

# Palaeomagnetic and Rock magnetic investigations on Gadwal “Dike 2”, eastern Dharwar craton, India

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## ABSTRACT

A rare crustally uncontaminated mafic magmatic dike “Dike 2” of alkaline affinity, which has a visible outcrop length of ~20 km trending NW-SE, transects the Neoproterozoic Gadwal greenstone terrane in the eastern Dharwar craton, India. Although, the age of the Gadwal schist belt is well constrained, the field relationship between the Dike 2 and the adjacent granitoids suggests a post-Archean age for its emplacement. There is no direct age information available for Gadwal Dike 2. Fifty oriented samples were collected from 10 sites along the strike length of the Dike 2. Rock magnetic studies (IRM and K-T) indicate that the main remanence carrier resides in multidomain Magnetite. Palaeomagnetic results infer a mean direction at  $D_m=225^\circ$ ;  $I_m= -21^\circ$  ( $N=8$ ,  $\alpha_{95}= 10.3$  and  $k=29.9$ ) and yield a paleo pole at lat.  $46^\circ S$ ; long.  $349^\circ E$  ( $dp=5.6$ ;  $dm=10.8$ ). This new pole position indicates an emplacement age of ~2.2 Ga for the “Dike 2”. This pole is in conformity with the poles determined for Cuddapah dykes and those in the peninsular India.

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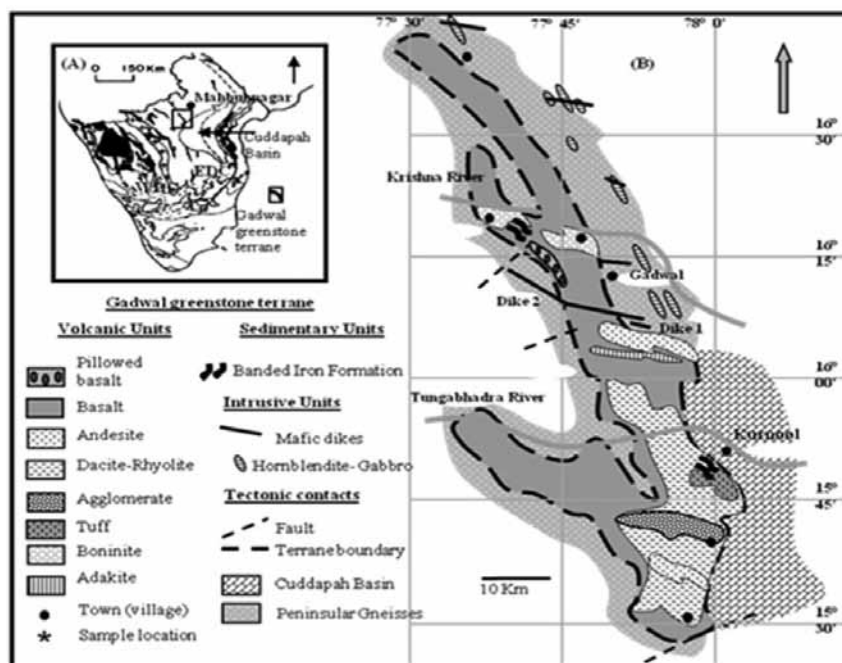
## INTRODUCTION

The mafic dikes and dike swarms, regardless of their age, composition and tectonic setting, provide an essential window to constrain the trace element inventory of their mantle source regions present at shallow and deeper levels of the Earth. The dikes serve as an expression of crustal extension and hence are keys to geodynamic interpretation (Srivastava, 2011). Studies by many Precambrian geologists have brought into light the existence of 2.3–1.8 Ga old orogenic belts and accretionary crustal growth across widely dispersed continental blocks (Rogers, 1996; Condie, 1998; Kusky et al., 2007; French and Heaman, 2010; Söderlund et al., 2010). These studies contribute towards proposal for a Meso- and Palaeoproterozoic supercontinent configuration. Recent reviews giving an account of these aspects include Bleeker (2003) and Zhao et al. (2004). One of the Neoproterozoic supercratons proposed is “Sclavia” in which Dharwar craton in India, Zimbabwe and Wyoming are suggested as the nearest neighbors to the Slave craton (Bleeker, 2003). Dyke swarms are considered to provide robust piercing points in palaeocontinental reconstructions although they may be subsequently fragmented and partially destroyed and dispersed globally. Palaeomagnetic investigations from the Precambrian cratons have recently attained significance in providing better insight into these models. The Indian shield comprises some of the most ancient cratonic blocks and includes the Dharwar craton in the south. The Dharwar craton has been central to many geological and palaeomagnetic studies (Halls et al., 2007; French and Heaman, 2010; Anil Kumar et al, 2012; Radhakrishna et al, 2013; Belica et al, 2014; Anil Kumar et al., 2015). Mafic dykes of Proterozoic age occur profoundly

in all Precambrian cratons and are potential targets for palaeomagnetic studies (e.g. Hargraves and Bhalla, 1983, Venkatesh et al., 1987, Dawson and Hargraves, 1994, Radhakrishna and Joseph, 1996a, b and Radhakrishna et al., 2003). The focus of this study is to present the palaeomagnetic results from an OIB-type mafic alkaline dyke emplaced in the Neoproterozoic Gadwal greenstone terrane, eastern Dharwar craton, India.

## Regional Geology

The Dharwar Protocontinent is subdivided into three distinct cratonic blocks comprising southern granulite terrane, western Dharwar craton and eastern Dharwar craton. The Dharwar craton, in general, comprises laterally extensive and linearly acute, Meso- to Neo-Archean greenstone terranes surrounded by younger granitoids (Jayananda et al., 2013). The western and eastern Dharwar blocks are separated by a NNW-SSE trending shear zone extending all along the eastern margin of Chitradurga greenstone belt (Naqvi and Rogers, 1987). The study area (Fig 1) is located in the eastern Dharwar craton and sandwiched between the eastern margin of Neoproterozoic Gadwal greenstone terrane (Khanna et al., 2014) and the north-west margin of the Proterozoic Cuddapah basin. Dike 2 is relatively fine grained, massive and melanocratic in appearance and linearly extensive. Dike 2 transects the metabasalts in the adjacent Gadwal greenstone terrane and extends in NW direction. It has a total strike length of ~20 km and a variable width of <10 m across. Interestingly, the Dike is undeformed and unmetamorphosed and exhibits a sharp contact with the adjacent granites.



**Figure 1.** (A) Simplified geological map of the southern India comprising of three major tectonic blocks: the western Dharwar craton (WDC), the eastern Dharwar craton (EDC) and the southern granulite terrane (SGT). Also shown in the box is the location of Gadwal greenstone terrane in the eastern Dharwar craton. (B) Generalised geological map of the Gadwal greenstone belt, modified after Srinivsan (1990), showing the disposition of the Gadwal dike 2 sampled for the study.

### Sampling And Analytical Techniques

Detailed geology, petrography and geochemistry of the Dike 2 are presented in Khanna et al. (2013). The focus of this study is to establish the palaeomagnetic age data and rock magnetic properties of this dike. Fifty oriented block samples were collected from ten sites using magnetic compass. The samples were collected from fresh exposures for this study. A minimum of three cores of 2.56 cm diameter each were later drilled from individual block samples and then cut into cylinders of 2.2 cm length, comprising approximately five cylindrical specimens from each block sample. Natural remanent magnetization (NRM) and susceptibility of all the prepared specimens was measured initially using JR-6 Spinner Magnetometer and Kappa Bridge (model MFK-1) [both from Agico, Czech Republic], isothermal remnant magnetization (IRM) studies were performed on pulse magnetizer (model MMPM-10, Magnetic Measurements Limited, U.K.) at palaeomagnetic laboratory of CSIR-NGRI. Curie temperature runs were conducted on Kappa Bridge (model KLY-2, Agico, Czech Republic) available at K.S. Krishnan Geomagnetic Research Laboratory (IIG), Allahabad, India. Standard demagnetization procedures including incremental alternating field (AF) and heat treatment (TH) were performed using Molspin Alternating Field demagnetizer and Thermal demagnetizer (MMTD – 80) both are of

Magnetic Measurements Limited, U.K respectively. After each step of incremental demagnetization, the natural remanent magnetization (NRM) was measured.

### RESULTS AND DISCUSSION

A minimum of three specimens per sample was selected for further detailed stepwise AF and/or thermal demagnetization, to a maximum of 150 mT or 600°C, in order to separate components based on their unblocking temperatures. Fig 2 shows the vector behavior of specimens during AF demagnetization. After removing a secondary component with coercivity less than 40 mT, clear linear segments to the origin defined a characteristic component. Fig 3 shows the vector behavior of specimens during thermal demagnetization. Variation of susceptibility with increasing temperature in these samples is illustrated in Fig 4. Susceptibility values in most of the samples increase gradually from room temperature to about 540–550°C, by about 5–10%. Beyond this temperature the values are seen to decrease to zero close to 580°C. This curve infers a sudden drop in intensity at 580°C. This indicates the presence of Magnetite, whereas the thermal demagnetization curves show the drop at 680°C. This variance indicates that this dike has multicomponent magnetic minerals. However, the thermo-remnant curve gives a strong evidence of Magnetite as the remanence carrier.

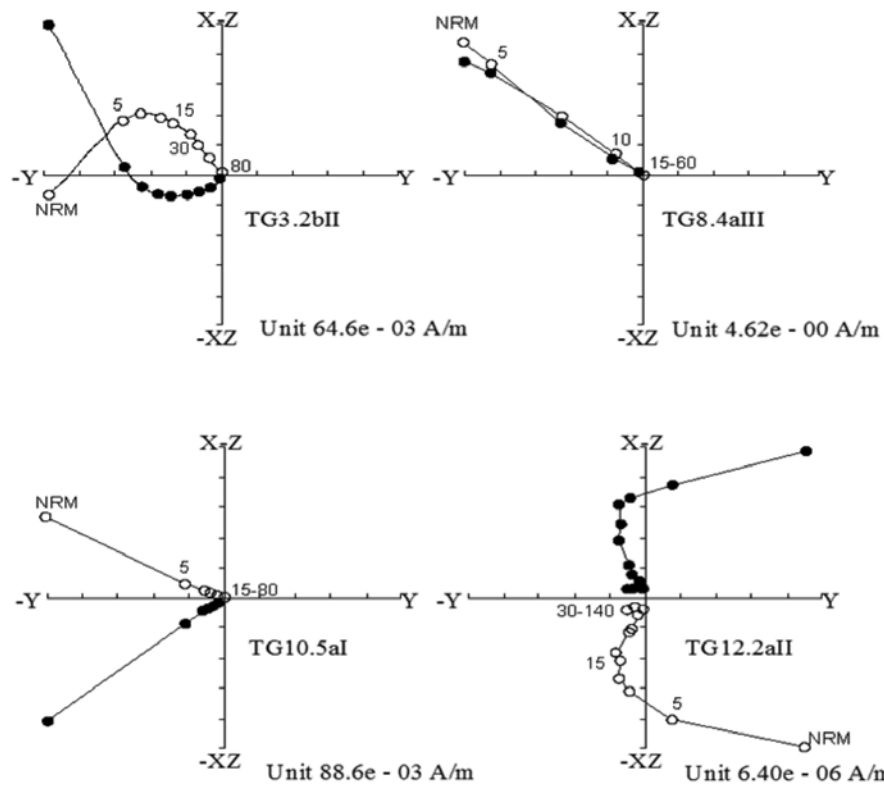


Figure 2. Vector behavior of Gadwal dike 2 specimens during Step-wise AFD. Steps are in mT.

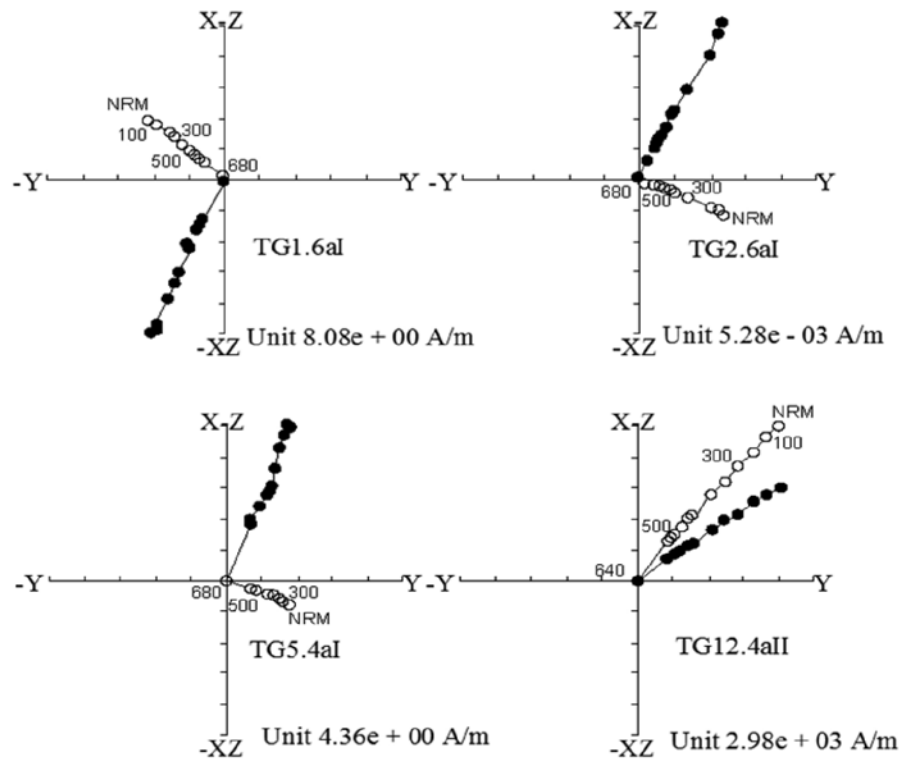


Figure 3. Vector behavior of Gadwal dike 2 specimens during Progressive Thermal Demagnetization. Steps are in °C.

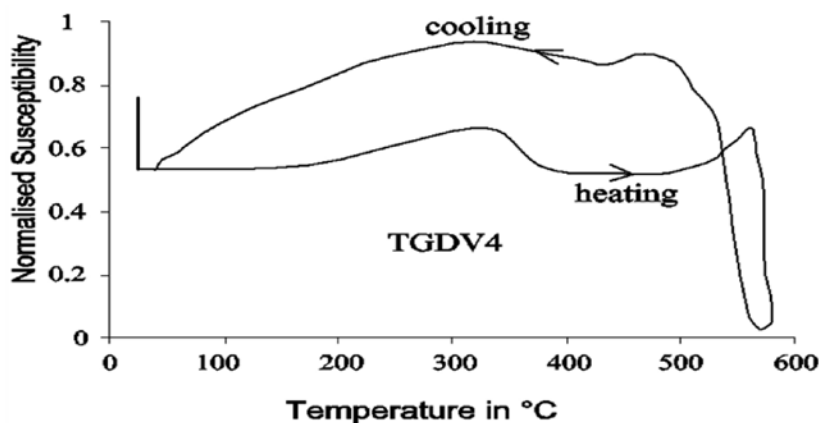


Figure 4. Thermoremanent curve for Gadwal dike 2.

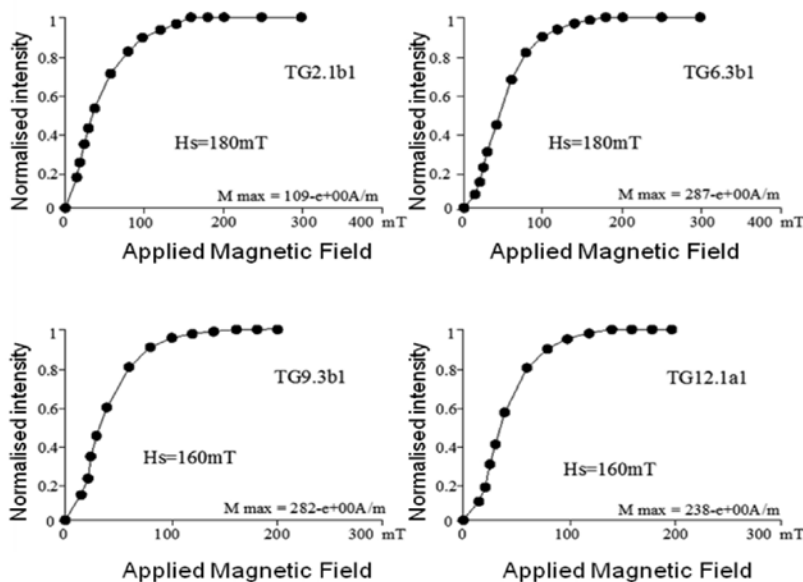
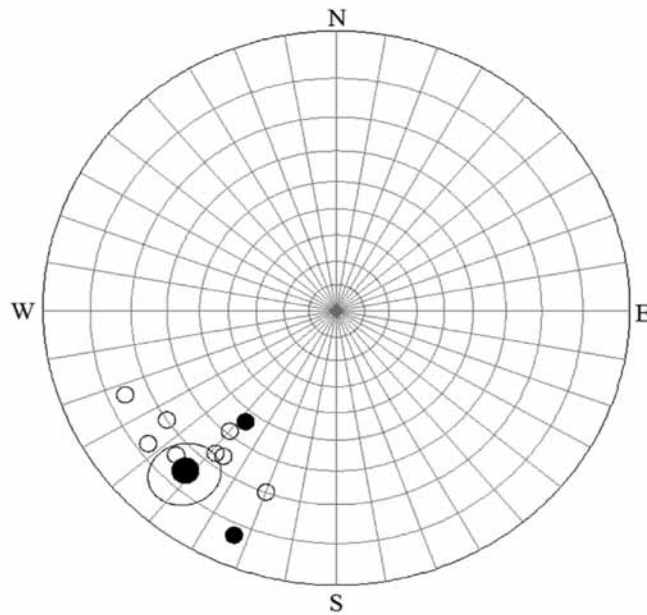


Figure 5. IRM curves for Gadwal dike 2 specimens.

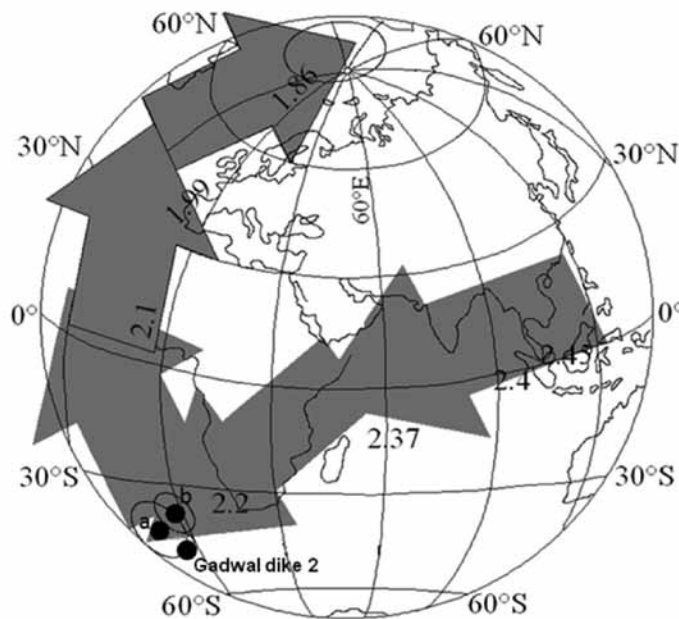
Table-A. Palaeomagnetic results of Gadwal dike 2.

Site	Lat. (°N)	Long. (°E)	n/N	Dec (°)	Inc (°)	k	$\alpha_{95}$ (°)	P lat. (°N)	P long. (°E)	dp (°E)	dm
TG1	16.366	77.719	5/9	247	-14	-	-	24.0S	347.0	-	-
TG2	16.381	77.720	5/9	233	-13	9.2	23.3	38.0S	351.9	12.5	24.5
TG3	16.242	77.668	5/12	220	-31	15.8	19.8	51.8S	341.0	12.3	22.1
TG4	16.258	77.670	2/2	226	-16	-	-	-	-	-	-
TG5*	16.256	77.670	3/5	203	7	159.9	9.7	64.1S	14.2	4.9	9.8
TG6	16.239	77.685	2/6	215	-24	-	-	-	-	-	-
TG7*	16.239	77.687	5/11	217	36	28.1	14.6	38.9S	31.7	9.9	17.0
TG8	16.225	77.730	6/9	200	-20	10.1	25.3	60.7S	351.8	16.6	31.2
TG10	16.228	77.754	1/5	236	-20	-	-	-	-	-	-
TG12	16.202	77.821	8/9	218	-23	9.2	19.2	53.2S	349.1	10.6	20.0
Dyke Grand mean			8/10	225	-21	29.9	10.3	46.3S	349.3	5.6	10.8

Lat. & Long. = latitude and longitude; n=number of specimens used; N=number of specimens analyzed; Dec=mean declination; Inc=mean inclination; k=precision parameter;  $\alpha_{95}$ = circle of 95% confidence about the mean; P lat. =Pole latitude; P long.=pole longitude; dp=semi-axis of the confidence ellipse; dm= semi-axis perpendicular to dp. Sites with asterisk mark are not considered for statistics.



**Figure 6.** Site mean directions along with mean direction of all sites for Gadwal dike 2.



**Figure 7.** Paleomagnetic Pole for Gadwal dike 2 (this study), the dikes from Cuddapah Basin (a) and overall mean of south Indian shield (b) paleomagnetic poles (Radhakrishna et al., 2013).

Conventional IRM acquisition studies were also conducted using a pulse magnetizer. Typical saturation curves for these samples are shown in Fig. 5. The magnetic minerals in them saturate between 160 and 180 mT, respectively. The rock magnetic studies conducted on samples clearly suggest that the dominant magnetic mineral is multidomain magnetite.

The directional data were analyzed using Fisher's (1953) statistics and Principal Component Analysis (Kirschvink,

1980) in combination with Zijderveld diagrams (Zijderveld, 1967), following standard palaeomagnetic procedures. Acceptance criteria for linear segments on vector diagrams were the number of consecutive demagnetization points ( $\geq 5$ ) and maximum angle of deviation  $\leq 10^\circ$  (Kirschvink, 1980). The site mean of all sites and the mean of all the sites were drawn and shown in Fig 6.

Palaeomagnetic results of all the ten sites are presented in Table-A. We were unable to obtain baked contact samples

during this study to prove the primary nature of the remanence direction obtained here, but several observations suggest that rocks in the study region have not been heated above their blocking temperature (450–550°C), after the emplacement of this dike.

The prime aim of this paper is to discuss palaeomagnetic results from this dyke. Poles were calculated for the Gadwal long dyke from the grand mean magnetization data for each component. The poles were plotted on the PaleoProterozoic APWP for the south India (Radhakrishna et al, 2013) and shown in Fig 7. Palaeomagnetic results infer a mean direction at  $D_m=225^\circ$ ;  $I_m= -21^\circ$  ( $N=8$ ,  $\alpha_{95}= 10.3$  and  $k=29.9$ ) and yield a paleopole at lat.46.3°S; long.349.3°E ( $d_p=5.6$ ;  $d_m=10.8$ ). This new Palaeomagnetic pole indicates an emplacement age of  $\sim 2.2$  Ga for the “Dike 2” in Gadwal region of eastern Dharwar craton. The ages of magnetization acquisition of the Dharwar craton is examined in the context of palaeomagnetic poles.

## CONCLUSIONS

This study provides a new palaeomagnetic pole for the Gadwal dike 2 at 46°S; 349°E ( $\alpha_{95}= 10.3^\circ$ ). This dyke has a multidomain magnetite as the main remanence carrier observed by thermoremanent as well as IRM study. The paleopole position plotted on APWP path correlates well with the dykes from Cuddapah Basin and overall mean of south Indian shield (Radhakrishna et al., 2013) and indicates that this dike was emplaced at  $\sim 2200$  Ma.

## ACKNOWLEDGEMENTS

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## REFERENCES

- Anil Kumar, Nagaraju, E., Jean Besse, and Bhaskar Rao, Y.J., 2012. New age, geochemical and palaeomagnetic data on a 2.21 Ga dyke swarm from south India: Constraints on Paleoproterozoic reconstruction, *Precambrian Research*, v.220, pp: 123-138.
- Anil Kumar, Parashuramulu, V., and Nagaraju, E., 2015, A 2082 Ma radiating dyke swarm in the Eastern Dharwar Craton, southern India and its implications to Cuddapah basin formation, *Precambrian Research*, v.266, pp: 490–505.
- Belica, M.E., Piispa, E.J., Meert, J.G., Pesonen, L.J., Jüri Pladod, Pandit, M.K., Kamenova, G.D., Matthew Celestino, 2014. Paleoproterozoic mafic dyke swarms from the Dharwar craton; palaeomagnetic poles for India from 2.37 to 1.88 Ga and rethinking the Columbia supercontinent, *Precambrian Research*, v.244, pp: 100–122.
- Bleeker, W., 2003. The late Archean record: a puzzle in ca. 35 pieces, *Lithos*, v.71, pp: 99-134.
- Condie, K.C., 1998. Episodic continental growth and supercontinents: a mantle avalanche connection, *Earth Planet. Sci. Lett.*, v.163, pp: 97–108.
- Dawson, E.M., and Hargraves, R.B., 1994. Palaeomagnetism of Precambrian dyke swarms in the Harohalli area, south of Bangalore, India, *Precambrian Research*, v.96, pp: 157–167.
- Fisher, R.A., 1953. Dispersion on a sphere, *Proc. Roy. London, Series A*, v.217, pp: 295-305.
- French, J.E., and Heaman, L.M., 2010. Precise U–Pb dating of Paleoproterozoic mafic dyke swarms of the Dharwar craton, India: Implications for the existence of the Neoproterozoic supercraton Scavia, *Precambrian Research*, v.183, pp: 416–441.
- Halls, H.C., Kumar, A., Srinivasan, R., and Hamilton, M.A., 2007. Palaeomagnetism and U–Pb geochronology of eastern trending dykes in the Dharwar craton, India: feldspar clouding, radiating dyke swarms and position of India at 2.37 Ga, *Precambrian Research*, v.155, pp: 47–68.
- Hargraves, R.B., and Bhalla, M.S., 1983. Precambrian palaeomagnetism in India through 1982: a review. In: Naqvi, S.M., Rogers, J.J.W. (Eds.), *Precambrian of South India*, *Geol. Soc.India Mem.*, v.4, pp: 491–524.
- Jayananda, M., Peucat, J.J., Chardon, D., Krishna Rao, B., Fanning, C.M., and Corfu, F., 2013. Neoproterozoic greenstone volcanism and continental growth, Dharwar craton, southern India: Constraints from SIMS U–Pb zircon geochronology and Nd isotopes, *Precambrian Research*, v.227, pp: 55–76.
- Khanna, T.C., Sessa Sai, V.V., Zhao, G.C., Subba Rao, D.V., Keshav Krishna, A., Sawant, S.S., and Charan, S.N., 2013. Petrogenesis of mafic alkaline dikes from the  $\sim 2.18$  Ga Mahbubnagar Large Igneous Province, Eastern Dharwar Craton, India: geochemical evidence for uncontaminated intra continental mantle derived magmatism, *Lithos*, v.179, pp: 84–98.
- Khanna, T.C., Bizimis, M., Yogodzinski, G. M., and Mallick, S., 2014. Hafnium-neodymium isotope systematics of the 2.7 Ga Gadwal greenstone terrane, eastern Dharwar craton, India: Implications for the evolution of the Archean depleted mantle. *Geochemica et Cosmochemica Acta.*, v.127, pp:10–24.
- Kirschvink, J.L., 1980. The least squares line and plane and the analysis of palaeomagnetic data, *Geophysical Journal of the Royal Astronomical Society*, v.62, pp: 699–718.
- Kusky, T.M., Li, J.H., and Santosh, M., 2007. The Paleoproterozoic North Hebei Orogen: North China Craton's collisional suture with Columbia supercontinent, *Gondwana Research*, v.12, pp: 4- 28.

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- Naqvi, S.M., and Rogers, J.J.W., 1987. Precambrian geology of India, Oxford Monographs on Geology and Geophysics, v.6, pp: 233.
- Radhakrishna, T., and Joseph, M., 1996a, Proterozoic palaeomagnetism of the mafic dyke swarms in the high-grade region of south India, *Precambrian Research*, v.76, pp: 31-46.
- Radhakrishna, T., and Joseph, M., 1996b. Late Precambrian (~850-800 Ma) palaeomagnetic pole of south Indian shield from the Harohalli alkaline dykes; geotectonic implications for the Gondwana reconstructions, *Precambrian Research*, v.80, pp: 77-87.
- Radhakrishna, T., Joseph, M., Krishnendu, N.R., and Balasubramonian, G., 2003. Palaeomagnetism of mafic dykes in the Karnataka Craton: possible geodynamic implications, *Geol. Soc. Lond. Mem.*, v.50, pp: 193-224.
- Radhakrishna, T., Krishnendu, N.R., and Balasubramonian, G., 2013. Palaeoproterozoic Indian shield in the global continental assembly: Evidence from the palaeomagnetism of mafic dyke swarms, *Earth-Science Reviews*, v.126, pp: 370-389.
- Rogers, J.J.W., 1996. A history of continents in the past three billion years, *Journal of Geology*, v.104, pp: 117-154.
- Soderlund, U., Hofmann, A., Klausen, M.B., Olsson, J.R., Ernst, R.E. and Persson, P.O., 2010. Towards a complete magmatic barcode for the Zimbabwe craton: baddeleyite U-Pb dating of regional dolerite dyke swarms and sill complexes, *Precambrian Research*, v.183, pp: 388-398.
- Srinivasan, K.N., 1990. Geology of Veligallu and Gadwal schist belts, *Geological Survey of India Records*, v.5, pp: 123.
- Srivastava, R.K., 2011. *Dyke Swarms: Keys for Geodynamic interpretations*, Springer, 978- 3-642-12496-9.
- Venkatesh, A.S., Poornachandra rao, G.V.S., Prasada Rao, N.T.V., and Bhalla, M.S., 1987. Palaeomagnetic and geochemical studies on dolerite dykes from Tamil Nadu, India, *Precambrian Research*, v.34, pp: 291-310.
- Zhao, G., Sun, M., Wilde, S.A., and Li, S., 2004. A Paleoproterozoic supercontinent: Assembly, growth and breakup, *Earth-Science Reviews*, v.67, pp: 91-123.
- Zijderveld, J.D.A., 1967. Demagnetization of rocks: analysis of results. In: Collinson, D.C., Creer, K.M., Runcorn, S.K. (Eds.), *Methods in Palaeomagnetism*, Elsevier, New York, pp: 254-286.



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