The stratigraphic significance of trace fossils from the Lower Paleozoic Baskahegan Lake Formation near Woodstock, west-central New Brunswick

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The first indication of organic activity in Lower Paleozoic siliciclastic turbidites of the Miramichi Terrane has been found in a small quarry at Grafton Hill, near Woodstock, west-central New Brunswick. These previously unnamed turbidites are assigned to the Baskahegan Lake Formation defined in adjacent Maine. The Grafton Hill site has yielded the ichnotaxa *Circulichnis montanus*, *Gordia? marina*, *Helminthopsis hieroglyphica*, *Planolites annularius* and *Planolites montanus*. The presence of *Circulichnus montanus* supports previous circumstantial evidence that a considerable part of the Baskahegan Lake Formation is Early Ordovician in age and substantiates correlation with other quartz-rich peri-Gondwanan sequences elsewhere in the Appalachian-Caledonide Orogen.

La première indication d'une activité organique dans les turbidites silicoclastiques du Paléozoïque inférieur du terrane de Miramichi a été observée dans une petite carrière de Grafton Hill, près de Woodstock, dans la région du centre ouest du Nouveau Brunswick. Ces turbidites non identifiées précédemment sont attribuées à la formation de Baskahegan Lake, circonscrite dans la région limitrophe du Maine. Le site de Grafton Hill contenait des traces fossilisées des espèces *Circulichnis montanus*, *Gordia? marina*, *Helminthopsis hieroglyphica*, *Planolites annularius* et *Planolites montanus*. La présence de l'espèce *Circulichnus montanus* corrobore des observations circonstancielles antérieures voulant qu'une partie considérable de la formation de Baskahegan Lake appartienne à l'Ordovicien inférieur et confirme la corrélation existant avec d'autres séquences lithologiques fortement quartziques en bordure de la Gondwanie ailleurs dans l'orogenèse appalachienne et calédonienne.

Traduit par la rédaction

Introduction

The bedrock geology of the Woodstock-Meductic area, west-central New Brunswick, has most recently been described by Anderson (1968) and Venugopal (1978, 1979, 1981). The latter author provides particularly detailed descriptions of the Paleozoic units underlying the region. The oldest strata in the Woodstock-Meductic area are a sequence of siliciclastic turbidites of presumed Cambrian-Early Ordovician age (Fig. 1). This sequence has never previously yielded fossils of any description, its age being inferred by Anderson (1968) and Venugopal (1979,1981) from its local relationship to stratigraphically overlying Lower Ordovician graptolitic shale and its overall lithologic similarity to known pre-Arenigian sequences in central Maine and New Brunswick (Neuman 1984).

We have examined extensive talus material derived from this Cambrian-Early Ordovician sequence in a small quarry at Grafton Hill on Highway 104, approximately 5 km south of Grafton, opposite the town of Woodstock (Fig. 1). The Grafton Hill quarry exposes medium- to thick-bedded quartz wackes and associated thin-bedded, typically rhythmically layered fine-grained sandstones and laminated mudstones. These lithotypes contain the ichnotaxa documented here. H.J. Hofmann had previously forwarded a rock slab (NBMG 10288) from this site to the senior author for further analysis. The slab was collected by W.H. Forbes and R.B. Neuman in the summer of 1999. We collected two additional trace fossil-bearing slabs from talus in the quarry (NBMG 10287 and NBMG 10289) to supplement the original material. Our two slabs and the one collected by Forbes and Neuman are figured herein (Figs. 2-4), and are now housed in the New Brunswick Museum, Saint John. The purpose of this contribution is to document our findings and to comment on their significance with regard to regional stratigraphy.

Regional Setting

Two tectonostratigraphic assemblages comprise the Woodstock-Meductic area (Fig. 1). The Matapedia Basin, situated to the northwest of the Woodstock Fault, contains deep-water, marine argillaceous carbonates (Carys Mills Formation) and siliciclastic turbidites (Smyrna Mills Formation) of Late Ordovician to Late Silurian age (Bourque *et al.* 1995). The Miramichi Terrane, located to the southeast side of the Woodstock Fault, is characterized by a thick

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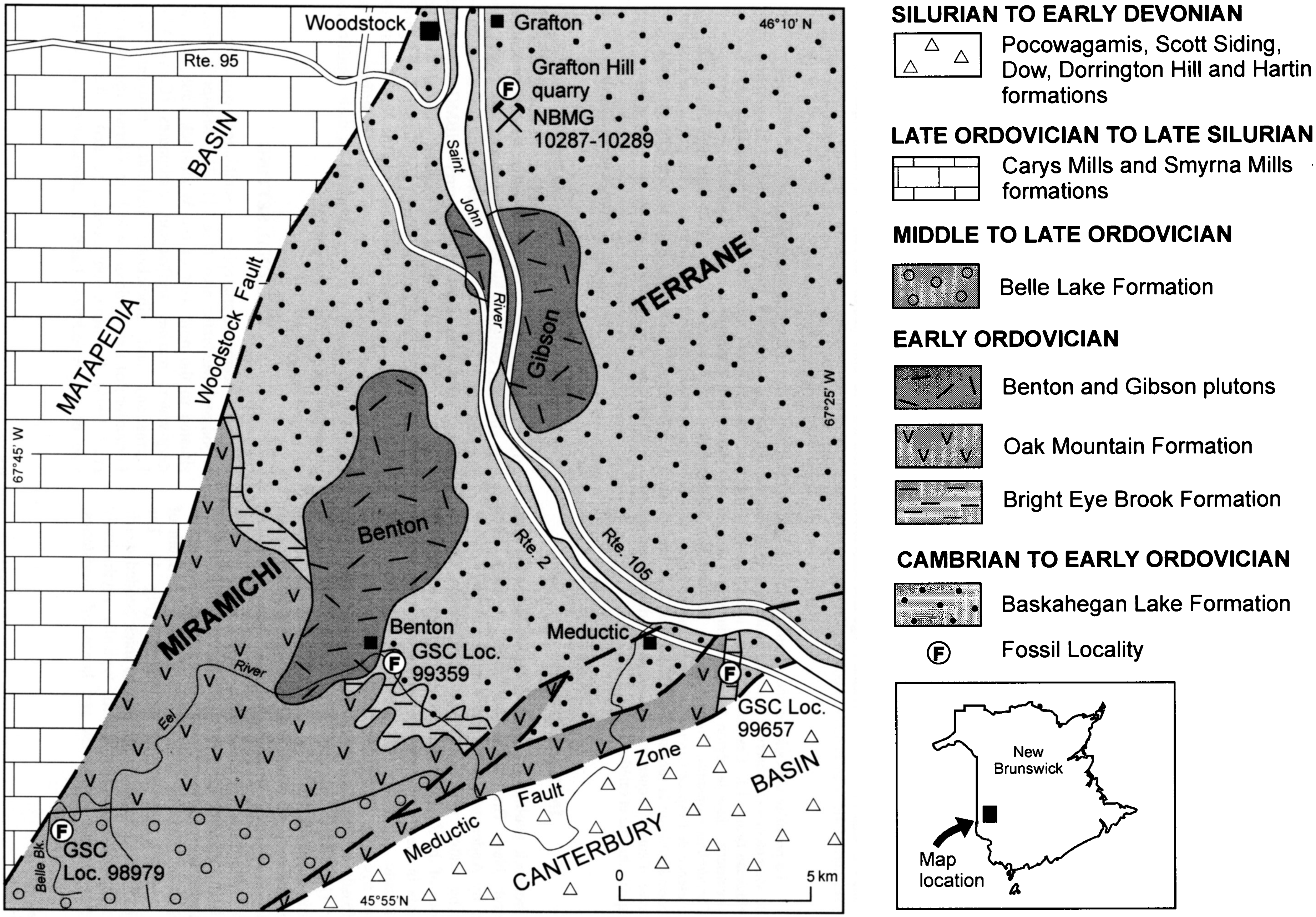

Fig. 1. Simplified geological map of the Woodstock-Meductic area of west-central New Brunswick (after Venugopal 1978, 1979, 1981 and Fyffe 1999) and location of the Grafton Hill road metal quarry on Highway 105, south of Grafton, from where the material documented herein was collected.

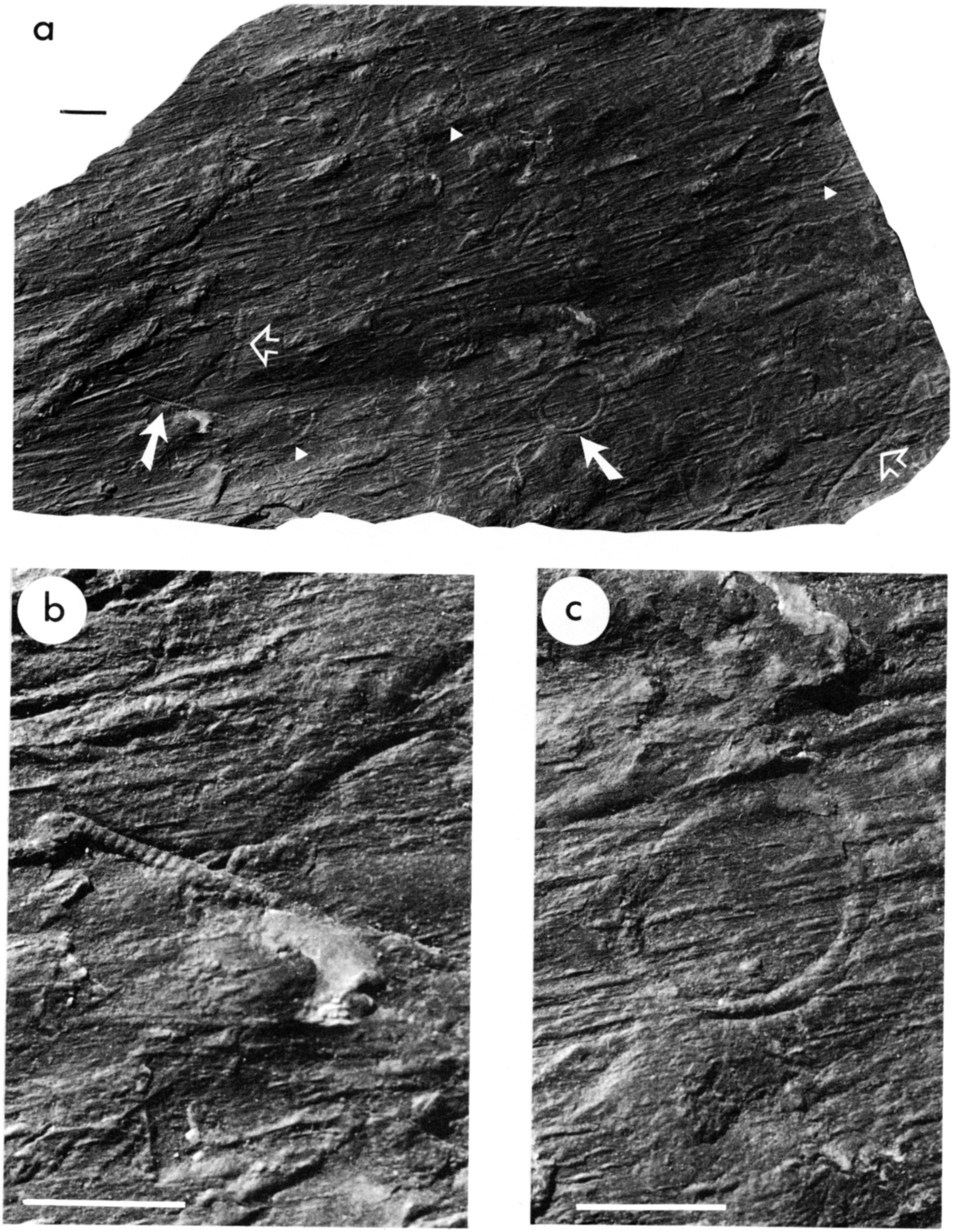

Fig. 2. Sample NBMG 10287. (a) Lower, tool-marked and current-lineated surface of 67 mm thick slab of mudstone/fine-grained sandstone interlayers; paleocurrent from lower left to upper right. Three ichnotaxa are present on this slab, namely *Circulichnus montanus* (several indicated by the larger solid arrow to the right and small arrowheads elsewhere), *Planolites annularius* (solid arrow to the bottom left) and *Planolites montanus* (open arrows). Bar scale is 10 mm. (b) and (c) Enlargements (bar scales 10 mm), respectively, of *P. annularius* and *C. montanus* as indicated by the solid arrows in (a). Note the post-depositional origin of *P. annularius* and the pre- depositional origin of *C. montanus*.

Fig. 3. Sample NBMG 10288. Lower surface of a 55 mm-thick, horizontally laminated mudstone. Three ichnotaxa are present on this slab, namely *Gordia marina* (open arrow), *Helminthopsis hieroglyphica* (solid arrows) and *Planolites montanus* (remaining burrows not indicated by arrows). Bar scale is 10 mm.

succession of quartz-rich turbidites of presumed Cambrian-Early Ordovician age that are overlain by interbedded volcanic and sedimentary rocks of known Early and Middle Ordovician age (Fyffe and Fricker 1987; van Staal and Fyffe 1995a, 1995b). Shallow-water marine conglomerates, limestones, calcareous sandstones and volcanic rocks were deposited in the Canterbury Basin (Rast *et al.* 1980) within the uplifted Miramichi Terrane during the Silurian and Early Devonian. An unconformity between Silurian conglomerate and underlying quartz-rich turbidites is preserved along the southern margin of the basin whereas the Meductic Fault delimits its northern boundary (Fig. 1) The restriction of Silurian debris flows to the northern part of the Canterbury Basin suggests that it formed as a half-graben (Venugopal 1978, 1979; Lutes 1979).

STRATIGRAPHY

The oldest rocks exposed in the Woodstock-Meductic area of New Brunswick are a thick sedimentary sequence comprising the Baskahegan Lake Formation (Ludman 1991; Ludman *et al.* 1993) and the overlying Bright Eye Brook Formation (van Staal and Fyffe 1991). These rocks were mapped in New Brunswick at 1:63 390 scale by Anderson (1968) and in more detail (1:15 480) by Venugopal (1979, 1981). Venugopal (1981) subdivided his unnamed Cambrian-Ordovician sequence into two broad lithological assemblages: (1) grey to greenish grey, thin- to medium-bedded quartz wacke and shale with minor interbeds of red sandstone and shale; and (2) light grey to light green, medium-to thick-bedded quartzite and olive green shale. The wacke beds are normally graded and locally exhibit load casts, current ripples, and flame structures. Ludman (1991) referred to the continuation of these rocks in adjacent Maine as the Baskahegan Lake Formation and we extend this terminology into New Brunswick. He distinguished two members in the Baskahegan Lake Formation equivalent to the two assemblages recognized in New Brunswick and demonstrated that the one containing the redbeds was the older part of the succession. It is apparently the upper member that contains the trace fossils from the Grafton Hill quarry in New Brunswick as no redbeds were observed in the vicinity.

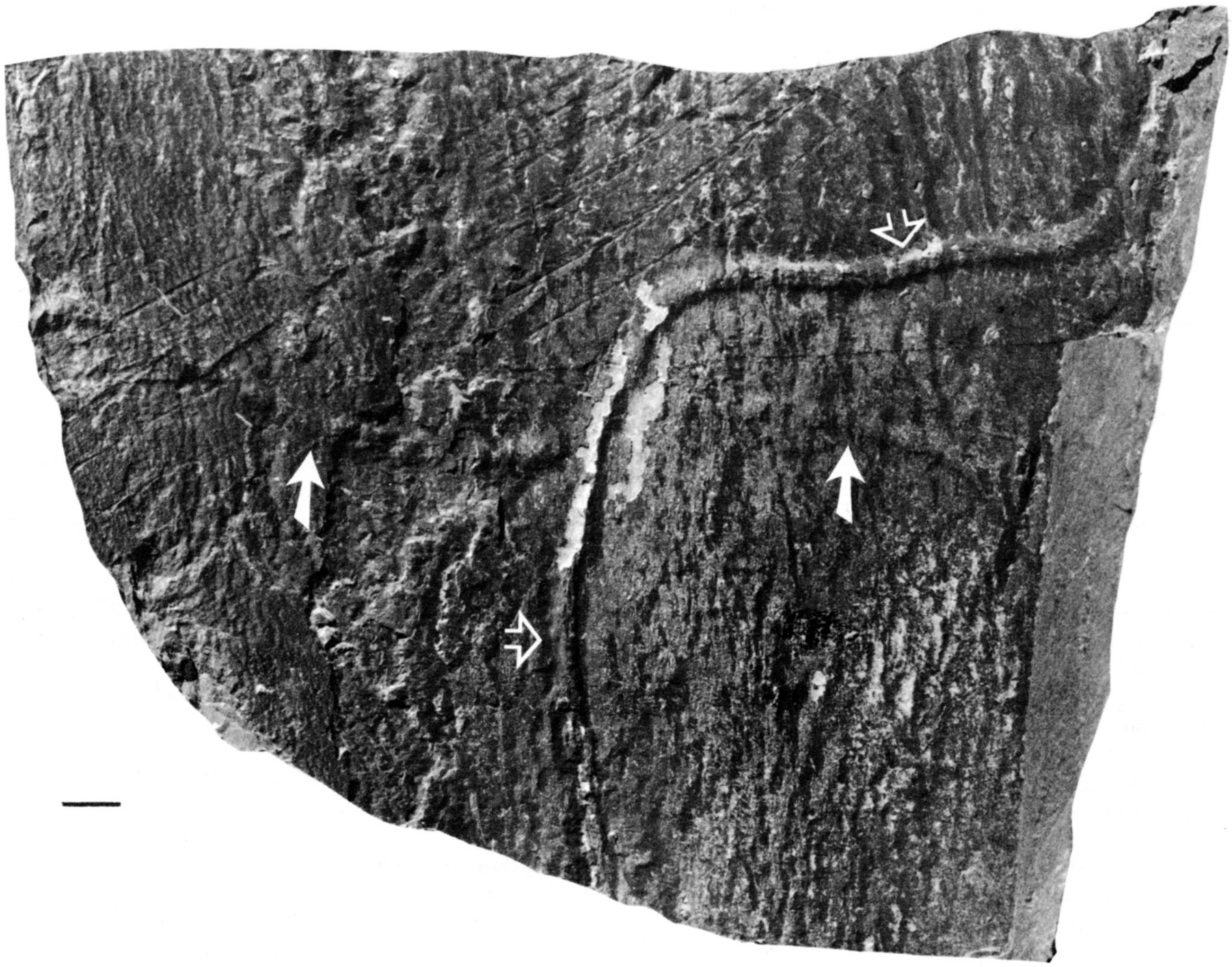

Fig. 4. Sample NBMG 10289. Lower surface of a 35 mm-thick slab of mudstone/fine-grained sandstone interlayers. The slab exhibits at least two examples (solid and open arrows) of *Helminthopsis hieroglyphica*, both preserved in negative epirelief. Bar scale is 10 mm.

The base of the Baskahegan Lake Formation is unexposed but a conformable relationship to black silty mudstones and pyritic shales of the overlying Bright Eye Brook Formation can be observed in New Brunswick on Rte. 2 southeast of Meductic (Fyffe and Pickerill 1993; Fyffe 1994). Graptolites in this section (GSC loc. 99359) restrict the age of the underlying Baskahegan Lake Formation to pre-late Tremadocian (Bailey 1901; Fyffe *et al.* 1983). A conformable relationship between the black shales and mudstones of the Bright Eye Brook Formation and iron-rich sedimentary rocks at the base of the overlying volcanic sequence of the Oak Mountain Formation can be inferred from the gradational lithological and geochemical profiles in the aforementioned section on Rte. 2 (Hennessy and Mossman 1996).

The Oak Mountain Formation contains felsic, intermediate and mafic pyroclastics and flows interbedded with maroon, green and grey mudstones rocks (Venugopal 1978, 1979; Fyffe 1999). The volcanic rocks have a continental calc-alkaline arc geochemical signature (Dostal 1989). Graptolites from the conformably underlying black shale of the Bright Eye Brook Formation indicate that volcanic arc activity in this area began in the Early Ordovician, possibly as early as early Arenigian. The younger (GSC loc. 99657) of the two graptolite assemblages in the Bright Eye Brook Formation was previously identified as middle or late Arenigian (Fyffe *et al.* 1983), but recent reassessment of conspecific graptolite age ranges in the Lévis Formation of the Quebec Lowlands (Maletz 1997) requires its reassignment to the early Arenigian (upper *Tetragraptus approximatus* Zone). The volcanic rocks of the Oak Mountain Formation are overlain by light grey, thin-bedded, feldspathic wacke and medium grey shale of the Belle Lake Formation (Venugopal 1978), Graptolites from the Belle Lake Formation (GSC loc. 98979) belong to the upper *Nemagraptus gracilis* Zone of the early Caradocian (Fyffe *et al.* 1983).

The volcanic rocks of the Oak Mountain Formation are intruded by weakly foliated granitoid rocks of the Benton pluton, northwest of Meductic (Fig. 1). The compositionally and structurally similar Gibson pluton, southeast of Woodstock, intrudes sedimentary rocks of the Baskahegan Lake Formation and is likely cogenetic with the Benton pluton. The Gibson pluton has been dated by Bevier (1989) as late Arenigian (U-Pb age of 473±1 Ma) based on the time-scale of Tucker and McKerrow (1995), providing strong evidence that arc volcanism and plutonism in west-central New Brunswick was essentially coeval. Deposition of the Caradocian sedimentary rocks of the Belle Lake Formation, therefore, post-dated both the eruptive and intrusive activity.

SYSTEMATIC ICHNOLOGY

Following conventional procedure (e.g., Häntzschel 1975), the ichnotaxa identified from the Grafton Hill quarry are described alphabetically. Preservation terminology follows that of Seilacher (1964) and Häntzschel (1975).

Ichnogenus *Circulichnus* (Vialov, 1971)
Type ichnospecies: *Circulichnis montanus* Vialov, 1971
***Circulichnus montanus* Vialov, 1971**
Figure 2a, c

Material: Four, possibly several smaller examples, on NBMG 10287.

Description: Smooth, completely or incompletely preserved, elliptical traces preserved in positive hyporelief on the sole of a 67 mm-thick slab of tool marked and current lineated mudstone/fine-grained sandstone interlayers. Geometry, orientation and ellipse size are variable, with a maximum (x) axis of 24 mm. Individual traces possess a fill of similar grain size to the lowermost preserving sandstone layer, are unlined, internally structureless and consistently 1.6 mm in observable diameter apart from areas where they have been partially exhumed by current activity. The possible smaller examples have been extensively eroded; as a result they cannot confidently be assigned to this ichnotaxon.

Remarks: The orthography of *C. montanus*, a monoichnospecific taxon, was recently addressed by Keighley and Pickerill (1997) who concluded that while the correct ichnogeneric descriptor *Circulichnus* should be adopted, the type ichnogenus should still be retained as *Circulichnis* (I.C.Z.N. 1985, Articles 11g, 26, 30a, 32c, i). The examples documented here are clearly pre-depositional in origin as they are intersected by current-produced structures. Currents were presumably also responsible for the variable erosion of individual specimens and the almost complete removal of suspected smaller examples.

Ichnogenus *Gordia* Emmons, 1844
Type ichnospecies: *Gordia marina* Emmons, 1844
***Gordia? marina* Emmons, 1844**
Figure 3

Material: One specimen on NBMG 10288.

Description: Smooth, unlined, unbranched, internally structureless, self-crossing, looped trace preserved in positive hyporelief on the sole of a 55 mm-thick horizontally laminated mudstone. Trace diameter is 0.8 mm; fill of similar grain size to enclosing host rock. Total area covered is approximately 10 mm^2.

Remarks: Because of the small size and surface area of this specimen, its ichnogeneric assignment is regarded as tentative. However, we do questionably favour an assignment to *Gordia* rather than *Helminthoidichnites* Fitch, the only morphologically similar ichnotaxon but with a less sinuous course, and reduced and more open loops (Hofmann and Patel 1989; Uchman 1998). If our ichnogeneric assignment is correct, the specimen can undoubtedly be referred to the ichnospecies *marina*, as the two other valid ichnospecies, *G. arcuata* Książkiewicz and *G. nodosa* Pickerill and Peel, are decidedly different morphologically (see Książkiewicz 1977; Pickerill and Peel 1990; Keighley and Pickerill 1997; Uchman 1998). Alternatively, if this specimen were regarded as *Helminthoidichnites*, a monoichnospecific and little used ichnotaxon, it would require assignment to *H. tenuis* Fitch. The upward-directed extremities of the trace suggest a post-depositional origin.

Ichnogenus *Helminthopsis* Heer, 1877
Type ichnospecies: *Helminthopsis hieroglyphica* Wetzel and Bromley, 1996
***Helminthopsis hieroglyphica* Wetzel and Bromley, 1996**
Figures 3, 4

Material: Four examples, two on NBMG 10288 (Fig. 3) and two on NBMG 10289 (Fig. 4).

Description: Horizontal, irregularly meandering, unbranched burrows or trails preserved in positive/ negative (NBMG 10288) and negative (NBMG 10289) epirelief, the former on the same surface as *G.? marina* and the latter on a 35 mm-thick slab composed of interbedded mudstone and thin, fine-grained sandstone layers. Individual traces exhibit generally broad and low amplitude, irregular meanders separated by straight segments. They are unlined, internally structureless, and those on NBMG 10288 possess a fill similar in grain size to the enclosing host rock. Length is variable, up to a maximum of 170 mm; width, consistent in single specimens, is 5 and 3.5 mm on specimens on NBMG 10289 and 0.35 mm on NBMG 10288.

Remarks: Recent discussion on *Helminthopsis* and its many historically defined ichnospecies has been presented by Han and Pickerill (1995), Wetzel and Bromley (1996) and Uchman (1998). Despite the slightly conflicting conclusions of these authors regarding its taxonomically valid and useful ichnospecies, all were in agreement that *H. hieroglyphica* is characterized by broad and low amplitude, irregular meanders interspersed with straight segments, a conclusion also supported herein. Accordingly, the specimens are assigned to *H. hieroglyphica*. A pre- or post-depositional origin for these specimens cannot confidently be ascertained though we do suspect that those on NBMG 10288 are post-depositional.

Ichnogenus *Planolites* Nicholson, 1873
Type ichnospecies: *Planolites vulgaris* Nicholson and Hinde, 1875
***Planolites annularius* Walcott, 1890**
Figure 2a, b

Material: One specimen on NBMG 10287.

Description: Straight, smooth, unlined, unbranched, horizontal burrow, somewhat flattened, 23 mm in length and 1.5 mm wide, preserved in positive hyporelief on the sole of NBMG 10287 (see *C. montanus* for details). The burrow is characterized by regularly spaced, 0.3 mm wide, annulations oriented slightly obliquely to its long axis. Small size precludes determination of its fill, though this appears to be similar to the host rock.

***Planolites montanus* Richter, 1937**
Figures 2a, 3

Material: Numerous specimens on NBMG 10287 and 10289.

Description: Straight, curved, or rarely slightly sinuous, smooth, unlined, internally and externally structureless, horizontal traces preserved in convex (typically) or concave hyporelief. Fill is similar in grain size to the host strata. Diameter, consistent in single specimens, varies from thread-size to 1.5 mm; length is variable, typically short, up to 35 mm.

Remarks: In contrast to *Gordia* and *Helminthopsis,* the morphologically simple burrow or trail of *Planolites* is neither self-crossing (as in *Gordia*) nor irregularly meandering (as in *Helminthopsis*). Its various ichnospecies, though somewhat subjectively defined (Stanley and Pickerill 1994), are essentially distinguished on course, diameter and, particularly, wall characteristics (see Pemberton and Frey 1982; Stanley and Pickerill 1994; Keighley and Pickerill 1995). Accordingly, the material documented herein can readily be assigned to both *P. annularius* and *P. montanus*.

The orthography of *P. annularius* was addressed by Fillion and Pickerill (1990) who noted that Walcott's (1890) original epithet *'annularis'* was grammatically incorrect. Despite this it continues to be adopted by several authors (e.g., Pacześna 1996) and so we reiterate that the correct descriptor is *'annularius'*. The example on NBMG 10287 is clearly a post-depositional burrow as it post-dates the primary current lineations on this surface. Though considerably smaller in diameter than previously reported examples (e.g., Osgood 1970; Pemberton and Frey 1982; Crimes and Anderson 1985), Pickerill (1994) concluded that size is not a reliable ichnospecific criterion. As such we therefore confidently assign the specimen to *P. annularius*.

P. montanus, arguably the most commonly occurring and reported ichnospecies of *Planolites*, is also likely post-depositional in origin. This is suggested by specimens that intersect primary current lineations on NBMG 10287 and by its preservation in both convex and concave hyporelief on NBMG 10289.

Discussion

As noted, no fossils have previously been recorded from the Baskahegan Lake Formation of west-central New Brunswick and adjacent Maine. Although organic remains are absent, it is clear that benthic organisms were responsible for the production of the pre- and post-depositional ichnotaxa documented herein, all likely produced by vagile vermiform epifaunal and infaunal deposit feeders, most probably annelids. Regrettably, all these ichnotaxa are eurybathic forms and cannot be utilized as specific paleoenvironmental indicators. However, their presence indicates that deposition occurred in an environment above the oxygen minimum zone (OMZ-see Brenchley and Harper 1998). This is consistent with the interpretation of Venugopal (1981), who concluded that the sequence represents a "proximal" turbidite succession and, therefore, one in which sufficient oxygen levels to sustain benthic organisms should have been available.

Being relatively simple structures, the described ichnotaxa have an extensive stratigraphic range and are therefore generally of little use in biostratigraphy. With one exception, all have previously been recorded, on a global basis, from Vendian to Holocene strata (Crimes 1994). The exception is *Circulichnus montanus*, which globally has only been recorded from Ordovician to Paleocene strata (Buatois *et al.* in press). In eastern Canada, it has been documented from the Middle Ordovician Trenton Group of Quebec (Fillion and Pickerill 1984), the Ordovician (Tremadocian) Halifax Group of Nova Scotia (Pickerill and Keppie 1981), the Ordovician (Tremadocian to Arenigian) Bell Island and Wabana groups of eastern Newfoundland (Fillion and Pickerill 1990), and the Carboniferous (Namurian to Westphalian A) Mabou and Cumberland groups of western Cape Breton (Keighley and Pickerill 1997). Broadly similar structures occur in strata as old as the Vendian (Pacześna 1996) but these possess a vertical spiral component with concomitant incomplete loops and therefore are more appropriately and correctly assigned to *Gyrolithes polonicus* Fedonkin. Accordingly, this suggests that at least the upper part of the Baskahegan Lake Formation is Ordovician in age. The only other alternative would be to extend the range of *C. montanus* into the Cambrian, and we are reluctant to do this given the number of previous recordings to the contrary. Because of structural complexities, it is impossible to ascertain the specific stratigraphic level represented in the quarry. However, lithologically the strata appear to belong to the upper member of the Baskahegan Lake Formation as defined by Ludman (1991). It is, nevertheless, quite possible that part of the siliciclastic sequence, in particular the lower member, extends down into the Cambrian.

As outlined above, the Miramichi Terrane of the Woodstock-Meductic area includes a thick succession of quartz-rich sedimentary rocks (Baskahegan Formation) and conformably overlying Lower Ordovician continental arc volcanic rocks (Oak Mountain Formation). A slightly younger back-arc volcanic sequence (Tetagouche Group) unconformably overlies similar sedimentary strata (Miramichi Group) in central and northeastern New Brunswick (van Staal *et al.* 1991; van Staal and Fyffe 1995a; 1995b). The age of the siliciclastic turbidites that characterize the Miramichi Group had previously been considered to be as old as Precambrian, based on lithological correlation with other poorly dated sequences found elsewhere along the southeastern margin of the Appalachian-Caledonide Orogen (Rast *et al.* 1976). However, recent fossil discoveries indicate that many of these peri-Gondwanan terranes are in fact early Paleozoic in age. Tracts of generally quartz-rich turbidites with thicknesses up to 5 km, including the Skiddaw Group in the English Lake District (Cooper *et al.* 1993), the Manx Group on the Isle of Man (Molyneux 1999), and the Ribband Group of southeastern Ireland (McConnell *et al.* 1999) are all largely, if not entirely, of Early Ordovician age based on new paleontological evidence.

The lower limit of the known age range of *C. montanus* strongly supports correlation of the Baskahegan Lake Formation with the Ordovician successions in the Lakesman Terrane (Gibbons and Gayer 1985) of northwestern England and southeastern Ireland. If previous correlations with the Grand Pitch Formation in Maine and Bray Group in southeastern Ireland (Rast *et al.* 1976) are correct, then the lower member of the Baskahegan Lake Formation may be Early to Middle Cambrian based on the presence of the trace fossil *Oldhamia* in redbeds of the former units (Hofmann and Cecile 1981). It thus seems likely that an extensive passive margin in the northeastern Appalachians was continually receiving an abundance of compositionally mature quartz-rich sands from the Gondwanan continent from the Early Cambrian to the Early Ordovician.

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