Occurrence of N–R–N sequence in the Malwa Deccan lava flows to the north of Narmada region, Madhya Pradesh, India

Deccan volcanism with a tremendous burst of volcanic activity at the end of Cretaceous marks a unique episode in the Indian geological history. This flood basalt province occupies a central position today because it focuses on the K/T boundary and mass extinctions and possibilities of meteorite impacts. Deccan, the Queen of 'Kingdom of Petrology', has played an important role in developing global models such as 'continental rifts, continental break-up, the formation of new oceans and uplift of continental land masses outside mountain belts' and generation of huge amounts of basaltic magma by melting[1]. Devey and Lightfoot[2] demonstrated that the lack of any evidence for compression tectonics in this area since the lava flows were erupted, leads to the conclusion that the rifting of the western Indian margin and India's rapid northward movement were probably important factors in the generation of fold structures in Deccan traps which might have been generated by vertical movements of the crust. Magnetostratigraphy has proved to be an important tool in understanding various geological problems related to polar wandering, structural and tectonic configuration of the lava flows. Even though most of the flows appear horizontal in the field, palaeomagnetic results have thrown some light on the structural configuration of the region by recognizing faults in Nilkanth and Bharudpura stratigraphic sections[3]. Khadri *et al.*[4] have provided new information on the possible extension of Western Ghat sequence into the Malwa region and also constraints on regional correlations and structure.

Palaeomagnetic investigations were carried out on 500 oriented block samples belonging to 32 lava flows from the north of Narmada river (Figure 1). Natu-

Table 1. Palaeomagnetic results of lava flows exposed in the Singarchori–Jamdarwaza–Mandaleshwar composite section, some showing later remagnetization

Flow no.	Sample no.	Ht (m)	T (m)	N	K	Q_n	NRM D	NRM I	NRM J_n	After AFD D	After AFD I	After AFD J_n	After TD D	After TD I	After TD J_n	P
xxxii	SIN1.1b	881	36	6 (18)	11.85	3.76	320	–47	11.76	330	–51	6.23	–	–	–	N
xxxi	SIN7.2a	840	20	4 (12)	8.93	2.31	284	+23	7.31	296	+42	3.76	–	–	–	M
xxx	SIN11.1a	815	10	3 (10)	7.65	0.98	121	+50	6.27	–	–	–	69	+48	1.22	M
xxix	SIN14.2c	790	10	2 (8)	14.51	1.76	161	+37	8.23	–	–	–	156	+51	3.18	R
xxviii	SIN16.1b	770	15	2 (13)	12.32	0.45	102	+21	7.66	138	+42	3.21	–	–	–	R
xxvii	SIN20.1a	730	40	4 (14)	6.45	3.12	138	+45	4.21	141	+49	1.76	–	–	–	R
xxvi	JAM1.1a	715	10	2 (6)	5.23	1.76	156	+31	7.62	–	–	–	157	+40	3.31	R
xxv	JAM3.2b	710	15	2 (8)	12.81	0.98	101	–10	5.42	–	–	–	134	+31	0.32	R
xxiv	JAM5.1c	700	10	2 (7)	9.78	0.45	129	+40	6.60	131	+43	1.32	–	–	–	R
xxiii	JAM7.2b	680	10	3 (9)	4.52	1.71	178	+21	11.10	152	+37	3.38	–	–	–	R
xxii	AM11.3a	665	20	3 (11)	16.98	0.43	157	+42	7.62	–	–	–	148	+38	1.70	R
xxi	JAM13.1b	650	15	1 (4)	6.53	0.87	165	+31	4.23	–	–	–	161	+39	1.02	R
xx	JAM14.2b	640	10	2 (8)	13.26	0.51	144	+29	5.51	154	+32	0.78	–	–	–	R
xix	JAM16.1c	620	35	1 (5)	5.66	1.62	198	+11	9.72	165	+30	2.16	–	–	–	R
xviii	JAM17.1a	605	15	2 (8)	21.17	0.98	137	+28	7.62	–	–	–	148	+38	1.70	R
xvii	JAM19.1b	580	25	2 (7)	12.45	1.77	145	+42	4.16	–	–	–	141	+46	0.73	R
xvi	JAM21.3b	560	20	1 (5)	10.32	0.37	171	+28	11.92	143	+40	2.32	–	–	–	R
xv	JAM22.1a	540	30	1 (4)	8.91	1.60	156	+32	6.16	157	+37	1.03	–	–	–	R
xiv	JAM23.1c	520	15	1 (5)	6.23	0.76	128	+29	5.42	–	–	–	140	+37	1.62	R
xiii	JAM24.1b	505	15	1 (4)	11.17	0.45	133	+41	4.21	–	–	–	138	+46	0.39	R
xii	JAM25.1a	475	35	2 (8)	8.92	1.07	189	+28	6.21	146	+38	0.98	–	–	–	R
xi	JAM27.1c	435	15	2 (7)	7.68	1.98	155	+36	4.42	154	+42	0.36	–	–	–	R
x	JAM29.3b	410	35	1 (5)	6.21	0.92	178	+51	6.27	–	–	–	161	+49	1.07	R
ix	JAM30.1b	395	15	1 (4)	15.32	1.86	150	+33	4.44	–	–	–	153	+41	0.91	R
viii	JAM31.1a	380	30	2 (8)	7.21	2.30	139	–11	6.21	154	-36	2.78	–	–	–	M
vii	JAM33.2b	355	35	2 (6)	9.76	1.88	327	–45	8.63	330	-46	4.40	–	–	–	N
vi	JAM35.1c	310	40	2 (8)	5.62	0.77	315	–20	14.20	–	–	–	337	–52	4.42	N
v	JAM37.2b	295	20	2 (7)	8.18	0.61	301	–29	7.62	–	–	–	323	–41	2.63	N
iv	JAM39.1a	275	20	2 (6)	4.20	0.98	210	–38	8.92	289	–47	1.64	–	–	–	N
iii	MAN1.2b	230	20	2 (8)	9.85	1.76	305	–40	5.10	310	–42	0.99	–	–	–	N
ii	MAN4.1a	180	60	4 (16)	11.63	0.31	278	–61	4.42	–	–	–	297	–58	1.02	N
i	MAN7.1c	160	20	2 (8)	13.72	0.62	332	–48	6.41	–	–	–	328	–47	1.64	N

Ht, Height; T, Thickness; N, Number of samples (specimens); K, Magnetic susceptibility $\times 10^{-4}$ emu/g; Q_n, Koenigsberger ratio (J_n/J_i); D, Declination (East of North); I, Inclination (downward inclination +ve; upward inclination –ve); J_n, Natural remnant magnetic intensity $\times 10^{-4}$ emu/gm; J_i, Induced remnant magnetic intensity $\times 10^{-4}$ emu/g. P, Polarity; N, Normal; R, Reversal; M, Mixed.

Table 2. Magneto-stratigraphic correlation of various epochs present in the study area and the adjoining areas across the Narmada river

Polarity	Wensink[15]	Sreenivasa Rao *et al.*[7]	Dhandapani and Subbarao[10]	Khadri and Nagar[3]	This study
Upper normal	Nipani Normal Epoch	Satpura Normal Epoch	Satpura Normal Epoch	–	Satpura Normal Epoch
Reversal	Deccan Reversal Epoch	Malwa Reversal Epoch	Deccan Reversal Epoch	Malwa Reversal Epoch	Malwa Reversal Epoch
Lower normal	–	Narmada Normal Epoch	Narmada Normal Epoch	Narmada Normal Epoch	Narmada Normal Epoch

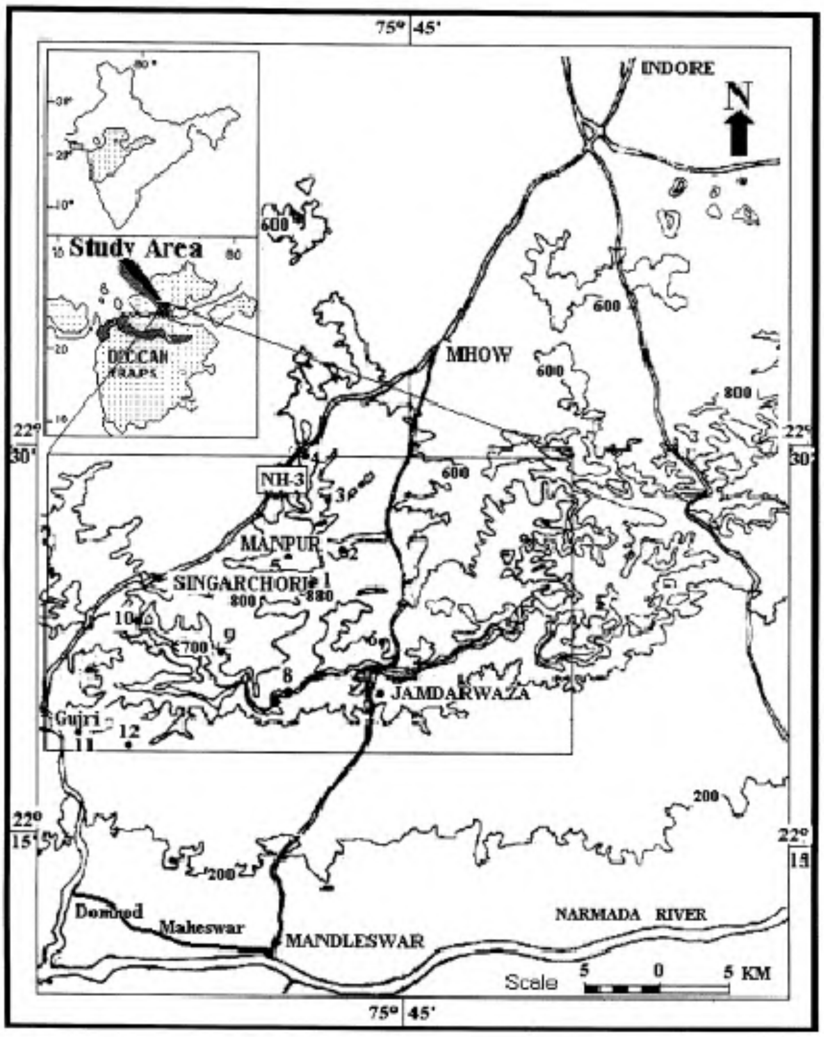

Figure 1. Location map of the study area showing field traverses. 1, Singarchori; 2, Sagwa; 3, Janapav Temple; 4, Nandlai Chowki; 5, Jhakroriya; 6, Dudmal; 7, Jamdarwaza; 8, Chapripura; 9, Kurda Peerpatar; 10, Jamanjhiri; 11, Gujri; 12, Rabarghat–Holimal–Manawar.

ral remnant magnetization (NRM) values were carried out using the astatic magnetometers with sensitivity 2.53×10^{-3} A/m – 2.33×10^{-5} A/m and Molspin spinner magnetometer. Induced magnetization (J_i) and magnetic susceptibility in a field of 0.5 Oe and Koenigsberger ratio ($Q_n = J_n/J_i$) were determined by using the low field susceptibility apparatus[5,6]. Alternating field demagnetization (AFD) and thermal demagnetization (TD) techniques were used for removing soft secondary components.

Existing palaeomagnetic data on Deccan Traps indicate the presence of N–R–N sequence of which N–R is the older one. In most of the areas, only one reversal is exposed, however, Sreenivasa Rao *et al.*[7] have reported the presence of N–R–N sequence to the south of Narmada river while northern side exposes only the N–R sequence. I have carried out magneto-stratigraphic investigations to the north of the Narmada river with an aim to probe further the presence of younger N polarity to the south.

The results show the presence of lower normal polarity for the seven flows from the base of the Narmada river followed by a thick sequence of twenty-four lava flows showing reversed polarity (Flow nos. ix to xxvi). A thin sequence of 'normal' flows on the top of the Singarchori hill (Flow no. xxxii). However, a flow of mixed polarity horizon indicating the transition zone has been identified below the upper normal horizon with positive inclinations, indicating a change in the Earth's magnetic field during that period which specifically denotes magnetic excursions (Table 1; Figure 2).

Even though the polarity transition (mixed polarity) is traced in many other traverses in the region, upper normal flows are absent in surrounding areas probably due to the complete removal of such younger flows by erosional processes. The transition from lower normal to middle reversed polarity has taken place at 380 m in the Jamdarwaza–Mandaleshwar traverse whereas the presence of R–N transition zone showing mixed polarity is noticed from 820 m onwards. However, in the Singarchori traverse the transition from the mixed polarity to upper normal flows has taken place at 845 m.

Relative susceptibility (77 K/300 K), coercive force (H_c), relative remnance (J_r/J_s) and Curie temperatures (T) are used in estimating titano-magnetite (TM) compositions. Majority of the specimens show TM 40 + x to TM 60 + x, where 'x' is an unidentified component. True TM0 magnetite grains are almost absent, however, combinations of TM0 to TM10 do appear to exist. In general, the Narmada volcanics showed varied compositions of titano-magnetite ranging from TM0 to TM60 with variable mixtures of magnetic domain states. A few specimens have showed MD magnetite grains. Whereas,

Table 3. Palaeomagnetic results of the Singarchori volcanics and related volcanic provinces

			Mean NRM		Pole position		Ancient latitude study				
Location	Lat.	Long	D°	I°	Lat.	Long	Nagpur	Area	P	ρ	m
Singarchori Normal (U)	22.58	75.5	346	−59	32°N	82°W	26°S	24°S	N	3	6
Malwa Reversed	22.45	75.65	156	+52	33°N	80°W	32°S	26°S	R	2	3
Narmada Normal (L)	22.35	75.58	314	−48	38°N	90°W	29°S	30°S	N	3	5
Mandu Reversed	22.35	75.43	150	+47	32°N	82°W	30°S	31°S	R	4	6
Mandu Normal (L)	22.35	75.43	355	−42	36°N	89°W	29°S	30°S	N	6	8
Khalghat Mhow Reversed	22.50	75.67	159	+50	33°N	83°W	31°S	32°S	R	3	5
Khalghat Mhow Normal (L)	22.33	75.57	347	−48	37°N	90°W	29°S	30°S	N	3	5
Satpura Normal (U)	21.46	75.58	356	−36	48°N	99°W	21°S	22°S	N	10	16
Bistan Pipaljhopa Reversed	21.83	75.67	1493	+51	29°N	74°N	33°S	34°S	R	3	9
Narmada Normal (L)	21.15	75.67		−65	17°N	87°W	48°S	49°S	N	5	6
Mahabaleshwar Normal (U)	17.9	73.70	339	−57	31°N	87°W	38°S	34°S	N	8	10
Mahabaleshwar Reversed	17.9	73.70	157	+57	35°N	83°W	33°S	29°S	R	3	5
Western Ghat	19.60	73.60	145	+54	28°N	75°W	35°S	31°S	R	4	6
Dyke Kalsubai	19.60	73.60	152	+52	31°N	78°W	33°N	29°N	R	3	4

D°, Declination; I°, Inclination; Lat, Latitude; Long, Longitude; P, Polarity; ρ, minor axis of eclipse; m, major axis of eclipse. See refs 3, 7, 16–18.

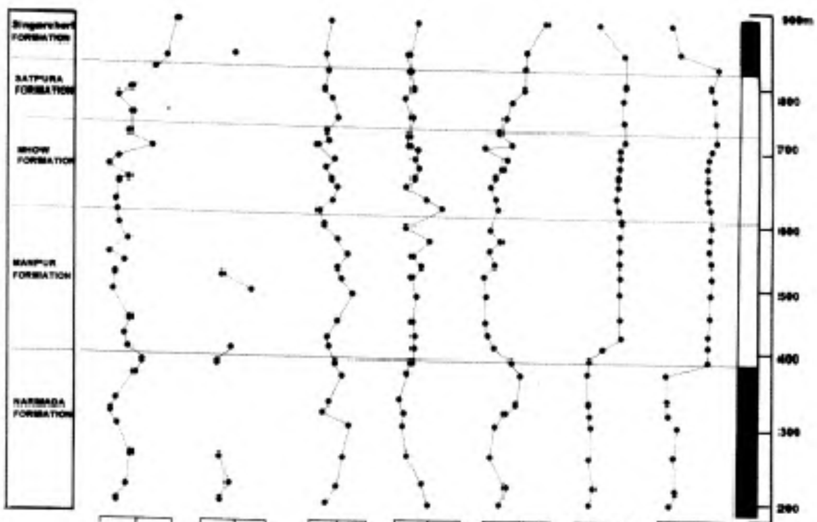

Figure 2. Magneto-stratigraphy of the study area vs Q_n, PS, RS, K, J_n, I and D. Q_n, Koenigsberger ratio (J_n/J_i); J_i, Induced magnetization × 10^{-4} emu/g; PS, Peak susceptibility at 120 K/300 K; RS, Relative susceptibility at 77 K/300 K; K, Magnetic susceptibility × 10^{-4} emu/g; J_n, Natural remnant magnetization intensity × 10^{-4} emu/g; D, Declination (east of North); I, Inclination (Downward inclination +ve and Upward inclination −ve).

about 85% of the specimens showed combination of SD, CD and SP magnetite grains in variable proportions. It is also clear that while SD grains and mixtures of SD + CD magnetite grains have given stable palaeomagnetic directions, the formations of MD magnetite partially or wholly obliterates the original NRM direction.

Geomagnetic polarity transition on the northern part of Narmada was correlated with that of the surrounding areas, the marine magnetic polarity time scale of Le Brecque *et al.*[8] and polarity epochs of Harland *et al.*[9] to understand the nature and time of polarity epochs. The lower normal and middle reversed sequences exposed in the study area are comparable with 'Narmada Normal Epoch' and 'Deccan Reversal Epoch' or 'Malwa Reversal Epoch' (Table 2; Figure 3). However, the Upper Normal exposed at the Singarchori region is comparable with the 'Satpura Normal Epoch'[7,10,11]. Ancient pole positions have been computed for the study area and the results have been correlated with the adjoining regions to understand the regional picture (Table 3).

Courtillot *et al.*[12], Duncan and Pyle[13] and Venkatesan and Pande[14] have indicated that a majority of volcanic episodes of Deccan Traps were spread over a maximum period of 6 Ma. The lower normal and reversed polarity epoch is comparable with 33R chron whereas the upper normal polarity epoch is comparable with 29R chron. The different epochs exposed in the study area are correlatable with the surrounding areas of the Narmada region (Table 2)[15–18]. A thick reversed pile capped by a thin normal sequence has been established through the present study to the north of the Narmada river. It can be concluded that at the time of formation of the Narmada

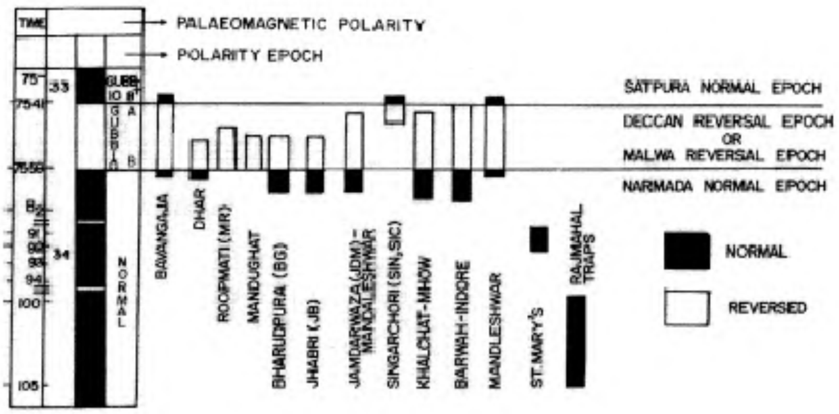

Figure 3. Correlations of geomagnetic polarity transitions of Singarchori sequence with other selected sequences from the Narmada region and Mesozoic volcanic traps with marine magnetic scale of La Brecque *et al.*[8] and polarity epochs of Harland *et al.*[9].

volcanics, India perhaps might have occupied the Southern latitude of 29° and drifted to 50° North to occupy the present position, which is more than 5000 km distance since the time of formation of these lavas.

1. Subbarao, K. V. (ed.), *Deccan Volcanic Province, West, Mem. Geol. Soc. India*, 1999, **1**, 547.
2. Devey, C. W. and Lightfoot, P. C., *Bull. Volcanol.*, 1986, **48**, 195–207.
3. Khadri, S. F. R. and Nagar, *J. Geol. Soc. India*, 1994, **29**, 199–209.
4. Khadri, S. F. R., Walsh, J. N. and Subbarao, K. V., *J. Geol. Soc. India*, 1999, **43**, 203–218.
5. Likhite, S. D. and Radhakrishnamurthy, C., *Curr. Sci.*, 1966, **35**, 534–536.
6. Radhakrishnamurthy, C., Likhite, S. D., Deutsch, E. R. and Murthy, G. S., *Proc. Indian Acad. Sci.*, 1978, **87**, 235–243.
7. Sreenivasa Rao, M., Ramasubba Reddy, N., Subbarao, K. V., Prasad, C. V. R. K. and Radhakrishnamurthy, C., *J. Geol. Soc. India*, 1985, **26**, 617–639.
8. Le Brecque, J. L. Kent, D. V. and Cande, S. C., *Geology*, 1977, **5**, 330–335.
9. Harland, W. B., Cox, A. V., Latewellyn, P. G., Pickton, C. A. G., Smith, A. G. and Walters, R. (eds), in *A Geological Time Scale*, Cambridge University Press, New York, 1982, pp. 63–84.
10. Dhandapani, R. and Subbarao, K. V., *Mem. Geol. Soc. India*, 1922, **24**, 63–79.
11. Khadri, S. F. R., *Gond. Geol. Mag.*, 1996, **2**, 17–29.
12. Courtillot, V., Feraud, G., Vendamme, D., Maluski, H., Moreal, M. G. and Besse, J. J., *Nature*, 1988, **333**, 843–844.
13. Duncan, R. A. and Pyle, D. G., *Nature*, 1988, **333**, 841–843.
14. Venkatesan, T. R. and Pande, K., Contributions from the seminar cum workshop IGCP, Chandigarh, 1990, vols 216 and 245, pp. 25–26.
15. Wensink, H., *Tectonophysics*, 1973, **17**, 41–59.
16. Sahasrabudhe, P. W., *J. Ind. Geophys.*, 1965, **2**, 17–27.
17. Radhakrishnamurty, C., *Palaeogeophysics* (ed. Runcorn, S. K.), London Academic Press, London, 1970, pp. 235–241.
18. Khadri, S. F. R., Ph D thesis, IIT, Mumbai, 1989, p. 418.

ACKNOWLEDGEMENTS. Financial assistance from the Department of Science and Technology, New Delhi and University Grants Commission, New Delhi in the form of major research projects are thankfully acknowledged. The assistance provided during the fieldwork by Shri P. Srinivasa Rao is thankfully acknowledged. I also thank Prof. K. V. Subbarao and Late Professor C. Radhakrishnamurthy for their constant encouragement, guidance and critical review of the manuscript. Comments made by the anonymous referee are thankfully acknowledged.

Received 11 March 2002; revised accepted 8 August 2003

S. F. R. KHADRI

Department of Geology,
Amravati University,
Amravati 444 602, India
e-mail: syedkhadrisfr@rediffmail.com

Role of micro-organisms in weathering of the Konkan–Goa laterite formations

Mineralogy, microbial ecology and weathering in the subsurface are an intimately linked biogeochemical system. It is established beyond doubt that the microorganisms play an important role as geologic agents. For example, it is known that since the early Precambrian, the microbes have played an active role in the evolution of the earth's surface including the uppermost lithosphere and the hydrosphere. All types of igneous, sedimentary and metamorphic rocks are susceptible to microbial weathering, including siliceous and calcareous rocks[1]. Bacterial communities dissolve the primary rock-forming minerals to obtain essential nutrients and also act as nucleation sites for the precipitation of secondary minerals. Generally, the biological weathering of silicates is driven by the nutrient requirements of the microbial communities. The progression of mineral weathering may also be influenced by a mineral's nutritional potential with the microorganisms destroying only the beneficial minerals.

Fungal activity is reported to release metallic and silicate ions from minerals and rocks[2]. Cyanobacteria are important actors in weathering of rock surfaces[3]. The activity of *Clostridium butyricum* results in reduction of pedogenic iron oxides[4]. Lichen activity in granites results in the formation of bioweathered granitic biotite[5]. Various kinds of bacteria, fungi, algae and protozoa serve as geochemical agents in the uppermost lithosphere, promoting rock weathering and mobilizing the mineral constituents[1]. Eubacteria