3) The presence of kankar suggests climatic fluctuations, perhaps indicating an arid subphase within a wet humid tropical set-up.

4) Flandrian Transgression is located from paleobiological evidences towards the top of the studied sequence.

1. Banerjee, M. and Sen, P. K., Proceedings of the National Symposium on Biol. Util. Conserv. Mangrove, Shivaji Univ., Kolhapur, 1986, pp. 393–397.
2. Gupta, H. P., *Palaeobotanist*, 1981, **27**, 138–160.
3. Hait, A. K., Das, H. K., Chakrabarty, S., Ray, A. K. and Chanda, S., *Indian J. Earth Sci.*, 1994a, **21**, 192–198.
4. Murray, J. W., *Ecology and Palaeoecology of Benthic Foraminifera*, Longman Scientific and Technical, Longman Group, UK, 1991, pp. 397.
5. Hait, A. K., Das, H. K., Ghosh, S., Ray, A. K., Saha, A. K. and Chanda, S., *Indian J. Earth Sci.*, 1996, **23**, 79–82.
6. Hait, A. K., Das, H. K., Ray, A. K. and Chanda, S., *J. Palynol.*, 1994b, **30**, 73–78.
7. Geyh, M. A., Kudras, H. R. and Streif, H., *Nature*, 1979, **278**, 441–443.
8. Banerjee, M. and Sen, P. K., *Indian J. Earth Sci.*, 1987, **14**, 307–320.
9. Chappel, J. and Shackleton, N. J., *Nature*, 1986, **324**, 137–140.
10. Chakrabarty, A. and Niyogi, D., Proceedings of the Seminar on Geomorphology, Geohydrology and Geotectonics of the Lower Ganga, IIT, Kharagpur, 1972, pp. 135–139.
11. Poddar, B. S., Chakrabarti, C., Banerjee, S. N. and Chakrabarty, P., *Geol. Surv. India Rec.*, 1992, **121**, 47–53.
12. Coulson, A. L., *Mem. Geol. Surv. India*, 1940, **76**, 1–150.
13. Thom, B. G., Wright, L. D. and Coleman, J. M., *J. Ecol.*, 1975, **63**, 203–232.
14. Umitsu, M., *Sed. Geol.*, 1993, **83**, 177–186.

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Breakup of Gondwanaland and the Jurassic record of the Kachchh Basin, Gujarat, Western India

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The pericratonic Kachchh basin of Gujarat, western India, hosts a succession dominated by siliciclastics punctuated by oolitic limestone horizons. The two horizons occur in distinct time frames, the older in the Bathonian and the younger in the Oxfordian. The younger horizon the Dhosa Oolite, Member of the Jumara Formation forms an important lithostratigraphic marker horizon. These two horizons are re-interpreted as ironstone horizons based on iron sequestration observed at field outcrop and petrographic scale. It is suggested that the iron content in the ironstones is on account of hydrothermal-plumes of a magnitude similar to the infrequent Event hydrothermal plumes observed in the case of Juan de Fuca ridge off the western coast of Canada. Therefore the ironstones could represent two phases of increased sea-floor spreading activity related to the breakup of Gondwanaland. The older ironstone known as Golden Oolite documents the formation of a mid-oceanic ridge system after a period of continental stretching, while the Dhosa Oolite is the manifestation of the migration of Greater India as a discrete continental landmass, from Gondwanaland.

THE breakup of Gondwanaland began about 180 million years ago with the formation of the Karoo Basalt Province of South Africa[1]. This resulted in the formation of several smaller plates, each of which underwent its own tectonic evolution. The breakup of Gondwanaland led to the formation of Greater India[2]; a conjoined land mass comprising India, Madagascar and the Seychelles. In the context of the Indian plate there is no direct evidence of the early Jurassic breakup in the form of oceanic crust remnants or associated igneous activity (on the Indian subcontinent). Therefore, as a working hypothesis, it is assumed that the breakup might be manifested in the stratigraphic record as a distinct facies/facies associations. With this assumption the Kachchh basin sediments have been analysed with a binary aim: i) Reinterpretation of a iron oolitic facies observed at two stratigraphic

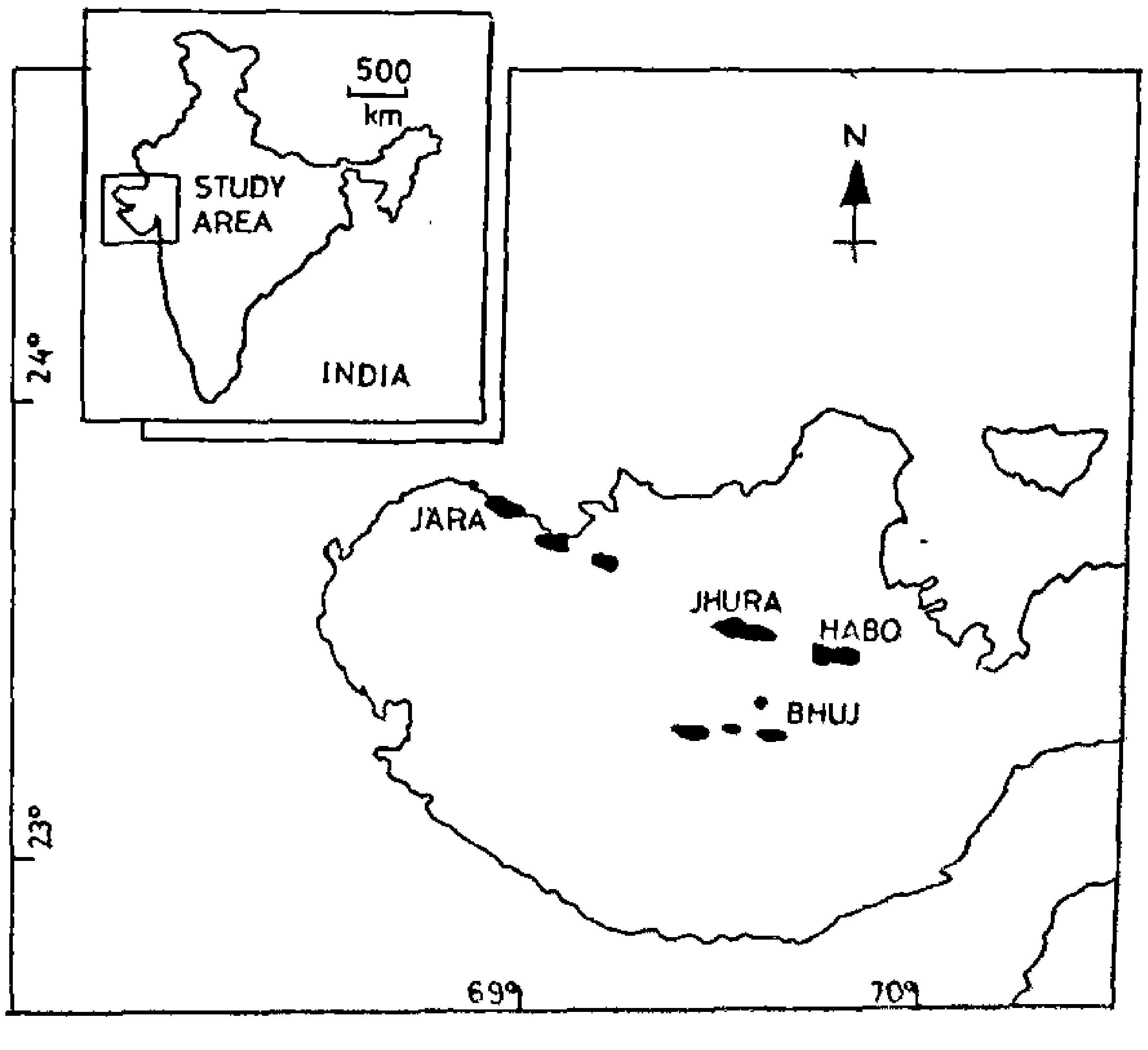

Figure 1. Geological map of the Kachchh Basin showing Mesozoic exposures in black.

Table 1. Lithostratigraphic classifications of the Kachchh Mesozoic sedimentary record

		KACHCHH BASIN	
CRETACEOUS	ALBIAN	UMIA FORMATION	BHUJ FORMATION
	APTIAN		
	NEOCOMIAN		JHURAN FORMATION
JURASSIC	TITHONIAN		
	KIMMERIDGIAN	KATROL FORMATION	
	OXFORDIAN	CHARI FORMATION DHOSA OOLITE MEMBER	JUMARA FORMATION
	CALLOVIAN		JHURIO FORMATION
	BATHONIAN	PATCHAM FORMATION	
	BAJOCIAN		
	AALENIAN		
		Fürsich *et al.*[3,10];	Biswas[9].

intervals, and ii) establishing the sequence of events which led to the breakup of Gondwanaland.

The pericratonic Kachchh basin[3,4] situated on the western margin of the Indian plate hosts a Mesozoic succession of +3000 m. The Mesozoic sediments are exposed primarily in two belts. A northerly Island belt which includes Pachham, Khadir, Bela and Chorar islands and a Mainland belt consisting of eroded domes arranged in an arcuate fashion (Figure 1). The Island belt receives its name from the linear distribution of these topographic highs amidst a flat salt sea; The Rann of Kachchh.

The Jurassic sedimentary record is dominantly siliciclastic punctuated by horizons of oolitic limestones[3,5]. The siliciclastic sediments are predominantly fine-grained siltstones and shales (calcareous and gypseous). These have been of specific interest to palaeontologists for the abundant fauna they contain[6–8]. The sediment record has been recently given a formal lithostratigraphic scheme[9], but owing to the current usage of two stratigraphic schemes, both have been given in Table 1. In the text, the new lithostratigraphic nomenclature shall be adhered to.

The Jhurio Formation outcropping at the cores of the domes consists of coralline limestones and oolitic calcareous ironstones. The white limestones are conspicuous in the field, more so by their colour, but on closer examination reveal bedded horizons of coral-rich layers and shell beds. The corals present a more or less monospecific cluster of *Stylina kachhensis* supported by species of *Montlivaltia*. At some sites there is a close association of sponges. The skeletal concentrations have distal tempestite taphonomic signatures which passes upwards into proximal tempestite. However Fürsich and Oschmann[10] suggest that a distinct categorization is not possible since both forms of concentrations result from storm flows. Hence, in the present case both modes of shell bed formation are clubbed together as tempestite concentrations formed at/below the storm wave base. The ironstones are either present as small lensoidal bodies or may form laterally persistent horizons. The ironstones depict a high content of iron which is reflected in their golden colour that results from the iron oxide coatings of the ooids. This morphological character of the unit has led to the nomenclature of this facies as 'Golden Oolite'. The Jhurio Formation dates back to Bathonian times as indicated by the ammonite faunal association of *Macrocephalites* (first occurrence) and *Sivajiceras congener*[11]. The limestones of the Jhurio Formation formed on a shallow shelf under conditions of sediment starvation, and were frequently under the influence of storms as revealed by the shell beds. Biswas[5] has interpreted the marl-ironstone association as deposits of a littoral environment during times of still stands (periods representing pauses during transgressions).

The basal portion of the overlying Jhurio Formation comprises shales interlayered with concretionary horizons and sandstone bands. The strata are richly fossiliferous containing temporally significant ammonites such as *M. formosus, M. demerus* and *M. semilaevis*. At Jumara the succession consists of interlayered *Zoophycos* sandstones and shell beds rich in *Plicatula* and *Nuculina* bivalves. This succession terminates in an iron-oolite rich polygenetic hardground complex underlain by calcareous and gypseous shales. These shales have recently yielded two skulls of the Callovian mesosuchian crocodile *Steneosaurus* sp.[12] which shows close affinity to *S. durobrivensis*[13]. The shales also contain calcareous nannoplanktons, the assemblage being dominated by *Watznaueria brittanica* and *Cyclagelosphaera margerelii*. The presence of *Stephanolithion bigotii bigotii* and *Lotharingius crucicentralis* places the sediments underlying the hardground (4 m below) at the NJ-13 to NJ-15 time interval (Callovian–Oxfordian)[14]. The oolitic hardground complex is an important component of the Kachchh stratigraphic record, being the only available datum in the whole succession. The Dhosa Oolite is a typical hardground showing encrusting oysters, borings by lithophagid bivalves, extensive undercuts and syn-sedimentary lithification. The Dhosa Oolite Member represents a transgressive horizon, its upper bounding surface being a plane of maximum flooding[3]. The oolitic limestone formed on a sediment starved shallow shelf in the littoral zone[9]. In most areas the Dhosa Oolite is capped by a stromatolitic crust[3]. Features suggestive of iron sequestering include stromatolitic crusts, iron to ankeritic ooids and oncoids. Based on the above evidences the Dhosa Oolite Member is identified as an ironstone horizon[15]. Although the ooids are ferruginous, they do not show a golden colouration like the older Golden Oolites. This indicates a depletion in iron sequestration in the Dhosa Oolite.

The source of iron observed in ironstones throughout the world has been attributed conventionally to pedogenic breakdown of iron-rich continental parent rocks and subsequent transportation to ocean waters through fluvial channels[16,17]. However, contrasting palaeogeographic and palaeoclimatic conditions during Ordovician and Jurassic times appear to contradict the prevalent perspective on iron derivation. Van Houten[18] has observed that globally the ironstones deposited during Ordovician times were formed in cold temperate climatic regimes while the younger Jurassic ironstones formed under tropical humid palaeoclimates. Some authors[19,20] have suggested that superplume induced increased sea-floor spreading activity results in the formation of ironstones. Such ironstones mark peak global transgressions which are tectonically induced drowning events[20].

Iron is contributed at the mid-oceanic ridges through hot spring fluids[21,22]. Measurements at the Mid Atlantic Ridge[21] for dissolved iron have yielded concentrations of around 2000 μmol kg^{-1}. Although it is evident that these concentrations are moderate, it is of interest to note that in the case of Juan de Fuca mid-oceanic ridge system between the Blanco and the Cobb offset fracture zones (off the western coast of Canada) which has a spreading rate of 6 cm yr^{-1}, dissolved iron concentrations are on an average 18,000 μmol kg^{-1}. The Juan de Fuca ridge is characterized by titaniferous basalts having total iron as FeO greater than 10% of whole rock composition[23]. The mid-oceanic ridge releases large amounts of hydrothermal fluids to the ocean waters. The release of hydrothermal fluids is maximum on those segments where the apparent magmatic budget is highest[24]. These hydrothermal plumes have a temporal and spatial variability and have been classified into two categories[25]: i) Chronic plumes are those which are habitually present and ii) infrequent Event plumes which are of extreme magnitude and lead to high concentrations of Fe. These event plumes are the hydrothermal manifestations of increased sea-floor spreading activity[26].

It seems plausible that the Kachchh ironstones sequestered iron from Fe-rich ocean waters during phases of Event hydrothermal plumes. The older Bathonian 'Golden Oolite', which extends into the lower Callovian in Keera dome[9], shows greater enrichment relative to the younger Dhosa Oolite of Oxfordian age. This aspect of iron depletion can be explained in an extensional passive margin situation. Progressive migration of the Indian plate away from the spreading centre would lead to a corresponding decrease in the concentration of iron in the oolites owing to incremental distancing from the hydrothermal Event plumes.

The occurrence of Fe oolitic limestones is not the norm in the Jurassic succession of Kachchh basin. Due to different palaeogeographic settings during early and late Jurassic, climates too differed. There was a change from tropical wet to temperate dry climate from Bathonian to Oxfordian[27]. Thus, iron may not be derived necessarily due to weathering of continental ferromagnesium rich rocks. It is proposed that these horizons represent distinct short-lived episodes of magmatic activity at the mid-oceanic ridges. The golden oolites represent the first stage of actual rupturing, resulting in the genesis of a mid-oceanic ridge system between Greater India and Africa. While there is a 26 Ma time gap between the formation of the Karoo Basalt Province of South Africa and actual sea-floor spreading, it has been suggested[1] that sea-floor spreading activity may have commenced around 170 Ma. This appears to be in agreement with the Kachchh record. The oolitic facies are not restricted to the Kachchh basin. Similar facies have been recorded in the Seychelles plateau[28] and have an early to middle Jurassic age. Bajocian oolites have

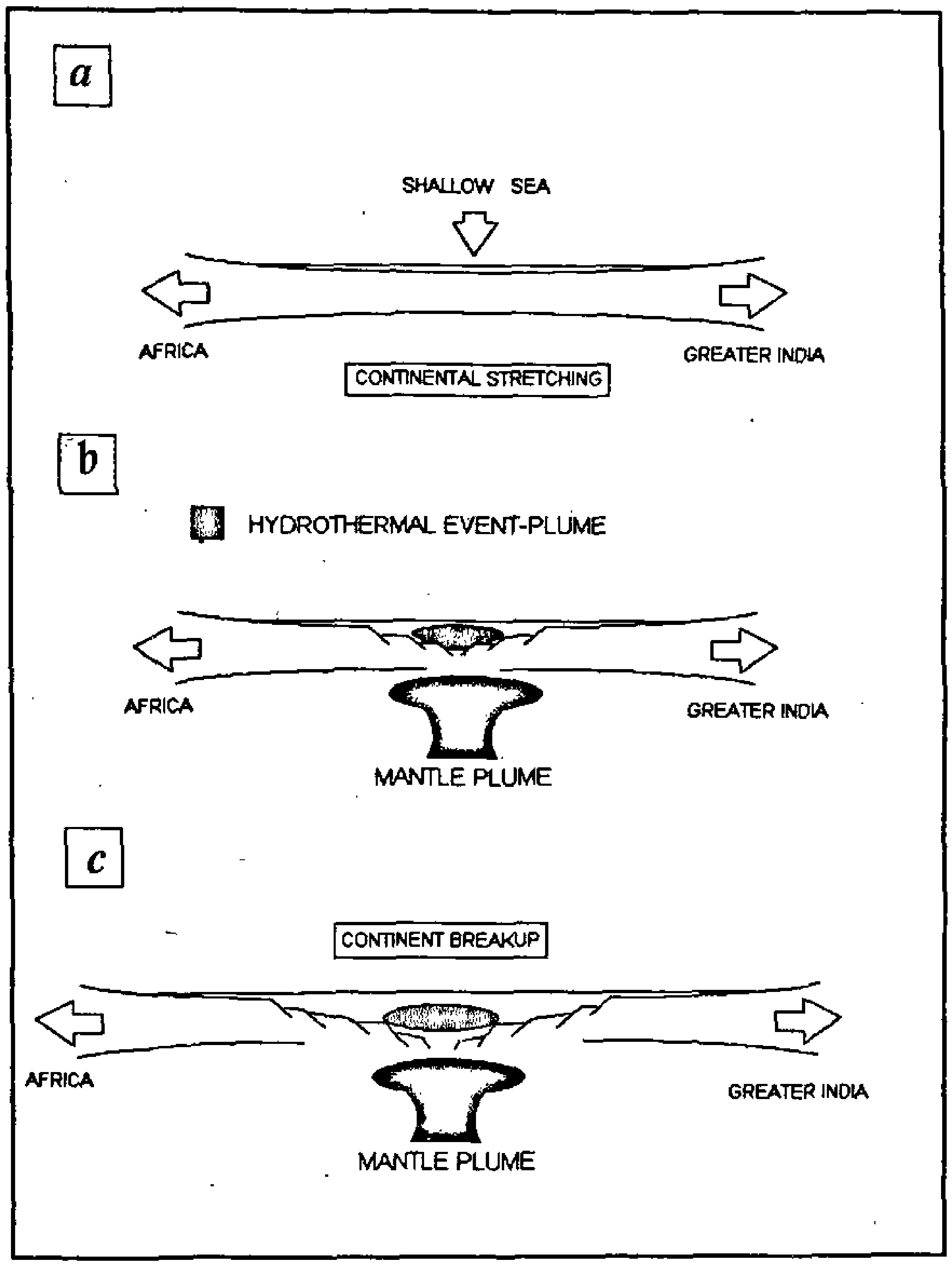

Figure 2. Relation between the phases of Gondwanaland breakup and the formation of the ironstone facies of the Kachchh sediment record. *a*, Initial phase of continental stretching which led to the formation of the coralline white marls; *b*, Formation of a mid-oceanic ridge system during Bajocian–Bathonian times. This led to the deposition of the Golden Oolite ironstone. Proximity to ocean waters charged with iron from Event plumes led to its high iron content; *c*, Final breakup between the African landmass and Greater India, which led to the formation of the Dhosa Oolite ironstone.

been also observed off the western part of the Seychelles plateau[27]. The Dhosa Oolite represents the detachment of Greater India during a more elaborate second phase (beginning of drift stage). The initial phase of continental stretching is manifested in the coralline Jhurio limestone, a facies which occurs only once throughout the Mesozoic sediment succession. Continental stretching led to the formation of a shallow high energy sediment starved sea which provided an environment conducive to the proliferation of corals (Figure 2).

Ironstones represent events of superplume activity[20]. Superplumes are known to aid and, in some cases, even initiate continent breakup[1]. The Golden oolite and Dhosa oolite show iron sequestration and qualify as ironstones. Iron was derived from element-rich infrequent hydrothermal Event-plumes, a modern example being that of the Juan de Fuca ridge. The ironstones thus document two phases of Event hydrothermal-plume generation related to excessive sea-floor spreading rates. One episode which resulted from the genesis of a mid-oceanic ridge system between Greater India and Africa, took place in the Bathonian, while the final breakup and migration of Greater India took place during the Oxfordian, which is manifested as the Dhosa Oolite.

1. Storey, B. C., *Nature*, 1995, **377**, 301–308.
2. Gombos, Jr. A. M., Powell, W. G. and Norton, I. O., *Sediment. Geol.*, 1995, **96**, 119–129.
3. Fursich, F. T., Oschmann, W., Singh, I. B. and Jaitly, A. K., *J. Geol. Soc. London*, 1992, **149**, 313–331.
4. Biswas, S. K., *Tectonophysics*, 1987, **135**, 302–327.
5. Biswas, S. K., in *Sedimentary Basins of India: Tectonic Context* (eds Tandon, S. K., Pant, C. C. and Casshyap, S. M.), Gyanodaya Prakashan, Nainital, 1987, pp. 74–103.
6. Spath, L. F., *Palaeontol. Ind. Ser. 9*, 1933, **2**, 945.
7. Cox, L. R., *Palaeontol. Ind. Ser. 9*, 1940, **3**, 157.
8. Kitchin, F. L., *Palaeontol. Ind. Ser. 9*, 1900, **3**, 87.
9. Biswas, S. K., *J. Geol. Mineral. Metall. Soc. India*, 1977, **49**, 1–52.
10. Fürsich, F. T. and Oschmann, W., *J. Geol. Soc. London*, 1993, **150**, 169–185.
11. Callomon, J. H., *Geol. Bl. NO-Bayern*, 1993, 43, 227–246.
12. Phansalkar, V. G., Sudha, G. and Khadkikar, A. S., *Curr. Sci.*, 1994, **67**, 460–461.
13. Khadkikar, A. S. and Phansalkar, V. G., *J. Geol. Soc. India*, 1995, **46**, 675–677.
14. Khadkikar, A. S., Unpubl. M Sc Diss., University of Poona, 1993, p. 51.
15. Van Houten, F. B. and Bhattacharya, D. P., *Annu. Rev. Earth Planet. Sci.*, 1982, **10**, 441–457.
16. Hallam, A. and Bradshaw, M. J., *J. Geol. Soc. London*, 1979, **136**, 157–164.
17. Gradstein, F. M., Von Rad, U., Gibling, M. R., Jansa, L. F., Kaminski, M. A., Kristiansen, I., Ogg, J. G., Rohl, U., Sarti, M., Thurow, J. W., Westermann, G. E. G. and Wiedmann, J., *Geologisch. Jahrbuch*, 1992, **B77**, 3–141.
18. Van Houten, F. B., *Geology*, 1985, **13**, 722–724.
19. Larson, R. L., *Geology*, 1991, **19**, 963–966.
20. Garzanti, E., *Geology*, 1993, **21**, 105–108.
21. Campbell, A. C., Palmer, M. R., Klinkhammer, G. P., Bowers, T. S., Edmond, J. M., Lawrence, J. R., Casey, J. F., Thompson, G., Humphris, S., Rona, P. and Karson, J. A., *Nature*, 1988, **335**, 514–519.
22. Von Damm, K. L., *Annu. Rev. Earth Planet. Sci.*, 1990, 173–204.
23. Delaney, J. R., Johnson, P. H. and Karsten, J. L., *J. Geophys. Res.*, 1986, **86**, 11747–11750.
24. Baker, E. T. and Hammond, S. R., *J. Geophys. Res.*, 1992, **97**, 3443–3456.
25. Baker, E. T., *J. Geophys. Res.*, 1994, **99**, 4889–4904.
26. Baker, E. T., Massoth, G. J. and Feely, R. A., *Nature*, 1989, **329**, 149–151.
27. Perlmutter, M. A., Brennan, P. A., Hook, H. C., Dempster, K. and Pasta, D., *Sediment. Geol.*, 1995, **96**, 93–118.
28. Plummer, Ph. S. and Belle, E. R., *Sediment. Geol.*, 1995, **96**, 73–91.

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A significant stage of metazoan evolution from the Proterozoic rocks of the Vindhyan Supergroup

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Skolithos linearis **was recently found to occur on the plateau of Chittaurgarh Fort, Rajasthan, in the Morwan Sandstone Formation of the Kaimur Group (Vindhyan Supergroup). The presence of identical burrows from the same stratigraphic horizon at Besla and Rampura in Mandsaur district of Madhya Pradesh has been reported[1,2]. Vertical burrows belonging to** ***Skolithos*** **are known to occur in the Proterozoic rocks of Australia, California, southwest Africa, Russian Platform and extra-peninsular India. Vertical burrows provide security against adverse environmental conditions and give protection from predators. Hence, development of capacity to construct vertical burrows must be considered as a significant step in metazoan evolution. Occurrence of** ***Skolithos*** **in widely separated Proterozoic basins proves the antiquity of the development of this faculty.**

PRIMITIVE metazoans that thrived during the Proterozoic times did not possess any hard parts. The only clues to their existence and evolution are the lebensspuren