Table 1. Apparent diffusion coefficient of ^{86}Rb in mica-rich soils at field capacity associated with soil properties

Surface soil	Da Rb (cm^2 sec^{-1})		Soil properties				
	0 ppm K	50 ppm K	Bulk density (g/cc)	Organic carbon (%)	Exch. K(me/100g soil)	Mica (% clay)	Kaolinite (% clay)
1	0.567×10^{-10}	7.02×10^{-10}	1.73	0.34	0.11	26.36	71.15
2	0.546×10^{-10}	2.856×10^{-10}	1.65	0.46	0.15	70.05	22.79
3	1.674×10^{-10}	1.788×10^{-10}	1.62	1.29	0.34	86.61	7.19
4	0.540×10^{-10}	4.839×10^{-10}	1.52	0.64	0.15	85.97	8.08

non-expandable minerals like mica and kaolinite having practically no interlayer space. Moreover, mica exhibits much higher binding force for K to restrict its movement in soils. Further, the high buffering capacity of these soils varying between 7.50 and 26.67 me/100 g $(M L)^{\frac{1}{2}}$ as reported by Mishra[9] might also have been associated with low Da-Rb values in these soils. Fairly high values of Da-Rb in the soil of Pedon 3 seem further to be associated with high value of organic carbon (1.29%). The Da-Rb values were, however, found positively and significantly correlated with exchangeable K of these soils ($r = 0.941$).

1. Barber, S. A., *Soil Nutrient Bioavailability—A Mechanistic Approach*, Wiley and Sons, New York, 1984.
2. Fried, M. and Broeshart, H., *The Soil-Plant System in Relation to Inorganic Nutrition*, Academic Press, New York, 1967, pp. 227–228.
3. Fried, M., Hawkes, G. and Mackie, W. F., *Soil Sci. Soc. Am. Proc.*, 1959, **23**, 360–362.
4. Evans, S. D. and Barber, S. A., *Soil Sci. Soc. Am., Proc.*, 1964, **28**, 56–57.
5. Place, G. A. and Barber, S. A., *Soil Sci. Soc. Am. Proc.*, 1964, **28**, 239–243.
6. Sen, A. and Deb, D. L., in *Improving Crop and Animal Productivity* (eds. Sethi, G. R. and Chatrath, M. S.), Oxford and IBH Pub. Co., New Delhi, 1978, pp 485–497.
7. Phillips, R. E. and Brown, D. A., *Soil Sci. Soc. Am., Proc.*, 1964, **28**, 758–763.
8. Schofield, R. K. and Graham-Bryce, I. J., *Nature*, 1960, **188**, 1048–1049
9. Mishra, B. B., Ph D Thesis, I. A. R. I., New Delhi, 1990.

ACKNOWLEDGEMENT. B. B. M. is grateful to BARC, Bombay for timely supply of rubidium isotope, and to Dr P. N. Tiwary, I. A. R. I., New Delhi for encouragement.

Received 25 June 1992; accepted 4 September 1992

Trace fossil *Limulicubichnus* from the Lower Miocene rocks of Kutch

S. J. Patel and D. M. Shringarpure

Department of Geology, M. S. University of Baroda, Vadodara 390 002, India

Trace fossils of *Limulicubichnus* indicating their production by the horseshoe crab are reported for the first time from the Lower Miocene rocks of Kutch. Two separate species of the traces are identified and described. The heavily excavated traces are accounted for as either deposit feeding structures or as resting traces made by an animal supported in water. These trace fossils and their associated forms indicate shallow water conditions, predominantly marine, which were subjected to repeated fluctuating water levels and at times exposed to the subareal condition.

THE authors have located trace fossils of *Limulicubichnus* within the Lower Miocene rocks exposed in the Suvernarekha River Section near Ramwada Mandir in Western Kutch (Lat. 23° 26′ 30″ N, Long. 68° 36′ 00″ E). These traces are found on the top of the 20 m thick buff to yellowish coloured argillaceous limestone sequence exposed in the River channel. Most of the argillaceous limestone beds here are hard, compact 3–5 m thick. They often contain a rich assemblage of gastropods, pelecypods, echinoderms and rarely corals. The microfossils include species of *Ammonia papillosus*, *Archaiaes angulaties*, *Miogypsina* sp. and *Taberina malabarina* indicating a probable Burdigalion age of the strata.

The trace fossils identified as *Limulicubichnus* are typically heart-shaped, lunate, often teardrop-shaped depressions on the bedding plane. They are characterized by traces exhibiting bilateral symmetry, serrate posterior margin, elongate terminus or appendage markings and rarely with a telson marking or cast indicating its production by a horseshoe crab (limulid Figure 1 *a*).

Incidentally, Molly Miller[1] was the first to attribute resting traces of such limulids to the ichnogenera *Limulicubichnus* (Latin Limulus—horseshoe crab and cubore—to lie down). The other well-established trace fossils include the ichnogenera *Kouphichnium* which is moderately common and stratigraphically and geographically widespread and is interpreted as trackways of Limulids. There appear to be two well-defined trace fossil resting burrows of horseshoe crabs in the limestone bed exposed in the Suvernarekha River

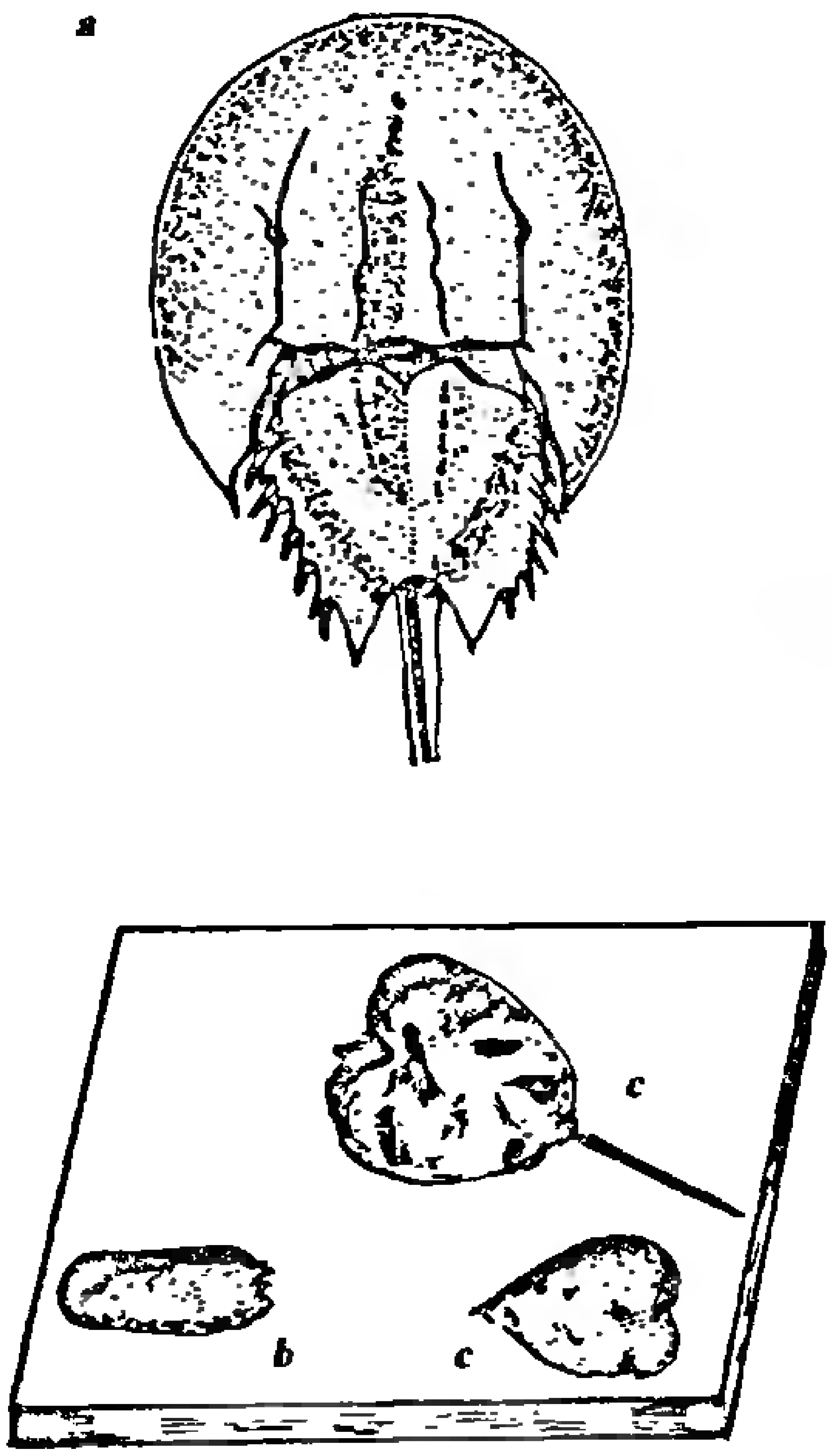

Figure 1. a, Line drawing of recent *Limulus polyphemus*. Sketches of two *Limulicubichnus* species, *b*, *L. serratus* and *c*, *L. rossendalensis* for comparison with the recent limulid.

Figure 2. a, *L. serratus*—lunate shaped depression preserved as negative relief and; *b*, *L. rossendalensis*—heart or lunate shaped epichnial traces preserved on top of the upper bedding surfaces of the argillaceous limestone.

channel near Ramwada Mandir in Kutch. Both of these can be grouped into two separate species of *Limulicubichnus*.

Ichnogenus-*Limulicubichnus*-Miller 1982.

Ichnospecies-*Limulicubichnus serratus* Miller 1982.

The trace fossil identified as *Limulicubichnus serratus* (Figures 1 *b*, 2 *a*) is typically a heart-shaped, lunate or tear-drop shaped depression found on the upper bedding plane of the topmost limestones exposed in Suvernarekha River. The trace has margins at the posterior end which are serrate and narrow and elongate. The horseshoe shaped depression is 5.4 cm long and 2.7 cm wide and shows correspondence in shape to the modern day limulids and their resting traces on the sediment. The specimen is further comparable to the ichnogenus *Limulicubichnus* erected by Miller[1] and the ichnospecies *Limulicubichnus serratus* of Miller[1]. The ichnospecies *Limulicubichnus* was erected by Miller[1] for the shallow depressions with features clearly indicative of their production by Limulids. Features of the *Limulicubichnus serratus* in the Suvernarekha section are consistent with her description, in their mode of burrowing, slightly raised posterior and lateral margins to represent accumulation of sediment swept out by the walking of Limulid crabs.

Traces of *Limulicubichnus serratus* are reported from Fentress Formation, USA[1]. Hardy[2] and Fischer[3] reported *L. serratus* from the nonmarine and estuarine deposits of Ordovician and Carboniferous age.

Ichnogenus-*Limulicubichnus* Miller, 1982.

Ichnospecies-*Limulicubichnus (Kouphichnium) rossendalensis*, Hardy 1970.

Epichnial trace consisting of lunate shaped depression corresponding in outline to the shape of a xiphosurid prosoma and associated with appendages and telson. Width of trace is 6.3 to 7.5 cm and length 5.2 cm (Figures 1 *c*, 2 *b*). Prosoma cast are either isolated or with or without two rows of appendage marks and a telson cast, or may occur in linear or curved series (Figure 2 *b*).

Similar traces are reported by Hardy[2] from several horizons and localities in Westphalian of England.

Recently, Miller[1] proposed the separation of Limulid trackways (ichnogenus *Kouphichnium*) from Limulid resting traces which she assigns to new ichnogenus, *Limulicubichnus* Miller 1982. Consequently, she renamed traces described here as *L. rossendalensis*[2].

The ichnospecies *L. rossendalensis*[2] differs from ichnogenotype *L. serratus*[1] by its lunate, rather than teardrop prosoma cast, and greatest relief at the anterior border.

Both *L. rossendalensis* and *Kouphichnium* traces in the Silesian of the Central Pennines are believed to have been produced by non-marine arthropods like *Belinurus* or *Euroops* rather than *Limulus*[2].

The behaviour patterns represented by the Kutch specimens show similarity to the recent *Limulus polyphemus*[1], however, the environmental implications appear to be quite different.

As claimed earlier the trace fossils in the Lower Miocene rocks exposed in the Suvernarekha River Section of Kutch represent two distinct species and the traces are possibly made by the xiphosurids like *Belinurus* and *Euroops*; [*Limulicubichnus* (*Kouphichnium*) *rossendalensis*], like non-marine shallow water forms and the *Limulicubichnus serratus* like typically marine forms. Both these forms occur side by side and therefore need explanation.

It is generally agreed that the occurrence of Limulids or horseshoe crabs is known since Devonian to Recent. As claimed by Stomer *et al.*[4], the environment in which these crabs lived has often changed during their geological existence. As argued by Caster[5], the Devonian forms were marine, whereas those from the Carboniferous and Permian were freshwater. As suggested by King[6] some occurrences of Limulid are marine, but may occur in brackish to freshwater deposits. Limulid traces are also known from the marine Jurassic Solenhofen Sandstones of Germany. Goldring and Seilacher[7] on the other hand, suggest that the Limulids have lived in marine and marginal marine environments, as they do today for much of their geological record. Furthermore, the occurrence of (Limulicubichnus) *Limulus polyphemus* is reported on drying intertidal mudflats by Fischer[3] and discussed by him in relation to their possible subareal activity like resting and spawing.

In the above context the most significant evidences with the traces of *Limulicubichnus* in Kutch are their associated trace fossils of *Arenicolites, Skolithos, Monocraterion, Thalassinoides, Ophiomorpha, Spongiliomorpha, Palaeophycus, Planolites,* etc.[8], which reveal a shallow-water marine environment.

The Kutch species are further characterized by two distinct modes of locomotion. There are frequent drag marks made by telson. These are made by an animal supported in water, while the main parts of some traces are deeply excavated with sunken areas corresponding to the position of the prosoma (head shield) and exhibit the animals' forward progress through the sediment rather than through water. According to Fischer[3], the walking type of traces are of purely locomotory purpose, while the heavily excavated traces could be accounted for either as deposit feeding structures, or as resting traces made by animals in danger of dehydration.

Based on all these evidences it may now be concluded that in the environment during the period the Lower Miocene argillaceous limestone in western Kutch was being deposited, the general conditions were most conducive to the life of the Limulid crabs. Such environmental aspects were perhaps characterized by extremely shallow water conditions, predominantly marine in nature, and subjected to frequent fluctuating water levels and at times subjected to subareal exposures and dehydrating conditions.

1. Miller, M. F., *J. Paleontol.*, 1982, **56**, 429–433.
2. Hardy, P. G., *Palaeontology*, 1970, **13**, 188–190.
3. Fischer, W. A., *Mountain Geologist*, 1978, **15**, 1–26.
4. Stomer, L. Petrunkevitch, A. and Hedgpeth, J. W., in *Treatise on Invertebrate Paleont.*, Part P, Arthropoda-2, (ed. Moore, R.C.), 1955, p. 4–41.
5. Caster, K. E., *J. Paleontol.*, 1938, **12**, 2–60.
6. King, A. F., *Proc. Geol. Soc.*, 1965, **1626**, 162–165.
7. Goldring, R. and Seilacher, A., *Neues. Jahrrb. Geol. Paleontol.*, 1971, **137**, 422–442.
8. Patel, S. J. and Shringarpure, D. M., *Micropalaeontol. Shelf Sea India*, Proceedings of the XII Indian Collo. Micro Palaeont. Strat., 1989, p 175–179

Received 21 August 1992; accepted 29 August 1992

Phenology of seasonally dry tropical forest

J. S. Singh and V. K. Singh

Department of Botany, Banaras Hindu University, Varanasi 221 005, India

There exists considerable diversity in leaf flushing, leaf-fall, flowering, fruiting and fruit-fall among plant species in a seasonally dry tropical forest. Leaf-fall is initiated with the onset of the post-monsoon, low-temperature dry period, and leaf flushing begins with the rise in temperature and peaks in the hottest and driest period (May) of the year renovating the canopy before the onset of the monsoon. Although flowering is staggered, its peak coincides with the peak in leafing. The fruiting phenology follows closely the flowering phenology. Fruit-fall culminates before or just at the beginning of the monsoon season and thus ensures availability of sufficient moisture to seeds for germination and seedling establishment. The phenological clock of the seasonally dry tropical forest appears to be set during the interphase of winter and summer ensuring full advantage of the short rainy season that follows.

INFORMATION on phenology (derived from the Greek word *Phaino* meaning to show or to appear) is important for the study of plant–animal interactions which affect pollination and dispersal, and are important for plant reproduction[1]. The periodicity in phenological events reflects the temporal distribution of various kinds of available food resources for animals. Selected phenological events can be useful as indicators on which major land management practices, productivity