

# Triangular-shaped Ediacaran fossil *Thectardis avalonensis* from the Sonia Sandstone, Jodhpur Group, Marwar Supergroup, western India

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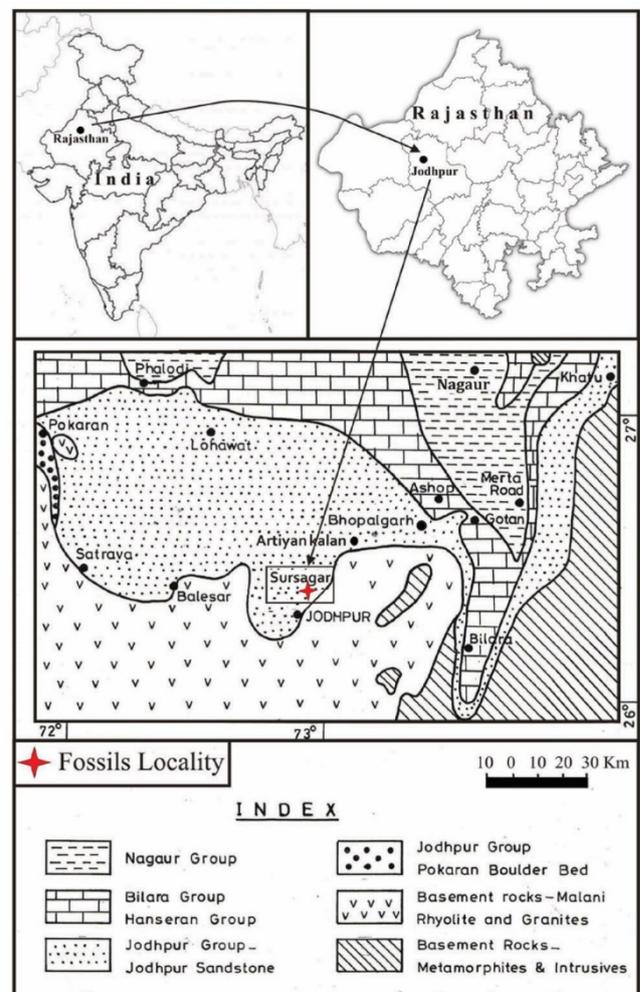
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The present study records the triangular-shaped Ediacaran fossil identified as *Thectardis avalonensis* from the Sonia Sandstone of Jodhpur Group, Marwar Supergroup, western India. These Ediacaran fossil specimens are preserved in convex (positive) relief, but one is in negative relief on the bedding planes of sandstone in the Sursagar mines area. *T. avalonensis* is well-preserved, unskeletonized, elongated and triangular in shape, with sharp, raised marginal rims or ridges that widen at the triangular base and taper towards the apex of the organism. This Ediacaran triangular-shaped *T. avalonensis* organism is recorded for the first time from India. The phylogenetic affinity of *T. avalonensis* is still uncertain, as some have interpreted it as a sponge based on a body plan consistent with the hydrodynamics of the sponge water-canal system, which lacked a mouth or movement and its length–width ratio of more than 1.6. As well as these, *T. avalonensis* may also belong to *Diskagma*-like lichen or living *Cladonia*-like lichen group and the *Auroralumina*-like cnidarian organisms of the Ediacaran crown group.

**Keywords:** Eukaryotic organism, fossil specimens, length–width ratio, phylogenetic affinity, sandstone, *Thectardis avalonensis*.

THE earliest and most remarkable group of macroscopic, soft-bodied, morphologically complex eukaryotic organisms included in the Ediacaran biota flourished during the Late Ediacaran<sup>1,2</sup>. It was originally considered to be the remains of porifera, ctenophorans, cnidarians, stem and crown group bilaterian metazoans<sup>1–6</sup>. It was also considered a fungus-like organism<sup>7</sup>, protist<sup>8</sup>, lichen<sup>9</sup> or microbial colony<sup>10–12</sup>. With the exception of Antarctica, these Ediacaran organisms have been obtained from more than 40 locations around the world<sup>4</sup>. The Ediacaran biota can be divided into three major groups of distinctive assemblages: the Avalon, White Sea and Nama assemblages<sup>13,14</sup>. In this study, the Avalon-type assemblages identified as *T. avalonensis*, an Ediacaran fossil with a triangular or cone-shaped morphology, have been reported in the yellowish–pinkish–brown, medium- to fine-grained sandstone of the Sonia Sandstone, Jodhpur Group, Marwar Supergroup (MSG), western India. The examined

*T. avalonensis* fossil-bearing section of the Sonia Sandstone is located in the Sursagar region of Jodhpur district, Rajasthan (Figure 1). The collected samples of *T. avalonensis* were maintained in a repository at the Palaeontological Laboratory, Department of Geology, Jai Narain Vyas University, Jodhpur. The present study describes *T. avalonensis* in the Sonia Sandstone along with its possible phylogenetic affinity and palaeoenvironmental implications.

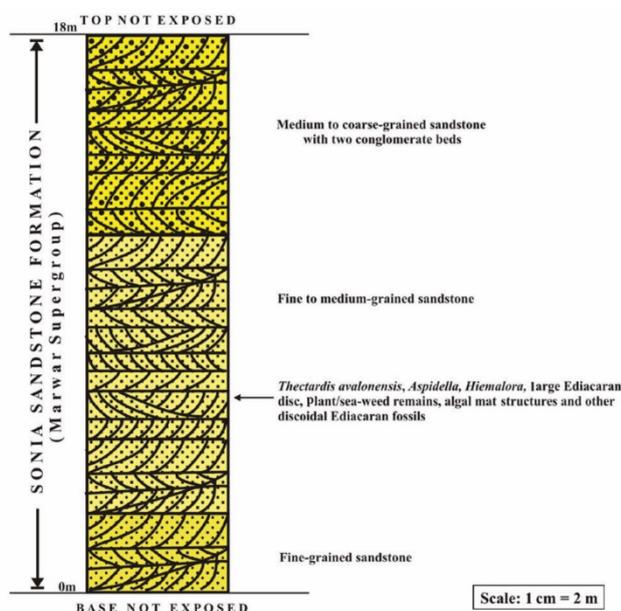


**Figure 1.** Geological map of western Rajasthan showing the distribution of rocks of Marwar Supergroup and location of *Thectardis avalonensis* Ediacaran fossils bearing the Sonia Sandstone of Jodhpur Group exposed at Sursagar area, Jodhpur district<sup>15</sup>.

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**Table 1.** Stratigraphic succession of the Marwar Supergroup, western Rajasthan, India<sup>15</sup>

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 Dhanapah 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 a few conglomeratic beds.
		Pokaran Boulder Beds	Sandstone, silty and shaly sandstone. Massive conglomerate, boulder spread and stratified conglomerate.
		Malani Igneous Suite: 780–680 Ma (refs 18, 19) and 771 ± 05 Ma (U–Pb) (ref. 20)	

**Figure 2.** Generalized lithostratigraphic section of the Sonia Sandstone showing *T. avalonensis* with other Ediacaran taxa-bearing horizons<sup>23</sup>.

## Geological setting

MSG, traditionally designated as the ‘Trans-Aravalli Vin-dhyans’, occupies a large area in western Rajasthan<sup>15–17</sup>. It is unconformably overlying on the Malani Rhyolites dated as 780–680 Ma (refs 18, 19) and as 771 ± 05 Ma on the basis of U–Pb minerals dating<sup>20</sup>. MSG’s strata and rocks typically have a thickness of 1000 m and are not deformed or metamorphosed<sup>15</sup>. In stratigraphic order, these strata have been split into the Jodhpur Group, Bilara Group and Nagaur Group<sup>15</sup>. Further, the Jodhpur Group of rocks is divided into three stratigraphically distinct formations: Pokaran Boulder Beds, Sonia Sandstone and Girbhakar Sandstone<sup>15</sup>.

Similar to the Jodhpur Group, rocks of the Bilara Group are stratigraphically separated into three formations: Dhannapah Dolomite, Gotan Limestone and Pondlo Dolomite, while rocks of the Nagaur Group are divided into two formations, viz. Nagaur Sandstone and Tunklian Sandstone<sup>15</sup> (Table 1). The Sonia Sandstone is mainly composed of quartz arenite and contains bookish forms of sedimentary structures like parallel laminations, ripple-marks, cross-beddings and graded beddings<sup>15–17</sup>. The Ediacaran age has been suggested for the Sonia Sandstone based on previous records of the Ediacaran fauna<sup>21–27</sup>. Based on an isotopic analysis of Bilara carbonates, the Bilara Group is considered to be of Late Ediacaran to Early Cambrian age<sup>28</sup>, whereas the Nagaur Group has been assigned an Early Cambrian age based on trilobite trace fossils<sup>29,30</sup>. The present recorded *T. avalonensis* Ediacaran taxon-bearing sandstone belongs to the Sonia Sandstone. Figure 2 shows the generalized lithostratigraphic section of *T. avalonensis* with other Ediacaran taxa-bearing horizons of the Sonia Sandstone.

## Systematic description

Genus: *Thectardis*<sup>31</sup>.

Type species: *Thectardis avalonensis*<sup>31</sup>.

*Thectardis avalonensis* sp. (Figures 3 and 4).

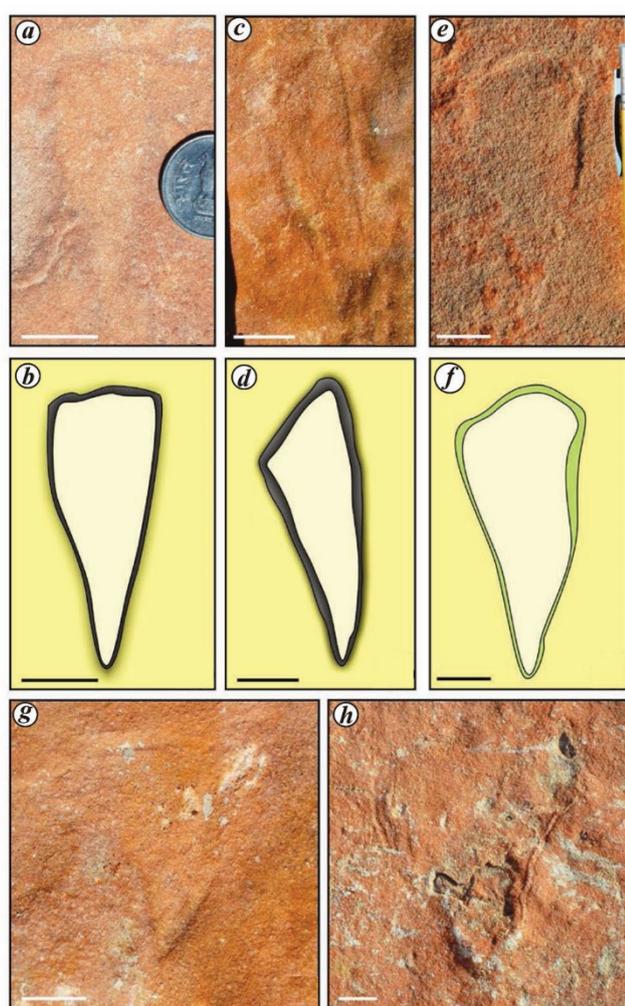
**Diagnosis:** A centimetre-scale imprint in the shape of a triangle, with a prominently raised margin and an interior that is featureless or exhibits faint transverse markings<sup>31</sup>.

**Materials:** Twelve specimens have been found on yellowish–pinkish-brown, medium- to fine-grained sandstone slabs at the Sursagar sandstone mines area.

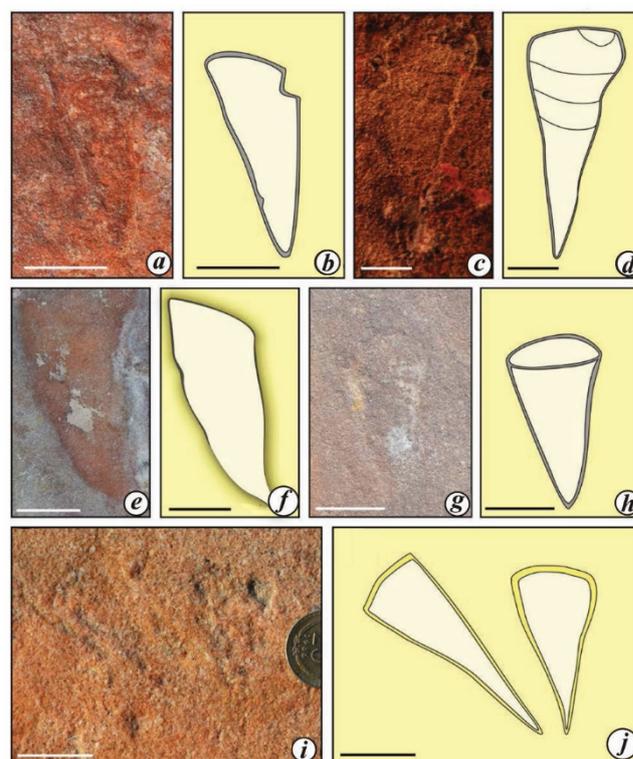
**Description:** *T. avalonensis* is well-preserved, soft-bodied, elongated and triangular in shape, with sharp, raised marginal rims or ridges preserved as convex or positive relief, as well as one specimen occurring as negative relief on the bedding planes of medium- to fine-grained sandstone (Figure 4 c). The fossil specimens are wide at their triangular base and taper towards the apex. Here, the 12 specimens of *T. avalonensis* had length × width (measured at their triangular base) as 50 mm × 20 mm (Figure 3 a), 70 mm × 20 mm (Figure 3 c), 70 mm × 30 mm (Figure 3 e), 45 mm × 30 mm (Figure 3 g), 90 mm × 50 mm (Figure 3 h), 40 mm × 20 mm (Figure 4 a), 60 mm × 25 mm (Figure 4 c), 50 mm × 25 mm (Figure 4 e), 40 mm × 20 mm

(Figure 4 g), 45 mm × 15 mm (Figure 4 i), 25 mm × 15 mm and 35 mm × 20 mm respectively. The raised marginal rims or ridges were found in the range 2–4 mm in width (Figures 3 and 4). All recorded *T. avalonensis* specimens showed sharp, raised marginal rims or ridges with partial (Figures 3 c, e, g, h and 4 a, g) to well-depressed central parts (Figures 3 a and 4 i). Generally, the interior part of the triangular-shaped organism is structureless, but some specimens showed fine transverse lining (Figure 4 c) as well as a rounded hollow or circle at the triangular base (Figure 4 g). In the Sonia Sandstone, the fossil specimens of *T. avalonensis* ranged in length from 25 to 90 mm and width from 15 to 50 mm.

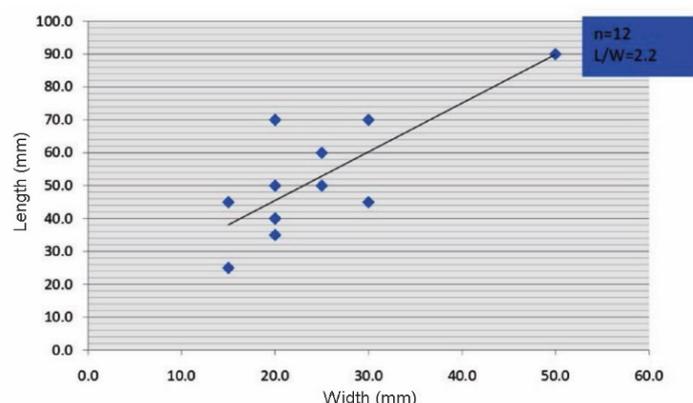
**Remarks:** The observed and recognized materials were comparable to the diagnostic features of *T. avalonensis*<sup>31</sup> – soft-bodied, elongated and triangular in shape, with sharp, raised marginal rims or ridges and a centrally depressed



**Figure 3.** a, Field photograph of *T. avalonensis* showing an elongated, triangular or cone-shaped body with sharp, raised marginal ridges and a well-depressed central part. b, Diagrammatic sketch of *T. avalonensis* fossil specimen shown in (a). c, Close-up view of *T. avalonensis* preserved with negative relief and fine transverse lining. d, Diagrammatic sketch of *T. avalonensis* fossil specimen shown in (c). e, g, Close-up view of *T. avalonensis* fossil preserved with elongated and triangular-shaped body plan and sharp, raised marginal rims or ridges morphology. f, Diagrammatic sketch of *T. avalonensis* fossil specimen shown in (e). h, Field photograph of *T. avalonensis* fossil specimen shown in (g). i, Close-up view of *T. avalonensis* fossil specimens having elongated, triangular or cone-shaped body with sharp, raised marginal ridges and a well-depressed central part. j, Diagrammatic sketch of two *T. avalonensis* fossil specimens shown in (i). Scale: Bar length = 2 cm.



**Figure 4.** a, Field photograph of *T. avalonensis* fossil found on the sandstone bedding plane in Sursagar area. b, Diagrammatic sketch of *T. avalonensis* fossil specimen shown in (a). c, Close-up view of *T. avalonensis* fossil specimen preserved with negative relief and fine transverse lining. d, Diagrammatic sketch of *T. avalonensis* fossil specimen shown in (c). e, Field photograph of elongated, triangular or cone-shaped *T. avalonensis* fossil preserved with convex or positive relief. f, Diagrammatic sketch of *T. avalonensis* fossil specimen shown in (e). g, Close-up view of *T. avalonensis* fossil specimen preserved with a rounded hollow or circle at the triangle base. h, Diagrammatic sketch of *T. avalonensis* fossil specimen shown in (g). i, Close-up view of *T. avalonensis* fossil specimens having elongated, triangular or cone-shaped body with sharp, raised marginal ridges and a well-depressed central part. j, Diagrammatic sketch of two *T. avalonensis* fossil specimens shown in (i). Scale: Bar length = 2 cm.



**Figure 5.** Graph showing length versus width data of the studied *T. avalonensis* Ediacaran fossils recovered from the Sonia Sandstone falling in length–width ( $L/W$ ) ratio ranges from 1.5 to 3.5 with an average  $L/W$  ratio of 2.2.

part, as recorded in the Drook Formation and Mistaken Point Formation of Newfoundland, Canada<sup>31</sup>. Therefore, they were assigned as *T. avalonensis*. In comparison, most of the recorded *T. avalonensis* specimens in the Sonia Sandstone also showed sharp, raised marginal rims or ridges with a well-depressed central part, similar to the Newfoundland *T. avalonensis* specimens. These fossil specimens are comparable and similar in size range (25–90 mm in length) to *T. avalonensis* specimens from the Drook Formation and Mistaken Point Formation (26–165 mm in length)<sup>31</sup>. Generally, the interior parts of the triangular-shaped *T. avalonensis* of the Sonia Sandstone are structureless, but one specimen showed fine transverse lining (Figure 4 c), and another specimen with a rounded hollow or circle at the triangular base (Figure 4 g) was found, similar to the Newfoundland specimens. The occurrence of *T. avalonensis* specimens in the upper Drook Formation at Pigeon Cove has been found in association with *Ivesia lobata* and *Charnia masoni*<sup>32,33</sup> as well as in the upper Mistaken Point Formation at Mistaken Point, Watern Cove, and Laurentian Gulch with spindle-like, bush-shaped and frondose taxa like *Bradgatia*, *Charnia*, *Charniodiscus*, *Fractofusus*, *Fronodophyllas*, *Ivesia*, *Pectinifrons* and *Primocandelabrum*<sup>32,34,35</sup>. However, in the Sonia Sandstone, no spindle-like, bush-shaped or frondose taxa have been recorded yet with *T. avalonensis* specimens. All the recorded *T. avalonensis* specimens in the Sonia Sandstone lack hold-fasts, similar to the Newfoundland specimens.

**Occurrence:** On the bedding planes of yellowish–pinkish-brown medium- to fine-grained sandstone of the Sonia Sandstone, Jodhpur Group, MSG, exposed at Sursagar area, district Jodhpur, western Rajasthan, India.

## Discussion

Earlier, these triangular-shaped *T. avalonensis* Ediacaran fossils were referred to as ‘triangles’<sup>32–34,36</sup>. Later this organ-

ism was reconstructed as an elongated cone-shaped form with a central depression, and generally, its apex has been anchored to the mat substrate or to microbially bound sediments<sup>31</sup>. Sperling *et al.*<sup>37</sup> suggested that these organisms are sponges based on their body plan, which is consistent with the hydrodynamics of the sponge water-canal system, their habitat below the photic zone and the apparent absence of an archenteron, movement, or a fractally designed body plan. They also mentioned that a perfect conical sponge must have a length–width ratio greater than 1.6, which ensures that the inhalant surface area is equal to or greater than the osculum of the sponge. All the recorded *T. avalonensis* specimens in the Sonia Sandstone (Figures 3 and 4) also fall in the length–width ratio range 1.5–3.5 (more than 1.6) with an average length–width ratio of 2.2 (Figure 5) and may suggest they are remains of sponge. *T. avalonensis* may also have been the fossil remains of lichen groups like *Diskagma* organisms (small, elongated, urn-shaped fossils with hollow, structured morphology) reported from the palaeoproterozoic paleosol in South Africa<sup>38</sup>. These *Diskagma* organisms have been superficially compared with the living *Cladonia*-like lichens<sup>38</sup>. The studied *T. avalonensis* might also be the fossil remains of a cnidarian, i.e. *Auroralumina* (thecate, medusozoan cnidarian with colonial polypoid morphology) discovered from the Ediacaran Charnwood Forest<sup>39</sup>. *Auroralumina* are considered the oldest crown-group cnidarians<sup>39</sup>. As a result, the palaeobiological affinities of *T. avalonensis* are still uncertain.

Originally, *T. avalonensis* (triangular-shaped Ediacaran fossils) was found in the upper Drook Formation (about 140 specimens) at Pigeon Cove in association with *I. lobata* and *C. masoni*<sup>32,33</sup> and 65 specimens from the ‘E Surface’ of the upper Mistaken Point Formation at Mistaken Point, Watern Cove, and Laurentian Gulch with spindle-like, bush-shaped and frondose taxa like *Bradgatia*, *Charnia*, *Charniodiscus*, *Fractofusus*, *Fronodophyllas*, *Ivesia*, *Pectinifrons* and *Primocandelabrum* in the deep-sea deposits<sup>31,32,34,35,37,40–42</sup>. Later Retallack<sup>43,44</sup> provided terrestrial to marginal-marine depositional settings for the Ediacaran

fossil-bearing rocks of Newfoundland based on geochemical and sedimentological studies of volcanic tuffs and sedimentary rocks (palaeosol depositional models). They reported that the Gaskiers, Upper Drook, Upper Briscal and Mistaken Point Formations were deposited in the coastal plains and intertidal zones, in contrast to the Mall Bay, Lower Drook and Lower Briscal Formations of the Conception Group, which were traditionally explained by marine turbidite depositional models<sup>32,34,40,45–48</sup>. In this study, *T. avalonensis* fossils have been found in yellowish–pinkish-brown, medium- to fine-grained sandstone strata of the Sonia Sandstone, which also have various types of ripple marks with mostly remains of Ediacaran benthic organisms like *Aspidella*<sup>23,26</sup>, *Hiemalora stellaris*<sup>27</sup>, small to giant Ediacaran discs<sup>24,25</sup>, trilobozoans (*Tribrachidium* and *Alburnares*)<sup>49</sup> and algal mats<sup>22,25</sup>. The Sonia Formation consists of light brown, yellowish–pinkish-brown, and reddish-brown sandstone with intercalations of maroon shales and siltstones and is considered to have been formed in a deltaic and beach environment<sup>16,17</sup>. The overlying Girbhakar Formation is made of gritty and pebbly sandstone of fluvial origin<sup>17</sup>. The Sonia Formation also has thin, maroon-to-reddish-coloured shale and siltstone beds between *T. avalonensis* and other Ediacaran fossil-bearing sandstone strata, suggesting palaeosol depositional models for the Formation. Thus, this study implies that the terrestrial to marginal–marine depositional settings with moderate hydrodynamics for the Sonia Formation are the same as those in *T. avalonensis*-bearing localities of Newfoundland.

## Conclusion

The present study describes the triangular-shaped Ediacaran organisms assigned as *T. avalonensis* from the Sonia Sandstone of the Jodhpur Group, MSG, western India. This is the first discovery of the *T. avalonensis* organism in India. These fossil specimens have been found with lengths ranging from 25 to 90 mm and widths from 15 to 50 mm, which are comparable to the worldwide occurrences of *T. avalonensis*, i.e. 26–165 mm length range and 24–96 mm width range<sup>31</sup>.

This suggests the Sonia Formation was deposited in terrestrial to marginal–marine environments with moderate hydrodynamics.

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