1. Nelson, R. J., *An Introduction to Behavioural Endocrinology*, Sinauer Associates Inc. Publishers, Sunderland, 1995.
2. Pevet, P., *Comparative Physiology of Environmental Adaptations*, S. Karger, Basel, 1987, vol. 3.
3. Pospichal, M. W., Karp, J. D. and Powers, J. B., *Physiol. Behav.*, 1991, **49**, 417–422.
4. Schilatt, S., Niklowitz, P., Hoffman, K. and Nieschlag, E., *Biol. Reprod.*, 1993, **49**, 243–250.
5. Hard, E. and Larsson, K., *J. Comp. Physiol. Psychol.*, 1968, **66**, 805–807.
6. Hsu, C., Huang, H-T., Hsu, H-K., Yu, J. Y-L. and Peng, M-T., *J. Pineal Res.*, 1990, **8**, 107–114.
7. Wallen, E. P., DeRosch, M. A., Thebert, A., Losee-Olson, S. and Turek, F. W., *Biol. Reprod.*, 1987, **37**, 22–27.
8. Nelson, *R. J.*, *Biol. Reprod.*, 1985, **33**, 418–422.
9. Haldar, C. and Pandey, R., *Indian J. Exp. Biol.*, 1988, **26**, 516–519.
10. Bronson, F. H. and Heidman, P. D., *Biol. Reprod.* 1992, **46**, 246–250.
11. Sinhasane, S. and Joshi, B. N., *Indian J. Exp. Biol.*, 1997, **35**, 719–721.
12. Thomas, B. B. and Oommen, M. M., *J. Bombay Nat. Hist. Soc.*, 1997, **94**, 149–151.
13. Thomas, B. B., Ph D thesis, University of Kerala, 1997.
14. Thomas, B. B. and Oommen, M. M., *Acta Theriol.*, 1998, **43**, 263–270.
15. Thomas, B. B. and Oommen, M. M., *Mammalia*, 1999, **63** (in press).
16. Thomas, B. B. and Oommen, M. M., *Indian J. Exp. Biol.*, 1999, **37**, 1201–1204.
17. Siegel, S. and Castellan, N. J. Jr., *Nonparametric Statistics for the Behavioural Sciences*, McGraw-Hill, Singapore, 1988.
18. Hoffmann, K., in *Hand Book of Behavioral Neurobiology* (ed. Aschoff, E. J.), Plenum Press, New York, 1981, vol. 4, pp. 449–473.
19. Morin, L. P., *Physiol. Behav.*, 1981, **27**, 89–94.
20. Vaughan, M. K., Vaughan, G. M., Blask, D. E. and Reiter, R. J., *Experientia*, 1976, **32**, 1341.
21. Cherry, J. A., *Physiol. Behav.*, 1987, **39**, 521–526.
22. Honrado, G. I., Bird, M. and Fleming, A. S., *Physiol. Behav.*, 1991, **49**, 277–287.
23. Bartness, T. J. and Goldman, B. D., *Experientia*, 1989, **45**, 939–945.
24. Ebling, F. J. and Foster, D. L., *Experientia*, 1987, **45**, 946–954.

Received 20 December 1999; revised accepted 29 February 2000

Large palaeolakes in Kaveri basin in Mysore Plateau: Late Quaternary fault reactivation

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Late Quaternary movements along the faults that demarcate tectonic boundaries of the N-S trending terranes of Biligirirangan and Closepet Granite in the Southern Indian Shield caused ponding of the River Kaveri and its tributaries Suvarnavati, Kabini and Shimsha of the Mysore Plateau. The resulting large lakes stretched tens of kilometres upstream in their valleys. Approximately 10 m thick black carbonaceous clay, characterized by prolific calcareous nodules including rhyzocretions in the top horizon, and covered locally by overbank fine sediments in floodways, represents the lakes that came into existence in the Late Pleistocene and lasted until Late Holocene. Subsequent fault movements were responsible for vertical displacement and attenuation of the lacustrine sediments. On-going movement is indicated by stream ponding in some segments and accelerated erosion of the elevated blocks.

THE much-faulted Southern Indian Shield (Figure 1) has time and again witnessed reactivation of faults of Precambrian antiquity[1]. Neotectonic activities on the multiplicity of faults are responsible for the evolution of the > 1200 m high Biligirirangan–Mahadeswaramalai Ranges in the east and > 1800 m Central Sahyadri mountain in the west. These high mountains bordering the Mysore Plateau enclose the basin of the Kaveri, an antecedent river of

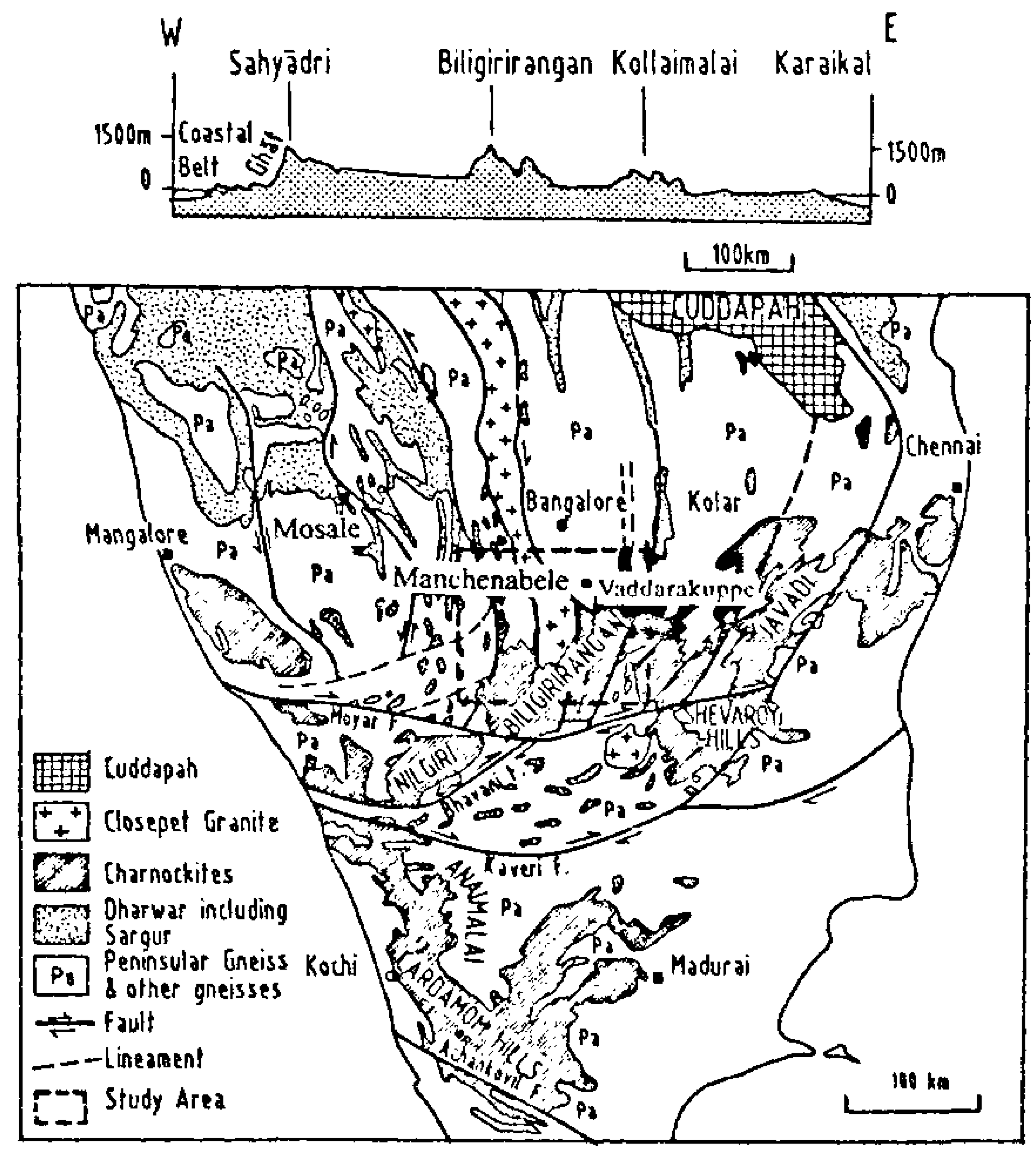

Figure 1. Much faulted Southern Indian Shield[1] showing the faults and shear zones that demarcate boundaries of Precambrian terranes. The profile across the Southern Indian Shield is after Vaidyanadhan[7]. The Kaveri basin lies between the BR and central Sahyadri.

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considerable maturity which breaks forcibly through the mountain barrier of the Biligirirangan–Mahadeswaramalai Ranges[2–9]. The Mysore Plateau is drained by the rivers that are strongly controlled by faults and shear zones[10], as evident from the remarkably straight courses and abrupt deflections.

Neotectonic movements on the N-S as well as NE-SW oriented fault caused blockade of streams, culminating in the formation of lakes now represented by black carbonaceous clay riddled with calcareous concretions in the upper part such as seen at Manchenabele in the Arkavati River Valley, at Uchchivalase in the Antargange Hole and at Vaddarakuppe in the Rayatmala stream (Figure 1), south-southeast of Bangalore[8].

The first author's fieldwork in the Kaveri basin encompassing the *talukas* of Maddur, Kollegal, Chamarajanagar

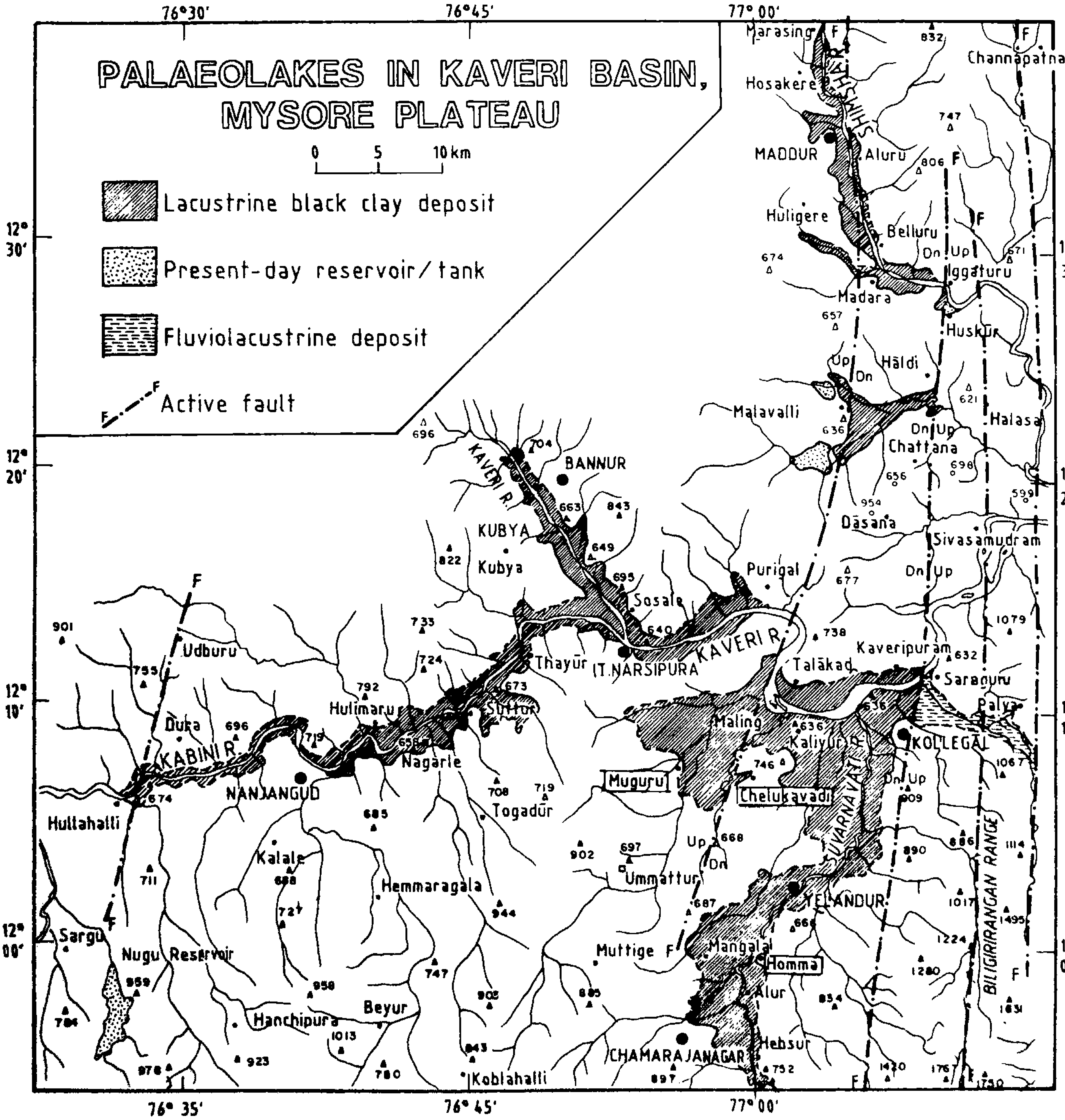

Figure 2. Upstream of the active Kollegal–Iggaturu fault the Kaveri and its tributaries are characterized by nearly 10 m thick accumulation of black carbonaceous clay deposited in the lakes resulting from stream blockade. Lakes were formed also in the Shimsha valley and its tributary Hulu Halla resulting from movements on faults that cross the streams (localities from where samples were collected for dating are shown in boxes).

and T. Narasipura demonstrated that what has been described[9] as 'black soils in the form of horizontal sea-like surface almost devoid of elevation contrast and indicative of their formation in shallow water environment' actually represents lacustrine carbonaceous black clay resulting from ponding of the River Kaveri and its tributaries Suvarnavati, Kabini and Shimsha. The black clay grades downwards and laterally into greyish-brown clay and mud. Near stream channels the black clay is underlain–overlain by as well as interfinger with fluvial silt and fine sand. The top layer of the lacustrine clay is characterized by prolific calcareous concretionary nodules, including rhyzocretions. Interestingly, a large part of this region of sedimentary mantle had earlier been depicted as the basin in the Mysore Plateau[11]. The present work shows that the lacustrine deposit is confined only to the floodways of the rivers (Figure 2). The black carbonaceous clay transitionally overlie fluvial gravel and sand in channels but rests directly on weathered countryrocks in wide valley flanks. Finer sediments brought by recurrent floods cover the lacustrine deposits as overbank alluvial sediments closer to the channels. Likewise at the foot of the uplifted hills eroded material – sheet wash – brought by hill torrents conceal the lake clay. The lacustrine deposits form remarkably flat stretches of uniform elevation in the otherwise undulating terrain of the Mysore Plateau (Figure 3 *a*). These are being intensely used for paddy and sugarcane cropping.

The Biligirirangan Range is demarcated by a series of N-S trending faults registering oblique-slip displacement[8]. One of these faults that passes by Kollegal and Iggaturu (Figure 2) demarcates the downstream limits of the deposits of black clay filling the valleys of the Kaveri and its tributaries. A linear series of ponds follows the fault line. Apart from the abrupt termination of the black lacustrine clay and sharp juxtaposition against brown alluvial coarser sediments, there is marked deflection of all the rivers as they cross the fault line. For example, the east-flowing Shimsha suddenly runs southward at Iggaturu, the Hulu Halla swerves south near Hadli, the Kaveri swings north-west of Saraguru and near Hebsur (ESE of Chamarajanagar) and the Suvarnavati deflects northward (Figure 2). Furthermore, there is accentuation of gully erosion and channel entrenchment on the block east of the fault. Clearly the Kollegal–Iggaturu fault is active and has caused uplift of the downstream eastern block. The fault

Figure 3. ***a***, Flat stretch of black carbonaceous lacustrine clay succession near Nanjangud in the Kaveri Valley; ***b***, Rayatmala stream at Vaddarakuppe has eroded its bank and exposed the full succession of the lake deposit. The basement gneisses overlain by fluvial gravel is succeeded by 7 m thick succession of black clay. The top of the clay sequence is characterized by calcareous concretions; ***c***, Closer view of the Vaddarakuppe palaeolake succession comprising predominant black clay resting on gneisses and grading upward into greyish-brown clay. The top is characterized by calcareous concretions in black clay. Samples were collected from this succession at a fixed interval of ~ one metre.

movements must have resulted in the blockade of rivers and streams and consequent formation of lakes. The lakes stretch far upstream – 8 km up to ESE of Chamarajanagar in the Suvarnavati, 14 km up to west of Nanjangud in the Kabini, 25 km up to NW of T. Narasipura in the Kaveri (Figures 2 and 3 *a*), up to Malavalli in the Hulu Halla, and 10 km up to north of Maddur in the Shimsha (Figure 2). The thickness of the black clay varies from less than 2 m in the Shimsha valley to 9–15 m in the Suvarnavati valley.

Similarly, the uplifts of the south-eastern block along the NE-SW trending active faults resulted in the impoundment in the two tributary streams of the Arkavati River – the Antaragange and Rayatmala – giving rise to lacustrine deposition at Uchchivalase and Vaddarakuppe, respectively (Figures 1, 3 *b*, *c* and 4).

Radiocarbon dating of the palaeolake sediments has been done by the second author. Samples of black clay rich in organic matter were collected at intervals of one metre from a nearly vertical section cut by the Rayatmala at Vaddarakuppe (Figures 3 *b* and 4). Radiocarbon dating of carbonaceous clay gives reliable ages if the organic matter content is more than 2–3%. Intensely cultivated and irrigated almost round the year for cash crops, the lake sediments are in the disturbed condition. The sediment samples were treated with 10% HCl solution to remove the carbonates. CO_2 was obtained from organic matter in the sediment by dry combustion using a standard procedure. Sample CO_2 was synthesized to C_2H_2 in a carbide reaction vessel supplied by Phonon Corporation, UK and then to benzene as described by Gupta and Polach[12]. Overall recovery of 75–85% was obtained consistently in CO_2 to C_6H_6 conversion. The ^{14}C activity in benzene (with butyl-PBD scintillator, 15 mg/ml C_6H_6) was counted in the ultra high sensitivity liquid scintillation counting system, QUANTULUS 1200 of LKB Wallac. The background and NBS oxalic acid standard (RM-49) counting rates in the system for 3 ml benzene sample in teflon vial are 0.453 ± 0.014 cpm and 30.73 cpm, respectively with a figure of merit of 8854. The dated samples give consistent chronology of ^{14}C ages (Figure 5). Noting that the thickness of various lacustrine successions in different valleys in the Kaveri basin varies uniformly between 7 and 10 m, it is assumed that they are the products of nearly contemporaneous fault reactivation. Being intensely cultivated and irrigated practically round the year for cash crops, the flat stretches of palaeolake sediments are in highly disturbed and contaminated conditions.

The Vaddarakuppe succession (Figure 3 *b*) provides an ideal setting for sample collections and the newly dug canal near Homma (Figure 2) provides good exposure of the upper part of the succession for sampling and dating. The life of the Vaddarakuppe palaeolake spanned the period from ~ 26,000 ± 825 to 11,800 ± 825 yr BP. Significantly, the basal samples from the depth of 7 m below the surface of the Uchchivalase palaeolake are dated 26,470 ± 900 yr BP, indicating that both the lakes came into existence at nearly the same time. East of Kollegal in the Kaveri Valley, the black clay sample collected from a depth of 25 cm below the surface at Muguru gave a date of 8290 ± 140 yr BP, while the one taken from just below the surface near Chelukavadi is dated 4420 ± 110 yr BP.

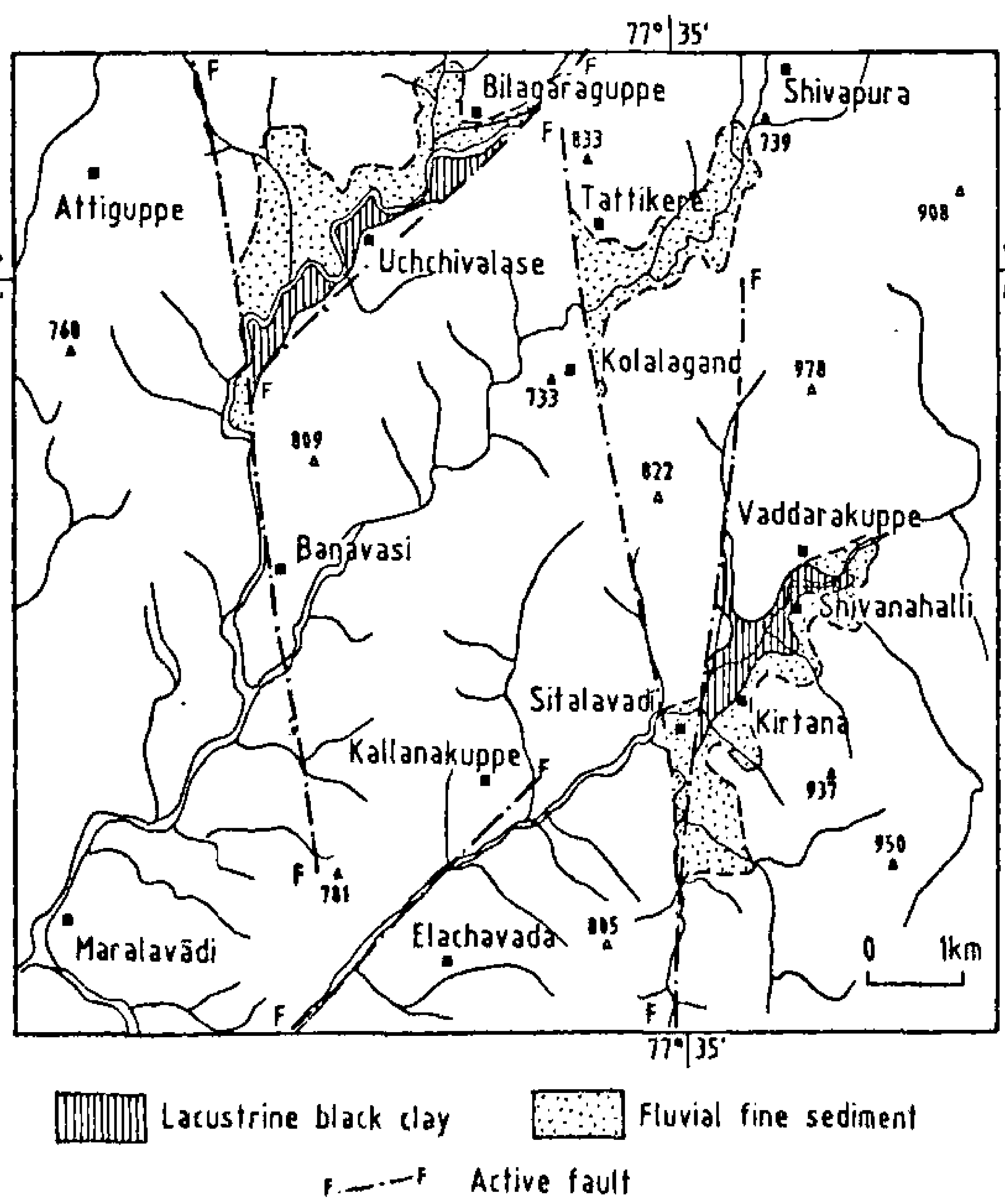

Figure 4. Antaragange and Rayatmala streams – tributaries of the Arkavati River – were ponded due to movements on the NE-SW oriented faults. Later movements on these and N-S faults uplifted and truncated the lacustrine deposits.

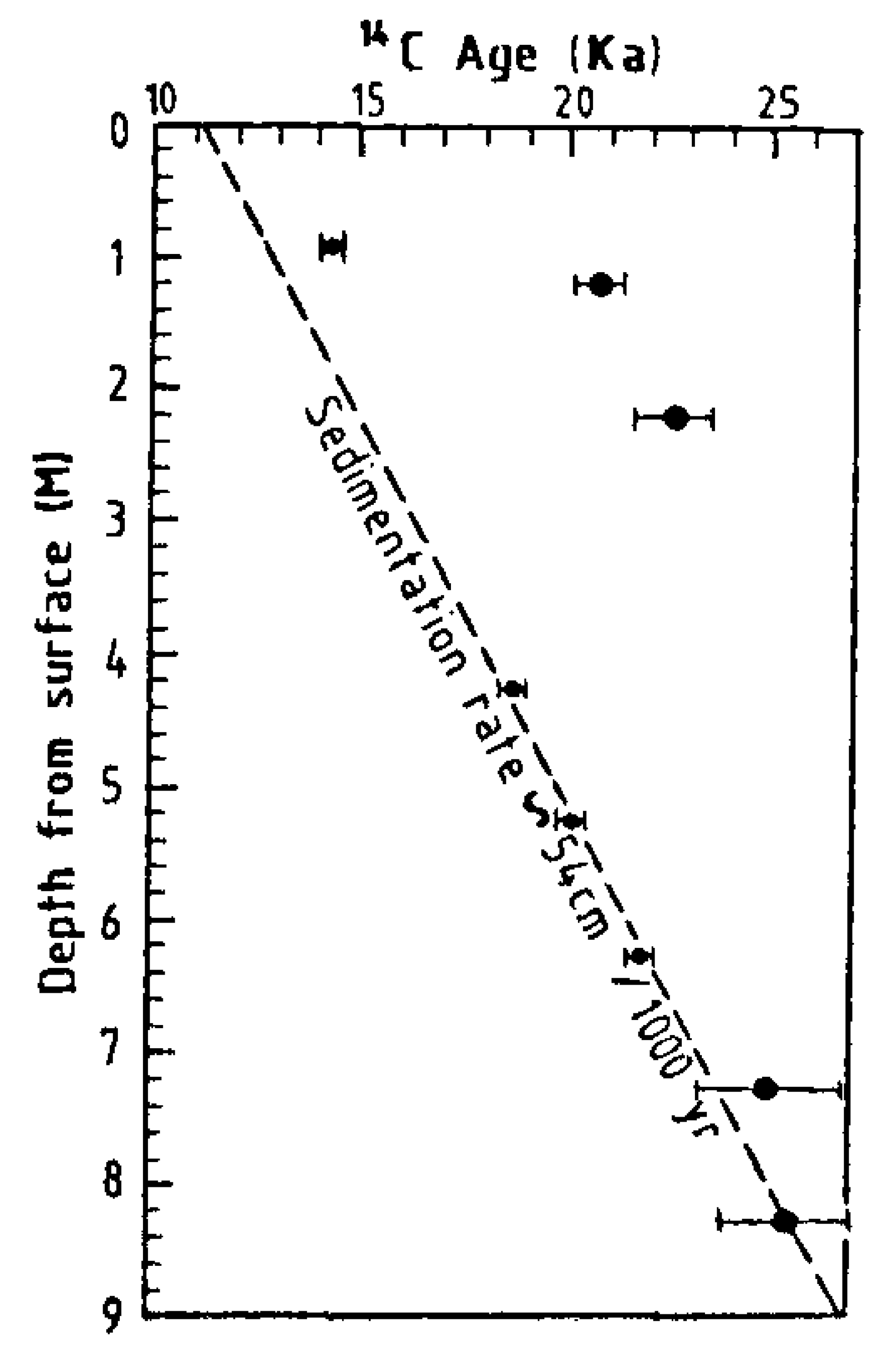

Figure 5. Plotting of measured radiocarbon (^{14}C) dates of samples against their depths (below surface) gives a straight line for the age of the Vaddarakuppe lake.

In the Suvarnavati valley, samples collected from depths of 20 and 140 cm at Homma (Figure 2) yield ages of 3540 ± 170 yr BP and 7850 ± 140 yr BP, respectively. The Muguru and Chelukavadi dates of the Kaveri sediments fall in the isochron of the Vaddarakuppe samples. From the calibrated age range it seems that the end of the lacustrine phase in the Kaveri Valley was sometime between 4860 and 5290 yr BP, and in the upper reaches of the Suvarnavati around 2600 to 3900 yr BP. In the Arkavati valley, the Manchenabele lake vanished around 1900 yr BP and the Mosalehosahalli lake south-east of Hassan dried up around 1300 yr BP.

It seems that these lakes did not dry up during the same period. Although substantial draining out of the impoundments could have been caused by revival of movements on the active faults, it was the growing aridity in the later Holocene that was responsible for the drying up of the lakes. Presence in abundance of calcareous nodules including rhyzocretions in the black clay succession implies growing aridity in the climate as was the case in the dryland of western Rajasthan[13]. The Indian subcontinent had experienced a spell of dryness beginning around 3500–4000 yr BP and ending at about 2000 yr BP[14–16]. The lakes of the Kaveri basin dried up possibly during this period. Revival of movements on active faults must have helped in the draining out of the impoundments as stated earlier in the article.

The expanse of the lacustrine clay deposit in the Kaveri valley has been dismembered and vertically displaced by the NNE-SSW trending fault that is traceable through Talakad (where the east-flowing Kaveri suddenly swings SSW) (Figure 2), and then past Malavalli to the straight N–S course of the Shimsha near Maddur. Not only is there a difference in the elevation of the order of 15 m but also the black lacustrine clay is sharply juxtaposed against brown fluvial sediment west of Talakad. In the Hulu Halla and Shimsha valleys, the elevation difference of the black clay surface is 15 m where the eastern side was downfaulted. Upstream of Maddur the black clay is considerably truncated, there being none on the eastern side. Likewise in the Antargange and Rayatmala valleys later movements have faulted up the black clay and exposed the sheared gneisses of the floor at Sitalavadi.

Ponding of these and other streams in some segments cut by the active faults suggests that the fault movements are continuing in the present.

1. Ramakrishnan, M., in *Geo Karnataka* (eds Ravindra and Ranganathan, N.), Karnataka Assistant Geologists' Association, Bangalore, 1994, pp. 6–35.
2. Radhakrishna, B. P., *Bull. Mysore Geol. Assoc.*, 1952, **3**, 1–56.
3. Radhakrishna, B. P., *Bull. Indian Geophys. Union*, 1966, **3**, 95–106.
4. Radhakrishna, B. P., *J. Geol. Soc. India*, 1992, **40**, 1–12.
5. Radhakrishna, B. P., *Curr. Sci.*, 1993, **64**, 787–793.
6. Vaidyanadhan, R., *J. Geol. Soc. India*, 1971, **12**, 14–23
7. Vaidyanadhan, R., in *Exploration in the Tropics* (ed. Jog, S. R.), Geography Department, University of Poona, Pune, 1987, pp 125–126.
8. Valdiya, K. S., *J. Geol. Soc. India*, 1998, **51**, 139–166.
9. Radhakrishna, B. P. and Vaidyanadhan, R., *Geology of Karnataka*, Geol. Soc. India, Bangalore, 1997, p. 353.
10. Jayananda, M. and Mahabaleswar, B., *Proc. Indian Acad. Sci (Earth Planet. Sci.)*, 1991, **100**, 31–36.
11. Demongeot, J., *Z. Geomorphol.*, N.F., 1975, **19**, 229–272.
12. Gupta and Polach, *Radiocarbon Dating Practices at ANU*, Austr Nat. Univ., Canberra, 1985.
13. Andrews, J. E. *et al.*, *Quat. Res.*, 1998, **50**, 240–251.
14. Naidu, P. D., *Curr. Sci.*, 1996, **71**, 715–718.
15. Rajagopalan, Geeta, Sukumar, R., Ramesh, R., Pant, R. K. and Rajagopalan, G., *Curr. Sci.*, 1997, **72**, 60–63.
16. Gasse, F., Fontes, J. Ch., VanCampo, E. and Wei, K., *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1996, 79–92.

ACKNOWLEDGEMENT. K.S.V. thanks S. G. Suresh and G. T. Vijaykumar for providing enjoyable and helpful company during the fieldwork.

Received 25 November 1999; revised accepted 9 February 2000

Occurrence of pteropods in a deep eastern Arabian Sea core: Neotectonic implications

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This paper reports pteropod shells (aragonitic) at 100, 200, 270–277 and 470 cm sediment depths in a core (EAST) recovered from 3820 m deep water from the eastern Arabian Sea. Ages of the four stratigraphic levels showing pteropod presence are estimated as 29, 52, 70–72 and 127 kyr. In normal circumstances microfaunal assemblages of this core are expected to be devoid of pteropod shells because the site is situated far below (~ 3.5 km) the Aragonite Compensation Depth. Therefore, the recorded pteropod shells are exotic to the location and may have been transported from the shallower depths by the turbidity currents. The plausible reason for the preservation of aragonitic shells at such greater depth appears to be quick burial of pteropods resulting from large-scale vigorous slumping triggered by neotectonic activity.

PTEROPODS are marine holoplanktic micro-gastropods having aragonitic shells. Living pteropods are abundant in pelagic environment, but rarely preserved in deep-sea sediments because of their dissolution-prone shells. Well

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