Carbonates Evaporites (2015) 30:373–386
DOI 10.1007/s13146-014-0209-2

ORIGINAL ARTICLE

Cambrian oncoids and other microbial-related grains on the North China Platform

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Accepted: 23 June 2014 / Published online: 25 July 2014

Abstract This study illustrates features of the Cambrian oncoids and provides a comparison with other microbial-related carbonate grains found in the Cambrian succession of the North China epeiric platform. Based on cortex structures, four types of oncoids were distinguished: thin-cortex (superficial) oncoids, laminated-cortex oncoids, clotted-cortex oncoids, and full-cortex (without nucleus) oncoids. Thin- and clotted-cortex oncoids are often associated with oolites, laminated-cortex oncoids are present within oolitic-bioclastic grainstones, and full-cortex oncoids occur in bioturbated wackestones. The oncoids with nucleus–cortex structures are easily distinguished from other carbonate grains due to the lack of nucleus–cortex structures, and from microbial-related ooids which have more circular shape and more continuous cortex than oncoids. Oncoids without nucleus and with only crudely laminated cortex (i.e., full-cortex oncoids) can be differentiated from microbialite intraclasts and microbial lumps by the following evidences: (1) microbialite intraclasts, either rounded or angular, are characterized by margins that sharply truncate the included calcified microbes or carbonate grains and, in addition, intraclast-bearing conglomerates commonly show clear sedimentary structures such as cross-stratification and normal grading; (2) microbial aggregates have irregular but smooth margins, and rather chaotic inner structures.

Keywords Oncoids · Cortex · Intraclasts · Ooids · Cambrian

Introduction

As an important component of shallow-marine carbonate sediment, oncoids are unattached, rounded nodules which commonly consist of nuclei of many kinds of grains and

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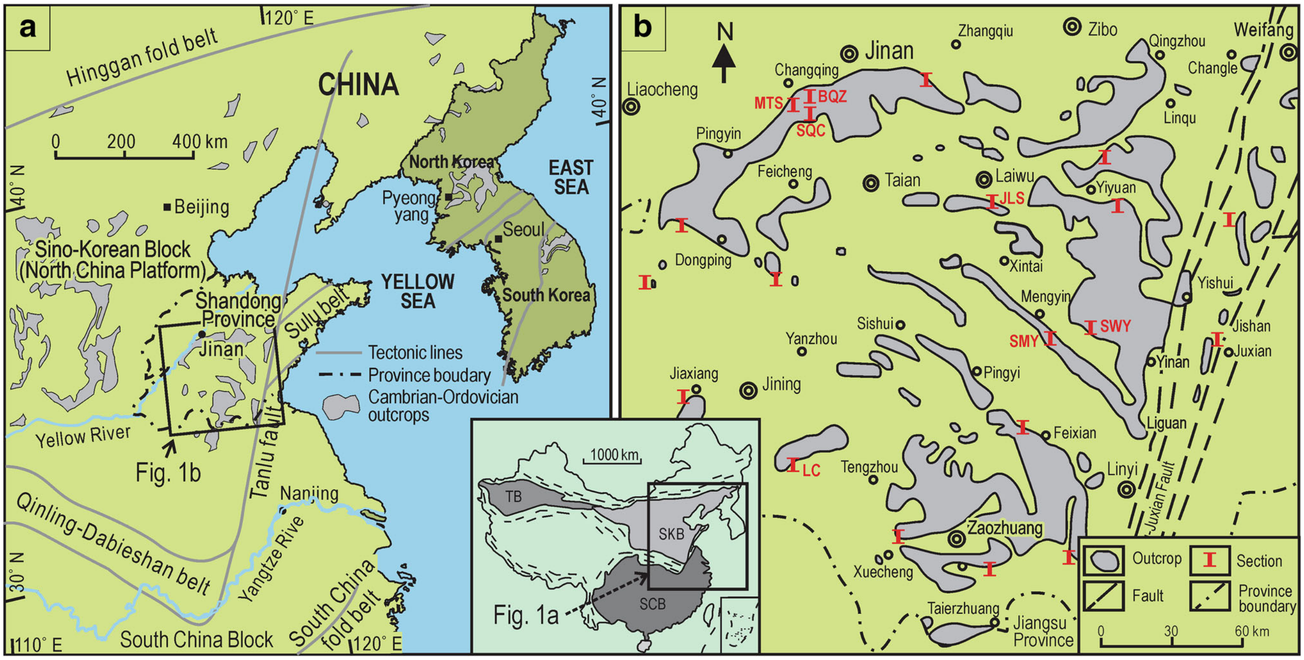

Fig. 1 **a** Major tectonic boundaries and Cambrian–Ordovician outcrops of the North China Platform. **b** Outcrop sections that yield oncoids from the Mantou and Zhangxia formations (Cambrian Series 2–3) in Shandong Province, China. *MTS* Mantoushan section, *SQC* Shangquancun section, *BQZ* Beiquanzi section, *JLS* Jiulongshan section, *SMY* Sunmayu section, *SWY* Shiwangya section, *LC* Liangcheng section

cortices made of either calcified microbes, algae or metazoans (e.g., encrusting foraminifera) (Peryt 1981; Tucker and Wright 1990; Riding 1991; Flügel 2004). They form in a wide variety of marine and non-marine environments through Precambrian to the modern time (Peryt 1981; Zhao 1992; Védrine et al. 2007; Jones 2011; Lan and Chen 2012). Most Cambrian oncoids were formed by calcified cyanobacteria (mainly *Girvanella*), commonly thriving in shallow-marine settings (Peryt 1981; Tucker and Wright 1990; Elicki et al. 2002; Flügel 2004; Liu and Zhang 2012), which have been specifically termed cyanoids (Riding 1983).

During the Cambrian, calcified cyanobacteria commonly flourished in shallow-water carbonate platforms under favorable conditions (e.g., shallow, warm, clear, and photic water, and abundant nutrient) (Riding 2000; Pratt 2001; Lee et al. 2010). Calcification and agglutination of cyanobacteria formed a variety of microbial carbonates including reefal microbialites (e.g., stromatolite, thrombolite, and dendrolite), and microbial carbonate mud and grains (Riding 2000; Pratt 2001). Reworking of these microbial carbonates by physical, chemical and biological processes may also result in such carbonate grains as microbialite intraclasts and microbial lumps. Oncoids are often confused with these grains due to their similar shape, size, and composition (cf. Yang et al. 2011, 2013; Liu and Zhang 2012).

This study takes the Cambrian succession of the North China Platform as an example to illustrate a comparison of oncoids with other microbial-induced carbonate grains. Abundant microbial carbonates exist in the Cambrian strata of the North China epeiric platform, especially in Shandong Province where the strata are superbly exposed (Meng et al. 1997; Mu et al. 2003; Chough et al. 2010; Chen and Lee 2014) (Fig. 1). In contrast with the extensive study on the various reefal microbial carbonates from the North China Platform (Lee et al. 2010, 2012; Woo and Chough 2010; Chen et al. 2011; Howell et al. 2011), microbial-induced carbonate grains have received little attention, except for a few examples of clotted oncoids, later re-classified as microbial lumps (Yang et al. 2011, 2013), and *Girvanella* oncoids and ooids (Liu and Zhang 2012).

Geological background

The North China Platform is a vast epeiric platform (ca. 1,000 km north–south, 1,500 km east–west) (Fig. 1a), formed on a stable craton (the Sino-Korean Block) in the tropical to subtropical zones during the Paleozoic (Meng et al. 1997). Marine sedimentation on the North China Platform started in the Early Cambrian and continued until the Middle to Late Ordovician. The entire platform was

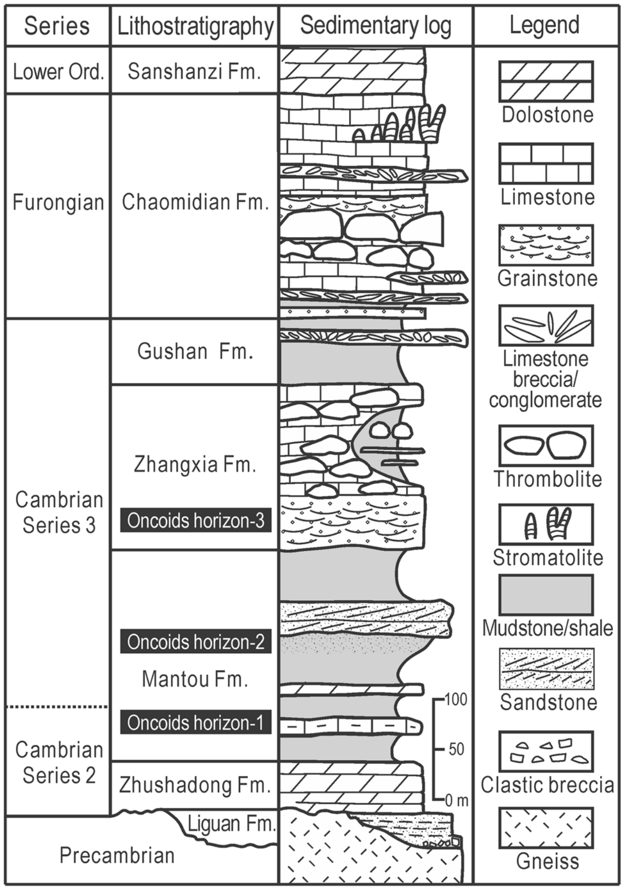

Fig. 2 Schematic stratigraphic succession of the Cambrian in Shandong Province, China. The oncoids occur only in the Mantou and Zhangxia formations

subaerially exposed and eroded from the Late Ordovician to the Early Carboniferous. An ~1,800-m-thick Cambrian–Ordovician marine succession of mixed siliciclastic–carbonate deposits formed during long-term sea-level rise (Meng et al. 1997; Kwon et al. 2006). The well-exposed Cambrian succession, especially in Shandong Province, mid-east of China (Fig. 1a), consists of six lithostratigraphic units (i.e., Liguan, Zhushadong, Mantou, Zhangxia, Gushan, and Chaomidian formations in ascending order), unconformably overlying Precambrian granitic gneiss or metasedimentary rocks and conformably underlying Ordovician dolostones and limestones (Chough et al. 2010) (Fig. 2).

The basal Cambrian unit, the Liguan Formation (laterally discontinuous, 0–30 m thick) consists mainly of quartzose sandstones and mudstones (Fig. 2). The Zhushadong Formation (15–40 m thick) is dominated by stromatolitic and dolomitic lime mudstones, and it locally contains bioturbated wackestones. The Mantou Formation (210–240 m thick) consists of mixed siliciclastic and carbonate rocks including purple mudstones, sandstones, and various carbonate rocks. The Zhangxia Formation (ca. 180 m thick) is characterized by a variety of microbialites and carbonate rocks, and locally shaly mudstones in the middle of the formation. The Gushan Formation (52–105 m thick) comprises shale-dominated rocks and the overlying Chaomidian Formation (190–260 m thick) is dominated by various carbonate rocks (Fig. 2).

Cambrian oncoids from Shandong region

The studied Cambrian oncoids and other carbonate grains were observed and sampled from 20 outcrop sections (Fig. 1). The oncoids originate from the lower and upper parts of the Mantou Formation, and the lower part of the Zhangxia Formation (Cambrian Series 2 to Series 3) in Shandong region (Fig. 3). Oncolitic limestone rock samples were cut into slabs, and polished and scanned for the textural and structural analysis. Individual oncoids were disintegrated from the rock samples with severely weathered matrix (e.g., bioclastic wackestone and dolomitic marlstone matrix) to examine the 3D morphology of oncoids. About 100 thin sections were observed for microstructural analysis of the oncoids and other carbonate grains under the polarizing and stereo microscopes, and scanning electron microscope (SEM).

The oncoids are mostly elliptic (ratio between long and short axes ranging from 1 to 3.5) in vertical section, and show more or less round shape and concentric laminae on bedding plane, which makes them a flattened spheroidal 3D shapes. In a few cases, the sphericity is relatively high. Sphericity of the oncoids is dependent mainly on the shape of nuclei which may include many types of grains, such as bioclasts, peloids (including fragments of calcified microbes), ooids (including aggregates of ooids), and oncoids (including aggregates of oncoids) (e.g., Dahanayake 1977).

Cortex is believed to be formed by microbial-mediated processes, which represents certain conditions that favor the growth and calcification of microbes and consequently the formation of oncoids (e.g., Logan et al. 1964; Flügel 2004). It is for this reason that according to the texture and structures of cortex rather than nuclei and morphology of oncoids, the oncoids in this study are classified as: thin-cortex oncoids, laminated-cortex oncoids, clotted-cortex oncoids, and full-cortex oncoids. Cortex of the studied Cambrian oncoids is mainly constructed by *Girvanella* with calcified tubular and unbranched filaments, each of them about 10–20 µm in width (Fig. 4), which indicates that these oncoids may be classified as *Girvanella* oncoids, porostromate oncoids, or cyanoids by definition.

Oncoids occur ubiquitously in the Cambrian shallow-marine successions worldwide, such as in North America,

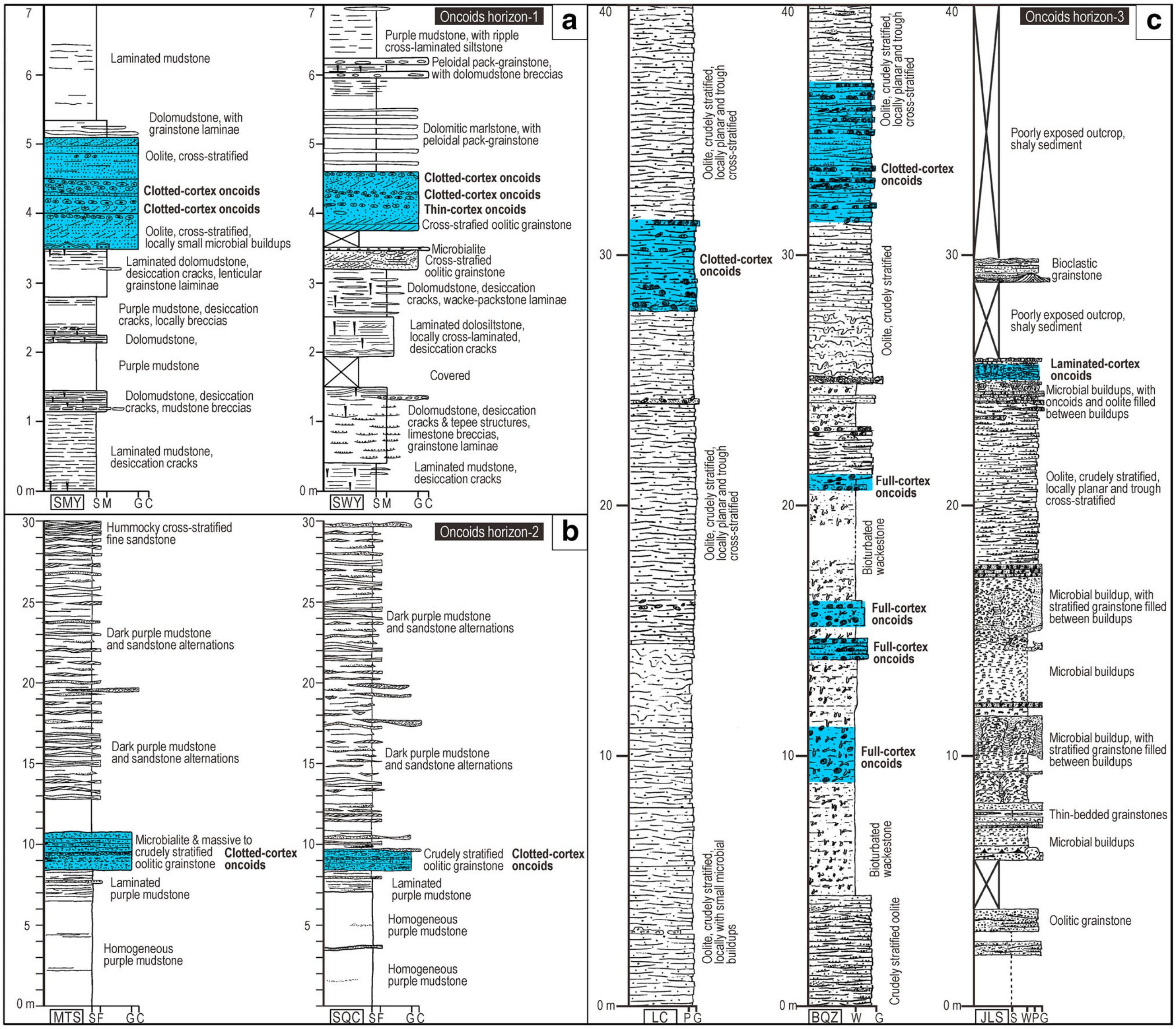

Fig. 3 Detailed columnar sections showing occurrences of the oncoids in the Shandong region. **a** Lower part of the Mantou Formation in SMY and SWY sections. **b** Upper part of the Mantou Formation in MTS and SQC sections. **c** Lower part of the Zhangxia Formation in LC, BQZ, and JLS sections. *S* Shale, *M* mudstone, *F* fine sandstone, *W* wackestone, *P* packstone, *G* grainstone, *C* limestone conglomerate

Europe, South and North China, Australia, Middle East, and Antarctic. Most of the Cambrian oncoids are constructed by identifiable *Girvanella* (Markello and Read 1981; Peryt 1981; Riding 1983, 1991; Elicki et al. 2002; Flügel 2004; Hicks and Rowland 2009; Liu and Zhang 2012). Some oncoids from Antarctic were reported to have both *Girvanella* and *Epiphyton* (a dendritic calcified microbe) in their cortices (Rees et al. 1989). As exceptions, however, the Cambrian spongiostromate oncoids (composed of mainly micrite) were reported from Spain (Adachi et al. 2013), which were most likely originated from micritization of porostromate oncoids (Flügel 2004), and some Cambrian oncoids from Sweden are composed of phosphatic cortex (Sturesson 1988).

Description and interpretation of Cambrian oncoids

Thin-cortex oncoids

Description

These oncoids are identified based mainly on the fact that the cortex is much thinner than the nucleus (Fig. 5). The

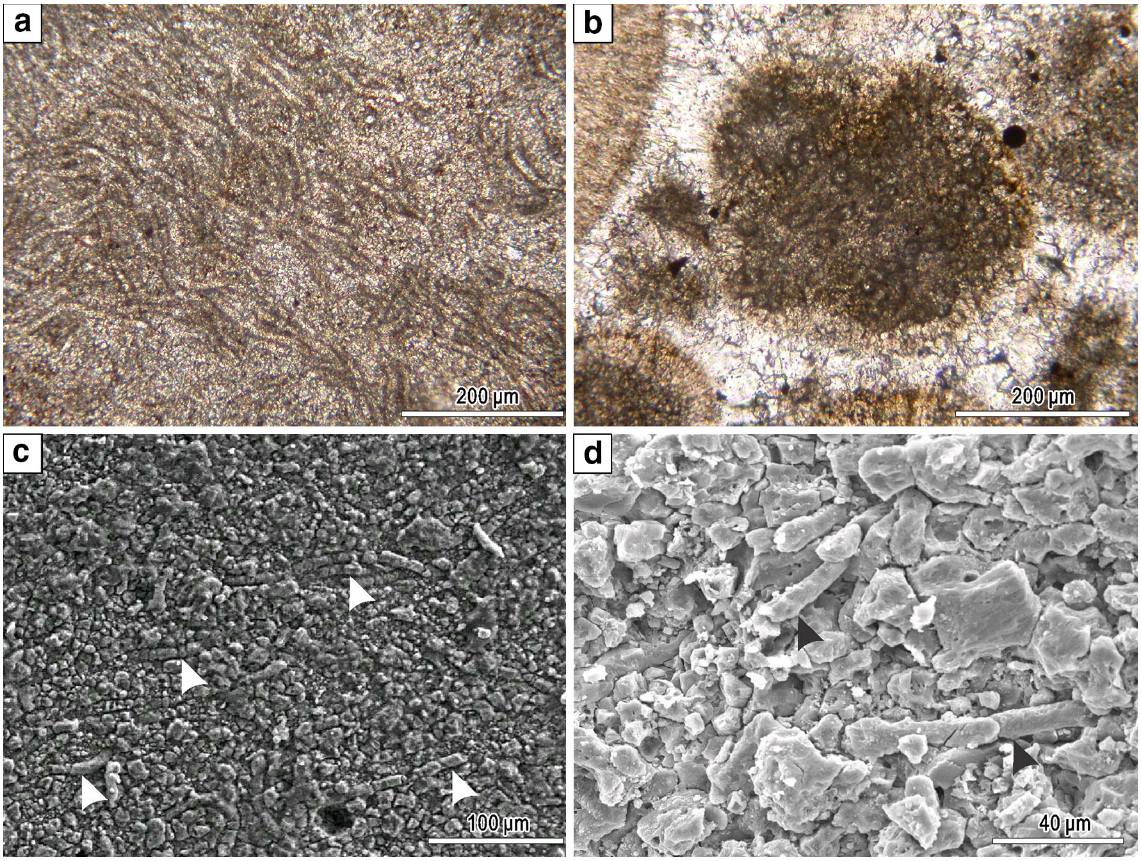

Fig. 4 Photomicrographs of calcified cyanobacteria, *Girvanella*. **a** Tubular filaments of *Girvanella*. **b** Transverse section of tubular Girvanella, showing circular feature. **c** SEM photo showing thread-like feature of *Girvanella* filaments. **d** SEM photo showing rod-like feature of *Girvanella* filaments

diameter of the oncoids ranges from a millimeter to a few centimeters, depending on the size of nuclei (Fig. 5). Nuclei often comprise bioclasts (mostly trilobite fossil fragments) and intraclasts or aggregates of ooids, which are either completely or partly coated by cortices (Fig. 5). Some of the large superficial oncoids show thicker cortices in the upper surface of the nuclei (Fig. 4a). Cortices are composed of recognizable *Girvanella* (Fig. 5c, d).

Interpretation

Thin-cortex oncoids are commonly interpreted as superficial oncoids (Dahanayake 1977). The thin-cortex oncoids of small size may reflect the initial stage of development of oncoids by short-term encrustation of cyanobacteria, whereas these with large nuclei could not develop into normal (i.e., thicker cortex) oncoids because they could not be agitated all around and continuously coated by microbial encrustation. Instead, microbial filaments would have accreted upward on the top surfaces of large nuclei, forming thicker cortices on upper sides of oncoids, resembling growth of stromatolites (Fig. 5a).

Laminated-cortex oncoids

Description

The oncoids are characterized by having a well-laminated cortex (Fig. 6). These oncoids are ellipsoidal and rounded with a smooth surface (Fig. 6a–c). Laminated cortices are composed of overlapping laminae of *Girvanella* and microsparry calcite (Fig. 6d). Laminae are continuous and concentric although the thickness of individual lamina is variable. The oncoids often occur in bioclastic packstone to grainstone. Fossil fragments are well rounded and often coated by a thin micritic envelope. The ellipsoidal oncoids are mostly oriented parallel to the bedding plane or imbricated (Fig. 6a). These oncoids are similar to Type C (concentrically arranged laminae) oncoids of Logan et al. (1964) and Flügel (2004).

Interpretation

The well-laminated and concentric cortices of laminated-cortex oncoids are indicative of constant agitation and

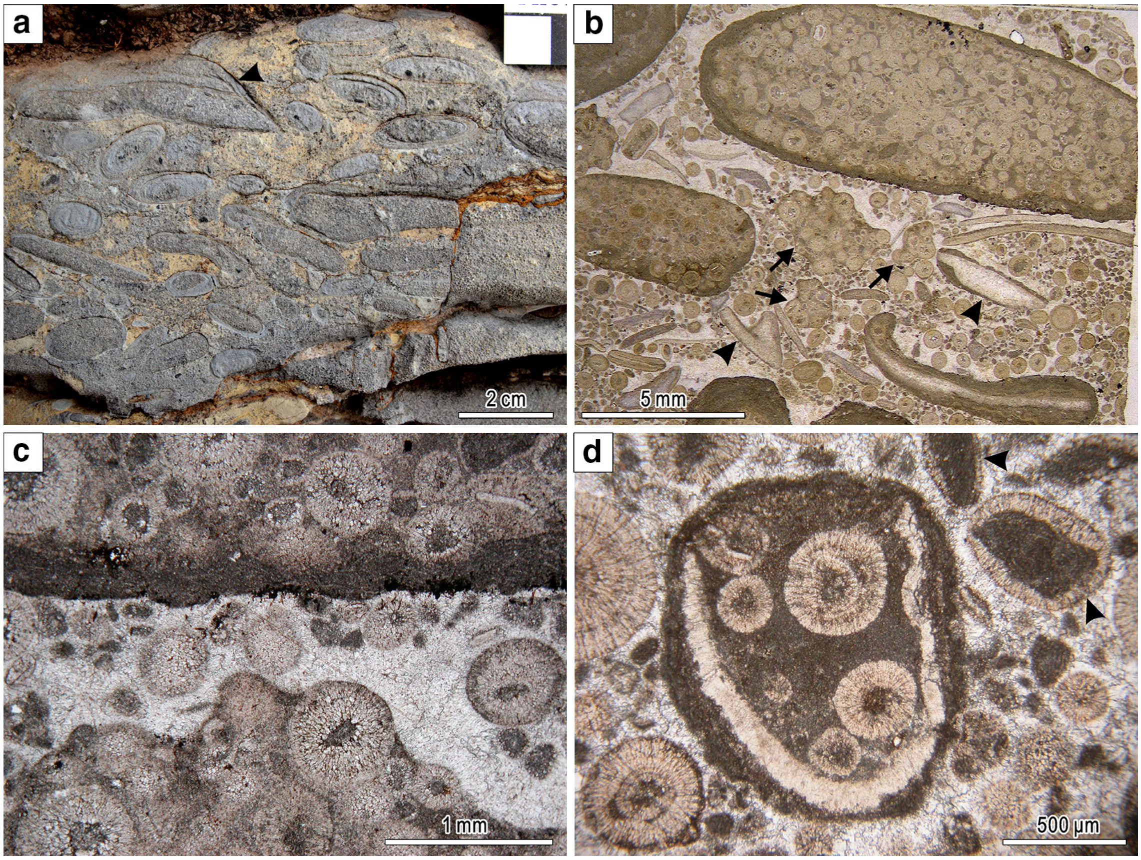

Fig. 5 Thin-cortex oncoids. **a** Outcrop photo, showing large nuclei and thin cortex of the oncoids. *Arrow* indicates upward growth of cortices on the upper surface of the nucleus. **b** Possibly reworked ooid aggregates as nuclei that are coated by thin cortices. Note a micro-oncoid (*right arrow head*), a cortoid (*left arrow head*), and several aggregates (*middle arrows*). **c** Thin *Girvanella* cortex of an oncoid (*upper*) and part of an uncoated ooid aggregate (*lower*). **d** A micro-oncoid with a large nucleus composed of ooids and bioclast and a thin cortex of Girvanella. Note the typical "*Nuia*" ooids (*arrows*)

active encrustation by cyanobacteria under relatively high-energy conditions (Dahanayake 1977). The associated bioclasts (trilobite fossil fragments) were rounded by constant reworking of currents or waves. Local irregular encrustation by microbes (Fig. 6c) reflects temporary low-energy conditions.

Clotted-cortex oncoids

Description

Clotted-cortex oncoids are characterized by clotted or crudely laminated cortices that are composed dominantly of calcified *Girvanella* (Fig. 7). They commonly occur in oolitic grainstone with sparry calcite cement (Fig. 7b, c). The oncoids are either concentric or asymmetric; the latter often shows discontinuous crude laminae that are thicker upward (Fig. 7c). The clotted cortex is characterized by *Girvanella*-formed mesh-like texture with microsparry clots (Fig. 7d). *Girvanella* tubes around nuclei are either parallel or vertical relative to the outline of nuclei (Fig. 7d). These oncoids are similar to Type R (randomly arranged, non-continuous and overlapping laminae) oncoids of Logan et al. (1964) and Flügel (2004).

Interpretation

Clotted (or mesh-like) texture of the oncoids resulted from the relatively large irregular fenestrae (but not those related to desiccation or gas bubbling) formed either during the sparse and erect growth of *Girvanella* or by agitation and tangling of *Girvanella* colonies by waves (cf. Riding 1991). The delicate growth of *Girvanella* indicates that the oncoids most likely formed under relatively low-agitation conditions. Asymmetric cortex is indicative of upward growth of *Girvanella* under relatively low-energy conditions.

Full-cortex oncoids

Description

These oncoids characteristically contain no nuclei (Fig. 8). They are made of a tuft of tangled calcified

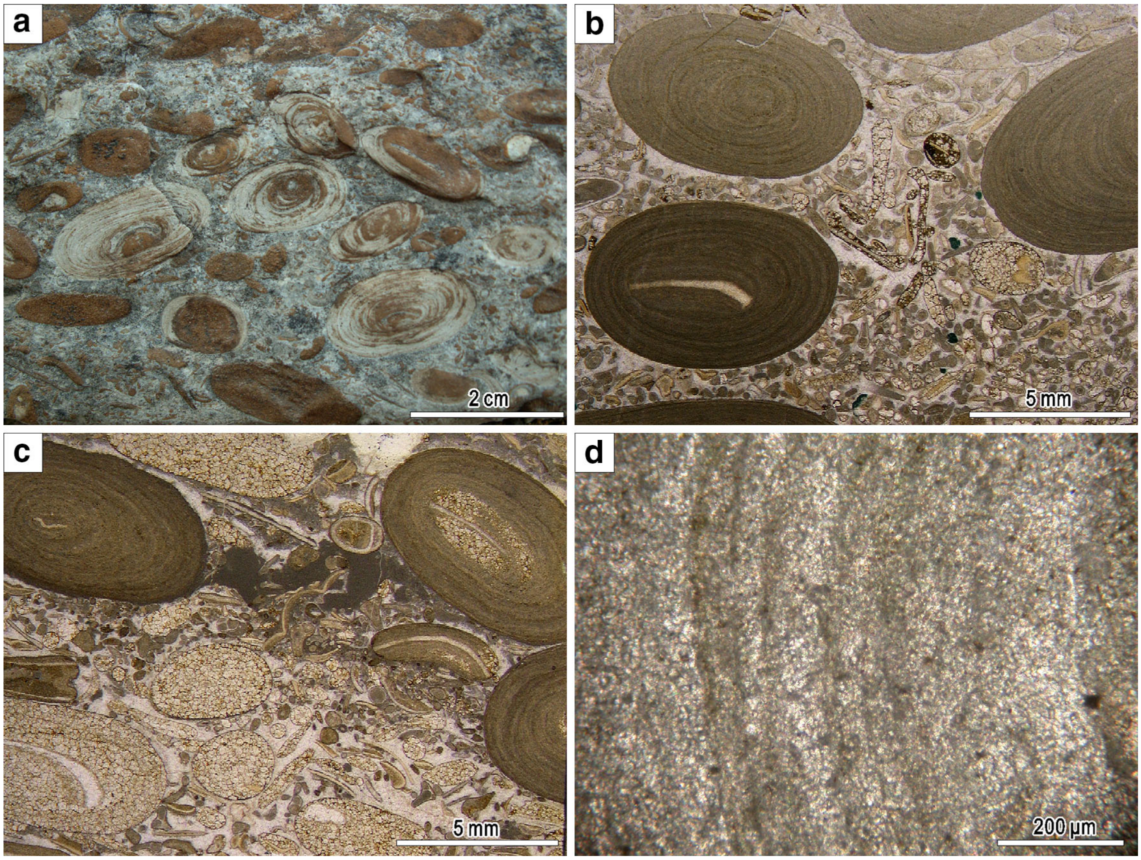

Fig. 6 Laminated-cortex oncoids. **a** Partly dolomitized (*dark-color part*) oncoids with a thick, well-laminated cortex. **b** Smooth-outlined and concentric oncoids with well-laminated cortices and nuclei of small bioclasts in a bioclastic grainstone. Note an oncoid does not show a nucleus which was most likely not cut out. **c** A thin micritic lamina encrusted an oncoid (*upper left*). Note partly dolomitized oncoids. **d** Superimposed *Girvanella* laminae (*dark*) and micro-spar laminae (*light*) in the cortex of laminated-cortex oncoids

microbes (mostly *Girvanella*), showing clotted and crudely laminated texture (Fig. 8b, c). They are rather spheroidal in shape with relatively ragged outline. These oncoids commonly occur in bioclastic wackestone or grainstone that consists of abundant fragments and debris of calcified *Girvanella* with irregular and angular shapes (Fig. 8d).

Interpretation

The occurrence of oncoids without nuclei may result from the fact that the nuclei are not cut out (if there exist nuclei). However, if significant amounts of oncoids lack of nuclei either in outcrops or slabs, or under microscopes, they most likely developed either without nuclei or with nuclei that were later modified. Nuclei could have been the organic matter that was later decayed and replaced with cement (Dahanayake 1977). The unrecognizable nuclei might also have resulted from either “aggrading neomorphism” (Folk 1965) or “grain diminution” (Wolf 1965).

Distribution and depositional environments of Cambrian oncoids

As mentioned earlier, the oncoids are present generally in three horizons of the Cambrian succession in the Shandong region (Figs. 2, 3). Horizon-1 oncoids occur in the lower part of the Mantou Formation and only in the southern sections such as SMY and SWY sections (Figs. 1, 3a), and include mainly clotted-cortex oncoids and a small portion of thin-cortex oncoids. These oncoids are present in a planar cross-stratified oolitic grainstone bed. The grainstone bed is intercalated within laminated mudstones and dolomudstones with pervasive desiccation cracks and locally tepee structures (Fig. 3a), indicating an upper intertidal to supratidal setting (Lee and Chough 2011). The oolitic grainstone bed was most likely formed by migration of oolitic shoals over tidal flat as a result of either hydrodynamic changes or relative sea-level changes.

Horizon-2 oncoids occur in the upper part of the Mantou Formation and only in the northern sections such as MTS

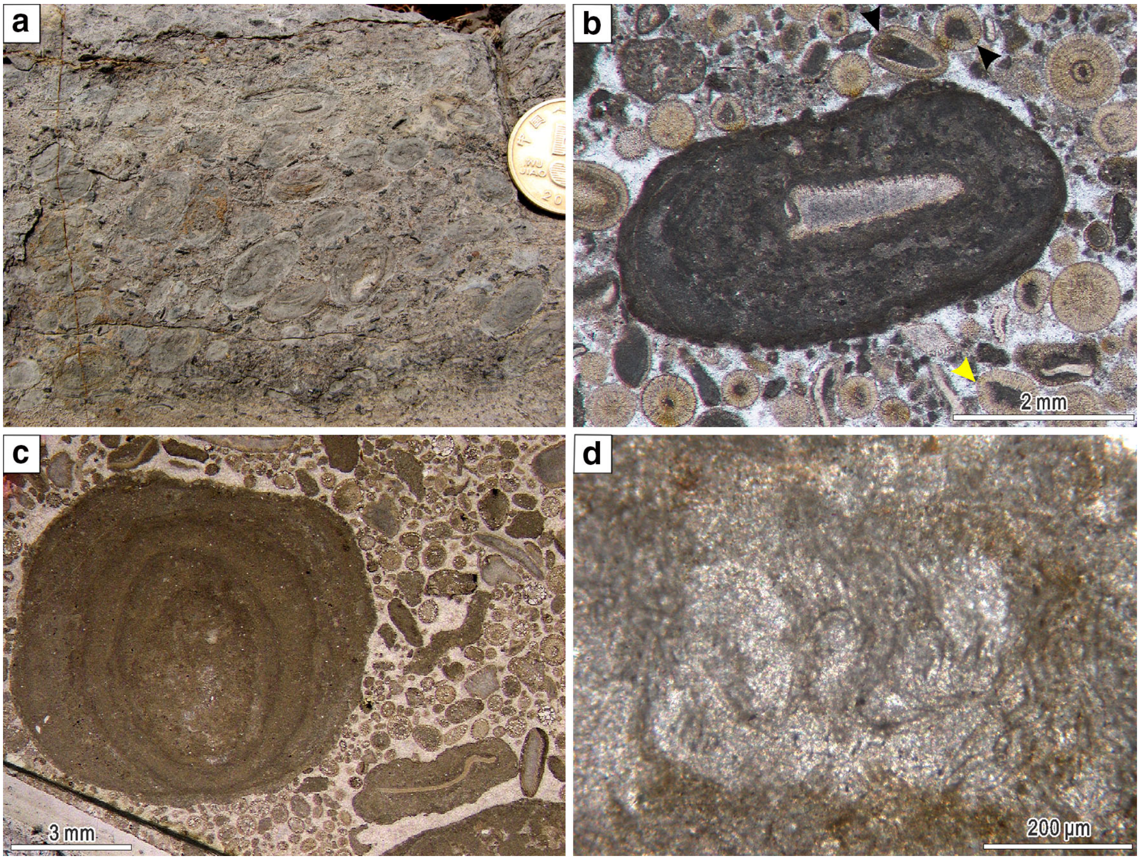

Fig. 7 Clotted-cortex oncoids. **a** Outcrop photo of oncoids made of thin bioclastic nuclei and cortices without distinct laminae. Coin for scale is 20.5 mm in diameter. **b** An ellipsoidal oncoid with a nucleus of calcareous algae and a clotted (only crudely laminated) cortex in an oolitic grainstone which contains many "*Nuia*" ooids (*arrows*). **c** An asymmetric oncoid with a crudely laminated cortex. Note the thick laminae upward and thin laminae downward. **d** Microbial clots in cortex, which resulted from erect growth of cyanobacteria (*Girvanella*) and sparry calcite fenestrae

and SQC sections (Figs. 1, 3b), and consist mainly of clotted-cortex oncoids. The oncoids are present in a bioclastic and oolitic grainstone bed, locally with dendritic microbialites. The grainstone bed is well correlated in the northern sections. Homogeneous purple mudstone below the grainstone bed indicates a siliciclastic tidal flat near coastal plain (Lee and Chough 2011), whereas dark purple mudstone and ripple-laminated sandstone alternations above the grainstone bed were most likely deposited in lower shoreface to offshore settings where waves and currents were not strong (Lee and Chough 2011). The base of the oncoids-bearing grainstone bed is thus indicative of a transgressive surface, and the grainstone bed formed during transgression.

Horizon-3 oncoids occur in the lower part of the Zhangxia Formation in most of the sections such as the LC section (southwest), BQZ section (northwest), and JLS section (middle part) (Figs. 1, 3c). This horizon is, however, not well correlated with respect to lithofacies. In LC section, the oncoids (mainly clotted-cortex oncoids) occur in a thick oolite succession, indicating an oolitic shoal setting. In BQZ section, there are two types of oncoids: the full-cortex oncoids are present in bioturbated wackestone, deposited in a lagoon environment, whereas clotted-cortex oncoids occur in oolite, indicating an oolitic shoal. In JLS section, only minor oncoids (mainly laminated-cortex oncoids) were developed in the uppermost part of an oolitic grainstone bed with microbialite buildups. Above the oolite bed was a thick poorly exposed succession, composed mainly of shales and minor limestone beds, indicating a deep-water, low-energy setting, most likely some regional depressions between thick oolitic shoals (Woo et al. 2008).

Comparison and discussion

In addition to oncoids, the Cambrian succession of the North China Platform also contains a variety of other microbial-related carbonate grains (e.g., microbialite

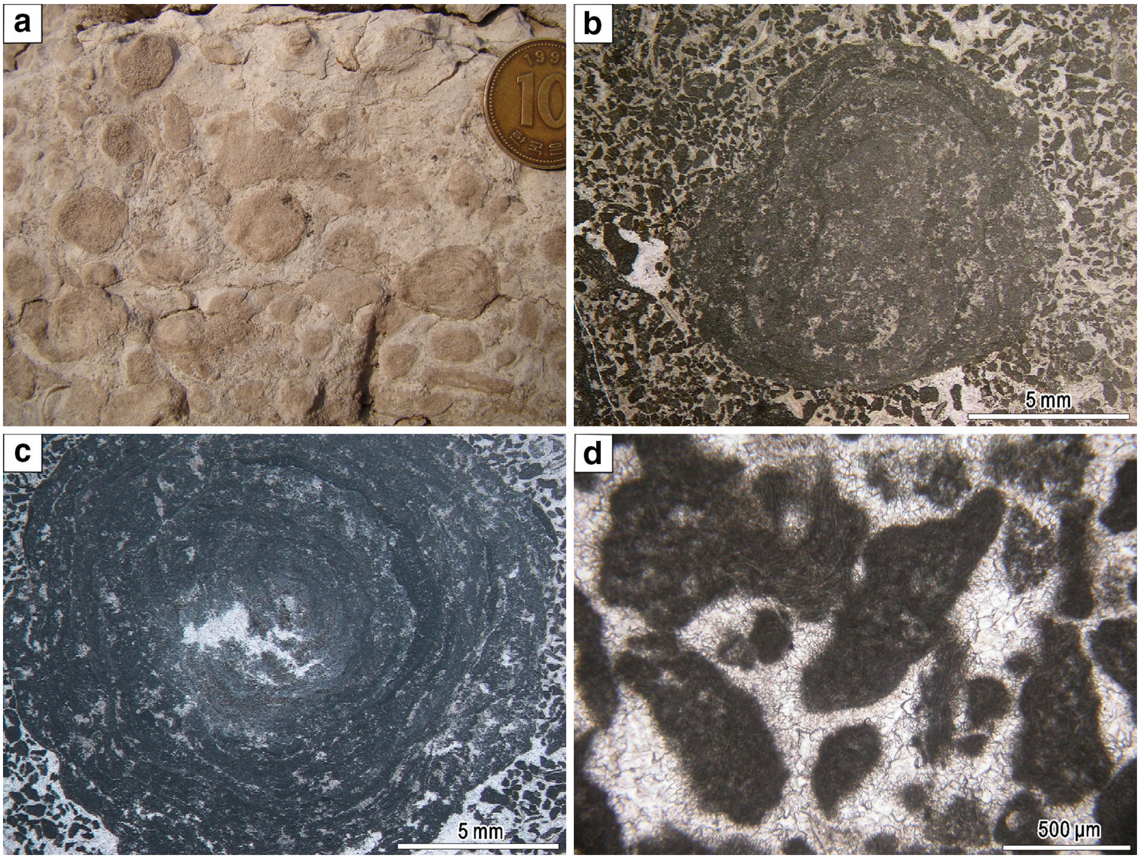

Fig. 8 Full-cortex oncoids. **a** Outcrop photo of spherical nucleus-less, full-cortex oncoids. Coin for scale is 23 mm in diameter. **b** An irregular-shaped oncoid with crudely laminated (clotted) texture in a grainstone composed mainly of fragments of calcified microbes. **c** A spheroidal oncoid with crudely laminated texture and ragged outline. **d** Subangular fragments of calcified *Girvanella* in the grainstone

intraclasts, and microbial lumps and ooids) (Figs. 9, 10). Many of these grains may be in some aspects confused with oncoids (cf. Yang et al. 2011, 2013; Liu and Zhang 2012). It is critical to differentiate all these carbonate grains since each type of the grains is indicative of certain physical, chemical, and biological processes (Peryt 1981; Flügel 2004; Pratt et al. 2012) (Fig. 11).

Comparison with microbialite intraclasts

Intraclasts result mainly from physical breakup of previously deposited, somewhat consolidated sediment (Tucker and Wright 1990; Flügel 2004) (Fig. 11). There is no doubt to differentiate oncoids with nuclei and cortices from any kinds of intraclasts because intraclasts do not comprise nuclei. It is also possible to identify nucleus-less, full-cortex oncoids from the intraclasts of non-microbial carbonate deposits (e.g., bioclastic wacke- to grainstone). Only reworked intraclasts (re-sediments) of previously deposited microbial carbonates are apt to be confused with full-cortex oncoids due to the presence of calcified microbes in both (Yang et al. 2011; Liu and Zhang 2012). The intraclasts are, however, either rounded and smooth (reworked) or angular and irregular (less reworked), but all with sharp margins that truncate the included calcified microbes or carbonate grains (Fig. 9), based on which they can be differentiated from oncoids. In addition, intraclasts-bearing conglomerates or rudstones often show clear sedimentary structures (e.g., cross-stratification, normal grading, and erosional features) which are indicative of reworking by strong currents and waves (Fig. 9), whereas oncoids-bearing deposits are often crudely stratified or massive, formed under relatively lower-energy conditions.

Comparison with microbial aggregates

Aggregates are formed by binding and cementation of carbonate grains (Fig. 11). They normally show many kinds of grains with irregular but smooth outline bound by physio- or biochemical processes. Depending on different shapes and variable binding processes, aggregates are

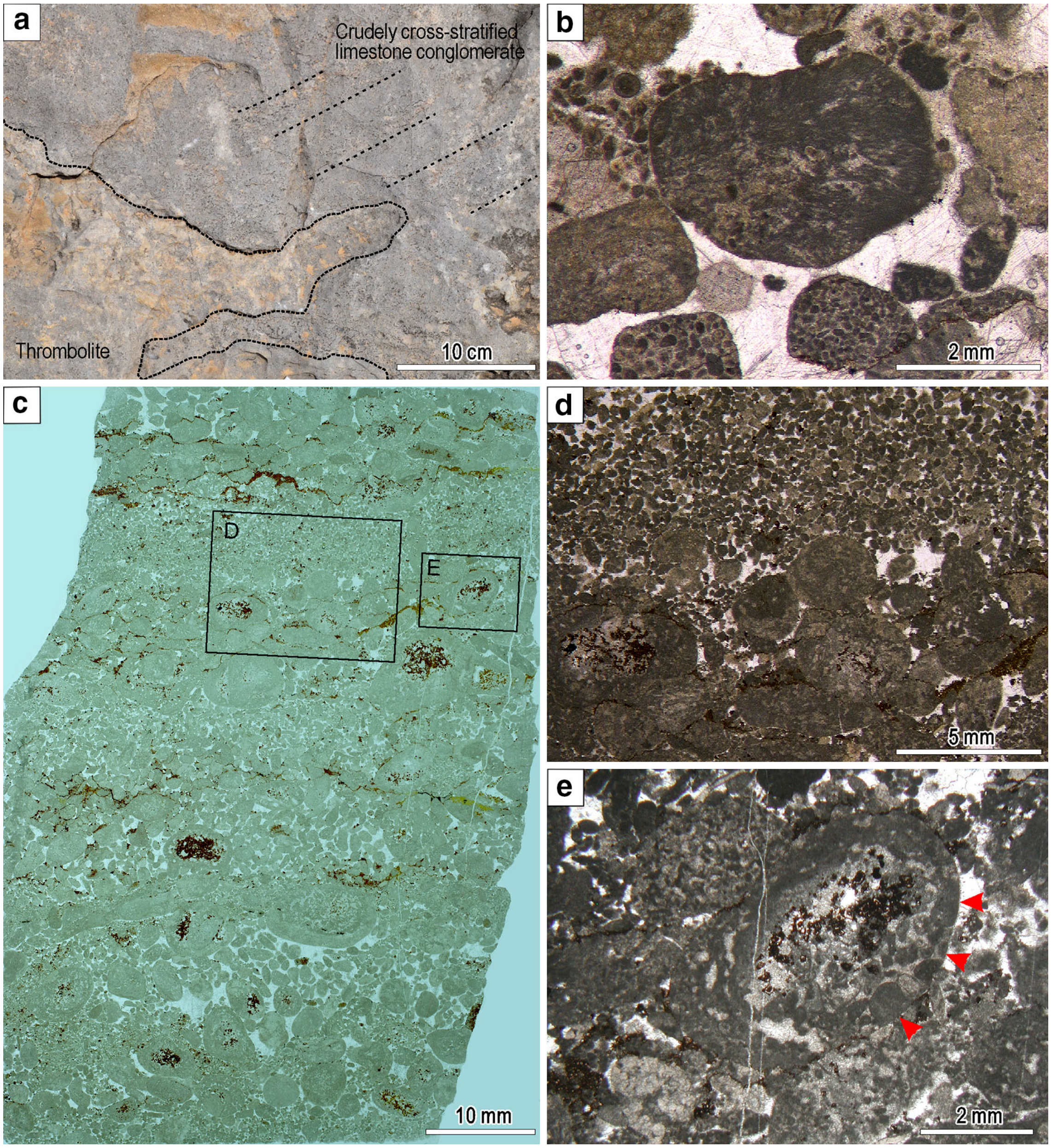

Fig. 9 Microbialite intraclasts. **a** Crudely cross-stratified limestone conglomerate and associated thrombolite bioherm with an irregular erosion boundary. The clasts of conglomerate are mostly oval and rounded; the size ranges from a few mm to a few cm, resembling full-cortex oncoids. **b** Photomicrograph of intraclasts that are composed of either calcified microbes (*center*) or peloids. Note the sharp edges of the clasts. **c** Thin section of stratified limestone conglomerate, showing stratification distinguished by variation in grain size. **d** Close-up of two laminae; the larger clasts resembling oncoids and the smaller similar to peloids. **e** Close-up of an intraclasts with sharp edges cutting the included grains (*arrows*)

classified as grapestones, lumps, oolitic lumps, microbial aggregate grains, and encrusted aggregate grains (Flügel 2004). Margins of aggregates do not cut the included grains in the aggregates (Fig. 5b, c), which are different from intraclasts. Aggregates are not characterized by nucleus–cortex structures, which assist in differentiating oncoids from aggregates. Although there might be some confusion between microbial aggregates and full-cortex oncoids, they can be differentiated based on the fact that the oncoids are often rounded and crudely laminated. The "microbial lumps" reported from the Cambrian Mantou Formation (Shandong region) by Yang et al. (2013) are generally oval in shape with rounded and smooth outlines that cut the internal components such as peloids and microbial clots

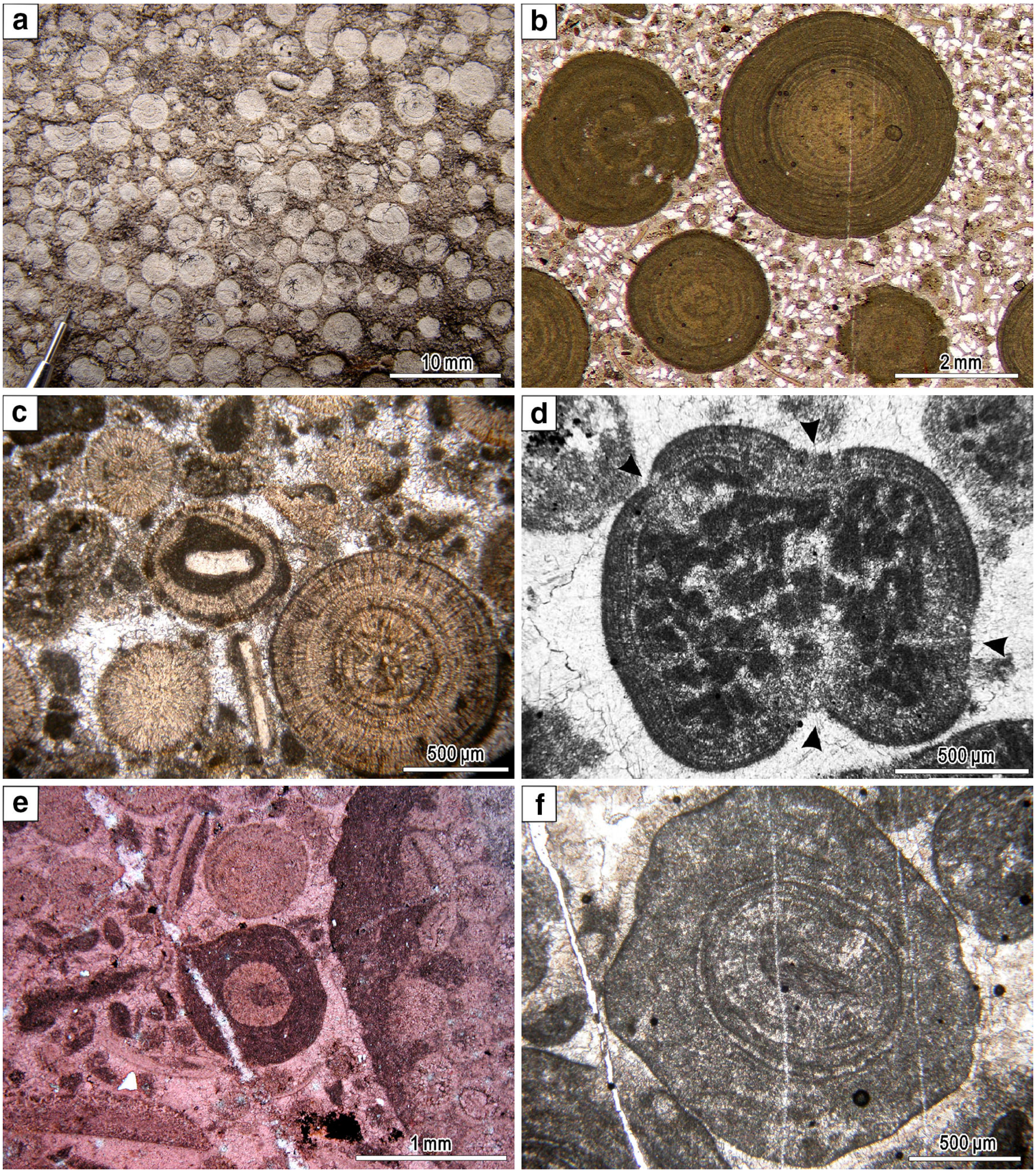

Fig. 10 Microbial ooids. **a** An outcrop photo showing large ooids (some are broken). **b** Giant ooids with concentric micritic cortex in the matrix of quartz grains and bioclasts. **c** An ooid (*center*) with a micro-oncoid as nucleus. **d** An ooid with a fragment of *Epiphyton* colonies as nucleus (from Woo et al. 2008). *Arrow heads* indicate discontinuity points in cortex of the ooid. **e** An ooid coated by *Girvanella* (*center*), forming a micro-oncoid. **f** A carbonate grain consisting of a nucleus of *Girvanella* fragments and a cortex by chemical precipitation and *Girvanella* encrustation

(Fig. 9c–e). The lump-bearing deposits are crudely cross-stratified (Fig. 9c). These "lumps" were initially described and interpreted as clotted oncoids (Yang et al. 2011), but they bear the characteristics of intraclasts, most likely reworked from previously deposited microbialites nearby. These intraclasts might have been later bound by microbial filaments, forming microbial lumps.

Comparison with microbial ooids

Ooids (<2 mm in diameter) and "giant ooids" (>2 mm in diameter; may be also termed pisoids, but pisoids commonly refer to a freshwater or terrestrial origin) are spherical, concentric, coated grains (Li et al. 2010; Mei and Gao 2012) (Fig. 10). There are a variety of ooids in the

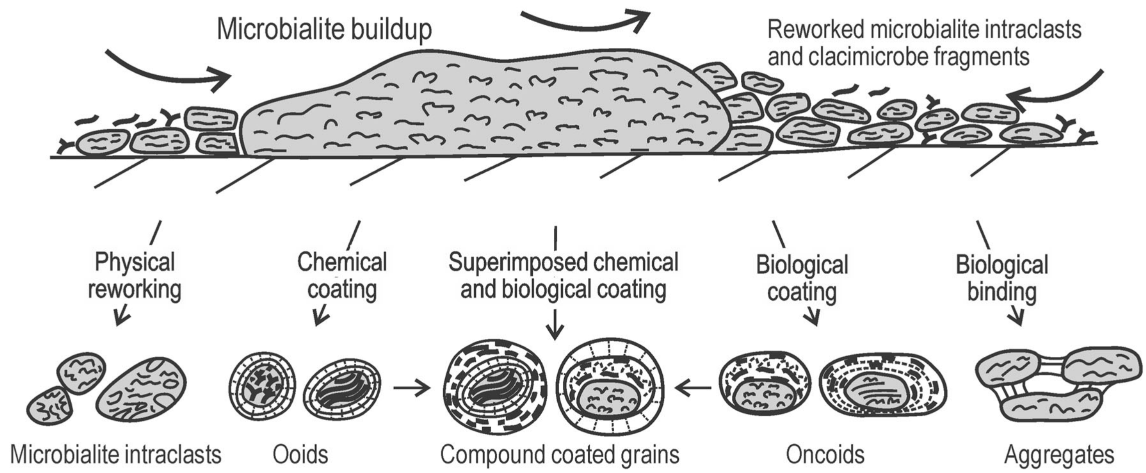

Fig. 11 Schematic model (not in scale) of microbial-related carbonate grains. Reworking of previously deposited microbialite buildups leads to formation of microbialite intraclasts and abundant calcimicrobe fragments. Some of microbialite intraclasts may resemble oncoids due to the presence of abundant calcimicrobes in both (cf. Liu and Zhang 2012). On the other hand, both the microbialite intraclasts and calcimicrobe fragments can be coated by chemical processes (forming ooids, which were previous misinterpreted as a problematic micro-organism fossil) and biological processes (forming oncoids). Superimposed chemical and biological coating may result in compound coated grains that are either ooids or oncoids. Microbialite intraclasts are bound by calcimicrobes, forming aggregates or lumps

Cambrian succession of the North China Platform including both radial-concentric and tangential ones (Figs. 5c, d, 10a–c). Ooids vary in size from ~200 µm to ~3 mm in diameter, and their shapes are largely dependent on the nuclei. Nuclei of the ooids include fossil fragments (e.g., trilobites), calcimicrobes (e.g., *Girvanella* and *Epiphyton*), and peloids (Fig. 10). The ooids are generally differentiated from oncoids by more circular shape and more continuous cortex. Oodization can be initiated around many other grains such as bioclasts, peloids, and occasionally micro-oncoids (<2 mm in diameter) (Fig. 4.21b in Flügel 2004 and Fig. 10c). Particularly, the ooids incorporated with calcified microbes (i.e., *Girvanella*) as nuclei were previously misidentified as a problematic micro-organism of uncertain affinity, *Nuia* (Maslov 1954 and many others afterwards) (Figs. 5d, 7b). They were, however, reappraised later and it turned out that they formed by oodization of fragments of calcified *Girvanella*, not organism fossil at all (Spincer 1998). In fact, oodization of fragments of other calcified microbes such as *Epiphyton* was also reported from the Cambrian strata (Woo et al. 2008) (Fig. 10d). The Cambrian *Girvanella* ooids (including the "*Nuia*" ooids and the ooids partially containing *Girvanella* in the cortex) are reiterated recently with some examples from China (Liu and Zhang 2012). Although *Girvanella* was involved in the ooid nuclei and cortices in such ooids, it does not necessarily mean that the ooids were formed by cyanobacteria (but just altered indeed). On the other hand, ooids, either biological- or chemical-induced in origin, can also provide hard substrate for encrusting microbes, as all other grains do, forming oncoids (Fig. 10e). As a result, the alternation of chemical precipitation and microbial encrustation may result in carbonate grains that are not typical of either microbial ooids or oncoids (Figs. 10f, 11).

Conclusions

Abundant oncoids of various features occur in the Mantou and Zhangxia formations (Cambrian Series 2–3) of the North China Platform (Shandong region). Four types of oncoids were distinguished according to the cortex structures: thin-cortex (superficial) oncoids, laminated-cortex oncoids, clotted-cortex oncoids, and full-cortex oncoids. Cortices of the oncoids were constructed of *Girvanella* filaments. The thin-cortex oncoids are the initial stage of oncoid development. Laminated- and clotted-cortex oncoids are associated with bioclastic and oolitic grainstone, and formed under relatively high-energy conditions. Full-cortex oncoids often occur in bioturbated wackestones and deposited in a relatively low-energy setting. The oncoids are generally distinguished from other carbonate grains due to the absence of nucleus and microbial cortex. Oncoids without nucleus and with only crudely laminated cortex can be confused with microbialite intraclasts and microbial aggregates due to the similar size, shape, and composition. These oncoids are differentiated from microbialite intraclasts and microbial aggregates by the following evidences: (1) microbialite intraclasts are characterized by margins that sharply truncate the included calcified microbes or carbonate grains and, in addition, intraclast-bearing conglomerates commonly show clear sedimentary structures;

(2) microbial aggregates have irregular but smooth margins, and rather chaotic inner structures.

Acknowledgments This study was financially supported by the National Natural Science Foundation of China (41372108 and 41302077), National Basic Research Program of China (2012CB723104), Program for Scientific Research Innovation Team in Colleges and Universities of Shandong Province, and SDUST Research Fund (2010KYTD103). J. Woo was supported by KOPRI (PE14050). H.S. Lee was supported by KETEP (2011201030006C). We thank the journal editor and an anonymous reviewer for their critical and constructive comments.

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