Earth-Science Reviews 126 (2013) 370–389

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Palaeoproterozoic Indian shield in the global continental assembly: Evidence from the palaeomagnetism of mafic dyke swarms

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A R T I C L E I N F O

Article history:
Received 16 March 2013
Accepted 18 August 2013
Available online 7 September 2013

Keywords:
Palaeomagnetism
Palaeoproterozoic
Mafic dykes
Indian shield
Continental reconstruction

A B S T R A C T

Palaeomagnetic study of Palaeoproterozoic mafic dykes in the basement along the margins of the Cuddapah basin, the largest Precambrian sedimentary basin in south India, is presented in detail for a general discussion of Palaeoproterozoic igneous activity in India. The results are compared with all earlier published data on mafic dykes in India and are integrated with recently-published high-precision U–Pb baddeleyite ages to provide a comprehensive account of Palaeoproterozoic igneous activity in India. The analysis consolidates palaeomagnetic poles for six age divisions between 2.45 and 1.85 Ga with robust statistical criteria. Our best estimates of overall mean poles from 241 dykes are situated at (1) $\lambda = 17.7°N$; $\Phi = 106.0°E$ ($A_{95} = 9.0°$; 7N = 24) at c. 2.45 Ga, (2) $\lambda = 7.1°N$; $\Phi = 57.2°E$ ($A_{95} = 4.5°$; N = 69) at c. 2.37 Ga, (3) $\lambda = 41.6°S$; $\Phi = 5.5°E$ ($A_{95} = 5.1°$; N = 34) at c. 2.22 Ga, (4) $\lambda = 4.7°N$; $\Phi = 343.0°E$ ($A_{95} = 4.4°$; N = 31) at 2.18 Ga, (5) $\lambda = 49.2°N$; $\Phi = 332.9°E$ ($A_{95} = 4.8°$; N = 24) at 1.99–1.89 Ga and (6) $\lambda = 73.7°N$; $\Phi = 282.6°E$ ($A_{95} = 2.9°$; N = 39) at 1.86 Ga. The data permit us to construct an apparent polar wander path for the Indian shield for an ~600 Ma interval of the Palaeoproterozoic eon (2.45–1.85 Ga). Testing and evaluation of continental reconstructions for this interval, which are mostly based on geological correlations, reveal many inconsistencies. Between 2.45 and 2.37 Ga, the Indian shield was situated at higher latitudes similar to the Yilgarn craton of Australia. It was subsequently located near the equator at 2.22, 2.18, 1.99 and 1.86 Ga. Thus, an India–Australia connection is supported during these times, but a proposed Australia–Kaapvaal link in "Zimvaalbara" and a Dharwar (India)–Slave connection in "Sclavia" or a Superior–Zimbabwe–India connection in "Superia" are inconsistent with Indian data. In addition, the close palaeomagnetic comparison between the Palaeoproterozoic dykes of Dharwar–Bastar–Bundelkhand cratons in India indicates an age of >2.45 Ga for orogenic activity along the central Indian tectonic zone; hence, matching this zone with the 2.0–1.8 Ga Trans-North China orogenic belt, or positioning North China adjacent to India or juxtaposition of the Indian shield along the western margin of Laurentia in the Columbia reconstructions is not supported. The Indian data appear to be in accord with the essential features of the refined Protopangaea model and the original Ur configuration. Finally, the results are interpreted in terms of four dyke emplacement events in the age range 2.45–2.18 Ga linked to short-lived (5–10 Ma) LIPs developed over mantle plumes. The dykes of ~1.99–1.89 Ga age probably relate to continued long lived igneous activity while the ~1.86 Ga dykes are relatively fewer in number and may represent waning stage of a large igneous event related to a major mantle plume.

Contents

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0012-8252/$ – see front matter
http://dx.doi.org/10.1016/j.earscirev.2013.08.011

1. Introduction

Estimates of continental crust generation (e.g. Abbott et al., 2000; Belousova et al., 2010) suggest that a significant (50–80%) part of crust was generated by the end of the Palaeoproterozoic. Therefore, the Palaeoproterozoic is an important interval of crustal growth in Earth's history and palaeomagnetic results provide crucial evidence for spatially constraining the configuration and global location of this early-formed crust. Mafic dykes have been regarded as promising targets for palaeomagnetic constraints because they occur in abundance in all Precambrian shield areas and belong to multiple episodes that punctured the crust repeatedly at different times during the Palaeoproterozoic, their magnetizations are easy to measure and their ages can often be defined with reasonable degrees of precision.

Palaeoproterozoic mafic dykes occur in profusion in the Indian shield. Palaeomagnetic studies of these dykes, initiated as early as in the 1960s, were not well focused and involved scattered sampling over large areas. Most of the studies are also of variable quality in terms of statistics and cleaning tests. Hargraves and Bhalla (1983) provided an excellent review of these studies. These authors classified the dykes into five distinct groups and emphasized the need for isotopic dating. In the past three decades, some significant studies have been reported mostly from the western Dharwar craton and the adjoining granulite region in the south (Dawson and Hargraves, 1994; Radhakrishna and Joseph, 1996a,b; Radhakrishna et al., 2003; Halls et al., 2007; Kumar et al., 2012; Dash et al., 2013). However, in spite of the extensive and widespread occurrence of mafic dykes around the Cuddapah basin, the largest Palaeoproterozoic sedimentary basin in the south Indian shield (Fig. 1), the available palaeomagnetic record is very meager. Notable additions in the past three decades include studies of about thirty five dykes (5 dykes by Kumar and Bhalla, 1983; 5 by Rao et al., 1990; 3 by Pradhan et al., 2010 and others by Poornachandra Rao, 2005 and Goutham et al., 2011), but these studies lack reliable age support.

We have carried out palaeomagnetic studies for over five years (1997–2002) on mafic dykes occurring over 1500 km^2 around the Cuddapah basin focusing on four areas where the dyke density is highest (Tirupati–Raychoti; Anantapur–Gooty; Mahabubnagar–Wanaparthy and Nalgonda–Khammam: see Fig. 1). Efforts to determine isotopic ages were not successful in yielding reliable ages although recently U–Pb baddeleyite age determinations have been reported for dykes from these and adjoining areas of our study (Halls et al., 2007; French et al., 2008; French and Heaman, 2010). Using these and other reliable ages, our aim here is to report a palaeomagnetic review for the Palaeoproterozoic of India based on a large regional sample and by comprehensive demagnetizations and integrating the results with high precision isotopic age data; we review the earlier work in the context of our results to consolidate the Palaeoproterozoic palaeomagnetic record for the south Indian shield, determine a Palaeoproterozoic apparent polar wander (APW) path and employ this to evaluate global continental reconstructions as well as testing the link to large igneous provinces related to mantle plumes.

2. Geological setting

The geological setting of the basement and the mafic dykes in the South Indian shield, including the dyke swarms around the Cuddapah basin, has been the subject of numerous publications and recent reviews (Halls, 1982; Drury et al., 1984; Murthy, 1987; Murty et al., 1987; Radhakrishna et al., 1999, 2003; Halls et al., 2007; Ramakrishnan and Vaidyanadhan, 2008; French and Heaman, 2010). The geological framework is shown in Fig. 1. The Archaean granite–greenstone terrain, popularly known as Dharwar craton, represents the oldest cratonic nuclei of the south Indian Shield. The western region of this craton is in Karnataka state and the eastern part extends into Andhra Pradesh state. The greenstone region grades into granulite facies terrain in the south. The whole region underwent tectono-metamorphism and had stabilized by 2.5 Ga, except in the extreme southern part of the granulite region where a Pan-African tectonothermal imprint is more strongly prevalent. A great thickness of ~9 km of sediments comprises the Cuddapah Basin that constitutes the easternmost part of the craton.

Mafic dykes of tholeiitic composition and diverse directional trends traverse the gneiss/granitic basement and the greenstone belts of the Dharwar craton and the proximal areas of the granulite region. Dyke occurrences are very prolific in the cratonic region adjoining the Cuddapah basin. Strike extensions of several dykes in the craton can be traced up to the close vicinity of the basin. Cross-cut relations of dykes in the field around the Cuddapah Basin (Murty et al., 1987) coupled with recent U–Pb baddeleyite/zircon dating (Halls et al., 2007; French and Heaman, 2010) suggest that the mafic dykes manifest widespread igneous activity in the Palaeoproterozoic. Igneous rocks also occur in the lower stratigraphic horizons of the Cuddapah Basin as lava flows and sills. Sills at Pulivendla and Tadpatri have been dated at 1899 ± 20 Ma by $^{40}Ar/^{39}Ar$ dating of phlogopite (Anand et al., 2003) and at 1885.4 ± 3.1 Ma by U–Pb dating of baddeleyite (French et al., 2008).

E–W trending dykes, designated as the ‘Bangalore Swarm’, are considered to constitute the most prominent dyke swarm in the Dharwar craton and are observed to extend for about 500 km across the South Indian shield (Halls, 1982; Halls et al., 2007). These dykes have highest density in Tirupati–Raychoti area (Figs. 1 and 2) at the southwestern margin of the Cuddapah Basin. The dykes trend westwards from the basin margin and can be traced across the Dharwar craton for over 400 km up to the west coast of India. E–W trending dykes are scarce on the western and northern margin of the basin where NW–SE and NE–SW dykes become predominant. The NE–SW trending dykes in these areas are suggested to constitute the E–W Bangalore swarm under the premise that the E–W swarm swings into a NE–SW direction towards the north (Halls, 1982). Although E–W dykes are predominant in the Tirupati–Raychoti area (Fig. 2D), NW–SE trending dykes also occur sporadically. These dykes are seen extending to the west of the Cuddapah basin for several kilometers. Further north on the western