sumed that they would sprout in the next season. In nature also the shoots have been noticed to dry up every year and the tubers perennate and subsequently produce new shoots. Flowering occurs only after 2 or 3 years (ripeness to flower stage) by which time the size of the tubers would have increased to a critical size specific to the species (R. R. Rao, personal communication).

Note added in proof: Perrenating tubers have sprouted and flowered after two years of transfer to soil and have produced seeds.

1. Jain, S. K. and Sastry, A. R. K., *The Indian Plant Red Data Book -1*, Botanical Survey of India, Howrah, 1984, p. 190.
2. Rao, R. R. and Garg, A., *Curr. Sci.*, 1994, **67**, 80–81.
3. Menges, E. S., in *Genetics and Conservation of Rare Plants* (eds Falk, D. A. and Holsinger, K. E.), Oxford University Press, Oxford, 1991, pp. 43–61.
4. Kartha, K. K., in *Cryopreservation of Plant Cells and Organs* (ed. Kartha, K. K.), CRC Press, Boca Raton, 1985, pp. 115–134.
5. Nehra, N. S. and Kartha, K. K., in *Plant Cell and Tissue Culture* (eds Vasil, I. K. and Thorpe, T. A.), Kluwer Academic, Dordrecht, 1994, pp. 37–70.
6. Lal, N., Ahuja, P. S., Kukreja, A. K. and Pandey, B, *Plant Cell Rep.*, 1988, **7**, 202–205.
7. Sharma, N., Chandel, K. P. S. and Srivastava, V. K., *Plant Cell Rep.*, 1991, **10**, 67–70.
8. Sharma, N. and Chandel, K. P. S., *Plant Cell. Rep.*, 1992, **11**, 200–203.
9. Tandon, P. and Rathore, T. R., *Plant Cell Tissue Organ Cult.*, 1992, **28**, 115–117.
10. Sulaiman, I. M. and Babu, C. R., *Plant Cell Tissue Organ Cult.*, 1993, **34**, 295–298.
11. Murashige, T. and Skoog, F., *Physiol. Plant*, 1962, **15**, 487–491.
12. Rathore, T. S, Deora, N. S. and Shekhawat, N. S., *Plant Cell Rep.*, 1992, **11**, 449–451.
13. Rao, L. P. V. and De, D. N., *Plant Sci.*, 1987, **51**, 263–267.
14. Siril, E. A. and Dhar, U., *Plant Cell Rep.*, 1997, **16**, 637–640.
15. Aggarwal, D. C., Banerjee, A. K., Kolala, R. R., Dhage, A. B., Kulkarni, A. V., Nalawade, S. M., Hazra, S. and Krishnamurthy, K. V., *Plant Cell Rep.*, 1997, **16**, 647–652.
16. Hoagland, D. R. and Arnon, D. I., *Calif. Agric. Exp. Stn. Circ.* 1950, p. 347.
17. Just after completing this manuscript for the press, we came across a paper published recently by Koul *et al.*, *Curr. Sci.*, 1997, **73**, 313–314.

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Mid-continent gravity 'high' and seismic activities in central India

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The epicenter of Jabalpur earthquake on 22 May 1997 coincides with a NE–SW oriented gravity gradient at the northern margin of Satpura Mobile Belt (SMB) extending from west coast of India up to central India. The width and amplitude of this gravity gradient coincide with Narmada–Son lineament (NSL) and suggest a system of faults north and south of Jabalpur, which is also confirmed by similar gradients in airborne and ground total intensity maps. The epicenter of several other seismic activities such as those around Khandwa during 1993–1996 and near west coast of India including Broach earthquake also coincides with this gravity gradient indicating its active nature. Significantly there are intersections of cross trends with the gravity gradient in the epicentral areas of the above-referred seismic activities. The epicenter of Jabalpur earthquake coincides exactly where this gravity gradient changes its direction from NE–SW to NNE–SSW which appears to be an intersection of two similar oriented faults. The gravity gradient is the northern margin of the mid-continent linear gravity high which in Jabalpur section is caused by the high density body in the middle crust. This high density body may represent magmatism related to paleorifts such as Mahakoshal Proterozoic rift exposed in the surrounding regions. As the hypocenter of Jabalpur earthquake is in the lower crust at the northern margin of the inferred high density body, it appears to be related to it.

MISHRA[1] has discussed an east–west elongated gravity 'high' extending almost for 1000 km from west coast of India up to SE of Jabalpur in central India (Figure 1). It is located south of Narmada–Son lineament (NSL) and coincides with Narmada–Tapti section and Satpura Mobile Belt (SMB). Based on the spectral analysis and modelling along a profile from Jabalpur to Mandla, he suggested a mid-crustal causative basic body of density 2.9 g/cc which might be the result of extensional tectonics in the geological past. The Bouguer anomaly map of Vindhyan basin[2] shows a sharp gradient north of Jabalpur which is indicative of a deep-seated fault. The airborne magnetic and ground magnetic profiles[1] have also delineated typical fault kind of magnetic anomalies north and south of Jabalpur. Besides these magnetic anomalies, the total intensity map[3] presents sharp gradient and several high amplitude short wavelength linear magnetic anomalies striking NE–SW in a zone approxi-

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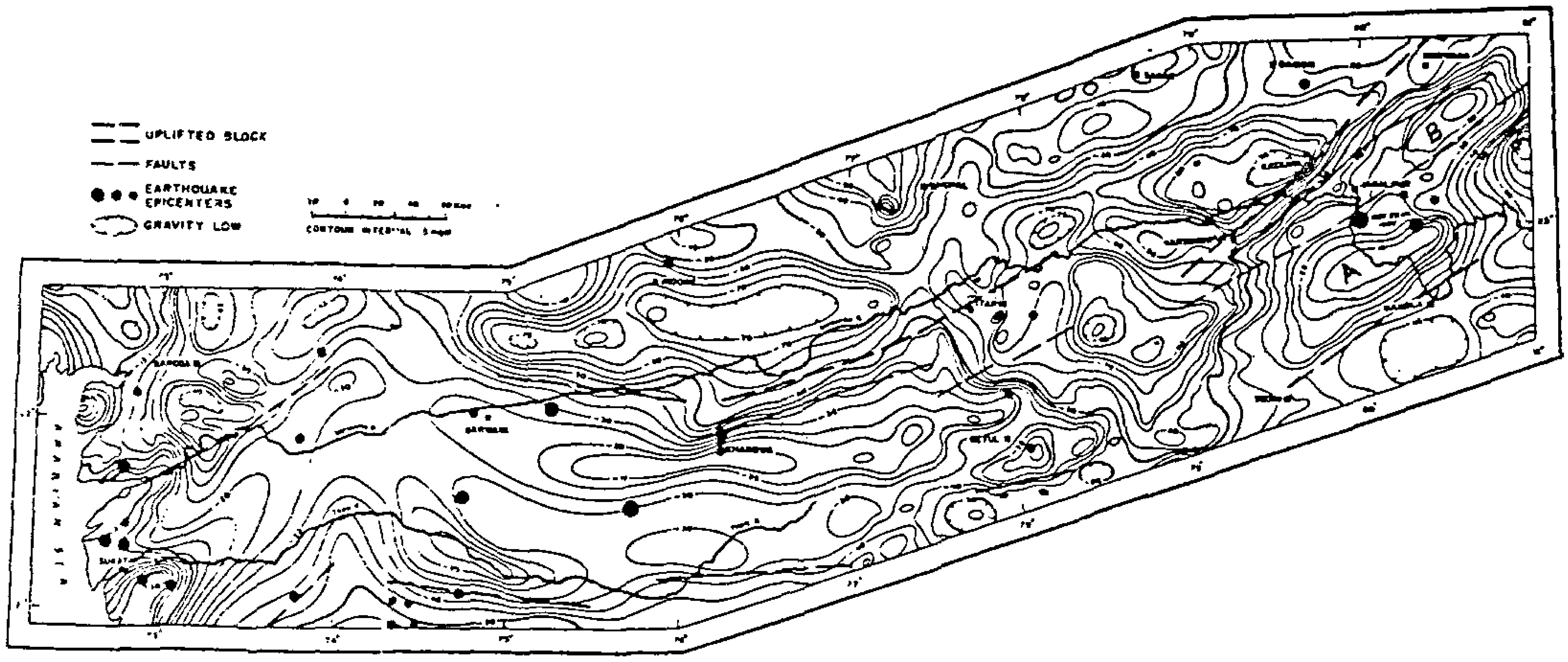

Figure 1. Bouguer anomaly map of Narmada–Tapti section with probable faults along gravity gradients and epicenter of seismic activities. Size of circles indicates the magnitude of earthquakes, largest being of magnitude 5–6, medium 4–5, and smallest 3–4.

mately 30 km north of Jabalpur up to 30 km south of it. Based on deep seismic sounding, an uplift of Moho south of Katangi up to Mandla and a high velocity layer (6.7 km/s) between Katangi and Jabalpur at a shallow depth of 1–2 km have been reported[4]. Seismic profiles have also delineated a fault at Katangi and another north of Jabalpur with a horst-like structure between them[5]. Regional geological map of Jabalpur area[6] is presented in Figure 2 which shows a NE–SW lineament (L1) from north of Mungwani to north of Matkuli defining the northern limit of Gondwana sediment. Another NE–SW lineament (L2) is shown north of Sleemnabad defining northern limit of Mahakoshal group of rocks and is joined to Son lineament towards east. This lineament is connected to Narmada river through Katangi fault[2] which defines the southern limit of Vindhyan sediment making it a trans continental Narmada–Son lineament (NSL). NSL is a fault/fracture which has been active in the geological past and separates the rocks of different ages. Vindhyan basin in this section adjoining Katangi fault shows considerable disturbances in the form of folds and fractures resulting into dome and basin structures[3] at Damoh and Jabera and Murwara–Tejgarh fracture zone[2,3]. South of Jabalpur, the area is largely characterized by Deccan Trap with small exposures of Lameta and Bagh beds (Cretaceous) just south of it. There are exposed Mahakoshal group of metasediments and volcanic rocks (Proterozoic) towards NE and SW of Jabalpur (Figure 2) and extend south of Jabalpur with high density and high resistivity values[6]. Besides Mahakoshal paleorift there are exposed Gondwana grabens south of NSL known as Satpura basin SE of Hosangabad (Figure 2) and S. Rewa graben east of Jabalpur beyond the area of the present study. The Narmada–Tapti section occupied by this gravity 'high' also defines a zone of high heat flow[7].

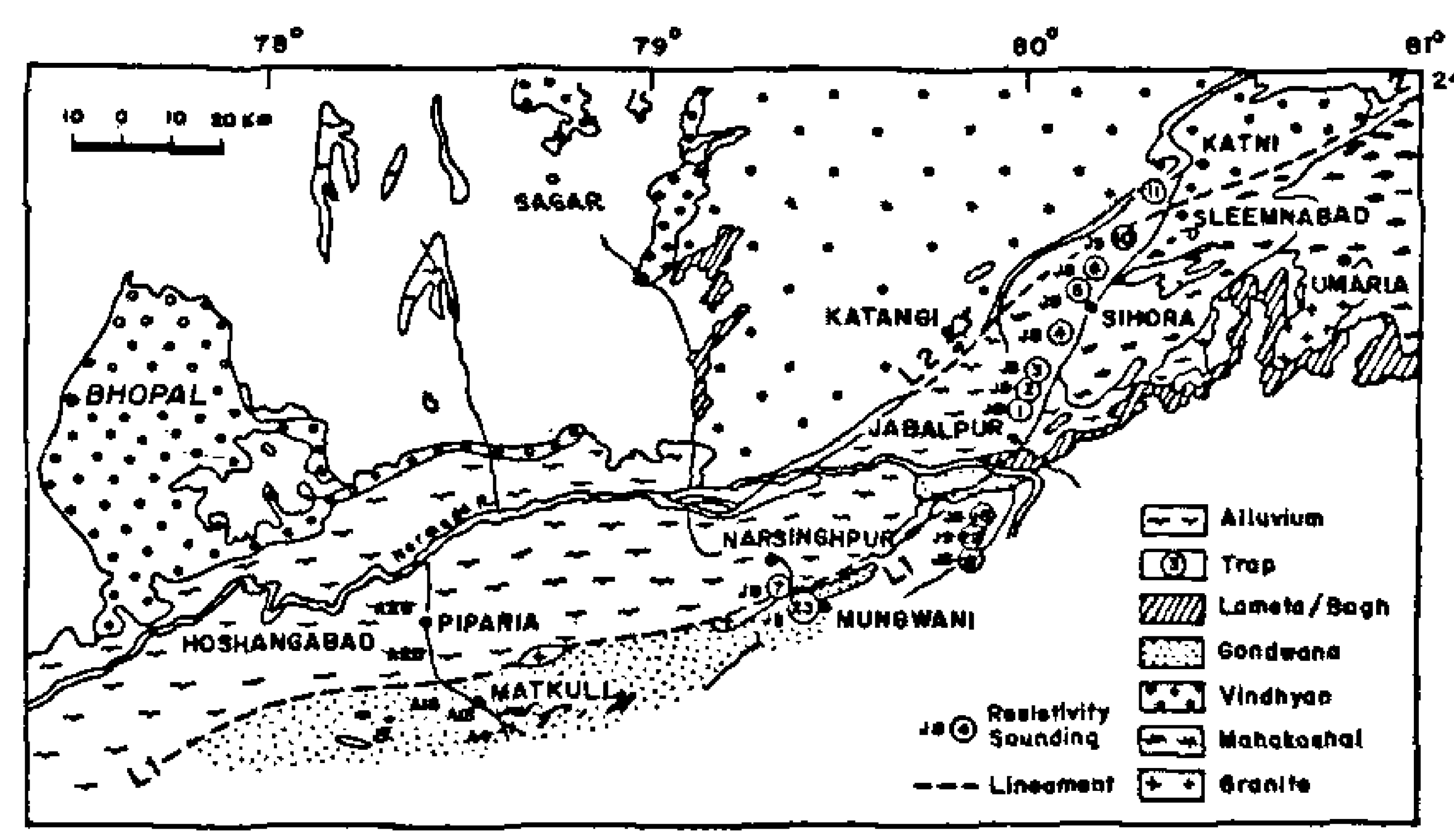

Figure 2. Geological map of Jabalpur section[6] with two large lineaments L1 and L2.

Figure 1 presents the Regional Bouguer anomaly map of Narmada–Tapti section which shows the gravity 'high' extending almost from west coast of India up to SE of Jabalpur in Central India[1] and coincides with Satpura Mobile Belt (SMB). It is similar in nature to midcontinent gravity 'high' of USA[8], which represents a paleorift of Proterozoic period. The seismic activities in this region[9] (Figure 1) coincide mainly with the northern gradient of the midcontinent gravity 'high' which may represent a deep seated fault or system of faults. As is apparent from Figure 1, its western part along west coast of India is much more active due to interaction of coastal tectonics where several earthquakes of magnitude 4 and above have been reported. Based on the gravity gradient, some faults are tentatively drawn in Figure 1. The Katangi fault which is located approximately 30 km north of Jabalpur separates Vindhyan rocks to the north from exposed alluvium, Deccan Trap and Mahakoshal group of rocks to the south (Figure 2).

The Katangi fault also represents the connection between Narmada and the Son lineaments which together forms Narmada-Son lineament (NSL) as discussed above. The part of this gravity high south and NE of Jabalpur is marked as 'A' and 'B' in Figure 1 which are the best-defined anomalies in the entire zone. Anomaly 'B' partly coincides with the exposed Mahakoshal group of rocks, suggesting a part of the observed field is due to high-density rocks of this group. Part of anomaly 'A' located south of Jabalpur may likewise represent a sub-basin of Mahakoshal group of rocks under exposed Deccan Trap. The gravity 'lows' SE of Itarsi and east of Jabalpur coincide with Gondwana graben. It is a well-known fact that rift valleys implying extensional tectonics are associated with large scale magmatism in the middle and the lower crust along its axis and shoulders. The gravity 'high' south of Jabalpur is modelled to be caused by high-density rocks in the crust and therefore appears to be caused by rift-related magmatism. The epicenter of Jabalpur earthquake coincides with the northern gradient of this anomaly which may represent a paleorift-related fault. This gravity gradient extends southwestward and passes through Khandwa (Figure 1) where several seismic activities of smaller magnitude have been reported during 1993–1996. It may be noted that in the epicentral zone of seismic activities at Jabalpur, Khandwa and along west coast of India, this gravity gradient is intersected by cross trends.

Figure 3 presents a part of Regional Bouguer 'high' around Jabalpur[6] which shows two prominent gravity 'highs' (H1 and H2) and gravity 'lows' L1, L2 and L3. Gravity lows L1 and L2 are occupied by Vindhyan sediments and L3 by Gondwana sediments and therefore, are mainly caused by them[2]. Gravity highs H1 and H2 occur over Mahakoshal group of rocks and the Deccan Trap. The bulk density of Mahakoshal group of rocks and Deccan Trap may be slightly higher than that of the basement (2.7 g/cc) but cannot explain the observed Bouguer anomaly of 25–30 mgal. It is therefore apparent that a significant part of gravity highs H1 and H2 originates from deep crustal levels as suggested previously by Mishra[1]. As the gravity high H1 is covered by Mahakoshal group of rocks and H2 being similar in nature to H1, it appears to represent the extensions of Mahakoshal group of rocks south of Jabalpur under Deccan trap. It is also confirmed from conductive nature of rocks inferred south of Jabalpur from resistivity soundings[6]. Based on gravity gradient, the lineament L1 and L2 (Figure 2) appear to be faults and are drawn along with their extensions in Figure 3 as F1 and F2. Faults F1 and F2 appear to be joined by another fault F3 drawn based on similar gravity gradient, and the epicenter of Jabalpur earthquake on 22 May 1997 coincides with the junction of fault F2 and F3.

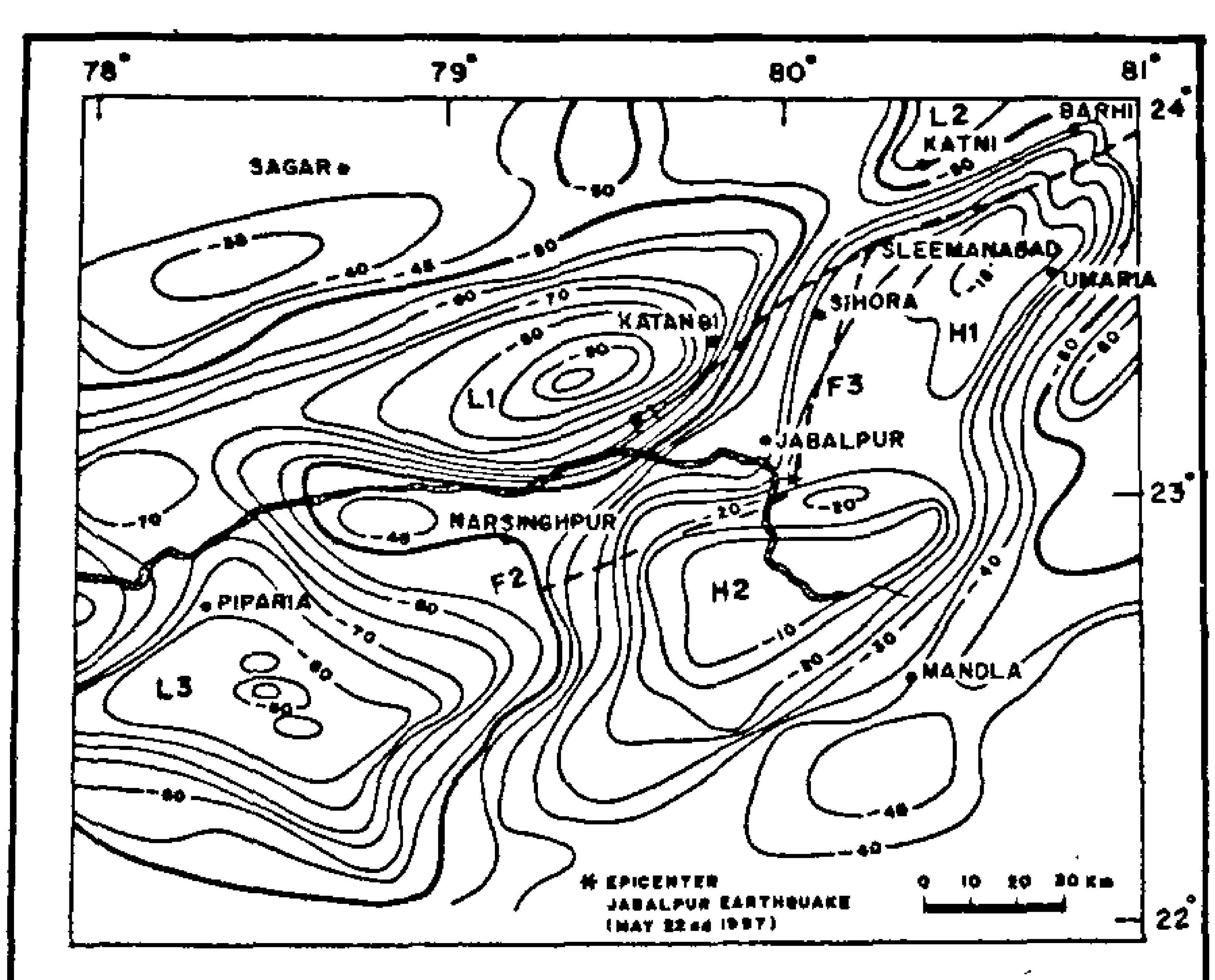

Figure 3. Bouguer anomaly map of Jabalpur section[6] with inferred faults F1, F2 and F3 based on gravity gradients.

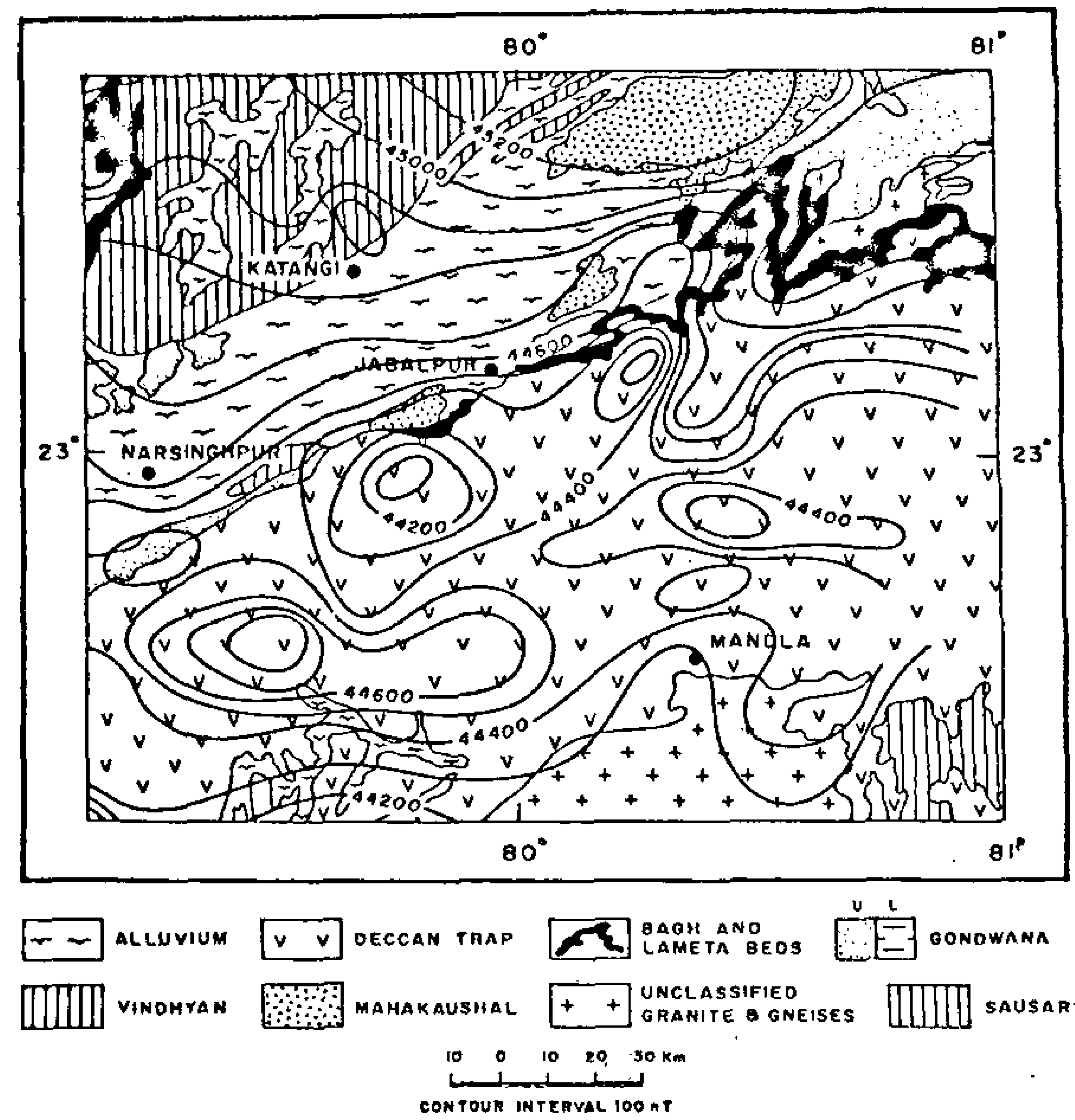

Figure 4. Total intensity map of Jabalpur area based on data recorded along roads and tracks at a spacing of 2–3 km. A well-defined magnetic 'low' and 'high' are characteristic south of Jabalpur. Regional geology is superimposed over it.

Figure 4 presents the total intensity map around Jabalpur along with the local geology. This map is prepared from measurements on ground along roads and tracks at 2–3 km spacing using a proton precession magnetometer of 1 gamma accuracy[10]. It shows a nicely delineated two-dimensional magnetic anomaly of approximately 800–1000 gamma over the exposed Deccan Trap south of Jabalpur. The consistent nature of this magnetic anomaly suggests that it does not appear to be caused by the exposed trap rocks and it may rather represent the extension of Mahakoshal group of rocks south of Jabalpur as inferred above from gravity data which are highly magnetic in nature. Its northern margin (Figure 3) coincides with the fault south of Jabalpur inferred from gravity gradient. This confirms that the Mahakoshal basins in this region are fault-controlled and may represent paleorift. The airborne total intensity map[3] referred to above also shows a sharp gradient north and south of Jabalpur, suggesting a system of faults as indicated by the present magnetic map and Bouguer anomaly map discussed above.

The recent seismic activity of Jabalpur on 22 May 1997 coincides with a sharp gravity gradient which represents a deep-seated fault or system of faults. This gradient striking ENE–WSW coincides approximately with NSL and extends from west coast of India up to central India. Several seismic activities of recent past such as around Khandwa and west coast of India coincide with it. However, in the epicentral areas of these seismic activities, this gradient is intersected by cross trends which are quite significant. This gradient is also reflected in airborne and ground total intensity maps around Jabalpur, confirming it to represent a system of faults. Landsat imageries reflect this gravity-magnetic gradient as set of lineaments north and south of Jabalpur extending SW up to west coast[10,11].

This gravity gradient is the northern margin of a gravity 'high' which extends from west coast of India up to central India and coincides with Satpura Mobile Belt. In Jabalpur sector, it is caused by a high-density body at mid-crustal level.

Gravity-magnetic signatures suggest the extension of Mahakoshal group of rocks of Early Proterozoic south of Jabalpur which were deposited in a Paleo rift. Further S–W and east of Jabalpur there are Gondwana grabens which also represent an extensional tectonics regime. Rift valleys implying extensional tectonics are known to be associated with large-scale magmatism along their axis and shoulders and therefore, this gravity 'high' appears to be caused by rift-related magmatism at mid-crustal level.

The epicenter of Jabalpur earthquake coincides with the intersections of two faults related to Mahakoshal paleorift in this section. The hypo center of this earthquake coincides with the northern margin of the high density body, thereby indicating its association with paleorifts.

Intersections of this gravity gradient with cross trends at other places should be examined in detail and monitored for future seismic activities. Intersections of structural trends are important for seismic activities as was also reported in case of Latur earthquake[12]. Study of such intersections along with neotectonics[13] and seismic activities[14] will provide significant information regarding future models.

1. Mishra, D. C., *Tectonophysics*, 1992, **212**, 153–161.
2. Mishra, D. C., *Mem. Geol. Soc. India*, 1996, **36**, 213–224.
3. Mishra, D. C., *Mem. Geol. Soc. India*, 1987, **6**, 357–368.
4. Kaila, K. L., Murthy, P. R. K., Mall, D. M. and Dixit, M. M., *Geophys. J. R. Astron. Soc.*, 1990, **28**, 99–117.
5. Reddy, P. R., Sain, K. and Murthy, A. S. N., *Curr. Sci.*, 1997, **73**, 796–800.
6. Venkata Rao, K., Srirama, B. V. and Ramasastry, P., *Geol. Surv. India, Spl. Publ.*, 1990, **28**, 99–117.
7. Ravishankar, *J. Geol. Soc. India*, 1991, **37**, 211–220.
8. O'Hara, N. W. and Lyons, P. L., in *The Utility of Regional Gravity and Magnetic Anomaly Maps* (ed. Hing, W. J.), SEG, USA, 1985, pp. 33–37.
9. Rastogi, B. K., 1997, personal communication.
10. Mishra, D. C., Rao, J. M., Rao, P. C., Gupta, S. B. and Rao, M. B. S. V., Project Terminal Report, 1990.
11. Rajurkar, S. T., Bhate, V. D. and Sharma, S. B., *Geol. Surv. India Spl. Publ.*, 1990, **28**, 214–259.
12. Mishra, D. C., Gupta, S. B. and Rao, M. B. S. V., *Mem. Geol. Soc. India*, 1994, **35**, 119–126.
13. Valdiya, K. S., *Aspects of Tectonics*, Tata Mcgraw-Hill, New Delhi, 1984, pp. 1–319.
14. Raval, U., in *Rifted Basin and Aulacogens* (ed. Kassayap, S. M.), Gyanodaya Prakasan, Nainital, 1993, pp. 47–72.

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Micropaleontological evidence for tectonic uplift of near-shore deposits around Bankot–Velas, Ratnagiri District, Maharashtra

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The neotectonic activity and the change in sea level have contributed to the present configuration of the Velas coast. This is evident by the elevated lignitic beds all along the west coast in general and at Velas in particular. At Velas, the lignite bed occurs about 100 m MSL and is dated >40000 years BP which is comparable to the Warkalli beds and therefore, appears to be contemporaneous with the other lignite beds reported so far from the west coast of India. The lignite bed at Velas is studied for its microfossil contents. The foraminiferal assemblage is cosmopolitan and shows the dominance of agglutinated foraminifera mainly represented by the species of *Trochammina, Jadammina* and *Haplophragmoides* characterizing the marsh environment. The palynoflora is also indicative of a near-shore environment and as such it supplements the foraminiferal data.

THE occurrence of the elevated lignitic beds (Warakalli beds and Sindhudurg Formation) is not uncommon

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