# Pelagic Manganese Nodules—A New Type of Oncolites

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**Abstract**

Pelagic manganese nodules from the East Pacific Ocean have been studied using polarizing, scanning electron and transmission electron microscopes. It has been revealed that the manganese nodules are composed of cores and stromatolite coatings. The structures and textures of these nodules are peculiar to oncolite. Consequently, the pelagic manganese nodules are manganese oncolites. Based on the stromatolites in the coatings, the manganese oncolites from the East Pacific Ocean can be divided into two types. One is smooth on surface and dense inside. Its coatings are composed mainly of *Minima*. The other has a knobby surface and is loose internally. Its coatings consist mainly of *Admirabilis*. The TEM investigation has also revealed that the constructors of the manganese oncolites are ultra–microbes. The *Minima* is constructed by *Miniactinomyces chinensis* sp. nov. and the *Admirabilis* is built by *Spirisosphaerospora pacifica* sp. nov.

**Key words:** pelagic manganese nodule, oncolite, stromatolite, ultra–microfossil

Since submarine manganese nodules were discovered during the H. M. S. Challenger Expedition in 1873, some scientists have recognized that microbes play a great role in the formation of these nodules. But only Monty (1973) and other few scientists regard them as stromatolites. Based on systematic observations and analyses of pelagic manganese nodules from the East Pacific Ocean that the authors conducted by polarizing, scanning electron and transmission electron microscopes, it has been revealed that these manganese nodules are not only stromatolites, but also oncolites. In addition, chain–like and spiral ultra–microfossils have been discovered as a result of TEM study (Zhang, Lin et al., 1995; Zhang, Bian et al., 1995). The discovered oncolites are generally calcareous, phosphorous or ferruginous ones, while manganese oncolites have not been reported so far.

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## 1 General Concept of Oncolite

Oncolites consist of cores (nuclei) and coatings. Coatings are roughly concentric, which present a historic record of biotic formation and can be an indicator of biostratigraphy. Peryt (1983) classified all the coated grains into chemical precipitates and biogenetically encrusted ones on the basis of their genesis. The chemical precipitates comprise oolites originating in shallow–water environment and vadolites in vadose environment. Rhodolites and oncolites are common among biogenetically encrusted grains. In brief, oncolites are coated grains that bear close genetic relation to activities of bacteria or algae.

The core of a nodule may be made up of rock fragments, bioskeletons or original fragmental manganese nodules, etc. Its features reflect only the environment and conditions of formation before the coatings grew. The coatings consist of stromatolites. When we call the manganese nodule simply stromatolite, we note only the features of its coatings and the core is not involved. This is not an exact designation since it does not describe the nature of manganese nodules comprehensively. These two terms, stromatolite and oncolite, are either related to or different from each other. Either of them is a microbial rock related to activities of bacteria or algae. Generally speaking, the stromatolite is a sessile form while the oncolite is not. Some microstromatolites may be a component of oncolites, but common stromatolites are not oncolites. To ascribe the pelagic manganese nodules from the East Pacific Ocean to oncolites or directly call them manganese oncolites will all–sidedly and properly reflect their genesis and features.

**Table 1 The classification of non–skeletal oncolites**

| Class | Name | Component of coatings |
|---|---|---|
| Non–skeletal oncolite | Columoids | Columnar microstromatolites |
| | Strigatoids | Stratiform microstromatolites |
| | Colu–strigatoids | Columnar–stratiform microstromatolites |

Oncolites are usually divided into skeletal and non–skeletal ones. Presently, most of the researchers consider the oncolites consisting of cryptalgalaminites as non–skeletal oncolites. The manganese oncolites studied in this paper are classified as this kind of oncolites, whose coatings are made up of various microstromatolites. Non–skeletal oncolites, in turn, can be subdivided into columoids, strigatoids and colu–strigatoids based on the classification of stromatolites (Bian and Huang, 1988) (Table 1).

## 2 Structural Characteristics of Manganese Oncolites

The specimens of the studied manganese oncolites were collected on the sea floor of silicious argillaceous sediments in the East Pacific Ocean. The collecting areas are located at latitudes 8–13° N and longitudes 141–14 4° W and 151–155° W. The depth is 5000 m. These specimens are mainly black and spherical or ellipsoidal with different sizes, 13 mm–115 mm in diameter. Morphologically these manganese oncolites can be divided into two types. One is smooth on surface and dense inside (Photos I–1 and I–2). The other is knobby on surface and loose internally (Photos I–3 and I–4). The individual weight of the gross volume (including cavities and fissures) is about $2g / cm^3$ and evidently smaller than the specific gravities of manganese minerals. It can be seen on polished cross–sections through their centres that the manganese oncolites are all composed of cores and coatings.

## 2.1 Core

The morphology and size of the core in the pelagic manganese oncolite are quite irregular. Some are round with diameters of 2–3 mm and others are semi–angular with cross–section of 7 × 32 mm. As reported in literatures, the core contains various components, including even such biological skeletons as shark' s teeth and some remains of human activities, such as knives and shell fragments. Stromatolites can grow on any solid fragments and are independent of the composition of cores. The cores of the studied manganese oncolites from the East Pacific Ocean are mainly fragments of volcanic rocks or manganese oncolites. The cores of rock fragments are commonly seen in the smooth and dense manganese oncolites (Photo I–2). The cores of knobby oncolites are all fragments of original manganese oncolites (Photo I–4).

The shape and size of the core controls the development of the coatings to some extent. Larger cores are stable, and in this case the coatings usually develop upwards (Photo I–2), whereas smaller cores lead to omnidirectional development of coatings, indicating a jumping and semi–suspended state. When the core is large and the coatings are thin, the shape of the oncolite almost shows the core' s form. If the coatings are thick, the oncolite tends to be spherical or ellipsoidal in shape. The ultimate shape of the manganese oncolites depends on the development features of its coatings.

There are possibly several cores in one oncolite. It can be seen in Photo I–2 that a micro–oncolite with a core of rock fragments is enclosed in the hollow in the middle part of a big manganese oncolite. The small core of the micro–oncolite is about 2 mm and its coatings are less than 1 mm in thickness. This phenomenon indicates that the micro–oncolite was semi–suspended above the sea floor before it was " trapped". The core of the manganese oncolite in Photo I–4 is a fragment of the originally formed oncolite. New coatings grew on the basis of the original core' s coatings.

## 2.2 Coatings

All coatings of the manganese oncolites from the East Pacific Ocean are composed of micro–stromatolites, which built the framework of the manganese oncolite. Cavities were formed between the stromatolite columns or the stromatolites. Consequently, the pelagic manganese oncolites can be regarded as a microbiolite build–up.

The coatings of the manganese oncolites are usually constructed of several coating strata as in other oncolites. The coating strata reflect the intervals and stages of the formation process of the oncolites. These strata are obviously separated by continuous trap interfaces, which can be determined based on the following situations. (1) Intervals in the process of stromatolite growth, which are entirely covered by clastic sediments (Photo I–2). (2) Extensions of radial fractures. (3) Angular unconformities appeared when the way of stromatolite growth changed, e.g. an upward growth of stromatolites attached to a base was turned into a semi–suspended growth or vice versa (Photo I–4). (4) Main cycles of stromatolite development. Columnar stromatolites can be gradually turned into stratiform ones and some time later new columnar stromatolites started developing and changed to stratiform ones again. If clear interfaces are formed as a result of this change, they can be used as a basis for separating the coating strata. Micro–stromatolites are the basic component of the coatings of manganese oncolites. These micro–stromatolites were also found in Ordovician ferric oncolites in China (Huang and Zhu, 1987). They can be morphologically divided into *Minima* and *Admirabilis*. According to the nomenclature rule (Bian and Huang, 1988) the manganese oncolites from the East Pacific Ocean can be called columoids (*Minima*) and columoids (*Admirabilis*).

**Columoids (*Minima*)** The core of the columoids (*Minima*) is usually a rock fragment. The first coating stratum begins growing around the core and keeps the form of the core. Then a concentric spheroid or ellipsoid will be gradually formed with smooth surface and dense interior. The interfaces are mainly determined based on situations (1) and (2). Outwards from the inside, the column branching style changes from *Jurusania* via *Kussiella* to *Inzeria* and finally back to *Jurusania* (Fig.1). This cyclic change is probably related to the periodic change of the micro–environment. It is worth noticing that this transformation of the column branching styles is frequently observed in the Middle and Late Proterozoic stromatolite reefs (Qian, 1991). It can also fully explain that " stromatolithic" and "sub–stromatolithic" structures are the typical structural forms of various stromatolites.

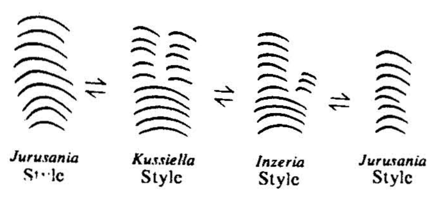

Fig. 1. The variation of branching styles in the pelagic manganese stromatolites.

Columns of *Minima* have a cylindrical form, 0.1–0.25 mm wide and over 2 mm long. They are laterally linked with bridges. No walls but cornices can be found on columns' margins (Photos I–5 and I–6). These features are conformable with the characteristics of *Minima* (Zhang, 1982).

**Columoids (*Admirabilis*)** The core of the columoids (*Admirabilis*) is usually a fragment of the original manganese stromatolite. The coatings are nodular on the surface and loose internally. Development of the coating strata usually started from columnar stromatolites and ended with stratiform ones. Therefore, stratiform stromatolites can be regarded as the boundary between two coating strata. Columnar stromatolites are nodular cylindrical or tuberose in shape. The length is up to 1.5 mm. They show *Anabaria* branching style with irregular short and thick buds. The parent columns are 0.5 mm wide and the daughter columns are only 0.15 mm wide (Photo II –1). The laminae in the columns exhibit a wavy arcuate form, thicker in the middle and thinner on both sides. These features are conformable with the characteristics of *Admirabilis* (Bian and Huang, 1988).

The coating strata of columoids (*Admirabilis*) can be determined mainly based on the above–mentioned situations (3) and (4). The stromatolites in the outmost coating stratum are usually assembled to form nodules with cavities in between. Filamentous algae and fungi live in these cavities. Argillaceous sediments and skeletons of diatoms, silicoflagellates and radiolaria are found there as well.

## 3 Constructors of the Columnar Stromatolites—Ultra–microbes

The electron photomicrographs have revealed that *Minima* is constructed by a large number of chain–like microbes (Zhang et al., 1995b) (Photos II –2 and II –3). The diameter of the chain–like hyphae is about 2–6 nm. These hyphae are branched and interwoven with each other. Moniliform spores, 3 nm across, are developed on the hyphae of reproduction. Sporangia can be also found within the net of intertwined hyphae of reproduction and their diameters are about 70 nm (Photo II –2).

The TEM observation shows that *Admirabilis* is constructed by many spiral ultra–microbes (Zhang et al., 1995a) (Photos II –4, II –5 and II –6). The colonies of these microbes are disk–like and the hyphae are arranged radially around the centre. As a result of successive growth and branching of the nutritive hyphae, substrata are formed. Spiral branched reproductive hyphae stretch out of the substrata. The screws formed by the spiral reproductive hyphae are 36–200 nm long and 3–25 nm wide. Spherical sporangia is developed among the mycelia and spherical spores are dispersed in the sporangia (Photo II –6).

The EDS analysis indicates that these ultra–microfossils have been mineralized by ferromanganese substances. The chain–like and spiral ultra–microfossils are very similar to actinomycetes in their morphology, structures and colony features and distinguished from actinomycetes and all other known microbes on a nanometre scale. This has never been reported both in China or abroad. The authors named the chain–like ultra–microfossils *Miniactinomyces chinensis* sp. nov.(Photo II –2 and II –3) and the spiral ultra–microfossils *Spirisosphaerospora pacifica* sp. nov.(3) (Photo II –4, II –5 and II –6).

## 4 Conclusions

(1) The pelagic manganese nodules from the East Pacific Ocean have the structures of oncolites. They can be classified and named according to the types of stromatolites in oncolites. Ascribing these pelagic manganese nodules to oncolites and naming them manganese oncolites will represent their genesis and features all–sidedly and exactly. (2) The manganese oncolites from the East Pacific Ocean can be divided into two types. One is smooth on surface and dense inside. Its coatings are composed of stromatolite *Minima*. The other is knobby on surface and loose internally. Their coatings consist of stromatolite *Admirabilis*. (3) The TEM investigation has revealed that the constructors of the manganese stromatolites are ultra–microbes, among which *Minima* is constructed by *Miniactinomyces chinensis* sp.nov and *Admirabilis* is built by *Spirisosphaerospora pacifica* sp. nov.

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## Explanation of Plates

### Plate I

1. The smooth pelagic manganese oncolite. Station 2401. ×0.6.
2. Polished section of the smooth pelagic manganese oncolite. Station 613. ×1.
3. The knobby pelagic manganese oncolite. Station 594. ×0.75.
4. Polished section of the knobby pelagic manganese oncolite. Station 594. ×1.
5. Polished section of the *Minima* in the manganese oncolite. Station 2341. ×100.
6. Polished section of the *Minima* in the manganese oncolite. Station 2341. ×100.

### Plate II

1. Polished section of *Admirabilis* in the manganese oncolite. Station 594. ×100.
2. Electron micrograph of *Miniactinomyces chinensis* sp. nov., showing spherical sporangia. Station 2401. ×200 000.
3. Electron micrograph of *Miniactinomyces chinensis* sp. nov., showing chain–like reproductive hyphae. Station 2401. ×100000.
4. Electron micrograph of *Spirisosphaerospora pacifica* sp. nov., showing branched spiral reproductive hyphae. Station 127. ×200000.
5. Electron micrograph of *Spirisosphaerospora pacifica* sp. nov., showing spiral reproductive hyphae. Station 594. ×150000.
6. Electron micrograph of *Spirisosphaerospora pacifica* sp. nov., showing spherical sporangia. Station 594. ×150000.

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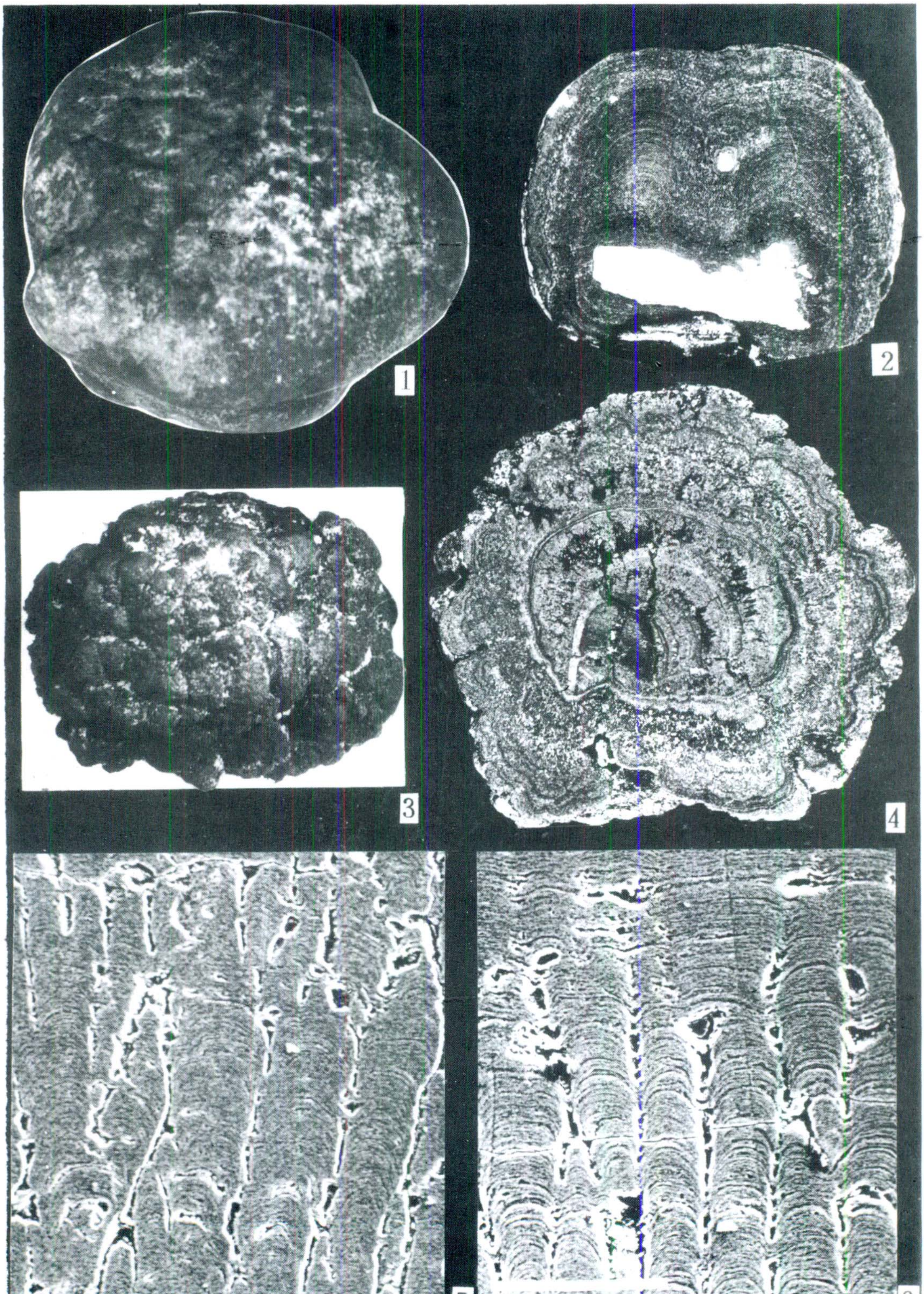
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