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Petrochemical studies on the epicentral region of the recent Jabalpur earthquake

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We report presence of five physically distinct and chemically dissimilar basaltic lava flows in the Kosamghat, the epicentral region of the Jabalpur earthquake. The major shift (~ 150 m) in the stratigraphic height of the fifth lava flow at the western flank of the Nagapahar range suggests the presence of a NE–SW trending post-Deccan normal fault in the region.

JABALPUR area has witnessed intensive investigations after the devastating earthquake (*M* 6) struck the Kosamghat region on 22 May 1997. Preliminary studies by Gupta *et al.*[1] on earthquake parameters, aftershocks and focal mechanism have indicated its epicentre to lie at 30 km south-east of Jabalpur near Kosamghat. Acharyya *et al.*[2] based on aftershock macroseismic and microseismic studies have delineated a 35 km long and 15 km wide, ENE–WSW trending meizoseismal zone of an intensity VIII (MSK). They also observed that five aftershocks of $M > 3.0$ and twenty-three aftershocks of $M = 1.5$ to < 3.0 were concentrated in an elongated area of 15×10 km^2 near the main shock epicentre. The epicentral region (long. 80.1°E, lat. 23.1°N), i.e. Kosamghat falls within the Deccan Trap outlier (commonly referred to in the literature as Eastern Deccan Volcanic Province) and its comprehensive stratigraphic framework is available elsewhere[3,4]. The main shock and aftershocks are considered to be the result of reactivation of a deep-rooted seismogenic ENE–WSW trending South Narmada Fault (Figures 2 and 3 in ref. 2) that lies

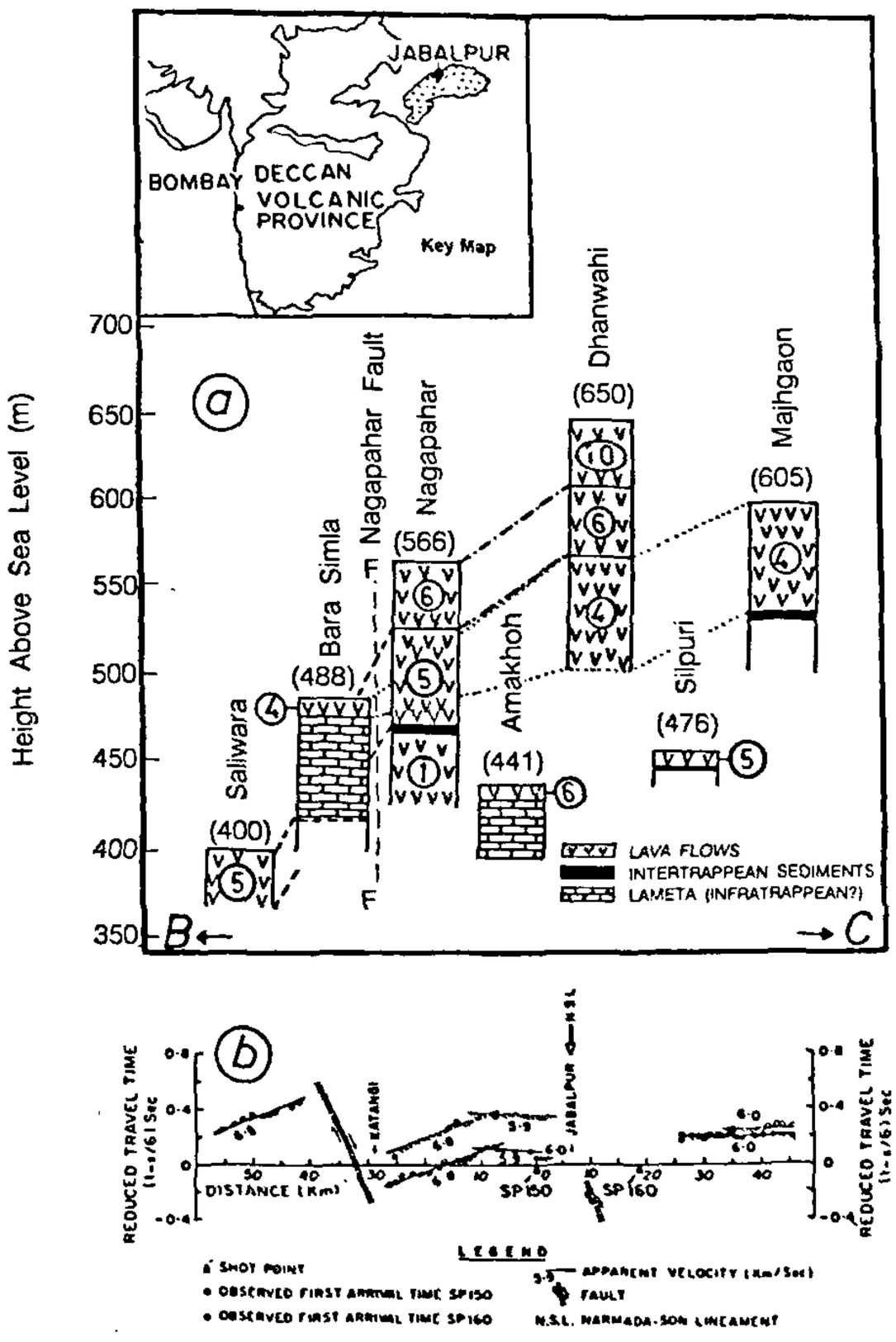


Figure 1. *a*, Stratigraphic correlation of lava flows in measured sections adjacent to Nagapahar Fault. Relative positions are from east to west along B–C traverse. The numbers encircled correpond to flow numbers (see Figure 2.5 in ref. 3); *b*, Faults shown in reduced travel time of DSS north and south of Jabalpur[11].

**For correspondence.

Table 1. Modal percentage of mineral phases and glass for fifteen basalt samples

Flow no.	Section	Py (P)	Pl (P)	Py (G)	Pl (G)	Ol	Mt + Opq	Ch	Glass	Total
1	Nagapahar	4.29	12.28	10.04	8.43	0.22	60.95	4.00	–	100.21
5	Nagapahar	7.90	23.20	11.30	12.90	–	33.20	11.50	–	100.00
6	Nagapahar	9.55	16.70	24.50	22.60	–	25.15	1.55	–	100.05
4	Barasimla	1.25	7.55	32.05	15.45	–	35.35	7.15	2.00	100.80
5	Saliwara	14.68	27.95	15.13	8.24	–	26.70	6.94	0.39	100.03
6	Amakhoh	2.50	9.20	25.85	27.15	–	19.60	13.55	2.15	100.00
4	Dhanwahi	3.95	3.65	32.05	37.75	–	16.30	6.40	–	100.10
4	Dhanwahi	5.72	6.62	31.89	31.54	–	15.87	8.61	–	100.25
4	Dhanwahi	10.75	30.85	16.02	21.94	–	10.85	7.56	2.14	100.11
6	Dhanwahi	7.26	27.01	21.14	26.57	–	6.37	11.39	0.05	99.79
6	Dhanwahi	1.40	12.69	28.06	28.25	–	21.19	7.26	0.65	99.50
10	Dhanwahi	21.13	19.40	14.87	21.77	2.65	7.50	13.50	–	100.82
10	Dhanwahi	29.55	26.87	8.51	23.93	2.75	6.68	2.44	–	100.79
5	Silpuri	15.75	25.40	16.20	9.80	–	20.00	10.35	3.10	100.60
4	Majgaon	1.87	12.30	47.30	26.30	–	6.65	5.25	0.50	100.67

Py (P), Pyroxene phenocryst; Pl (P), Plagioclase phenocryst; Py (G), Pyroxene groundmass; Pl (G), Plagioclase groundmass; Ol, Olivine; Mt + Opq, Magnetite + opaque; Ch, Chlorophaeite; Gl, Glass (r).

Table 2. Major oxide data and calculated parameters for the five different lava flows around Kosamghat

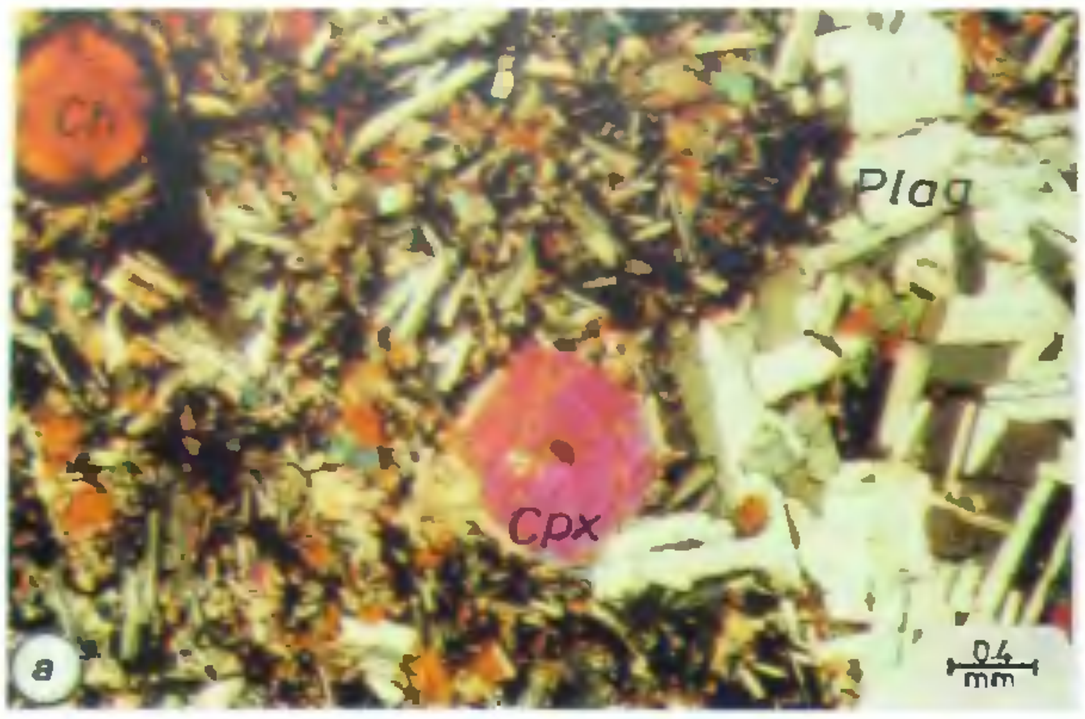
Flow no.	1	4	5	6	10
Oxides					
SiO_2	48.01	48.90	49.05	48.65	47.20
TiO_2	1.96	2.63	2.77	2.47	1.56
Al_2O_3	13.80	14.43	12.85	13.10	14.09
Fe_2O_3*	14.32	15.10	15.42	14.22	14.05
MnO	0.13	0.17	0.16	0.13	0.22
MgO	5.75	5.25	5.40	5.10	7.72
CaO	10.39	9.79	9.68	9.74	11.28
Na_2O	2.62	2.76	2.34	2.91	1.95
K_2O	0.22	0.39	0.38	0.34	0.20
P_2O_5	0.17	0.23	0.26	0.19	0.16
LOI	2.63	1.35	1.69	2.15	1.57
Total	100.00	100.65	100.00	99.85	100.00
CIPW norms (in mole%)					
Q	0.02	0.81	3.82	1.42	–
Oth	1.30	2.31	2.25	2.01	1.18
Ab	22.17	23.35	19.80	24.62	16.50
An	25.25	25.84	23.44	21.68	29.11
Ne	–	–	–	–	–
Di	20.89	17.66	19.03	21.10	21.22
Hy	19.29	19.59	19.45	16.58	17.98
Ol	–	–	–	–	–
Mt	3.11	3.28	3.35	3.09	3.06
Il	3.72	4.99	5.26	4.69	2.96
Ap	0.40	0.54	0.62	0.45	0.38

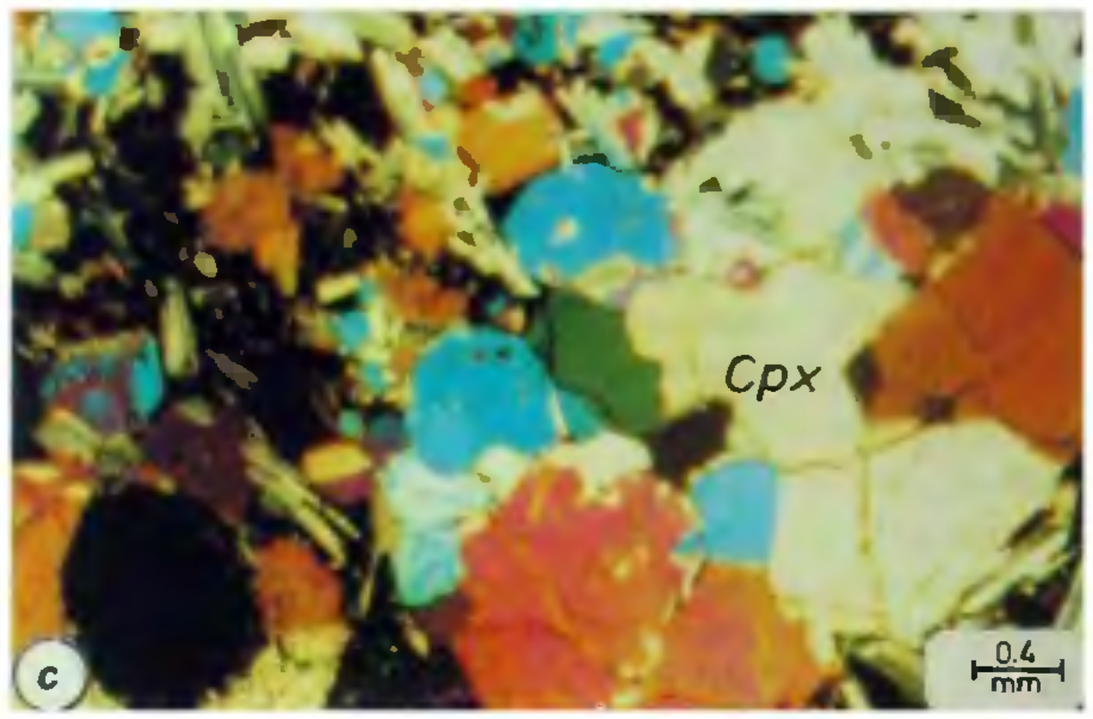
*Total iron determined as Fe_2O_3.

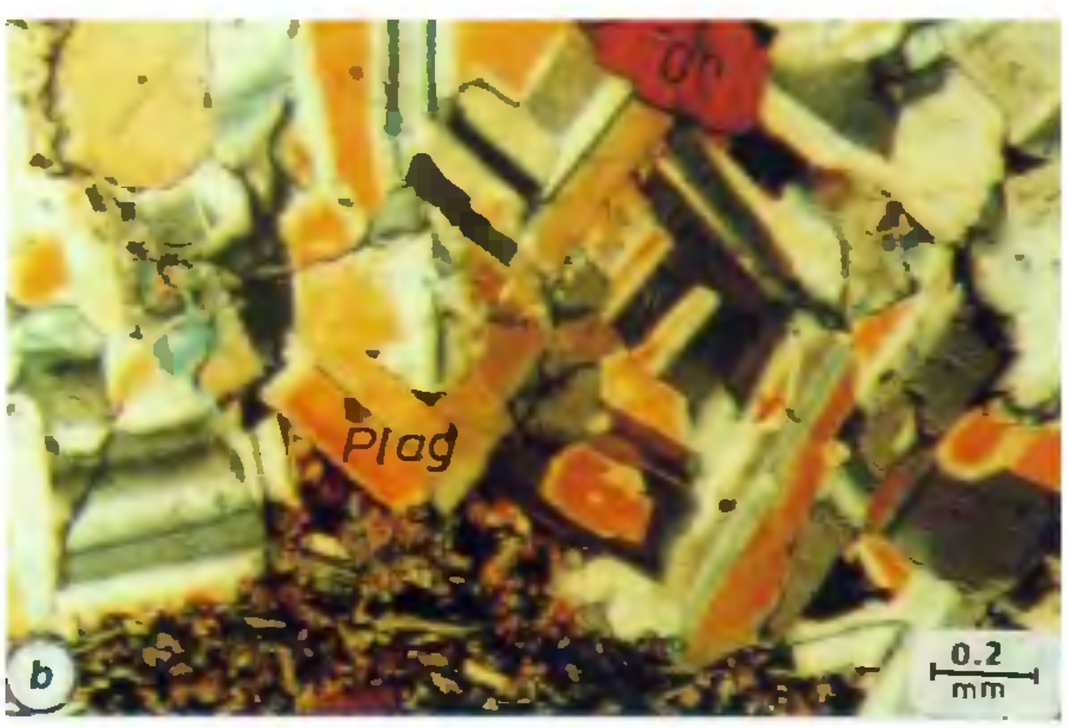
Table 3. Trace, rare earth element data, elemental ratios and calculated parameters for the lava flows around Kosamghat

Flow no.	1	4	5	6	10
Trace elements					
Sc	33.15	35.18	42.65	38.90	41.83
Zn	102.15	123.16	135.01	119.66	93.63
Nb	12.53	33.94	21.62	25.89	10.69
Hf	3.39	4.52	4.56	4.33	2.93
V	377.36	348.28	415.73	414.74	326.80
Ga	21.22	22.60	22.88	22.03	18.22
Ta	2.06	4.86	2.97	7.60	1.76
Cr	138.10	77.12	59.13	56.20	394.99
Rb	4.09	6.06	6.05	2.79	5.40
Cs	0.13	0.71	0.32	3.18	0.37
Pb	2.47	4.12	4.06	2.60	2.69
Co	51.69	48.27	51.21	51.96	51.44
Sr	192.07	279.33	202.45	197.30	157.93
Ba	44.00	196.04	145.88	84.21	79.97
Ni	151.07	93.95	155.81	182.83	184.33
Y	29.43	32.48	32.18	35.99	27.98
Th	1.21	2.92	1.98	2.22	1.30
Cu	215.88	259.20	296.08	263.40	187.21
Zr	125.77	177.10	180.42	163.68	114.83
U	0.36	0.68	0.49	0.54	0.29
Rare earth elements					
La	9.55	21.32	16.36	15.57	13.30
Ce	21.80	45.73	37.05	34.11	21.82
Pr	2.90	6.05	5.04	4.77	2.99
Nd	15.28	27.19	24.82	22.49	15.83
Sm	4.24	6.07	5.98	5.82	3.84
Eu	1.49	2.22	1.95	1.90	1.47
Gd	4.95	6.71	7.54	6.53	4.64
Tb	0.95	1.13	1.17	1.11	0.83
Dy	5.05	5.55	6.63	6.13	4.54
Ho	1.05	1.13	1.31	1.38	0.97
Er	2.35	2.68	3.44	3.00	2.46
Tm	0.48	0.57	0.68	0.55	0.41
Yb	2.44	2.62	3.43	2.82	2.35
Lu	0.37	0.41	0.48	0.47	0.39

20 km south-east of Jabalpur (along Mandla–Jabalpur road which occurs within the Narmada South Fault zone). Such revelations were primarily based on geophysical data that provided scope for further geological studies. The work contained in the present paper is mainly aimed at the petrography and geochemistry of the Deccan lava package that occur in and around the epicentral region.







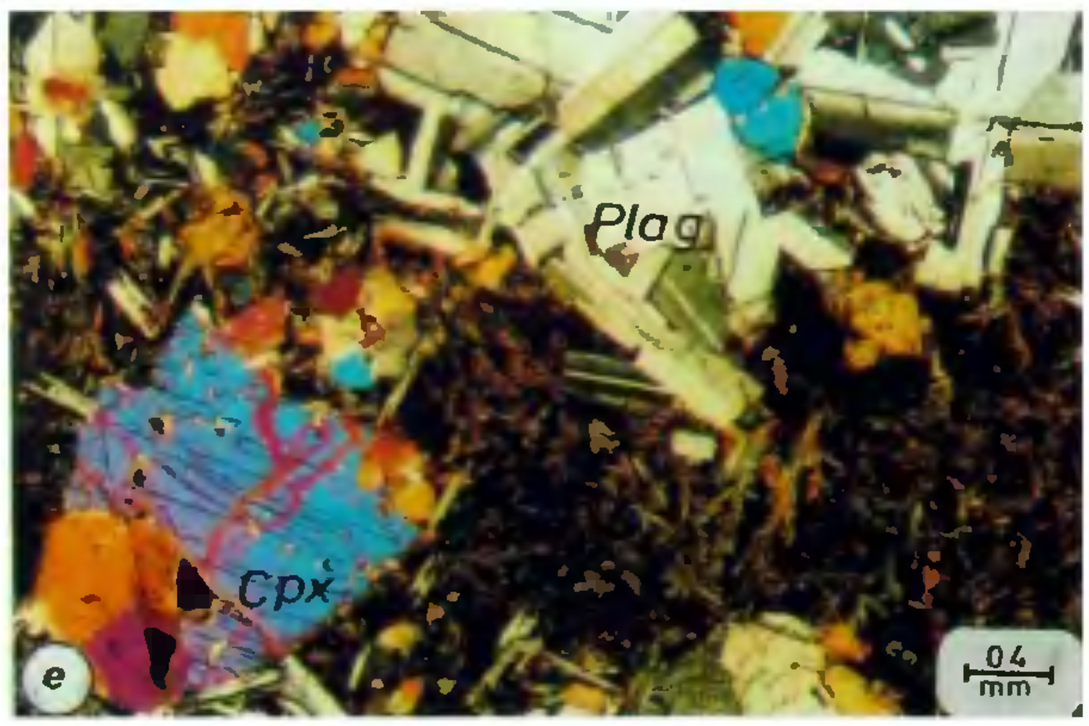


Figure 2. Photomicrograph illustrating textural and structural signatures present in the lava flows which lie adjacent to the Nagapahar fault. *a*, Lava flow number 1; *b*, Lava flow number 4; *c*, Lava flow number 5; *d*, Lava flow number 6; *e*, Lava flow number 10. cpx, clinopyroxene; plag, plagioclase.

Field criteria[5–8] were used to recognize flow boundaries. Sections were measured with an altimeter using contour lines on 1:50,000 toposheets as checks. Seven measured sections around Kosamghat with their lava flow boundaries are shown in Figure 1 *b*. Lava flows around Kosamghat are mainly basalts with clinopyroxene (cpx), calcic-plagioclase, olivine, magnetite, glass and secondary minerals including chlorophaeite, zeolite, calcite and secondary silica. Modal data for different lava flows are given in Table 1. The lateral tracing of lava flows and comparison of modal data resolved five distinct lava flows, their correlation is shown in Figure 1 *b*. The oldest lava flow in the stratigraphic sequence of Pattanayak and Shrivastava[4] is exposed at the base of

Figure 3. Fifth lava flow of the Eastern Deccan Volcanic Province resting over intertrappean horizon at the western flank of Nagapahar range.

the Nagapahar section. This lava flow is fine grained to glassy and pitch black in colour. It is composed of Fe-rich cpx (phenocryst 2Vx = 58°) and calcic plagioclase (phenocryst An% = 69; microphenocryst An% = 54) that exhibit glomeroporphyritic texture – 0.5–4 mm and 1–3 mm long plagioclase and cpx crystals, respectively (Figure 2 *a*). The top of the lava flow is marked by vesicles and topographic break. The second and third lava flows are exposed at Deori and Matka sections, but are absent in the Kosamghat area. The fourth lava flow is present in this area showing two-tiered collonade-entablatured structure that is separated by infra-trap (Lameta) at the bottom and inter-trap at the top. It is pitch black, plagiophyric (6 cm) with colloform zoning and clumping (phenocryst An% = 73; microphenocryst An% = 45). The 2Vz obtained for cpx is 42°. Vesicles are filled with radiating zeolite crystals (Figure 2 *b*). In the Nagapahar section, the fifth lava flow is directly resting over the first lava flow with inter-trappeans and red boles sandwiched between them (Figure 3). The top of this lava flow is amygdular. This lava flow (Figure 2 *c*) exhibits glomeroporphyritic to mafic phyric texture with cpx (phenocryst 2Vx = 48°; microphenocryst 2Vx = 50°) clumping (3 mm). The sixth lava flow is entablatured with vesicular and weathered top. It is steel grey with metallic lustre and microophitic to plagiophyric (6 mm, phenocryst An% = 99, microphenocryst An% = 45) with several pyroxene inclusions (Figure 2 *d*). The seventh, eighth and ninth lava flows are missing in this area. However, the sixth lava flow is directly overlained by the tenth lava flow in the nearby Dhanwahi section (Figure 1 *b*) which is doleritic, plagiophyric (5 mm) to mafic phyric (cpx, 4 mm; magnetite, 3 mm). Glomeroporphyritic and ophitic to subopitic textures are juxtaposed forming ophimottling relationship (Figure 2).

On the basis of the field and petrography data correlation, representative samples from five different lava flows were selected for major and trace element analysis by XRF and ICP-MS techniques, respectively. The chemical data so obtained are given in Tables 2 and 3. Major oxide data revealed that the first lava flow is typically a normal tholeiite whilst the fourth lava flow is high alumina quartz normative tholeiite. The fifth and sixth lava flows are low alumina quartz normative tholeiites whereas the tenth lava flow is diopsidic and olivine normative tholeiite. The first lava flow is poor in Ba and Rb, however, shows moderate LREE content. More specifically it shows high Tb concentration. This flow is characterized by high La/Yb and Ta/Yb ratios. The overlying fourth lava flow shows high Ba, V and LREE (Ce) concentrations whereas Lu is very low. Low value of Zr/Nb is recorded in this flow. The fifth flow is resting over intertrappean bed (Figure 3) that shows physical discontinuity whilst it is directly overlained by the sixth flow that represents more or less similar chemistry (viz. high Sr, low V and Ga, moderate LREE and high Tb values). The topmost tenth lava flow is composed of low Ba, Rb, MREE and very low LREE content (Table 3). The high Ce/Yb and low Ti/Tb values characterize this lava flow. Thus, major and trace element chemistry confirmed the presence of five physically distinct lava flows around Kosamghat. This also supports the idea that the lava flows of dissimilar petrochemical nature are abetted against each other in the south-east of Jabalpur. The earlier palaeomagnetic work by Athavale[9] on Mandla lobe suggested the possible uplift of the Amarkantak region in the east. However, Vandamme and Courtillot[10], in their recent palaeomagnetic studies observed two possibilities – existence of two major faults with vertical offsets of about hundred metres or the presence of a synform structure of smooth cylindrical symmetry that reconciles the entire data set with the proposed N-R-N reversal sequence – and stressed the latter. The stratigraphic shifts (~ 150 m) of the fifth lava flow in the Kosamghat region shows the presence of a NE–SW trending post-Deccan fault at the western flank of Nagapahar (Figures 1 *b* and 3). This draws support from the outcome of the reduced travel time of Deep Seismic Sounding (Figure 1 *b*) profiling undertaken by Kaila *et al.*[11], in the north and south of Jabalpur.

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MEETINGS/SYMPOSIA/SEMINARS

International Seminar on Analytical Techniques in Monitoring the Environment

Date: 18–20 December 2000

Place: Tirupati

Themes include: Spectral methods, Electroanalytical methods, Chromatographic methods, Radioanalytical and other miscellaneous methods, Biosensors, Air quality monitoring, Metal speciation, Environmental specimen banking and preparation of SRMs.

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National Seminar on Institute/Industry Co-operation Pr for Developing Skills in Students of Seed Technology

Date: 20–21 November 1999
Place: Bhopal

Themes include: Threats of terminator seeds to Indian a Seed production technology, Seed germination, HRD nomic/seed enterprise/marketing related to fertilizer, etc.

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