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## Record of *Metagoniolithon* (Corallinales, Rhodophyta) from the Burdigalian of western India

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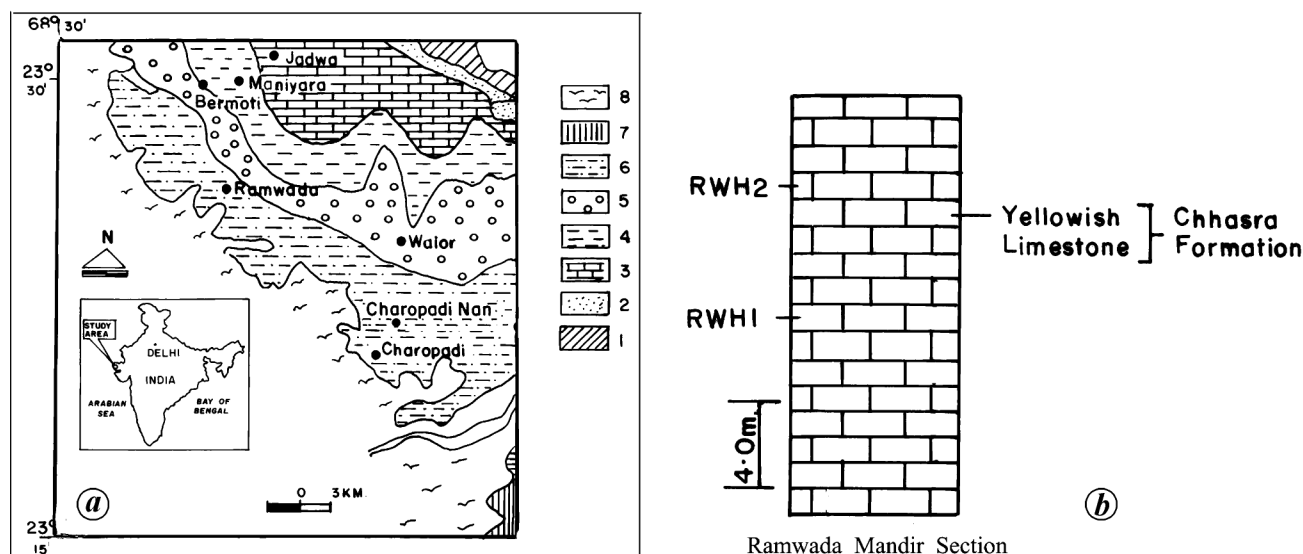
**Well-preserved *Metagoniolithon* (Corallinales, Rhodophyta) identified as *Metagoniolithon* sp. has been recovered in thin sections of limestone of the Burdigalian age, the Chhasra Formation, India. By its small size, *Metagoniolithon* sp. differs from *M. radiatum* (Lamareck) Ducker, a living species. *Metagoniolithon* sp. is associated with rich dasycladacean algae, and this points out that the species was thriving in shallow, warm, tropical environments. The present fossil discovery of *Metagoniolithon* sp. is significant, as prior to this, two species of *Metagoniolithon* were dubiously documented from the Oligocene and the Aquitanian of Cuba. The present finding of the fossil representative of *Metagoniolithon* has enabled us to extend the stratigraphic range of this genus to the Burdigalian.**

**Keywords:** Burdigalian, fossil coralline algae, Rhodophyta, palaeoenvironment, western India.

CORALLINES are strongly calcified red algae of the order Corallinales, division Rhodophyta<sup>1</sup> and are important components of shallow water sedimentary sequences throughout the Cenozoic<sup>2</sup>. Corallines are dominant carbonate sediment producers and major reef builders<sup>3,4</sup>. The Corallinales is a monophyletic group comprising three families (Sporolithaceae, Corallinaceae and Hapalidiaceae) with living species and one family (Graticulaceae) with fossil species<sup>5</sup>. The Corallinales is architecturally subdivided into two groups, the geniculate and nongeniculate forms<sup>6</sup>. The thallus of the geniculate corallines is composed of the intergenicula alternating with the genicula, while the thallus of the nongeniculate corallines lacks the intergenicula and the genicula<sup>7</sup>. There are seven geniculate coralline genera, namely *Amphiroa*, *Arthrocardia*, *Calliarthron*, *Jania*, *Metagoniolithon* and *Subterraneanophyllum* reported from fossil records<sup>8</sup>. However, out of these seven genera, fossil records of six genera are explicit and the record of *Metagoniolithon*, subfamily Metagoniolithoideae as a fossil is dubious.

Hitherto, the only provisional and tentative fossil record of *Metagoniolithon* as *Metagoniolithon* (?) *gaschei* and *Metagoniolithon* (?) sp. indet. A exists from the Oligocene and the Aquitanian of Pinar del Rio and Oriente Provinces, Cuba<sup>9</sup>. Prior to that, some fossil species described under *Jania* from the Miocene of the Western Pacific were thought to resemble *Metagoniolithon*<sup>10</sup>. Without proper

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**Figure 1.** *a*, Location and geological map around Ramwada, Kachchh, Gujarat, India<sup>15</sup>. 1, Naredi Formation (Upper Palaeocene to Lower Eocene/Upper Thanetian to Ypresian); 2, Harudi Formation (Middle Eocene/Middle Lutetian); 3, Fulra Limestone Formation (Late Middle Eocene/Upper Lutetian to Lower Bartonian); 4, Maniyara Fort Formation (Oligocene/Upper Rupelian to Chattian); 5, Khari Nadi Formation (Early Lower Miocene/Aquitainian); 6, Chhasra Formation (Late Lower Miocene/Burdigalian); 7, Sandhan Formation (Pliocene/Serravallian-Messinian) and 8, Recent. *b*, Lithosection at Ramwada Mandir Section showing sample locations of yellowish limestone of the Chhasra Formation which yielded *Metagoniolithon* sp.

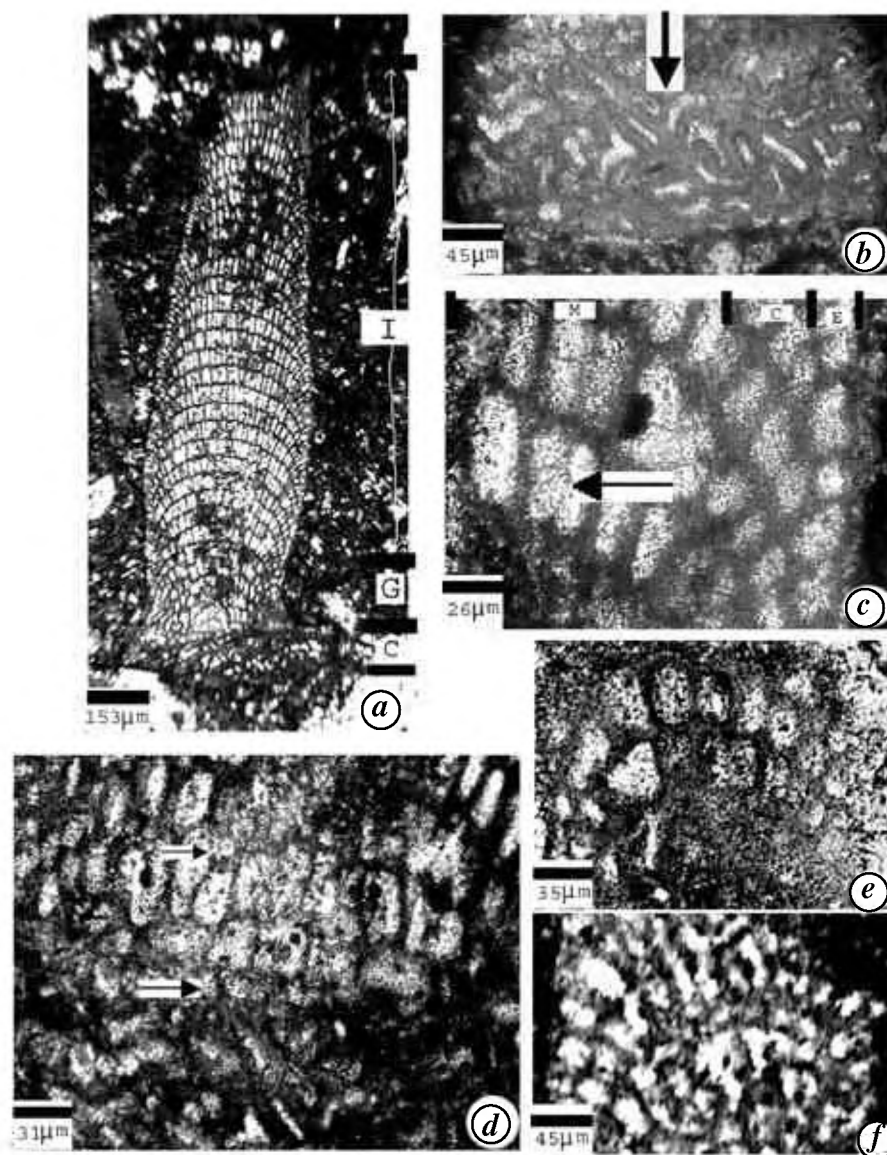
database<sup>9,10</sup>, *Metagoniolithon* was considered to range from the Upper Paleocene to the Recent<sup>11–14</sup>.

Here, we record well-preserved fossils of *Metagoniolithon* showing the basal crust followed by a perpendicular geniculum and intergeniculum from the Late Lower Miocene (Burdigalian), the Chhasra Formation outcropping at Ramwada Mandir in Kachchh district, Gujarat, India (Figure 1*a*)<sup>15</sup>. The Kachchh sedimentary basin is a storehouse of calcareous algae as nearly 87 species belonging to Coralline, Dasycladaceans, Halimeda and Udoteaceans algae have been reported<sup>16–28</sup>. The Ramwada Mandir Section (Figure 1*b*) exposes a 20 m thick yellowish limestone succession belonging to the Chhasra Formation. Thin sections of limestone sample numbers RWH1 and RWH2 contain the specimens of *Metagoniolithon*.

The thallus is composed of the crust, geniculum and intergeniculum (Figure 2*a*). The crust is at the base, prostrate, 125  $\mu\text{m}$  in height and consisting of pseudoparenchymatous coherent filaments (Figure 2*a, b, d*). The cells in the coherent filaments appear to be highly irregular and polygonal, measuring 10–15  $\mu\text{m}$  in size. From this crust a short primary geniculum (Figure 2*a* and *d*) arises. The geniculum is 210  $\mu\text{m}$  in height and 345–420  $\mu\text{m}$  in width. The cells in the geniculum (Figure 2*a, e, f*) are not aligned in tiers and this arrangement of cells corroborates the genicular anatomy of *Metagoniolithon*<sup>29</sup>. The geniculum is made up of the medulla, transition zone from medulla to cortex and the epithallium. Cells of the transition zone of the geniculum measure 35–40  $\mu\text{m}$  in height and 15–20  $\mu\text{m}$  in width, cortical cells measure 12–15  $\mu\text{m}$  in height and 8–10  $\mu\text{m}$  in width while the epithallial cells measure 10–

15  $\mu\text{m}$  in height and 8  $\mu\text{m}$  in width and are in a single row (Figure 2*c*). In the medullary cells of the geniculum, cell fusion (Figure 2*c*) is prominent. The geniculum is followed by the longer, tapering intergeniculum (Figure 2*a* and *c*) having a height of about 1275  $\mu\text{m}$  and varying width of 270–460  $\mu\text{m}$ . The intergeniculum is composed of the medulla, cortex and epithallium (Figure 2*a* and *c*). The medullary cells of the intergeniculum are subrectangular in shape and in regular tiers with a height of 45–55  $\mu\text{m}$  and width of 12–18  $\mu\text{m}$  and show cell fusion (Figure 2*c*). Cortical cells of the intergeniculum are 9–25  $\mu\text{m}$  in height and 12–15  $\mu\text{m}$  in width. Cell fusion is present in the cortical cells which are subrectangular, smaller than medullary cells and radiate towards the margins. The single row of epithallial cells of the intergeniculum (Figure 2*a* and *c*) is 15–25  $\mu\text{m}$  in height and 6–9  $\mu\text{m}$  in width. Conceptacles are absent. Ducker<sup>29</sup> described the genicula and intergenicula of living *M. radiatum* (Lamarck) with the help of text figures. He mentioned that the cells of the medulla of the geniculum are not aligned in distinct rows and there is no apparent regularity in their arrangement. The fossil *Metagoniolithon* sp. represented by three specimens exhibits similar genicular and intergenicular anatomy as shown by living material of *M. radiatum* (Lamarck). Here, we reproduce text figures (Figures 3*a* and *b*) of *M. radiatum* (Lamarck) Ducker<sup>29</sup>. Formal name to the *Metagoniolithon* sp. is not assigned, as the number of fossil specimens is only three.

As mentioned earlier, *Metagoniolithon* was arbitrarily considered to range from Upper Palaeocene to Recent<sup>11–14</sup>. However, the explicit occurrence *Metagoniolithon* sp. in



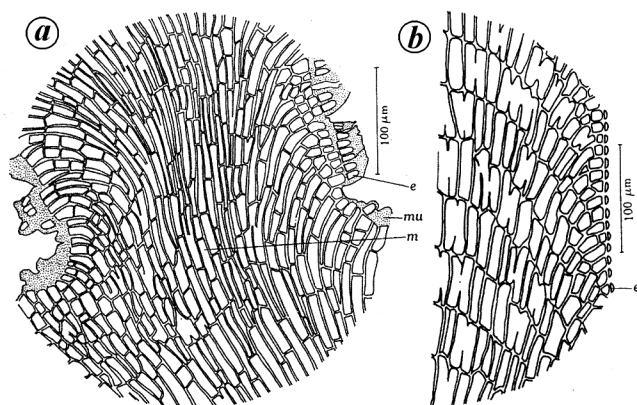
**Figure 2.** *Metagoniolithon* sp. **a**, Thallus showing prostrate crust (C), perpendicular geniculum (G) and intergeniculum (I) (specimen no. PGTDG/MF/SCA/325). **b-d**, Same specimen under high magnification showing prostrate crust exhibiting pseudoparenchymatous coherent filaments with polygonal cells (arrow) (**b**), intergeniculum, medulla (M), cortex (C) and single row of epithallium (E), arrow shows cell fusion (**c**) and geniculum (**d**). Upper arrow shows fusion between two adjacent cells and lower arrow contact between prostrate crust and geniculum. **e, f**, Geniculum showing transition zone from medulla to cortex with rectangular to subrectangular cells (specimen no. PGTDG/MF/SCA/326) (**e**) and subrectangular cells (specimen no. PGTDG/MF/SCA/405) (**f**).

the Burdigalian of the Chhasra Formation, Kachchh, India indicates that *Metagoniolithon* appeared in the Burdigalian and therefore its generic range should be from the Burdigalian to the Recent.

We scrutinized the description and illustrations of the two provisionally described species of *Metagoniolithon* as *Metagoniolithon* (?) *gaschei* and *Metagoniolithon* (?) sp. indet. A recorded respectively, from the Oligocene and the Aquitanian of Pinar del Rio and Oriente Provinces, Cuba<sup>9</sup>. We suggest that these species of *Metagoniolithon* do not belong to *Metagoniolithon* as they do not possess

the basal crust, regular arrangement of tiers in medulla and epithallial cells. They look like the intergenicula of the another geniculate taxon, *Jania* and *Metagoniolithon* (?) *gaschei* and *Metagoniolithon* (?) sp. indet. A were compared with *Jania*<sup>9</sup>.

The *Metagoniolithon* sp. is associated with rich dasycladacean algal assemblage. Based on dasycladacean algal assemblage, Kundal and Humane<sup>25</sup> inferred that the limestone of the Chhasra Formation was deposited in shallow marine tropical waters at a depth of about 10–12 m below low tide level. The cyclic carbonate depositional patterns



**Figure 3.** *Metagoniolithon radiatum* (Lamarck) Ducker (after Ducker<sup>29</sup>). **a**, Details of geniculum showing cell fusion in medulla (m), transition zone from medulla to cortex and epithallial cells (e) in the mucilage layer (mu). **b**, Details of intergeniculum showing cell fusion and epithallial cells (e).

of the Tertiary carbonate sequence of Kachchh during Lower Miocene are suggestive of subtidal environmental conditions<sup>30</sup>. Thus sedimentological evidences support the shallow, warm, tropical environmental conditions inferred based on algal assemblages.

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