been established till date. In the present observation almost similar pattern was noticed. The phenomenon appears to have more relevance in predicting the degree of infection.

Macrophage activation is the indicator of nonspecific response against the foreign invaders. To measure the degree of activation, macrophage migration is a relative parameter. The unimmunized challenged hamsters showed declining trend of migration index with the advancement of infection. Immunization with single antigen, either with FKP or with *M. habana*, exhibited decrease in MMI after the challenge though the inhibition was not significant. On the other hand, there was only slight suppression in macrophage migration index in hamsters immunized with combined immunogens and was comparable to normal control. The DTH response was also found increased in animals immunized with combined immunogens. These findings corroborate with earlier reports[12,28].

The preliminary studies on cross protection by *M. habana* have opened up a new vista in the vaccination against experimental leishmaniasis where antigenic advantage of nonpathogenic organism could be beneficially exploited to produce functional immunity against a fatal disease, leishmaniasis, and call for more organized and concerted efforts to investigate the potentiality of *M. habana* in VL.

1. Ashford, R. W., Desjuex, P. and Dereath, P., *Parasitol. Today*, 1992, **8**, 104–105.
2. Allison, A. C. and Gregoriadis, G., *Immunol. Today*, 1990, **11**, 427–429.
3. Convit, J., Rondon, A., Ulrich, M., Bloom, B., Castellanos, P. L., Pinardi, M. E., Castes, M. and Garcia, L., *Lancet*, 1987, **1**, 401–405.
4. Sutherland, I., *Post Grad. Med. J.*, 1971, **47**, 756–758.
5. Frommel, D. and Lagrange, P. H., *Parasitol. Today*, 1989, **5**, 188–190.
6. Gupta, H. P., Singh, N. B., Mathur, I. S. and Gupta, S. K., *Indian J. Exp. Biol.*, 1979, **17**, 1190–1193.
7. Gupta, H. P., Mathur, I. S. and Singh, N. B., *Curr. Sci.*, 1984, **53**, 695–697.
8. Singh, N. B., Srivastava, A., Gupta, H. P., Sreevatsa, and Desikan, K. V., *Indian J. Lep.*, 1985, **57**, 278–281.
9. Singh, N. B., Lowe, A. C. R. E., Rees, R. J. W. and Colston, M. J., *Infect. Immun.*, 1989, **57**, 653–655.
10. Convit, J., Ulrich, M., Aranzazu, N., Castellanos, P. L., Pinardi, M. E. and Reyes, O., *Lepr. Rev.*, 1986, **57**, 263–273.
11. Holbrook, T. W., Cook, J. A. and Parker, B. W., *Am. J. Trop. Med. Hyg.*, 1981, **30**, 762–768.
12. Pal, A., Gupta, S., Katiyar, J. C., Puri, A., Sahai, R. and Saxena, R. P., *Serodiagn. Immunother. Infect. Dis.*, 1995, **7**, 115–120.
13. Choudhury, A., Guru, P. Y., Saxena, R. P., Tandon, A. and Saxena K. C., *Trans. R. Soc. Trop. Med. Hyg.*, 1990, **84**, 363–367.
14. Lowry, O. H., Rosebrough, N. J., Farr, A. L. and Randal, R. J., *J. Biol. Chem.*, 1951, **193**, 265–275.
15. Voller, A., Bidwell, D. E. and Bartlett, A., *A Guide with Abstracts of Microplate Application*, Fileroline Press, Guernsey, 1979, pp. 1–125.
16. Gupta, S., Srivastava, J. K., Ray, S., Chandra, R., Srivastava, V. K. and Katiyar, J. C., *Indian J. Med. Res. A*, 1993, **97**, 242–246.
17. Saiki, I., Tanio, Y., Yamawaki, M., Uemiya, M., Kobayashi, S., Fukuda, T., Yukimasa, H., Yamamura, Y. and Azuma, I., *Infect. Immun.*, 1981, **31**, 114–121.
18. Saxena, K. C., Puri, A., Sumati, Saxena, R. and Saxena, R. P., *Immunol. Invest.*, 1991, **20**, 431–440.
19. Alexander, J. and Russell, D. G., in *Advances in Parasitology*, Academic Press, London, 1992, **31**, 176–253.
20. Katiyar, J. C., Anuradha, and Sharma, S., *Med. Res. Rev.*, 1992, **12**, 473–504.
21. Gutteridge, W. E., *Parasitol.*, 1989, **98** (Suppl), S87–97.
22. Bechelli, L. M., Garbajosa, G., Uemura, K., Engler, Y., Dominguez, V. M., Paredes, L., Sundaresan, T., Koch, G. and Matejka, M., *Bull. World Health Org.*, 1970, **42**, 235–281.
23. Khaleque, K. A., *J. Pathol. Bacteriol.*, 1962, **83**, 284–287.
24. Torrealba, J. W. and Chaves-Torrealba, J., *Rev. Inst. Med. Trop. Sao Paulo*, 1964, **6**, 252–253.
25. Smrkovski, L. L. and Larson, C. L., *Infect. Immun.*, 1977, **16**, 249–257.
26. Holbrook, T. W. and Cook, J. A., *Am. J. Trop. Med. Hyg.*, 1983, **32**, 51–53.
27. Heinzel, F. P., Sadick, M. D., Mutha, S. S. and Locksley, R. M., *Proc. Natl. Acad. Sci. USA*, 1991, **88**, 7011–7015.
28. Rezai, H. R., Ardehali, S. M., Amirhakimi, G. and Kharazmi, A., *Am. J. Trop. Med. Hyg.*, 1978, **27**, 1079–1083.

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Anomalous fluoride in groundwater from western part of Sirohi district, Rajasthan and its crippling effects on human health

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Anomalously high concentration of fluoride (upto 16 ppm) has been observed in dug/tube well water, which is being used for drinking and irrigation purposes, around Palri, Andor and Wan villages, in western part of Sirohi district, Rajasthan. Fluoride concentration in groundwater is much higher than the permissible limit of 0.6–1.5 ppm of fluoride recommended for potable purposes. Water samples with more than 5 ppm fluoride are confined to Andor and Wan villages. Mottling is commonly observed in people of this area with a few cases of crippling

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fluorosis. Areas with such a high fluoride content require serious attention and remedial measures like setting up of large-scale defluoridation plant, use of simple domestic defluoridation methods and public awareness for preventing harmful diseases like fluorosis.

THE first case of endemic fluorosis in India was reported in 1937 in Prakasam district, A.P. (erstwhile Nellore district). More than 500,000 people in different parts of the country are affected with crippling bone disease (fluorosis) due to consumption of drinking water having fluoride (F) content of more than 1.5 ppm[1,2]. In Rajasthan, isolated pockets of higher fluoride concentration (8.5–19 ppm) are reported from Ganganagar, northwestern Jodhpur, eastern Nagaur and western Sirohi[3].

High content of fluoride (upto 16 ppm) has been analysed in water samples collected from irrigational and drinking water dug wells and tube wells, depths varying from 25 to 75 m, during the hydrogeochemical surveys carried out for the exploration of uranium in parts of Sirohi district, Rajasthan, where Proterozoic meta-sediments of Sirohi Group with intrusions of Erinpura granites and Malani rhyolites are exposed (Figure 1). It is pertinent to note that significant fluorite mineralization associated with granite and acid volcanics, has already been reported from adjoining areas of Jalore district[4], thereby making the present area interesting for studies.

Ill-effects of high fluoride on human health, such as, dental fluorosis, mottling (discoloration of teeth) are commonly observed in people living at and around Andor, Wan and Sogaliya villages of Sirohi district, with a few case of deformed bone structure (crippling fluorosis); though complete statistics have not been collected. An attempt has been made to evaluate hydro-geochemical data for the demarcation of different zones, based on fluoride content, along with their aerial extent, and to suggest possible remedial measures to prevent crippling fluorosis.

Water sampling was done in two phases, following standard hydrogeochemical sampling techniques[5,6], covering 151 sq.km area around Palri, Andor, Ora and Wan villages. Initially 85 dug well and tube well water samples were collected with sampling density of 1.5–2 sq.km. Based on the results of analysis of these samples, 32 additional close spaced samples (one sample/0.5 sq.km) were collected from the western part of the area showing higher fluoride content.

Samples were analysed for SO_4^{--}, CO_3^{--}, HCO_3^-, Cl^-, P_2O_5 and elements like Na, K, Ca, Mg, V and U using conventional analytical procedures. The F^- content was determined using Micron-2 pH/ion meter of Toshniwal Process Instruments Pvt. Ltd., Ajmer. The total ionic strength adjusting buffer (TISAB) used is one litre solution of pH 5.5 containing 57 ml of glacial acetic acid, 58 g of sodium chloride and 0.2 g of CDTA (trans-1,2-diamino cyclo-hexane tetra acetic acid). The potential of a series of standard solutions of fluoride in the range 10^{-5} M to 10^{-1} M was measured treating 50 ml of the solution with 50 ml of TISAB, while stirring with a magnetic stirrer for 3 min. The potential of the sample solution is also measured similarly. The

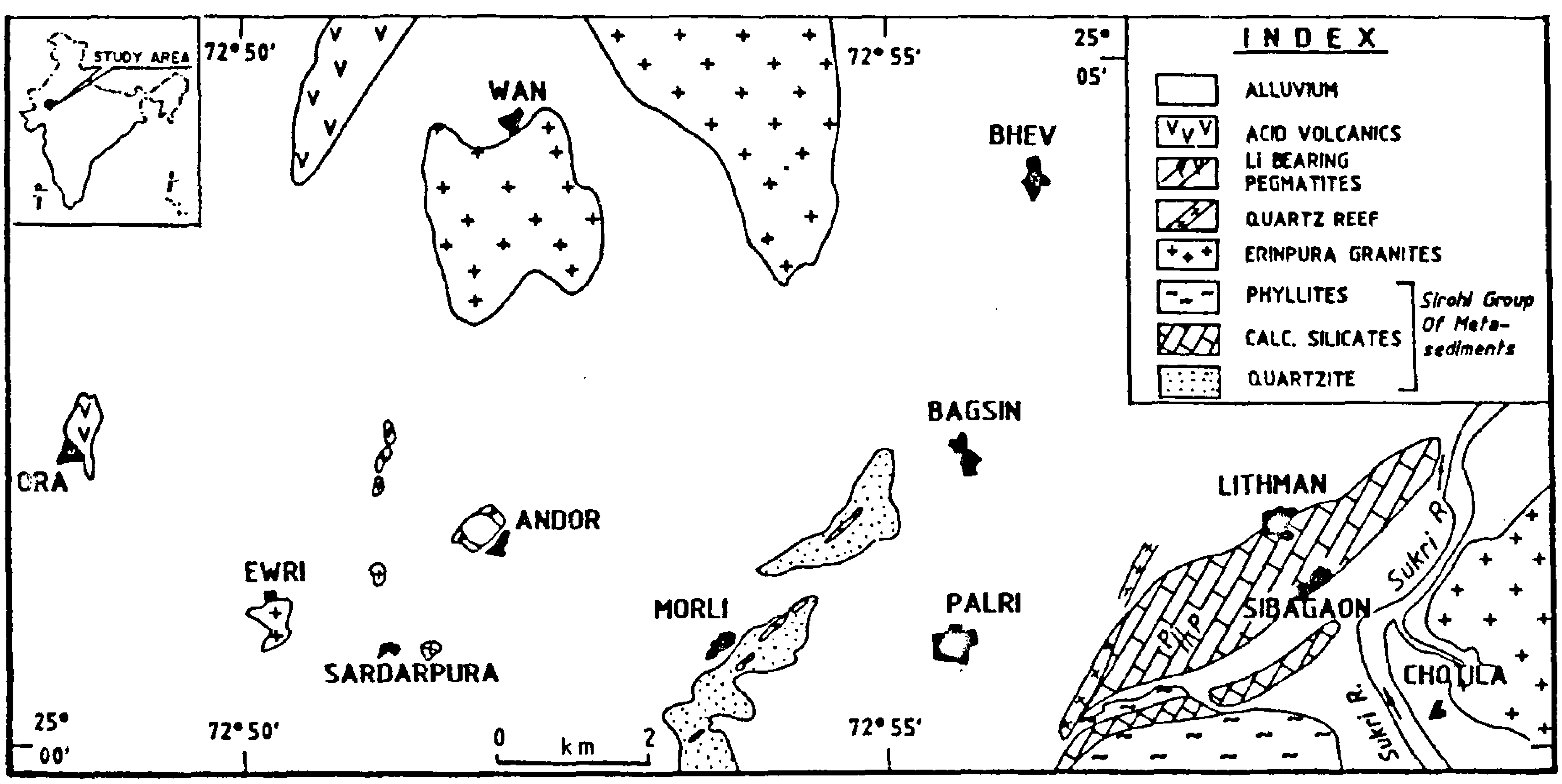

Figure 1. Geological map of parts of Sirohi district, Rajasthan.

fluoride content of the sample is computed from the calibration plot for the standard.

Analytical results of critical elements and selected radicals are presented in Table 1. General abundance of fluoride in samples is < 1 ppm to 16 ppm with majority of samples having fluoride concentration more than the permissible limit of 1.5 ppm. Higher fluoride concentration (5–16 ppm) is recorded in Western part (Figure 2) compared to eastern part (< 1 ppm). Based on fluoride concentration, the area has been divided into five zones namely, I (< 1.5 ppm), II (> 1.5 to 5 ppm), III (> 5 to 6.5 ppm), IV (> 6.5 to 10 ppm) and V (> 10 ppm) (Figure 3).

Frequency distribution of various elements and radicals related to present study are shown in Figure 4. The F^- concentration of more than 1.5 ppm accounts for about 65% of total sample population. Correlation matrix (Table 2) indicates positive relationship of fluoride with HCO_3^- (0.29) and moderate negative correlation with Ca^{++} (–0.5), Mg^{++} (–0.36) and P_2O_5 (–0.32) while strong negative correlation is indicated by Ca/F ratio (–0.912). It is interesting to note that high fluoride content is always associated with lower Ca/F ratio (Table 1) in the study area.

In general, the main source of fluoride in circulating waters is considered to be fluorite, fluorapatite, mica, hornblende and soil consisting of clay minerals[7]. Alkalic rocks and hydrothermal solutions may also contribute towards the higher concentration of fluoride.

High fluoride content in groundwater of study area could be attributed to the fluorite disseminations and veins in Erinpura granites and Malani rhyolites. Besides, fluorite mineralization is also recorded in the contact zones of basic dykes with granites in the area around Wan and Andor.

Interpretation of the data indicates that out of 151 sq.km studied area, 127 sq.km shows > 1.5 ppm fluoride content in water which is above permissible limit (upto 1.5 ppm (ref. 1); 0.6–1.2 ppm with max. upto 1.5 ppm (ref. 8); 0.8–1.7 ppm with tolerance limit of 1.4–2.4 ppm (ref. 9)). Further subdivision of the area based on fluoride content indicates coverage of 8.74% in Zone I, 63.84% in Zone II, 10.26% in Zone III, 16.35% in Zone IV and 0.59% in Zone V. Strikingly high fluoride concentration (> 5 ppm) is noticed around Wan, Sogaliya, Andor, Ewri and Ora, compared to low fluoride concentration in eastern part around Uthman, Sibagaon and Chotila. High fluoride concentration in western parts can be attributed to the circulation of groundwater through fluorite-bearing granites and acid volcanics, and basic dykes (acting as barriers resulting in ample contact time for circulating water to dissolve fluorite). It is an established fact that the waters high in calcium are low in fluoride content[10] and, therefore, the low fluoride concentration in eastern part can possibly be explained by the presence of high Ca in water due to the movement of groundwater through carbonate rocks and higher recharge from surface water of Sukri river possibly diluting further the fluoride content.

Effect of fluoride content on human health has already

Table 1. Zonal distribution of F, Ca and Ca/F (all data in ppm, except Ca/F)

Zone	F^- Range	F^- Av.	F^- STD	Ca^{++} Range	Ca^{++} Av.	Ca^{++} STD	Ca/F Range	Ca/F Av.	Ca/F STD
I ($n = 16$)		All values < 1		29–216	85.62	48.94			
II ($n = 69$)	1–4	2.38	1.15	12–308	83.80	49.18	6–308	51.43	50.82
III ($n = 15$)	5–6	5.33	0.49	14–72	44.13	17.05	2.8–14.4	8.35	3.35
IV ($n = 7$)	7–8	7.43	0.53	20–34	28.57	5.83	2.5–4.7	3.86	0.90
V ($n = 6$)	10–16	11.17	2.40	8–48	28.50	13.29	0.5–4.8	2.76	1.43

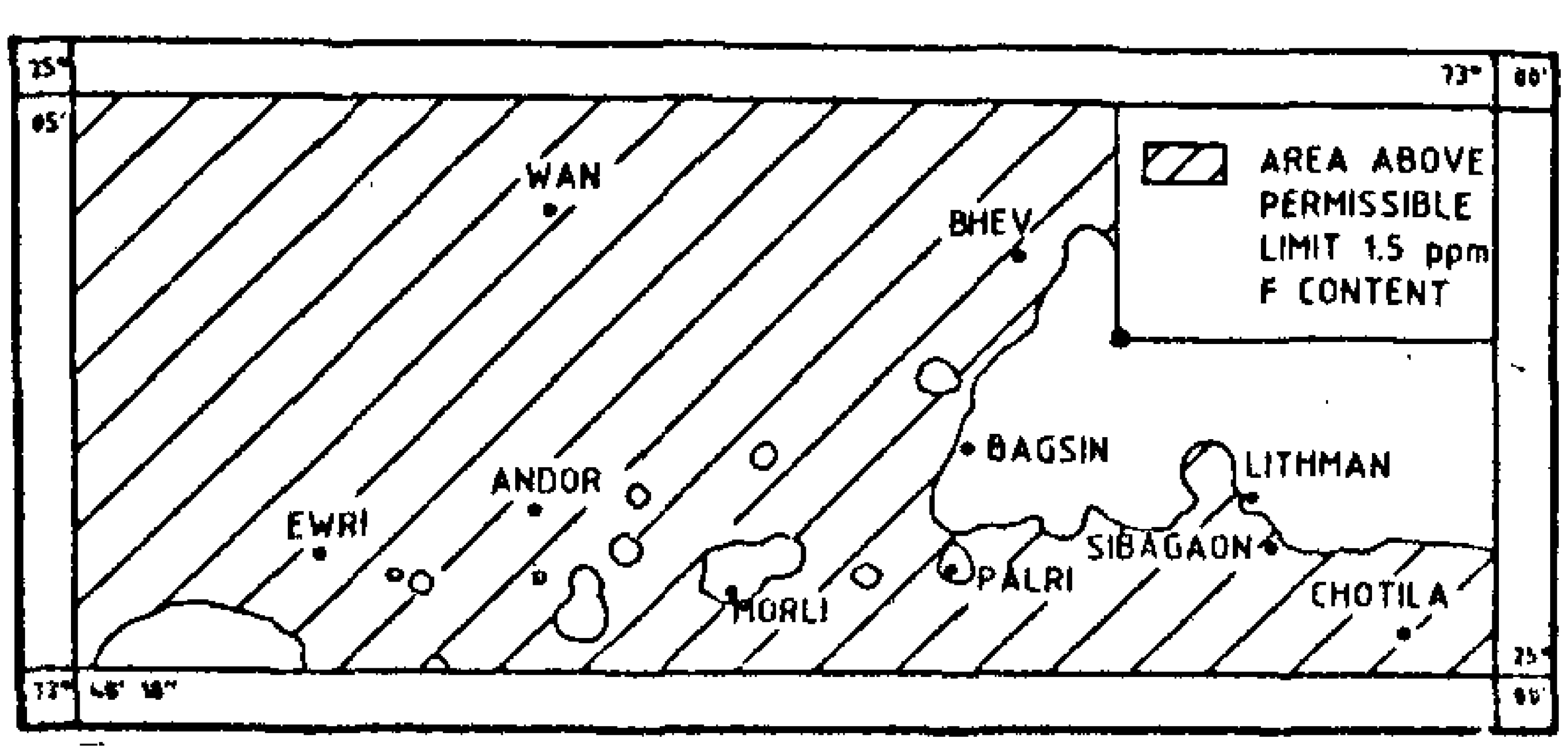

Figure 2. Map showing area above maximum permissible limit of fluoride content in parts of Sirohi district, Rajasthan.

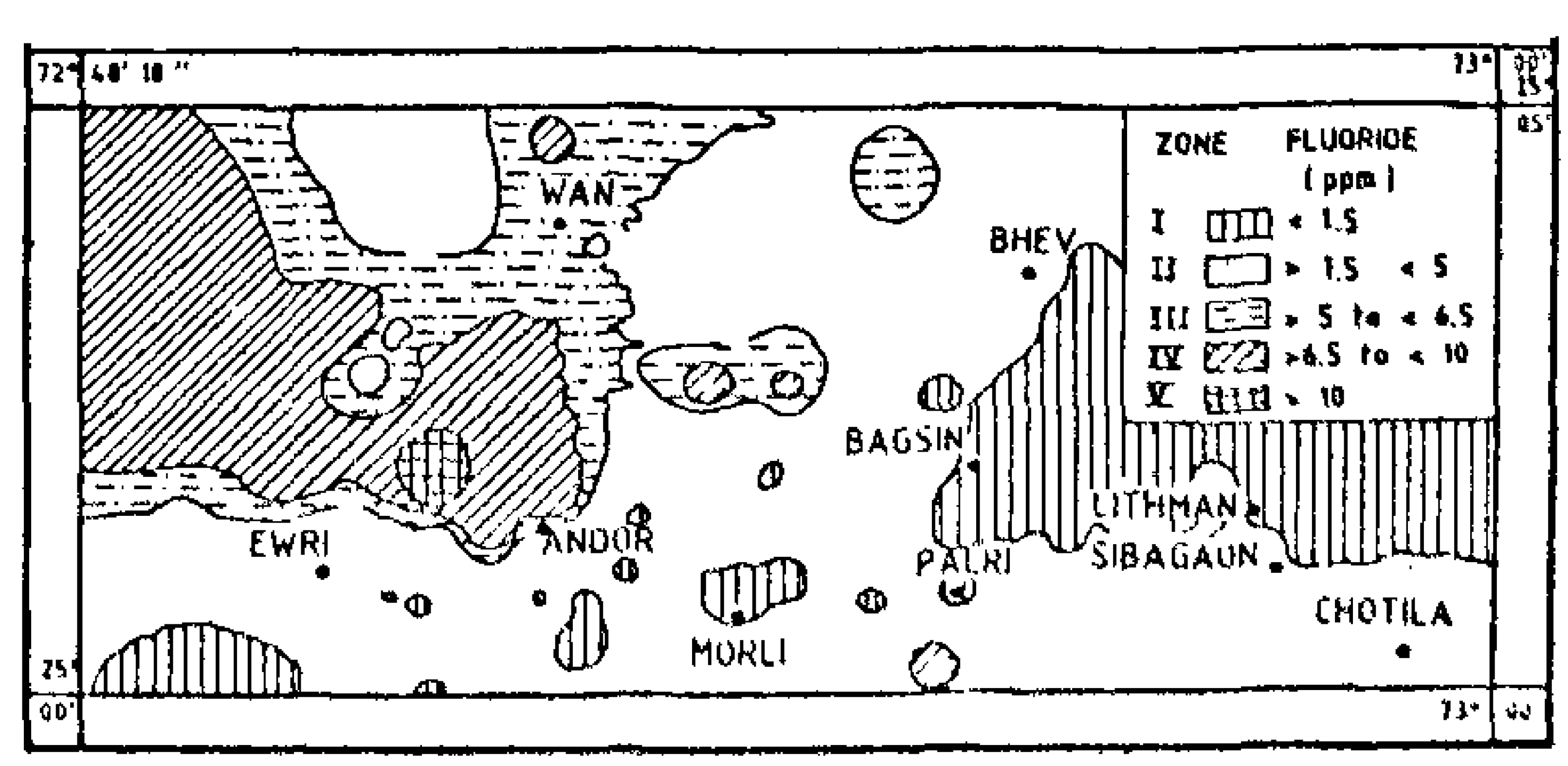

Figure 3. Fluoride content in well/tube well water in parts of Sirohi district, Rajasthan.

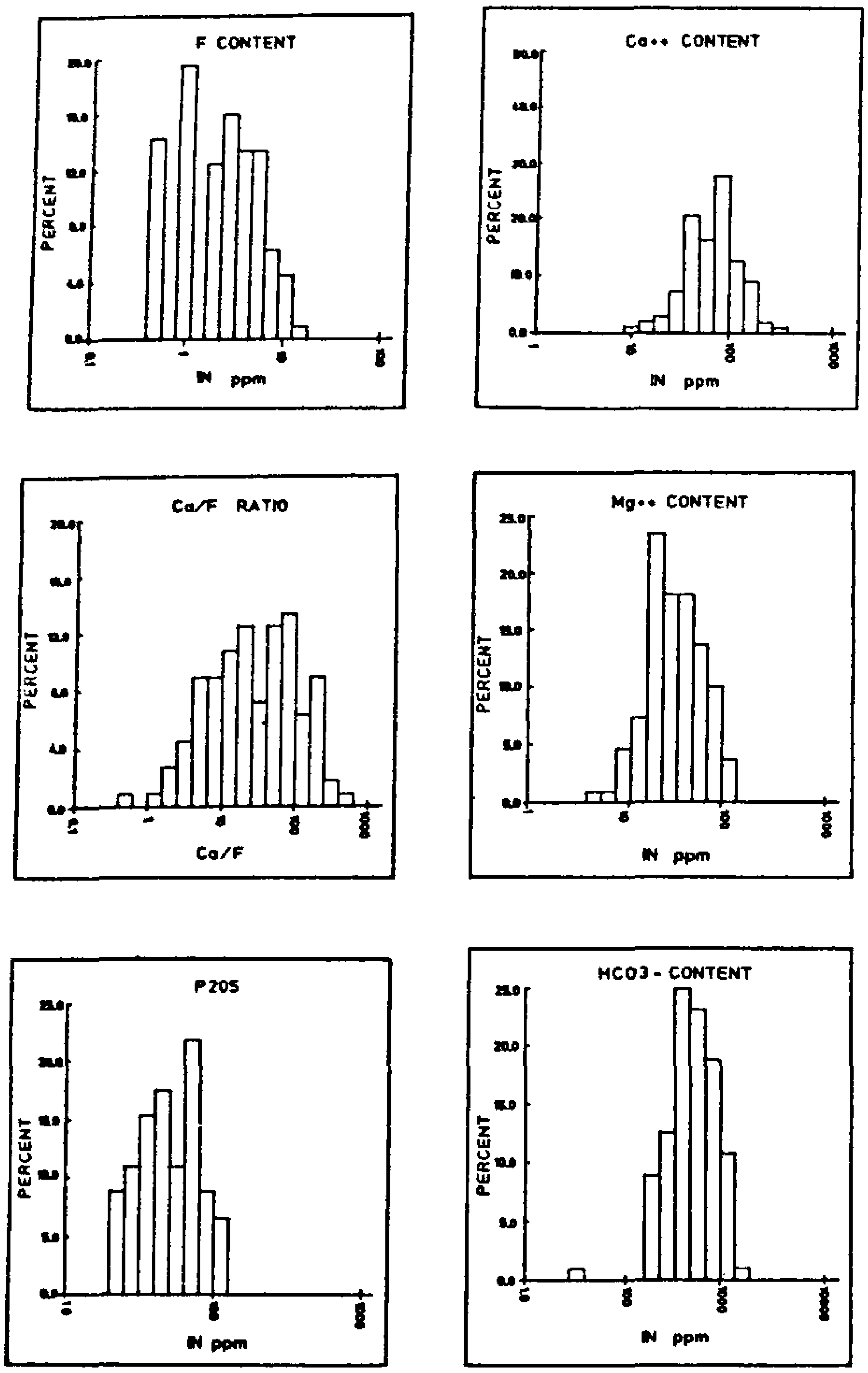

Figure 4. Histogram showing frequency distribution of F, Ca, Ca/F, Mg, P_2O_5 and HCO_3 in water samples.

Table 2. Sample statistics and correlation matrix of selected radicals and elements of water samples, Sirohi district, Rajasthan

	Ca^{++}	Mg^{++}	HCO_3^-	F^-	Ca/F	P_2O_5
Sample statistics (All values in ppm, except Ca/F)						
N	113.00	113.00	113.00	113.00	113.00	46.00
Min	8.00	0.00	37.00	0.50	0.50	22.00
Max	308.00	117.00	1292.00	16.00	432.00	118.00
Avr	72.41	35.09	525.20	3.28	57.04	54.83
STD	47.67	24.46	259.50	2.77	73.49	24.76
Correlation matrix						
Ca^{++}	1.00					
Mg^{++}	0.47	1.00				
HCO_3	–0.34	0.13	1.00			
F^-	–0.50	–0.36	0.29	1.00		
Ca/F	0.71	0.40	–0.31	–0.91	1.00	
P_2O_5	0.11	–0.002	0.17	–0.32	0.09	1.00

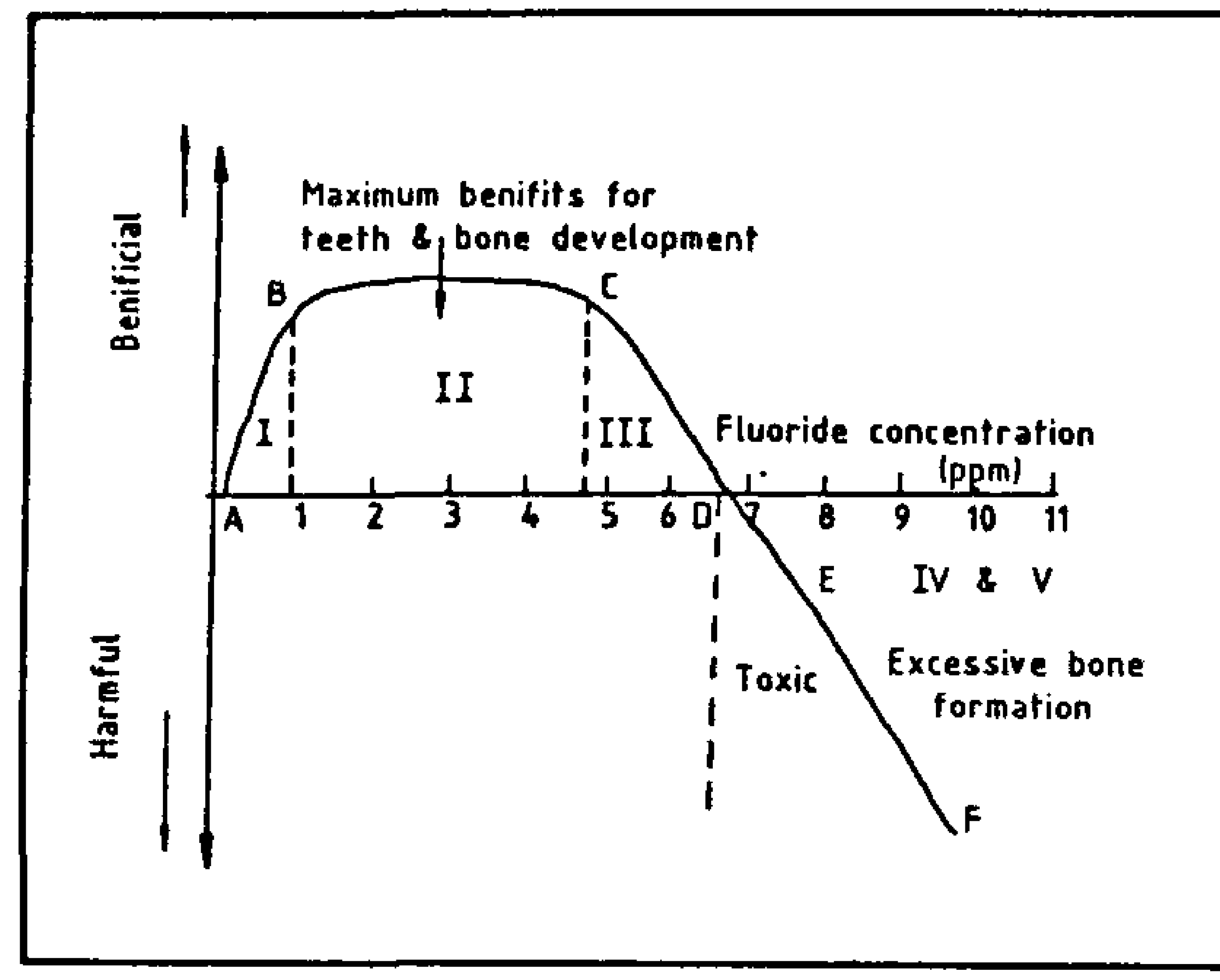

Figure 5. Fluoride concentration zones of study area plotted on the fluoride dose response curve (After Keller, E. A., *Environmental Geology*, Bell & Howell, Columbus, 1976, pp. 488, figure II.4.).

been established[11]. Fluoride, as calcium fluoride compound is an important ingredient of teeth and bone and facilitates in the development of perfect teeth and bone structure. Relation between fluoride content and health indicates a specific dose response curve (Figure 5). The data indicates that the inhabitants of Zone I and II may be benefited by way of bone and teeth development with some side effects like dental fluorosis whereas those living in Zones III to V are highly susceptible to dental fluorosis, skeleton fluorosis, calcification of ligaments, physiological mongolism, cancer mortality, birth defects, constipation, anemia and insomnia[2].

High concentration of fluoride content in study area needs urgent attention to prevent possible health hazards by way of setting of de-fluoridation plants for the supply of proper drinking water. Other remedial measures like public awareness about the toxic effects of fluoride and their prevention by using lime and alum, bone char filters, etc. on domestic scale[2,12]. Besides, outcome of this study warrants detailed hydrogeochemical sampling in adjoining areas of Rajasthan and Gujarat having similar geological setup to isolate the hazardous areas of high fluoride concentrations.

1. Aggrawal, A., Chopra, R. and Shukla, K., in *The State of India's Environment*, 1982, pp. 189.
2. Valdiya, K. S., in *Environmental Geology Indian Context*, Tata McGraw-Hill, New Delhi, 1987, pp. 479–481.
3. Biswas, A. B. and Saha, A. K., in *Water Pollution and Management Reviews*, 1982, pp. 113–127.
4. Kochhar, N., Dhar, S. and Sharma R., *Mem. Geol. Surv. India*, 1995, **33**, 375–389.
5. Wenrich-Verbeek, K. J., *U.S. Geol. Surv. Open-File Rep.*, 1976, **76–77** , 1–30.
6. Wenrich-Verbeek, K. J., *J. Geochem. Explor.*, 1977, **8**, 337–355.
7. Robinson, W. D. and Edington, G., *Soil Science*, 1946, **61**, 341.

8. Karanth, K. R., in *Hydrology*, Tata McGraw-Hill, New Delhi, 1989, Table 6.3, pp. 155–156.
9. Todd, D. K., in *Groundwater Hydrology*, John Wiley and Sons, New York, 1980, Table 7.6, pp. 292.
10. Hem, J. D., *U.S. Geol. Surv. Water Supply Paper*, 1985, **2254**, 264.
11. Keller, E. A., in *Environmental Geology*, Bell & Howell, Columbus, 1976, Fig 11.4, p. 488.
12. Ramamohana Rao, N. V., International Symposium on Applied Geochemistry, Osmania University, Hyderabad, 1991, pp. 24–26.

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A lithospheric mantle source for the proterozoic kimberlites and lamproites from the eastern Dharwar craton, India: Evidence from rare earth element inversion modelling

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Inversion of rare earth element (REE) concentrations of a Proterozoic kimberlite (Maddur) and lamproite (Ramannapeta) from the eastern Dharwar craton, India is carried out to discover the partial melt distribution with depth that could have been responsible for producing their REE distribution patterns. In order to reproduce the observed REE patterns, the source regions of these rocks need to undergo an extensive initial depletion event (~ 20%) in the garnet stability field before being subjected to metasomatic enrichment and subsequent partial melting. The extensive initial depletion, probably represented by 'komatiitic type' melt extraction during the Archaean, necessitates the partial melting of the eastern Dharwar craton kimberlite and lamproite source regions to have taken place in lithospheric, but not convecting, mantle. This study rules out a 'transition zone' source recently invoked for such rock types from eastern Dharwar craton and elsewhere and therefore imposes important constraints as to the source regions of kimberlites and lamproites.

DESPITE great deal of research, the source regions of small-volume mafic potassic-ultrapotassic melts such as kimberlites remain controversial[1-3]. The presence of syngenetic inclusions of majoritic garnets within diamonds[4,5] and ultra-deep (> 400 km) xenoliths[6] in some southern African kimberlites with ocean island basalt (OIB) like isotope signature, i.e. group I type kimberlites[7] led some workers to suggest that such kimberlites were derived from a 'transition zone' source or even from the core-mantle boundary[8]. Invoking similar criteria, some of the kimberlites with group I type isotopic signature from the eastern Dharwar craton have been suggested[9] to be products derived from partial melting of sources in the 'transition zone'. The present paper, which arose from a detailed geochemical and isotopic study[10] of nearly 20 kimberlite and lamproite diatremes from the eastern Dharwar craton, aims to model the melting process responsible for the generation of these magmas so as to constrain their source region(s).

In the petrogenetic modelling of mafic and ultramafic rocks, peridotite mantle is assumed to be primary melt source of the magmas[11,12] and the partial melting processes may be represented by either batch melting or fractional melting[13]. Recent theoretical studies suggest that once formed, even small volumes of melt may separate rapidly from the matrix[14–16]. Hence, fractional melting may better represent mantle melt generation than the batch melting process[17], and so, given appropriate constraints on D_i (bulk partition coefficient), the mantle melting process may be modelled, using appropriate equations given by Shaw[13].

Based on this premise, McKenzie and O'Nions[17] developed an inversion technique to model the rare earth elements (REE) of mafic igneous rocks and to constrain the partial melt distributions with depth. The aim of the REE inversion modelling is to discover the model melt distribution with depth that could have been responsible for producing the observed REE pattern in the sample. In order to obtain the melt distribution, the REE composition of the sample has to be inverted, using the techniques similar to geophysical inverse theory[18]. The depth to top of the melting column is varied through plagioclase-, spinel- and garnet-stability fields to obtain a best fit to the observed REE concentrations. The inversion technique uses both the abundances of REE and the slope (La/Yb) of the normalized pattern to constrain the melt distribution with depth. REE are chosen in preference to major oxides and other trace elements as (i) their bulk partition coefficients in the upper mantle vary with depth from plagioclase through spinel to garnet stability fields, (ii) their concentrations may be precisely determined, (iii) the REE behave as chemically coherent series, and (iv) the partition coefficients for the REE between important mantle phases and melt are better known than many other elements. The mathematical expressions involved in REE inversion are described in McKenzie and O'Nions[19]. The