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Neoarchean (ca. 2746–2501 Ma) magmatism: Evidence from east coast dykes of northeastern Southern Granulite Terrain, India

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We report new Sm–Nd whole rock-mineral isochron ages of 2514 ± 13 Ma (MSWD = 0.79) and 2651 ± 95 Ma (MSWD = 7.4) from two east coast dykes (ECD) of Southern Granulite Terrain (SGT), India. The ages from the representative mafic dyke samples correspond to the time of intrusion of ECD into the eastern part of SGT, indicating the presence of an older Archean crust in SGT near the Pondicherry coast. The Sm–Nd ages obtained from the present study, along with geochronological information from Singhbhum Craton, suggest a magmatic linkage between SGT (including southern Dharwar Craton) and Singhbhum Craton during the Neoarchean period. The older ages obtained from the mafic dykes of the present study are comparable with the Sm–Nd ages of older mafic dykes from Nuggihalli green stone belt of Western Dharwar Craton (WDC), Pb–Pb ages of mafic dykes from Singhbhum Craton of India and the U–Pb ages from Pilbara and Kaapvaal cartons. These comparisons unlock a clue to Neoarchean (2.8–2.5 Ga) paleogeographic reconstructions of Pilbara, Kaapvaal, Singhbhum cratons, northern SGT (including southern Dharwar Craton) and also provide an opportunity for wide windows of research to be undertaken considering the dykes from SGT.

Keywords. Sm–Nd geochronology; Neoarchean magmatism; geochemistry; east coast dykes; Southern Granulite Terrain.

1. Introduction

The tectonic evolution of the primordial continental crust can be well understood with the study of the Neoarchean dyke swarms (Hunt *et al.* 1995; French and Heman 2010; Dash *et al.* 2013; Samal *et al.* 2019). An integrated palaeomagnetic and geochronological study of the basaltic dykes is a suitable approach to place constraints on the paleogeographic reconstructions and could establish various models for the breakup and assembly of paleo supercontinents (McFadden 1990, 1998; Butler 1992; Joseph 1994; McElhinny and McFadden 2000; Pradhan *et al.* 2010; Dash *et al.* 2013). Various crustal elements from the Indian subcontinent also contribute a significant role in paleogeographic reconstructions for every

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supercontinent (Rogers and Santosh 2003; Halls *et al.* 2007; Meert *et al.* 2010; Pradhan *et al.* 2010; Meert 2012, 2014; Dash *et al.* 2013; Pivarunas *et al.* 2018).

Southern Granulite Terrain (SGT) positioned to the south of Dharwar Craton (DC) of India is a compilation of crustal segments ranging from Archean to Neoproterozoic ages into which multiple age group of mafic dykes has been intruded (Subramanian and Selvan 2001; Pivarunas *et al.* 2018). An integrated paleomagnetic and geochronological study of dolerite and alkaline dykes from eastern DC placed constraints on the paleopole position for the Proterozoic period (Halls *et al.* 2007; Pradhan *et al.* 2008). Previous studies suggest that the K–Ar ages obtained for the SGT dykes are $\sim$600 Ma younger than the easterly trending Dharwar dykes, though their paleopole positions are comparable (Radhakrishna and Joseph 1996a; Halls *et al.* 2007). Our earlier paleomagnetic and geochronological study (Dash *et al.* 2013) on mafic dykes from Tiruvannamalai region of SGT established a 2.3 Ga pole. It revealed the contiguity of southern Dharwar Craton into northern SGT. The study also reveals northern SGT and southern DC were placed at high latitudinal positions during early paleo-proterozoic. The above study revealed two distinct paleomagnetic poles from east coast dykes (ECD) and Tiruvannamalai dykes (TD) in northeastern SGT. Though the paleomagnetic pole from Tiruvannamalai region (obtained from TD) was well constrained with isotopic ages, there were no proper isotope ages for the ECD pole. A recent study by Pivarunas *et al.* (2018) also confirmed our results. However, it has been emphasized that the dykes intruded nearer to the Pondicherry coast, which reveal a different pole position (Dash *et al.* 2013) need direct dating using modern techniques to avoid any delusions (Pivarunas *et al.* 2018). Earlier studies compare the coastal dykes (ECD) either with the 1100 Ma old Oddanchatram anorthosites outcropped 200 km SW of Kunnam (Venkatesh *et al.* 1987) or it has been grouped with the dykes from the Tiruvannamalai region (Radhakrishna and Joseph 1996a), due to lack of a suitable geochronological age data. The recent study by Pivarunas *et al.* (2018) assigned a tentative younger age of 527 ± 2.6 Ma to the east coast dykes and emphasized the need for direct dating of these dykes. Hence it is essential to find the actual intrusion age of the coastal dykes in northeastern SGT to avoid such delusions. Therefore, this study has been undertaken to upgrade and strengthen the existing geochronological information and understand the crustal evolution in northeastern SGT. The present study reveals Neoarchean (ca. 2.7–2.5 Ga) magmatism on the east coast of India near Pondicherry of SGT.

2. Regional geological framework and study area

2.1 *Madras–Tiruvannamalai region*

The Mettur Shear Zone (MSZ) and Palghat–Cauvery shear zones to the northwest and south, respectively and the Bay of Bengal to the east, define the Madras–Tiruvannamalai (MT) topography in the northern block of SGT. In the MT region, dominant NE–SW trending foliation planes parallel to the MSZ have been observed enormously. In general, this region constitutes charnockites (granulites containing hypersthene), hornblende biotite gneiss, granites and mafic dyke swarms. The charnockites have evolved as a result of peak metamorphism at temperatures nearing to 800°C and pressures of 7–9 kb (Weaver 1980; Condie *et al.* 1982; Raith *et al.* 1982; Manglik 2006; Dash *et al.* 2013). Srivastava and Kanishkan (1977) argued that the Dharwarian granitoid gneisses were the protolith for these granulites.

2.2 *South Indian mafic dykes*

The dykes in the peninsular gneiss are extensively spread over, with cross-cutting dyke swarms outcropping in many localities in southern India (Geological Survey of India 1981; French and Heaman 2010; Dash *et al.* 2013; Khanna and Jaffiri 2021). Such dyke swarms have been traced and reported from Hyderabad, southwest of the Cuddapah basin, surrounding Bangalore region, and in the northwest sector of the Dharwar Craton; nevertheless, such manifestations of dyke swarms are rare within the SGT (Geological Survey of India 1981; French and Heaman 2010). The presence of basaltic dykes is more common in northern Tamil Nadu than in the southern territory of the state (Subramanian and Selvan 2001). In the northern section, four episodes of dyke intrusions have been identified, where meta-norites represent the earliest phase. The phase-II dykes are characterized by meta-dolerite, which generally trends in WNW–ESE directions. The phase-III dykes are dark in colour and characterized by clouded feldspars. The phase-IV of dyke swarms comprises fresh and younger dolerites that have emplaced in N–S and E–W directions and have been extended up to the boundary of Cuddapah basin in Andhra Pradesh (Subramanian and Selvan 2001).

The dykes from southern India have been classified into three types: (i) Metamorphosed but undeformed meta-dolerite and meta-norite dykes, (ii) un-metamorphosed dolerite dykes and (iii) alkaline dykes (Ikramuddin 1968; Ikramuddin and Stueber 1976; Halls *et al.* 2007; Kumar *et al.* 2012). The U–Pb ages of mafic dykes are classified into three age groups: (a) 2369–2365 Ma, (b) 2221–2209 Ma, and (c) 2181–2177 Ma (French and Heaman 2010), whereas alkaline dykes are significantly younger and ranges between 1192 and 1027 Ma (Pradhan *et al.* 2008, 2010). The mafic dyke intrusion events within the eastern Dharwar Craton span over 200 million years (2369–2177 Ma), reflecting several episodes of mafic magmatism and are analogous to the dyking pattern reported for Scotland's Paleoproterozoic Scourie dyke swarm (Heaman and Tarney 1989; French and Heaman 2010; Dash *et al.* 2013).

The compositions of the dykes from the DC and the SGT range from picrites to basaltic andesite and tholeiitic, with a distinct negative Nb anomaly (Murthy *et al.* 1987; Rao *et al.* 1990; Radhakrishna *et al.* 1991; Radhakrishna and Joseph 1998; Halls *et al.* 2007; Radhakrishna 2009; French and Heaman 2010). Dharwar dykes have a lower silica content than dykes found in high-grade SGT (Radhakrishna and Joseph 1998; French and Heaman 2010). Petrographic studies of SGT dykes have revealed clouding of plagioclase feldspar, which is associated with CO_2 metasomatism during carbonatite and syenite intrusions along shear zones (Radhakrishna and Joseph 1996a; Halls *et al.* 2007; Dash *et al.* 2013). The existing geochemical data for Tamil Nadu dykes indicate that they are quartz normative tholeiites with SiO_2 ranging between 49 and 54.5% (Venkatesh *et al.* 1987).

The dykes from SGT's western MT terrain are large and massive, with a primary NW–SE trend and a secondary NE–SW trend (Dash *et al.* 2013). They have a homogeneous composition and are thought to be formed as a result of one magmatic event along conjugate sets of ruptures (Radhakrishna and Joseph 1998; Subramanian and Selvan 2001). The NW–SE trending dykes near Tiruvannamalai dominate across an extent of 50–60 km and across a breadth of 20–30 m. The Tiruvannamalai dykes range in length from 5 to 25 km. The dyke rocks are fresh, huge, coarse-grained, and black. Plagioclase, clinopyroxene and opaques are the primary mineral constituents of dolerite dykes; olivine and orthopyroxene constitute the major accessory minerals (Subramanian and Selvan 2001).

Dharmapuri region dolerite dykes are emplaced into older charnockite, which mostly trends in NW–SE direction and occurs in a 50-km wide zone. The dykes are exposed throughout a strike length of roughly 4–5 km, with an average width of 30–50 m. These dykes are coarse-grained, dark, huge and fresh looking. Plagioclase, clinopyroxene, and titano-magnetite are typical mineral assemblages of these dolerite dykes. Olivine, orthopyroxene and quartz are the constituents of accessory mineral components. There are three types of dolerite dykes that occur in this region: quartz normative, sub-alkalic and Fe-rich tholeiites. The Dharmapuri dykes are dated at 1800 Ma by the K–Ar method (Radhakrishna and Joseph 1996a). The Dharmapuri and Tiruvannamalai dykes are thought to have formed during two separate episodes of magmatic activity during the Proterozoic (Subramanian and Selvan 2001). However, the geochemical properties of the dykes in both the regions are comparable. They are all Fe-rich tholeiites with low abundances of Mg# (60), Cr (300 ppm), and Ni (150 ppm). The dyke rocks are low in Nb and Ta but high in Li and light rare earth elements (LREE). Due to the above geochemical properties, it is proposed that the dyke material came from the continental lithospheric mantle (Subramanian and Selvan 2001).

The dykes intruded near Kunnam and Alattur, which are close to the Pondicherry coast, with primary NW–SE, NNE–SSW, and subordinate E–W trends have been traced. The coastline dykes are fresh, enormous, and black. While compared to the Tiruvannamalai dykes, the dykes of this region can be traced across a shorter strike length (5–10 km). The dykes' overall geochemical data show that they are quartz normative tholeiites with SiO_2 ranging from 51.5 to 54.5% (Venkatesh *et al.* 1987). Though the geochemical properties of the east coast dykes (near Pondicherry) are comparable to those of Tiruvannamalai, a distinct pole position for the Kunnam dykes (near Pondicherry coast) with a weak age constraint has been observed (Venkatesh *et al.* 1987). Dash *et al.* (2013) reported a different pole position for east coast dykes.

3. Field studies and petrography

For the current investigations, representative samples were chosen from five mafic dykes outcropping near Kunnam, Marakanam, and Alattur, neighbouring the east coast in the MT terrain (figure 1). The sampled dyke width ranges between 20 and 60 meters, with sharp chilled margins preserved in some places (figure 2) and grain size coarsening towards the middle of the dyke. Except for a few sampling sites where sampling was done from *in situ* surface exposures, mostly fresh and oriented dyke samples were gathered utilizing a portable rock driller from deep active rock quarries. The dyke samples contain medium to coarse-grained pyroxene, plagioclase, and opaque minerals and retain their original igneous texture. Plagioclase and pyroxene laths often have ophitic to sub-ophitic textures with uniformly dispersed subhedral to anhedral grains of opaque minerals (figure 2). Some of the dyke samples have myrmekitic/skeletal exsolution microstructure of quartz and feldspar (figure 2). All of the dyke samples have brownish clouding of plagioclase feldspar. Magnetite is the most common opaque mineral (with uncommon ilmenite), while sulphides are present in trace amounts.

4. Methodology

Based on the photomicrograph study, unaltered and unweathered dyke samples were chosen towards additional mineral picking and isotopic analysis. After mineral separation, 70–90 mg of the cleanest minerals were taken for isotope studies. HF, HNO_3 and HCl acids were used in a 7-ml savilex vial for the digestion of mineral samples through open acid digestion technique till obtaining clear mineral solutions. Then, the digested mineral solutions were dried up using an electric hot plate till the mineral residue was left on the vial, and the residue was dissolved using 5 ml of 2N HCl. Isotope dilution (ID) technique was followed to determine the elemental concentration of Rb, Sr, Sm and Nd using one-third of the spiked rock solutions enhanced with ^{87}Rb, ^{84}Sr, ^{152}Sm and ^{150}Nd. To determine the isotopic composition (IC) of Sr and Nd, the remaining two thirds of the rock solutions were utilized. Homogeneous and thoroughly mixed spiked solutions were obtained by heating the portion of the ID solution up to 90°C and allowed to dry. Similarly, the dried residue of the sample was obtained from the IC portion by heating the IC solutions in the electric hot plate. Column chromatography procedures were followed; the residual IC and ID samples dissolved in 2 ml of 2N HCl were passed through Bio-Rad AG50-WX8 (200–400 mesh) cation-exchange resin-filled HCl columns. During this column chromatography, 2N HCl was used to separate the Rb and Sr; while HDEHP coated Teflon® resin at 0.4N and 0.3N HCl were used to isolate the Sm and Nd, respectively. Prior to each batch of column chromatography procedure for REE separation, the HDEHP columns were equilibrated using 0.18N calibrated HCl. A complete procedure for isotopic analysis including sample digestion technique and elemental separation of Rb, Sr, Sm and Nd has been elaborated in Anand and Balakrishnan (2010).

1N HCl was used to dissolve and pick the Rb sample and was loaded on the oxidized single Ta filament. Then 1 μl of TaO activator was added on top of the fully dried sample filament and the filament was glowed up to 10 s to fuse the Rb with the Ta filament. Similarly, 1N HNO_3 was used to pick the Sr sample and then was loaded on the pre-warmed W filament coated with 0.5 μl of TaO and then was glowed till red hot for about 15 s to fuse the Sr sample with the W filament. 1N HNO_3 was used to pick the Nd and Sm samples and were loaded on the pre-warmed Re double filaments. With this procedure, Rb, Sr, Sm and Nd samples loaded on the respective filaments are ready to be loaded on the turret of the Thermal Ionization Mass Spectrometer (TIMS) for isotopic analysis.

Internal normalizing ratios of $^{86}Sr/^{88}Sr = 0.1194$ and $^{146}Nd/^{144}Nd = 0.7219$ were used for the mass bias corrections of Sr and Nd isotopic compositions, respectively. Several isotopic standards: SRM-987 and AMES (for Sr and Nd, respectively), have been measured throughout the analysis to determine the external correction factors to be used for the mass fractionation corrections for the spiked fractions external fractionation correction of –0.0033, 0.00040, 0.00247 and 0.00039 per amu for ID of Rb, Sr, Sm and Nd has been applied respectively. The average value for the $^{87}Sr/^{86}Sr$ ratio obtained from repeated analysis of SRM-987 throughout the sample analyses is 0.710263 ± 12.9 (2σ and $n = 32$) and the average $^{143}Nd/^{144}Nd$ ratio measured from repeated AMES is 0.511971 ± 9.8 (2σ and $n = 33$) [recommended values: SRM-987 $^{87}Sr/^{86}Sr = 0.710244$ and AMES $^{143}Nd/^{144}Nd = 0.511968 \pm 4$ (Govindaraju 1994)]. The published middling values of SRM-987 from other laboratories are $^{87}Sr/^{86}Sr = 0.710184 \pm 17$ at NGRI, Hyderabad (Dalai *et al.* 2003), 0.71034 ± 4 at Nanjing University (Wu *et al.* 2009) and 0.71022 ± 2 at US Geological Survey at Menlo Park, CA, USA (Smith *et al.* 2009). The outcome values of

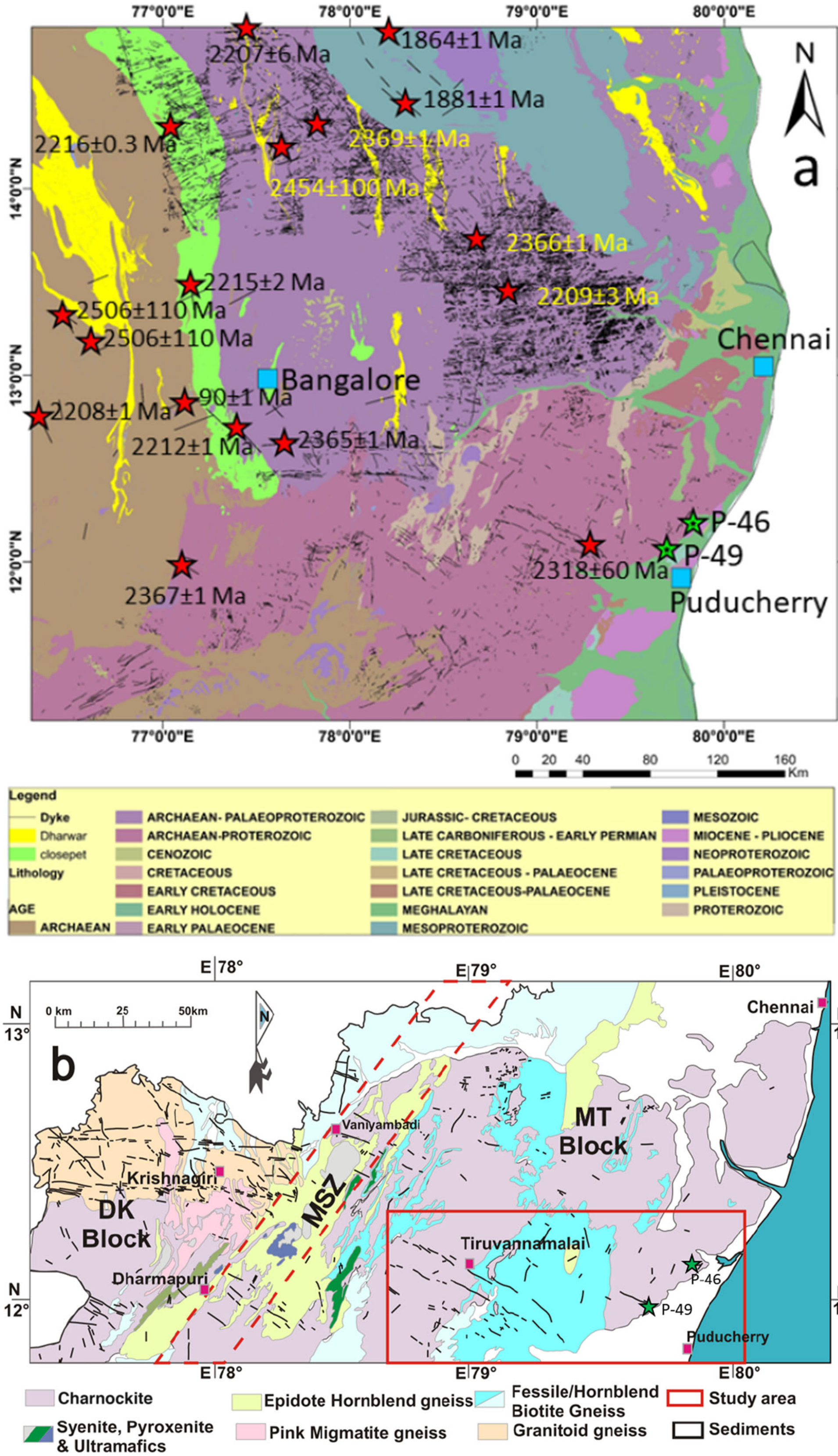

Figure 1. **(a)** Regional geological map of South India (part) with location and reported geological ages of the dykes surrounding the study area (modified from Geological Survey of India 1981; French and Heaman 2010; Dash *et al.* 2013; Khanna and Jaffiri 2021) and **(b)** detailed geological map of the study area showing the sampling site of east coast dykes (ECD) in Madras–Tiruvannamalai (MT) block (modified after Dash *et al.* 2013).

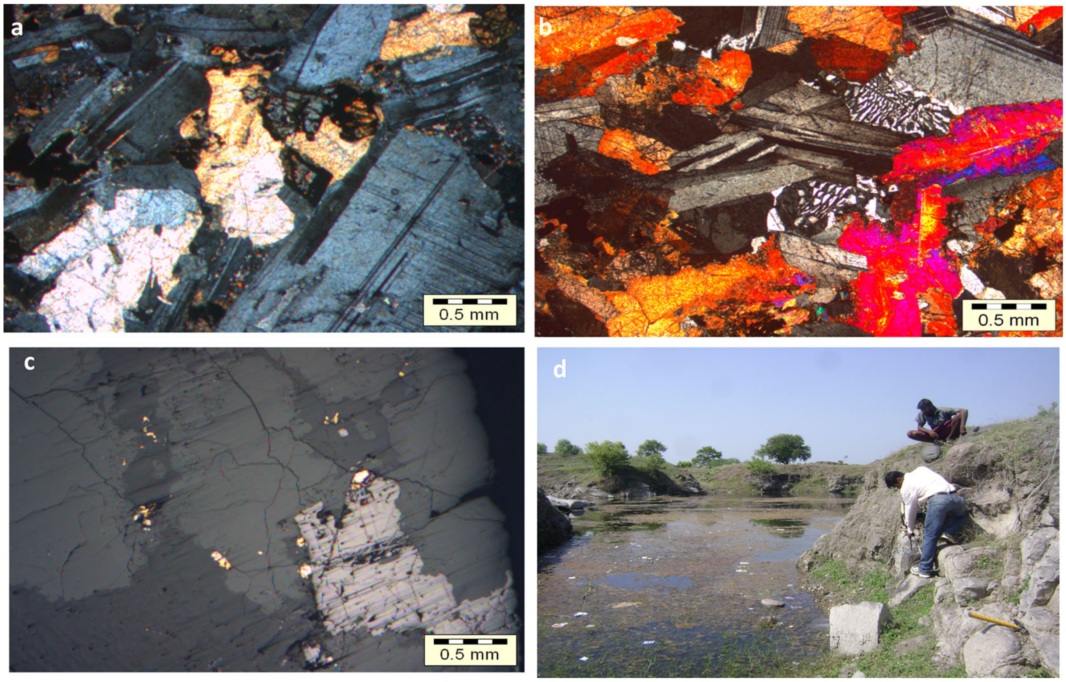

Figure 2. **(a)** Laths of plagioclase and pyroxene phenocrysts are observed in east coast dykes, **(b)** intergrowth of quartz and feldspar shows myrmekitic/skeletal exsolution texture, **(c)** magnetite along with ilmenite tint observed in the coastal dyke, and **(d)** sampling at east coast dyke near a chilled margin (dyke quarry filled with water).

Table 1. *Rb–Sr isotopic results of the eastwest trending dyke (P-46) traced nearer to the Pondicherry coast. The error (2σ) of 0.5% and 0.03% has been given for the $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$, respectively all through the computation of the isotopic age.*

Minerals/samples	Rb (μg/g)	Sr (μg/g)	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr	2σ (10^{-6})
Mgt	23.7	97.3	0.7054	0.723087	±8.4
WR	6.7	56.0	0.3489	0.714504	±10.4
Mgt_L	1.0	1.6	1.7934	0.750024	±6.7
PX_0.5	0.7	4.7	0.4417	0.71414	±6.1
Plag	28.9	59.4	1.4133	0.757461	±9.4
Px_0.3	2.5	18.6	0.3966	0.71473	±2.7

Rb–Sr data (table 1) and Sm–Nd data (table 2) and isotopic analysis on various minerals and whole-rocks were presented. The isotope evolution diagrams have been reflected in figures 3 and 4. The Rb–Sr evolution diagram has been plotted by using the uncorrected values of Sr–IC.

The geochemical analysis of the major, trace and rare earth element (REE) were determined (presented in table 3) from the prepared 'B-solution' by the help of flame photometer (for Na_2O, K_2O) and Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) facility available at the Department of Earth Sciences, Pondicherry University. The REE was pre-concentrated through HNO_3 and HCl column procedure and analyzed in ICP-AES. The analytical errors are within ±5% for major elements and ±10% for trace elements as judged from the reported values of rock standards. For the Sm–Nd and Rb–Sr isotopic analysis, Thermal Ionization Mass Spectrometer (TIMS, Thermo-Finnigan, Triton-model) facilities available at the Department of Earth Sciences, Pondicherry University have been utilized. The routine blank value of the laboratory, throughout the progression of the dyke sample analysis, associated with Sm and Nd are 0.000084 and 0.0004831 ng, respectively, whereas those blank values associated with Rb and Sr are 0.002466 and 0.010846 ng, respectively.

5. Results

5.1 *Geochemistry*

The samples analyzed during the present study show basaltic composition of 0.19–23.05% of

Table 2. *Sm–Nd isotopic results for the two dykes (P-46 and P-49) traced nearer to the Pondicherry coast. The error (2σ) of 0.01% has been allocated for the $^{147}Sm/^{144}Nd$ throughout the computation of age.*

Samples/minerals	Sm (μg/g)	Nd (μg/g)	^{147}Sm/^{144}Nd	^{143}Nd/^{144}Nd	2σ (10^{-6})
P-46					
Plag	0.999	5.10	0.10361	0.511451	±3
WR	0.597	2.39	0.13230	0.511929	±4
Mgt*R	0.052	0.23	0.12053	0.511736	±13
PX_0.5	0.177	0.50	0.18813	0.512851	±7
PX_0.15	0.956	3.58	0.14132	0.512049	±6
P-49					
Plag	0.456	2.23	0.10809	0.511516	±9
WR	0.729	2.91	0.13257	0.511955	±4
Px_0.5	0.193	0.53	0.19226	0.512987	±8
Px_0.4	0.368	1.17	0.16631	0.512548	±5

normative quartz and 3.57–48.18% of normative hypersthene. The normative magnetite varies from 3.52 to 7.35%, whereas ilmenite is from 0.76 to 4.77%. The conventional AFM plots of the analysis group the dykes as high Fe–Mg tholeiites (figure 5). In TAS diagram, the samples are grouped within the field for basaltic rock with Fe_2O_3/FeO ratio of about 0.3 (figure 5). The Harker plot for the major element against the MgO indicates a decreasing trend for SiO_2, K_2O, MnO, and FeOt, and an increasing trend for Al_2O_3 and Na_2O. From the present geochemical study, it has been observed that the increase in Y, K_2O and P_2O_5 with increasing Zr reflects the incompatible behaviour of these elements during fractional crystallization (figure 5).

5.2 *Geochronology*

The isotope evolution diagrams for Rb–Sr and Sm–Nd isotopic studies carried out for different mineral fractions and whole-rocks were plotted for two coastal dykes (P-46 and P-49) that have been intruded and outcropped near Pondicherry region along the east coast of India. The Rb–Sr isotope evolution diagram, which defines a co-linear array for the magnetite, leached magnetite and whole-rock representing the dyke P-46 (figure 3a), yielded an isotopic age of 1712 ± 18 Ma (MSWD = 1.5). The Rb is recognized to have been mobilized even by low-temperature thermal events (Jäger *et al.* 1967; Faure 1986; Rollinson 1993); therefore, this age perhaps corresponds to the time of low-temperature metamorphism. The Rb–Sr data on mineral fractions and whole-rock for the other dyke sample (P-49) yielded an errorchron and could not be used.

The Sm–Nd isotope evolution diagram (figure 3b) define a co-linear array with the pyroxenes, plagioclase, magnetite and whole rock for the dyke (P-46, E–W trending) whose slope yielded an age of 2514 ± 13 Ma (MSWD = 0.79). Similarly, for another east coast dyke (P-49, NW–SE trending); plagioclase, whole-rock, and two pyroxene fractions define a collinear array in the Sm–Nd isotope evolution plot (figure 4) whose slope yielded an age of 2651 ± 95 Ma (MSWD = 7.4). The different geological ages obtained for east coast dykes having dissimilar trends (P-46: E–W trending from Alattur region and P-49: NW–SE trending from Kunnam region) and are geographically separated by 30 km.

Photomicrographic study reveals that, the minerals that define the Sm–Nd isochrons preserves original igneous textures. Therefore, the relatively older age of 2651 ± 95 Ma obtained for the dyke (P-49) from Kunnam region could represent the time of emplacement of the NW–SE trending dykes. However, the 2514 ± 13 Ma Sm–Nd isochron age obtained from the E–W trending ECD dyke (P-46) near Alattur, represents later magmatic intrusion which might have disturbed the Rb–Sr system of the older Kunnam (P-49) dyke, near Pondicherry coast.

6. Discussions

The distinct geochronological results of the present study, obtained from two dykes near the east coast of India (Kunnam and Alattur), close to Pondicherry, were discussed along with the reported geochronological data, mostly on mafic to ultramafic dykes and Archean crustal domain

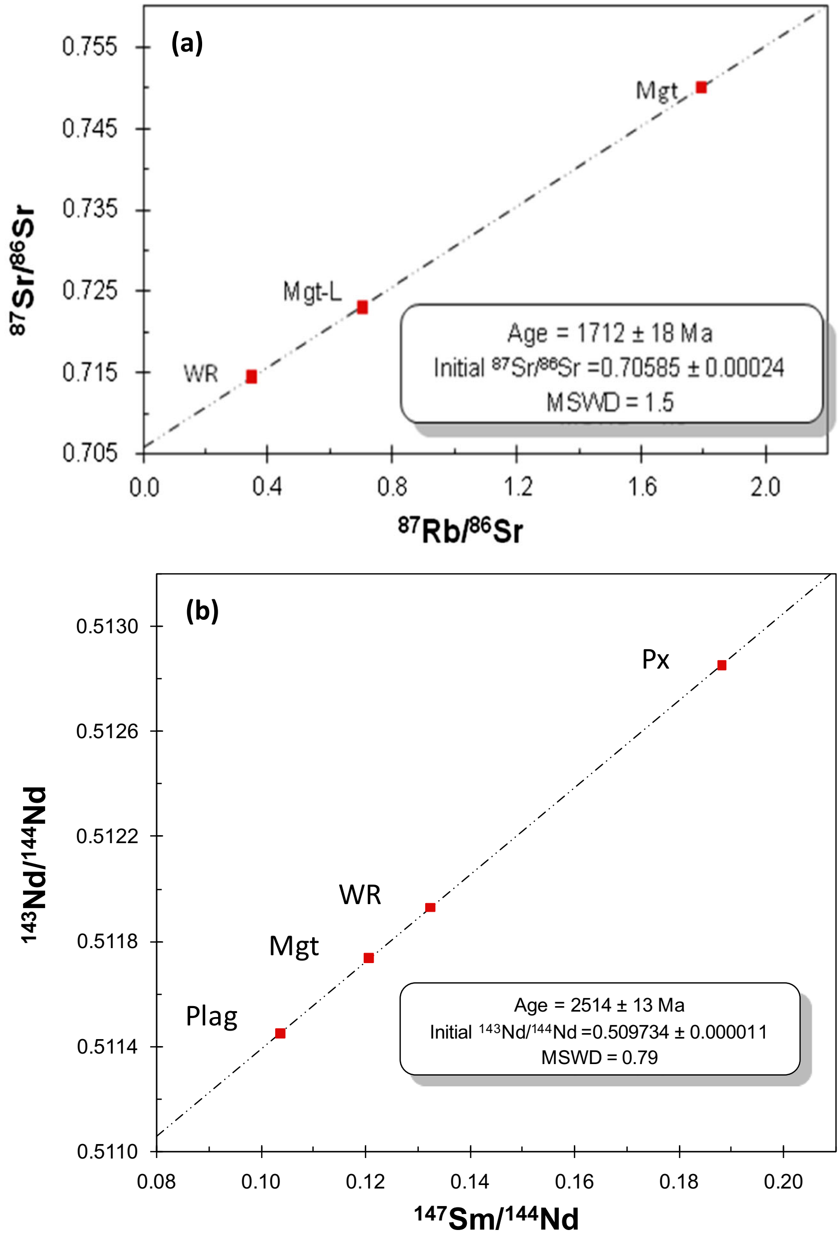

Figure 3. Rb–Sr and Sm–Nd mineral–whole rock evolution diagram for one of the E–W trending dykes (P-46) occurring close to the east coast, near Alattur, from M–T block of the northeastern part of the SGT. **(a)** Represents the Rb–Sr evolution diagram for leached magnetite–whole rock–magnetite. **(b)** Sm–Nd evolution diagram for pyroxene–plagioclase–whole rock–magnetite. The error (2σ) of 0.5% and 0.03% has been assigned for the ^{87}Rb/^{86}Sr and ^{87}Sr/^{86}Sr, respectively, during the calculation of isotopic age, while an error (2σ) value of 0.01% has been considered for ^{147}Sm/^{144}Nd, whereas the absolute error has been considered for ^{143}Nd/^{144}Nd during the calculation of age.

(presented in table 4) from Indian sub-continent (SGT, Dharwar and Singhbhum cratons) and compared with Pilbara and Kaapvaal cratons due to its similar Archean geology (as the older geochronological ages from these two cratons are comparable with the ages of the dykes from Indian craton) and its similar paleopole positions (Nelson *et al.* 2014; Hofmann *et al.* 2016; Kumar *et al.* 2017) for the proposed paleogeographic reconstructions and its linkage with Large Igneous Province events.

6.1 *Southern India (including SGT and Dharwar Craton)*

6.1.1 *Reported isotope ages from crustal domain of Southern India*

Southern India, to the south of Dharwar Craton preserves the prolonged history of the earth in ca. 3400–500 Ma (Talukdar 2022). Older and younger rocks of various ages from several crustal domains have been reported from SGT. Recent studies

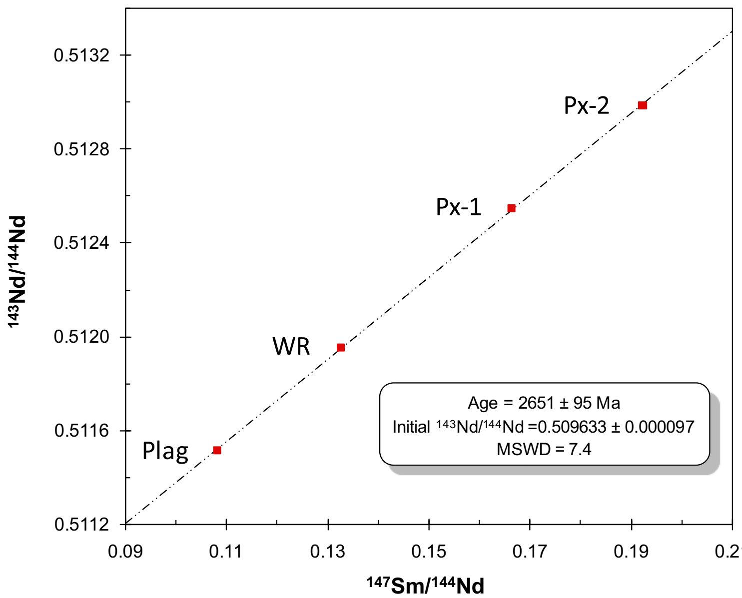

Figure 4. Sm–Nd mineral–whole rock evolution diagram for the NW–SE trending dyke (P-49) occurring near Kunnam, close to the east coast from M–T block of the northeastern part of the SGT. The evolution diagram has been plotted for two pyroxenes–plagioclase–whole rock. An error (2σ) value of 0.01% has been considered for $^{147}Sm/^{144}Nd$, whereas the absolute error has been considered for $^{143}Nd/^{144}Nd$ during the calculation of age.

reveal, Mesoarchean ages from Mercara Shear Zone (MSHZ-between the Coorg block and the Dharwar Craton of southern India) and have been dated at ∼3100–2400 Ma (Basak *et al.* 2023). Older rocks of various ages have been reported from several rock types of Mercara Shear Zone (MSHZ). Isotope ages of 3229 ± 80, 3168 ± 25 and 3181 ± 20 Ma have been reported from metagabbro, charnockite and mafic granulite, respectively (Amaldev *et al.* 2016). Pb–Pb zircon ages ranging from 3248 ± 28 to 3506 ± 26 Ma have been reported from the metapelites of MSHZ (Amaldev *et al.* 2016). Zircon ages of 3335 ± 44, 3135 ± 14, 3145 ± 17 to 3292 ± 57 Ma and 3153 ± 15 to 3252 ± 36 Ma have been reported from khondalite, garnet biotite gneiss, quartz mica schist and TTG gneiss rocks from MSHZ of southern India (Amaldev *et al.* 2016). Relatively younger ages of 829 ± 3.7 and 831 ± 4.7 Ma have also been reported from alkaline rocks of MSHZ (Amaldev *et al.* 2016). Quartz-monzonite rocks from Madurai block of SGT has been reported to be emplaced at 2498 ± 16 Ma, carbonatite at 2470 ± 15 Ma and syenite rocks were emplaced at 608 ± 6 Ma (Renjith *et al.* 2016). Sm–Nd whole-rock age of 2898 ± 52 Ma (Bhaskar Rao *et al.* 1996) has been reported from Metabasites of Bhavani Layered Intrusion of Bhavani Shear Zone. U–Pb ages of ca. 2800 Ma from biotite gneiss; 2547 ± 17 Ma from metagabbro and 2547 ± 7 Ma from trondhjemite rocks from Bhavani Shear Zone have been reported by Santosh *et al.* (2013). U–Pb ages of 3034 ± 170 Ma (Ghosh *et al.* 2004) from mafic granulite of Namakkal block, Sm–Nd whole rock and mineral (Grt–Hbl–Pl) ages of 2935 ± 60 Ma (Bhaskar Rao *et al.* 1996) from Metabasite of Sittampundi Layered Complex has been reported from Southern India. U–Pb ages of 2545 ± 56 and 2528 ± 61 Ma from Trondhjemite rocks of Devanur Ophiolite Complex have been obtained by Yellappa *et al.* (2012). Lu–Hf whole rock and garnet ages of 2536 ± 300 Ma from Metabasites of Kanjamalai Mafic Complex has been reported by Noack *et al.* (2013).

6.1.2 *Reported isotope ages from dykes of southern India*

The dykes of Tiruvannamalai region (Tamil Nadu) were earlier studied by Radhakrishna and Joseph (1996a). In their study, the K–Ar method of dating assigned an age of ∼1650 Ma to the Tiruvannamalai group of dykes (dykes outcropped around Tiruvannamalai), whereas an age of 1800 Ma was assigned to the Dharmapuri group of dykes (dykes outcropped around Dharmapuri). However, geographically, these two regions are separated by 60 km only. Later studies highlighted the need for the revision of the older K–Ar ages of such dykes with some suitable and robust techniques (Halls *et al.* 2007;

Table 3. *Bulk-rock major element oxides (wt%), trace element concentrations (ppm) and REE of the mafic dykes near Pondicherry coast, SGT, India.*

Sample name	P-49	P-51	P-05	P-57	P-38	P-58	P-59-1	P-59-2	P-44
SiO_2	54.2	52.0	54.2	52.4	55.5	57.6	57.3	56.8	59.7
TiO_2	0.58	1.15	2.07	1.74	1.06	1.01	1.10	1.09	1.40
Al_2O_3	18.3	18.5	15.7	17.4	16.9	16.5	15.8	16.2	13.7
Fe_2O_3	1.72	2.42	2.98	2.57	2.24	2.23	2.26	2.33	2.67
FeO	5.73	8.06	9.93	8.57	7.47	7.43	7.53	7.75	8.90
MnO	0.10	0.15	0.20	0.15	0.13	0.13	0.13	0.14	0.17
MgO	10.36	8.73	6.46	7.53	7.67	7.87	7.78	7.34	3.40
CaO	5.83	5.51	4.12	4.94	4.89	5.08	4.92	4.95	8.32
Na_2O	1.78	2.53	1.50	2.34	2.25	2.34	2.25	2.34	1.50
K_2O	0.39	0.61	0.97	0.62	0.53	0.53	0.55	0.59	0.97
P_2O_5	0.25	0.51	0.91	0.78	0.52	0.15	0.49	0.51	0.21
Mg#	64.7	52.3	39.7	47.1	51.0	51.8	51.1	49.0	27.9
Rb	16	29	–	23	32	32	28	26	–
Ba	138.8	202.7	660.5	342.3	210.9	207.6	214.6	223.4	337.9
Sr	138.1	134.3	377.9	261.5	130.6	133.7	134.0	157.4	155.2
Th	–	–	–	–	–	–	–	–	1.2
Nb	–	–	–	–	–	–	–	–	13.7
Cu	77.8		254.9	82.1	130.3	127.2	126.7	136.4	120.3
Cr	–	–	–	–	–	–	–	–	51.1
Ni	182.6	140.4	122.4	121.1	124.7	109.3	101.6	110.7	58.6
Pb	15.8	14.6	13.7	15.6	14.8	15.0	15.0	15.0	35.2
Zn	63.7	68.7	126.6	106.9	87.4	100.7	105.8	94.6	91.3
Co	34.4		54.9	46.7	41.3	38.4	38.2	40.5	35.0
Zr	61.1	93.4	183.0	122.2	105.3	102.0	101.5	105.9	127.7
Sc	6.4	14.1	28.9	19.5	14.5	13.8	14.4	15.1	322.3
V	231.5	332.1	291.9	325.9	321.9	312.3	318.5	315.5	369.3
Y	14.6	26.7	43.9	29.3	27.6	26.8	26.9	28.5	33.4
La	6.28	8.81	21.48	17.39	9.76	9.27	8.66	10.59	13.68
Ce	12.37	18.27	44.51	38.23	20.23	19.41	18.61	22.13	28.65
Nd	6.76	10.64	24.20	22.07	11.21	11.01	10.70	12.95	15.08
Sm	1.72	2.58	5.71	5.05	2.83	2.85	2.80	3.40	3.01
Eu	0.75	1.14	2.07	1.88	1.17	1.17	1.12	1.29	1.17
Gd	2.08	3.57	7.61	5.99	4.05	3.86	3.78	4.43	4.27
Dy	2.45	4.22	7.84	5.34	4.50	4.42	4.18	4.99	4.79
Er	3.14	2.89	4.95	3.29	3.07	3.02	2.88	3.41	3.24
Yb	1.81	2.78	4.58	2.88	3.08	2.94	2.86	3.40	3.13
Lu	0.32	0.46	0.72	0.45	0.51	0.51	0.46	0.55	0.55

Radhakrishna 2009). The easterly trending diabasic dykes of Dharwar Craton were dated at 2367 ± 1 Ma. This U–Pb baddeleyite age represents the time of intrusion of these dykes (Halls *et al.* 2007). Comparing the palaeomagnetic data with the age data, Halls *et al.* (2007) have linked the 2367 Ma Dharwar dykes with the Tiruvannamalai dykes as well as with the 2418 Ma old western Australian dykes from the Yilgarn Craton. In their study, it was also indicated that the 2418 Ma Australian dyke was part of the giant radiating Dharwar dyke swarms and was suggested an active magmatic event of 50 My between 2418 and 2367 Ma.

A dyke with NW–SE strike direction from the Tiruvannamalai region (of SGT) has been dated at 2318 ± 60 Ma (Sm–Nd method) and the pole position for the dyke is similar to the easterly trending Dharwar dykes (Dash *et al.* 2013). This integrated study also emphasizes the contiguity of MT block with the Dharwar Craton at 2.3 Ga. An N–S trending dyke yields an Sm–Nd age of 2477 ± 37 Ma and has been reported from the Gingee area of northern SGT (Dash 2012). Fresh diabasic dyke of 2454 ± 100 Ma (Sm–Nd age) has also been reported from Eastern Dharwar Craton (EDC) in the Ramagiri schist belt (Zachariah *et al.* 1995). A recent study by Khanna and Jaffiri (2021) dated

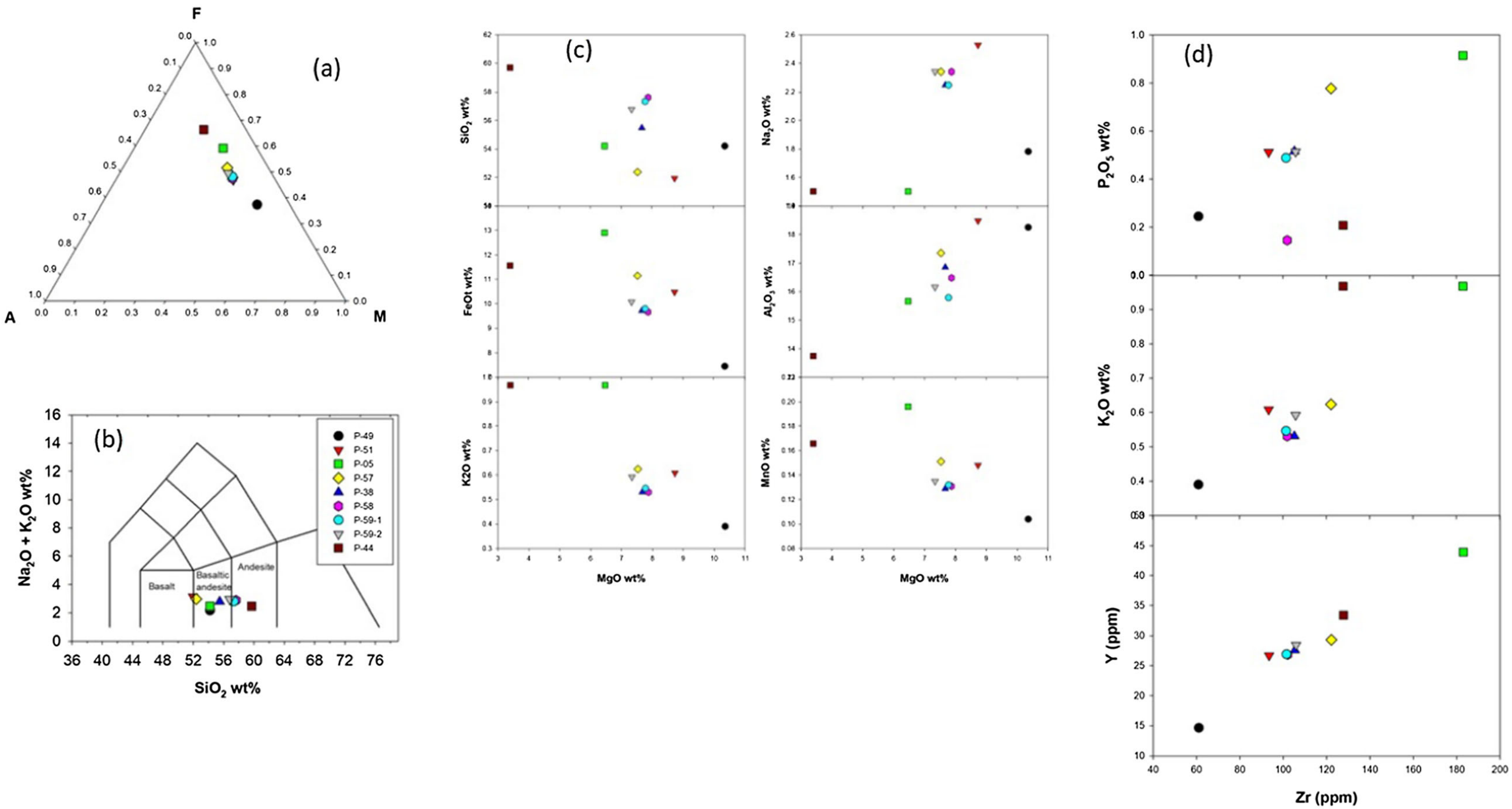

Figure 5. The figure showing the **(a)** AFM diagram, **(b)** TAS diagram, **(c)** Harker's plot for MgO and **(d)** Harker's plot for Zr from representing samples of east coast dykes near Pondicherry coast, SGT.

Table 4. *A compilation of Neoarchean to early Proterozoic Geochronological information of dykes and crustal rocks from Southern India and Singhbhum Craton.*

Location	Dyke/rock types	Emplacement ages	Dating method	Reference
Southern India				
Thiruvannamalai	Dykes	∼1650 Ma	K–Ar	Radhakrishna and Joseph (1996a)
Dharmapuri	Dykes	1800 Ma	K–Ar	Radhakrishna and Joseph (1996a)
Thiruvannamalai	Basaltic dykes	2318 ± 60 Ma	Sm–Nd whole rock mineral	Dash *et al.* (2013)
Dharwar Craton	Diabasic dykes	2367 ± 1 Ma	U–Pb baddeleyite	Halls *et al.* (2007)
Dharwar Craton	Dykes	2454 ± 100 Ma	Sm–Nd mineral-whole	Zachariah *et al.* (1995)
Harohalli	Dykes	2365.4 ± 1 Ma	U–Pb baddeleyite	French and Heaman (2010)
Karimnagar	Dykes	2368 ± 2.6 Ma	U–Pb baddeleyite	Kumar *et al.* (2012)
Bhabani Shear Zone	Metabasites	2898 ± 52 Ma	Sm–Nd whole rock	Bhaskar Rao *et al.* (1996)
Bhabani Shear Zone	Metagabbro	2547 ± 17 Ma	U–Pb	Santosh *et al.* (2013)
Bhabani Shear Zone	Trondhjemite rocks	2547 ± 7 Ma	U–Pb	Santosh *et al.* (2013)
Bhabani Shear Zone	Biotite gneiss	ca. 2800 Ma	U–Pb	Santosh *et al.* (2013)
Namakkal block	Mafic granulite	3034 ± 170 Ma	U–Pb	Ghosh *et al.* (2004)
Sittampundi Layered Complex	Metabasite	2935 ± 60 Ma	Sm–Nd whole rock and mineral (Grt–Hbl–Pl)	Bhaskar Rao *et al.* (1996)
Devanur Ophiolite Complex	Trondhjemite rocks	2545 ± 56 Ma	U–Pb	Yellappa *et al.* (2012)
Devanur Ophiolite Complex	Trondhjemite rocks	2528 ± 61 Ma	U–Pb	Yellappa *et al.* (2012)
Kanjamalai Mafic Complex	Metabasites	2536 ± 300 Ma	Lu–Hf whole rock and garnet	Noack *et al.* (2013)
Madurai block	Charnockites	2689 ± 26 Ma	U–Pb	Plavsa *et al.* (2012)
Madurai block	Charnockites	2521 ± 13 Ma	U–Pb	Plavsa *et al.* (2012)
Eastern Salem block	Charnockites, granitoids & migmatites	∼2.75–2.65 Ga	U–Pb & Lu–Hf	Glorie *et al.* (2014)
Western Nilgiri block, SGT	TTG gneisses	2521 ± 13 Ma and 2522 ± 17 Ma	Pb–Pb mean ages	Yang *et al.* (2015)
Western Nilgiri block, SGT	Amphibolites	2590 ± 13 Ma and 2470 ± 17 Ma	Pb–Pb mean ages	Yang *et al.* (2015)
Western Nilgiri block, SGT	Charnockites	2601 ± 25 Ma	Pb–Pb mean ages	Yang *et al.* (2015)
Western Nilgiri block, SGT	Banded iron formation	2493 ± 17 Ma	Pb–Pb	Yang *et al.* (2015)
Madurai block, SGT	Shoshonitic syenite	2533 ± 16 Ma	U–Pb zircon	Renjith *et al.* (2016)
Madurai block, SGT	Quartz monzonite	2498 ± 16 Ma	U–Pb zircon	Renjith *et al.* (2016)
Madurai block, SGT	Carbonatite	2470 ± 15 Ma	U–Pb zircon	Renjith *et al.* (2016)
Nuggihalli green stone belt, WDC	Mafic dykes	2506 ± 110 Ma	Sm–Nd whole rock	Khanna and Jaffiri (2021)
Mercara Shear Zone, South India	Metagabbro	3229 ± 80 Ma	Pb–Pb zircon	Amaldev *et al.* (2016)
Mercara Shear Zone, South India	Charnockite	3168 ± 25 Ma	Pb–Pb zircon	Amaldev *et al.* (2016)
Mercara Shear Zone, South India	Mafic granulite	3181 ± 20 Ma	Pb–Pb zircon	Amaldev *et al.* (2016)
Mercara Shear Zone, South India	Metapellites	3248 ± 28 Ma	Pb–Pb zircon	Amaldev *et al.* (2016)

Table 4. *(Continued.)*

Location	Dyke/rock types	Emplacement ages	Dating method	Reference
Mercara Shear Zone, South India	Metapellites	3506 ± 26 Ma	Pb–Pb zircon	Amaldev *et al.* (2016)
Mercara Shear Zone, South India	Khondalite	3335 ± 44 Ma	Pb–Pb zircon	Amaldev *et al.* (2016)
Mercara Shear Zone, South India	Khondalite	3135 ± 14 Ma	Pb–Pb zircon	Amaldev *et al.* (2016)
Mercara Shear Zone, South India	Garnet biotite gneiss	3145 ± 17 Ma	Pb–Pb zircon	Amaldev *et al.* (2016)
Mercara Shear Zone, South India	Garnet biotite gneiss	3292 ± 57 Ma	Pb–Pb zircon	Amaldev *et al.* (2016)
Mercara Shear Zone, South India	Quartz mica schist	3153 ± 15 Ma	Pb–Pb zircon	Amaldev *et al.* (2016)
Mercara Shear Zone, South India	TTG	3252 ± 36	Pb–Pb zircon	Amaldev *et al.* (2016)
ECD of SGT	Mafic dykes	2514 ± 13 Ma	Sm–Nd bulk rock–mineral	Present study
ECD of SGT	Mafic dykes	2651 ± 95 Ma	Sm–Nd bulk rock–mineral	Present study
Singhbhum Craton				
North Singhbhum Craton	Ultramafic dyke	2613 ± 177 Ma	Rb–Sr whole rock	Roy *et al.* (2004)
Ghatgaon swarm	Mafic dykes	2760–2764 Ma	–	Kumar *et al.* (2017)
Ghatgaon dyke	Dykes	2763.7 ± 0.8 Ma	Pb–Pb baddeleyite	Kumar *et al.* (2017)
Ghatgaon dyke	Dykes	2764.4 ± 0.8 Ma	Pb–Pb baddeleyite	Kumar *et al.* (2017)
Nuapada dyke	Dykes	2763.2 ± 0.9 Ma	Pb–Pb baddeleyite	Kumar *et al.* (2017)
Jhumpura dyke	Dykes	2760 ± 0.6 Ma	Pb–Pb baddeleyite	Kumar *et al.* (2017)
Dumuria dyke	Dykes	2763.5 ± 0.8 Ma	Pb–Pb baddeleyite	Kumar *et al.* (2017)
Khairpal dyke	Dykes	2761 ± 1 Ma	Pb–Pb baddeleyite	Kumar *et al.* (2017)
Keshargaria	Dykes	2800.2 ± 0.7 Ma	Pb–Pb baddeleyite	Kumar *et al.* (2017)

the mafic dykes from Nuggihalli greenstone belt, Western Dharwar Craton (WDC) at 2506 ± 110 Ma by Sm–Nd method. The 2514 ± 13 and 2651 ± 95 Ma old dykes from the ECD of the current study are in good agreement (within error) with that of the 2454 ± 100 Ma old dykes from EDC reported by Zachariah *et al.* (1995) and 2506 ± 110 Ma mafic dykes from WDC reported by Khanna and Jaffiri (2021).

Isotope age of 2365.4 ± 1 Ma (U–Pb method) has been reported for the E–W trending Harohalli dykes (French and Heaman 2010). Similarly, U–Pb baddeleyite age of 2368 ± 2.6 Ma for the ENE–WSW trending dykes from Karimnagar has been reported by Kumar *et al.* (2012). Relatively, younger age of 1027.3 ± 13 Ma (U–Pb zircon age) has been reported for the Anantapur dykes (Pradhan *et al.* 2010). The youngest dyke of 69 ± 1 and 81 ± 2 Ma (^{40}Ar–^{39}Ar method) has been reported for two different doleritic and leucogabbroic dykes, respectively, from the west coast of India near Kerala. These younger magmatic events from the west coast of India have been linked with Deccan volcanism classifications (Radhakrishna *et al.* 1994).

Palaeomagnetic study by Dash *et al.* (2013) reveals a distinct pole position for the east coast dykes (ECD) in comparison to the Tiruvannamalai dykes (TD). Due to the lack of a proper geochronological age for the ECD, these dykes have either been merged with the TD group of dykes (Radhakrishna and Joseph 1996a) or have been compared with the Oddanchatram anorthosites (igneous complex) of ca. 1100 Ma (Venkatesh *et al.* 1987), which is outcropped ∼200 km SW of Kunnam. The latest study, assigned a tentative younger age of 527 ± 2.6 Ma to the ECD group and also emphasized the need for direct dating of these ECD dykes to place a better constraint on the emplacement age of ECD (Pivarunas *et al.* 2018).

The present study reveals two Sm–Nd mineral whole rock ages of 2514 ± 13 Ma and 2651 ± 95 Ma, and was obtained for coastal dykes near Alattur and Kunnam, respectively. A recent study of mafic dykes from Nuggihalli greenstone belt, WDC has been dated at 2506 ± 110 Ma by Sm–Nd whole rock dating method (Khanna and Jaffiri 2021). The 2.5 Ga dykes have been interpreted to be derived from asthenospheric melt. This 2.5 Ga Sm–Nd age from mafic dykes is comparable (within error) with both the Sm–Nd whole rock–mineral isochron ages of 2514 ± 13 and 2651 ± 95 Ma obtained for two ECD of SGT obtained from the present study. From the different isotope ages obtained for the present study, it is inferred that the coastal dykes (ECD) of southern India could have been emplaced at a different time compared to the other dykes from northeastern SGT and Dharwar Craton (including EDC and WDC).

6.2 *Reported isotope ages from Singhbhum dykes*

Geochronological information of ultramafic to mafic dykes from Singhbhum Craton has been discussed here. A NNE–SSW trending dyke (ultramafic) from northern Singhbhum Craton has been dated at 2613 ± 177 Ma (Roy *et al.* 2004). NNE–SSW trending mafic dykes from Singhbhum Craton (Ghatgaon swarm) have been reported with emplacement ages between 2760 and 2764 Ma dated by Pb–Pb method (Kumar *et al.* 2017). The Pb–Pb isotopic system dates the different dykes from Singhbhum Craton at 2763.7 ± 0.8 Ma and 2764.4 ± 0.8 Ma (Ghatgaon dyke), 2763.5 ± 0.8 Ma (Dumuria dyke), 2763.2 ± 0.9 Ma (Nuapada dyke), 2760 ± 0.6 Ma (Jhumpura dyke) and 2761 ± 1 Ma (Khairpal dyke). A NE–SW trending mafic dykes of 2752.0 ± 0.9 Ma have been reported from the Hakai locality of Singhbhum Craton (Kumar *et al.* 2017). The Paleomagnetic directions obtained from SGT and reported by Dash *et al.* (2013) are comparable (within error) with that of the Ghatgaon dyke swarm.

6.3 *East coast dykes (ECD) and Tiruvannamalai dyke (TD)*

The results of the ECD of the present study have been discussed and compared along with the results of TD of Dash *et al.* (2013). The present geochronological study of ECD occurring in the Madras–Tiruvannamalai block of the SGT reveals 2.74–2.5 Ga magmatic events in south India. The Sm–Nd ages of 2318 ± 60 Ma (Dash *et al.* 2013) for TD group of dykes, which is at least 200 my (approx.) younger than that of the ECD. The Sm–Nd isochron age reveals that the coastal dyke (ECD) was intruded between 2514 ± 13 Ma and 2651 ± 95 Ma ago.

The pole position (2.32°S and 188.2°E) reported for ECD is distinct from that of the TD pole, which outcrops ∼40 km west of ECD region (Dash *et al.* 2013). The pole position obtained for the ECD group of dykes and reported by Dash *et al.* (2013) are in good agreement with the pole positions reported earlier and studied from similar geographic locations (Venkatesh *et al.* 1987; Radhakrishna and Joseph 1996a). The distinct pole positions obtained for the basaltic dykes from these two geographical regions which are geographically separated from each other by a few tens of km only. To justify this possibility; either these dykes (ECD and TD) were emplaced at different magmatic episodes or ECD and TD provinces were separated from each other in space and time; and later on, they joined together. However, the field studies and the existing geological maps do not reveal any major tectonic features that could support the hypothesis about separating these two regions. The photomicrograph studies from the dyke samples of TD province show exsolution lamellae of ilmenite within titano-magnetite; however, such signatures are absent for the dykes from the ECD province. These features indicate a different magmatic process, and therefore these two dykes may not be cogenetic. It is likely that the dykes of ECD province might have been emplaced at a markedly different time than that of TD (Dash *et al.* 2013).

In the absence of suitable age data for ECD, these dykes have been linked with the paleomagnetic poles obtained from the anorthosite rocks of Oddanchatram region (Satyanarayana *et al.* 2003) exposed in Dindigul district of Tamil Nadu and also with the paleopole representing the Anantapur alkaline dykes (Pradhan *et al.* 2010). These two studies report the pole positions (9.7°S; 182°E) for the Oddanchatram anorthosite and (10°N: 211°E; 1027 ± 13: U–Pb age) for the Anantapur alkaline dykes, respectively, which are in good agreement with the ChRM and VGP reported for the ECD (Dash *et al.* 2013). Though the palaeomagnetic results (VGP and ChRM) of ECD are comparable with the Anantapur alkaline dykes; their chemical compositions are different. The ECD dykes are reported to be subalkaline and tholeiitic with medium to fine-grained in nature (Venkatesh *et al.* 1987; Radhakrishna and Joseph 1996a; Dash 2012; Dash *et al.* 2013), whereas the Anantapur dykes are tholeiitic to alkaline in composition, fine to coarse-grained and shows ophitic to sub-ophitic or a rare granular texture (Balakrishna *et al.* 1979; Halls 1982; Kumar and Bhalla 1983; Murthy 1987; Murthy *et al.* 1987; Chalapathi Rao *et al.* 2005).

The 1090 ± 20 Ma (Rb–Sr age) Wajrakarur kimberlites have been compared (Kumar *et al.* 1993) with the main pole position obtained for the anorthosite rocks of Oddanchatram region. These anorthosite rocks have also been compared with the Tirupati dykes for which the isotope ages are unconstrained. A later study by Ghosh *et al.* (2004) reports a Pan-African (563 ± 9 Ma, U–Pb Zircon age) regional igneous and metamorphic events for the Oddanchatram anorthosite. Probably this age might represent the crystallization of zircon during the events (Söderlund *et al.* 2002). Thus, it seems that comparable VGPs from dyke rocks or any intrusive igneous rocks outcropped in diverse geographical locations do not essentially mean that these rocks were intruded at the same geological times.

The E–W trending dykes (representing ECD of the present study) near Alattur have been dated at 2514 ± 13 Ma (Sm–Nd age), whereas another NW–SE trending dyke near Kunnam representing ECD has been dated at 2651 ± 95 Ma, using Sm–Nd mineral–whole rock dating method. The photomicrograph study of ECD rocks indicates primary igneous texture, thereby inferring multiple incidents of dyke emplacement near the Pondicherry coast. Considering these two different emplacement ages obtained for the two coastal dykes, it is inferred that the crustal block in the northern section of the Madras–Tiruvannamalai province into which the ECD has been intruded must be older than 2.6 Ga. Analogous ages of 2.66 Ga (Anand and Balakrishnan 2010) and 2.61 Ga (Balakrishnan *et al.* 1999) have also been reported for the crustal rocks of Hutti and Ramagiri schist belt, respectively. Mafic dykes from Nuggihalli greenstone belt, Western Dharwar Craton, have been dated at 2506 ± 110 Ma (Khanna and Jaffiri 2021). This infers that the WDC and the northern SGT were coeval with each other.

A comparative study, considering the three distinct geochronological results (2514 ± 13 Ma and 2651 ± 95 Ma obtained for the ECD of the present study) and the 2318 ± 60 Ma ages obtained for the dykes of Tiruvannamalai region (Dash *et al.* 2013); it is suggested that at least three episodes of dyke emplacement occurred in the northeastern segment of the SGT. In view of the obtained ages for ECD, it could be inferred that the granulitic gneisses, into which these dykes have been intruded, must be older than 2556 Ma. Therefore, it is suggested that an older section of continental crust is present in the northeastern part of SGT, near the Pondicherry coast.

6.4 *Comparison: Southern India, Singhbhum, Pilbara and Kaapvaal cratons*

Geochronological and paleomagnetic information from southern India (including SGT and Dharwar Craton) and Singhbhum Craton of the Indian subcontinent have been discussed along with the isotope ages and paleopoles from Pilbara and Kaapvaal cratons. Comparative studies and Archean geology from Pilbara, Kaapvaal and Singhbhum cratons revealed numerous similarities between these three cratons (Nelson *et al.* 2014; Hofmann *et al.* 2016; Kumar *et al.* 2017). Similar Archean geology and paleogeographic reconstructions suggest that the Singhbhum Craton could have maintained its relative positions with Pilbara and Kaapvaal during Neoarchean period and found its place in Vaalbara supercraton (Kumar *et al.* 2017). Interestingly, the paleopole positions obtained from Singhbhum, Pilbara and Kaapvaal cratons (Wingate 1998; Strik *et al.* 2003; Blake *et al.* 2004; de Kock *et al.* 2006; Denyszyn *et al.* 2013; Kumar *et al.* 2017) are comparable with that of SGT poles reported by Dash *et al.* (2013). These 2.7 Ga poles (Wingate 1998; Strik *et al.* 2003; Blake *et al.* 2004; de Kock *et al.* 2006; Denyszyn *et al.* 2013; Kumar *et al.* 2017) from Pilbara Craton, Western Australia and Kaapvaal Craton has been derived from volcanic rocks and basalts and the Singhbhum poles has been derived from mafic dykes. The Sm–Nd mineral whole rock ages of 2514 ± 13 and 2651 ± 95 Ma, obtained from the ECD dykes of the present study, are in good agreement with that of the Singhbhum, Pilbara and Kaapvaal cratons (within error). The oldest dated mafic dyke swarms of Singhbhum Craton with ca. 2.75–2.80 Ga are known as the Ghatgaon swarm and Keshargaria swarm and have been compared with the global LIP events (Samal *et al.* 2019). A ∼3 Ga reconstruction of supercontinent 'Ur' is also proposed (Rogers 1996; Rogers and Santosh 2002) for

Western Dharwar, Singhbhum, Kaapvaal and Pilbara cratons. A new paleomagnetic pole (VGP) obtained from EDC also supports the amalgamation of Dharwar, Singbhum and Bastar cratons (Miller *et al.* 2023) with southern India.

Based on the above discussions, along with the compiled geochronological and paleomagnetic information from the Pilbara, Kaapvaal, Singhbhum cratons and SGT (along with southern Dharwar Craton), it could be possible that Indian subcontinent might have maintained same relative positions with that of Kaapvaal and Pilbara cratons during its Neoarchean (2.5–2.8 Ga) ancestral period.

7. Summary and conclusions

1. The present geochronological results suggest that the coastal dykes (ECD) were intruded between 2514 ± 13 and 2651 ± 95 Ma and are at least 200 Ma older than the 2318 ± 60 Ma old dykes (TD) reported by Dash *et al.* (2013), suggesting three episodes of magmatic events occurred between 2.7 and 2.3 Ga in the northeastern part of SGT.
2. Considering the geochronological results obtained for the present study, it is suggested that the crustal segment into which the ECD has been intruded must be older than 2.7 Ga and also denote an older crustal segment in SGT, near the Pondicherry coast of India.
3. Considering the older dykes of 2.8–2.5 Ga from Keshargaria swarm and Ghatgaon swarm and 2.5 Ga mafic dykes from the Nuggihalli greenstone belt, which are comparable with the ages of the ECD, we propose a magmatic linkage between SGT (including southern Dharwar Craton) and Singhbhum Craton during Neoarchean period.
4. Further, we suggest Pilbara, Kaapvaal, Singhbhum cratons and the northern part of Southern Granulite Terrain (including southern Dharwar Craton) could have maintained the same relative positions during its Neoarchean (2.8–2.5 Ga) ancestry.
5. Though a $\sim$3 Ga paleogeographic reconstruction is beyond the scope of this manuscript, it provides an opportunity for the researcher to focus on the proposed connection of Dharwar (including northern SGT), Singhbhum, Kaapvaal and Pilbara cratons.

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Author statement

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