Rock debris on abyssal plains in the Northeast Atlantic : a comparison of epibenthic sledge hauls and photographic surveys

Epibenthic sampling
Bottom photography
Ice rafting
Bioturbation

Drague épibenthique
Photographie sous-marine
Sédiments erratiques
Bioturbation

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ABSTRACT

Quantitative estimates of spatial distributions of rock debris on the abyssal seafloor made using photographic surveys show a discrepancy with those calculated from epibenthic sledge hauls. Processes of bioturbation and local sedimentation are capable of rapidly burying relatively recently deposited debris. Ice-rafted debris on present-day abyssal plains appears to be confined to areas north of 40°N. Clinker material dumped during the steamship era is of greater extent on present abyssal plains than any debris deposited by geologic agents.

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RÉSUMÉ

Débris rocheux sur les plaines abyssales du Nord-Est Atlantique : comparaison des résultats des dragages épibenthiques et des prises de vue sous-marines.

L'évaluation quantitative de la distribution spatiale des débris rocheux sur les fonds abyssaux, effectuée à partir de prises de vue sous-marines, fournit des résultats différents des évaluations effectuées à partir d'une drague épibenthique. Il apparaît que la bioturbation et les processus sédimentaires peuvent aboutir à l'enfouissement rapide du matériel récemment déposé. Les débris rocheux d'origine erratique présents à la surface des plaines abyssales paraissent être confinés aux zones de latitude supérieure à 40°N. Les débris scoriacés (clinker) rejetés par les navires à vapeur sont les débris les plus communément rencontrés dans les fonds sédimentaires des plaines abyssales.

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INTRODUCTION

This paper outlines some of the preliminary findings of a study of the distribution of rock and other debris on the sea bed of the Northeast Atlantic. The eventual aims of this project are: 1) to define more clearly the latitudinal limits of glacial, ice-rafted sedimentation in the abyssal environment; 2) to assess the hazard presented by such rock and other debris to some methods proposed for the disposal of radioactive waste in the deep ocean. Here we report on a part of the study, which involved a comparison of rock materials collected during biological sampling using an epibenthic sledge, with simultaneously-taken bottom photographs. Results of the latter highlight some observations which, we believe, will be of interest to both sedimentologists and biologists.

Table
Summary of stations

Station	Position	Depth (m)	Distance run (m)	Total volume (cm³)	Rock debris collected: Dominant rock type	Rock debris collected: Estimated clasts/(10 m)²	Data from photographs: Estimated clasts/(10 m)²
BS D7709 72	60°07′N 19°42′W	2650	2425	76	92% Erratic	0.359	–
BS D9775 3	50°57′N 12°22′W	2016	400	440	90% Clinker	13.5	0.0
BS D9756 14	50°04′N 13°56′W	3690	631	456	52% Erratic	5.72	2.62
BS D9756 9	49°47′N 14°02′W	4050	456	624	68% Clinker	12.4	9.15
OT D9640 1	50°03′N 13°51′W	3750	–	514	97% Clinker	–	–
OT D9756 3	49°48′N 14°15′W	4100	–	29	100% Clinker	–	–
OT D9756 5	49°49′N 14°06′W	4015	–	53	56% Erratic	–	–
OT D9638 2	49°50′N 14°07′W	4050	–	26626	99% Erratic	–	–
BS D7424 1	37°27′N 26°52′W	2630	5930	15	100% Pumice	0.0073	–
BS D9035 1	34°06′N 11°56′W	4454	–	247	72% Clinker	–	–
BS D7423 1	37°51′N 27°04′W	2283	1201	158	100% Pumice	7.41	–
BS D8519 7	24°02′N 16°59′W	1000	127	23	100% Clinker	6.97	–
OT D8933 3	24°56′N 18°01′W	2985	–	558	100% Clinker	–	–
OT D8933 4	24°58′N 17°57′W	2970	–	1516	96% Clinker	–	–
BS D9128 10	24°18′N 30°28′W	6059	2338	118	99% Pumice	0.372	–
BS D9129 1	23°06′N 27°59′W	5590	1588	648	99% Pumice	0.164	0.0
BS D9128 6	24°11′N 30°27′W	5726	–	220	82% Clinker	–	–
BS D8524 1	20°46′N 22°43′W	4412	3749	72	85% Clinker	0.174	–
BS D8524 6	20°44′N 22°44′W	4415	–	392	100% Clinker	–	–
BS D8521 1	20°47′N 18°53′W	3053	765	27	100% Clinker	0.057	–
BS D8521 6	20°48′N 18°53′W	3050	755	307	100% Clinker	0.346	–
BS D8682 5	25°34′N 16°40′W	2995	–	819	97% Clinker	–	–
BS D8532 6	13°48′N 18°08′W	2956	–	102	100% Clinker	–	–
BS D8540 1	11°16′N 18°23′W	3998	1290	148	97% Clinker	0.607	–
BS D9131 10	20°15′N 21°36′W	3950			Control station		

OT, otter trawl.
BS, benthic sledge.

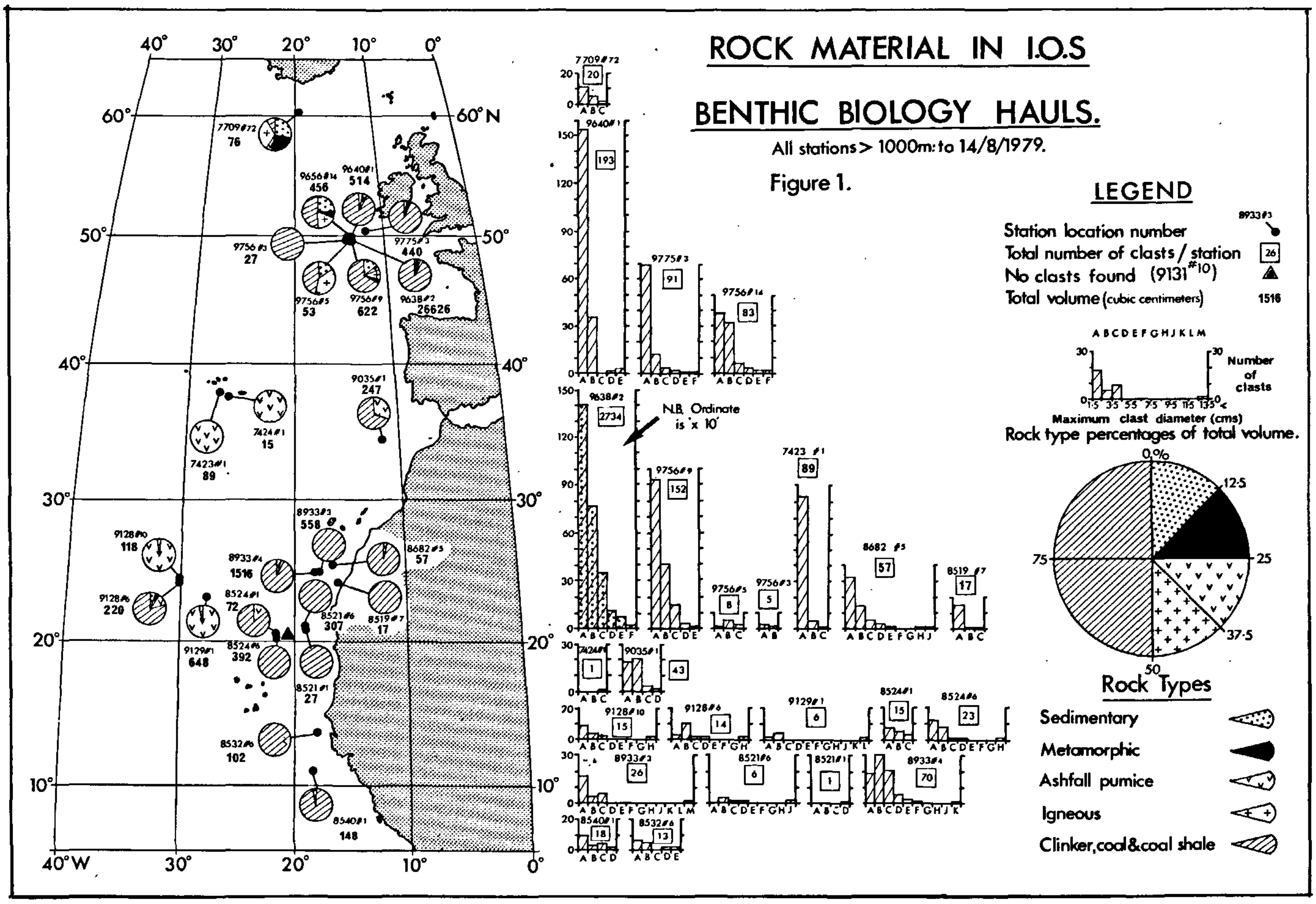

Figure 1
Rock material in IOS Benthic Biology hauls at stations in the Northeast Atlantic, see legend and text for explanation.

DATA COLLECTION

Sampling

Benthic net sampling by biological research groups provides an obvious source of data on the spacial distribution of rock and other debris on open abyssal plains, where traditionally geological sampling is restricted to isolated sediment core and grab stations (Ruddiman, 1977; Conolly, Ewing, 1965). The samples examined in this study were obtained on cruises of "RRS Discovery" between October 1970 and April 1978, using epibenthic sledges and otter trawls (Table). The total haul in each case had been sorted into biological categories and the residues, comprising both biogenic and non-biogenic material, had already been sieved into size categories.

Eighteen of the twenty-four hauls examined here were recovered using the acoustically monitored, epibenthic sledge developed by the Institute of Oceanographic Sciences (Aldred *et al.*, 1976). It consists of a steel frame on skids, to the rear of which is a terylene (4.5 mm) mesh net bag, with a mouth size of 2.3 × 0.6 m. The design is aimed at skimming the sea bed to collect organisms living above, and within the few centimetres below the water-sediment interface. At the later stations an odometer wheel was installed, so improving estimates of distance travelled across the sea bed.

Hauls taken after 1976 have been monitored by a simultaneous photographic survey using a deep sea (35 mm) camera and electronic flash unit mounted on the forward part of the sledge. This is capable of taking up to 400 frames per haul, usually at frequencies of 15 or 30 seconds. Because of fall-off in light intensity and an acute camera angle, the usable area for studies of spatial distribution of objects in a single frame is small (around 2.6 m^2). Note also that even using the combined photographs of a single haul, the area covered is relatively small when compared with the surface area sampled by the sledge (Rice *et al.*, 1979).

Sorting of residues

Because we were interested in rapidly determining the rock types as well as size distribution from the sorted material, no rock debris was included of less than 1.5 cm maximum diameter.

Most of the debris was pebble and gravel size material and was measured for maximum, median and minimum dimensions (maximum pebble diameter being taken as grain size). Rock type and surface features were also recorded for each. The rock types were categorised into: ashfall pumice, igneous, metamorphic, sedimentary and "clinker" (including coal and coal shale) (Fig. 1). From calculations of the area sampled in a given distance run by the sledge estimated numbers of rock clasts per $(10\ m)^2$ can be given (Table).

Analysis of photographs

Five of the twenty-five stations at which rock debris was found had been dredged using the benthic sledge with the deep sea camera attached. The full coverage of black and white prints (size 210 × 297 mm) was examined for comparison with the residues recovered. In addition, photographic coverage from one station (D9131#10), which recovered no rock or other debris, was similarly analysed as a control on the identification of animals versus rocks. The grid outlined in Figure 2*a* was constructed as an overlay, to provide scale for each photograph. Its lines would be 20 cm apart at the seafloor, thus any pebble material greater than 1.5 cm diameter should be visible.

An attempt was made at each station to make a quantitative estimate from photographs of the distribution of rock clasts on the seafloor (Table). In each case, it was assumed that the distribution of clasts was random, and that the photographs revealed a representative sample. Counts were made of the number of rocks visible, and each count was scaled up to the area of sea bed sampled by the sledge (Table).

RESULTS

Part of Figure 1 shows clast size distributions for the hauls examined. A comparison of the histograms with their station locations on the map, shows that there is no appreciable latitudinal change in the size distributions over the area. Also, material recovered is in most cases around 2 cm maximum diameter.

The map in Figure 1 shows pie diagrams depicting percentages of the individual rock categories at each station. Distributions are fairly predictable. Near recently active volcanic islands like the Azores and Canaries, hauls are dominated by pumice and tephra. Mixed rock assemblages, presumed to be of ice-rafted origin, are most frequent north of 40°N. However, a most striking feature of this figure is the high proportion of clinker recorded. It appears in all but one of the stations.

The analysis of the photographs shows a number of discrepancies with the sledge hauls. As examples, Figures 2 and 3 show a collection of photographs from two stations in the Porcupine Seabight, southwest of Ireland, in an area where icebergs have been observed (Usno, 1968). The haul from station D9756#9 yielded 152 pieces (12.4 clasts/10 m^2), 30% of which were of presumed glacial origin. Pebble and gravel material can be clearly seen on the photographs of Figure 2. The estimated yield from the photographs in this particular haul gave a figure of 9.15 clasts/10 m^2, well below what was collected (Table). This 26% shortfall could be accounted for by the collection of material buried within the top 4 cm of sediment. We have some evidence to suggest that this may be the case.

Figure 3 shows four photographs from station D9775#3, which yielded 83 rock fragments (13.5 clasts/10 m^2) and 90% of these were clinker. On the simultaneously-taken photographs however, no pebble material is visible,

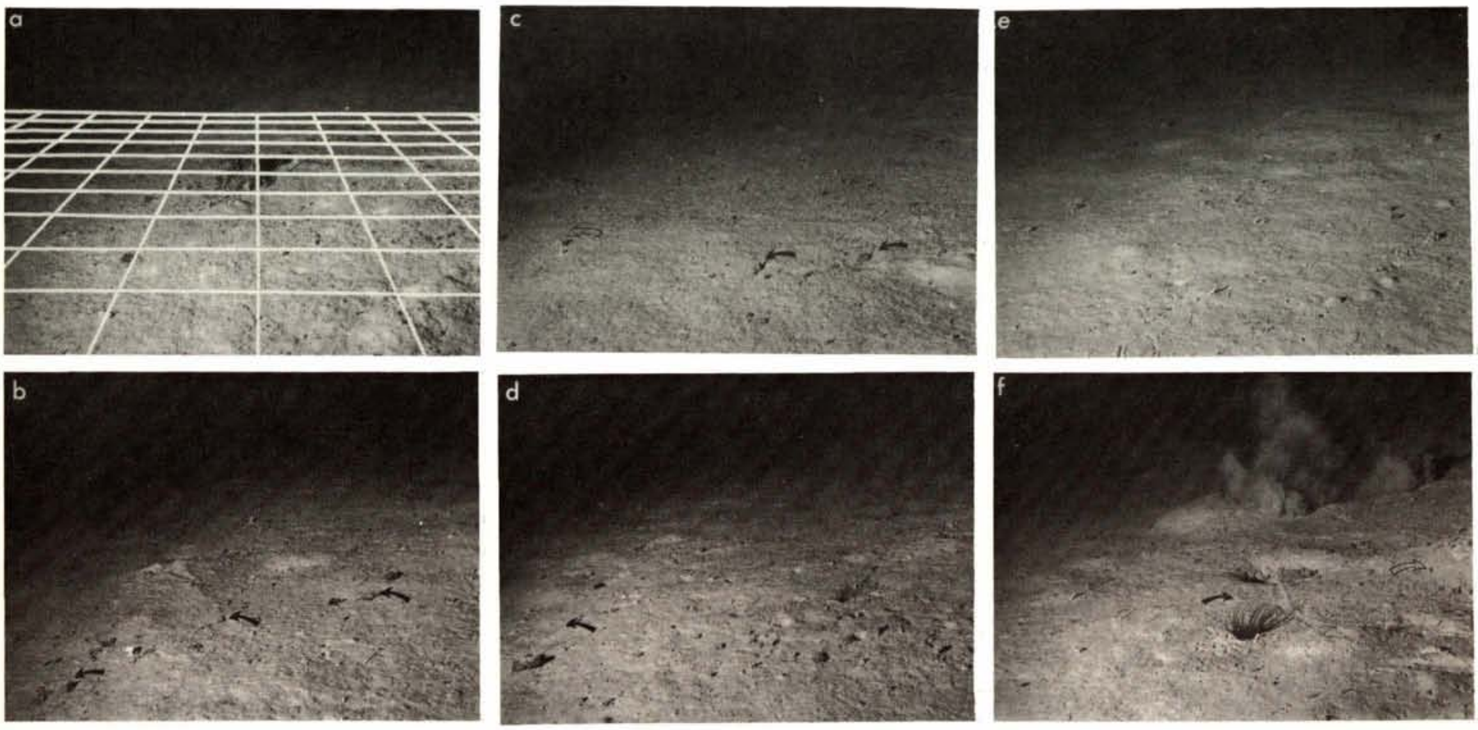

Figure 2

Seafloor photographs taken at station D9756#9 located at 4 012 m water depth in the Porcupine Seabight: a) *grid overlay with lines representing a spacing 20 cm of seafloor apart;* b) *relatively smooth but rock strewn seafloor; arrows indicate three objects positively identified as rock clasts;* c) *relatively smooth rock strewn seafloor; solid arrows show rocks; open arrow indicates an object identified as a xenophyophore* (Gooday, *pers. comm.*)*;* d) *slightly rougher seafloor, again rock strewn; arrowed is a piece of clinker with a protruding coelenterate stem indicating current activity;* e) *smooth seafloor showing sparse bioturbation (tracks and trails), to be compared with Figure 3 a;* f) *smooth seafloor with a single trail, hole and mound resulting from biogenic activity; most objects visible are benthic animals; open arrow shows small holothurians* (Kolga hyalina, *Billett, pers. comm.*)*; solid arrow shows an anemone with an indication of current activity.*

contrasting strongly with the above station. Photographs 3 *a* and *b* show that large scale bioturbation of the seafloor has taken place. Similar features were seen on most of the photographs in this survey. In addition, photograph 3 *c* shows that biogenic activity is extremely variable over a small area. Here only small scale bioturbation is observed, but again no fragments are visible. Photographs 3 *c* and *b* were taken within 2 minutes of one another, that is less than 100 m apart. Photograph 3 *d* shows clear evidence that buried gravel is being unearthed by the towing cable, even though none is visible at the surface. Thus most of the debris collected at this station must have been unearthed from the upper few centimetres of sediment, and we are left to consider whether bioturbation could have caused this burial.

DISCUSSION

Ice transports land-derived sediment out into the ocean with no regard for particle size. It is subsequently dropped by the floating ice as "glacial erratic" material onto the sea bed. Thus distribution of this material is characteristically irregular (Heezen, Hollister, 1971). During glacial maxima, icebergs migrated to lower latitudes than in periods such as the present interglacial. Most rock dredge hauls recovered from ridges and seamounts in the Northeast Atlantic are dominated by glacial erratic boulders as far south as latitudes 40°-45°N, and some boulder erratics have been recovered from largely sediment free topographic highs, even as far south as 30°N (Davies, Laughton, 1972).

In our data compilation of rock debris on the surface of abyssal plains, we are considering Holocene to present day distributions. It is tacitly assumed that any non-volcanic or non-clinker rock material found on abyssal sediment surfaces is likely to be of ice-rafted origin. Our finding of striations, rounding, faceting and other surface features, along with minimal thicknesses of manganese coating on the residues, would support this assumption. We recognised at the outset, however, that other natural agencies, such as kelp, floating trees and mammal carcasses, along with artificial agencies, such as ships ballast and other dumping could contribute debris, but we considered this to be a minor contribution in relation to geologic agents. Sedimentary rocks associated with any clinker material and probably Carboniferous in age, such as shales, sandstones and coal, were taken to be unburnt material dumped with the clinker.

So far we have little evidence of ice-rafted debris actually at the seafloor on abyssal plains south of latitude 40°N.

A surprising discovery from our sampling is that clinker from coal-burning ships can, even in northern areas, be more abundant on abyssal seafloors than any debris material deposited by ice-rafting or other geologic agents (Fig. 1). Coal-powered shipping spanned a relatively short period from the early 1800's to around 1940, so that materials of this origin should now be at or near the sediment surface.

Nowhere do the hauls or photographs show clasts larger than 14 cm maximum diameter, even though the sledge mouth has accommodated boulders elsewhere, with maximum volume of around 1 m^3 (Thurston, Merrett, pers. comm.). Ranges of material recovered in these hauls rarely extend beyond 6 cm maximum diameter, and we consider that boulders may be rare at the sediment/water interface on abyssal plains south of the present day polar regions.

Ice-rafted debris dropped by the end of the last glacial period (approx. 11 000 years B.P.) should have been buried in locations away from upstanding current scoured ridges and seamounts, since sedimentation rates vary from around 2 cm/10^3 years on abyssal plains to around 7 cm/10^3 years on the margins of the N.E. Atlantic (Ruddiman, 1977). Our discovery of buried clinker, however, does require explanation. Even at sedimentation rates approaching 10 cm/10^3 years in the Porcupine Seabight area, we would not expect such rapid burial of the clinker we describe. It is interesting to consider which mechanisms may have caused this burial.

Bioturbation is the major process modifying the sediment-water interface in abyssal environments (Heezen, Hollister, 1971). These IOS photographic surveys show the extreme variability of this bioturbation in a small area (Fig. 3*b* and *c*). There is more evidence of large-scale bioturbation at locations where rock materials have been buried (Fig. 3*a*). Since the larger animals would require organic rich sediments as a food source, and these would characterise high sedimentation rate locations, this is not an unexpected finding here. However, debris has apparently been buried, even where small scale bioturbation is evident (Fig. 3*c*).

It is worth noting at this point that a number of authors have suggested that bioturbation should have the opposite effect. They consider that it might be a means, for example, of keeping manganese nodules at the sediment surface by continual foraging around and under such objects (Menard, 1976; Glasby, 1977; Piper, Fowler, 1980), and epifaunal cleaning of their surfaces (Paul, 1976). If true, we would expect a similar process to occur around other objects of similar size, such as our residual material, keeping it exposed rather than burying it.

Certain sedimentation events could alone have caused the rapid burial of the clinker. Bottom current activity is in evidence in the photographs of one of the stations (Fig. 2*d* and *f*), but this could be expected to winnow the sediment surface and keep the clinker exposed. Remembering that the Porcupine Seabight hauls were from a lower slope environment, a plausible explanation might be that at these locations, small-scale slumping or turbidity current activity has occurred. Our evidence of clinker having been buried does, however, extend to more distal areas away from the slope environments.

The possibility that debris may become buried by sinking into the sediment under its own weight or by penetrating the sea bed after its initial fall, must also be considered. Piper and Fowler (1980) showed that for Pacific pelagic clays, manganese nodule loadings are exceeded by the shear strength of the sediment by a factor of 70. Thus, it would appear that our rock debris, which is mostly of smaller size, should not sink under its own weight. Burial of boulders by sinking may however happen. Initial penetration, after dropping through the water column, is possibly more likely to be a factor in the burial of the clinker debris, and even more so for boulder-size erratics. Clearly, further work is required to increase our knowledge of both the physical properties of the sediments on the deep seafloor, and of the effects of benthic communities on these sediments.

Our comparisons of the materials sampled with visual evidence from simultaneous photographic surveys concur to some extent with the findings of Rice *et al.* (in prep.) for macrobenthos sampling. The epibenthic sledge clearly samples the few centimetres below the sediment-water interface, as it is designed to do (Fig. 2 and 3). Often the visual evidence from seafloor

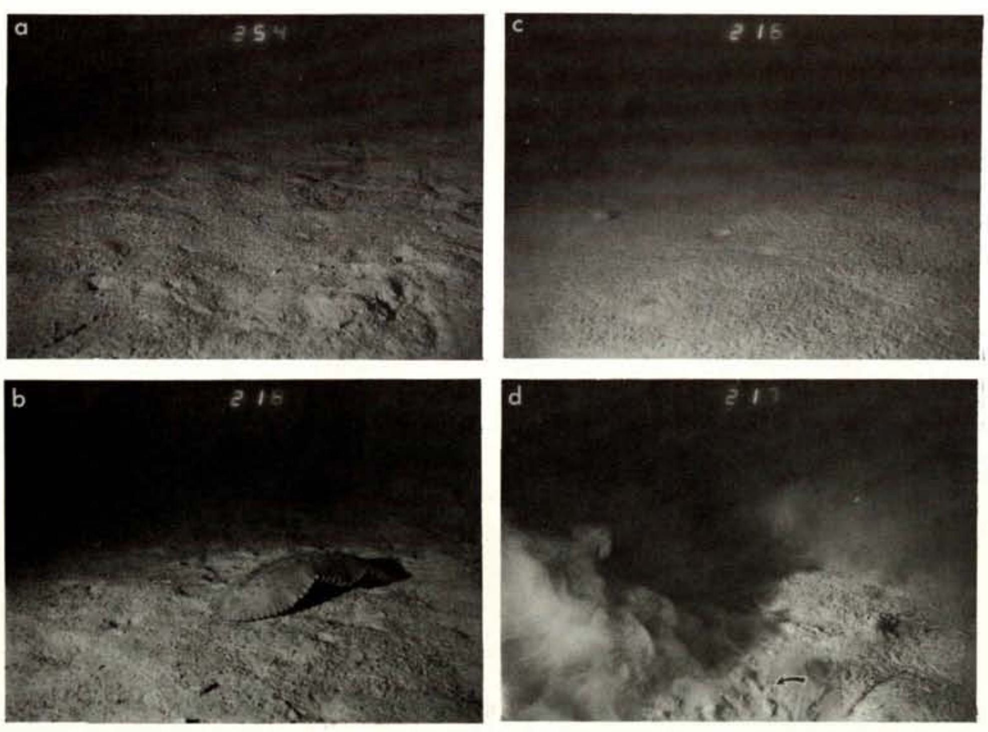

Figure 3

Seafloor photographs taken at station D9775#3 in the Porcupine Seabight (3 690 m w.d.): a) *seafloor showing large-scale bioturbation (tracks, trails and mounds) but no rock debris;* b) *seafloor with large-scale bioturbation; no rock debris and a large holothurian (approximately 25 cm long,* Palaeopatides gigantea; *(Billett, pers. comm.);* c) *smooth seafloor with small scale bioturbation which was crossed by the sledge only about 2 minutes before that seen in 3b; indicating extreme variability of bioturbation. No rock material is visible; small echinoid left of centre;* d) *mud cloud thrown up by the towing cable; arrow shows unearthed rock material; to the left the undisturbed seafloor appears to lack debris.*

photographs is at odds with what is recovered as residue in the hauls because of this subsurface sampling (Table). On the other hand, our study shows that processes exist, which are capable of causing the burial of even relatively recently deposited debris. Thus it clearly would be impossible to make quantitative estimates of rock debris near the sediment-water interface from photographic surveys alone.

CONCLUSIONS

Photographic surveys alone provide insufficient information with which to make quantitative estimates of spacial distributions of rock debris on the abyssal seafloor. This is because local processes of bioturbation and/or sedimentation are capable of rapidly burying debris. Combined epibenthic sledge sampling and bottom photography provides better estimates, but it remains possible that the larger material dropped through the water column may penetrate beyond the range of sledge sampling. Scales of bioturbation vary rapidly in any one survey across the abyssal seafloor, and our results appear at odds with published works, which promote bioturbation as the process which keeps objects such as manganese nodules at the sediment-water interface.

We have no evidence thusfar of present-day ice-rafting reaching latitudes south of 40°N. Further combined sledge and photographic surveys on abyssal plains are planned to define this limit more accurately. More precise determination of the limits for Pleistocene ice-rafting could be gained from studies of rock dredge collections taken at sediment-free ridge and seamount locations, or from detailed near bottom seismic profiling on the abyssal plains.

Rock debris at the sediment surface is relatively small, generally around 2 cm diameter, and material supplied by geologic agents is at the present day of lesser extent than clinker debris dropped during the steamship era.

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REFERENCES

Aldred R. G., Thurston M. H., Rice A. L., Marley D. R., 1976. An acoustically monitored opening and closing epibenthic sledge, *Deep-Sea Res.*, **23**, 167-174.

Conolly J. R., Ewing M., 1965. Pleistocene glacial marine zones in North Atlantic deep sea sediments, *Nature*, **208**, 135-138.

Davies T. A., Laughton A. S., 1972. Sedimentary processes in the North Atlantic, *Initial Rep. Deep Sea Drill. Proj.*, **12**, 905-934.

Glasby G. P., 1977. Why manganese nodules remain at the sediment/water interface, *N.Z. J. Sci.*, **20**, 187-200.

Heezen B. C., Hollister C. D., 1971. *The Face of the Deep*, Oxford Univ. Press, New York, 659 p.

Menard H. W., 1976. Time, chance and the origin of manganese nodules, *Am. Sci.*, **64**, 519-525.

Paul A. Z., 1976. Deep-sea bottom photographs show that benthic organisms remove sediment cover from manganese nodules, *Nature*, **263**, 50-51.

Piper D. Z., Fowler B., 1980. New constraint on the maintenance of manganese nodules at the sediment surface, *Nature*, **286**, 880-883.

Rice A. L., Aldred R. G., Billett D. S. M., Thurston M. H., 1979. The combined use of an epibenthic sledge and a deep-sea camera to give quantitative relevance to macrobenthos samples, *Ambio Spec. Rep.*, **6**, 59-72.

Rice A. L., Aldred R. G., Darlington E., Wild R. A., in prep. Quantification of the deep sea megabenthos; a new attempt to solve an old problem.

Ruddiman W. F., 1977. Late Quaternary deposition of ice-rafted sand in the sub-polar North Atlantic (lat. 40° to 65°N), *Bull. Geol. Soc. Am.*, **88**, 1813-1827.

US Navy Oceanographic Office, 1968. *Ice*, Publ. No. **700**, 111.