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REVIEW ARTICLE

Dyke Swarms in the Dharwar Craton: A Key to Understanding the Late Archean to Early Proterozoic Cratonic Correlations

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Abstract | Mafic dyke swarms are abundantly distributed in the Archean Dharwar craton. Previous studies have focused mainly on the major mafic dyke swarms in EDC; however, those in the WDC are yet to be studied in detail. Here we present preliminary geochemical data for the dykes in the Tiptur area, WDC and compare them with the dyke swarms in the EDC. Petrological studies indicate that the dykes in the Tiptur area fall into two distinct groups. The NW–SE trending dolerite dykes are unaltered, with characteristic ophitic textures and are geochemically comparable to 2.3 Ga EDC dykes. In contrast, the NE–SW trending meta-doleritic dykes showed high degree of alteration. The difference in petrography, major, trace and rare earth element geochemistry between the dolerites and meta-dolerites lead to a preliminary inference that these two suits of rocks might not be co-genetic. Meta-dolerites have not been reported from the EDC and it is possible to assume that they are a part of an earlier event, restricted in WDC, that might have emplaced prior to the amalgamation of WDC and EDC. In a global perspective, we compare our results with those reported in Archean cratons during late Archean to early Proterozoic around the world to constrain similarities that can lead to understanding the global scale magmatic activity and to aid in correlations between cratons.

1 Introduction

Earth's surface is being constantly modified due to the processes that shape the Earth over time. From the present day active volcanism, orogenic mobile belts to the stable shield which preserves the remnants of earliest continents, our Earth offers a wide variety of geologic processes that modify its surface. Studying the early formed cratons in the world will help to understand the evolution of Earth during the earliest recorded geologic time and will help to deepen the knowledge about Earth's history.

There have been various episodes of magmatic activity recorded in some of the well-preserved cratons which is found to be greenstones, granites and as extensive mafic dyke swarms. The Braberton greenstone belt in the Kaapvaal craton, Yellowknife greenstone belt in Slave craton, Abitibi greenstone belt in the Canadian shield, Chitradurga and Kolar greenstone belts in the Dharwar craton are some of the major greenstone belts in the world. Similarly, giant dyke swarms are also distributed in these cratons. Swarms are extensive exposures of mafic dykes which had emplaced during the later stages of stabilization of craton. Unlike greenstones which are formed as extrusive events over time, dykes are short-lived events where the mantle materials after the craton formation are emplaced into the surface[18, 23, 26]. Sometimes, the dykes are spatially extensive over several geographically separated continents, which often help in the global correlation between the cratons. This will help to identify the past supercontinents that made

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up the Archean Earth. Mafic dyke swarms are abundantly distributed in cratons all over the world especially in Archean Canadian shield, North China craton, Western Australian Yilgarn craton and the Dharwar craton of Indian shield. They are often related to a mantle plume or large igneous provinces that are major events that trigger the breaking up of massive supercontinents over the time. Large igneous provinces (LIPs) are pulses of igneous events during which large volumes of magma will be transferred to the crust in a short period of time and is often associated with regional-scale uplift, continental rifting and break up. This can produce flood basalts, greenstone belts with Komatiites or giant continental scale mafic dyke swarms, sills or layered intrusions[6, 10, 11, 17, 19]. Hence the presence of giant dyke swarms in the Archean cratons can be used as markers for reconstructing supercontinents in Earth's history.

While a dyke is emplaced, the hot magma comes in contact with the much cooler surrounding rock and this leads to the rapid crystallization of the melt, resulting in the formation of glass or a fine-grained zone in its immediate contact. Such kind of a contact, called as chilled margins—often can be identified in the field. However, the cooling rate within the dyke is slow and will give rise to a peculiar texture called ophitic texture, where lath-shaped plagioclase grains are enclosed within a matrix of pyroxenes.

Although the dykes are found in large numbers, those that are found in a particular region may not be of the same composition or might not have formed during the same event. Detailed geochemical studies will help to differentiate the different sets of dykes emplaced in the same area and geochronological studies of these dykes will give the time of its formation and this together gives insights into the evolution of mantle composition through time[19, 32, 52, 59].

2 Dyke Swarms in the Dharwar Craton

Dharwar craton in the Indian subcontinent is a well-preserved Archean (older than 2.5 Ga) craton. It is composed mainly of 4.0–2.56 Ga Tonalite–Trondjemite–Granodiorite (TTG) type gneisses and two generations of greenstone belts—3.35–3.20 Ga; volcano-sedimentary Sargur group and low to medium-grade metamorphic sequence of Dharwar supergroup (2.90–2.54 Ga) which are intruded by calc-alkaline to potassic granites (2.62–2.52 Ga)[4, 7, 14, 27, 28, 40, 47–49]. Furthermore, the entire craton is intruded by younger mafic dyke swarms (Fig. 1). The felsic continental crust that is composed of TTG which forms the basement of the craton and the granite intrusions together are considered to be part of the accretionary processes that led to the amalgamation of the different blocks of the craton. This cratonization processes continued till 2.5 Ga and the end of Archean is marked by a major shift in the petrogenetic and geodynamic processes[28]. The mafic dykes intruded into these TTGs and other granites. The Dharwar craton has been divided into two blocks based on the differences in lithology and tectonic evolution as an older and thicker Western Dharwar craton (WDC) and a younger and thinner Eastern Dharwar craton (EDC). The thick mylonitic boundary shear zone along the eastern boundary of the Chitradurga greenstone belt is considered as a dividing zone between the two blocks[22, 58]. A central block is also being proposed in recent studies, dividing the craton into Western, Central and Eastern blocks based on age and accretionary histories[5, 28, 43]. The boundary between the central block and the western block is defined by the Chitradurga shear zone, whereas to the east it is bounded by the margin of Kolar–Hadiri–Hungund belt. The entire craton is characterized by abundance of mafic dykes criss-crossing the generally seen NNW–SSE trend of the gneisses and greenstone belts.

2.1 Dyke Swarms in the Eastern Dharwar Craton

The mafic dykes in the EDC have been studied in detail by several researchers previously[2, 13, 21, 24, 30, 31, 39, 41, 45, 46, 54–56]. The dyke swarms in the EDC are grouped into the following categories based on their age, geochemistry and paleomagnetic features. The oldest E–W to WSW trending swarm emplaced at around 2.36 Ga, N–S trending Andhra–Karnataka long dykes of 2.2 Ga, NW–SE 2.2 Ga dykes, NW–SE to WNW–ESE swarm emplaced at 2.18 Ga, NE–SW trending 2.0 Ga dyke and the youngest 1.8 Ga dykes [31, 38]. The origin of 2.3 Ga Bangalore swarm is associated with Bangalore LIP, 2.21 Ga Kunigal dyke swarm and 2.18 Ga Mahbubnagar dyke swarm related to a long lasted Pan-Dharwar dyking event and the 1.8 Ga dykes is linked to the Bastar–Dharwar LIP[21, 29, 53]. French and Heaman[21] suggested that the 2.3 Ga dykes reported in EDC are of two distinct varieties—the dykes characterized by coarse-grained plagioclase with poikilitic texture and the other medium-grained dolerites. They are classified as sub-alkaline tholeiitic in composition with SiO_2 wt% ranging from 49–53 and MgO wt% varies from 5–14. Trace element contents show incompatible element-enriched

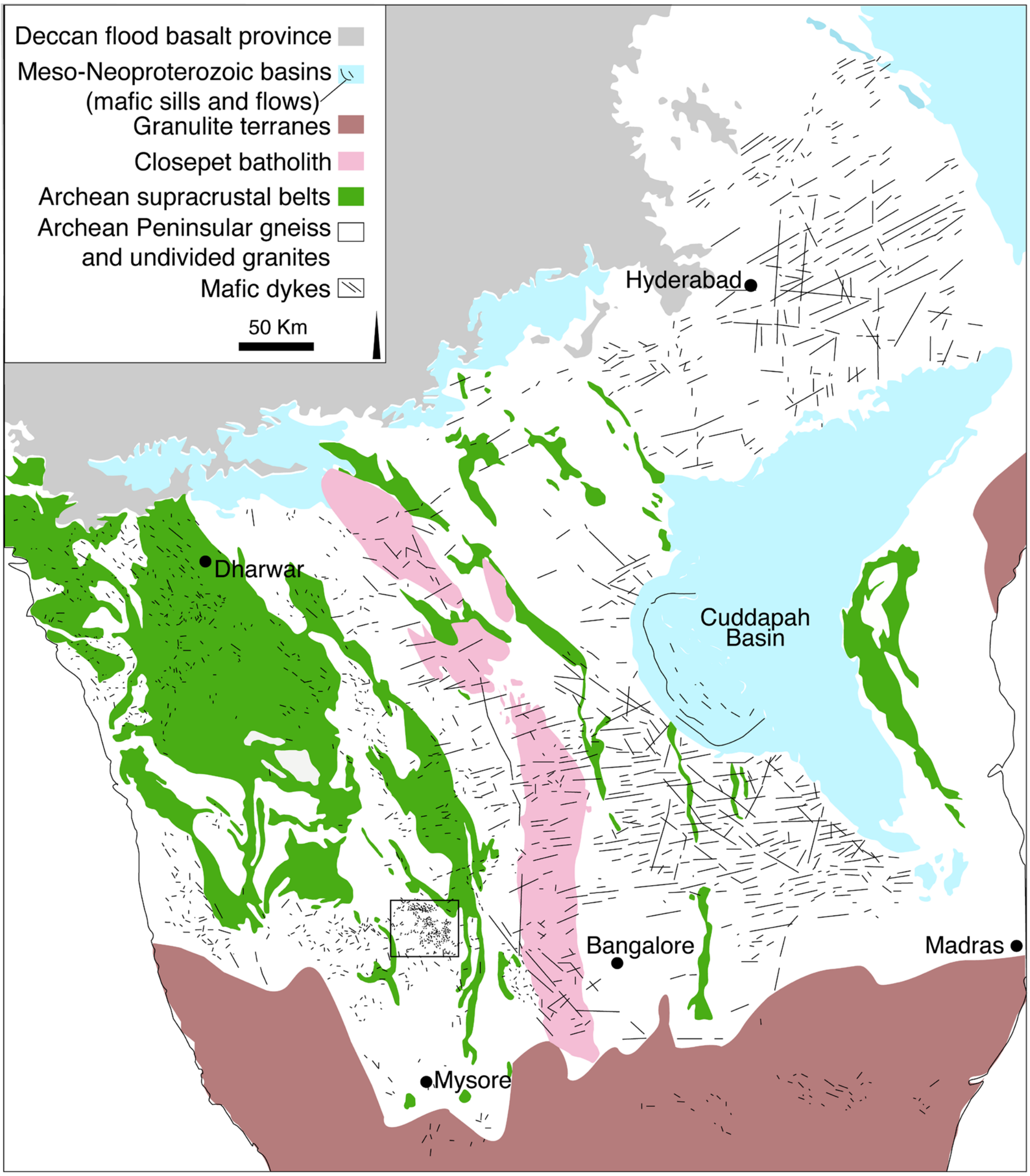

Figure 1: Simplified geological map of Dharwar craton showing the distribution of mafic dykes (Modified from French and Heaman[21]). Marked area is Tiptur dyke swarm, one of the major swarms in Western Dharwar Craton.

patterns with distinctive negative Nb anomalies. This can either be because of the crustal contamination or because of the derivation of the source region which has been previously influenced by subduction. REE patterns are characterized by LREE enrichment with more or less flat HREE. Srivastava et al.[53] concludes that younger 1.8 Ga dykes reported in EDC are not co-genetic with the 2.3 Ga dykes and are geochemically distinct and thought to be derived from different magmatic events. The 2.2 Ga dyke swarm shows limited variations in the major element concentrations. However, it was found that these dykes have paleolatitudes similar to Slave, Superior and Rae provinces and has wide distribution in regions including North America, Greenland, Australia, Africa and India[29].

2.2 Dyke Swarms in the Western Dharwar Craton

Only very limited data is available for the dykes in the Western Dharwar craton. Meert and Pandit[37] hinted the presence of two suites of amphibolitic and epidioritic swarms along with a more widespread dolerite dykes, although detailed studies on petrogenesis, geochemistry and age constraints are lacking. In the current study, one of the major dyke swarms of the Western Dharwar craton in the Tiptur area (Fig. 2) was considered as a representative example for studying the significance of dykes in cratonization process in the region. Unlike the dyke swarms in the Eastern Dharwar craton, those in the Western Dharwar craton occur as patches of massive exposures, most of which are without a clear relation with the country rock and chilled margins. Establishing the cross-cutting relationship with the country rock and within different sets of dykes exposed in the same area is the primary challenge faced as far as the dykes in the Western Dharwar craton are concerned. The dykes were most commonly NE–SW and NW–SE trending with a very few of them trending N–S and E–W. They have varying dimensions, the width was generally less than 3 m, whereas the lengths vary widely from a few meters to traceable over several tens of meters and most of them were massive with huge boulders with weathered surfaces or sometimes form hillocks. At one outcrop, a chilled margin with direct contact could be identified (Fig. 3a), and another one with chilled margin but no direct contact with the country rock (Fig. 3b) and in two other localities a sharp contact relation with the surrounding country rock could be identified (Fig. 3c, d).

3 Petrological Features of the Dykes in the Tiptur Area

In the present study, multiple samples were collected from each dyke exposure and preliminary petrography and geochemistry were carried out. The thin section observation revealed two different types of dykes based on the mineral assemblage, texture and the degree of alteration. The NW–SE trending dolerite dykes were fresh, composed of medium-grained, euhedral to subhedral minerals predominantly plagioclase, clinopyroxene and orthopyroxene, though clinopyroxene being more common, and minor

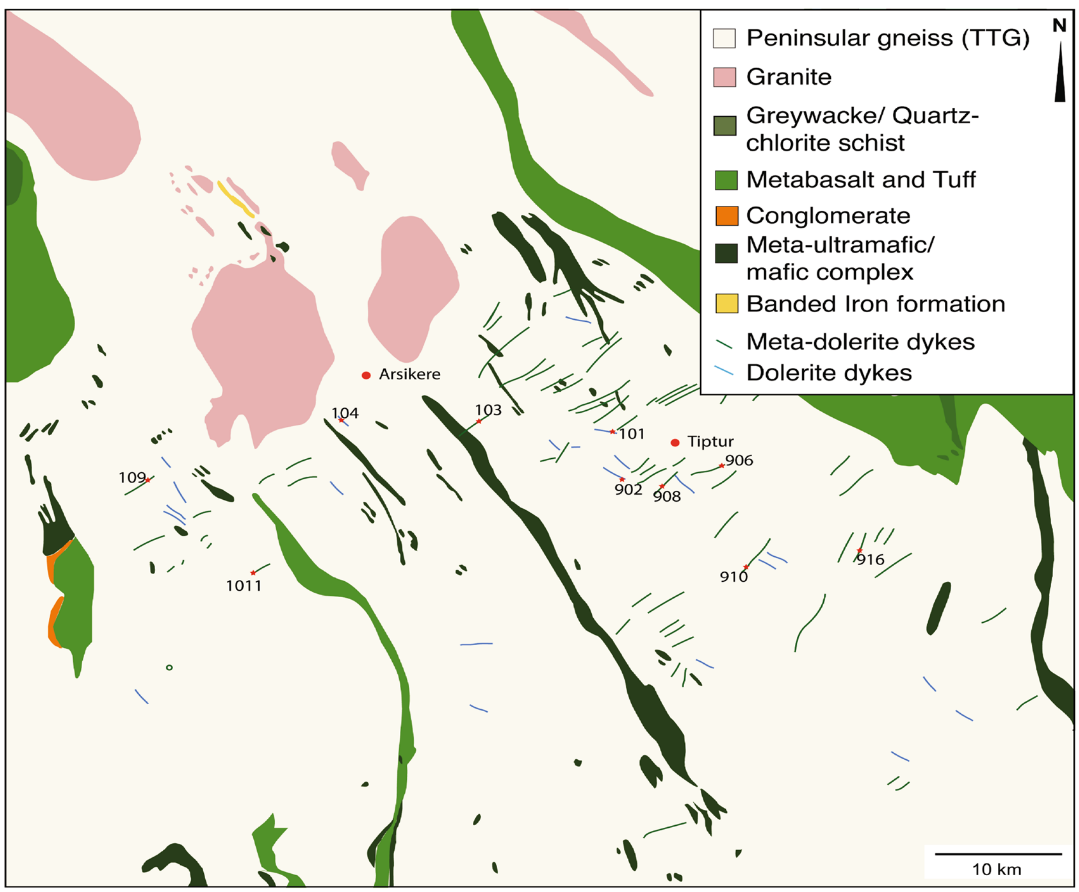

Figure 2: Geological map of the study area showing the distribution of Tiptur dyke swarm (Modified after Geological Survey of India Map 1997).

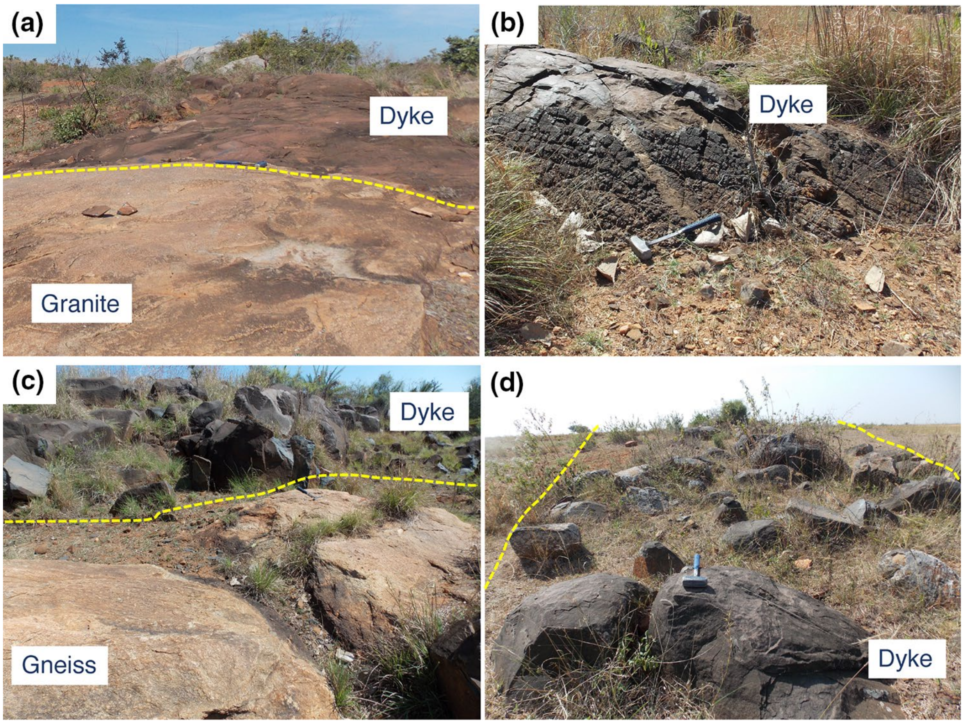

Figure 3: Field photographs of the dykes that are exposed in the study area. **a** NE–SW trending dolerite dyke with a sharp contact and chilled margin with the adjacent granite. **b** Dolerite dyke with a chilled margin and no direct contact. **c** NE–SW trending dyke with a contact relation with the adjacent gneiss. **d** E–W trending dolerite dyke exposed as patches of massive boulders with poor relation with the country rock. The yellow dashed lines indicate the contact relation of the dyke with the surrounding country rock.

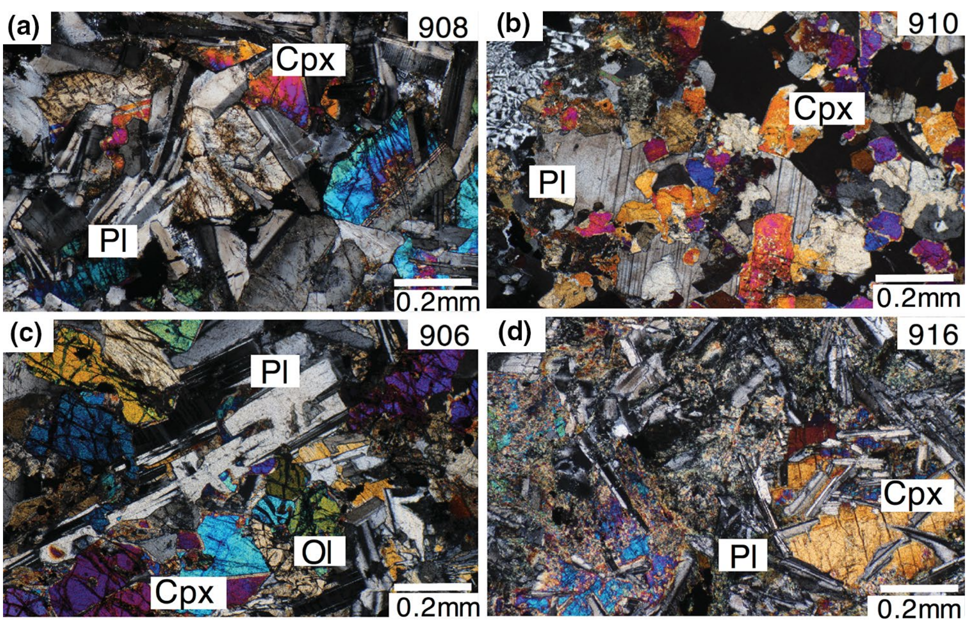

Figure 4: Photomicrographs of the studied dolerites showing **a** ophitic texture with lath-shaped plagioclase in a matrix of pyroxene, **b** poikilitic texture with a large plagioclase oikocryst where smaller pyroxene minerals are enveloped in plagioclase, **c** poikilitic texture with a larger plagioclase and smaller pyroxenes, olivine is also present in this dyke, **d** meta-dolerite dyke showing remnant ophitic texture where the plagioclase laths are preserved but pyroxenes are altered to amphiboles.

opaque minerals. Figure 4a shows the characteristic ophitic texture observed in dolerite dykes, where lath-shaped plagioclase is enveloped in a matrix of larger pyroxene minerals. In some cases, poikilitic texture is observed, where smaller pyroxene minerals are enveloped in a plagioclase oikocryst (Fig. 4b). This texture is normally a result of the different rates of nucleation and growth of the minerals, the mineral that nucleate slowly and grow into a larger grain (oikocryst) encloses the other minerals that have a higher nucleation rate which remain as smaller grains. A few samples contained olivine as well (Fig. 4c). Dolerite dykes that have similar petrographic features are reported extensively throughout the craton (e.g.,[24, 29, 30, 53]).

The other group of dyke samples showed high degree of alteration and remnant ophitic textures with the preservation of very less plagioclase laths as well as original mineralogy (Fig. 4d). We term this group as meta-dolerites, because of the prominent metamorphism. The remnant ophitic texture had 50% or less plagioclase laths preserved and pyroxenes had mostly altered to amphibole. Chlorite was also present in some samples which are confined within areas of lower grade metamorphism in Dharwar craton. Opaque minerals were present in varying concentrations in almost all the samples.

4 Geochemical Characteristics of Dykes in the Tiptur Area

Whole rock geochemical analysis using XRF has been conducted for the dykes in the present study for their preliminary geochemical characterization and its comparison with available data from the Eastern Dharwar dykes. Trace element compositions were measured using ICP-MS at Niigata University for further understanding the geochemical evolution of the parent magma of the dykes. The results are presented in Table 1. The dolerites and meta-dolerites show different variation trends. Major element concentrations vary with SiO_2 ranging from 48–53 wt%, CaO, Fe_2O_3 and alkalies shows smaller variations, whereas MgO and Al_2O_3 show very large differences, 5–17 and 9–16 wt%, respectively. A positive correlation was observed for SiO_2 and alkali elements (Fig. 5). SiO_2 against MgO Harker variation diagram have a negative correlation as observed for normal magmatic crystallization patterns (Fig. 6).

Meta-dolerites have a high Mg# (Mg/Mg + Fe), ranging from 40–46 in contrast to dolerites which have a lower Mg# of 30–35 indicating the possibility of derivation of the former from a more primitive mantle melt and the latter from a slightly evolved melt which has gone through fractional crystallization as seen in the decreasing trend of MgO wt% with the increasing SiO_2 wt%. High concentration of incompatible elements for the dolerites indicates a more evolved source as suggested by its low Mg#. To understand the crystallization trends and behavior of the melt, various geochemical discrimination diagrams have been constructed using MgO and some key trace elements, such as Cr, Ni, Nb and Zr (Fig. 7). MgO against incompatible elements show a negative trend whereas with Ni and Cr it shows a positive trend. The Dharwar dykes that are investigated in the present study was first classified on the basis of their total alkali and silica (TAS) content, which is a common way of nomenclature of volcanic rocks. The TAS diagram classifies them as sub-alkaline tholeiitic magma and they are generally basaltic in composition, with most of the NE–SW meta-dolerite dykes falling into basalt field and NW–SE dolerite dykes in basaltic andesite fields (Fig. 8). This is also consistent with the earlier studies carried out in the different swarms in the craton by Srivastava et al.[54], and references therein.

The primitive mantle-normalized multi-element diagram and chondrite-normalized rare earth element patterns of dolerites and meta-dolerites show two distinct patterns (see Fig. 9a, b). The dolerites in the current study have geochemically similar characteristics with the dykes in the Eastern Dharwar craton[21, 24, 29, 30].

The primitive mantle-normalized multi-element spidergram for dolerites shows a higher concentration of incompatible minerals including an enrichment of LILE like Rb, K and Sr but a negative anomaly for Nb and Ta. Although Nb can be an indicator of possible crustal contamination, the absence of negative anomalies for other incompatible elements like Zr, Hf and Sr anomaly excludes the possibility of such a crustal component. The presence of positive Sr anomaly could be attributed to a later-stage accumulation of plagioclase resulting from the evolution of the source melt. Also, the trace element ratio of Y/Zr shows a low crystallization trend indicating the origin from an evolved melt or an LILE-enriched magma source. In the incompatible element tectonic discrimination diagram, the dolerite samples plot away from the continental crust (Fig. 10a). Possibility of crustal contamination was further evaluated using Nb/Th-La/Sm relation. (Figure 10b). It can be seen that the dolerite samples plot away from the crustal enrichment curve. This, together with the trace element

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Table 1: Major and trace element data for selected dykes in Tiptur area, Western Dharwar Craton.

Sample No	109	104	908	906	910	1011	103	101	902	916
(wt%)										
SiO_2	52.24	48.21	49.65	54.87	52.65	49.20	49.22	48.97	49.78	50.20
TiO_2	1.36	0.32	0.46	1.04	0.82	1.05	0.99	1.10	1.68	0.98
Al_2O_3	9.96	11.89	10.37	14.88	9.11	15.32	15.14	15.17	13.72	14.83
Fe_2O_3	13.81	10.84	10.41	10.46	10.89	11.06	11.07	11.89	13.60	11.58
Mno	0.22	0.19	0.18	0.15	0.20	0.19	0.19	0.20	0.22	0.20
MgO	7.71	15.45	16.90	5.52	11.16	8.04	8.17	7.86	5.74	7.84
CaO	11.04	9.83	8.73	8.67	13.20	11.45	11.30	10.99	10.29	11.19
Na_2O	2.02	1.30	1.51	3.50	1.33	1.75	1.84	1.86	2.25	1.87
K_2O	0.57	0.31	0.37	0.45	0.11	0.19	0.22	0.20	0.24	0.11
P_2O_5	0.10	0.04	0.05	0.08	0.05	0.06	0.06	0.07	0.12	0.06
L.O.I	1.61	1.94	1.86	1.29	1.43	1.94	2.23	2.35	2.11	1.69
Total	100.62	100.32	100.49	100.92	100.95	100.26	100.43	100.67	99.75	100.56
(ppm)										
Rb	27.86	17.80	23.43	17.56	7.19	3.13	8.10	6.99	8.69	12.57
Ba	16.55	8.28	10.10	17.54	3.61	3.62	2.02	4.10	5.09	3.53
Th	19.44	10.05	13.32	10.76	6.09	2.97	2.68	3.24	6.34	2.87
K	18.97	10.45	12.30	18.37	5.12	6.54	7.37	6.82	8.15	3.81
Nb	6.40	1.91	2.61	5.14	2.98	4.30	4.28	3.23	8.99	3.85
Ta	7.01	2.27	3.07	5.29	2.94	4.82	3.82	4.67	9.65	4.34
Sr	10.40	4.00	5.40	18.44	4.89	5.53	5.16	4.70	5.43	4.60
Zr	7.88	2.97	4.61	6.09	4.42	5.11	4.67	5.46	9.21	4.71
Hf	6.96	2.67	4.14	5.75	3.88	4.78	4.14	4.94	8.37	4.61
Ti	4.74	1.60	2.22	3.90	2.98	3.23	2.95	3.12	5.07	3.16
Tb	6.62	2.86	4.06	4.46	5.13	5.24	4.75	5.55	8.77	5.28
Y	4.83	3.06	3.69	3.38	4.00	4.85	4.59	5.11	7.86	4.98
Ta	0.29	0.09	0.13	0.22	0.12	0.20	0.16	0.19	0.40	0.18
La	40.96	21.69	29.86	34.23	16.65	15.99	12.70	14.79	29.79	14.01
Ce	35.67	16.95	23.52	28.37	15.98	15.61	13.24	15.28	30.18	13.99
Pr	32.82	13.25	18.72	25.02	14.90	15.85	13.89	15.91	30.53	14.60
Nd	31.30	11.35	15.96	23.22	15.76	16.54	14.46	17.29	31.13	15.44
Sm	26.38	8.55	12.70	18.48	14.58	16.12	14.21	15.97	26.86	15.82
Eu	22.89	7.71	10.72	18.86	14.42	15.59	14.23	15.07	24.51	15.26
Gd	21.51	8.18	11.92	14.97	13.58	15.44	14.62	15.07	25.36	15.02
Tb	19.11	8.26	11.73	12.89	14.82	15.12	13.73	16.02	25.32	15.24
Dy	14.70	7.82	9.58	10.38	11.60	13.35	12.40	13.45	21.10	13.27
Ho	13.99	8.45	10.90	9.74	12.31	13.66	13.19	14.82	22.91	14.34
Er	14.19	8.88	10.49	9.78	11.26	14.52	13.93	15.63	22.12	15.53
Tm	12.34	8.35	8.88	8.54	10.08	12.95	12.58	14.23	21.63	14.00
Yb	8.74	7.51	7.48	6.89	8.26	10.49	10.44	11.49	18.00	12.15
Lu	9.39	8.47	8.16	7.37	8.76	12.48	12.40	14.62	19.48	14.68

pattern indicates that the possibility of crustal contamination is highly unlikely.

The rare earth element distribution of the dolerites shows an LREE-enriched pattern with a more or less flat HREE pattern. This could be because of the derivation from an enriched source. Assuming that the dykes were formed by the melting of a peridotite source, the low degree

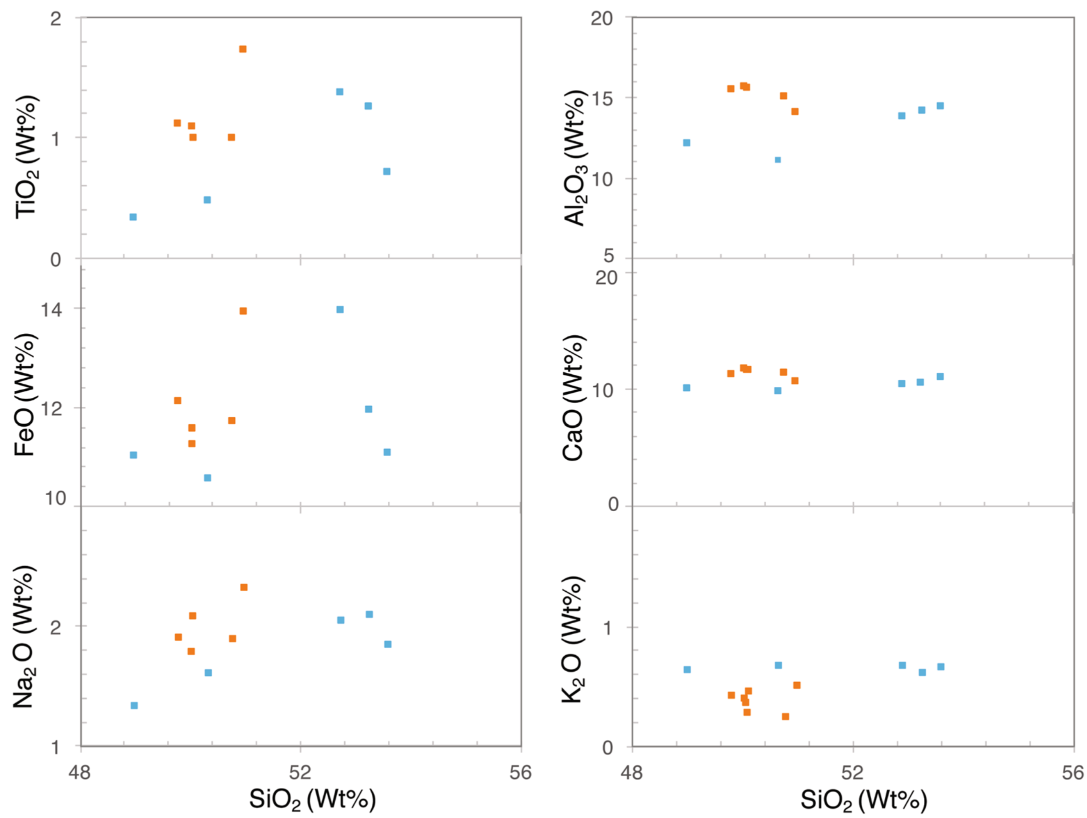

Figure 5: Harker diagram of silica vs. major oxides for the samples in the current study, dolerites (blue) and meta-dolerites (orange).

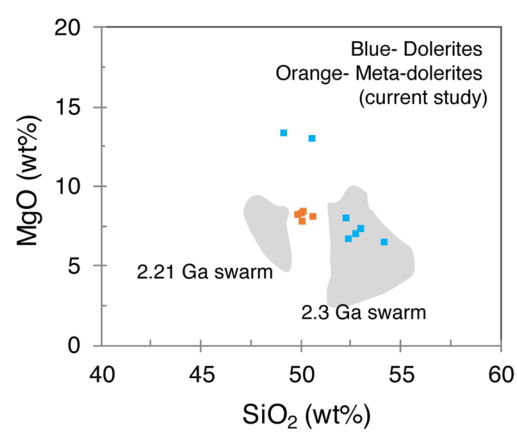

Figure 6: Geochemical discrimination diagram between SiO_2 and MgO (wt%). The yellow area is the dykes in the present study which is compared with the previous data (gray shaded area) from Eastern Dharwar craton[53].

of melting, an enriched LILE pattern and moderately incompatible nature of *Y*, indicate that these dolerites originated from an enriched source or a more evolved magma.

On the other hand, the meta-dolerites show only a nominal LILE enrichment in the primitive mantle-normalized multi-element spidergram with negative Ba, Nb, Ta and Ti anomalies. Chondrite-normalized REE pattern is more or less flat or undepleted. The highly incompatible nature of REE with absence of positive Sr anomaly assigns a more primitive mantle source for this suite of meta-dolerite dykes.

5 Significance of Dharwar Dyke Swarms in a Global Perspective

The present study also aims at understanding the nature and composition of the dykes in the Western Dharwar Craton and attempts to compare and contrast the chemical characteristics of similar dykes in other parts of the cratons as well as cratons of similar ages around the world. The major, trace and rare earth element characteristics of dolerites are different compared to the meta-dolerites. The difference in petrography and geochemistry between the dolerites and meta-dolerites can lead to a preliminary inference that these two suits of rocks might not be co-genetic and might have formed from different batches

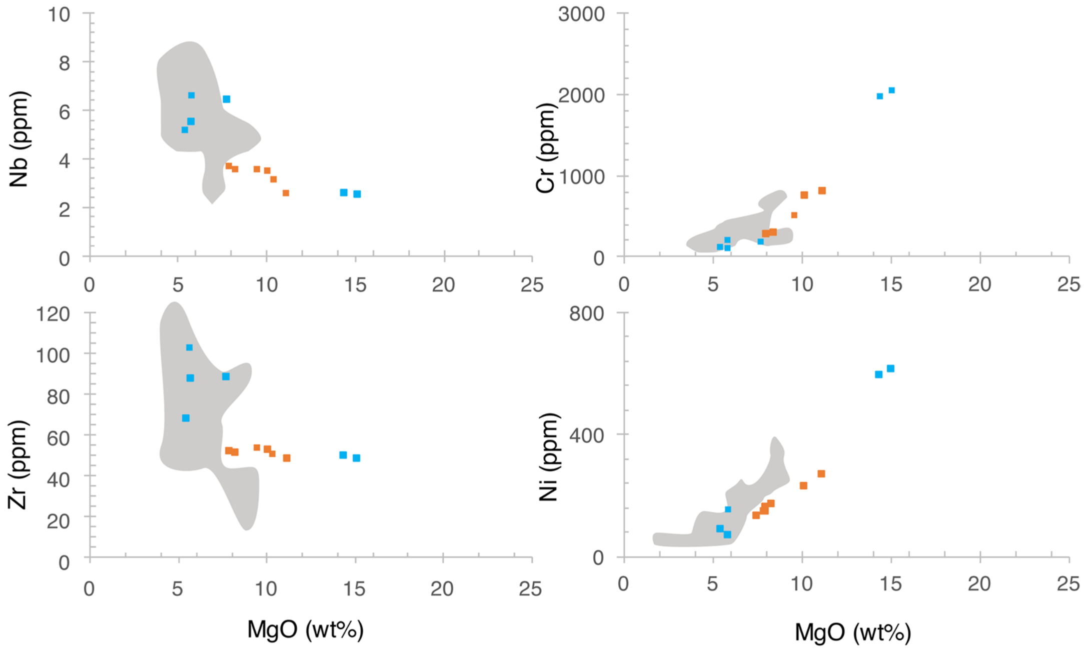

Figure 7: Geochemical variation diagram between MgO vs. Zr, Nb, Ni and Cr showing the different trends exhibited by dolerites (blue) and meta-dolerites (orange) and is compared with previous studies.

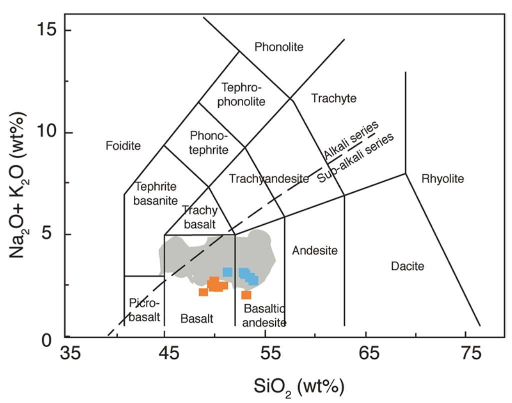

Figure 8: Total alkali vs. silica (TAS) diagram (after Le Maitre[33] showing the general classification of dykes as sub-alkaline tholeiitic in composition. Blue and orange areas indicate dolerite dykes and meta-dolerite dykes in the current study, respectively. The values from French and Heaman[21] are shown in gray for comparison.

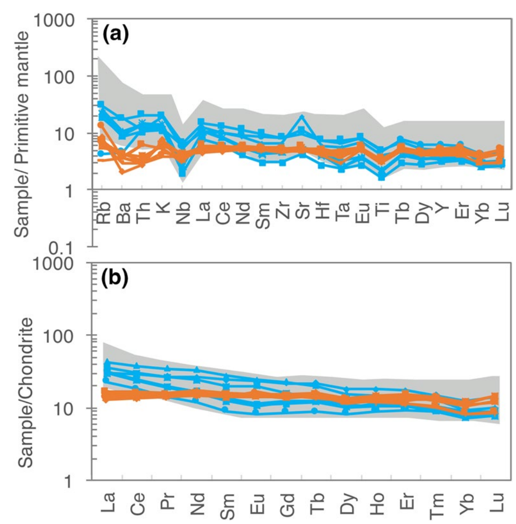

Figure 9: **a** The primitive mantle-normalized multi-element spidergrams for the studied dolerite and meta-dolerite dyke samples from the Western Dharwar craton. The dolerite samples from the current study are consistent with the dykes in the Eastern Dharwar craton. Primordial mantle values are taken from McDonough et al.[35]. **b** Chondrite-normalized rare earth element patterns for the studied mafic dyke samples from the Western Dharwar craton. The dolerite samples are comparable with the previously studied dykes from the Eastern Dharwar craton Normalizing values are taken from McDonough and Sun[36].

of melting or derived from distinctly different sources of magma, although more data on isotope systems such as Sr, Nd and Hf are required to confirm the same.

The evolution of the Dharwar craton suggests that both the cratons were separated during the early Archean and later amalgamated at around 2.5 Ga along the Chitradurga shear zone.

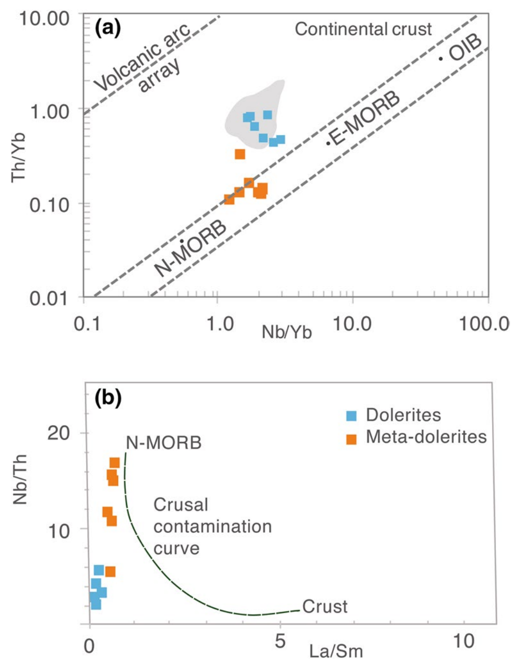

***Figure 10:* a** Immobile incompatible element (Th–Nb–Yb) ratio diagram (after Pearce[42] for the studied dykes compared with the Eastern Dharwar craton dykes. Blue and orange indicate dolerites and meta-dolerites, respectively, and gray for the Eastern Dharwar craton dykes (from[21, 29, 53], which is used for comparison. **b** (La/Sm) vs. (Nb/Th) diagram shows the dykes plotting away from the crustal contamination curve (values are taken from Sun and McDonough[57].)

EDC is argued to have formed during the Neoarchean times by the subduction of the hot orogeny, which is characterized by magmatic accretion beneath the Mesoarchean WDC. The WDC, therefore, acted as the foreland continental margin and is believed to have cratonized by 2.6 Ga[5, 7–9, 22, 34]. WDC is considered to be older than EDC and has a thicker lithosphere than EDC. There are clear differences in lithology, genesis and evolution between the WDC and EDC. Dykes similar to the dolerites in the current study have been reported from the EDC and a preliminary evaluation of the geochemical characteristics like incompatible element concentration, rare earth element patterns along with the petrography suggests that they are comparable to the 2.3 Ga dykes in the EDC. Therefore, the dolerites in the Tiptur area can be thought to be coeval with those in the EDC; however, the meta-dolerites could be an event that is restricted to WDC and perhaps have no temporal and spatial relation with the EDC preserving valuable information on mantle evolution prior to Archean–Proterozoic transition. The mineralogical and geochemical characteristics of meta-dolerites also indicate that they might have formed during an older event when compared to the EDC dykes. A possible assumption could be that the dykes might be feeders to extrusive events in the large igneous provinces. For example, the greenstone volcanic sequences in the WDC and meta-dolerites might have been part of the same event and the dykes were metamorphosed during the regional metamorphism of the entire craton at around 2.5 Ga. Another possibility could be that the amalgamation of the EDC and WDC is thought to have occurred through an oblique convergence that resulted in the exposure of deeper levels of crust in the WDC and this might have led to the exposure of an older event, i.e., the meta-dolerites in the current study. The mineralogical and geochemical characteristics of meta-dolerites also indicate that they might have formed during an older event when compared to the EDC dykes.

The 2.3 Ga event in the EDC has been correlated with dyke swarms in the other cratons globally as well[2, 21, 54]. The Yeragumballi dykes in Western Australian craton and Amundsen dykes in the Napier complex in Antarctica as well as those in the Greenland portion of North Atlantic craton are considered as correlatives[1, 15]. The origin of this event is attributed to a long-lived stationary plume by[24]. However, French and Heaman[21] suggest a period of protracted global mafic magmatism which lead to the breakup of Yilgarn craton and several other cratons from the pre-existing super craton named as "Sclavia". There have been reports of 2.4 Ga Widgiemooltha dyke swarm in the Eastern Australia[20, 24], and another plausible interpretation is that there have been two separate events in nearby continental masses due to the plume activity. The presence of a large igneous province is also discussed in Kumar et al.[30]. The younger 2.2 Ga and 2.1 Ga dykes in the EDC[29, 41, 54] have been assigned a plume origin or are suggested to have formed as a result of a large-scale mantle perturbation, but are geochemically distinct. French and Heaman[21] proposed the possibility of dyke emplacement as a part of a protracted Pan-Dharwar dyking which might have lasted for ~ 40 m.y. The youngest 1.8 Ga dykes have less regional extent, and they may be related to an intracontinental extension and basin formation and is not significant like the older ones for continental reconstruction[2, 21, 53]. Mafic dyke swarms reported from other important Archean cratons (Fig. 11), as that in Dharwar craton, are significant when it comes to past continental reconstruction. Thus, combined

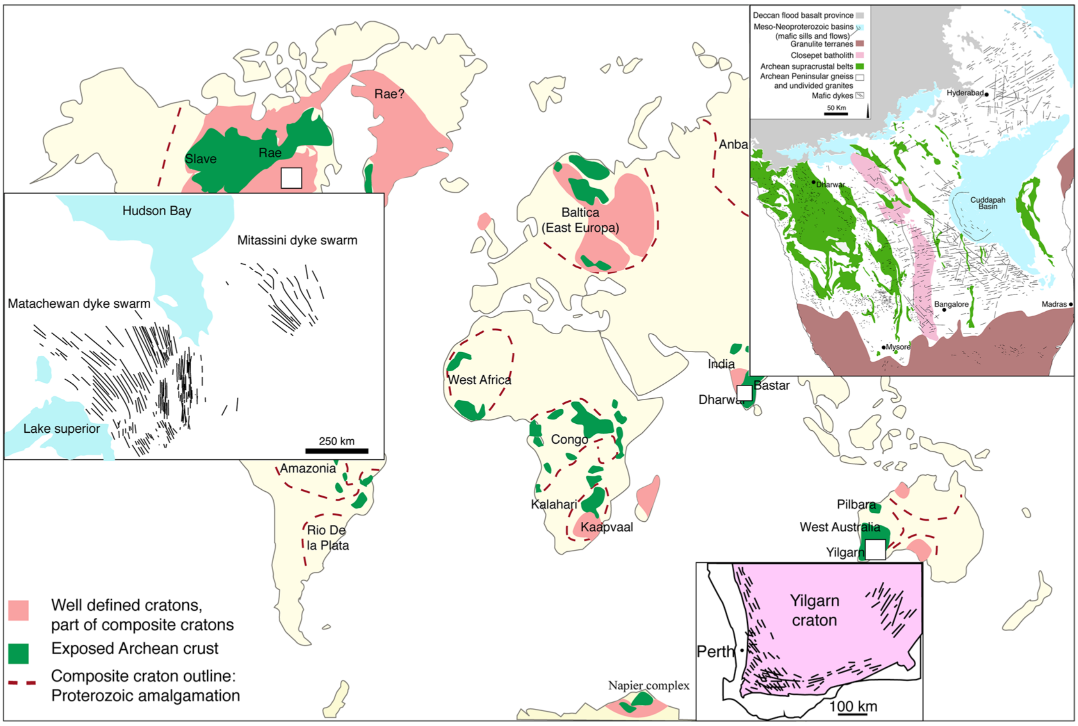

Figure 11: Preserved Archean cratons around the world and some of the major dyke swarm occurrences in the cratons. Matachewan and Mistassini dyke swarms in the Superior Craton, Canadian shield (Modified from Ernst and Buchan[16]), Dyke swarms in the Yilgarn Craton, Western Australia (Modified from Pigeon and Cook[44]) and Dharwar craton, Southern Indian shield (Modified from French and Heaman[21]).

with previous studies on correlation of WDC with supercontinent Ur and possible coexistence with Pilbara and Kaapvaal cratons or the Slave craton[3, 12, 25, 50, 51] studies on dykes will give a better understanding not only on the evolution of the cratons and the crustal processes during early Archean to Proterozoic, but also possible clues on mantle evolution in early Earth.

Studying the dykes in the Dharwar craton is key to understanding the evolution of the mantle during the Precambrian, especially in the Archean to Proterozoic transitional period. Dykes are emplaced after the period of major continental crust formation at around 2.7 Ga and hence the variation in mantle composition through time can be constrained. The dykes can be a result of a plume activity or an indicator of large igneous province and hence the study of which will give valuable information about the mantle source, the degree of melting and the source regions where melting occurred. Although dykes are, in general, more homogenous in nature, the evolution of magma or modification of the source through assimilation can also be constrained from the trace and rare earth element characteristics. Dyke swarms and LIPs are the products of major magmatic events in the Earth's history that probably was the driving force in the breaking up of supercontinents, and they provide clues regarding the cratonic evolution through time. Due to their wide distribution, geochemically coherent dykes can be found in many cratons, thus providing key information on the close proximity of now separated supercontinents.

6 Concluding Remarks

The preliminary petrography, major and trace element geochemical characteristics of the dolerite dykes and meta-dolerite dykes in the current study, show distinct differences as follows:

- Petrography—dolerites were fresh with well-preserved plagioclase and pyroxene minerals and ophitic to sub-ophitic and poikilitic textures. On the other hand, meta-dolerites do not preserve much of the original mineralogy, pyroxenes were altered to amphiboles in most of the samples although it still shows remnant ophitic texture with 50% or less preserved plagioclase laths.
- Geochemistry—dolerites are characterized by higher silica content and lower Mg# as

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compared to meta-dolerites. The rare earth element characteristics shows enrichment of LILE and LREE for dolerites; however, no significant enrichment was observed for meta-dolerites. Dolerites can be thought to have formed from a more enriched source or a more evolved magma, whereas meta-dolerites were formed from a comparatively more depleted source

- It is possible to assume that dolerites and meta-dolerites might not be co-genetic and meta-dolerites could be a part of an earlier event, not reported in EDC and may provide significant information regarding the evolution of the craton prior to 2.3 Ga and the evolution of the mantle composition during early Archean.

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