COILED CARBONACEOUS MEGAFOSILS FROM THE MIDDLE PROTERozoic OF JIXIAN (TIANJIN) AND MONTANA

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ABSTRACT. Coiled carbonaceous impressions on bedding planes of the 1400Ma Greyson Shale (Belt Supergroup) of Montana and the similarly aged Gaoyuzhuang Formation (Changcheng “System”) of Tianjin are the oldest indubitable megafossils now known. They were first found by C.D. Walcott in the 1890’s; recent discoveries have allowed a much fuller description and interpretation than was possible before. They are all included here in the taxon Grypania spiralis (Walcott) (Walter, Oehler, and Oehler, 1976). Previous interpretations have ranged from non-fossil to metazoan trace fossils, but they are considered here most probably to be eucaryotic algae. No cellular structure has been detected. A record of comparable megafossils of Middle and Late Proterozoic age is gradually being uncovered, consistent with other evidence that eucaryotes evolved at least 1.7Ga ago.

INTRODUCTION

In 1899, C.D Walcott described carbonaceous films and impressions on bedding surfaces of gray shale from the 1400Ma old Greyson Shale and Chamberlain Shale of the lower Belt Supergroup in Montana; he interpreted them as metazoan trace fossils. Referring to Beltina danai, one of the carbonaceous impressions, Raymond (1935, p. 382) wrote that it “is not at all improbable that they are of algal origin, perhaps remains of brown algae, though nothing definite can be ascertained from their structure.” They were regarded by Cloud (1968, p. 55) as “probably algal.” They were redescribed by Walter, Oehler, and Oehler (1976) who concluded that “Although certain of the fossils are problematic, it seems most reasonable to interpret at least Proterotainia and Lanceoforma as remnants of megascopic, eucaryotic algae, and probably related, therefore, to the brown, red, or green algae.” They noted the resemblance of one coiled form, Grypania, to segmented “worms” but concluded nonetheless that an algal affinity was most likely. Because of the lack of cellular preservation or indeed of any structural detail even a eucaryotic origin could not be demonstrated unequivocally. Attempts to relocate Walcott’s collecting localities were unsuccessful because of changes in the region in this century and because of the generality of the available information, and all interpretations had to be based on Walcott’s small collection preserved in the U.S. National Museum. There was very little sedimentological information with the original descriptions. No other examples of the more distinctive fossils were reported.

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from anywhere following Walcott’s original discovery. The fossils are hundreds of millions of years older than any other megascopic body fossils known until recently. For all these reasons the interpretation that they were the remains of megascopic algae was greeted with considerable scepticism (Horodyski, 1986).

Then Du Rulin and Tian Lifu (1985) illustrated but did not name or describe a coiled carbonaceous impression in 1400Ma shale from the Gaoyuzhuang Formation in the type section of the Changcheng “System” at Jixian in Tianjing, near Beijing. They interpreted this as a trace fossil. The formation proved to be a rich source of well preserved examples of these fossils, which were later described and named *Sangshuania sangshuannensis* and *S. linearis* (Du Rulin, Tian Lifu, and Li Hanbang, 1986), although the close similarity to *Grypania spiralis* was noted. In this second paper the importance of these fossils as evidence for megascopic life of this early age was discussed, and it was pointed out that it can be very difficult to differentiate simple metazoan and metaphyte fossils. It was concluded that they most probably are algal. A single fragmentary specimen possibly of *G. spiralis* was described from the Middle to Late Proterozoic of Canada by Hofmann (1985b), who also interpreted it as probably algal; he noted some similarities to other previously described coiled fossils.

Interest in these fossils was increased further when one of us (RJH) started preparing a compilation of Precambrian paleontology of the western United States for a Geological Society of America volume on the Proterozoic of western North America. Having already found carbonaceous films (Walcott’s *Beltina danai*) in shales of the lower Belt Supergroup (Horodyski, 1980) and a single specimen resembling another of Walcott’s fossils during the summer of 1984, he renewed the search for Walcott’s fossils, at first finding only a limited number of specimens of *Grypania spiralis*, then in 1987 discovering horizons where they are relatively common. Approx 300 specimens have been collected. As a result we now have available both better specimens and accompanying sedimentological observations.

Comparison of Walcott’s original specimens and those collected by Du Rulin and Horodyski has shown that they are indistinguishable in all significant features, and that they are clearly genuine megafossils. They are all therefore redescribed here as *Grypania spiralis* (Walcott) Walter, Oehler, and Oehler. Despite the relatively good preservation of the Chinese examples the biological affinities remain elusive.

**JIXIAN**

*Locality.*—The fossils occur in the Gaoyuzhuang Formation on the side of the hill near Sangshuan village in Dahongyu Valley, Xiaying Commune, 28 km north of Jixian town. The Gaoyuzhuang Formation conformably overlies the Dahongyu Formation and is conformably overlain by the Yangzhung Formation (fig. 1), although locally there is a slight disconformity. The Gaoyuzhuang Formation dips uniformly to
Fig. 1. Measured section through the Gaoyuzhaung Formation near Sangshuan Village, Jixian, China. Thicknesses are in meters.
the southeast and is composed of fine sandstone, sandy shale, marly dolomite, dolomite, dolomite with chert bands, and stromatolitic dolomite (fig. 2). These rock types occur in rhythmic alternations. The formation is 1600 m thick, and 7 members are distinguished. The fossils occur in a single 5 to 8 cm thick bed of green or dark gray carbonaceous marly dolomite in the lower part of member 4.

For this research Du Rulin measured a detailed section through the fossiliferous unit. It is described below and shown in figure 2. The strata are very uniform. The fossil stratum occurs in grayish green to dark gray thin pelitic dolomite, which contains a few black carbonaceous shale breaks. The carbonaceous shales and the pelitic dolomite are composed of several rhythmites each of which is 0.5 to 1 m thick. At the base of the rhythmites is silty pelitic dolomite. The rocks overlying and underlying the fossil layer are black thin bedded carbonaceous pelitic dolomite, which contains some pyrite nodules and 1 to 4 percent organic carbon. The columnar stromatolite Eucapsiphora sp. occurs in the dolomite about 0.5 to 1 m above the fossil layer. Bedding is planar and smooth, and there are well developed fine laminations. Some cross lamination has been observed.

Description of the section (from top down, refer to fig. 2):

8. Gray medium bedded pelitic dolomite intercalated with cherty and calcareous dolomite. 19.5 m
7. Gray medium bedded dolomite intercalated with thin bedded pelitic dolomite and dolomite with limestone. 2.8 m
6. Gray to yellowish green thin to medium bedded pelitic dolomite. 6.2 m
5. Green to yellowish green thin bedded pelitic dolomites and stromatolitic dolomite intercalated with black carbonaceous thin bedded pelitic dolomites. 2.6 m
4. Black thin-bedded shaly carbonaceous pelitic dolomite with 1 to 4 percent organic carbon, including in the upper part a 4 to 5 cm thick layer of dolomitic claystone with Grypania. 1.5 m
3. Black thin-bedded shaly carbonaceous pelitic dolomite. 14.3 m
2. Interbedded grayish black siltstone and yellowish green thin-bedded pelitic dolomite. There are 2 to 5 cm thick beds of fine sandstone and pelitic dolomite at the base, with well developed cross lamination in the siltstone. 14.2 m

1. Gray to pink thick-medium bedded fine-grained pelitic dolomite with thin beds of chert. 4.8 m

This is interpreted as a sequence of shallow shelf carbonates. The fossils may have been deposited in a lagoon protected from the open ocean by a stromatolitic barrier bar. The pelitic dolomites may represent the shallow water eulittoral area.

**Age.**—Together with the overlying Jixian and Qingbaikou “Systems” the Changcheng “System” constitutes what formerly was called the Sinian Suberathem, a name now abandoned. Estimates of the age of this sequence are based on the interpretation of the contained stromatolites and on various techniques of geochronology. The data are reviewed in some detail by Chen and others (1980), Hofmann and Chen (1981), Zhu (1982), and Liang and others (1985). The stromatolite assemblages are consistent with the correlation of the Changcheng “System” with the Lower Riphean of the USSR, 1600 to 1350 Ma old. Mica from porphyry intrusive into the lower part of the Changcheng “System” has yielded K/Ar dates of 1817 and 1875 Ma. The Gaobanhe statobound Pb/Zn deposit in the Gaoyuzhuang Formation, in Xinglong County 150 km from Jixian, has yielded model Pb/Pb ages ranging from 1200 to 1550 Ma, with most being around 1400 Ma (Chen, 1985): 1400 Ma seems to be the best current estimate of the age of the formation, but it could be older, and indeed Plumb and James (1986) consider an age of about 1700 Ma to be probable (for reasons that are not stated but presumably relate to the older dates given above).

**Montana**

**Locality.**—Walcott (1899) gave the locality for the coiled fossil that he named *Helminthoidichnites? spiralis* (now *Grypania spiralis*) as “near the mouth of Deep Creek canyon, a short distance above Glenwood post office,” Big Belt Mountains, Montana. The locality for the second coiled fossil, which he named *Helminthoidichnites meekii*, was given as “the grey fissile shale in which *H.? spiralis* occurs.”

The locality where Horodyski found abundant *G. spiralis* is a roadcut in the Greyson Shale along an unpaved road on the north side of the mouth of Deep Creek Canyon and about 100 to 200 m north of U.S. highway 12, Big Belt Mountains, Montana (Universal Transverse Mercator coordinates, zone 12, 5130200 m north and 478500 m east, U.S.G.S. Duck Creek Pass, MT [1950] 15’ Topographic Quadrangle). The fossils occur in medium gray shale, which commonly has a greenish tinge; they are abundant in a layer several millimeters thick, but they also are present in lesser abundance over several meters of section. This probably does not represent the precise locality from which Walcott collected his material as it does not match Walcott’s locality photographs (Wal-
cott, 1915; Yochelson, 1979), and the rocks may not have been well exposed at this site 90 yrs ago. Additional specimens were found in a roadcut along a private road about 50 m to the east. Although more than 300 specimens of *G. spiralis* have been collected from these two localities, no specimens of the larger coiled structure, *H. meekii*, were found at either locality, suggesting that Walcott collected his material from different horizons in this general area.

**Stratigraphy and sedimentology.** — The Belt Supergroup is a thick sequence consisting largely of argillaceous, arenaceous, and impure calcitic and dolomitic rocks, which are exposed in western Montana, northern Idaho, and parts of Washington state, Alberta, and British Columbia (Harrison, 1972). In many areas the total thickness of Belt strata is difficult to determine accurately owing to faulting and incomplete exposure, but thicknesses commonly exceed 5 km and locally exceed 10 km (Harrison, 1972); the maximum reported thickness exceeds 15 km (Wells, 1973, 1974). Most Belt rocks are allochthonous, having been thrust substantial distances in a generally eastward direction during late Mesozoic and early Tertiary time (Harrison, Griggs, and Wells, 1974; Hoffman, Hower, and Aronson, 1976; Mudge and Earhart, 1980). Only the extreme southeastern exposures of the Belt Supergroup are autochthonous. The metamorphic grade of the Belt rocks is highly variable, ranging from sub-greenschist facies in some autochthonous strata (Maxwell, 1974) to sillimanite-muscovite subfacies of the amphibolite facies near the Idaho batholith (Hietanen, 1963, 1968).

The Greyson Shale consists mainly of shale, muddy siltstone, and fine grained sandstone. Most of the Greyson Shale was deposited in an offshore setting, although the uppermost part was deposited in shallower water (Connor, Reynolds, and Whipple, 1984). The fossil-bearing strata discussed in this paper are part of a monotonous sequence of gray to slightly greenish gray shale, muddy siltstone, and laminae and thin beds of very fine-grained sandstone in the middle part of the formation. The strata lack desiccation cracks, mudchips derived from desiccation cracks, and other evidence of subaerial exposure. They also lack hummocky cross-bedding, and except for uncommon and relatively subdued ripple cross-lamination they are not cross-bedded. These strata are interpreted to have been deposited below storm wave base. A lagoonal depositional setting is rejected as there is no evidence for a barrier in this part of the section. They could, however, have been deposited in a protected setting as they occur in the 100 km wide Helena embayment, which extended eastward from the southeastern part of the Belt basin (Harrison, Griggs, and Wells, 1974). Associated with the fossil-bearing strata is a 1 cm-thick limestone unit which contains thickenings ranging from several decimeters to 1 m across and 2 cm or so high. These structures are crudely laminated and initially were considered to be poorly developed stromatolites. However, petrographic studies revealed that the calcite crystals have a lensoid morphology, and they tentively
are interpreted as calcitized sulfate crystals. No other evidence for elevated salinities was observed in the fossil-bearing strata.

Age.—The Belt Supergroup is largely if not entirely of middle Proterozoic age. This is based upon: (1) Belt strata being younger than the metamorphic basement, which has Rb-Sr and K-Ar ages of 1.6 ± 0.1 Ga in southwestern Montana (Giletti, 1966), a K-Ar age of 1740 (Obradovich and Peterman, 1973), and a U-Pb age of 1576 ± 13 Ma in Idaho (Evans and Fisher, 1986); (2) an about 1433 ± 13 Ma U-Pb age for a sill intruding lower Belt rocks in Idaho (Zartman and others, 1982) and a 1455 ± 11 Ma U-Pb age for a sill intruding lower Belt rocks in British Columbia (Hoy, 1989); (3) a 1304 ± 50 Ma Rb-Sr age on a granodiorite stock that intrudes lower Belt rocks in British Columbia (Ryan and Blenkinsop, 1971); and (4) Belt strata being older than the Windermere Supergroup, which unconformably overlies Belt rocks in the northwestern part of the Belt basin and contains basalts having a K-Ar age of between 827 and 918 Ma (Miller, McKee, and Yates, 1973) and a Sm-Nd whole-rock-mineral age of 762 ± 44 Ma (Devlin, Brueckner, and Bond 1988). Ages of 1300 Ma for lower Belt rocks, 1100 Ma for middle and upper Belt rocks, and 900 Ma for uppermost Belt rocks were proposed from Rb-Sr whole rock isochrons obtained from argillites in different portions of the Belt basin (Obradovich and Peterman 1968). Based upon a review of radiometric dates, Harrison (1972) proposed that strata of the Belt Supergroup range from 1400 to 900 Ma old, and Obradovich and others (1984) concluded that the Belt Supergroup ranges from 1500 to 900 Ma old. Hunt (1962) reported an age of ~1.1 Ga K-Ar for a diabase sill intruding the Helena (Siyeh) Formation; the sill was considered to be co-magmatic with a lava higher in the Belt section. However, it has been suggested that this and other young radiometric ages for parts of the Belt Supergroup may be reset ages and that Belt sedimentation terminated between 1300 to 1350 Ma ago (McMechan and Price, 1982). Paleomagnetic data support an age for the Belt Supergroup of 1500 to 1250 Ma (Elston, 1984).

The Greyson shale occurs in the lower part of the Belt Supergroup (fig. 3). Some workers have correlated the upper part of the Pritchard Formation with the Greyson Shale (Winston, 1986), others have correlated it with the Newland Limestone (Harrison, 1972; Connor and others, 1984), and still others maintain that the Pritchard Formation is overlain by the Newland Limestone and Greyson Shale (Thorson, 1984). The 1433 Ma U-Pb age cited above is for a sill intruding the Pritchard Formation in Idaho, the 1304 Ma Rb-Sr age is for a granodiorite intruding the Aldridge Formation (equivalent to the Pritchard Formation) in British Columbia, and the 1455 Ma U-Pb age is for a sill intruding the Aldridge Formation in British Columbia. Considering the age of the basement, the different possible correlations, and different interpretations of the amount of overburden necessary to contain the sill in the Pritchard Formation, it is reasonable to conclude that the Greyson Shale is between 1500 and 1300 Ma old. Extensive paleomagnetic data,
Western Belt Basin  Southeastern Belt Basin
Wallace Formation  Helena Dolomite
St Regis Formation  Empire Formation
Revett Formation  Spokane Formation
Burke Formation  Greyson Shale
Prichard Formation  Newland Limestone
base not exposed  Chamberlain Shale
                       Neihart Quartzite

Fig. 3. Generalized stratigraphy of the lower part of the Belt Supergroup for the western and southwestern parts of the Belt Basin (modified from Harrison, 1972). This is not a correlation chart.

including both polarity reversals and apparent polar-wandering curves, indicate that the Greyson Shale is between 1450 and 1400 Ma old (Elston, 1984).

SYSTEMATICS

Grypania Walter, Oehler, and Oehler, emended

Emended diagnosis Unbranched, ribbon-like, carbonaceous bodies, films or faint impressions on bedding planes, generally in the form of coils or fragments of coils, but also straight, sinuous and cuspate: ribbons up to 2mm wide; rounded terminations rarely observed.

Grypania spiralis (Walcott) Walter, Oehler and Oehler, emended

Figure 4

Helminthoidichnites? spiralis Walcott 1899, Geological Society of America Bulletin, v. 10, p. 236, pl. 24, figs 5,6
Helminthoidichnites meekii Walcott 1899, Geological Society of America Bulletin, v. 10, p. 236, pl. 24, fig. 7
Trace fossil Du Rulin and Tian Lifu 1985, pl. 1, fig. 28
?Grypania spiralis, Hofmann 1985b, Palaeontology 28, p. 349, pl. 39, fig. 4
Sangshuania linearis Du Rulin, Tian Lifu, and Li Hanbang 1986, Acta Geologica Sinica, 1986, no. 2, p. 117, pl. 1, figs 6–9, 12–14
See Hoffman (1985b) for other possible synonyms

Emended diagnosis As for the genus.
Additional description Some new information can be added to the descrip-
Fig. 4. Grypania spiralis from the Gaoyuzhuang Formation (A–I) and the Greyson Shale (J–L) at the localities given in the text. A rounded probably original end to a ribbon is shown excavated in D. Scale bar equivalent to 5 mm for A, B; 10 mm for E, J, K; 15 mm for C, F to I; 8 mm in D; 20 mm in L. J is USNM 448962, K is USNM 448963, L is USNM 448964.
tion provided by Walter, Oehler, and Oehler (1976) as a result of the discovery of additional specimens.

Sangshuania sangshuanensis and S. linearis were distinguished only by the presence or absence of coiling. Du, Tuan Lifu, and Li Hanbang, (1986) noted that they occurred together, sometimes interwined, and that they graded into each other (fig. 4I). Those ribbons with a cuspatel form have cusps the radius of curvature of which is the same as for the coiled forms. The ribbons of contiguous cusps overlap, forming a darker area (fig. 4G). In a small number of examples the preserved segments of ribbons are straight (fig. 4H). The ribbons are 1 to 2 mm wide, the coils are 8 to 18 mm in diameter, and the sinuous forms are up to 130 mm long (without the ends being preserved).

The segmentation faintly apparent on some of the specimens described by Walter, Oehler, and Oehler (1976) is clearer on a number of the Chinese specimens (fig. 4B). The segments are about 1 mm long and are defined by narrow, darker, and somewhat irregular bands set across the ribbons. These are faint in some specimens, prominent in a few, and absent in others. They occur in both coiled and sinous ribbons. What are probably the original ends of the ribbons are rarely observed (fig. 4D). They are smoothly rounded and otherwise featureless.

The newly collected specimens of G. spiralis from the Belt Supergroup generally are shades of gray with some specimens being only slightly darker than the adjacent mineralic matrix. When exposed on bedding surfaces, many of the Belt specimens have somewhat smoother surfaces than the adjacent mineralic matrix, which splits along a surface that is slightly irregular, especially at the microscopic level. Because of these properties the Belt specimens, when viewed in limited number, are not as obviously true fossils as are the Chinese specimens. At one time Horodyski (1986) interpreted them as pseudofossils; however, upon viewing the Chinese specimens he became convinced that the Belt specimens are biogenic and the same as the Chinese material. This view has been reinforced with the collection and study of additional material from the Belt Supergroup.

The Belt specimens of G. spiralis collected by Horodyski range in width from about 0.5 to 1.7 mm (fig. 4J-L). Some of the smaller coils, which are composed of narrow ribbons, are ~5 mm across; however, they may be incomplete. Most of the coils are ~8 to 20 mm across, and rare coils exceed 25 mm across. Little internal detail is exhibited by most of the Belt specimens. Several of the wider ribbons exhibit an indistinct mottled structure, and rare individuals exhibit an apparent segmentation (fig. 4J). In one specimen, where this “segmentation” is prominent, it appears that the organism contracted and broke, possibly along transverse weak zones, into fragments while encased within the sedimentary matrix, or the apparent segmentation could have resulted from degradational collapse of organic material contained within a coherent envelope.
Specimens resembling the sinous form *S. sangshuanensis* have not been found in the Belt Supergroup. However, this apparent absence might be due to the manner in which these shales split. Recognition of such forms requires that the surface of a single lamina be exposed over a distance of 5 cm or more, but such surfaces are rare. The shales do contain some ribbon-like structures with width and surface appearance similar to that of *G. spiralis*, but these structures are linear and do not exhibit any coiling. Studies of the Belt fossils are continuing.

Walcott's (1989) original *Helminthoidichnites? spiralis* and *H. meekii* differ in that the latter is slightly larger and more deeply impressed in the mineral matrix. There is only one small specimen of *H. meekii*. With the much more extensive collection now available it has become apparent that both taxa can be accommodated within the natural range of biological and preservational variation of *G. spiralis*. The deeper impression of this specimen is consistent with the thickness of the Chinese specimens seen in thin sections.

In thin sections cut perpendicular to bedding the Chinese examples of the ribbons can be seen to be about 100 μm thick and clearly defined. Three techniques were used to search for cellular structure: thin sections parallel to bedding, acetate peels, and acid maceration. All failed, although small fragments of the ribbons were found in the macerate; however, they were black, opaque, and apparently structureless. Walter, Oehler, and Oehler (1976) had previously tried scanning electron microscopy, also without success. Analyses by Du Rulin show that the fossiliferous dolomitic claystone from Jixian contains 0.10 to 0.15 percent organic carbon. The low organic carbon contents preclude accurate estimation of thermal maturity, and therefore biomarker analysis has not been attempted.

**Repositories.**—Specimens from the Belt Supergroup are housed in the U.S. National Museum, Washington, D.C.; those from Jixian are in the Hebei Institute of Geology.

**PALEONTOLOGICAL CONTEXT**

Evidence is mounting that eucaryotes had evolved by 1.4 Ga ago (large, thick-walled acritarchs in the Roper Group and the Belt Supergroup) and indeed by 1.7 Ga ago (steranes in the McArthur Group). This is discussed by Summons and Walter (1990) elsewhere in this volume. Evidence for megascopic size in the Middle Proterozoic is still rare (Hofmann, 1985a). Apart from the fossils described here and by Walter, Oehler, and Oehler (1976), it consists of the enigmatic "chains of beads" described from the Belt Supergroup by Horodyski (1982) and from the >1.05 Ga old Manganese Subgroup by Grey and Williams (1990). What these latter are is obscure, and the one of us (RJH) who has studied the Belt specimens is uncertain whether they are truly biogenic; both sets of authors make comparisons with metazoan traces and megascopic algae. The second of these interpretations is strongly supported by Grey and Williams (1990). Hofmann and Chen (1981) report a small
number of megascopic carbonaceous impressions from the Changcheng “System” near Jixian; these are older than those described here. The *Chuaria*-like forms in that assemblage are regarded by Hofmann and Schopf (1983) as only “possibly biogenic,” suggesting the need for some caution in interpreting these objects until more and better preserved specimens are found. There is a growing record of megascopic carbonaceous fossils of probable algal affinity in the Upper Proterozoic (in fact probably extending back to about 1.1 Ga, in the upper Middle Proterozoic), including the distinctive form *Longfengshania*, shaped like a balloon on a string (Du Rulin and Tian Lifu, 1986), and the *Chuaria-Tawuia* assemblage (Hoffmann, 1985a,b). Uppermost Proterozoic sequences often contain the ribbon-like vendotaenids (Gnilovskaya, 1971; Hoffmann, 1985a), which are usually considered to be algae, although they have recently been compared to bacteria (Vidal, 1989). The fossils described here are the oldest indubitable megafossils now known.

**BIOLOGICAL AFFINITIES**

*G. spiralis* occurs in the Belt Supergroup with other carbonaceous impressions that Walter, Oehler, and Oehler (1976) interpreted as probable megascopic, eucaryotic algae. Of *G. spiralis* itself however, they wrote: “*Grypania* appears to lack counterparts among the extant megascopic algae. The apparent segmentation in some specimens of *Grypania* resembles that of segmented worms, but the segmentation is vague and may be a preservational artifact. Moreover, preservation as carbonaceous films is extremely rare for soft-bodied metazoans, but is common for algae and higher plants, suggesting that these fossils most likely represent plant material, perhaps from a type of alga unknown in the modern biota.” The interpretation of all these Belt fossils as eucaryotes was based on their megascopic size and regular shape, although Walter, Oehler, and Oehler (1976) did note that there are regularly shaped megascopic aggregates of some cyanobacteria, and that such an affinity could not be dismissed. Du Rulin, Tian Li Fu, and Li Hanbang (1986) concluded that the Jixian objects are true fossils “probably allied to primitive algae”. The new material confirms the interpretation as megascopic body fossils. It also confirms the presence of segmentation, although whether or not it is primary can still not be demonstrated.

It is our view that the living form of the organism was as a loose coil 0.5 to 2.5 cm wide and maybe 5 to 15 cm long. On death, some individuals were buried such that the axis of the coil was perpendicular to the sediment-water interface (and thus they show the coiled form), whereas others were buried with the axis parallel to the interface (giving the cuspate and sinuous forms). The body was flexible and did not break when folded to generate the cuspate form. In experiments with a range of materials, both natural and artificial, only those with a cylindrical form could be made to kink into a cuspate shape (like a kink in a garden hose). We were unable to make coiled ribbons do this. To achieve this
shape it was necessary to apply both torsion and tension. If this comparison is valid it suggests that one end of each coil was attached to allow tension to be applied, perhaps by water currents. Attachment would also explain why the most common form of preservation is as a coil rather than the linear form; coils attached at the sediment-water interface would be likely to collapse down on themselves on death or burial. We have found no other evidence of attachment, and this aspect of the interpretation must be regarded with particular caution.

We tentatively view these fossils as being of megascopic algae with a cylindrical thallus and a coiled form, but we know of no extant analogues. They were preserved in low energy settings, including quiet lagoons and protected embayments. The fossil-bearing strata in Montana are interpreted here as having been deposited in relatively deep water, below wave base. If this is correct it might suggest that the organisms were either not benthic or not algal (photoautotrophic and therefore requiring light); however, this is not straightforward, as algae occur at considerable depths in clear water. If they were benthic then occurrence in “deep” water encourages comparison with sulfide-oxidizing bacteria such as the extant Thioploca, aggregates of which can reach megascopic size (Vidal, 1989); as far as we know, no such aggregates have the regular, coiled form characteristic of Grypania.

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