Clay Oncoids and Crypto-microbial Laminites from the Late Paleoproterozoic Manitou Falls Formation, Athabasca Basin, Saskatchewan

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Abstract

Bean-sized, laminated structures from basal Manitou Falls strata near Hook Lake in the Athabasca Basin are re-interpreted to be clay oncoids which grew in ephemeral pools or lakes in a flashy river system. Comparable micro-laminated structures in microcrystalline quartz from the McArthur River area are also of probable microbial origin. These structures add to a growing body of evidence for life in Proterozoic non-marine environments and contribute to our understanding of regional paleo-environments in early Manitou Falls time.

Keywords*: Paleoproterozoic, Athabasca Basin, Manitou Falls Formation, clay oncoids, laminites, stromatolites, apatite, crypto-microbial, early terrigenous life.*

1. Introduction

Although generally identified with carbonate rocks (e.g., stromatolites), crypto-microbial structures, including stromatolites and oncoids, may be common in siliciclastic successions (e.g., Schieber, 1999; Noffke *et al.*, 2001; Donaldson and Hilowle, 2002), including non-marine Proterozoic strata (Prave, 2002). Two occurrences of micro-laminated structures of possible microbial origin from the Athabasca Basin are described in this paper.

Oncoids (Peryt, 1983; Tucker and Wright, 1990) or oncolites (Logan *et al*., 1964) are irregularly shaped coated grains greater than 2 mm in diameter and made up of irregular overlapping laminae. Biogenic structures may be present. Carbonate oncoids typically form by encrusting, but in high energy, shallow water settings oncoids can be formed like snowballs, with clastic sediment trapped and bound by microbial mats (Jones and Goodbody, 1985; Tucker and Wright, 1990). Oncoids probably originate as tiny stromatolites, which become detached by current activity and continue to grow as they are moved around (Gebelein, 1974). Tucker and Wright (1990) have suggested that the term oncolite be reserved for a rock composed of oncoids, and this usage is followed here.

Concentrically laminated, ellipsoidal structures from 2 to 15 mm long are in an 8 cm thick, massive to horizontally laminated, gritty red mudstone bed 1.8 m above the base of the Manitou Falls Formation in core from DDH HK-12 (Figure 1A and 1B) drilled by Cameco Corporation in 2001 about 4 km northwest of Hook Lake (NTS 74F/15; NAD 83 Zone 12: 621676mE, 6408904mN; collar elevation: 525 m).

On the basis of macroscopic appearance, the structures were originally interpreted to be banded soil pisoliths (Yeo *et al.*, 2001), but petrographic examination shows that sets of laminae truncate and overlap one another; hence the structures are re-interpreted as oncoids.

Micro-laminated structures have also been observed in an intensely silicified red sedimentary breccia comprising basement quartzose gneiss and quartzite clasts, immediately overlying the sub-Athabasca unconformity in core from DDH RL-92 (Figure 1A), drilled in 1999 by Cameco Corporation at the south end of Read Lake, about 2 km west of the McArthur River mine in eastern Athabasca Basin (NTS 74H-14, NAD 85, Zone 13: 492831mE, 6402123mN; collar elevation: 535 m).

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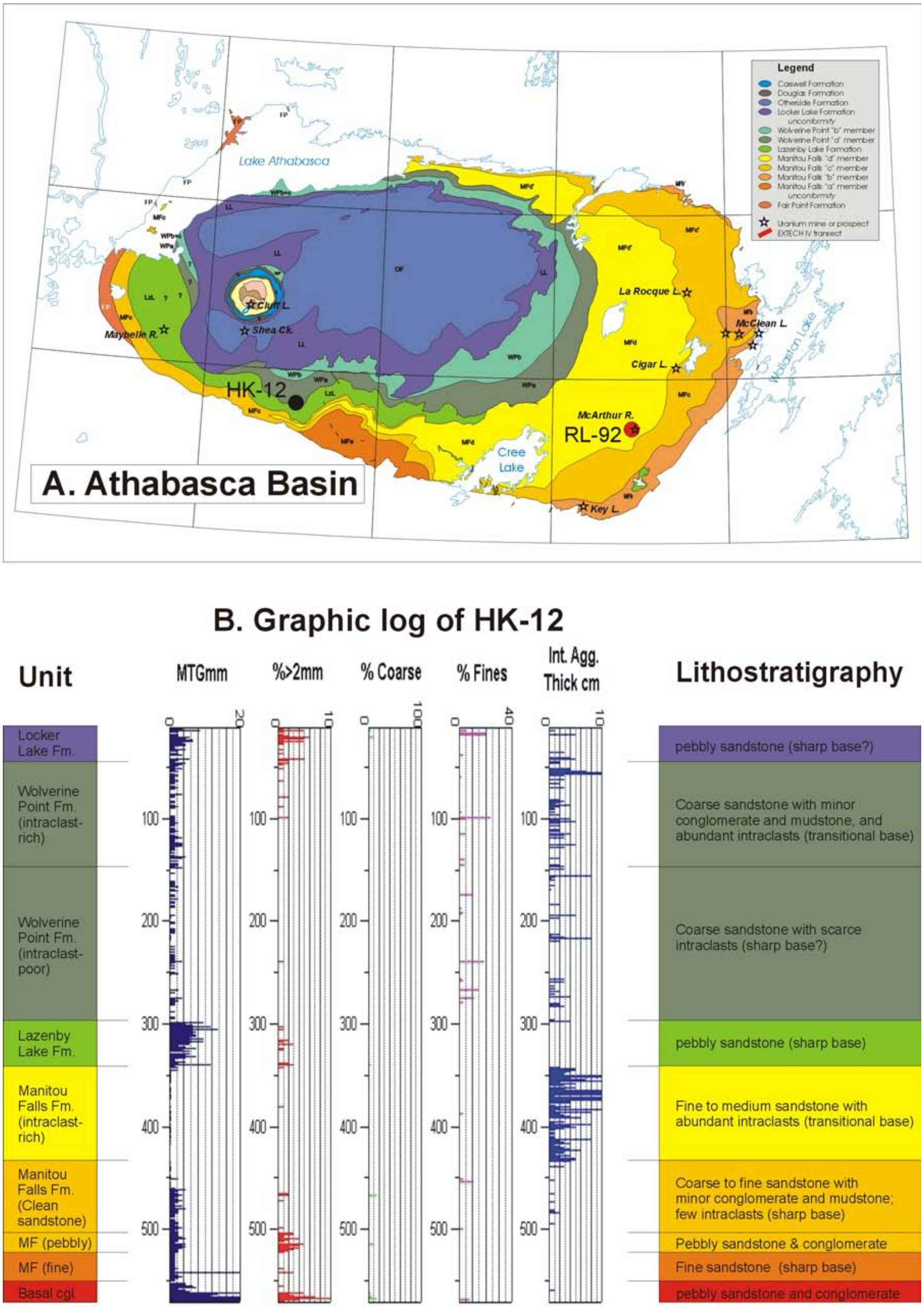

Figure 1 - A) Geological sketch map of Athabasca Basin (after Ramaekers* et al.*, 2001) showing the locations of DDH HK-12 and RL-92. B) Metre-by-metre graphic log of DDH HK-12. Parameters shown are maximum grain size in millimetres (MTGmm), percent coarser than sand (%>2 mm), percent of conglomerate beds more than 2 cm thick (% Coarse), percent of mudstone beds (% Fines), and aggregate thickness of strata containing intraclasts (Int. Agg. Thick cm).

2. Stratigraphic Setting

The stratigraphy of the southwestern Athabasca Basin is described elsewhere (Yeo *et al*., 2001; Ramaekers *et al.*, 2001). Only the basal member of the Manitou Falls Formation in the Hook Lake core is described in this report.

The basal member of the Manitou Falls Formation (MFa member?) in the Hook Lake core is 48.5 m thick. It comprises a thin basal conglomerate, overlain by interbedded quartz sandstone and pebbly sandstone with interbedded conglomerate in the lower part, capped by a relatively thick succession of pebble-free sandstone. Granulite gneiss below the unconformity is hematized to a depth of about 80 m, but the clay alteration recognized elsewhere in the Athabasca Basin appears to be only weakly developed.

The oncoid-bearing mudstone occurs in the lower part of a 9.5 m thick succession of maroon to brown, cross- and horizontal-laminated, medium- to coarse-grained pebbly quartz sandstone with up to 15 percent interbedded massive conglomerate. Beds are up to 9 cm thick, except immediately above the unconformity, where 35 cm of massive basal conglomerate occurs. Clasts in this basal conglomerate are up to 16 cm in diameter, but those in overlying conglomerate beds are much smaller, from 1.2 to 3.5 cm.

The conglomerate-bearing interval is transitional upwards into a 9 m thick succession of cream-coloured, cross- and horizontal-laminated, medium-grained sandstone in beds up to 11 cm thick, with scattered pebbles and one-clast-thick pebble lag layers. Pebbles continue to fine upward, ranging from 0.3 to 2.5 cm. The pebbly sandstone is overlain in turn by 29 m of cream-coloured, cross-bedded, medium- to coarse-grained sandstone in beds up to 12 cm thick.

The association of conglomerates, pebbly sandstones and sandstones, generally poor sorting, and well-developed horizontal lamination and cross-bedding all indicate a fluvial environment. Similar features have been described in well-exposed basal Manitou Falls (MFa member) strata in the eastern Athabasca Basin, where they were interpreted to be flash flood deposits (Long, 2001; Collier and Yeo, 2001). The scale of the bedding suggests water depths were rarely much more than ten centimetres.

The stratigraphy of the eastern Athabasca Basin is also described more fully elsewhere (Bernier *et al*., 2001; Bernier, this volume; Jefferson *et al.*, 2001; Ramaekers *et al.*, 2001). Only the basal member of the Manitou Falls Formation in the McArthur River area is described here (after Bernier *et al*., 2001). The MFa member in the McArthur River area comprises interbedded conglomerate and sandstone, but is locally variable. Distinctive red mudstones are present in some sections. A thick basal conglomerate (sub-unit MFa0 of Bernier, this volume) commonly lies directly on the unconformity. In DDH RL-92 this contains angular blocks of basement quartzite.

3. The Hook Lake Clay Oncoids

Sample 5101-35 (Figure 2A) was collected at 569.30 to 569.37 m in DDH HK-12. It contained several oncoids in a gritty, mainly massive, red mudstone matrix. The oncoids are equant to elongate in shape, and from 2 to 15 mm long (Figure 2A). They comprise alternating clay-rich and clay-poor laminae (Figures 2B to 2G). The clay-rich laminae are 10 to 50 µm thick (Figure 2G) with a gently curved to crenulated structure (Figures 2E and 2F). The laminae are composed of felted, iron oxide-coated illite flakes up to 20 µm long (Figure 2G). The clay flakes formed diagenetically, but their precursor mineralogy is unknown. The clay-poor laminae are 30 to 70 µm thick (Figure 2G) and composed of quartz silt and scattered clay particles in a sugary mosaic of apatite cement. The apatite commonly shows iron-calcium (siderite?) overgrowths (Figure 2F and 2G). Scattered grains of quartz, iron oxide, rutile, zircon, and ilmenite up to 1 mm in diameter occur within the laminae. The laminae enclose both fragments of older laminated structures (Figures 2B and 2D) and layers of sandy mudstone containing rounded quartz grains up to 1 mm in diameter (Figures 2B and 2C). One-grain-thick sand layers are locally present (Figure 2D).

4. The Read Lake Micro-laminites

Micro-laminated structures were observed in polished thin sections of an intensely silicified breccia of basement fragments at 533.75 m in DDH RL-92, the base of MFa at Read Lake (Figure 3). These micro-laminae are preserved in micro-crystalline quartz, highlighted by hematite, but otherwise strongly resemble laminae in the Hook Lake oncolites.

The micro-crystalline quartz of the laminae contrasts in composition with the coarse sand and silt which makes up much of the matrix of the quartzite breccia. Detrital muscovite and rutile are present as well as quartz. Kaolinite (or dickite) and illite are in the laminae.

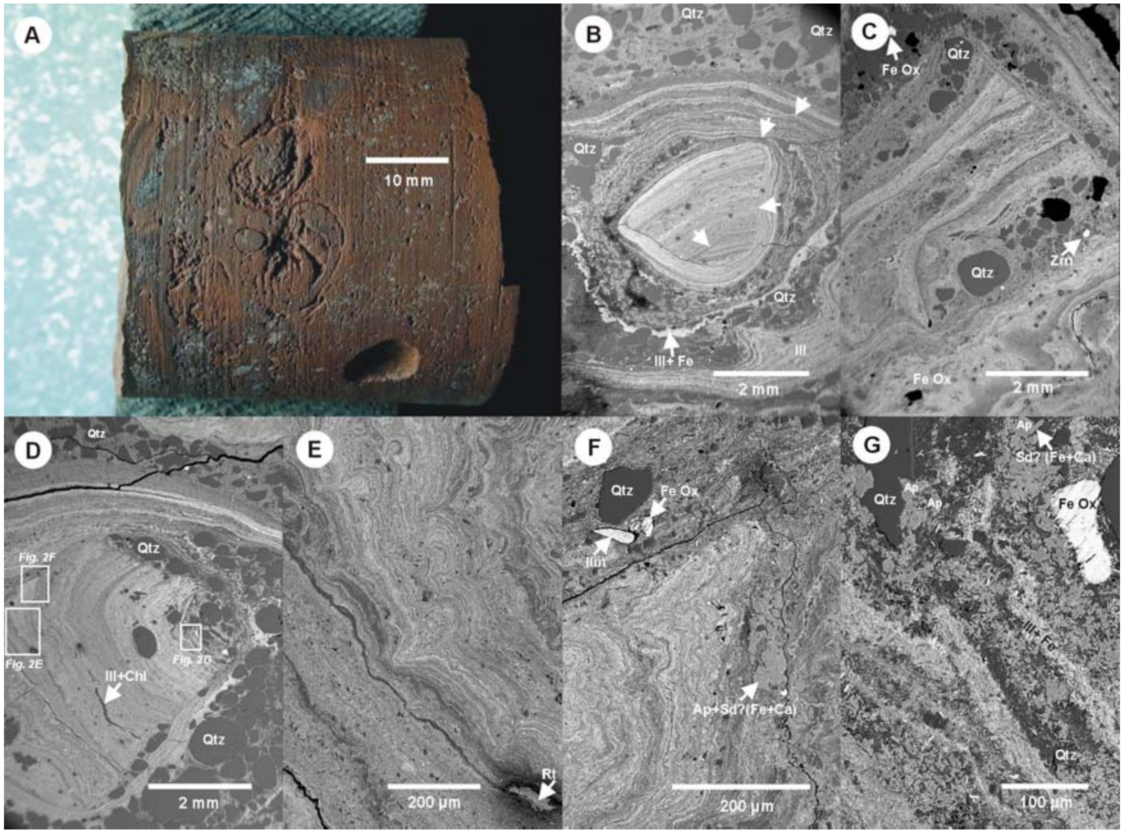

Figure 2 - Saskatchewan Industry and Resources sample 5101-35.
A) Oncoids in HK-12 at 569.3 m, about 1.8 m above the basal Athabasca unconformity (Sask Energy and Mines sample 5101-35). Top is to the left. SEM images 2B to 2G are from thin sections of this sample, and are all oriented stratigraphically right-way-up. B) Back-scattered SEM image (BSI) showing a typical Hook Lake oncoid. Bright areas are iron oxide (probably hematite), and less bright areas are hematite-coated illite (Fe + Ill). In addition to quartz grains (Qtz), detrital micas are present. At least four episodes of truncation and overgrowth of laminae (arrows) are distinguished. C) BSI image of part of a Hook Lake oncoid showing truncation of one set of laminae by another. Most of the fine-grained material is illite. The bright laminae are mainly hematite-coated illite. The quartz-rich layers probably formed during episodes of burial. The bright grain at the right of the image is a detrital zircon (Zrn), whereas the bright grain in the upper left is iron oxide (Fe Ox), possibly magnetite. D) BSI image of a Hook Lake oncoid whose core appears to be a broken stromatolite. The matrix is mainly illite with quartz sand grains. The bright laminae are hematite-coated illite, with late chlorite (Ill + Chl). Note quartz grains concentrated along laminae. The areas of close-up images in Figures 2E to 2G are outlined. E) BSI image showing crenulated lamination of alternating illite and hematite-coated illite in a Hook Lake oncoid. The bright grain in the lower right corner is a corroded rutile grain (Rt).
F) BSI image showing truncation of the crenulated laminae in Figure 2D. The bright grains below the quartz grain in the upper left are probably ilmenite (Ilm) and corroded iron oxide (hematite after magnetite?). Near the right side of the image is an area of apatite cement rimmed and partly replaced by an iron-calcium mineral, possibly siderite (Ap+Sd? (Fe+Ca)). G) BSI image. "Hairy" illite with and without hematite coating (Ill + Fe) predominates in the clay-rich laminae. These alternate with layers containing abundant apatite cement (Ap). The apatite grains commonly have rims of an iron-calcium mineral, possibly siderite (Sd? (Fe+Ca)). The bright, corroded grain at the right is iron oxide (probably hematite after detrital magnetite).

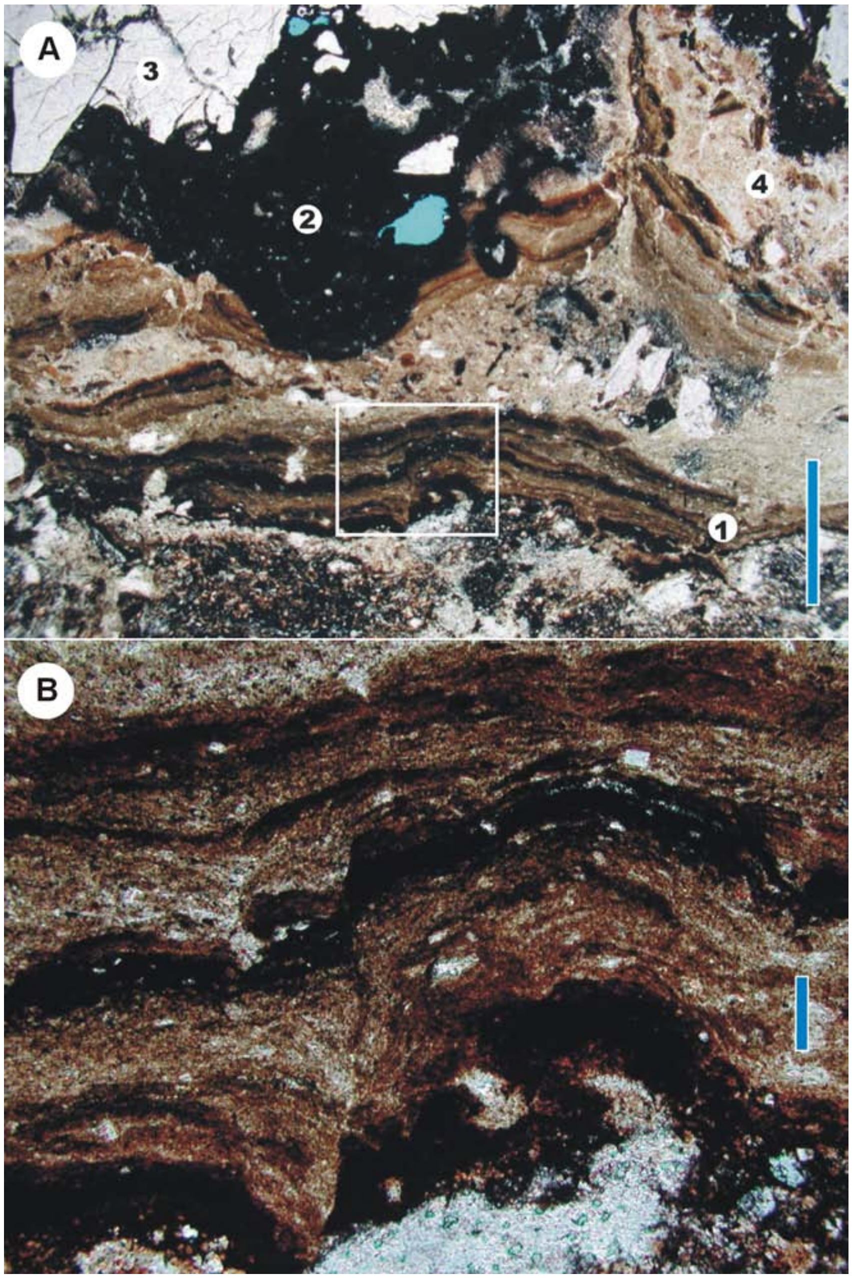

Figure 3 - Sample SBRL092 at 533.75 m.
A) Polished thin section of MFa breccia in plane transmitted light from DDH RL-92 near McArthur River (Figure 1A) showing graded laminae highlighted by hematite concentrations and preserved in micro-crystalline quartz. ① Upward-convex hummocky laminae; ② cross-cutting amorphous quartz with abundant hematite; ③ very angular quartz grain; and ④ brecciated and re-cemented micro-laminae. Box outlines area of Figure 3B. Scale bar is 100 µm. Way up in the core is towards the top of the image.
B) Detail of hummocky micro-laminae in Figure 3A (white box) showing a syn-sedimentary micro-fault overlapped by unbroken laminae. Scale bar is 100 µm.

A composite band of micro-laminae about 9 mm thick appears to have formed above sand and silt and reworked as a clast in the breccia, prior to burial beneath relatively coarse clastic debris (Figure 3A). Angular, quartz-rich clasts nearby also host micro-laminae in vertical and overturned orientations. Thus these laminates were reworked as were the Hook Lake oncolites.

Within the composite band of micro-laminae is a micro-fault which offsets the lower laminae in this structure, but is truncated by the undeformed upper laminae. This must be a syn-sedimentary feature (Figure 3B) and is evidence that the laminae are primary structures. Two orders of laminae are distinguished. First-order dark-coloured laminae are 20 to 120 µm thick, whereas light-coloured laminae are somewhat thicker, from 50 to 220 µm thick. Upward-convex, hummocky structure is developed in some of these. Paleo-growth relief on the laminae is 50 to 150 µm. The first-order light-coloured laminae are composed of second-order light and dark laminae up to 10 µm thick. All are in micro-crystalline quartz, with laminae outlined by sub-microscopic hematite.

5. Discussion

In addition to oncoids, a range of other small, rounded, irregularly shaped, and internally laminated sedimentary structures are known. These include banded soil pisoliths, calcrete pisolites, geyersites, and cave pearls. In contrast with oncoids, they are mainly abiogenic. Banded soil pisoliths (McFarlane, 1976) have concentric lamination (e.g., Gutzmer and Beukes, 1998, Figure 4B) due to uniform outward growth during diagenesis, while oncoids have overlapping laminae due to upward growth of sediment-trapping microbial mats between episodes of reworking. In contrast, calcrete pisolites (Read, 1977) are carbonate structures which typically show evidence of repeated *in situ* brecciation due to desiccation, and whose laminae are commonly due to colour banding. Oncoids are typically associated with current-laid deposits and abundant uncoated grains, whereas calcrete pisolites are not. Geyserites (Walter, 1977) are characterized by very thin (<4 µm) regular lamination. They are associated with hot springs and only form where little clastic sediment is being deposited. The laminations of oncoids and stromatolites are typically an order of magnitude thicker than that of geyserites, and they are invariably associated with clastic sediment. Cave pearls (Thrailkill, 1977) are speleothems or structures precipitated from solution in underground spaces. They are associated with more prominent speleothems, such as stalagmites and stalactites. There is no evidence, however, that the Hook Lake structures may have formed in a subterranean setting.

Although unequivocal evidence for a microbial mat origin (e.g., fossilized sediment-binding microbial filaments) has not been observed in the Hook Lake oncoids, several features suggest such an origin (Schieber, 1999). These include: domal buildups (Figure 2D); anomalous cohesive sediment behaviour (discussed below; Figure 2D); wavy or crenulated laminae (Figures 2E and 2F); and lamina-specific distribution of early diagenetic minerals (Figure 2G).

The stratigraphic setting of the Hook Lake oncoids is remarkably similar to that of Tertiary oncoids in the Skunk Ranch Formation of southwestern New Mexico (Wilson, 1991). There an oncoid-bearing conglomerate unit, overlies red conglomerate and silty sandstone, and is overlain by a tan sandstone. As at Hook Lake, the oncoids are interpreted to have formed in braided river channels.

Segregation of sand grains and clay particles into discrete laminae indicates that the Hook Lake oncoids accreted under variable conditions within the channel pools or billabongs in which they probably formed. Sand grains most likely accreted on the lower surfaces of the oncoids or during episodes of burial. One-grain-thick sand layers (Figure 2D) suggest that the grains were bound to the structures by microbial laminae, rather than attached to sticky organic material or clay. The clay particles likely accreted from suspension on the upper surfaces of the oncoids.

A striking feature of the Hook Lake oncoids is blocky apatite cement in the clay-poor laminae (Figure 2F and 2G). Outside the Wolverine Point Formation, in which apatite cement is locally common, apatite in the Athabasca Basin typically occurs as scattered crystals of goyazite but only rarely as cement (David Quirt, pers. comm., 2002). Apatite stromatolites and oncoids are known from much of the geologic record (e.g., Soudry and Champetier, 1983; Cook and Shergold, 1986; Martin-Algarra and Sanchez-Navas, 1995; Bertrand-Sarfati *et al.*, 1997; Rao *et al.*, 2000). The apatite in these structures was likely produced through diagenesis of phosphate initially concentrated by micro-organisms (O'Brien *et al.*, 1981; Rao *et al*., 2000), and is further evidence of a biogenic origin for the structures. The phosphate concentration of typical micro-organisms is 5 to 10 percent (O'Brien *et al.*, 1981). Clay in the apatite-rich laminae of the Hook Lake oncoids may also be biogenic (Sanchez-Navas *et al.*, 1998). Although apatite overgrowths commonly deform any microbial fossils so that they are difficult to recognize (e.g., Soudry and Champetier, 1983), biogenic apatite microfossils are also among the best-preserved ones known from the Proterozoic (Xiao *et al.*, 1998).

Overgrowth of the apatite in the Hook Lake oncoids by an iron-calcium mineral (siderite?) suggests that the apatite formed relatively early in diagenesis. Hence a radiometric date from the apatite could provide an upper age limit on deposition of the Manitou Falls Formation, presently only constrained by the ca. 1.78 Ga youngest metamorphic age of underlying crystalline basement rocks (Annesley *et al.*, 1999).

Although the Read Lake laminites lack compositional evidence for a microbial mat origin, such as the apatite of the Hook Lake oncoids, their laminae are better preserved, and they do contain structures that suggest microbial origin. These include: domal buildups (Figure 3A), sediment binding and encrusting behaviour (Figure 3B), hummocky laminae (Figure 3A), and laminae-specific distribution of hematite, which must be early diagenetic (Figure 3B). The micro-laminae are similar to those of silicified stromatolites. Alternation of thin dark-coloured laminae and thick light-coloured laminae is also observed in modern fluvial stromatolites and oncolites (e.g., Ordonez and Garcia Del Cura, 1983).

The possible organic origin of these structures was not recognized in the field, but was through petrographic investigation. This suggests that microbial mat structures may be much more common in basal Athabasca strata, but difficult to recognize. These structures record water bodies that persisted long enough for growth of micro-organisms above the sediment-water interface. They also record repeated aquatic reworking and renewed growth of the structures. Organo-sedimentary structures at two localities 230 km apart supports a regional, humid environment for at least the early stages of deposition of the Manitou Falls Formation. Paleo-weathering in such an environment would have been intense, providing an explanation for the quartz- and clay-dominant mineralogy of these strata. The amount of organic material generated during diagenesis by these highly oxidized, organo-sedimentary structures is probably too small to be considered a significant source of hydrocarbons for fixing uranium. This contrasts with the Douglas Formation, parts of which are still oil shale in composition and probably did release fluid hydrocarbons during diagenesis (Stasiuk *et al.*, 2001).

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