Trace fossils in a Lower Palaeozoic submarine canyon sequence — the Siegas Formation of northwestern New Brunswick, Canada

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The Siegas Formation (Silurian - early Llandovery) of northwestern New Brunswick represents, in part, an ancient example of a submarine canyon sequence, erosive into and partially coeval with the Carys Mills Formation of late Ordovician—middle Llandovery age. The canyon succession contains a moderately diverse ichnofauna consisting of *Buthotrephis*, *Chondrites*, *Cochlichnus anguineus*, *Diplichnites*, *Fucusopsis*, *Gordia arcuata*, *Gordia*, *Gyrochorte*, *Helminthoida labyrinthica*, *Helminthopsis* cf. *abeli*, *Neonereites biserialis*, *Neonereites uniserialis*, *Planolites beverleyensis*, *Protopaleodictyon*, *Scalarituba missouriensis* and *Skolithos*. These trace fossils are described in detail.

Contrary to previous predictions that dwelling burrows and associated traces would predominate in submarine canyon sequences, the Siegas Formation contains traces produced essentially by vagile sediment eaters. This is perhaps best explained by the absence within the canyon, at least for the majority of time, of sufficiently strong bottom currents, which precluded inhabitation by an active and abundant suspension feeding population. Instead, the sediments probably contained sufficiently abundant organic detritus to support an active population of infaunal sediment feeding organisms.

Située au nord-ouest du Nouveau-Brunswick, la formation de Siegas (Silurien — Llandovery inférieur) représente, en partie, un exemple ancien de séquence de canyon sous-marin; elle recoupe la formation de Carys Mills (Ordovicien supérieur — Llandovery moyen) et est en partie contemporaine à cette dernière. On rencontre dans la séquence une ichnofaune modérément diverse comprenant *Buthotrephis*, *Chondrites*, *Cochlichnus anguineus*, *Diplichnites*, *Fucusopsis*, *Gordia arcuata*, *Gordia*, *Gyrochorte*, *Helminthoida labyrinthica*, *Helminthopsis* cf. *abeli*, *Neonereites biserialis*, *Neonereites uniserialis*, *Planolites beverleyensis*, *Protopaleodictyon*, *Scalarituba missouriensis* et *Skolithos*. Ces traces fossiles sont décrites en détail.

Selon les prédictions antérieures, les terriers d'habitation et les traces connexes devraient prédominer dans les séquences de canyon sous-marin mais contrairement à ceci, la formation Siegas contient plutôt des traces produites essentiellement par des ingesteurs de sédiment vagiles. Au mieux, ceci pourrait s'expliquer par l'exclusion d'une population active et abondante d'animaux filtreurs, due à l'absence dans le canyon, au moins la plupart du temps, de courants de fond significatifs. Au lieu de cela, les sédiments devaient contenir suffisamment de détritus organiques pour accomoder une population active d'organismes endobiontes limnivores.

[Traduit par le journal]

INTRODUCTION

Oceanographic research has demonstrated that penetration and stirring of sediment by benthic and other organisms is a common phenomenon in modern submarine canyons (e.g. Shepard and Dill 1966, Trumbull and McCamis 1967, Dillon and Zimmerman 1970, Heezen and Hollister 1971, Scott and Birdsall 1978, Valentine *et al.* 1980). Yet little research has thus far been undertaken on the nature of trace fossils and trace fossil assemblages in ancient submarine canyon sequences. In part this has arisen from the inherent difficulties of recognizing ancient submarine canyons but also by research workers placing more emphasis on their detailed facies associations and sediment emplacement mechanisms (e.g. Stanley and Bertrand 1979).

One exception is the recent documentation by Hayward (1976) of the trace fossils from a Miocene submarine canyon sequence in New Zealand. Hayward described *Tigillites*, *Scalarituba*, *Planolites* and branching "*Planolites*"*, from the unconsolidated sediments of the canyon floor and *Tigillites*, *Rhizocorallium* and several varieties of horizontal and inclined branching burrows from the semiconsolidated but unlithified canyon walls. More recently Crimes (1977) produced a table which, in part, recorded both the known and anticipated ichnofaunas of ancient submarine canyon sequences. This

* Strictly speaking branching forms are not available for the ichnogenus *Planolites* (Häntzschel 1975).

paper is therefore intended to document the trace fossils occurring in an ancient submarine canyon sequence and to add to the data presented by Crimes (*ibid.*) so that eventually more realistic and predictable models will be realized. The definition of a submarine canyon adopted here is the same as that proposed by Heezen and Hollister (1971) i.e. "any persistent valley found on the continental margin regardless of shape or size", or alternatively but less specifically, following Bates and Jackson (1980), a "general term for all valleys of the deep-sea floor".

STRATIGRAPHIC BACKGROUND

Strata under consideration in this paper are referred to as the Siegas Formation of Hamilton-Smith (1970), which crops out in the Siegas area of northwestern New Brunswick (Fig. 1). The formation occurs within a (now) relatively narrow northeast-southwest elongate trough which extends from Gaspé through New Brunswick and into Maine and termed the Central
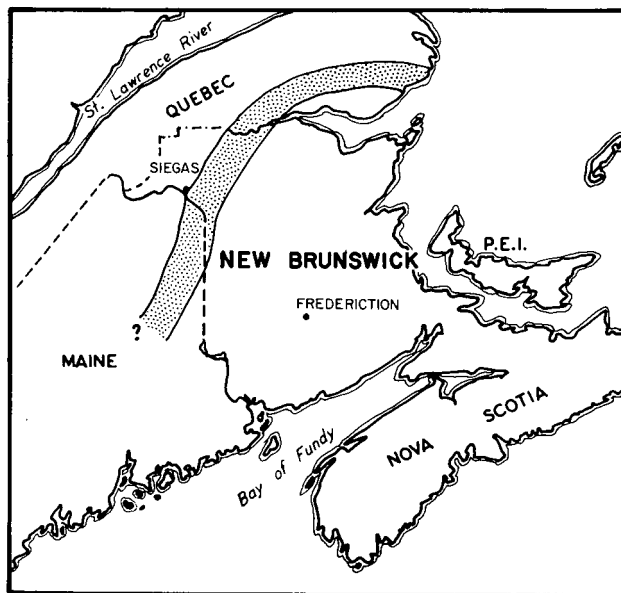

Fig. 1 - The Aroostook-Matapedia Carbonate Belt (stippled) of Gaspé, northwest New Brunswick and northeast Maine.

Clastic Belt and/or Aroostoock-Matapedia Carbonate Belt by Ayrton *et al.* (1969). In terms of recently proposed plate tectonic models (Rast and Stringer 1980) the trough represents a remnant of the Lower Palaeozoic Iapetus Ocean.

The Siegas Formation is of restricted areal extent, persisting some 11 km to the north and north west of Siegas and 9.5 km to the south and southeast. In thickness it ranges from between c. 107-244 m in the Siegas area to zero at its northwestern and southeastern limits where it passes into coeval strata of the Carys Mills Formation (Hamilton-Smith 1971a).Both this latter formation and the Siegas Formation are conformably overlain by the Perham Group of post-early Llandovery to early Ludlow age (Hamilton-Smith 1970, Roy and Mencher 1976).

Fragmentary brachiopod faunas recognized by Ayrton *et al.* (1969) have indicated an early Llandovery age for the Siegas Formation.

SEDIMENTOLOGY AND
DEPOSITIONAL ENVIRONMENT

The sedimentology and depositional environment of the Siegas Formation has been studied in detail and succinctly described in a series of papers by Hamilton-Smith (1971a, 1971b, 1980). This section presented below therefore summarizes the major conclusions of Hamilton-Smith together with observations made by the present author. In view of the purpose of this paper, only a brief summation will be presented here, and the interested reader is referred to the above papers for a more detailed appraisal and for detailed geological maps of the area.

Detailed mapping of the Siegas area by Hamilton-Smith (1970) de-

monstrated that in the north and northwestern part of the area the Siegas Formation was erosive into the underlying Carys Mills Formation. The depth of erosion was estimated to be in the order of between 25-50 m, i.e. comparable to known erosional depths of many present day small submarine canyon systems (see Shepard and Dill 1966, Whitaker 1976, etc.), and much larger than reported modern and ancient inner and middle fan channels (see Walker and Mutti 1973). This, combined with a detailed sedimentological appraisal, led Hamilton-Smith (1971b) to suggest that in the north and northwestern part of the area, the Siegas Formation represented a submarine canyon-fill. Indeed, the absence of thinning and fining upward sequences and thickening and coarsening upward sequences, characteristic of mid-fan and suprafan lobes respectively, combined with the nature of the sediments, do suggest deposition in an extremely 'proximal' environment comparable to many modern-day and ancient submarine canyon systems (see Middleton and Bouma 1975, Whitaker 1976, Stanley and Kelling 1978 and Doyle and Pilkey 1979).

Although it is difficult to generalize on the nature of these sediments, particularly as there are demonstrable proximal-distal relationships across the entire studied area, the canyon – fill strata or the 'lithic wacke facies' of Hamilton-Smith (1970) exhibit the following characteristics.

(i) Organized and disorganized matrix-supported conglomerates up to 8.5 m in thickness. Clasts are dominantly of limestone but also include slate, chert and mafic volcanics, and the matrix is generally mud and/or fine silt. Many of the organized conglomerates are erosive (a maximum of 2 m having been observed), normally graded and/or imbricated and contain clasts up to 80 cm in diameter. In others, the preferred clast orientation is essentially parallel to bedding, similar to those recently described by Keith and Friedman (1977) from canyon and slope channelized and, or, sheet flow deposits from the Cambrian of New York and Vermont.

The graded and imbricated varieties are interpreted as the product of deposition from turbulent flows (turbidity currents) whereas the other varieties were probably produced by various forms of mass flow, such as debris flow or from incoherent slumping to a complex sliding of relatively coherent lenticules one over another with most of the shear stress concentrated near lenticule margins Hamilton-Smith 1980). Conglomerates resembling those described briefly here have been mentioned in the literature quite extensively (see Walker and Mutti 1973 and Walker 1975 for a review) and are considered by the majority of authors to be characteristic of submarine canyon or inner fan channel deposits. This lithofacies association constitutes some 13% of the succession (Hamilton-Smith 1970).

(ii) Medium – coarse sandstones up to 2.75 m in thickness and dominated by varieties exhibiting complete and/or partial Bouma sequences. These sandstones exhibit a variety of sole features including ripples, flutes, tools, loads and gutter casts and are typically graded. Convolute lamination is also commonly developed. They are clearly a product of deposition by turbidity currents in a 'proximal' regime. Other sandstones are massive, internally structureless, and contain outsize pebble and cobble carbonate clasts

randomly distributed throughout. Since there are no fluid escape structures the origin of these beds may possibly be explained by several processes: (i) deposition under upper flow regime, (ii) shearing by loosely compacted sediment, (iii) deposition by a rapidly decelerating current that failed to produce an equilibrium bedform (cf. McCabe 1978), (iv) fluidized sediment flow, (v) late stage fluidization during deposition of a turbidity current deposit. Irrespective of their origin, they are still considered by other authors (e.g. Keith and Friedman 1977) to be indicative of 'proximal' environments. The sandstone lithofacies constitute some 72 % of the succession (Hamilton-Smith 1970).

(iii) The remaining 15% of the succession is composed of thinly bedded laminated and cross-laminated small-scale micaceous and calcareous siltstones and shales with minor carbonates and cherts. These beds probably represent the end products of material reworked by normal bottom currents within the canyon and deposition of pelagic and hemipelagic material carried into deeper water by contour currents, nepheloid layers and, or, dilute turbidity currents. Both processes are active in many modern submarine canyons (see Stanley and Kelling 1978) and produce similar lithofacies. It is within these sediments that, in fact, Hamilton-Smith (1970) made reference to the "obscure trails" described in detail in this paper.

Further evidence that the 'lithic wacke facies' of Hamilton-Smith (1970) represents a submarine canyon-fill is afforded by a more regional and paleocurrent analysis of the Siegas Formation and coeval strata. The Siegas Formation was derived from the north and northwest (Hamilton-Smith 1971a), whereas the coeval Carys Mills Formation, into which the former is erosive, was, in the immediate area, derived from the northeast. The Carys Mills Formation has been recently interpreted by Stringer and Pickerill (1980) and Rast and Pickerill (in preparation) as a succession of contourites deposited by deep thermohaline currents on a slope which paralleled the ancient basin margin. The Siegas Formation is therefore a deep channel or submarine canyon which is cut approximately perpendicular into the slope succession of the Carys Mills Formation.

The canyon-fill strata are, unfortunately, generally poorly exposed, though an excellent and almost completely exposed sequence is present in the Siegas Quarry (EMH 558 of Hamilton-Smith 1970). Here approximately 230m of strata are continuously exposed and it is from here that the majority of trace fossils described herein were located. Exposures elsewhere are essentially 2-dimensional and somewhat inadequate for the purpose of detailed ichnological analysis.

SYSTEMATIC DESCRIPTIONS

For ease of reference, trace fossils in the Siegas Formation are described alphabetically (cf. Häntzschel 1975) rather than ethologically (cf. Chamberlain 1971). In terms of relative abundance the following format has been adopted: Abundant = >50 specimens recorded, Common = 30-50 specimens recorded, Frequent = 10-30 specimens recorded and Rare = <10 specimens recorded. Representative examples of specimens described and illustrated in this paper are housed in the Department of Geology, University of New Brunswick.

Ichnogenus *Buthotrephis* Hall, 1847

Buthotrephis sp.

(Fig. 2d, 2e)

Description: Irregularly branched cylindrical or subcylindrical burrows, parallel or slightly oblique to stratification and typically preserved on upper and lower surfaces of shales, calcareous shales and siltstones. Individual burrows may be up to 8 mm in diameter but are commonly smaller (mean 4 mm), posses smooth walls and a burrow fill which is typically of identical grain size to the enclosing sediment. The trace may be distinguished from the morphologically similar ichnogenus *Chondrites* by its non-systematic branching patterns.

Associated forms: *Gordia, Helminthopsis, Neonereites*

Relative abundance: Abundant

Discussion: There still exists considerable confusion in the literature regarding the definition and differentiation of the irregularly branched burrows of *Buthotrephis* and *Palaeophycus*, and a restudy of both is necessary. Although most of Hall's (1847) original specimens of *Buthotrephis* are undoubtedly chondritids (Häntzschel 1975, Ksiażkiewicz 1977) some of them (e.g. *B. palmata* and *B. succulens*) cannot be justifiably assigned to *Chondrites*. *B. palmata* may in fact belong to the ichnogenus *Phycodes* Richter, 1850 but a restudy of Hall's material is necessary to resolve this. Similarly, *Palaeophycus* is also a poorly defined ichnogenus, with some authors (e.g. Osgood 1970, Chamberlain 1977) assigning only unbranched or sparsely branched forms, and others (e.g. Alpert 1975, Pickerill and Forbes 1979) assigning irregularly branched forms to this ichnogenus. The majority of Hall's

(1847, 1952) specimens of *Palaeophycus* exhibit longitudinal striations, whereas *Buthotrephis* is more typically smooth. As the Siegas material is irregularly branched and has smooth walls, it is therefore diagnosed as *Buthotrephis*, but in view of the confusion, only at ichnogeneric level.

Buthotrephis is a facies crossing ichnogenus, Cambrian - Recent in age, and probably represents the feeding burrow of an infaunal polychaete annelid (Ksiażkiewicz 1977).

Ichnogenus *Chondrites* von Sternberg, 1833

Chondrites sp.

(Fig. 2g)

Description: Plantlike dendritic patterns of small burrows, individual tunnels neither crossing nor intersecting. Burrow diameter ranges from 4-8 mm but is consistent within individual specimens. The burrows are generally observed parallel to stratification on both upper and lower surfaces of shales, calcareous shales and siltstones. Two and three orders of branching, generally in regular pinnate or variable patterns, may be observed. Branching angles vary, even within individual specimens, from between 20-50°.

Associated forms: *Gordia, Helminthopsis, Planolites, Neonereites*

Relative abundance: Abundant

Discussion: The facies crossing ichnogenus *Chondrites*, which ranges in age from Cambrian-Recent, is an extremely variable form. Many ichnospecies of the trace purportedly exist (e.g. Chamberlain 1977), the majority subjectively based on variations in size, preservation and angle of branching. In view of the generally poor preservation of the

Siegas material and the unsatis-
factory taxonomic status of the
ichnogenus, it is here only iden-
tified at ichnogeneric level.

Chondrites is normally regarded
as a feeding burrow of sipunculid
annelids (Simpson 1947), tiny
arthropods (Ekdale 1977) or un-
known tentacle-bearing organisms
(Taylor 1967).

Ichnogenus *Cochlichnus*
Hitchcock, 1858

Cochlichnus anguineus Hitchcock, 1858
(Fig. 2c)

Description: Small, regularly sin-
usoidal traces, parallel to stra-
tification and commonly preserved
in convex hyporelief and more
rarely in concave epirelief.
Specimens are generally 1mm in
diameter, up to 70mm in length and
smooth throughout their extent.
Occasionally a slight thickening
may be observed at the apices of
the meanders.

Associated forms: *Diplichnites,
Gordia, Neonereites*

Relative abundance: Frequent

Discussion: The ichnogenus *Coch-
lichnus* is a facies crossing form,
having previously been described
from a wide range of palaeoenvi-
ronments of late Precambrian-Ter-
tiary age. It is generally re-
garded to have been produced by
nematodes or annelids lacking
well-developed parapodia (Michelau
1956, Hakes 1976). The trace may
represent a true burrow, as in the
case of *Cochlichnus serpens* (see
Webby 1970), but this is impos-

sible to ascertain with the Siegas
material, as diagenesis has masked
its former nature. For this rea-
son, the material is included
within the ichnospecies *C. angui-
neus*, as Hitchcock (1958) des-
cribed the trace as a 'trackway'
and not a burrow.

Ichnogenus *Diplichnites* Dawson, 1873
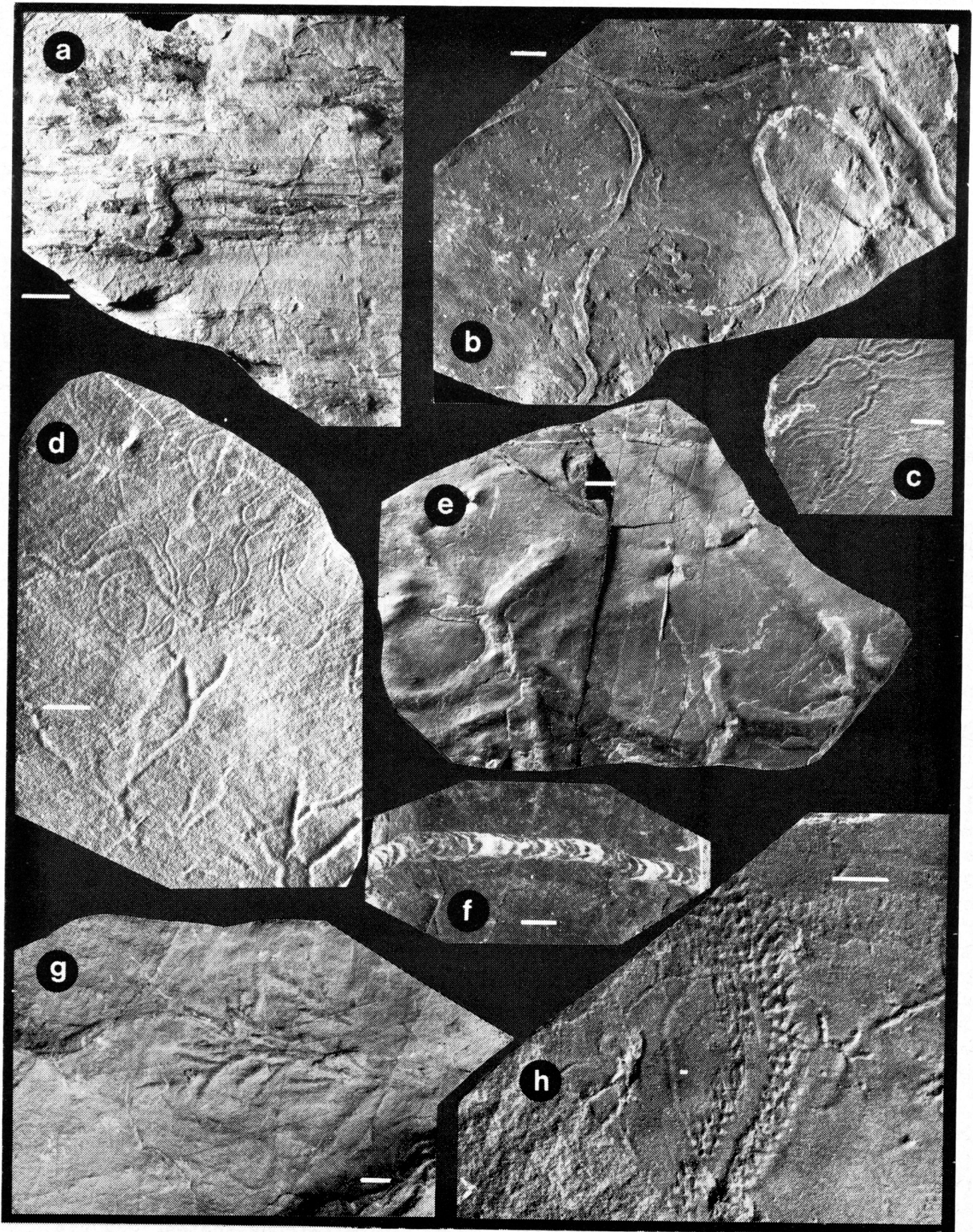*Diplichnites* sp.

(Fig. 2h, 5f)

Description: Paired rows of small
dot-like or slightly elongate
(normal to the trace axis) im-
prints, approximately 1 mm in di-
ameter. In rare examples the im-
prints assume an obtuse V-shape
rather than simply being elongate.
The pairs of imprints remain sep-
arated and evenly spaced through-
out the length of the trace. The
width of an individual set is 4-6
mm. Dactyl impressions are absent.

Associated forms: *Cochlichnus,
Gordia*

Relative abundance: Frequent

Discussion: *Diplichnites* is a mor-
phologically simple trace and is
usually interpreted as the walk-
ing track of a trilobite (Crimes
et al., 1977). It has been report-
ed in rocks of Cambrian-Permian
age (Häntzschel 1975) and is re-
garded as a typical shallow water
(neritic) form (e.g. Crimes,
1975). The recording by Pickerill
(1980) and this example here now
extend its environmental distri-
bution to deeper water strata.
Although the preservation of the
Siegas material is not suffici-
ently good for ichnospecific iden-

Fig. 2 a. *Skolithos* sp. in thinly bedded, parallel laminated calcareous silts
and shales. b. *Helminthopsis cf. abeli* on sole of turbiditic sandstone. c.
Cochlichnus aniguineus on sole of laminated siltstone. d. *Gordia* sp. in asso-
ciation with small *Buthotrephis* sp. on sole of calcareous shale. e. *Buthotrephis*
sp. on upper surface of parallel laminated calcareous siltstone. f. *Scalarituba
missouriensis* on upper surface of calcareous shale. g. *Chondrites* sp. on sole
of parallel laminated calcareous shale. h. *Diplichnites* sp. on side of parallel
laminated siltstone. Bar scale = 1 cm.

tification, the specimens closely resemble Osgood and Drennen's (1975) Type A *Diplichnites* from the Silurian Clinton Group of New York State.

Ichnogenus *Fucusopsis*

Palibin in Vassoevich, 1932
Fucusopsis sp.
(Fig. 5b)

Description: Straight to slightly curved, longitudinally striated cylindrical burrows up to 12mm in length that are unbranched and parallel to stratification. The burrows are clearly post-deposi-tional in origin, up to 10 mm in diameter and may occur as solitary specimens or in groups on the same bedding plane. The most common mode of preservation is in convex hyporelief and the burrow fill is typically of the same grain size and, or, slightly coarser than the enclosing sediment.

Associated forms: *Chondrites, Gordia, Helminthopsis, Planolites*

Relative abundance: Frequent

Discussion: Though a number of ichnospecies of *Fucusopsis* have been described (see Ksiazkiewicz 1977), the Siegas material is not well enough preserved for ichno-specific assignment. Furthermore, some specimens are apparently in-termediate between *F. angulata* Palibin, 1932, where the longi-tudinal striations are discon-tinuous, and *F. striata* Hall, 1852, where the striations are continu-ous and more closely spaced. In view of this, the material is only identified at ichnogeneric level.

Fucusopsis is a well documented facies crossing form ranging in age from Ordovician-Oligocene, and represents the feeding burrow of an infaunal organism (? annelid), the ridge-like sculptures, accord-ing to Seilacher (1959), appar-

ently reflecting the burrowing activity of its producer.

Ichnogenus *Gordia* Emmons, 1844
Gordia arcuata Ksiazkiewicz, 1977
(Fig. 3b)

Description: Thin, thread-sized burrows preserved in convex hypo-relief and all assuming an incom-plete loop-like (arcuate) form. The burrow diameter is 1 mm and the surface is always smooth. The burrow fill is typically of iden-tical grain size as the enclosing sediment. Specimens may be dif-ferentiated from the morphologi-cally similar trace *Furculosus*
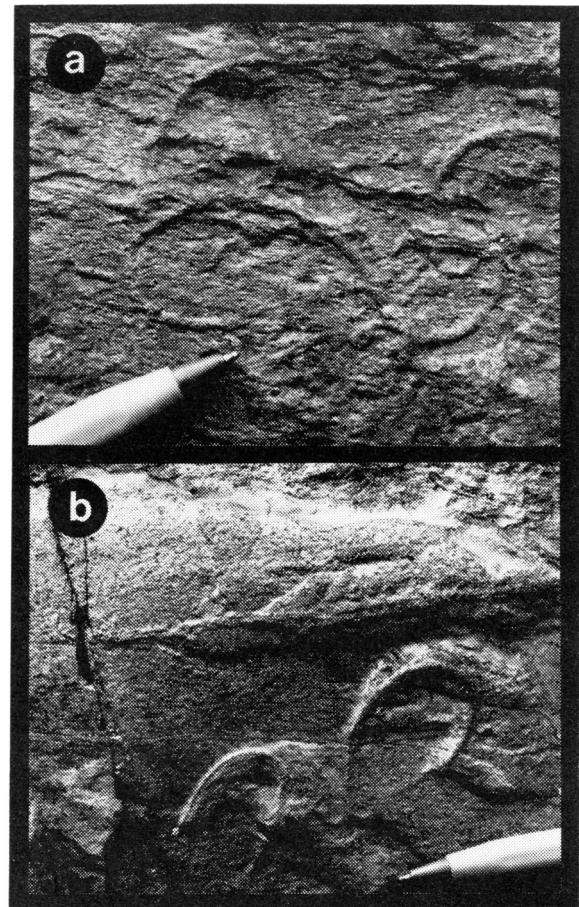

Fig. 3 - Field photographs of *Gordia* sp. (a) and *Gordia arcuata* (b) on upper sur-face of calcareous shales. Pen tip = 9 mm.

carpathicus Roniewicz and Pień- kowski, 1977 by their more arcuate shape and smaller burrow diameter.

Gordia sp.
(Fig. 2d, 3a)

Description: Slender thin burrows preserved in convex hyporelief and convex/concave epirelief which wind and curve non-systematically and cross-cut in an irregular man- ner. The burrows are smooth and up to 2 mm in diameter. The bur- row fill is typically of identical grain size as the enclosing sedi- ment. The traces can be differ- entiated from the morphologically similar trace *Helminthopsis* in that they commonly cross-cut one another.

Associated forms: *Buthotrephis, Chondrites, Cochlichnus, Diplich- nites, Fucusopsis, Helminthopsis, Neonereites*

Relative abundance: *Gordia arcu- ata* - Rare, *Gordia* - Abundant

Discussion: *Gordia arcuata,* re- cently described from flysch of the Polish Carpathians by Ksiaż- kiewicz (1977), is a rare form in the Siegas Formation but can be clearly distinguished by its dis- tinctive morphology. The second form, however, resembles both the type specimen *G. marina,* as for example recently figured by Cham- berlain (1977), and *G. molassica* as described by Heer (1865). The latter may, in fact, prove to be a junior synonym of *G. marina,* as the two ichnospecies appear to be identical. Until the detailed synonymy is resolved, the Siegas material is only identified at ichnogeneric level.

Gordia is a facies crossing ich- nogenus of late Precambrian-Oligo- cene age and, according to Ksiaż- kiewicz (1977) and Chamberlain

(1977), probably represents the post-depositional feeding burrow of a polychaete annelid.

Ichnogenus *Gyrochorte* Heer, 1865
Gyrochorte sp.
(Fig. 5e)

Description: Cylindrical or sub- cylindrical bilobate burrows of post-depositional origin and up to 15 mm in diameter and a maximum observed length of 123 mm. The burrows are straight to slightly curved and are characterized by the development of a distinctive obliquely transverse, densely spaced but irregular, biserial surface ornament, consisting of incisions which join in a medium and generally shallow apical groove. The burrow fill is typically of silt grade whereas the burrows cut thinly laminated silts and shales. They are commonly pre- served in convex epirelief, though hyporelief preservation has been rarely observed.

Associated forms: Unknown

Relative abundance: Frequent

Discussion: A number of ichno- species of *Gyrochorte* have been described in the literature (see Hallam 1970, Häntzschel 1975, Ksiażkiewicz 1977) but the Siegas material is not well enough pre- served and, or sufficiently abun- dant to warrant formal ichno- specific identification. It is also apparent that the criteria presently adopted for ichnospeci- fic separation of *Gyrochorte* are somewhat subjective and therefore at this time the present author prefers an ichnogeneric assign- ment. Nevertheless, the traces do resemble *G. obiterata* Ksiaż- kiewicz, 1977 in that the median groove is shallow and the oblique incisions are irregular and dense-

ly spaced, but differs from this ichnospecies in that the ribbing is usually well-developed. The Siegas material is wider than *G. cosmosa* Heer, 1865 and *G. imbricata* Ksiażkiewicz 1977, but narrower than *G. burtani* Ksiażkiewicz, 1977.

Gyrochorte is 'normally' regarded as a shallow water neritic form (e.g. Seilacher 1978) though deep water recordings have also been made (e.g. Ksiażkiewicz 1977, Pickerill 1980). It ranges in age from Ordovician-Oligocene and was most probably produced by the burrowing activity of small amphipods (Abel 1935) or annelids (Heinberg 1973).

Ichnogenus *Helminthoida*
Schafhautl, 1851
Helminthoida labyrinthica Heer, 1865

(Fig. 5c, 5d)

Description: Tightly spaced, regularly and parallel meandering burrow system, the burrow width being 5-6 mm, separated from adjacent meanders by 1-2 mm of sediment. Individual meanders are curved and occasionally even coiled. Typically, an individual meander is 4-5 cm high. The trace is generally poorly preserved and has only been observed in float material in calcareous siltstones.

Associated forms: *Neonereites*

Relative abundance: Rare

Discussion: *Helminthoida* is a characteristic deep water trace fossil, usually associated with the *Nereites* ichnofacies of Seilacher (1967). Although *H. labyrinthica* is commonly regarded as a Mesozoic form (Häntzschel 1975), it has recently been recorded (Pickerill 1980, Fig. 3c) from Ordovician strata. Crimes (1977) noted that its most common

occurrence was in association with outer fan and basin plain environments. The recording here thus extends its environmental range to submarine canyons.

Helminthoida has been recorded from Ordovician-Oligocene strata and is normally regarded as the grazing product of worm-like organisms, presumeably polychetes (Ksiażkiewicz 1977).

Ichnogenus *Helminthopsis* Heer, 1877
Helminthopsis cf. albeli
Ksiażkiewicz, 1977

(Fig. 2b).

Description: Irregularly and loosely winding or meandering unbranched burrows, parallel and, or, sub-parallel to stratification, and usually preserved in convex hyporelief, rarely in concave epirelief. Burrow diameter ranges between 3-7 mm but is consistent for a single specimen. The burrows are cylindrical and, or subcylindrical, smooth throughout their extent and in contrast to the related ichnogenus *Gordia*, never intersect. The winding or meandering path is extremely variable and non-systematic. Specimens are preserved in shales, calcareous shales and, or, siltstones.

Associated forms: *Buthotrephis, Chondrites, Fucusopsis, Gordia, Neonereites, Planolites*

Relative abundance: Abundant

Discussion: Based on the parameters presently adopted for ichnospecific assignment of *Helminthopsis*, viz:- the nature and type of winding, the burrow diameter and the presence or absence of surface ornamentation (Ksiażkiewicz 1977), a number of ichnospecies have been proposed. However, the Siegas material exhibits
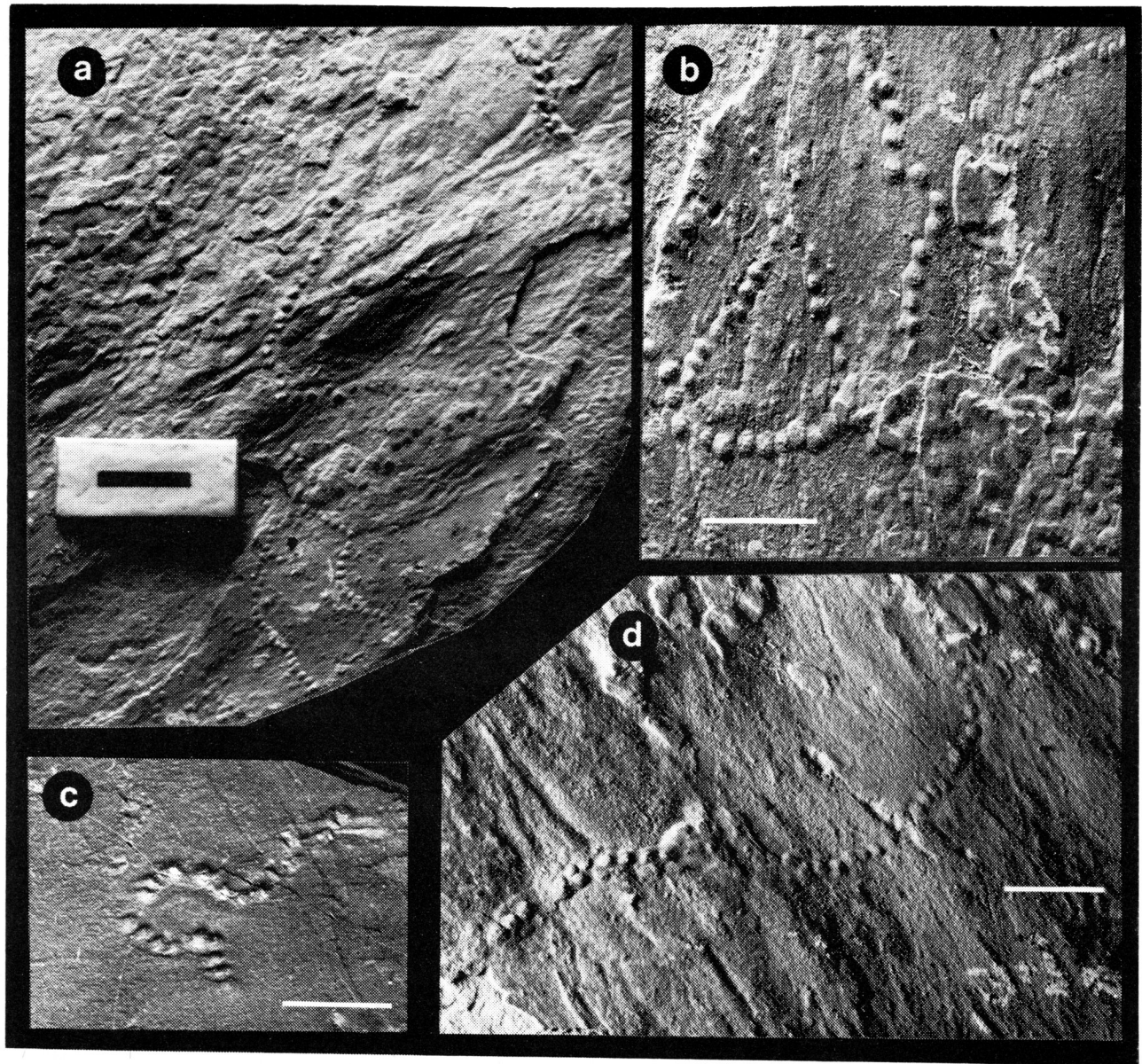
Fig. 4 Variation in *Neonereites* spp. from the Siegas Formation; a illustrates both *N. uniserialis* and *N. biserialis* (upper right), b and c show *N. uniserialis* and d shows *N. uniserialis* progressing in to *N. biserialis*. All specimens are sole structures preserved in calcareous shales. Bar scale = 1 cm.

variable winding and meandering patterns within a single specimen and different burrow diameters may exhibit the same or different behavioural patterns. Nevertheless, the material is closely comparable, both in terms of burrow diameter and the variable and loosely winding and meandering patterns, to *Helminthopsis abeli* and is tentatively diagnosed as such. In view of the considerable variation, however, it is deemed that previously adopted ichnospecific criteria are perhaps unsatisfactory and are in need of careful reassessment.

Helminthopsis is a facies crossing form, though more commonly reported from deep water successions. It ranges in age from Cambrian-Oligocene and is regard-
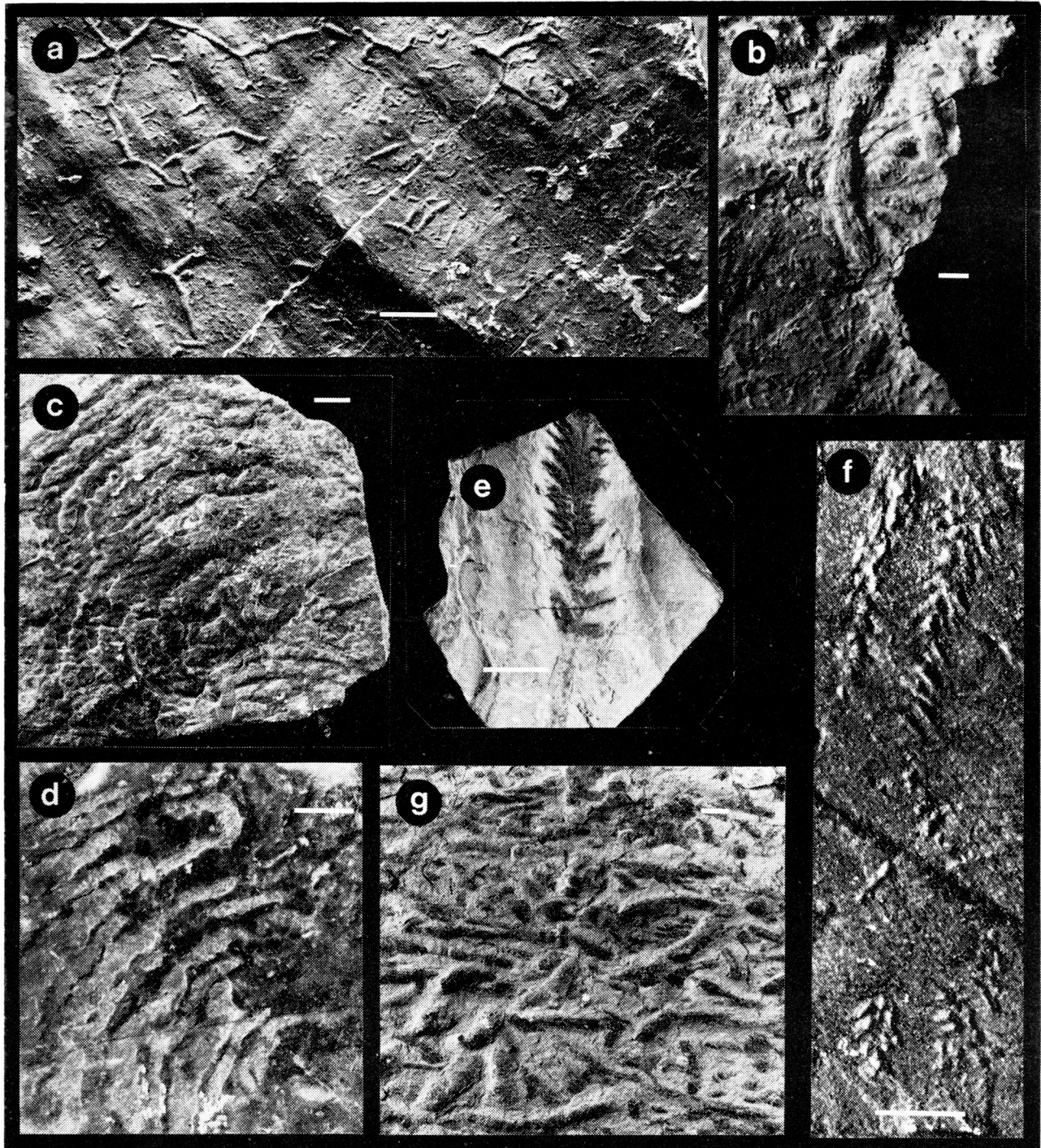
Fig. 5 – a *Protopaleodictyon* sp. on sole of current fluted (top left to bottom right) turbidite sandstone. b. *Fucusopsis* sp. on sole of turbiditic sandstone. c – d. *Helminthoida labyrinthica* on upper surface of parallel laminated calcareous shale. Note the poor preservation. e. *Gyrochorte* sp. on sole of calcareous siltstone. f. *Diplichnites* sp. on sole of parallel laminated siltstone. g. *Planolites beverleyensis* on sole of parallel and cross laminated calcareous siltstone. Bar scale = 1 cm.

ed as having been produced by polychete annelids (Ksiazkiewicz 1977).

Ichnogenus *Neonereites*
Seilacher, 1960

Neonereites uniserialis
Seilacher, 1960

(Fig. 4)

Description: Sinuous or curved chains of closely spaced rows of uniserially arranged subcircular to oblong knobs preserved in convex hyporelief. The long axis of individual knobs is normal to the chain length and varies in size from 1-4 mm. Individual chains, however, are composed of knobs of the same size. In general, adjacent knobs do not come into contact, though the gap is extremely small, commonly <1 mm. The chain shape and length exhibit considerable variation - some are sine-like and up to a length of 300mm, some are horseshoe-shaped but the majority are irregular. Occasionally the trace is preserved in concave epirelief as a series of closely spaced depressions.

Neonereites biserialis Seilacher, 1960

(Fig. 4)

Description: In contrast to *N. uniserialis*, *Neonereites biserialis*, the type species of the ichnogenus, consists of chains of two closely spaced rows of subcircular knobs preserved in convex hyporelief. Knobs of adjacent rows are not opposite but alternate in position. As with *N. uniserialis*, the chain shape, length and width vary considerably, though the latter is again consistent within an individual specimen. The trace is only rarely preserved in concave epirelief.

Associated forms: *Buthotrephis*,

Chondrites, Gordia, Helminthoida, Helminthopsis, Planolites

Relative abundance: *N. uniserialis* - abundant, *N. biserialis* - common.

Discussion: *Neonereites* is a facies crossing ichnogenus, probably representing the fodinichnia of infaunal annelids (Hakes 1976) and has been recorded from strata of late Precambrian-Tertiary age (Häntzschel 1975, Fedonkin 1977). Seilacher and Meischner (1964) grouped *Neonereites* with the ichnogenera *Nereites* and *Scalarituba* but not as strict synonyms, but later Chamberlain (1971) regarded *Nereites* and *Neonereites* as preservational variants of *Scalarituba*. Subsequent authors, however, again separated these three related ichnogenera (e.g. Häntzschel 1975, Hakes 1976, Brasier and Hewitt 1979). In view of their distinctive morphology and the absence of *Scalarituba* - like and, or, *Nereites* - like preservation (as recorded by careful sectioning of the traces), *Neonereites* is also regarded here as a separate and distinctive ichnogenus.

Although the two distinctive ichnospecies *N. uniserialis* and *N. biserialis* are generally easily separated, occasional specimens from the Siegas Formation exhibit transitional forms with one passing directly into the other (Fig. 4d), thus providing yet a further example of the persistent nomenclatural difficulties faced by ichnologists (*cf.* Bromley and Frey 1974, Frey and Seilacher 1980).

Ichnogenus *Planolites*
Nicholson, 1873
Planolites beverleyensis
Billings, 1862

(Fig. 5g)

Description: Unbranched, smooth-

walled cylindrical, subcylindri-
cal and flattened sediment filled
burrows, generally parallel and
rarely sub-parallel to stratifi-
cation. The burrows are straight
or only slightly curved, thus
distinguishing them from the mor-
phologically similar trace *Helmin-
thopsis*, which is characterized
by loose winding and, or, mean-
dering patterns. The sediment
fill may be coarser, finer or of
identical grain size to the en-
closing sediment, which is com-
monly calcareous siltstone. The
burrow diameter varies from 3 - 12
mm and is typically consistent
within an individual trace.

Associated forms: *Chondrites,
Fucosopsis, Helminthopsis, Neo-
nereites, Protopaleodictyon.*

Relative abundance: Abundant

Discussion: *Planolites* is a facies
crossing ichnogenus ranging in
age from late Precambrian-Recent
(Häntzschel 1975) and commonly.
attributed to the burrowing acti-
vity of annelids (Hallam 1970).
It is similar to *Palaeophycus*
Hall, 1847 and the distinction
between these two ichnogenera
still remains controversial. Fol-
lowing Häntzschel (1975), Alpert
(1975) and McCarthy (1979), how-
ever, *Palaeophycus* is only avail-
able for irregularly branched
burrows. Furthermore, *Palaeo-
phycus* burrows also commonly pos-
sess irregular walls which often
display collapse structures (Frey
and Chowns 1972). The Siegas
material is therefore diagnosed
as *Planolites*. The taxonomy of
Planolites has been recently re-
viewed by Alpert (1975) and the
Siegas material is identical to *P.
beverleyensis*.

Ichnogenus *Protopaleodictyon*
Ksiazkiewicz, 1970

Protopaleodictyon sp.

(Fig. 5a)

Description: Thread-like, incom-
plete network burrow system, 2 mm
in width and smooth throughout
their length. Each system con-
sists of wide first order mean-
ders upon which are superimposed
smaller second order sine-shaped
undulations with distinct appen-
dages. The trace is horizontal
and preserved on the sole of cur-
rent fluted turbidite sandstones.

Associated forms: *Planolites*

Relative abundance: Rare

Discussion: There is still no
general agreement on what con-
stitutes a distinctive ichno-
species of the graphoglyptid trace
Protopaleodictyon, with Seilacher
(1977) utilizing the number of
branches/undulation and Ksiaz-
kiewicz (1977) the regularity and
spacing of the first order mean-
ders and the size and thickness
of the strings. In view of this
inconsistency, the Siegas material
is only identified at ichnogeneric
level. *Protopaleodictyon* is a
deep water trace fossil character-
istic of the *Nereites* ichnofacies
of Seilacher (1967). It ranges
in age from Ordovician-Tertiary
and was presumeably constructed
by some unknown infaunal annelid.

Ichnogenus *Scalarituba* Weller, 1899
Scalarituba missouriensis
Weller, 1899

(Fig. 2f)

Description: Straight, curved or
winding traces preserved in con-
cave epirelief and up to 6 mm in
width and variable length. Each
trace is characterized by closely
spaced crescentric partitions which
are transversely oriented and dis-
tinguishable by slight colour

variation from one to the next. The traces are preserved in dark shales and have only been observed in float material.

Associated forms: Unknown

Relative abundance: Frequent

Discussion: *Scalarituba* is a monotypic ichnogenus and has been previously reported from environments ranging from tidal flat (Conkin and Conkin 1968) to deep water flysch (Seilacher and Meischner 1965, Chamberlain 1971, Pickerill 1980). It ranges in age from Ordovician-Permian and represents the activity of worms burrowing within the sediment and episodically back-filling the burrows, thereby creating the transverse partitions (Hakes 1976).

Ichnogenus *Skolithos* Haldeman, 1840
Skolithos sp.

(Fig. 2a)

Description: Smooth and unlined, vertical or slightly oblique, cylindrical or subcylindrical, unbranched burrows which frequently possess irregular walls. The burrows may be isolated or clustered but never densely crowded. Burrow diameter ranges up to an observed maximum of 8 mm. Burrow fill is generally coarser than the enclosing sediment, which is typically laminated calcareous shale.

Associated forms: Unknown, as the trace is only observed in vertical section.

Relative abundance: Abundant

Discussion: *Skolithos* is an ichnogenus of late Precambrian-Recent age and represents the dwelling burrow of annelids or phoronids (Alpert 1974). The presence of abundant specimens is usually indicative of a shallow marine environment (Seilacher 1967) though deep water recordings have also been made (e.g. Hayward 1976, Crimes 1977). The Siegas material also resembles *Tigillites* Rouault, 1950, which is usually reserved for noncrowded vertical burrows. However, burrow density is regarded as a palaeoecological variable and should not be utilized in taxonomic decisions. *Tigillites* is therefore regarded as a junior synonym of *Skolithos*. Because of the unsatisfactory taxonomic status of the trace at the present time, the specimens are only identified at ichnogeneric level.

DISCUSSION

It must be emphasized that the trace fossils described in this paper are from strata deposited within the canyon and not the canyon walls. The latter are generally poorly exposed in the Siegas area, and where present (see Hamilton-Smith 1970), no trace fossils have been observed in association with them. It must also be noted that the traces generally occur in sediments of category (iii) as outlined previously, or, alternatively, as sole structures on the base of turbidites described under category (ii). No trace fossils were observed in association with the organized and disorganized resedimented conglomerates of category (i).

The majority of the variety of trace fossils described from the Siegas Formation, which are shown schematically in Figure 6, are well-known facies crossing forms, having been previously reported from a variety of shallow and deep water environments. These include *Buthotrephis*, *Chondrites*, *Cochlichnus*, *Fucusopsis*, *Gordia*, *Gyro-*
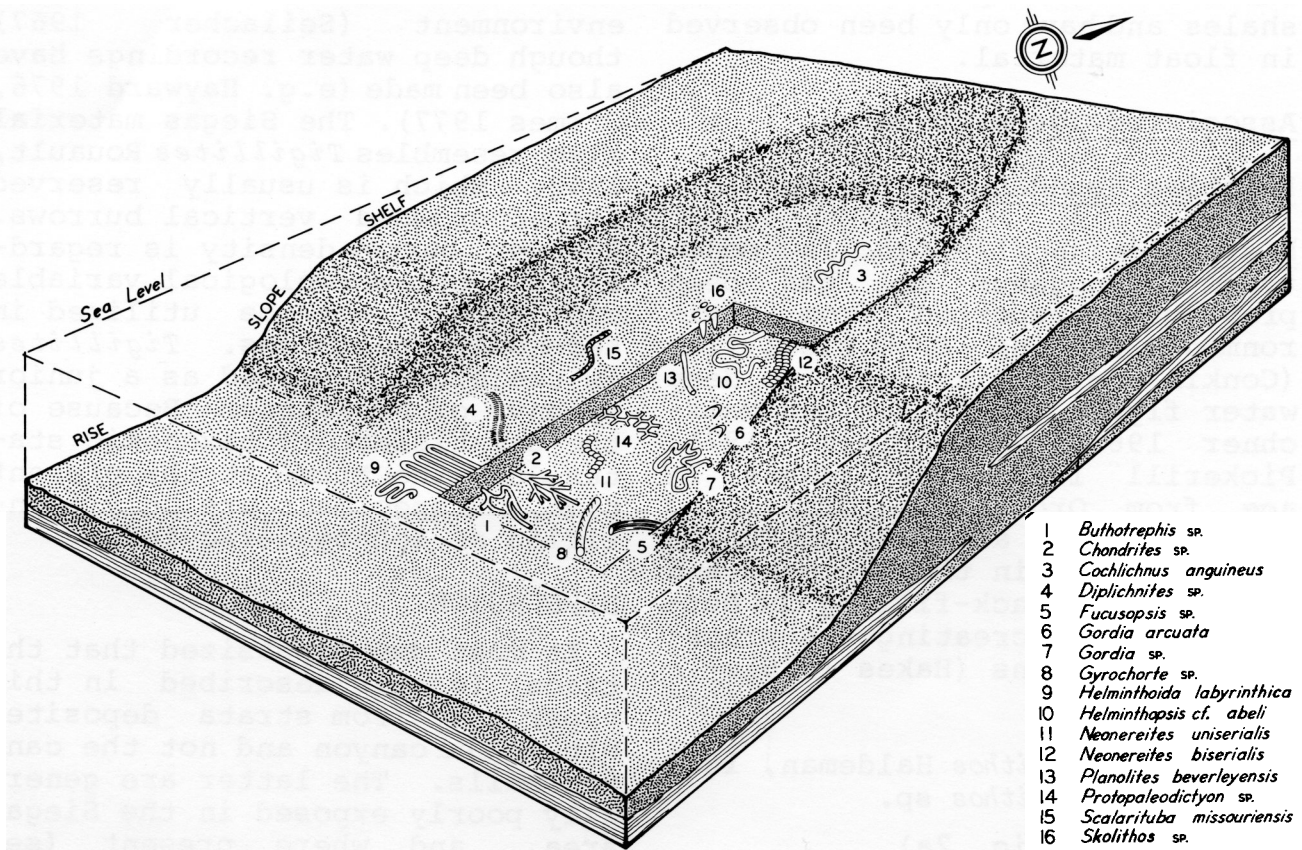
1	*Buthotrephis* sp.
2	*Chondrites* sp.
3	*Cochlichnus anguineus*
4	*Diplichnites* sp.
5	*Fucusopsis* sp.
6	*Gordia arcuata*
7	*Gordia* sp.
8	*Gyrochorte* sp.
9	*Helminthoida labyrinthica*
10	*Helminthopsis* cf. *abeli*
11	*Neonereites uniserialis*
12	*Neonereites biserialis*
13	*Planolites beverleyensis*
14	*Protopaleodictyon* sp.
15	*Scalarituba missouriensis*
16	*Skolithos* sp.

Fig. 6 – Schematic representation of the Siegas Formation submarine canyon ichno-assemblage. No scale is implied.

chorte, *Neonereites*, *Planolites* and *Scalarituba*. The assemblage does, however, contain the typical or more typical "shallow water" traces *Skolithos* and *Diplichnites* and those commonly recorded in the *Nereites* ichnofacies of Seilacher (1967) in middle fan, outer fan and trough sediments, *Helmintho-ida*, *Helminthopsis* and *Protopaleo-dictyon*. *Diplichnites*, *Helmin-thoida*, *Helminthopsis* and *Proto-paleodictyon* represent new trace fossil recordings in submarine canyon sequences (see Crimes 1977, Table 4, p. 80), whereas, as mentioned previously, *Skolithos* has already been recorded. To this list of new recordings must be added *Zoophycos* (= *Zoophycus*)

and *Nereites*, recently noted by Stanley *et al.* (1978) from Eocene canyon-fill strata of the French Maritime Alps. Unfortunately Crimes (*ibid.*) does not mention which facies crossing ichnogenera are likely to be present in submarine canyon sequences (with the exception of *Chondrites*, *Neonerei-tes* and *Scolicia*), but if the Siegas material is representative, the list is likely to be a reasonably extensive one providing that the trace fossils are preserved and not eroded by periodically powerful currents.

The mutual occurrence of "shallow" and "deep" traces in association with the facies crossing variety suggests that substrate,

food availability, temperature and/or ecological interactions rather than bathymetry *per se* were important parameters regarding their presence (*cf.* Crimes 1970, Frey and Howard 1970). Contrary to the proposal by Crimes (1977, p. 79) regarding ancient submarine canyon ichnofaunas, the assemblage is composed essentially of traces produced by vagile infaunal sediment eaters and grazers and does not include dwelling burrows. In fact, the 'anticipated' submarine canyon traces of Crimes (*ibid.*) viz:- the dwelling burrows *Arenicolites*, *Corophioides*, *Diplocraterion*, *Monocraterion* and *Ophiomorpha* and *Thalassinoides*, are all absent. The absence of *Ophiomorpha* and *Thalassinoides* is hardly surprising, as these trace fossils have yet to be recorded in Lower Palaeozoic sediments (Häntzschel 1975). The absence of the additionally listed dwelling burrows, however, cannot be reconciled stratigraphically, as all these traces have been commonly observed and recorded in many sequences of Lower Palaeozoic age. However, these ichnogenera are most commonly recorded in shallow water environments, themselves characterized by active and medium-high velocity currents. Indeed, the presence of active bottom currents to provide sufficient organic material and water turbulence appears to have been particularly important regarding the occurrence of these latter traces, which are all produced by filter feeding (? annelid) organisms. Crimes (*op. cit.*), in fact, predicted their presence in submarine canyon sequences for this very reason.

Nevertheless, recent observations by Shepard *et al.* (1979), have demonstrated that relatively slow velocity currents can be commonplace in modern submarine canyons. Sedimentological considerations would tend to confirm that this situation probably existed for the majority of time in the Siegas Formation, and currents only became periodically strong with the introduction of mass-flow deposits. This is also suggested by the good preservation of the delicate traces produced at the sediment-water interface, such as *Diplichnites* and *Neonereites*, which show no evidence of fluting by currents (*cf.* Crimes 1973) or rheotactic orientation. The absence of traces produced by filter feeding organisms in the Siegas Formation may therefore well be related (in addition to the potential preservational difficulties) to the absence of sufficiently strong bottom currents, which, in turn, precluded the presence of an active and abundant suspension feeding population of organisms. Instead, the Siegas Formation is characterized by traces produced by deposit feeders, particularly infaunal deposit feeders, thus suggesting that the sediments contained sufficiently abundant organic detritus to support such a population of organisms.

Crimes (1977) also noted that submarine canyon environments could probably only support an ichnofauna of low abundance and diversity. Nevertheless, and indeed as noted by Crimes himself, data on submarine canyon environments is sparse. This particular conclusion was based on the assumption that medium-coarse grained sandy substrates swept by fast-flowing currents could not support a diverse population of organisms. As outlined above, however, current conditions are extremely variable and, in addition, modern canyons are characterized by a variety of substrate types (Shepard *et al.* 1979). This study has, in

fact, recorded a minimum of 14 ichnogenera (16 ichnospecies), which according to the latest proposed Phanerozoic trace fossil diversity models (Frey and Seilacher 1980), is diverse for deep water strata of Silurian age. In addition, many of the traces can also be termed abundant in the sense that over 50 specimens of each were recorded over a large stratigraphic interval.

In conclusion, therefore, this example of an ancient submarine canyon sequence has demonstrated that such strata may, in fact, possess a wide variety of trace fossils, comparable in many respects to other ancient deep sea environments. Although data on ancient submarine canyon sequences is still sparse, it is anticipated that as research is undertaken in comparable sequences, similarly diverse trace fossil assemblages will be revealed. Only with the careful collection and description of trace fossil material will meaningful and realistic models of submarine canyon ichnocoenoses through time be realized.

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