Age of the Lower Vindhyan sediments, Central India

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The basic issue raised by the two simultaneous and sensational reports[1,2] in 1998 of body fossil evidence (worm tracks and small shelly fauna, respectively) of multicellular life in the Lower Vindhyan sediments, is the true age of the latter. Is the true age Mid-Proterozoic as believed so far, on limited geochronological data and assumed by Seilacher *et al.*[1]? Or is it only Early Cambrian, as was argued by Azmi[2] and supported by a single preliminary Ar–Ar age of 617 Ma measured soon after the reports? Although both the fossil evidences are now equivocal, the basic issue remains. We report consistent Rb–Sr ages for glauconies from the Lower Vindhyan sediments (Semri Group) near Chitrakut, which constrain the onset of the earliest Vindhyan sedimentation to not later than 1600 Ma. Considering other available chronological constraints, the Vindhyan basin is likely to preserve a rare, very long and least disturbed record of Precambrian sedimentation.

LARGEST (presently exposed area ~ 104,000 sq km) among the Precambrian sedimentary basins in India (Figure 1), the Vindhyan basin in Central India, contains a thick (~ 4000 m in the eastern parts) sequence of largely unmetamorphosed and undeformed succession of shales, sandstones, limestones, dolostones with subordinate conglomerates and volcanics[3]. According to the generalized lithostratigraphy in the Son Valley[4] (Table 1), the Lower Vindhyan consists of the Semri Group and the Upper Vindhyan includes the Kaimur, Rewa and Bhander Groups. Based on conventional K–Ar ages measured in 1960s[5,6], the more recent fission track ages[7] for glauconies and Lower Riphean affinity of stromatolites from the Semri Group of rocks[8], the base of the Vindhyan sediments is believed to be ~ 1400 Ma (1 Ma = 10^6 years). A strict younger limit of the top of the Semri Group is 1100 Ma, this being the reliable age of kimberlite intrusions into the Kaimur Group[9,10]. No animal body fossils were expected and in fact found in such an old sequence as Semri Group[11]. Hence, the nearly simultaneous reports of small shelly fauna and brachiopods by Azmi[2] and triploblastic worm burrows by Sailacher *et al.*[1] in the Rohtas and Chorhat formations, respectively of the Semri Group (Table 1) created a sensation internationally, because of their far-reaching implications. Since small shelly fossils date back only to early Cambrian (~ 550 Ma ago), Azmi's finding implied that the Vindhyan could be much younger than previously believed. On the other hand, Seilacher *et al.*[1] relied on the previously believed antiquity of the Vindhyan to propose the existence of triploblastic metazoans as early as 1100 Ma ago, thus lending support to the 'slow-burn' scenario of biomolecular evolution[12].

Crucial to the reconciliation of the dramatically contrasting interpretations of the two fossil evidences of multicellular life is the true absolute age of the Semri Group. A preliminary report, soon after these fossil discoveries, of an Ar–Ar plateau age of 617 ± 4 Ma for the Porcellanite Formation (stratigraphically even lower than the Rohtas and Chorhat formations, Table 1) and interpreted as its depositional age, supported Azmi's biostratigraphic inference[13,14]. While a close scrutiny of fossil evidences has shown them to be equivocal[15,16], the much younger Ar–Ar age is in conflict with the intrusion of 1100-Ma-old kimberlites through the Semri Group. We therefore believe that the true age of the Vindhyan is still an open question. As a meaningful first step on this question[17], we report here Rb–Sr ages of glauconies from the unmetamorphosed sediments at the base of the Semri Group in order to set a firm minimum age for the onset of Vindhyan sedimentation.

Glaucony, an authigenic, K- and Rb-rich, millimetre sized, greenish marine clay mineral, occurs commonly in sedimentary rocks. Mature (> 7 weight% K_2O) glauconies have been widely used for direct K–Ar (Ar–Ar) and Rb–Sr dating of sediments lacking or very poor in datable igneous rocks/minerals[18,19] as the Vindhyans. Glauconies

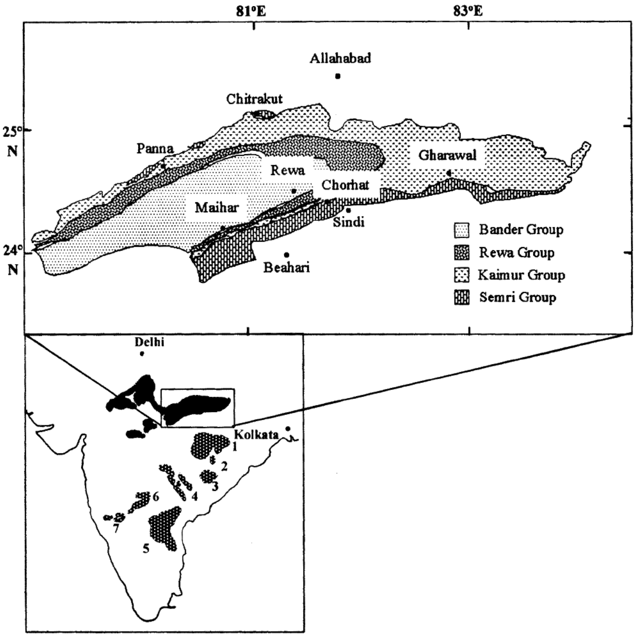

Figure 1. Distribution of Proterozoic sedimentary basins in India. Vindhyan basin shown in darker shade. 1, Chattisgarh; 2, Khariar; 3, Indravati; 4, Pakhal; 5, Cuddapah–Kurnool; 6, Bhima; 7, Kaladgi. (Top) Geological sketch map of the Vindhyan in the Son Valley.

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Table 1. Generalized stratigraphic succession of Vindhyan Supergroup[4] in the Son Valley

		Unconfomity	
Upper Vindhyan	Bhander Group	Sand, shale and limestone	
	Rewa Group	Sandstone and shale	
	Kaimur Group	Sandstone and shale	
		Unconformity	
Lower Vindhyan	Semri Group	Rohtas Subgroup	Bhagwar shale Rohtas limestone
		Kheinjua Subgroup	Rampur shale Chorhat sandstone Koldaha shale
		Mirzapur Subgroup	Deonar porcellanite Kajrahat limestone Basal shale Deoland quartzite
		Unconformity	
	Metamorphics and granites		

for our study come from Lower Vindhyan deposits near Chitrakut town (Figure 1) on the northern boundary of the Vindhyan basin. Singh and Kumar[20] have shown that the thin veneer of sediments (10–30 m thick) lying on the 2.5-Ga-old Bundelkhand granite in this area is a condensed, but fully representative Lower Vindhyan sequence. They consist of breccia, pellet limestone, stromatolitic limestone, shale and glauconitic sandstone. These authors[20] have equated the glaucony-bearing horizons underlying the stromatolitic limestones with the Basal shales in the Semri Group (Table 1). We have selected two glaucony-rich sandstone samples from each of three sites – Lodhwara north (LN) and south (LS) hillocks and Sangrampur hillock (S), as shown in Figure 2. Relative to the granite base, samples LS.4 and LS.9 are about 1.5 and 4.5 m respectively, above in south hillock, LN.1 and LN.4 about 2 and 4 m respectively, above in the north hillock, and S.3 and S.9 about 3 and 9 m respectively, above in the Sangrampur hill.

Glaucony grains were separated in a Frantz isodynamic separator from about 50 g each of crushed samples and then screened for smooth-textured, dark-green pellets under a binocular microscope. A few grains of each sample were checked for their maturity (K_2O content > 7%) using an electron probe microanalyser (R. Srinivasan, private commun.). About 15–20 mg of each sample was leached in 1 M HCl for about 15 min at room temperature, sonicated in Milli-Q water and dried to remove potential contaminants, including adsorbed Rb and Sr (ref. 19). Dissolution in HF + HNO_3 mixture, spiking with enriched Rb and Sr tracers, ion exchange separation of Rb and Sr and mass spectrometric analysis followed standard procedures in our laboratory[10]. Total process blank was less than 1 ng for both Rb and Sr. Replicate analyses of SRM 987 Sr-standard gave its $^{87}Sr/^{86}Sr$ ratio as 0.710221 ± 12 ($2\sigma_m$, $n = 6$).

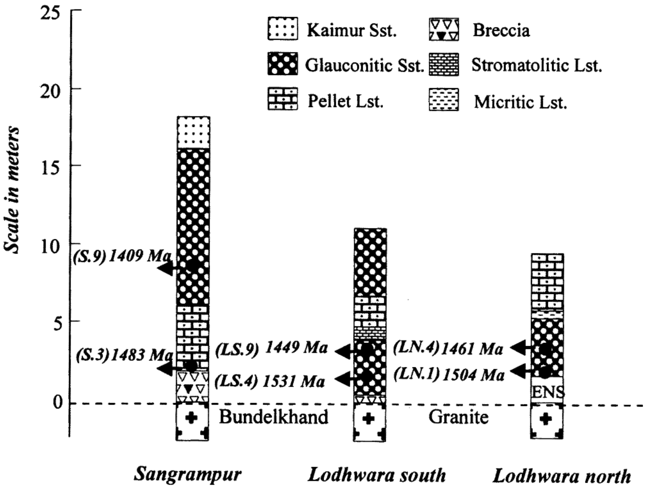

Figure 2. Lithostratigraphy in the three localities Sangrampur, Lodhwara south and north hills[7]. Sample positions and Rb–Sr model ages also shown.

The six samples show a large mutual spread in their $^{87}Rb/^{86}Sr$ ratios from 58 to 309 (Table 2). As the samples are highly radiogenic (1.99 to 7.37), their model ages are insensitive to the initial $^{87}Sr/^{86}Sr$ ratio assumed. Assuming isotopic equilibration with sea water Sr in mature glauconies[19], model ages have been calculated (Table 2) for an initial ratio of 0.7066, as measured in associated carbonates.

The samples from the lower level in the three locations give nearly the same ages – 1483 ± 15 Ma (S.3), 1504 ± 15 Ma (LN.1) and 1531 ± 15 (LS.4). This close agreement precludes significant open system behaviour of the samples, considering especially that the two samples LS.4 and S.3 are very different in their Rb/Sr ratios and are widely separated (~ 15 km) in space. The samples fit a straight line closely, which, though strictly not an iso-

Table 2. Rb and Sr data of Vindhyan glauconies

Sample	Rb (ppm)	Sr (ppm)	^{87}Rb/^{86}Sr (atomic)	^{87}Sr/^{86}Sr (atomic)	Model age (Ma)
S.9	348	5.27	308	6.92400 ± 8	1409 ± 14
S.3	315	5.00	295	6.98466 ± 3	1483 ± 15
LN.1	308	4.77	309	7.37651 ± 15	1504 ± 15
LN.4	322	5.22	281	6.59281 ± 12	1461 ± 14
LS.4	266	14.80	58.4	1.99030 ± 4	1531 ± 15
LS.9	304	13.30	76.6	2.29901 ± 15	1449 ± 14

Uncertainty in ^{87}Rb/^{86}Sr ratio is ± 1.0% (2σ). Errors in the ^{87}Sr/^{86}Sr ratios are 2σ of mean and given as the least significant digits. Model ages were calculated for an initial ratio of 0.7066.

chron, corresponds to an age of 1485 ± 14 Ma and initial ^{87}Sr/^{86}Sr ratio of 0.746 ± 0.019 (1σ). The three upper level samples are distinctly younger, 1409 ± 14 (S.9), 1461 ± 14 (LN.4) and 1449 ± 14 (LS.9). More significant than their consistency with younger stratigraphic position of the samples in this condensed sequence is that these systematically younger ages preclude the remote possibility of detrital derivation of glaucony grains from pre-Vindhyan rocks. Three of our six samples were dated earlier by F–T method at 1203 ± 132 Ma (S.3), 1242 ± 231 Ma (LN.1) and 1220 ± 211 Ma (LN.4)[7]. Although the F–T ages overlap within their large error envelopes with the more precise Rb–Sr results, they are systematically younger by about 200 Ma. This difference seems to be real, as Srivastava and Rajagopalan[7] measured a blind F–T age of 95.5 ± 5 Ma for the international glaucony standard GL–O, in very good agreement with its reported mean K–Ar and Rb–Sr ages of 95.0 ± 1.1 Ma (ref. 18). So a small loss of fission tracks due to thermal annealing is quite likely. Since the blocking temperature of tracks in glaucony is very low, ~ 60°C (ref. 21), the gross agreement between F–T and Rb–Sr ages indicates that the thin sediments in the study area were never heated even to about 60°C. That the F–T ages[7] of Lower Vindhyan glauconies in much thicker sections in the Son Valley are still younger could be due to larger annealing effects in them. As the Rb–Sr system is more robust than the F–T system, post-formational thermal resetting of Rb–Sr systematics in the analysed glauconies is quite unlikely.

It is reasonable therefore to conclude that the Rb–Sr ages of the glauconies are geologically meaningful. Reasonable extrapolation of the ages of the lower level rocks to the base of the deposits in the study area would be close to 1600 Ma. While glauconies have sometimes given ages younger than their stratigraphic ages, they rarely give ages older than their stratigraphic ages[22], especially in the case of Precambrian samples. Our preferred interpretation of the present results is that they set a firm minimum age of 1600 ± 50 Ma for the onset of the earliest Vindhyan sedimentation.

This minimum age is about 200 Ma older than that set by conventional K–Ar ages of glauconies from the Semri Group determined in the early 1960s[5,6]. Considering that K–Ar ages are less robust than Rb–Sr ages and samples dated were more deeply buried, our estimate does not seriously conflict with the younger K–Ar results. As it is now feasible to measure single-grain Ar–Ar ages of glauconies by laser heating[23], we believe that such measurements on Lower Vindhyan glauconies will give ages closely matching our Rb–Sr results. Regarding the preliminary results of a younger Ar–Ar age of 617 Ma on a single porcellanite sample[13], it is now learnt that more detailed work on zircons from this rock indicates ages very close to our results on glauconies (D. M. Banerjee, private commun.).

As pointed out in the introduction, a strict younger limit to the top of the Lower Vindhyans is 1200 Ma. The base of the Rewa Group should be younger than 1100 Ma, as it contains placer diamonds derived from kimberlites of this age. The age of the top of the Vindhyan Supergroup is still uncertain[11]. However, Kumar[24] has inferred an age of about 650 Ma for the limestones in Bhander Group based on siliceous sponge spicule-like forms in it. The available evidence therefore indicates that the total duration of continuous or punctuated sedimentation in the Vindhyan basin is almost 1000 Ma. That the sediments are also unmetamorphosed, undeformed and barely heated, shows that the Vindhyan basin could be one of the rare repositories in the world for the record of metazoan evolution, if any, long before the Cambrian explosion. Also as Crawford and Compston[9] pointed out long ago, Vindhyans could also carry valuable records of Precambrian glaciation.

1. Seilacher, A., Bose, P. K. and Pfluger, F., *Science*, 1998, **282**, 80–83.
2. Azmi, R. J., *J. Geol. Soc. India*, 1998, **52**, 381–389.
3. Soni, M. K., Chakraborty, S. and Jain, V. K., *Mem. Geol. Soc. India*, 1987, 6, 87–138.
4. Rao, K. S. and Neelakantan, S., *Rec. Geol. Surv. India*, 1978, **110**, 180–193.
5. Vinogradov, A. and Tugarinov, A. I., Proc. 22nd Int. Geol. Congress, New Delhi, 1964 (abstract).
6. Tugarinov, A. I., Shanin, L. L., Kazakov, G. A. and Arakelyanta, M. M., *Geokhimiya*, 1965, **6**, 652–660.
7. Srivastava, A. P. and Rajagopalan, G., in *Nuclear Tracks* (ed. Sharma, K. K.), 1986, pp. 31–40; 41–52.
8. Valdiya, K. S., *J. Geol. Soc. India*, 1969, **10**, 1–25.

9. Crawford, A. R. and Compston, W., *Q. J. Geol. Soc. London*, 1970, **125**, 351–371.
10. Anil Kumar, Padmakumari, V. M., Dayal, A. M., Murthy, D. S. N. and Gopalan, K., *Precambrian Res.*, 1993, **62**, 227–237.
11. Venkatachala, B. S., Sharma, M. and Shukla, M., *Mem. Geol. Soc. India*, 1996, 36, 137–165.
12. Wray, G. A., Lewinton, J. S. and Shapiro, L. H., *Science*, 1996, **274**, pp. 568–573.
13. Banerjee, D. M. and Frank, W., Workshop on Vindhyan Stratigraphy and Palaeobiology, Lucknow, 1999 (abstract volume).
14. Kerr, R. A., *Science*, 1999, **284**, 412.
15. Brasier, M., *Nature*, 1998, **395**, 647–648.
16. Brasier, M., *J. Geol. Soc. India*, 1999, **53**, 727–730 (also see other discussions in this issue).
17. Anil Kumar, Gopalan, K. and Rajagopalan, G., Goldschmidt 2000, J. Conf. Abstr., 2000, vol. 5, p. 608.
18. Odin,G. S., *Green Marine Clays* (ed. Odin, G. S.) Elsevier, Amsterdam, 1988, p. 445.
19. Clauer, N., Keppens, E. and Stille, P., *Geology*, 1992, **20**, 133–136.
20. Singh, I. B. and Kumar. S., *J. Geol. Soc. India*, 1978, **19**, 359–367.
21. Saini, H. S., Srivastava, A. P. and Rajagopalan, G., *Proc. Indian Nat. Sci. Acad.*, 1986, **52**, 694–698.
22. Grant, N. K., Laskowski, T. E. and Foland, K. A., *Chem. Geol.*, 1984, **2**, 217–239.
23. Smith, P. E., Evensen, N. M., York, D. and Odin, G. S., *Science*, 1998, **279**, 1517–1519.
24. Kumar, S., *J. Paleontol. Soc. India*, 1999, **44**, 141–148.

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Earthquakes over Kutch: A region of 'trident' space–time geodynamics

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Kutch peninsula exhibits enigmatically rapid stress accumulation/release like the New Madrid Seismic Zone. Geodynamically, it is a junction of three structural trends and three tectonothermal episodes (69–64 Ma). Combination of mobile belts and plume, evidenced here, favours lithospheric splaying, reactivation, rifting, alkaline complexes; resulting tectonic network may link Kutch with plate boundaries. The 1819 and 2001 events have occurred near the intersection, of such lineaments and accretionary belts, with its margins. Thus, Plate-boundary forces and loading (uplifts/sediments) appear to superimpose here, over relatively weakened lithosphere; and resulting litho/hydro-spheric instability would contribute to development of the Rann. The crust–mantle interactions are supported by (i) positive gravity anomalies, whose obliquity to Kutch rift indicates later reactivation, (ii) lower uppermantle velocity near Kutch, and (iii) differential uplift/subsidence. Deep geophysical probing is necessary to gain greater understanding of earthquake process.

COUNTRY-wide attention suddenly turned from Allahabad (i.e. Mahakumbh) to Allahbund (earthquakes in Kutch) following the tragic seismic event near Bhuj in the morning of 26 January 2001. It brought out, by now a familiar response from the geoscientists (after the Uttarkashi, Latur, Jabalpur and Chamoli earthquakes) that the 'culprit' is the ever ongoing compressional force following the collision of Indian subcontinent with Eurasia, along the great Himalayan belt. This implies that the Indian lithospheric plate is being pushed in the nearly NNE direction by the subterranean convection. However, this forms only a part of the story because if the continental scale compression alone is responsible then many other places in the country should also become seismically active. But the relative placidity of a large part of the Indian shield means that there have to be certain additional causes on regional as well as local scales, which when combined with continental compression complete the scenario. Figure 1 shows the various forces and plate boundaries active above Kutch.

An attempt is made here to depict the peculiar and probably unique geodynamics that puts the Kutch region in the highest seismic risk zone (zone-V), in spite of being in the intraplate (or midcontinental) region. As described below, this area appears to have undergone a 'trident' of geodynamics, both in space as well as in time.

It may be noted from Figure 2, that the epicentre of the January 26 earthquake lies in the close vicinity of the junction between three major tectonic (or mobile) belts, viz. (1) NE-SW oriented palaeo-orogenic corridor of Delhi fold belts, (2) ENE-WSW trending early Cretaceous Kutch rift, and (3) NW-SE directed late Cretaceous Cambay graben[1]. Actually, not too far from this location there is another younger tectonic structure, namely the Narmada–Tapti trend, which developed in the early Tertiary[1]. These rift structures imply doming, extension, subsidence and thermomagmatic influxing in the deep crust[2]. This is corroborated by examination of the Bouguer gravity anomaly[3], which indicates intrusion and/or under plating of high density material during the rejuvenations/formations of these aborted rifts (Figure 3). The trend of

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