Uranium and thorium abundances in some graphite-bearing Precambrian rocks of India and implications

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Graphite schists from parts of Gujarat in the Aravalli Supergroup show maximum contents of uranium (70–95 ppm), hosted mainly in the graphites, whereas such schists from the Tamil Nadu granulite terrain contain distinctly lower amounts of uranium (7–9 ppm). Graphite-bearing hornblende gneiss and calc-granulites from Madurai, Tamil Nadu, contain higher amounts of uranium (12–28 ppm) than the schists, and uranium is mainly hosted by the magnetite and allanite occurring as independent grains with flaky graphite and also as inclusions within quartz. Khondalites from Andhra Pradesh are depleted in uranium (0.9–1.3 ppm) compared to Th (17.5–20.2 ppm). Except for the khondalites, which have high Th/U ratio (13.5–22.4), all the other samples have very low Th/U ratios (0.10–0.80) compared to the crustal average (3–4). Such variations among similar rock types, may in part be related to uranium and thorium abundances inherited from parental rocks, modified later by hydrothermal and/or metasomatic processes. Graphites from such rock types can provide both *in situ* and migrant reductants for hosting a variety of uranium and other metallic deposits.

GRAPHITE-bearing rock formations constitute an important and interesting assemblage in the Precambrian terrains of the world. Besides their interest as possible relicts of primitive life forms, they have an important bearing on the genesis of several metallic and non-metallic elemental concentrations. Although the importance of graphitic rocks, in Archaean and Lower Proterozoic sequences, in the genesis of uranium deposits has been well recognized[1], their exact role, however, has been poorly understood. As a part of a major research programme on understanding the role of graphite-bearing lithologies in uranium mineralization, we have attempted here a preliminary study of the abundances of U and Th in ten selected samples from different areas of the Precambrian of India (Figure 1). These include graphite-bearing gneisses and granulites of Madurai–Usilampatti region in Tamil Nadu[2], graphite schists from the Proterozoic Champaner Group/Aravalli Supergroup of Gujarat and the khondalites of Andhra Pradesh (see Table 1). Published data on uranium and thorium abundances of graphite-bearing rocks in India are very scarce or non-existent.

Field work and detailed sampling were carried out in one of the main graphite-bearing localities around Usilampatti in Madurai district, Tamil Nadu. Samples from other areas were obtained from Dr N. K. Rao of the Ore Dressing Section, BARC, Hyderabad. Samples were analysed chemically as well as radiometrically for their uranium and thorium contents and the results are given in Table 1 along with average U and Th abundances for similar rock types[3,4]. Petrographic studies with special reference to identification of discrete uranium- and/or thorium-bearing mineral phases were carried out using α-sensitive solid-state nuclear track detectors (SSNTD) in contact with polished thin sections of the rocks for a period ranging from 8 to 72 hours.

The graphite-bearing lithologic assemblages such as calc-granulites, schists and gneissic rocks of Tamil Nadu, as listed in Table 1, contain significant amounts of uranium. Uranium concentration has been found to be higher, close to the contact between calc-granulites and amphibolites. The graphite-bearing calc-granulites from Madurai district show distinctly higher abundances of uranium compared to the schists. SSNTD show that radioactivity stems largely from disseminated magnetite and partly metamict allanite (0.1–0.4 mm across) occurring either as inclusions in quartz or as independent grains with flaky graphite. The graphite does not indicate any significant α-track and thus does not appear to contribute to the uranium content of the rock. It is possible that the higher content of uranium in these rocks compared to the average values listed in Table 1 might

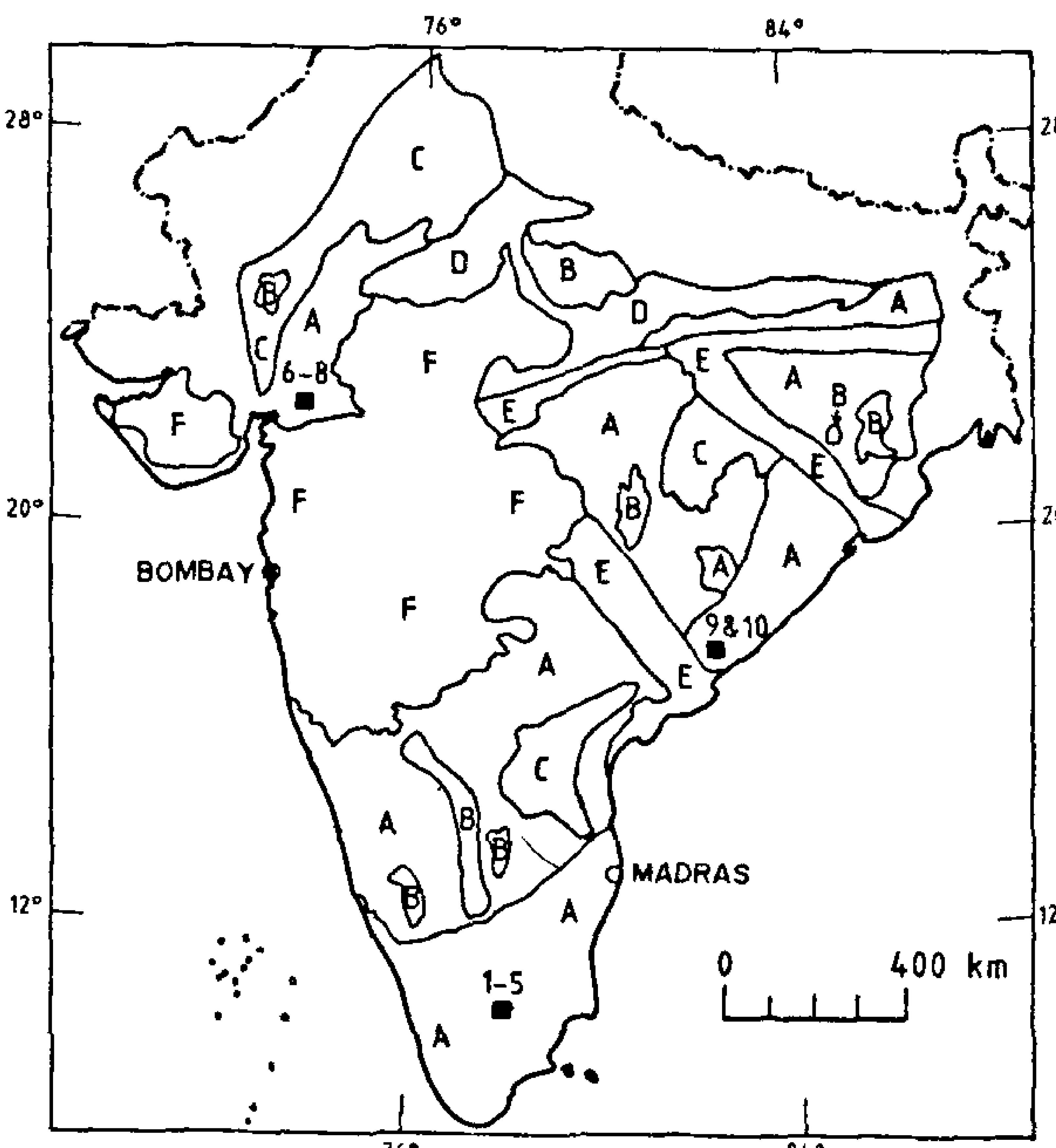

Figure 1. Generalized geological map of the peninsular India showing the location of samples. A Precambrian basement rocks and supracrustals, B. Granite plutons, C: Lower Proterozoic sediments (Cuddapah, Delhi and others), D Vindhyan sediments (Upper Proterozoic), E. Gondwana sediments, F: Deccan basalt

Table 1. Distribution of uranium and thorium in some graphite-bearing Precambrian metamorphic rocks of India (all data in parts per million)

Sample numbers and area	Rock type	U	Th	U/Th	Th/U
1 Karatupatti, Madurai district, Tamil Nadu	Graphite-bearing hornblende–biotite gneiss	28	7	4	0 25
2 Malaipatti, Tamil Nadu	Graphite-bearing calc-granulite	28	2 6	10.8	0 1
3 Pommampatti, Tamil Nadu	Graphite-bearing calc-granulite	12	9 7	1 2	0 8
4 Minakshipuram, Tamil Nadu	Graphite schist[12]	7	3 5	2 0	0.5
5 Chokkampatti, Tamil Nadu	Graphite schist[12]	9	5 3	1 7	0.6
6 Shivrajpur, Gujarat	Graphite schist	95	21 1	4 5	0 22
7 Agucha, Gujarat	Graphite schist	70	8 8	8 0	0 13
8. Deoghar Baria, Gujarat	Graphite schist	71	11.4	6 2	0 16
9 Burugubanda, Andhra Pradesh	Khondalite	1 3	17 5	0.07	13 5
10. Tapasi Konda, Andhra Pradesh	Khondalite	0 9	20 2	0 05	22 4
Average abundances[3, 4]					
	Gneiss	3 0	6 4	0 46	2 13
	Granulite	<1 0	21.0	–	–
	Graphite schist	3 5	7 5	0 47	2.14

Stratigraphic position of samples· 1–5 and 9 and 10, Late Archaean/Lower Proterozoic (Khondalite–Charnockite Group); 6, Lower Proterozoic? (Champaner Group), 7 and 8, Lower Proterozoic (Aravalli Supergroup)

Uranium by fluorimetry (accuracy and precision less than ±10%) and thorium by low-energy γ-ray spectrometry (accuracy and precision less than ±15%) at the AMD Chemistry and Physics Laboratories, respectively, Hyderabad

be derived from the late Proterozoic (*ca.* 850 Ma) younger intrusive granites[5]. The pegmatites, which in all probability are related to these younger intrusive granites, contain uranium-bearing refractory minerals like fergusonite, gadolinite, allanite and others and thus support the above possibility. Hydrothermal degradation of graphite from these rocks, however, may provide the mobile reductants for fixing up uranium in the system during such granitic activity.

The thorium abundances in these graphite-bearing lithologies are distinctly lower than those of uranium (except for the khondalites) and show limited variation (see Table 1). The Th/U ratios are very low (0.1–0.8) compared to the crustal average of 3–4, further emphasizing that graphite-bearing rocks are distinctly richer in uranium and may have inherited or acquired it from later metasomatic processes and/or hydrothermal action.

The graphitic schists from Gujarat show higher amounts of uranium than those of Tamil Nadu. Petrographically, it is seen that the α-tracks are closely matched with graphite in the graphite schist from Deoghar Baria, Gujarat, belonging to the Lower Proterozoic Aravalli Supergroup, indicating that the graphite either scavenged the uranium from the system or inherited it from the precursor carbonaceous matter. Graphite schists from the Shivrajpur area of Champaner Group (Lower Proterozoic age?) as well as from Agucha area (Aravalli Supergroup) also show higher U and Th concentrations in general, similar to that from Deoghar Baria.

The khondalites from the Eastern Ghats are depleted in uranium (0.9–1.3 ppm) compared to thorium (17.5–20.2 ppm). This is in conformity with the general observation of depletion of radioelements like uranium and thorium in high-grade granulite facies metamorphism[4]. It has been shown that the high-grade granulite facies rocks from Archaean–Proterozoic terrains are depleted in uranium and related large-ion lithophile (LIL) elements such as K, Rb, Ba and rare-earth elements[4]. They contain on an average <1 ppm of uranium. However, recent studies on rocks from the granulite terrain south of the Athabaska basin and granulite facies rocks within the Carswell structure show no such depletion and in fact are found to contain enriched uranium values over a wide range (1–100 ppm of U)[6–8]. Gneisses from Dharwar craton have also been shown to contain anomalous uranium contents (3.3–4.6 ppm) compared to those from the Canadian shield (1.5 ppm), attributed to metasomatic activity[9].

The role of graphite-bearing lithologies in the genesis of uranium deposits appears to be twofold. Firstly, the graphite in such rocks can be a source or protore for uranium, but more importantly it provides the mobile reductants (gaseous methane, CO_2, CO and H_2) after hydrothermal degradation[10, 11]. The latter, it is known, can permeate through fracture zones and/or porous media and reduce U^{6+} to U^{4+} and fixes it either in clays, iron oxides, or in other minerals. In addition, the carbonaceous matter, which after metamorphism becomes graphite, maintains a low oxygen fugacity condition and thus inhibits or slows down the mobility of uranium and other LIL elements and thus may serve as a sink to the lithophile elements, including uranium[6–8]. Thus, a study and understanding of graphite-bearing lithologies assumes greater importance in the exploration of uranium and other metallic mineral deposits.

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Discovery of microvertebrates from the Pleistocene deposits of the Central Narmada Valley, India

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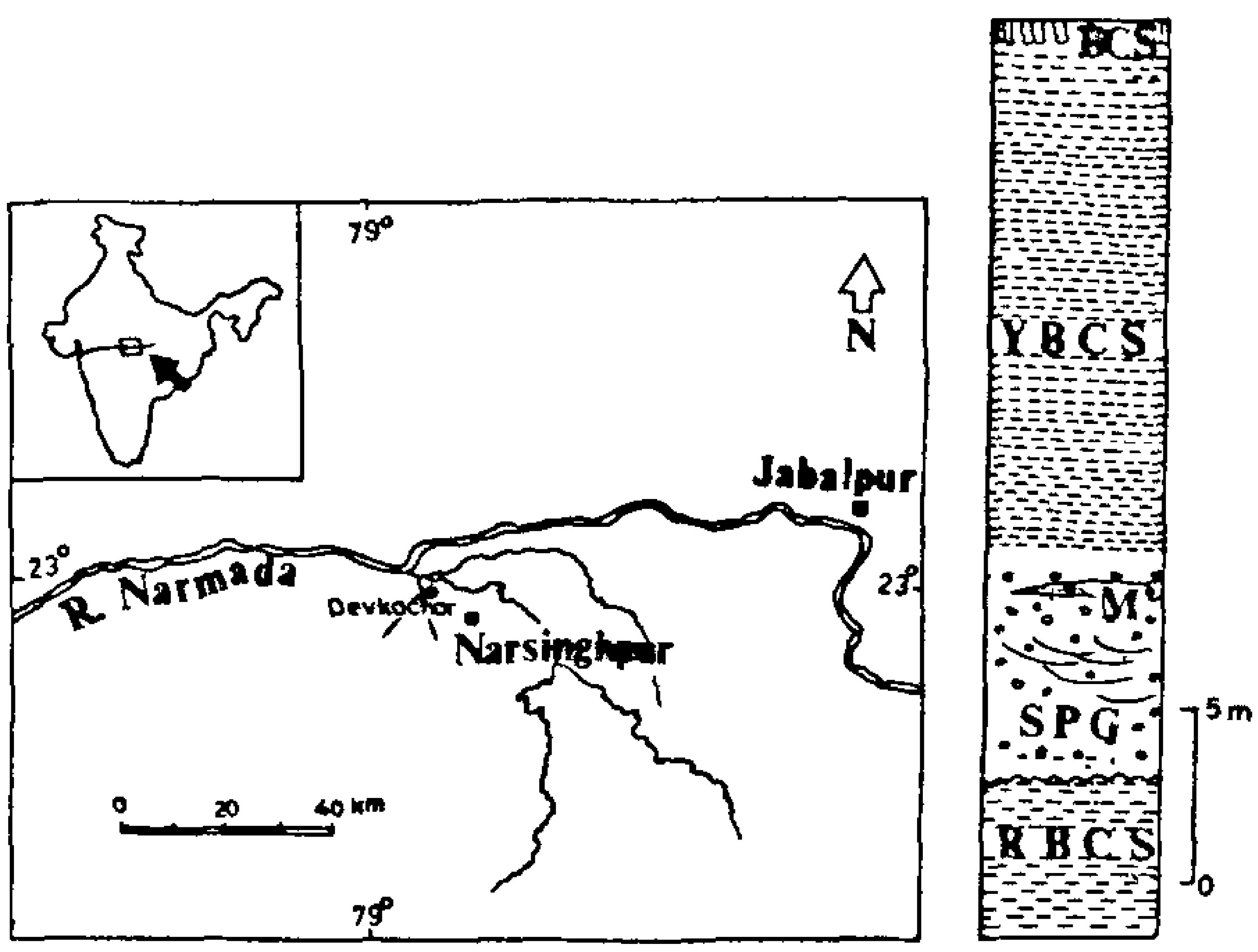
Pleistocene sediments of the Central Narmada Valley, Madhya Pradesh, widely known for their wealth of large vertebrates[1–4], have yielded a partial hominid skull[4,5] and an array of Stone Age implements[6] for the first time, along with a diverse microvertebrate assemblage (micromammals, fish, amphibian and reptiles) during the 1991–92 field season. Preliminary taphonomical investigations reveal that the small mammal remains, primarily derived from scats, were deposited by fluvial processes. Faunal assemblage suggests the presence of sandy plains, grasslands with high sub-soil moisture content and shallow stream systems. Rodents like *Millardia* cf. *M. meltada*, *Bandicota* cf. *B. bengalensis*, *Tatera* cf. *T. indica* and *Gerbillus* sp. indicate an early emergence of the modern rodents of the Indian subcontinent.

THE present announcement marks the first report of fossil microvertebrates from the Pleistocene sediments of the Central Narmada Valley. It may be noted that taphonomical and palaeoecological interpretations of the Central Narmada Valley were so far based on large mammal assemblages[7,8]. However, due to the absence of fossil microfauna, paleoecological interpretations could not be deduced with precision. In this context, the recent discovery of microvertebrate assemblage from the Narmada Valley assumes greater significance. The present collection (Table 1) comes from a freshwater mollusc-bearing pebbly horizon (Figure 1 *b*) exposed near village Devakachar (23°23′N: 79°07′E) in Distt. Narsinghpur of Madhya Pradesh state (Figure 1 *a*).

As regards the chronological framework for the fossil occurrences, the molluscan shells (collected around Devakachar) were earlier analysed for ^{14}C dating, which yielded a radiocarbon date[9] of $31,750^{+1820}_{-1625}$ BP. Apart from this, based on fluorine/phosphate correlation[10], palaeomagnetic studies[11], percentage of nitrogen (late K. P. Oakley, personal communication) and occurrence of fossilized remains of large mammals like *Cervus duvauceli*, *Hexaprotodon palaeindicus*, *Elephas hysudricus*, *Bubalus* cf. *B. bubalis*, *Equus namadicus* and *Bos namadicus*[8,12], the fossiliferous sediments at Devakachar were assigned a Middle to Upper Pleistocene time bracket.



a *b*

Figure 1. Locality map (*a*) and lithostratigraphy (*b*) at Devakachar (after Badam and Grigson[24]) BCS (black cotton soil), YBCS (yellow brown concretionary silt), M (microvertebrate-yielding horizon), SPG (sandy pebbly gravel) and RBCS (red brown concretionary silt)

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