Trilobozoan (*Tribrachidium* and *Albumares*) Ediacaran organisms from Marwar Supergroup, Western India

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Here we describe the *Tribrachidium* and *Albumares* Ediacaran organisms belonging to phylum Trilobozoa in the Sonia Sandstone of Marwar Supergroup, western India. Between the two Ediacaran genera, *Albumares brunsae* was the first to be discovered in India, while *Tribrachidium heraldicum* was the first record from the Marwar Supergroup. *T. heraldicum* is soft-bodied, discoidal or disc-shaped (in plane view) and slightly conical-shaped (when found with up to 2 mm vertical relief) with three elevated lobes (arms) or ridges bounded by a well-defined peripheral ring. *A. brunsae* is soft-bodied, flattened, low-relief, circular to sub-circular and with a tri-lobed (three elevated arms/rays) shield having branching rays that radiate outward from the centre to the outer edge of the peripheral ring. Both Ediacaran taxa occur here as convex or positive reliefs with tri-radial symmetry on medium to fine-grained sandstone bedding planes in the Sursagar area and show the Flinders Ranges style of preservation.

Keywords: *Albumares*, Ediacaran organisms, sandstone, *Tribrachidium*, trilobozoans.

THE Ediacaran biota is the oldest and distinct group of macroscopic, morphologically complex eukaryotic organisms that flourished in the late Ediacaran period[1,2]. They are mainly soft-bodied organisms with unusual body plans[3] and have been historically interpreted as the evolutionary precursors of Cambrian organisms or animals, including annelids, cnidarians, arthropods and echinoderms[4,5]. Among these, many Ediacaran taxa have tri-radial symmetry or body plan[2,3] and occur as three elevated, equal-spaced features or forms such as lobes, bumps, ridges or canals, as well as some elements of threefold symmetry arranged or bound in a peripheral ring[2,6,7]. These organisms have been grouped under phylum Trilobozoa[8], while some workers have designated them as Tribrachiomorpha[9,10] or Triradialomorpha[2,7,11]. Presently, six genera, viz. *Albumares*, *Anfesta*, *Hallidaya*, *Skinnera*, *Rugoconites* and *Tribrachidium* have been described and included under Trilobozoa. These fossil remains are commonly found in the Ediacara Member of South Australia and Vendian deposits of the White Sea regions of Russia[8,12–18]. The *Hallidaya* was recently discovered in the Early Cambrian Flathead Sandstone of Fishtrap Lake, Montana, USA[19]. In the present study, three *Tribrachidium heraldicum* and two *Albumares brunsae* specimens have been reported in the sandstone beds of Sonia Sandstone of the Jodhpur Group, Marwar Supergroup (MSG), Western

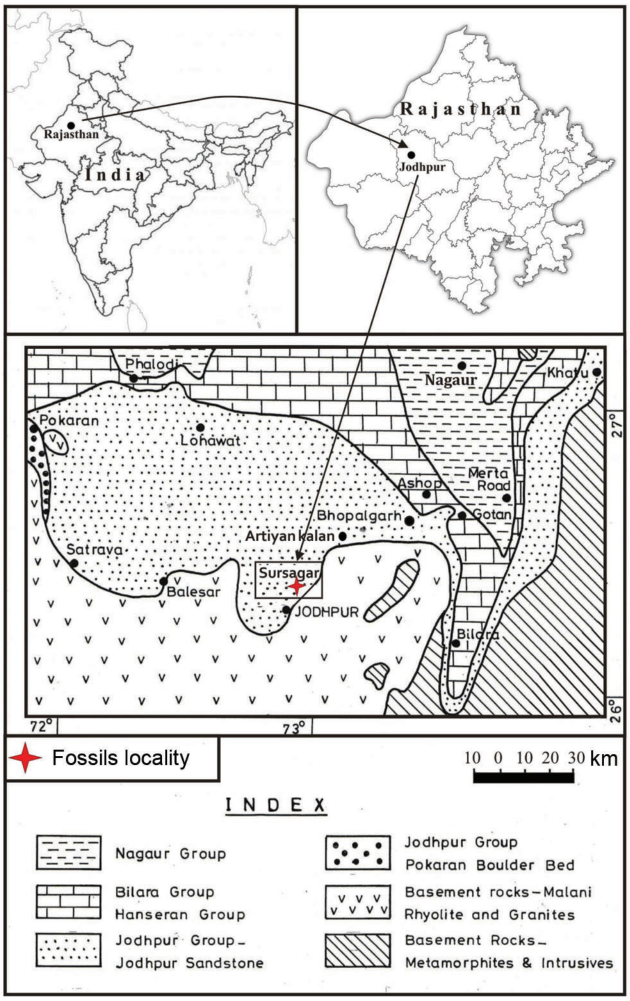

Figure 1. Geological map of western Rajasthan, India showing distribution of rocks of Marwar Supergroup (MSG) and location of the *Tribrachidium* and *Albumares* (trilobozoans) Ediacaran fossils-bearing Sursagar area of Jodhpur district[20].

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Table 1. Stratigraphic succession of the Marwar Supergroup, western Rajasthan, India[20]

Permo-carboniferous	Bap boulder bed	Rounded, sub-rounded, ellipsoidal pebbles and cobbles	
Marwar supergroup (Late Neoproterzoic to Early Cambrian)	Nagaur Group (75–500 m)	Tunklian Sandstone	
		Nagaur Sandstone	
	Hanseran Group (up to 60 m)	Claystone, siltstone, dolostone, anhydrite, halite	
	Bilara Group (100–300 m)	Pondlo Dolomite	
		Gotan Limestone	
		Dhanapa Dolomite	
	Jodhpur Group (125–340 m)	Girbhakar Sandstone	Buff, brownish, purplish to reddish-white, spotted, gritty, pebbly, massive to thickly bedded sandstone and siltstone sequence
		Sonia Sandstone	Yellowish-brown, purple, pinkish-brown, medium to fine-grained, fine-grained sandstone, brown siltstone and shale, and few conglomeratic beds
		Pokaran boulder bed	Sandstone, silty and shaly sandstone. Massive conglomerate, boulder spread and stratified conglomerate

Malani igneous suite: 780–680 Ma (refs 23, 24) and 771 ± 05 Ma (U–Pb)[25].

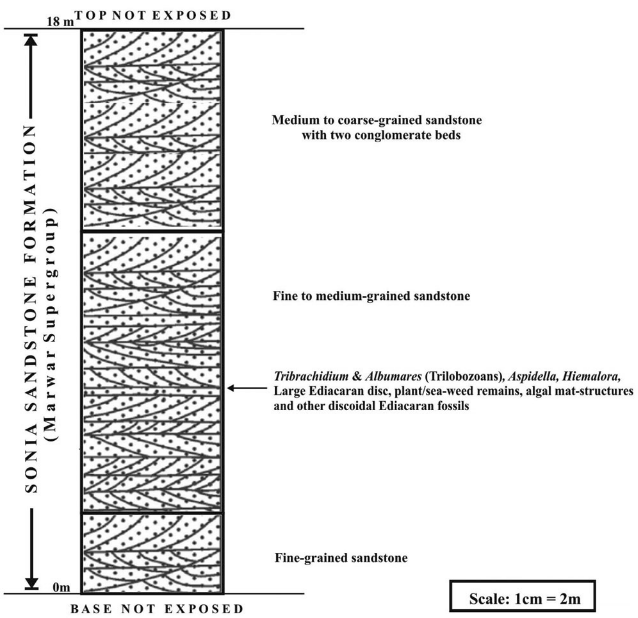

Figure 2. Generalized lithostratigraphic section of Sonia Sandstone of MSG showing *Tribrachidium* and *Albumares* (trilobozoans) with other Ediacaran fossil assemblage-bearing horizons[28].

India. The fossil-containing sandstone beds (Sonia Sandstone Section) are exposed in the Sursagar area and lie about 8 km north of Jodhpur city, Rajasthan (Figure 1). The collections of *T. heraldicum* and *A. brunsae* are deposited as repositories in the Palaeontological Laboratory of the Department of Geology, Jai Narain Vyas University, Jodhpur.

Geology of the study area

The present trilobozoan organisms bearing sandstone is part of Sonia Sandstone of the Jodhpur Group, MSG and exposed in the Sursagar area, Jodhpur (Figure 1). MSG (previously attributed as 'Trans-Aravalli Vindhyans') occupies a large area in western Rajasthan[20–22]. It unconformably overlies Malani rhyolites, dated as 780–680 Ma (refs 23, 24), as well as 771 ± 05 Ma on the basis of U–Pb dating[25]. The strata/rocks of MSG are generally undeformed and unmetamorphosed, and 1000 m thick[20]. These strata have been divided into the Jodhpur Group Bilara Group, and Nagaur Group in stratigraphic order[20]. The Jodhpur Group is further sub-divided into three formations: the Pokaran boulder beds, Sonia Sandstone and Girbhakar Sandstone in stratigraphic order[20]. The Bilara Group of rocks is also subdivided into three formations, viz. Dhannapah Dolomite, Gotan Limestone and Pondlo Dolomite. The rocks of the Nagaur Group are divided into two formations, viz. Nagaur Sandstone and Tunklian Sandstone in stratigraphic order (Table 1)[20]. The beds of Sonia Sandstone mainly comprise quartz arenite with almost horizontally occurring bookish forms of sedimentary structures like parallel laminations, ripple-marks, cross-beddings and graded beddings[20–22]. The Ediacaran age of Sonia Sandstone (a basal member of MSG) has been proposed based on previous records of Ediacaran biota from the area[26–32]. The Bilara Group belongs to the Late Ediacaran–Early Cambrian period based on the isotopic study of Bilara carbonates[33], whereas the Nagaur Group has been assigned an Early Cambrian age based on trilobite trace fossils[34,35]. Figure 2 shows the generalized lithostratigraphic section of trilobozoan (*T. heraldicum* and *A. brunsae*) Ediacaran taxa with other Ediacaran fossil-bearing horizons of Sonia Sandstone of the Sursagar area.

Systematic Description:
Tribrachidium:
Systematic palaeontology:
Phylum: Trilobozoa
Order: Aspidellomorpha[36]

Family: Tribrachididae[37]
Genus: *Tribrachidium*[12]
Type species: *Tribrachidium heraldicum*[12]
Tribrachidium heraldicum sp., (Figure 3 *a–f*)
Materials: Three specimens on three sandstone slabs.

Description: Three *T. heraldicum* specimens preserved as convex or positive reliefs with tri-radial symmetry have been recorded in medium to fine-grained sandstone bedding plane in the Sonia Sandstone of MSG. These are soft-bodied, discoidal or circular to subcircular in shape (in plane view) and slightly conical-shaped (when found with up to 2 mm vertical relief) having three elevated lobes (arms) or ridges with a well-defined outer peripheral ring (ridge). The width of the elevated lobes or arms ranges from 2 to 5 mm. All three elevated lobes or arms are arranged in an S- or spiral-shaped pattern with close to 90° clockwise in the central part of the discs. The tapered arms originate from the central part and extend to the outer peripheral ring of the organism. The outer peripheral ring of the disc is generally occupied by numerous radiating grooves or furrows of 2–5 mm width (Figure 3 *a*, *c* and *e*); but these radial features have not been observed in the present materials. Generally, the upper surface of the disc of *T. heraldicum* also has numerous branching grooves, which are separated by thin ridges, but these were not found in the present materials. Here, the recovered *T. heraldicum* fossils had a diameter of 45 (Figure 3 *a*), 22 (Figure 3 *c*) and 20 mm (Figure 3 *e*), with dimensions ranging from 20 to 45 mm, and were well comparable with their worldwide occurrences (size range), i.e. 3–50 mm in dimension[12,13].

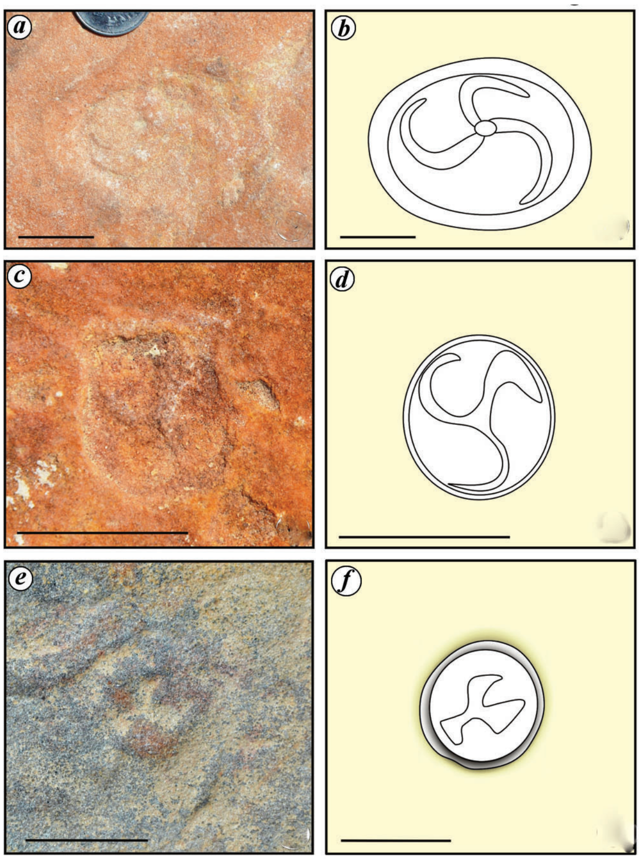

Figure 3. ***a***, Field photograph of *Tribrachidium heraldicum* specimen showing a discoidal or disc-shape with three elevated lobes (arms) or ridges bounded in a well-defined peripheral ring. ***b***, Sketch of the specimen shown in (*a*). ***c***, Close-up view of *T. heraldicum* specimen preserved as convex or positive relief with tri-radial symmetry on medium to fine-grained sandstone bedding plane in Sonia Sandstone. ***d***, Sketch of *T. heraldicum* the fossil specimen shown in (*c*). ***e***, Close-up view of discoidal or disc-shaped *T. heraldicum* fossil with tri-radial symmetry or body plan. ***f***, Sketch of the fossil specimen shown (*e*). Scale: Bar length is 2 cm.

Remarks: The present study materials have several characteristics with diagnostic aspects, such as being soft-bodied, discoidal or disc-shaped (in plane view) and a slightly conical-shaped (found with higher vertical relief) shield with three elevated lobes (arms) bounded by a well-defined peripheral ring morphology of *T. heraldicum* recorded from Rawnsley Quartzite of Ediacara Member, Flinders Ranges of South Australia[12,13]. Therefore, they have been assigned as *T. heraldicum*. Globally, this Ediacaran taxon compares well with *T. heraldicum* recorded previously from the Verkhovka, Zimnie Gory and the Yorga Formation of Arkhangelsk region, Russia[38]; the White Sea region of Russia[39,40], the Mogilev Formation in Dniester River Basin, Podolia, Ukraine[16] and from the Late Vendian, Ust Pinega Formation, Syuzma, Zimnie Gory, Erga Beds, southeastern White Sea area, Arkhangelsk region[18]. The locomotion traces of *T. heraldicum* (Ediacaran trilobozoan) with its negative body imprint have also been discovered from the Vendian deposits of the southeastern White Sea region[17]. When compared to *T. heraldicum* specimens in the Ediacara Member of South Australia, where these organisms have been found with higher relief and well-defined preservations[12,13], specimens from the Sonia Sandstone under study display low relief and are less defined. These specimens show larger forms (20–45 mm in dimension) in MSG than the Ediacara Member of South Australia (3–40 mm in dimension)[7]. The outer peripheral ring of the disc of *T. heraldicum* has a width of 9 mm and is generally occupied by numerous radiating grooves in Ediacara Member of Flinders Ranges of South Australia. In present materials, however, this outer peripheral ring ranges in width from 2 to 5 mm, and the radial features have not been observed (Figure 3 *a–f*). Generally, the upper surface of the disc of *T. heraldicum* has numerous branching grooves, which are separated by thin ridges in Ediacara Member of South Australia specimens, but these branching grooves have not been found in the present materials (Figure 3 *a–f*). The *T. heraldicum* shield specimen from the Sonia Sandstone lacks a short, Y-shaped groove that may be the animal's mouth and is found in specimens from the Ediacara Member of South Australia.

Occurrences: Yellowish to pinkish-brown, medium to fine-grained sandstone of Sonia Sandstone, MSG, exposed at Sursagar area, Jodhpur District, western Rajasthan, India.

Albumares:
Systematic palaeontology:
Phylum: Trilobozoa
Order: Aspidellomorpha[36]
Family: Albumaresidae
Genus: *Albumares*[41]
Type species: *Albumares brunsae*[41]
Albumares brunsae sp. (Figure 4 *a–d*)
Materials: Two specimens on sandstone slab in Sursagar Sandstone mines.

Description: Two *A. brunsae* specimens preserved as positive relief with a tri-radial symmetry shield have been observed on the medium to fine-grained sandstone bedding plane in the Sursagar area. These are soft-bodied, flattened, low-relief, circular to sub-circular and with a tri-lobed (three elevated arms/rays) shield having branching rays which radiate outward from the centre to the outer edge of the peripheral ring. These arms/rays are equally spaced with elevated features, tapering outwards to their ends and moved left-sided in the shield. The branching rays have three thin ridges and bifurcate dichotomously four times towards the outer edge of the peripheral ring. Numerous thin tentacles are also found at the outer edge of the organism in the form of ridges. The upper surface of the whole shield is also covered by thin ridges. The specimens of *A. brunsae* found in this location have a diameter of 60 (Figure 4 *a*) and 65 mm (Figure 4 *c*), and show a larger form.

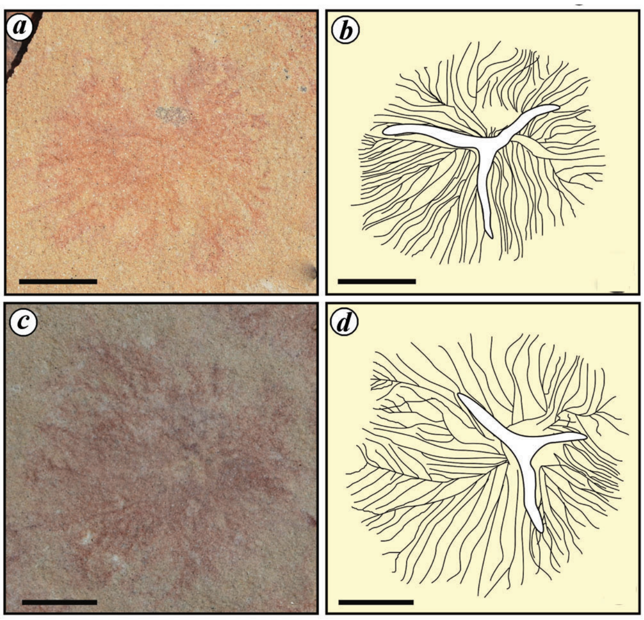

Figure 4. ***a***, Well-preserved *Albumares brunsae* specimen showing flattened, low-relief circular to sub-circular and tri-lobed (three elevated arms/rays) shield with branching rays. ***b***, Sketch diagram of the specimen shown in (*a*). ***c***, Close-up view of *A. brunsae* specimen preserved as positive relief with tri-radial symmetry on medium to fine-grained sandstone bedding plane in Sonia Sandstone. ***d***, Sketch of the specimen shown in (*c*). Scale: Bar length is 2 cm.

Remarks: The present studied materials have several characteristics with diagnostic features of *A. brunsae* recorded from the Onega Peninsula of the White Sea region of Russia[41] and Ediacara Member of South Australia[16]. Therefore, they are assigned as *A. brunsae.* Globally, this compares well with *A. brunsae* reported from the Late Vendian, Ust Pinega Formation, Syuzma, southeastern White Sea area, Arkhangelsk region, Russia[18]. Similar to the Ediacara Member of South Australia, the Onega Peninsula, and the Late Vendian Ust Pinega Formation of Syuzma locality in the Arkhangelsk region of Russia, the Sonia Sandstone *A. brunsae* specimens also have thin ridges and low-relief preservation (2 mm) covering the upper surface of the entire shield. The arms or rays of the shield in *A. brunsae* specimens from the Sonia Sandstone are long, *Y*-shaped, and taper from the centre to the ends; however, in specimens from the White Sea region of Russia and the Ediacara Member of South Australia, these arms or rays are short, are found to the left in the shield and have rounded ends. The present study *A. brunsae* specimens recorded larger forms with dimensions ranging from 60 to 65 mm (Figure 4 *a* and *c*) than specimens from the Onega Peninsula of the White Sea region of Russia[41] and Ediacara Member of South Australia[16] (13 mm in dimension) as well as from the Late Vendian, Ust Pinega Formation, Syuzma, southeastern White Sea area, Arkhangelsk region, Russia[18].

Occurrences: Yellowish to pinkish-brown, medium to fine-grained sandstone of Sonia Sandstone, MSG, exposed at Sursagar area, Jodhpur district, western Rajasthan, India.

Discussion

Originally, *Tribrachidium* was treated as an enigmatic benthic organism with a tri-radial body plan[12,13]. *T. heraldicum* are discoidal or disc-shaped, soft-bodied organisms with tri-radiated symmetry and a known member of the extinct Ediacaran Trilobozoa group[8]. Furthermore, Fedonkin proposed the Trilobozoa phylum for soft-bodied, disk-shaped organisms with tri-radial symmetry Fedonkin[8,15]; some of them are given the name Tribrachiomorpha[9,10] or Triradialomorpha[6,40]. The fossil remains of *Tribrachidium* are imprints of the upper side of the body as well as some elements that are part of its external and internal anatomy[8]. They are found in medium to fine-grained sandstone bedding planes in the Sonia Sandstone of MSG. These *S*-shaped or spirally twisted elevated lobes or ridges were interpreted as tentacle arms and chaetae[12,13,42–44], or even as parts of the conduction system of the organisms[45]. Typically, in *T. heraldicum,* the upper part of the entire disc has numerous grooves separated by thin ridges[8]. Fedonkin[46] mentioned that these grooves helped transport food substrates to the oral openings on top of the discs. Generally, *Tribrachidium* is considered a soft-bodied sessile benthic organism that is attached temporarily to the food substrates, mainly microbial or algal mats[7,8,12,13,15,17,18,42,44].

Originally, *A. brunsae* was described from the Onega Peninsula in the White Sea region of Russia[47]. Later, it was also recorded in South Australia[16]. Recently, 15 specimens of *A. brunsae* have been reported from the Late Vendian, Ust Pinega Formation, Syuzma, southeastern White Sea area, Arkhangelsk region, Russia[18]. *Albumares* is soft-bodied, flattened, low-relief, circular to sub-circular and has a trilobed (three elevated arms/rays) shield with branching rays that radiate outward from the centre to the outer edge of the peripheral ring of the organism. This ridge structure has been identified as its gastrovascular system[47].

The recorded *T. heraldicum* and *A. brunsae* Ediacaran taxa have been found on medium to fine-grained sandstone bedding planes in the Sonia Sandstone of Jodhpur Group, MSG and show the Flinders Ranges style of preservation. These sandstone beds are mainly quartz arenitic in nature with thin layers of intercalation of shale and siltstone (Figure 2). These sandstone beds were formed by the process of lithification of medium to fine sediments in the Marwar Basin, which was covered with algal or microbial mats in the Edaicaran period. Here, *T. heraldicum* and *A. brunsae* trilobozoan organisms have been buried (after death) in medium to fine sediments in benthic environments. They were slightly compressed under the weight of the sediments during the process of fossilization (taphonomic event) and occurred as in discoidal or disc-shaped imprints with previously recorded Ediacaran macroscopic organisms, viz. *Aspidella*[28,30,31], *Hiemalora stellaris*[32], small–large discs[29,30] and algal/microbial mat structures[27,30,48] in benthic or shallow marine settings.

Conclusion

(i) This study has documented the well-preserved *T. heraldicum* and *A. brunsae* Ediacaran organisms in MSG. *T. heraldicum* specimens occurred in 20–45 mm diameter ranges and compared well with their worldwide occurrences (in size range of 3–50 mm in dimensions)[12,13]. *A. brunsae* fossil specimens in the Sonia Sandstone MSG had dimensions ranging from 60 to 65 mm, indicating four times larger forms than their worldwide occurrences. The MSG specimens showed flattened, low-relief (2 mm) and hemispherical umbrella with three lobes (arms/rays) and were compared well with *A. brunsae* of the Ediacara Member of South Australia.

(ii) This study suggests the Ediacaran Sonia Sandstone of MSG is another place/section of *A. brunsae* in India after the White Sea assemblages (Ediacran Member of South Australia and White Sea region of Russia). This finding (*T. heraldicum* and *A. brunsae* trilobozoan Ediacaran organisms) also confirms the juxtaposition of India–Australia in the Late Ediacaran period after the discovery of the Ediacaran bilaterian *Dickinsonia* fossils in India[49].

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