

The Ichnofossils of the Triassic Hope Bay Formation, Trinity Peninsula Group, Antarctic Peninsula

Ismar de Souza Carvalho

Universidade Federal do Rio de Janeiro, CCMN, Instituto de Geociências, Departamento de Geologia, Rio de Janeiro, Brazil

Antonio Carlos Sequeira Fernandes

Universidade Federal do Rio de Janeiro, Museu Nacional, DGP, Rio de Janeiro, Brazil, and Universidade do Estado do Rio de Janeiro, Faculdade de Geologia, Rio de Janeiro, Brazil

Renato Rodolfo Andreis, Fabio Vito Pentagna Paciullo, André Ribeiro, and Rudolph A. J. Trouw

Universidade Federal do Rio de Janeiro, CCMN, Instituto de Geociências, Departamento de Geologia, Rio de Janeiro, Brazil

The Triassic Hope Bay Formation (Trinity Peninsula Group) includes a diverse ichnocoenosis in the Puerto Moro succession (Hope Bay, Antarctic Peninsula). The Hope Bay Formation is a thick turbidite succession with a minimum vertical exposure of 533 meters along the Hope Bay coast. The rocks are locally affected by contact metamorphism related to later arc magmatism. The ichnofossils are found mainly in thick- and thin-bedded sandstone-mudstone facies composed of a monotonous repetition of sandstone-mudstone cycles. The sandstones are usually medium grained, massive or parallel laminated; the mudstones are massive and rarely laminated. In the fine-grained rocks, mainly the mudstones, there are distinct densities of bioturbation, and at least six patterns were observed. The following ichnogenera were recognized: *Arenicolites* Salter 1857, *Lophoctenium* Richter 1850, *Taenidium* Heer 1877, *Palaeophycus* Hall 1847, *Phycosiphon* von Fischer-Ooster 1858 and *Rhizocorallium* Zenker 1836. All appear to be feeding-traces. The trace fossil assemblages occur mainly in black mudstones rich in organic material that suggest a low oxygen environment. The stratigraphic interval in which they occur is interpreted as progradational supra-fan lobes with channel fill and levee deposits. The thin-bedded turbidite and mudstone lithofacies, where the ichnofossils are abundant, is interpreted as a distal fan turbidite or levee deposit related to a long-term channel fill. This study is the first significant report of trace fossils in the Hope Bay Formation.

Keywords Hope Bay Formation; Triassic; invertebrate ichnofossils; Antarctica

Address correspondence to Ismar de Souza Carvalho, Universidade Federal do Rio de Janeiro, CCMN, Instituto de Geociências, Departamento de Geologia, 21.949-900, Cidade Universitária, Rio de Janeiro, RJ, Brazil. E-mail: ismar@geologia.ufrj.br

INTRODUCTION

The Hope Bay Formation, Trinity Peninsula Group (Hyden and Tanner, 1981) is a thick turbidite succession exposed in the northern Antarctic Peninsula (Figs. 1 and 2). It is unconformably overlain by Early Jurassic alluvial deposits of the Mount Flora Formation (Botany Bay Group) and cut by magmatic arc-related granitoids. The presence of Permian detrital zircons (Miller et al., 2003) constrains the age of the turbidites from late Permian to early Jurassic.

The Hope Bay turbidites comprise five main lithofacies: massive sandstones, laminated sandstones, thick- and thin-bedded classical turbidites composed of sandstone-mudstone couplets and massive mudstones. These facies are grouped in three facies associations (Paciullo et al., 2002). The fossiliferous content of the turbidites is restricted to ichnofossil assemblages and rare plant debris. Birkenmajer (1992) first recognized rare trace fossils in the investigated lithostratigraphic unit represented by trails of mudeaters and probably *Skolithos* tubes. Plant remains occur locally in the mudstones, while ichnofossils are common in the sandy and muddy facies, especially in the Seal Point area (Fig. 3). Due the high sand/mud ratio and the lack of conglomerates, Paciullo et al. (2002) suggested that the succession observed at Hope Bay represents channel fill and levee deposits related to progradational lobes in a submarine mid-fan setting, and also distal fan turbidites.

SYSTEMATIC ICHNOLOGY

The following ichnogenera have been recognized: *Arenicolites* Salter 1857, *Lophoctenium* Richter 1850, *Palaeophycus* Hall 1847, *Phycosiphon* von Fischer-Ooster 1858, *Rhizocorallium* Zenker 1836 and *Taenidium* Heer 1877. The repository of these

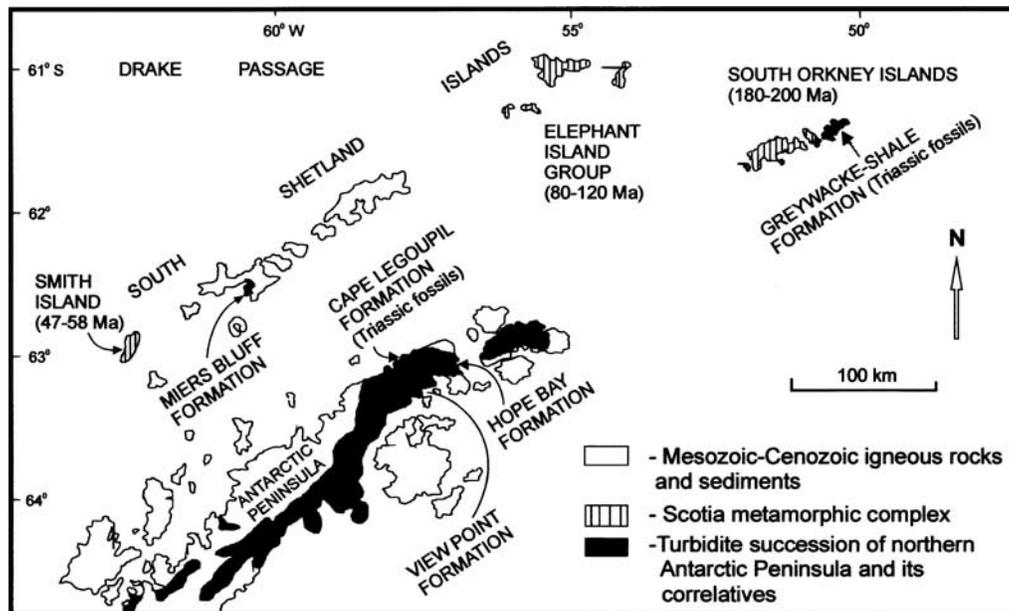


FIG. 1. The tectonic units in northern Antarctic Peninsula with the location area of the Hope Bay Formation (modified from Trouw et al., 1997).

ichnofossils is the Paleontological Collection (Geology Department) of Rio de Janeiro Federal University and in which samples are labelled as UFRJ DG.

Ichnogenus *Arenicolites* Salter 1857

***Arenicolites* ichnosp.**

(Fig. 4)

Material. Field observations and sample UFRJ DG 168-Ic.

Description. Simple, unornamented U-tubes without spreite perpendicular to beds, with some specimens penetrating 20 cm down into the substrate. Openings appear as crowded double circular structures with variable diameters between 1.2 and 2.8 cm (Fig. 4C). The U-shape form is visible in cross-sections (Fig. 4D) normal to bedding. They are of common occurrence in many sandy levels.

Remarks. *Arenicolites* is a dwelling trace typical of the *Skolithos* and *Cruziana* ichnofacies, but it also occurs in the *Glossifungites* ichnofacies. It is attributed to wormlike organisms.

Ichnogenus *Lophoctenium* Richter 1850

***Lophoctenium* ichnosp.**

Material. Field observations.

Description. The specimen comprise epichnial traces consisting of branched, radiating twig-like grooves preserved in fine-grained sediments. No dimensions noted in the field. This ichnofossil is present as isolated specimens at several horizons.

Remarks. Interpreted as a grazing trace produced by worm-like organisms, *Lophoctenium* is a common trace fossil in flysch

deposits ranging in age from Ordovician to Miocene (Uchman, 1995).

Ichnogenus *Palaeophycus* Hall 1847

***Palaeophycus tubularis* Hall 1847**

(Fig. 5)

Material. Field observations.

Description. Unbranched, smooth, lined, curved and straight, cylindrical, mainly horizontal burrows, with diameters between 1 and 1.5 cm.

Remarks. There is some controversy about the distinction between the ichnogenera *Palaeophycus*, *Planolites* and *Macaronichnus*, as discussed by Pemberton and Frey (1982), Fillion (1989) and Fillion and Pickerill (1990). The identification as *Palaeophycus* is due to the lined aspect and the dominant cylindrical shape in cross-section. This ichnogenus is considered a dwelling trace and a eurybathic facies-crossing form, produced probably by polychaetes, with a range from Precambrian to Recent (Häntzschel, 1975; Pemberton and Frey, 1982; Uchman, 1995).

Ichnogenus *Phycosiphon* von Fischer-Ooster 1858

***Phycosiphon incertum* von Fischer-Ooster 1858**

(Fig. 6)

Material. One sample, UFRJ DG170-Ic.

Description. Repeated small horizontal U-shaped lobes with a dark infill, and without spreite. The lobes are 0.4 cm in diameter and up to 3.5 cm long, being usually curved.

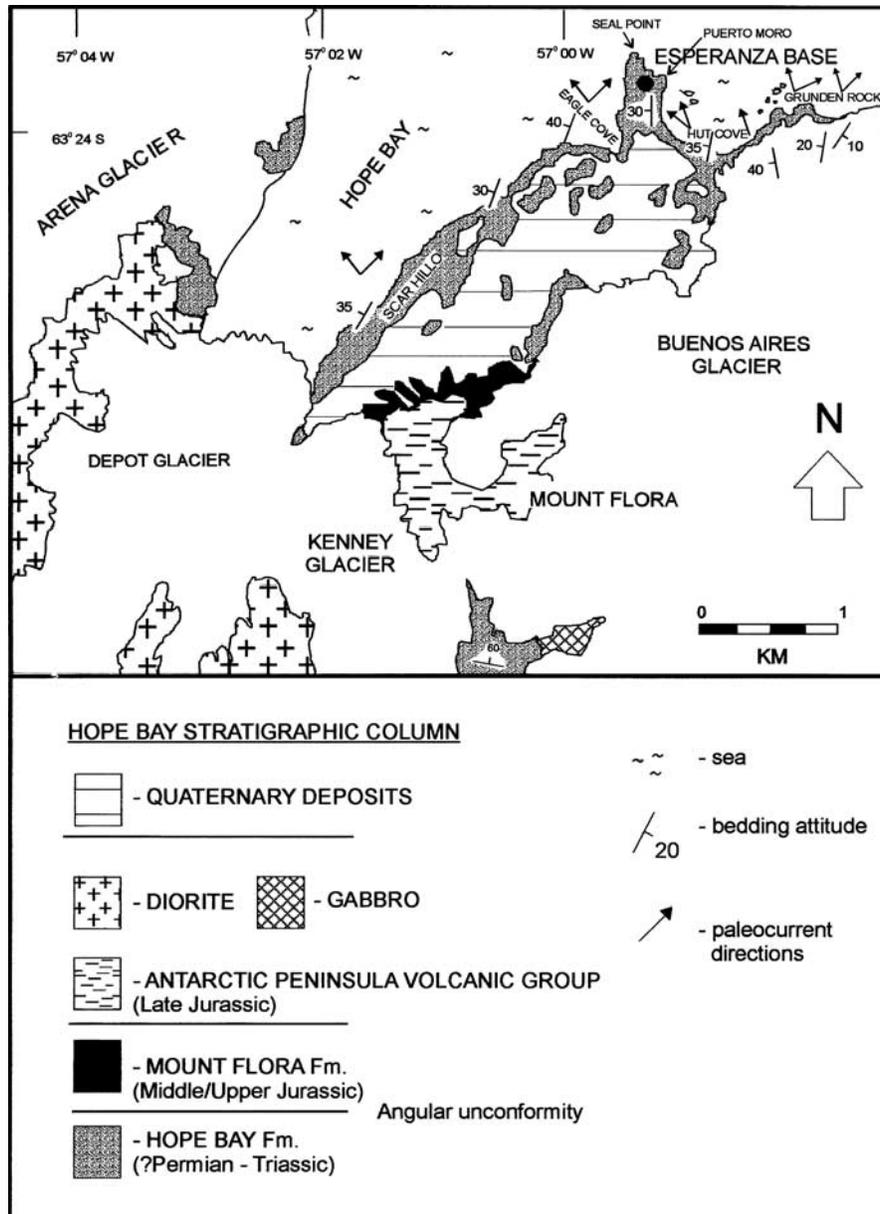


FIG. 2. Geological map and stratigraphic column of the Hope Bay area (simplified from Birkenmajer, 1992).

Remarks. *Phycosiphon* is a monospecific ichnogenus represented by *Phycosiphon incertum*, and is common in poorly oxygenated sediments (Ekdale and Mason, 1988; Uchman, 1995).

Ichnogenus *Rhizocorallium* Zenker 1836
***Rhizocorallium* ichnosp.**

(Fig. 7)

Material. Field observations and sample UFRJ DG 158-Ic.

Description. Straight, horizontal U-shaped burrow with spreite. The specimen is 7 cm long and 1.5 cm wide, with U-tubes 2 cm in diameter.

Remarks. Interpreted as a feeding or dwelling burrow, probably of a crustacean, being present in the *Glossifungites* and *Cruziana* ichnofacies. *Rhizocorallium* ranges from Cambrian to Tertiary and is known from deltaic settings (Eagar et al., 1985; Miller and Knox, 1985)

Ichnogenus *Taenidium* Heer 1877
***Taenidium* ichnosp.**

(Figs. 8, 9)

Material. Field observations and sample (UFRJ DG 175-Ic).

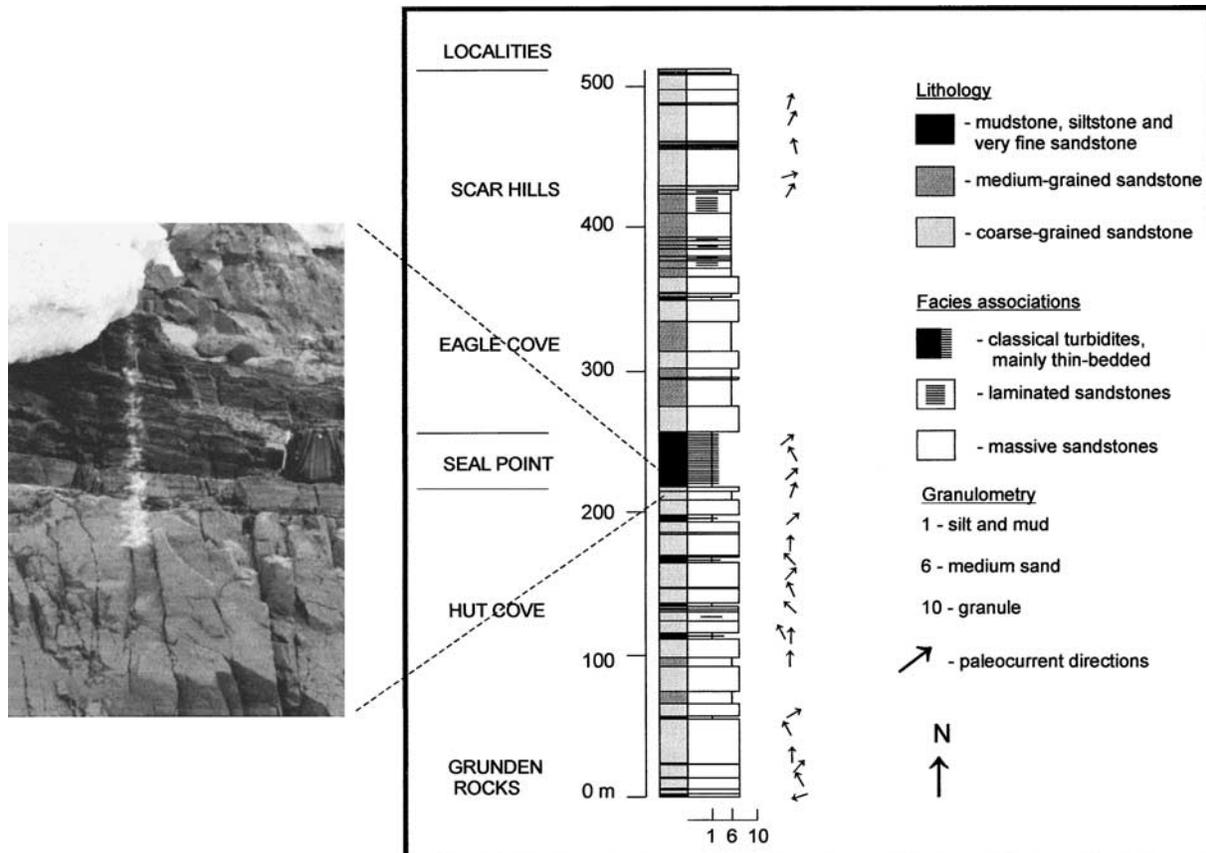


FIG. 3. Simplified stratigraphic section of the Hope Bay Formation along the Hope Bay coast. The ichnofossils occur in sandy and muddy lithofacies (illustrated in the photograph) composed of a monotonous repetition of sandstone-mudstone couplets.

Description. Slightly or usually strongly horizontal sinuous cylindrical burrows with back-fill of alternating meniscus-shaped packets. The burrows vary in diameter from 1 to 2 cm, but width is regular for each specimen. The length is usually incomplete; some are up to 13 cm.

Remarks. The taxonomic problems of *Taenidium* and other meniscate forms were discussed by D'Alessandro and Bromley (1987). *Taenidium* is thought to have been produced by a worm-like organism and has a distribution from the Lower Cambrian to Quaternary (Uchman, 1995). It occurs in marine and also in the *Scoyenia* ichnofacies (Buatois et al., 2002).

DISCUSSION

The ichnofossils occur in sandy and muddy lithofacies composed of a monotonous repetition of sandstone-mudstone couplets (Fig. 3). The sandstones are usually medium grained, massive or parallel laminated, and *Arenicolites* were frequently observed on bedding planes as densely spaced twinned circular structures; the mudstones are massive and rarely laminated, and

contain *Lophoctenium*, *Taenidium*, *Palaeophycus*, *Phycosiphon* and *Rhizocorallium*.

The relative abundance of trace fossils within sand-dominated and mud-dominated facies in slope apron and proximal submarine fan deposits was also observed in the Kotick Point and Whisky Bay formations (Aptian-Coniacian) of James Ross Island (Antarctica). In this geological context, facies-independent forms include *Planolites* and *Chondrites* (Ineson, 1987). The mud-dominated association is characterized by *Zoophycos*, *Planolites*, *Chondrites* and *Teichichnus*. The sand-dominated facies contains an association of *Palaeophycus*, *Thalassinoides* and *Ophiomorpha*. *Phycosiphon* was recorded within both sedimentary associations. The trace fossils recorded from this succession are considered to represent both deep- and shallow-water ichnofacies. The fine-grained sediments, representing deposition at the base-of-slope, marginal to submarine fans, are characterized by an assemblage of traces produced by infaunal deposit feeders, while the coarse-grained facies is characterized by assemblages of domichnial burrows. This reflects the local sediment grain size, energy level and oxygenation rates rather than absolute bathymetry. Corbo (1979)

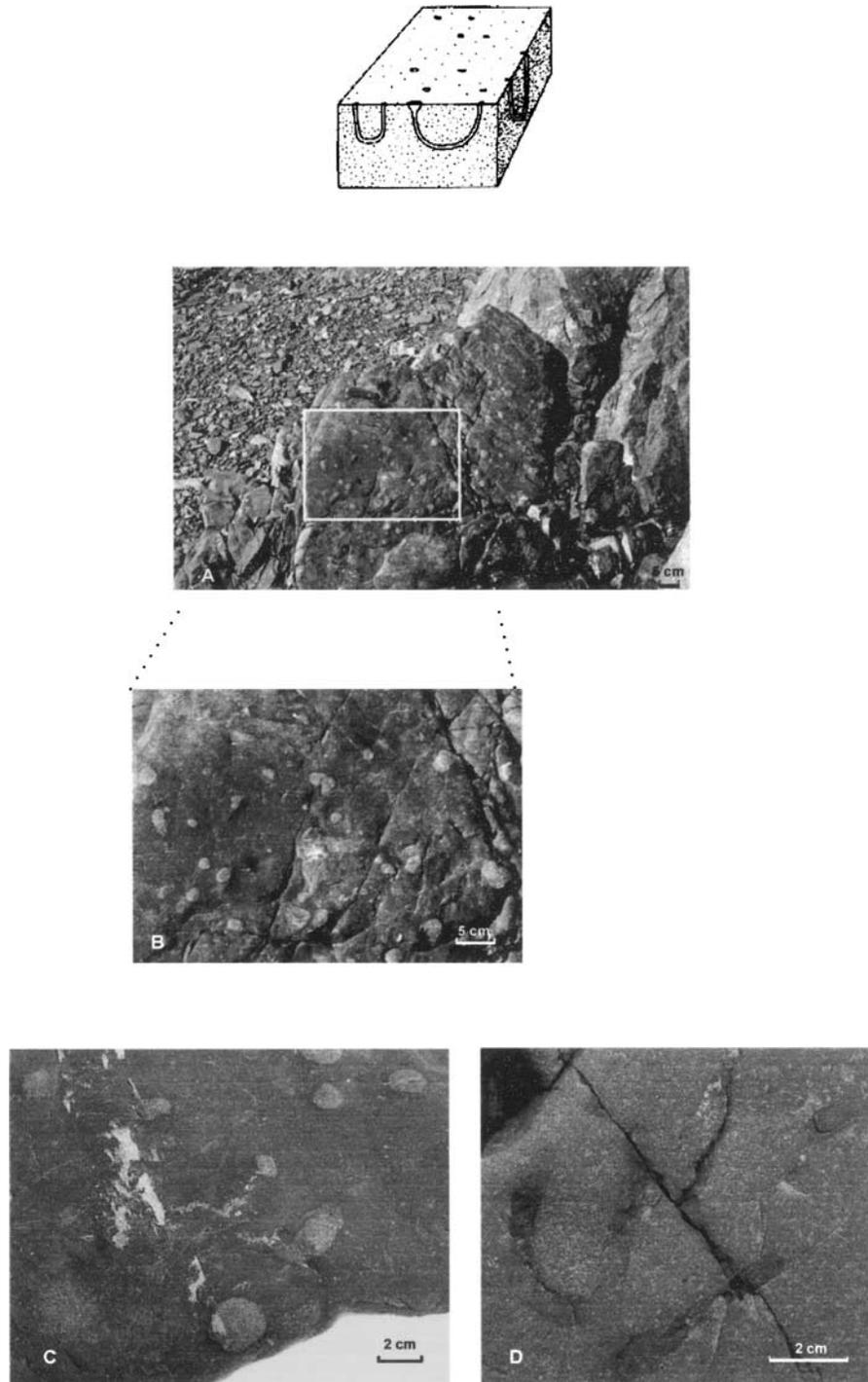


FIG. 4. *Arenicolites* Salter 1857. (A), (B) Field occurrence of a bedding plane with circular openings. (C) Detail of paired circular openings in sample UFRJ DG 168-Ic. (D) "U"-shaped vertical section.

observed similar aspects in an analysis of a Devonian turbidite sequence (Rock Stream Formation, New York, USA). Here the physical structures and biogenic aspects suggested that the vertical change in the ichnogenic assemblage was related

to food resources and oxygen availability rather than to water depth.

The level of oxygenation in bottom waters can be inferred from the degree of bioturbation (Savrda and Bottjer, 1986).

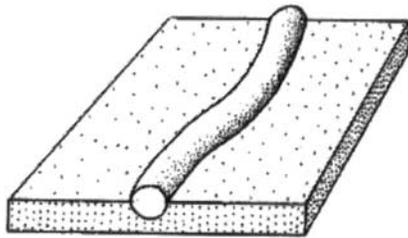


FIG. 5. *Palaeophycus* Hall 1847. Cylindrical and horizontal burrows, with diameters between 1 and 1.5 cm, observed in the Seal Point turbidites. Field observation.

An ichnocoenosis from strata deposited under more or less uniform or similar levels of bottom-water oxygenation is referred to as an oxygen-related ichnocoenosis unit. In the Hope Bay Formation there are distinct densities of bioturbation activity and at least six patterns were observed: cylindrical, meniscate, successive scratches, sinusoidals, circular and parabolic. The bioturbation density is defined through qualitative intensity as (1) low, (2) low to medium, (3) medium and (4) high degree. The black carbonaceous mudstone environment of this lithostratigraphic unit, associated with *Lophoctenium*, *Taenidium*, *Palaeophycus*, *Phycosiphon* and *Rhizocorallim*, and the degree of bioturbation, is typical of environments in which the level of oxygenation in bottom waters decreases gradually through time, with a progressive decline in ichnospecies diversity. In this case, deeper-dwelling organisms decrease their penetration depth and are found in progressively higher levels in the sediments. Savrda and Bottjer (1986) used the term gradual deoxygenation for this type of event. This leads to a dysaerobic benthic environment (Ekdale and Mason, 1988) with sparsely populated communities of small, soft-bodied, deposit-feeding organisms, living in oxygen concentrations between 0.1 and 1.0 ml O₂/L H₂O.

The ichnocoenosis of the Hope Bay Formation also reflects the feeding strategies of the endobenthos. The occurrence of *Phycosiphon* indicates non-selective sediment ingestors. Ekdale (1985) observed that sediment ingestors may feed in localized areas by constructing complex feeding burrows, like

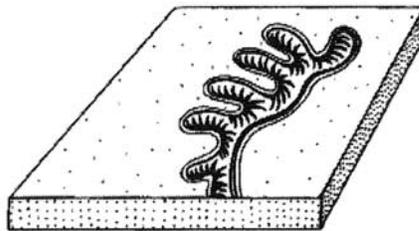


FIG. 6. *Phycosiphon* von Fischer-Ooster 1858, sample UFRJ DG 170-1c, showing repeated small horizontal U-shaped lobes with a dark infill, and without spreite.

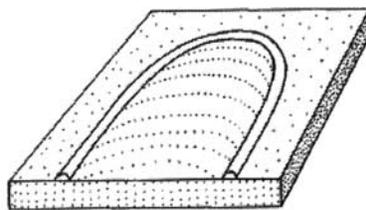


FIG. 7. *Rhizocorallium* Zenker 1836, sample UFRJ DG 158-Ic. Bedding plane view of a burrow showing movement to the right.

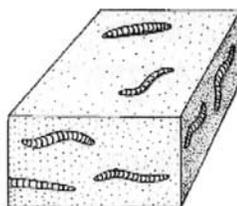


FIG. 8. *Taenidium* Heer 1877, strongly preserved sinuous cylindrical burrow with distinct meniscus-shaped packets. Field photograph.

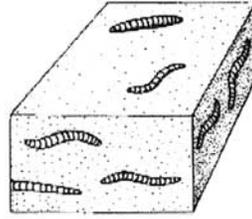


FIG. 9. *Taenidium* Heer 1877. (A) Field observation and (B) sample UFRJ DG 175-Ic.

thalassinidean crustaceans, who construct elaborate branched burrow systems as they mine the sediment for nourishing organic material.

Arenicolites comprises dwelling burrows, produced by organisms that apparently circulated water through their burrows

for respiration and food, similar to the behavior of the recent worm *Arenicola*. The burrowing behavior of the *Arenicolites* organism is an adaptation for a quiet environment, living in a permanent burrow used for feeding from the water column and the substrate surface (Corbo, 1979).

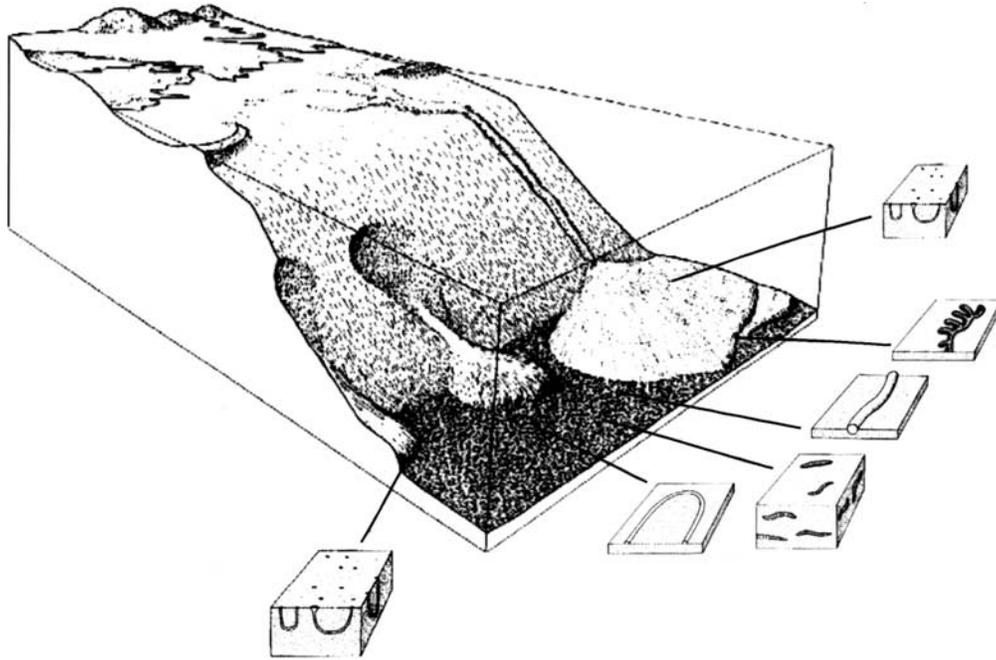


FIG. 10. Environmental interpretation of the trace fossil distribution of Hope Bay turbidites in progradational supra-fan lobes with channel fill and levee deposits.

CONCLUSIONS

The importance of the ethology of organisms with respect to the hydrodynamic energy level, salinity, oxygen concentration, food availability, temperature and substrate sedimentological aspects in comparison to absolute bathymetry has been demonstrated by many studies (Farrow, 1966; Dörjes and Hertweck, 1975; Seilacher, 1978; Corbo, 1979; Pemberton et al., 1982; Wetzel, 1984; Frey and Pemberton, 1984; Howard and Singh, 1985; Ineson, 1987; Ekdale, 1988; Bromley and Asgaard, 1991; Uchman, 1995; Buatois et al., 2002). The assemblage of paschichnial trace fossils and feeding-trace specimens (*Lophoctenium*, *Taenidium*, *Palaeophycus*, *Phycosiphon* and *Rhizocorallium*) generally occur in black mudstone, rich in organic material, probably in the context of a low oxygen environment. *Chondrites* was not identified in this assemblage indicating moderate levels of oxygen in the sediment-water interface (Bromley and Ekdale, 1984). *Arenicolites*, found in the massive or parallel laminated sandstones, was probably related to the sandy fills of continental slope channels. Areas with high, often irregular rates of sedimentation and shifting sand substrates (lobe shifting or nearshore marine environments) are characterized by trace fossil associations that have abundant agglutinated worm tubes, pellet-walled crustacean burrows and U-shaped burrows (e.g., *Arenicolites*; Ekdale, 1985). With increasing water depth and decreasing sediment grain size, fodinichnia and paschichnia such as *Palaeophycus* and *Phycosiphon* progressively appear. The rare plant debris in the Hope Bay turbidites probably records the resedimentation of shelf deposits.

The stratigraphical interval where the Hope Bay ichnofossils occur is interpreted as progradational supra-fan lobes with

channel fill and levee deposits. The thin-bedded turbidite and mudstone in which the trace fossils are more abundant is interpreted as representing a distal fan turbidite or levee deposit related to long-term channel fill (Fig. 10).

ACKNOWLEDGEMENTS

We thank Professor Margaret A. Bradshaw, Professor Murray Gregory and Professor Ronald K. Pickerill for their reviews and helpful comments. The drawings were prepared by Luiz Antonio Sampaio Ferro (UFRJ). We thank the Instituto Virtual de Paleontologia/Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, grant n° 300571/03-8 and 301240/03-5) and Fundação Universitária José Bonifácio (FUJB-UFRJ) for financial support for this research project.

REFERENCES

- Birkenmajer, K. 1992. Trinity Peninsula Group (Permo-Triassic?) at Hope Bay, Antarctic Peninsula. *Polish Polar Research*, 13:215–240.
- Bromley, R. G. and Asgaard, U. 1991. Ichnofacies: a mixture of taphofacies and biofacies. *Lethaia*, 24:153–163.
- Bromley, R. G. and Ekdale, A. A. 1984. *Chondrites*: a trace fossil indicator of anoxia in sediments. *Science*, 224:872–874.
- Buatois, L., Mángano, G., and Aceñolaza, F. 2002. Trazas fósiles. Señales de comportamiento en el registro estratigráfico. Museo Paleontológico Egidio Feruglio. Edición Especial MEF n° 2, 382 pp.
- Corbo, S. 1979. Vertical distribution of trace fossils in a turbidite sequence, Upper Devonian, New York State. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 28:81–101.

- D'Alessandro, A. and Bromley, R. G. 1987. Meniscate trace fossils and the *Muensteria-Taenidium* problem. *Palaeontology*, 30:743–763.
- Dörjes, J. and Hertweck, G. 1975. Recent biocoenoses and ichnocoenoses in shallow-water marine environments. In: Frey, R. W. (ed.), *The Study of Trace Fossils*. Springer-Verlag, New, N.Y, pp. 459–491.
- Eagar, R. M. C., Baines, J. G., Collinson, J. D., Hardy, P. G., Okolo, S. A., and Pollard, J. E. 1985. Trace fossil assemblages and their occurrence in Silesian (Mid-Carboniferous) deltaic sediments of the Central Pennine Basin, England. In: Curran, H. A. (ed.), *Biogenic structures: their use in interpreting depositional environments*. Society of Economic Paleontologists and Mineralogists, Special Publication, 35:99–149.
- Ekdale, A. A. 1985. Paleocology of the marine endobenthos. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 50:63–81.
- Ekdale, A. A. 1988. Pitfalls of paleobathymetric interpretation based on trace fossil assemblages. *Palaios*, 3:464–472.
- Ekdale, A. A. and Mason, T. R. 1988. Characteristic trace-fossil associations in oxygen-poor sedimentary environments. *Geology*, 16:720–723.
- Farrow, G. E. 1966. Bathymetric zonation of Jurassic trace fossils from the coast of Yorkshire, England. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 2:103–151.
- Fischer-Ooster, C. von. 1858. *Die fossilen Fucoiden der Schweizer-Alpen, nebst Erörterungen über deren geologisches Alter*. Bern, Huber, 72 p.
- Fillion, D. 1989. Les critères discriminants à l'intérieur du triptyque *Palaeophycus-Planolites-Macaronichnus*. Essai de synthèse d'un usage critique. *Comptes Rendus de l'Académie des Sciences de Paris, Série 2*, 309:169–172.
- Fillion, D. and Pickerill, R. K. 1990. Ichnology of the Upper Cambrian? to Lower Ordovician Bell Island and Wabana groups of eastern Newfoundland, Canada. *Palaeontographica Canadiana*, 7, 119 p.
- Frey, R. W. and Pemberton, S. G. 1984. Trace fossil facies models. In: Walker, R. G. (ed.), *Facies Models*. Geoscience Canada. Reprint Series, I:189–207.
- Hall, J. 1847. *Paleontology of New York*. Volume I. C. van Benthuysen, Albany, 338 p.
- Häntzschel, W. 1975. Trace fossils and problematica. In: Teichert, C. (ed.), *Treatise on Invertebrate Paleontology, part W, Miscellanea*, Supplement I: W1-W269. Boulder, Colorado, and Lawrence, Kansas, Geological Society of America and University of Kansas Press.
- Heer, O. 1877. *Flora fossilis Helvetiae Die Vorweltliche Flora der Schweiz*, J. Würster and Co., Zurich, 182 pp.
- Hyden, G. and Tanner, P. W. G. 1981. Late Paleozoic—Early Mesozoic fore-arc basin sedimentary rocks at the Pacific margin in western Antarctica. *Geologische Rundschau*, 70:529–541.
- Howard, J. D. and Singh, I. B. 1985. Trace fossils in the Mesozoic sediments of Kachchh, Western India. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 52:99–122.
- Ineson, J. R. 1987. Trace fossils from a submarine fan-slope apron complex in the Cretaceous of James Ross Island, Antarctica. *Bulletin of the British Antarctic Survey*, 74:1–16.
- Miller, M. F. and Knox, L. W. 1985. Biogenic structures and depositional environments of a Lower Pennsylvanian coal-bearing sequence, Northern Cumberland Plateau, Tennessee, USA. In: Curran, H. A. (ed.), *Biogenic structures: their use in interpreting depositional environments*. Society of Economic Paleontologists and Mineralogists, Special Publication 35:67–97.
- Miller, I. L., Vaughan, A. P. M., Flowerdew, M. J., Fanning C. M., Trouw, R. A. J., and Bradshaw, J. D. 2003. Provenance of the Trinity Peninsula Group, northern Antarctic Peninsula. In: Fütterer, D. K. (ed.), *Antarctic Contributions to Global Earth Sciences*. 9th International Symposium on Antarctic Earth Sciences, Potsdam, Germany, 2003; Programme & Abstracts, p. 222.
- Paciullo, F. V. P., Ribeiro, A., Andreis, R. R., and Trouw, R. A. J. 2002. Facies associations in the Permian-Triassic Hope Bay Formation, Antarctic Peninsula. Antarctica at the close of a millennium. *Royal Society of New Zealand Bulletin*, 35:175–183.
- Pemberton, S. G. and Frey, R. 1982. Trace fossil nomenclature and the *Planolites-Palaeophycus* dilemma. *Journal of Paleontology*, 56:843–881.
- Pemberton, S. G., Flach, P. D., and Mossop, G. D. 1982. Trace fossils from the Athabasca Oil Sands, Alberta, Canada. *Science*, 217:825–827.
- Richter, R. 1850. Aus der thüringschen Grauwacke. *Deutsche Geologische Gesellschaft, Zeitschrift*, 2:198–206.
- Salter, J. W. 1857. On annelide-burrows and surface-markings from the Cambrian rocks of the Longmynd. No. 2. *Geological Society of London Quarterly Journal*, 13:199–206.
- Seilacher, A. 1978. Use of trace fossils for recognizing depositional environments. In: Basan, P. B. (ed.), *Trace fossil concepts*. Society of Economic Paleontologists and Mineralogists. Short Course, 5:175–201.
- Savrda, C. E. and Bottjer, D. J. 1986. Trace-fossil model for reconstruction of paleo-oxygenation in bottom waters. *Geology*, 14:3–6.
- Trouw, R. J. A., Pankhurst, R. J., and Ribeiro, A. 1997. On the relation between the Scotia Metamorphic Complex and the Trinity Peninsula Group, Antarctic Peninsula. In: Ricch, C.A. (ed.), *The Antarctic Region: Geological Evolution and Processes*. Terra Antarctica Publication, Siena, Italia, pp. 383–389.
- Uchman, A. 1995. Taxonomy and palaeoecology of flysch trace fossils: The Marnoso-arenacea Formation and associated facies (Miocene, Northern Apennines, Italy). *Beringeria*, 15, 83 p.
- Wetzel, A. 1984. Bioturbation in deep-sea fine-grained sediments: influence of sediment texture, turbidite frequency and rates of environmental change. In: Stow, D. A. V. and Piper, D. J. W. (eds.), *Fine-grained sediments*. Geological Society of London, Special Publication, 15, pp. 595–608.
- Zenker, J. C. 1836. Historisch-topographisches Taschenbuch von Jena und seiner Umgebung besonders in naturwissenschaftlicher und medicinischer Beziehung. In: Zenker, J. C. (ed.), Jena, Wackenhoder, 338 p.