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The sedimentary features of Proterozoic microspar (Molar-tooth) carbonates in China and their significance

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On the North China platform Molar-tooth (MT) carbonates were formed during 1600-650Ma (i.e. the Middle to Late Proterozoic), within various supercyclic sequences, such as the Changcheng, Jixian, Qingbaikou and Sinian Systems. Detailed field observations on the MT carbonate sections and microscopic studies show that MT carbonates may be divided into two major groups—autochthonous and allochthonous and 6 sub-groups according to their depositional features. The autochthonous MT may be subdivided into four types, i.e. filamentous MT, curved banded MT, complicated sheet-like MT and dotted-tumorous MT, while the allochthonous MT may be subdivided into two types, i.e. mimicry-intraclastic MT and intraclastic MT. Based on sequence statistics and analysis of megascopic microfabrics, a sedimentary model of MT carbonates is proposed. MT structures occur within a range of facies from the subtidal to the basin margin zone. Various megascopic microfabrics may serve as useful environmental markers. MT structures might be a link to the revolutionary changes in the biosphere, which heralded the appearance of complex multi-cellular metazoan in the Late Precambrian. It is proposed that MT carbonates occupied the interval between Archean Times without life (but with an interval of inorganic aragonite, and tuff precipitation) and the Phanerozoic with skeletal carbonate precipitation. After a detailed discussion on many hypotheses for the origin of MT, and five evidences against their seismic origin it was concluded that the structures of MT carbonates are various and distributed so randomly that they may be related to the geological complexity. But the components of microsparite show MT's common characteristics, so the key to solve the origin of MT carbonates lies in the research on the origin of the microsparite. Hence, the most important factor for the origin of MT may be

traced from the biological and geological evolutionary events of the Pre-Cambrian ocean. Most likely the formation of MT structure and microspar carbonates were terminated due to the obvious changes of particular organism and geochemistry in the paleo-oceanic environment of the Proterozoic in Phanerozoic era. A comprehensive study of MT carbonates will greatly enhance our understanding of the history of Proterozoic marine carbonate deposition as well as the history of early organic evolution. This forms the main objective of IGCP project 447.

Introduction

There is abundant evidence for the study of organic evolution in Precambrian sedimentary records, which help to interpret the early evolution of life. It is suggested that the existence of Molar-tooth (MT) structure was related to this.

Molar-tooth structures are contortedly folded and microspar-filled cracks in fine-grained carbonates of Precambrian age. The term was first used in the geological literature by Bauerman (1885) for structures "resembling the markings on the molar tooth of an elephant" in carbonates of the Belt Supergroup near the Canada-USA border in Western Montana. The structure consists chiefly of vertical, contortedly-folded sheets of finely crystalline calcite-spar in dolomitic lime mudstone (Smith 1968; O'Connor 1972; Furniss et al. 1997), but the present authors think that the structure also includes some microspar sheets and dotted line parallel to the bedding.

MT structures have been found in more than 40 countries and regions, including Canada, U.S.A, Europe, Australia, Africa, Siberia and China (in Tonghua-Hunjiang, Liaodong and Xu-Huai regions, and the Yanshan Mountains). Since MT carbonates were formed in the distant Precambrian and are rare in younger deposits, their origin has been debated for over a century without reaching a consensus of opinion.

Studied area by the authors in the Lower Sinian include Wanlong Formation in Hunjiang, Jilin Province, Changlingzi, Nanguanling and Yingchengzi Formation in Jinxian, Liaoning Province and the Qingbaikouan Nanfung Formation in Benxi, the Sinian Jiayuan Formation, Zhao Formation, Jiudingshan Formation, Weiji Formation and Wangshan Formation in North Anhui (Figure 1).

Figure 1 Comparison of Neoproterozoic sequence stratigraphy and distribution of MT carbonates in the eastern part of North China.

The microspar (Molar-tooth) carbonates in the North China platform

Classification and megascopic features of MT limestone in the North China platform

Classification of MT carbonates

Detailed field observations on the MT limestone sections and microscopic studies show that MT carbonates may be divided into two major groups: autochthonous and allochthonous and 6 subgroups (Figure 2). The autochthonous group may be further divided into 4 subgroups:

a) **Filamentous type**—It is seen chiefly in argillaceous-sparry limestone, each reaches 1-10 cm long and 1-2 mm wide, mainly sub-

Genesis	Structure-fabric
Autochthonous MT (originally pygmatial)	1. Filamentous MT
	2. Curved banded MT
	3. Complicated sheet-like MT
	4. Tumorous MT
Allochthonous MT (Intraclastic)	1. Mimicry-intraclastic MT
	2. Intraclastic MT (Subdivided by grain-size)

Figure 2 Structure-fabric classification of MT carbonates.

- vertical to bedding (Figure 3-6), appearing from the Middle Proterozoic to the Sinian.
- b) **Curved, banded type**—Several to 10 cm long and 1-5 mm wide; bowed, hooked, molar-shaped, pygmatial MT in cross-section, and the curved-banded MT extending towards the bedding plane, but mostly didn't penetrate them (Figure 3-1, 3, 4). This type was commonly developed in Late Proterozoic carbonates, such as the Wanlong Formation.
- c) **Complicated sheet-like type**—Complicated and multi-superimposed molar-like, giving rise to an assemblage of multi-periodic parallel bands (sheets). Each reaches over 10 cm in length and 3-5 mm in width (Figure 7-3).
- d) **Dotted and Tumorous type**—Dot-line-shaped and tumor-shaped microspar structures with irregular boundaries. Their distributive trends and extending directions are related to bedding, and also randomly distributed sometimes (Figure 4).

The four types presented above were developed one or two and more together in carbonates.

The allochthonous MT carbonates may be divided into two subgroups, i.e. mimicry-intraclastic MT (Figure 5) and intraclastic MT (Figure 6-2, 3, 4, 5, 6). The latter subgroup may be subdivided by grain-size.

Micro-features of MT carbonates

MT carbonates clearly differ from their carbonate matrix in terms of composition, texture, and mineralogy. The matrix is generally composed of impure argillo-sparry calcite, commonly containing clay and fine silt grains, whereas the interior of the MT structures was filled purely with micro-sparry calcite, whose crystal sizes are around 0.01 mm in diameter and texturally homogeneous. EDAX analysis shows that the matrix is dominated by Ca, Mg, Al, Si, K,

Figure 3 Autochthonous Molar-tooth carbonate: Filamentous type and curved type MT structure, showing the sedimentary control:

a – mudlimestone;

b – fine-grained mudstone.

1. Curved sheet-type: MF5 (Xingmincun Fm., Dalian);

2. Curved, bended type: MF4/MF3 (Wanlong Fm., Jilin Province);

3. Curved, banded type: MF6/MF7 (Jiudingshan Fm., Lingbi, Anhui Province);

4. Curved sheet-like: MF3 and MF5 (Jiudingshan Fm., Suzhou, Anhui Province);

5. Hook-like curved banded type, MF2 (Wanlong Fm., Baishan, Jilin Province);

6. Filamentous type: MF1 (Wanlong Fm., Jilin Province).

Figure 4 Dotted and tumorous type of autochthonous MT carbonates (Jiudingshan Formation, Lingbi, Anhui Province.)

a – Large dotted and tumorous type of autochthonous MT carbonates: The maximum diameter reaches 20cm, MT9 (Yingchengzi Formation, Qipanmo section, Dalian);

b – Little dotted and tumorous type of autochthonous MT (Anhui Province).

Figure 5 Mimicry-intraclastic MT of allochthonous MT carbonates, MF10 (Wanlong Formation, Jilin Province, Northeast China).

Figure 6 Sedimentary sequence and allochthonous micro-sequence. 1. One part of cross-section of Wanlong Fm.: 1–6, Autochthonous micro-sequence of MT, 7–8, Transition part, few Molar-tooth, 11–15, Terrigenous sedimentary micro-sequence of MT; 2. Allochthonous MT beds, with scour-surface (e.g. marked by arrows); 3. Allochthonous MT beds (marked by arrows); 4. Allochthonous micro-sequence, magnification of sequence (No. 8 of 1), intraclastic MT with cross-stratification structure and erosion surface (marked by arrows); 5. Allochthonous micro-sequence, magnification of sequence (No.7 of 1), mimicry-intraclastic MT, showing discontinuous lamination of MT and erosion-surface (marked by arrows); 6. Allochthonous micro-sequence, magnification of sequence (No.6 of 1), the lower and middle part are autochthonous MT, the upper part are allochthonous MT (marked by arrows).

Figure 7 Three-dimensional analysis of Molar-tooth carbonates structural configuration of Sinian in Nanganling Formation, Dalian, Northeast China.

and Cr, whereas the material comprises peaks of Si and Ca only. Most of the MT microsparite in many of macro-structures are homogenous in general, but there are some heterogenous microsparite, for example, some heterogenous microcrystal grains in the dot-line-shaped type were found (Figure 4).

Sequences and microfacies analysis

Sedimentary succession of carbonate ramp margin

The environmental interpretation of ancient limestone mostly involves the same facies approach as is used for siliciclastics (e.g. Walker, 1984, Reading, 1986), along with more detailed laboratory studies to identify microfacies.

The Late Precambrian strata of the Hunjiang-Tonghua region and Anhui region were deposits of a ramp margin of the North China platform (Meng and Ge, 1996, 2002). Terrestrial and marine carbonates are very well-developed, e.g. during Wanlong-Badaojiang time when the region concerned was chiefly marked by tidal-flat, platform-margin, gentle slope and steep-slope systems, where the sedimentary succession is composed of three units: the upper ramp (UR) on the platform margin, middle gentle slope (MR) and the deep (lower) gentle slope (DR) (Figure 8 and Figure 9) described below:

- The upper gentle slope of the platform margin is composed of stromatolite limestone, tidal-flat limestone and dolomite.
- The middle gentle slope consists mainly of sandy limestone and thin-bedded fine quartzitic sandstone. The sandy limestone is marked by an alternation of cross-bedded tidal and wave beds; mostly reflecting deposition in an environment of high-energy, shallow beach and subtidal channel.
- The deep carbonate ramp is mostly made up of argillo-sparry limestone, bioclastic argillaceous sparry limestone, silty-argillo-sparry limestone, argillo-sparry shale and nodular limestone, locally forming marly mounds, reflecting deposition in quiet water below storm wave-base.

Microfacies and micro-sequences of the MT carbonates:

The autochthonous MT carbonates are mainly formed in argillaceous-sparry limestone or silty carbonaceous sparry limestone; they are locally found in grainstone, such as coarse sandy limestone and oolitic limestone. The following aspects are worth noting:

According to the components of MT carbonates and the relationship between them and their sequences, in an upward-shallowing sequence they consist of three units: the lower unit (a), the middle unit (b) and the upper unit (c). The unit a is of argillaceous or micritic lamination and deposited in the quiet water and below the fair-weather wave-base or the storm wave-base. Terrigenous clasts and MT structures were not developed in this unit.

The unit b consists of silty-bearing micritic limestone with irregular laminae or massive structure. In this unit, MT structures are diverse and exhibit the above four types of autochthonous MT. The tumorous MT often become numerous and larger from the lower to the upper part, and they usually developed in the lower part of this unit. The subvertically growing banded MT developed in the laminated micritic limestone of this unit, often terminating or being folded in the lithologic change surface. In the homogenous massive micritic limestone of this unit there often formed smooth filamentous MT with hook-like end and the extended MT. The hook-like structures occur in the lithologic change surface when they stretched to the upper part.

The unit c consists of clastic grainstone and allochthonous MT bedding. The clastic grainstone was caused by grainstones that suffered from the scouring of wave and current, and then formed troughs which was filled with clastics and allochthonous MT. There remained no autochthonous MT structure in the Unit c. But the allochthonous MT bedding appears in the erosion surface and the scour channels (Figure 6-2), and sometimes some trace-fossils also occur in this unit.

Based on the MT carbonates classification presented above and study of both cyclic and facies sequences in the Wanlong Formation, a detailed subdivision of the MT microfacies is given in Figure 10, which also illustrates the microfacies (from MF1 to MF11) of the MT carbonates, shown by the SF (the function of sedimentary filling of the microsparite) and DC (the function of the depositional covering of the inlet sediments, as caused by current wave and storm current)

According to the detailed analysis of the microfacies and cyclic sequences of the stratigraphic section from Wanlong Fm., the relationship between cyclic sequence and sea level change is clearly shown in Figure 11.

Figure 8 The carbonate micro-sequences and distribution of Molar-tooth (MT) structure from Wanlong Formation in Jilin Province.

Figure 9 Microsequence of deep ramp allochthonous MT carbonate, an example from Jiudingshan Formation in Anhui Province.

a – intraclastic graded bedding of MT;
b – fine-grained mudlimestone;
c – mudlimestone.

Figure 10 Microfacies and sedimentary environment of Molar-tooth carbonates in North China.

A – [MF1, MF8, MF9]. MT grew freely up and down, they haven't been influenced by coarse-grained sediments, but on the contrary the growing MT structure has an effect on the type of the syn-sedimentary lamination;
B – [MF2, MF3]. The top of MT growth was limited by coarse-grained DC inset Sediments;
C – [MF4, MF5, MF6, MF7]. MT growth was only limited by fine DC inset Sediments;
D – [MF10, MF11], MT growth suffered from some forcing (for example, Long term storm, etc.);
E – [MF12, MF13]. MT growth was under the influenced belt, [MF12], MT grew in nodular limestone with covered by storm induced allochthonous MT clastic flow.
HQW – (Wanlong Fm., Qinggouzi section, Hunjiang);
GE – geological environment.

Figure 11 The range of paleoenvironments in which Molar-tooth MF1-MF12 occurred.

HCS – Hummocky cross-stratification;
FWB – Fine weather wave base;
LT – Low tidal;
HT – High tidal.

The geological significance of MT carbonates

Specific time-range of MT carbonates

Within the Archaeozoic-Early Proterozoic carbonates calcite cement is commonly and typically sheet-like to fibrous calcite spar and fan-like micro-digitate travertine stromatolites. MT structures are rarely seen within the oldest carbonates, as they mostly appeared around 1500-1600 Ma. This coincides with the appearance of bedded evaporites and is close in time to the disappearance of the micro-digitate travertine stromatolites (Grotzinger, 1989; James, 1998).

The later half of the Late Proterozoic marks the disappearance of MT carbonates, and this appears to correspond to the large $\delta^{13}\text{C}$ anomaly in the stratigraphic record (Knoll and Walter, 1992; Knoll et al. 1995; Kaufman et al. 1997). There are no MT carbonates in the Phanerozoic and according to James (1998), MT degeneration is related to two biotic changes: biomineralization and bioturbation. Skeletal calcification developed in the Late Proterozoic (pre-550 Ma), and skeletal invertebrates and calcified bacteria became more varied and diverse. Hence, calcified skeletons replaced carbonate precipitation, and the latter process was so decreased that MT structures finally stopped forming. The increasing bioturbation also helped to reduce the formation of MT structures; bioturbation probably destroyed the microbial sheet which often covered the seafloor (Seilacher and Pflüger 1994; Narbonne 1998). These microbes (eucaryotes), and especially the ultra-microbiota may have been the main cause of the formation of MT structures.

G. A. Shields (1999, 2001) proposed that the decrease in CaCO_3 saturation and/or an increase in the concentration of precipitation inhibitors (those include Fe^{2+} , Mg^{2+} , SO_4^{2-} and PO_4^{3-}) in Mid-Neoproterozoic sea water may have contributed to MT carbonate disappearance.

Some scholars (Qiao and Gao, 1999), who stick to the seismic origin for MT, attempt to prove that there were MT carbonates during Cambrian to Ordovician periods. Their so-called MT structures should be regarded as dissolution pipes and dissolution evaporite signifying a drought climatic event (Meng and Ge, et al. 2002).

This study shows that the maximum spike distribution of the Middle-Late Proterozoic MT limestones occurred in 1000 or 900 to 600 Ma period.

Palaeo-environmental significance of MT carbonates

MT carbonates are especially well-developed in China, particularly in Liaoning and Jilin provinces, and they occur in a variety of sedimentary facies. From the sequence statistics and analysis of megascopic microfabrics, a sedimentary model for MT carbonates has been drawn up. The MT carbonates occur from the basin margin's sublittoral zone through to the basin center. Various megascopic microfabrics may serve as useful environmental markers. As an example the Qinggouzi section in Hunjian and the Jiudingshan Formation in Lingbi show the following features (Figure 9 and Figure 10):

The shallow ramp deposits (SR illustrated in Figure 2 and Figure 8 A and B) contain mainly sandy and conglomeratic limestones with spherulites of argillo-sparry limestone, but MT structures are only rarely developed. The stiped MT occurs locally. In shallow foreshore facies there occur MT fragments, broken in site or transported, forming laminated "sparry clastic" grainstone (Figure 6-2 and 3). The middle gentle ramp facies (MR) is composed of grey, thick-bedded argillo-sparry limestones, intercalated with thin intraclastic limestone and conglomeratic limestone, with hummocky bedding. The argillo-sparry spherulitic limestones commonly contain large to medium-sized ptymatically folded MT structures.

The upper deep ramp deposits (UDR) are composed of an alternation of silty limestone with cross-bedded laminae and argillo-

sparry limestone, and large-scale irregularly and vertically distributed MT structures are common. The input of clastics was unfavorable to the formation of MT structures. In the tidal-flat facies with planar stromatolites, where the supply of terrestrial clastics was restricted, MT structures were rarely formed. They were also very rarely seen in neritic stromatolitic carbonate zone. They were more common in lime-mudstone deposited in deep-water. They may be disrupted by waves, tides and storms, forming tidal channel crossing-bedding and tempestite beds of broken MT intraclasts (i.e. allochthonous MT carbonates, see Figure 9 and Figure 10D).

In the deeper part of the basin, there was no clastic deposition, and because the water was deeper (about > 100m), so rarely microbial sheet covered the seafloor, hence there formed muddy argillaceous shale or mud limestone with MT structures, such as MT-bearing nodular limestone and MT-bearing bioherm (Figure 9DR and Figure 10E).

MT structures typically formed in subtidal environments and occurred especially in the basal parts of shallowing-upward cycle.

MT limestones and their role in the origin and evolution of life

Eucaryotes appeared before 1300 Ma (Schopf, 1978) or 1300-1600 Ma (Sokolob, 1979) and it is generally considered that since then life evolved gradually (Margulis 1970). According to Zhu, Xing, Zhang et al. (1994), protozoans might possibly have appeared earlier than generally supposed as based on the following reasons: (1) Though the Ediacara fauna (700-600 Ma) was more primitive and simpler than the Cambrian metazoans, palaeoecologically speaking, they included pelagic to benthic types, embracing many phyla, such as *Coelenterata*, *Porifera*, *Annelida*, *Brachiopoda* and *Arthropoda*, all of which were soft-bodied, but they had reached a fairly high level of metazoan evolution; (2) In the Upper Sinian of Xu-Huai region (ca 700-600 Ma), coelenterates, sponge spicules, annulates and brachiopods were found, while in the Lower Sinian (Changlingzi Fm. in S. Liaoning) undoubted Verms (Sabellidites and Palevian) occurred. The Changlingzi Fm yielded an isotopic age of 750 Ma, proving the existence of pre-Ediacara metazoans. In many cases it appears that the inner and middle ramp (sea-floor) was covered by a microbial foam, which is considered a pre-requisite condition for the formation of MT structures, and probably the exploding interval for the development of MT structures was 1500-1600 Ma.

Discussion on the origin of the MT carbonates

Review on the origin of the MT carbonates

Molar tooth structures have been receiving wide attention in view of their possible close connection with organic evolution (Kaufmann, 1997; Knoll et al. 1972; James et al. 1998). Some people believe that MT structures resulted from underwater sediment-shrinkage (Horodyski 1976; Knoll and Sweet 1990; Pratt et al. 1999; Winston, Don et al. 1999), but others consider that earthquakes caused the dewatering (Pratt 1992; Fairchild et al. 1997).

Although cracks formed by dewatering or contraction might resemble MT structures, they lack the interior fillings. In cross-sections MT structures are generally contortedly-folded. Under the scanning microscope the MT filling material is distinctly shown and composed of fine-grained crystalline calcite, which grew perpendicular to cracks. According to Hofmann's observations (1985) the microspar filling MT structures is identical to that filling the non-deformed spherical or cylindrical organic fossils such as *Chuarina* and *Tawuia*. According to experiments of Furniss et al (1997), the muds produced molar tooth-like cracks only when the surface was sealed. James (1998) proposed: "the most parsimonious explanation is that the muds were covered by microbial mats. The implication of

this interpretation is that Molar-tooth is the testimony to what we have long suspected, that the muddy carbonate seafloor in intertidal and most subtidal environments was veneered with microbial scum restricted to the Mesoproterozoic and Neoproterozoic most likely reflected the evolutionary acme of microbial communities suited to this environment. Our observations imply that this community did not extend into deep subtidal or basinal settings, possibly because it was phototrophic".

Some seismic origins have been held by some scholars, about which several points should be mentioned. Firstly, Roep (1992) emphasized that in a carbonate-depositing basin the presence of pillow-beds is the strongest evidence of earthquakes, but so far no such rock structure has been reported within MT carbonates in our study area. Secondly, it is known that liquefaction of sandstone is common in an area of seismite formation (Allen 1986). Within coarse-grained sandy sediments liquefaction occurs comparatively easily, but not so easily in fine-grained rocks (fine silty sands, fine argillo-calcareous mud and mudstone). Dewatering structures finally only dewater in coarse-grained sediments, but rarely in fine-grained rocks; MT limestones are originally very rarely granular. Thirdly, it is well-known that tectonically related seismicity occurred throughout the geological record, whereas MT limestones are limited within the Middle and Late Proterozoic. Some Chinese scholars have considered that MT limestones occur preferentially in the ancient Tan-Lu fault zone. However, a majority of workers hold that the Tan-Lu fault was active mainly during the Meso-Cenozoic times, as a result of strike-slip tectonism (Xu Jiawei et al. 1994). Employing the Milankovich's cycle concept, the present authors have prepared a precise isochronous palaeogeographic maps for the North China platform from lower Cambrian to upper Permian (Meng Xianghua et al. 1995, 1996, 2002), which shows that there is no relationship between the facies distribution plus sediment thickness with the Tan-Lu fault.

Hence, the origin of MT carbonates may be summarized as follows: (a) Spatially speaking, MT carbonates were formed in extremely ancient shallow seas on the carbonate platforms and lower and middle ramp environments, all of which were favorable habitats for eucaryotes; (b) Temporarily speaking these structures began to form before 1500-1600 Ma (James 1998), flourishing to a maximum during 1000 Ma or 900 Ma to 650 Ma (our information). According to Zhu (1993), single-celled organisms appeared around the beginning of the Proterozoic (1800 Ma), while texturally complex eucaryote multi-cellular algae appeared in the middle stage of the Middle Proterozoic 1300 or 1300-1600 Ma. Metazoans might have appeared around 1000-650 Ma. All of these important intervals are closely connected with the occurrence of the MT limestones; in other words, these limestones appeared step by step in accordance with the evolution and decline of the earliest life in geological history. Hence, the formation of Middle to Late Proterozoic MT limestones depends on the then developing eucaryotes. The abrupt disappearance of MT structures within the latest Proterozoic as mentioned above is probably related to biomineralization and bioturbation.

Some deliberations on the origin of MT

MT appears most abundantly in muddy or silt-bearing micritic limestone, a most important MT limestone. Curved banded type, complicated sheet-like type and dotted type MT structures mostly developed in this MT limestone. The authors think that the following features of this MT limestone may help to trace the origin of the MT structure.

- The MT structure growing perpendicular to lamination usually spreads widely in its middle part and taper both upward and downward (Figure 12). Such a distinctive feature has no relationship to waterscape structure and others caused by gravity-flow.
- There usually appear deformed MT structures and thickening or/and fragmentation caused by fold superimposed between the laminae of the siltstone (or silt)-bearing or none muddy micritic limestones. The phenomena and features are just the same as Smith described and discussed detailedly in 1967, they formed by the differentiation of agillaceous laminae with sand and mud

Figure 12 The relationship between microspar (Molar-tooth) structure and the lamina of micritic limestone: a neap-spring super micro-cycle sequence from Nanguanling Formation in Fuzhou, Liaoning Province, Northeast China.

content and of the water content, plasticity, stickiness and other characters of the sediments. The authors think that the deformed MT, thickening and fragmentation caused by fold superimposition could occur without any other external factors such as earthquake and so on.

- There usually occurs the distorted lamination of the enclosing rock forming extruded ridge caused by different compaction at the top and bottom of the MT structure. This may be interpreted as follows: MT structure is composed of pure microsparite, their crystallization and solidification being stronger and earlier than the enclosing rocks that are muddy limestone, so in the process of compaction, MT structure usually appeared as a ridge framework, which is unlike the product of seismic liquefaction as proposed by some scholars holding seismic origin.
- The last problem is the development of MT structure and the number of lamination that it has penetrated. Take an example of Figure 12, which shows that during the forming of MT structure, the laminae number that it penetrated reached more than 60 (Figure 12). Based on the above analysis, the lithofacies of these laminated micritic limestone reflects a sedimentary environment of shallow-marine deeper gentle slope. Based on the modern carbonates' depositional ratio (0.01–2.5)m/1000a, the average ratio is 1m/1000a (Tucker, 1990), the forming time range of a millimeter-scale lamina (Figure 2) is 10–300a, the average time limit is 100 years. If the MT structure is related to seismic events, then how did the seismic event influence the MT structure's forming—did it need several to one hundred years? Obviously, it is impossible.

The latest researches on bio-molecular structures (Zhou 1998, Masterton and Slowinski 1980) indicate that the second-level structural unit of the basic component of life is protein (molecular peptide chain of α -spirochaeta and β -fold). Both of these have electron-magnetic wave. The protein molecule is life-type amino acid. Peptide chain has two ends, amino-group NH_3 and carboxyl COOH , which are pH^+ and pH^- respectively. The electric current is produced while the enzymes on the two ends activate the protein-molecule; once the protein peptide chain performs an electric movement, it forms a current, which produces an electron-magnetic wave whose length is equivalent to the microwave range. The energy generated by the micro-bioelectromagnetic wave may activate the chemical reaction of the surrounding medium.

The implication for the theory of biowave might be a new way to explain the mechanism of carbonate precipitation within the molar-tooth structure.

During the Middle and Late Proterozoic the atmosphere and hydrosphere were still low in P_{CO_2} content and the pH value was still acidic. The living protein, and its energy generated by the micro-biowave may have helped to increase the pH value and so cause chemical precipitation of pure micro-sparry carbonates; at the same time CO_2 would have increased and the preserved space could lead to the formation of the cracks of the MT structures. Some MT limestones contain as much as 50% of the total amount of carbonate.

To summarize, it is suggested that a great significance should be attached to MT structures, which serve as a key to Precambrian biological and geochemical events. They might be a link of the revolutionary changes in the biosphere, which heralded the appearance of the complex multi-cellular animals of the Late Precambrian.

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