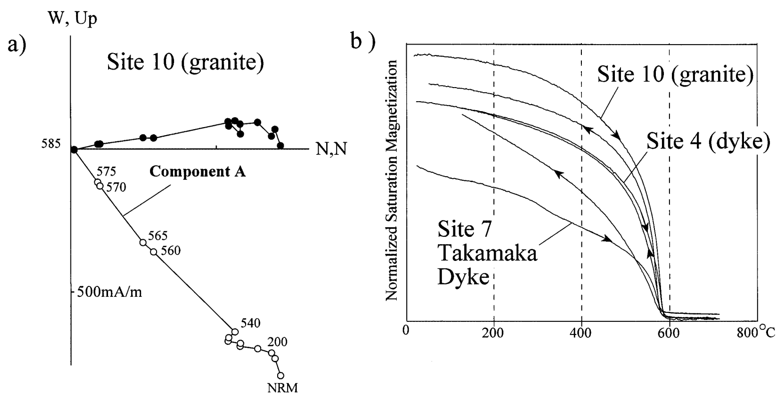

Fig. 6. (a)Typical example of thermal demagnetization of a ‘Northern’granite sample from site 10. The ‘Northern’ granite is dated to 755 ± 1 Ma (Stephens et al., 1997). (b) Thermomagnetic analysis (TMA) of site 4 and 7 dyke samples and granite sample from site 10 which all show Curie temperature of ca. 580°C. TMA performed in air (magnetic field = 0.5 T).

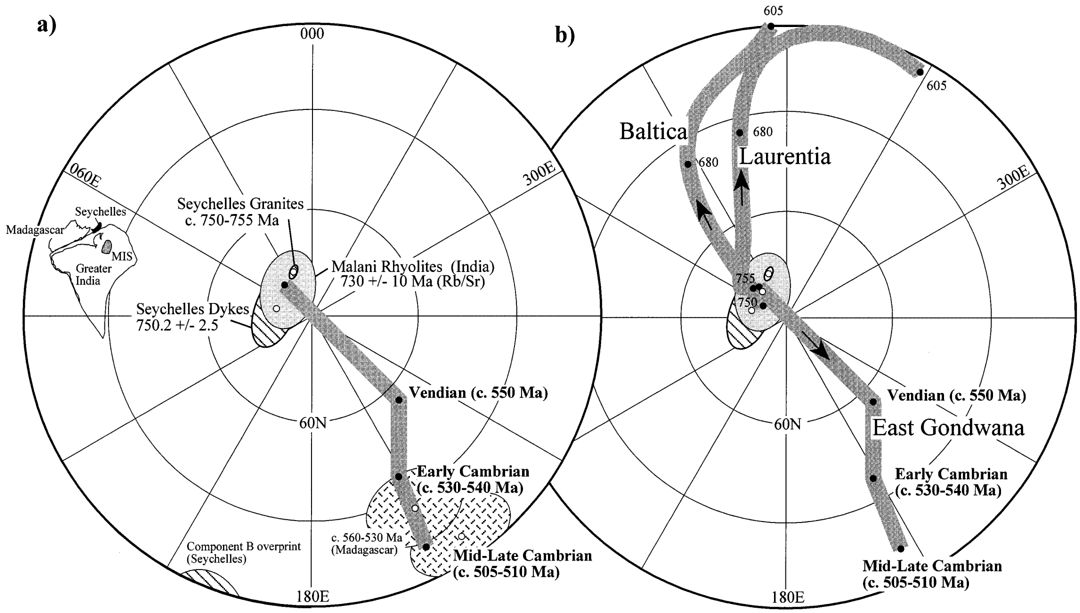

Fig. 7. (a) Palaeomagnetic poles derived from the Seychelles dolerites and granites (Table 3) plotted with 95% confidence levels. Poles are shown together with a Malani rhyolite pole from NW India (Klootwijk, 1975), and a suggested Neoproterozoic–early Palaeozoic APWP for East Gondwana (Powell et al., 1993). The APWP is displayed in Indian co-ordinates. Seychelles poles are plotted in Indian co-ordinates using an Euler fit of Lat. = 25.8°, Long. = 330° and a rotation angle = 28°. The resulting continental fit of India and the Seychelles is shown as well (India is fixed in present co-ordinates). Madagascar fit after Lawver et al. (1992). Our B-component poles (ca. 560–530 Ma) from Central Madagascar (Meert et al., personal communication). All poles are displayed in Indian co-ordinates. (b) Comparison of East Gondwana (Powell et al., 1993), Baltica and Laurentia APWPs (paths after Torsvik et al. (1996) but plotted in Indian co-ordinates). The Malani and Seychelles poles are included with the fit of Fig. 8.

from Mahé (Hargraves and Duncan, 1990; Suwa et al., 1994). Component B is of dual polarity and is recognized as an LB remanence, whereas component C is seen as an LB component only from a single dyke. When two of these components coexist at sample level, the A-component is always the HB component, and we assign an age of ca. 750 Ma for the A-component (from both dykes and granites). The age of the B- and C-components is as yet uncertain, but the mode of remanence acquisition is probably hydrothermal (thermo-chemical) in nature; hydrothermal alteration probably contributed locally to the disturbance in the Rb–Sr system and led to Ar loss.

A new Seychelles–India fit produces a match of palaeomagnetic poles from ca. 750 Ma magmatic rocks in the Seychelles and NW India (Malani), and the new reconstruction suggests that the Seychelles and the Malani Igneous Suite were separated by only 600 km. Since the seminal papers of Dalziel (1991, 1992) and Hoffman (1991), the relative positions of Rodinia fragments are understood on a first-order basis, but finer-scale reconstructions based on palaeomagnetic constraints and state-of-the-art geochronology and isotope studies are needed to resolve the detailed kinematic histories of Rodinia assembly, break-up and lithospheric evolution.

We place Seychelles–India–Madagascar at 15–30°N and as outboard continental terranes of Rodinia that faced the former Mozambique Ocean at 750 Ma (Fig. 8). The position of the Seychelles at this time marks the incipient birth of this microcontinent, since there is no evidence for older continental crust than the 750–755 Ma granitoid rocks. The palaeomagnetic data imply that the Seychelles formed at ca. 30°N, and we conclude that the Neoproterozoic igneous rocks of Malani (NW India), the Seychelles and northern Madagascar probably constituted an Andean-

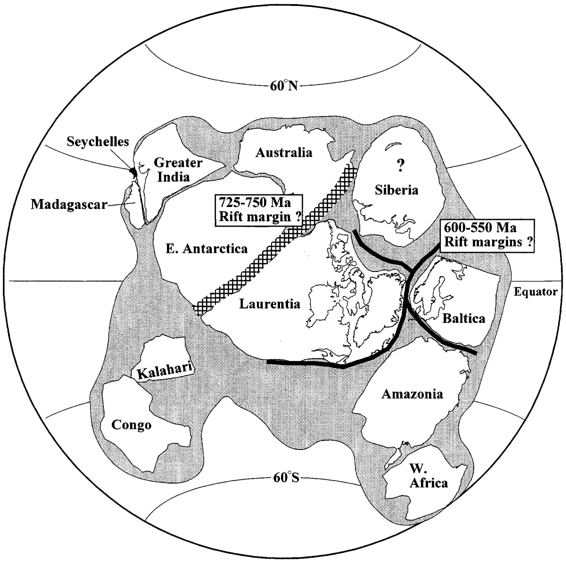

Fig. 8. Rodinia supercontinent reconstruction at ca. 750 Ma (similar to that of Torsvik et al., 1996) with the Seychelles added. Location of Congo and Kalahari after Weil et al. (1998). We have adopted a mean reconstruction north pole of Lat. = 80.4°N, Long. = 46.7° ($\alpha_{95} = 3.3°$); this is a mean pole for East Gondwana, Baltica and Laurentia palaeomagnetic data (Indian co-ordinates).

type arc, formed on the western margin of East Gondwanaland, above an east-dipping subduction zone.

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