Microbial cements in Holocene beachrocks of South Andaman Islands, Bay of Bengal

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Holocene beachrocks from the South Andaman Islands exhibit early cementation, which was greatly influenced by microbial activity. Our studies suggest that microbes (fungi and bacteria) play an important and active role in carbonate beachrock cementation. The microbial cement occurs as needle-fibre growth, fungal filaments and relating borings and calcispheres; however the needle-fibre cement is most abundant. The needle-fibre cement forms dense patchy meshwork on the allochems and occurs either as single or paired microrods. At places, the needles also show rhombic overgrowths. The morphological variations of the microbial cement in the beachrock highlight the immense scope for studies in this less-understood branch of geology – carbonate geomicrobiology.

PRECIPITATION of carbonate cement in beach sediments may be inorganic or biologically mediated[1,2]. The inorganic route predominates most beachrock cementation histories, with aragonite being the initial cement that alters subsequently to either high Mg or low Mg calcite through diagenetic alteration in the meteoric environment[3]. Early studies by Krumbein[4] demonstrated that beach environments are microbiologically active, but the products of such microbial activity, especially in carbonate environments, are not well known. Here we report cement of microbial origin from the Holocene beachrocks of the South Andaman Islands. Such instances of microbial cementation have not yet been reported from beachrocks that form under a monsoonal climate.

We studied beachrocks[5] from two locations – Wandoor and Chidyatapu (Figure 1) from the southern fringe of the Andaman archipelago. In the present context, 'beachrock' refers to those indurated sediments that form in a beach environment. Mean annual precipitation in these localities is between 1000 and 1200 mm that is rainfall received both during the summer and the winter monsoons. The beachrocks occur both within and above the modern inter-tidal zone (Figure 2 *a*). The exposures range in thickness from 0.5 to ~ 1 m. Further details are reported in Rajshekhar and Reddy[5]. Whole-rock radiocarbon ages on the two beachrocks suggest that the Chidyatapu beachrock is older (3760 ± 150 ^{14}C yr BP; 4410 to 3900 cal yr BP) than the Wandoor beachrock (1580 ± 80 ^{14}C yr BP; 1540 to 1350 cal yr BP)[5].

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Allochems in both beachrocks consist of foraminifera, coralline algae, corals, pteropods and molluscan shell debris (Figure 2 *b* and *c*). The younger Wandoor beachrock is coarse-grained and the framework is supported with minor inter-granular cementation. In contrast, the older Chidyatapu beachrock is finer-grained, but contains repeated upward fining cycles at the mesoscale. Petrographically, in the Chidyatapu beachrock a complex cementation history is observed (Figure 2 *d*). The earliest cements occur as micritic envelopes, which are in many instances coated by a stage of isopachous bladed cement. As this cement is bladed in morphology, it could be a high-Mg calcite. The final stage of cementation is represented by void-filling, blocky, equant calcite spar (Figure 2 *d*). Cements suggestive of microbial activity were not readily observed under the microscope. Hence, six gold-coated samples (three each from Wandoor and Chidyatapu) were studied using a Cambridge S120 Scanning Electron Microscope.

The needle-fibre cement is more abundant in the younger Wandoor beachrock. The needles vary in length from ~ 50 to 10 μm. These needles are very thin (1 μm), rarely exceeding 3 μm in diameter. The larger diameters are due to overgrowths. In the Wandoor samples, the needles drape allochems as patches and form an intricate meshwork (Figure 3 *a* and *b*) that can be best described as chaotic. The needles are accompanied by crystal forms that are irregular (Figure 3 *c*). In the Chidyatapu beachrock samples, the needle-fibre cement is overlain by isopachous calcite cement. Morphologically, the needles occur as both solitary and paired (Figure 3 *b*). Some needles show significant overgrowth of calcite, which often take the form of rhomb chains (Figure 3 *d*).

The morphology of the needles does not match with that of aragonite. The latter are commonly 10 μm in diameter and 100 to 50 μm in length[3]. Also aragonitic needles do not have cylindrical, smooth surfaces and more commonly show distinct acicular pyramidal shapes[1]. High Mg-calcite is also not known to depict such morphologies when formed organically. On the other hand, the association of needle cement with microbial activity is well known. The morphology and origin of needle-fibre cement has recently been reviewed by Verrecchia and Verrecchia, and Jones and Kahle[7]. According to their classification[6], these needles are similar to MA monocrystalline rods. Such needle-fibre cements are believed to originate from fungal biomineralization[6]. Initially enclosed in fungal sheaths, the needles burst out of the sheath and are rearranged as chaotic masses on the surface of allochems. Needle-fibre cement has been reported from Belize[1] too, where it forms a cement in cayrocks but does not occur in the beachrock. Such cements are relatively less common in beachrocks around the world, but appear to be more frequent in calcretes, aeolianites and palaeosols[6,7].

Apart from needle-fibre cement, the other unusual forms in the beachrocks are fungal filaments[8]. These filaments

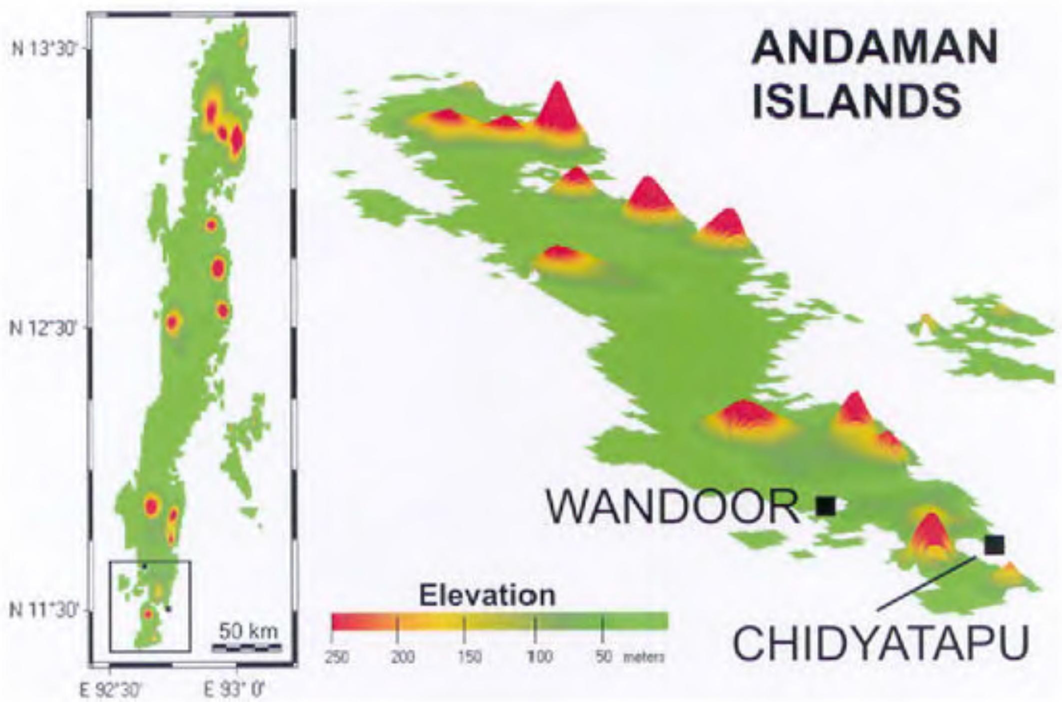

Figure 1. Location map of the Andaman Islands showing the two sites, i.e. Wandoor and Chidyatapu from where samples of beachrocks were collected. The map and perspective view is based on a digital elevation model with coarse resolution (1 km). The 3D perspective is with vertical exaggeration.

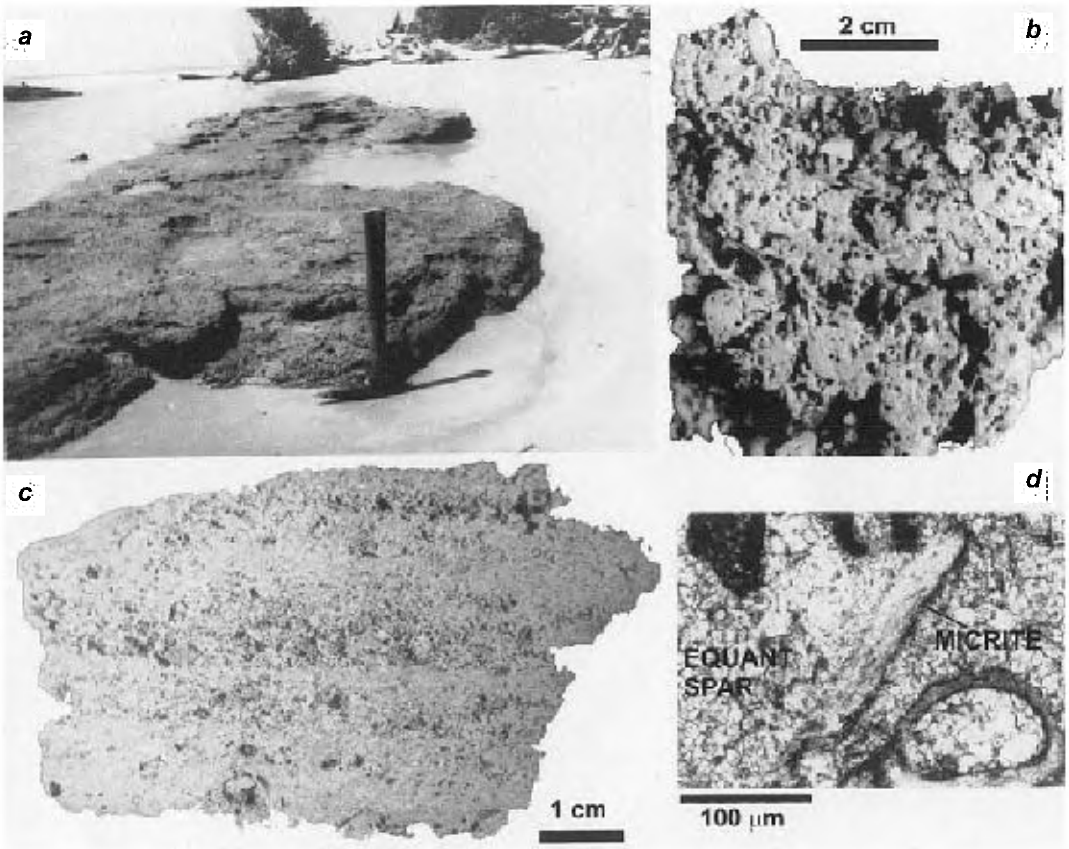

Figure 2. (***a***) Beachrock at Wandoor occurs within the modern inter-tidal zone and is coarse grained (***b***) when compared to the Chidyatapu beachrock (***c***). The Chidyatapu beachrock has a complex cementation history beginning with micritic envelopes and ending with pore-filling blocky spar (***d***).

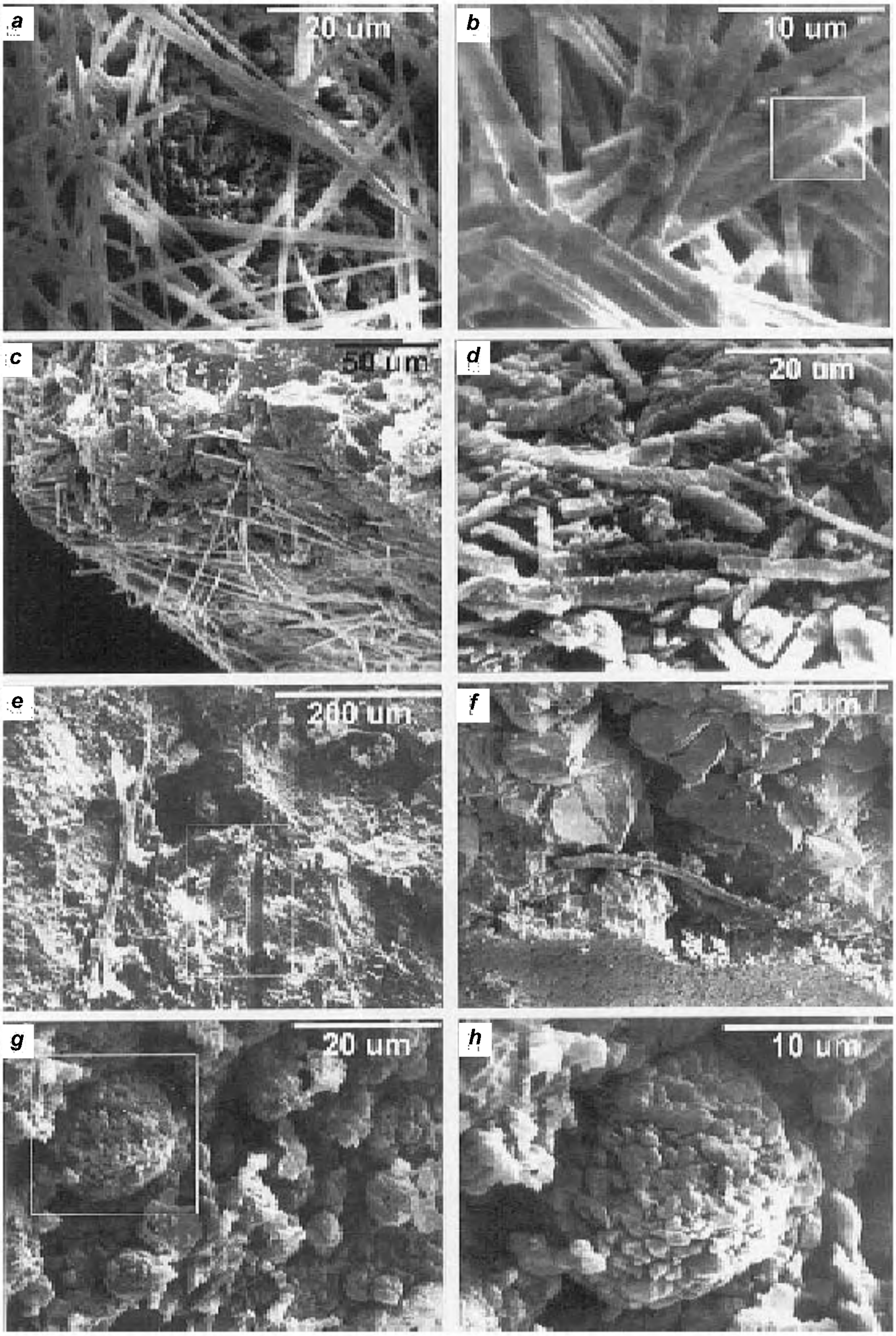

Figure 3. Various morphologies of microbial cement found in the beachrocks of South Andaman Islands. ***a*** and ***b***, Disposition of needle cement on the allochems of the beachrock. Needles occur both as solitary as well as paired microrods (rectangle marked in ***b***). Needles occur chaotically or in random dense patches (as seen in ***c***). Some needles show a large degree of overgrowth, which leads to the formation of rhomb chains or irregular morphologies ***d***. Apart from needle cements, microbial activity is manifested as fungal filaments also ***e***, ***f*** that bore through the rock (marked by rectangle in ***e***) and calcified spheres (framboidal) which occur in clusters, the latter being relatively rare ***g***, ***h***. ***h***, Enlarged view of ***g***.

occur both close to the allochem and along with borings (Figure 3 *e* and *f*), and may either be calcified or non-calcified. The filaments are usually ~ 100 μm in length and are curved. The surface of such filaments is irregular and they have small crystals adhering to their surfaces. The filaments are associated with needle-fibre cement, supporting their fungal origin. The third and somewhat rare form of microbial cement is calcisphere that is sub-rounded in shape (Figure 3 *g* and 3 *h*). The spheres occur in clusters and consist of smaller crystals that are sub-rounded to irregular, leading to a framboidal structure. The origin of calcispheres of the form observed in the present study is not clear. Calcispheres have often been interpreted to be either of bacterial origin[9] or fruiting bodies associated with fungi[10]. We interpret these calcispheres of microbial origin with the possibility of their being related to either fungal or bacterial biomineralization.

The role of prokaryotic and eukaryotic microbes in mediating mineral precipitation is being increasingly appreciated as significant[11–13]. Although they usually have a subsidiary role (volume-wise) in mineral precipitation relative to inorganic processes, some exceptions occur, as in the case of calcretes from Israel[14] and certain dolomites[15] in which the dominant role of microbes has been demonstrated. Biomineralization may either be controlled by microbes (in which the crystals form within the organic structure)[11] or be mediated or induced by microbes. In the latter case, the precipitation of calcium carbonate takes place through a variety of processes that ultimately lead to an increase in the HCO_3^- concentration in the extracellular region[13]. Of the two processes, the formation of needle-fibre cement belongs to the 'microbially-controlled' category. Apart from these categories, the fungal filaments and other microbes may provide sites for carbonate precipitation and may themselves be calcified. Our initial results suggest that, in the Andaman Holocene beachrock microbial activity was primarily responsible for the early cementation of the beach sediment. This cement could be either calcium carbonate or calcium oxalate in composition[6,14]. The diversity in the morphology of the beach microbial cements highlights the immense scope for such studies in this less understood branch of geology – carbonate geomicrobiology[16].

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Suitability of coastal magnetite for ferrite preparation

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Density, magnetic, surface roughness and SEM studies on synthesized pellets of two size grades of magnetite from three beach placer deposits of the East Coast of India were carried out using standard ceramic techniques, to explore its suitability as raw material for fabrication and characterization of ferrite. Results of this preliminary study are presented here.

AS a result of liberalization and globalization, the inflow of private investments, especially in iron, steel, electronic and ferrite industries, has increased, and some of the major user industries have gone in for expansion of their capacities to meet the increasing demand for their products. The increase in production in these sectors demands an enhanced supply of basic raw materials like Fe, Mn and Zn oxides of various specifications. Among these, FeO is the major constituent, which is consumed almost 80% by weight, in all the ferrite products.

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