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Preliminary Results

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The Distribution of Pebble Material on the Northeast Atlantic Seabed
Preliminary Results

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(Part of a study of the distribution of glacial erratics in the Northeast Atlantic; commissioned by the Department of the Environment)

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ABSTRACT

An analysis has been made of pebble material present in residues from biological epibenthic net hauls in the Discovery collections. These residues and their associated bottom photographic surveys represent immediately available material with which to assess sediment surface distributions of glacial debris on abyssal plains.

Preliminary findings indicate that below 2500 metres water depth almost all of the pebble material on the seabed is of small size, mostly around 2 cm maximum pebble diameter and that size ranges are remarkably constant between latitudes 10 °N and 60 °N. Although numbers of pebbles recovered were greater in the north and decreased southwards nowhere was boulder material located on the abyssal plains. Stations located near volcanic islands like the Azores or Canary Islands contained large amounts of volcanic pumice and tephra. Those north of latitude 40 °N contained a mixed rock assemblage presumably of glacial origin.

One striking discovery is that clinker dropped from coal burning ships appears in all but two of the hauls, most contain more than 50% clinker and some have pebbles exclusively from this source. Some attention needs now to be given to the hazards presented by man-made "deposits" on the ocean floor.

Studies relating pebble recovery in the hauls with photography taken ahead of the dredge gear suggest that, in high sedimentation rate areas at least, much pebble material is masked and that photographic surveys alone would be insufficient to characterise the nature of the surface sediments.

INTRODUCTION

To date most attempts at identification of potential areas for disposal of high-level radioactive wastes on or beneath the ocean seabed have recognised the importance of avoiding high latitude regions where transport by icebergs and other sea ice supplies much of the sedimentary and rock material to the seafloor, (Hollister et al, 1976; Searle, 1979). The problems posed by these glacial materials, along with a desire to avoid areas with rapid vertical mixing in the water column and a preference for disposal operations to be conducted in reasonable climatic and sea conditions, have resulted in a general recommendation that disposal sites should be sought within latitudes 50°N to 50°S, (International Atomic Energy Agency, 1978).

This report outlines the preliminary findings of a study of the distribution of glacial materials on the deep sea floor, with a view to defining more clearly their latitudinal limits. Here we examine pebble material dredged in biological net hauls from abyssal plains as opposed to the more usual geological sampling of seamounts and ridges.

BACKGROUND

Ice transports land-derived sediment out into the ocean with no regard for particle size. Thus it becomes possible that even large boulders can occur as "glacial erratics" in areas where local hydraulic energy levels provide only for fine-grained sedimentation. Rock and other loose debris is irregularly frozen into the ice during its passage over the land and sea depending upon local climatic conditions and availability of material. It is subsequently dropped from the floating ice as glacial erratic material onto the seabed, depending upon local oceanographic conditions. Thus transport and distribution of material by this sedimentary process is characteristically irregular. At the seafloor the result is envisaged to be a sediment-water interface strewn with patches of pebble and boulder material. Bottom photographs confirm this for polar regions at least, (Heezen & Hollister, 1971).

During glacial maxima, fields of sea ice and icebergs migrate to lower latitudes than in periods such as the present interglacial. Most dredge hauls recovered from scarps and seamounts in the Northeast Atlantic are dominated by glacial erratic boulders as far south as latitudes 40°-45°N, (Davies & Laughton, 1972), and some erratics have been recovered even as far south as 30°N. Layers of ice-rafted sand recovered in sediment cores are another guide to the distribution of Pleistocene glacial debris and have been used to outline changing patterns of glacial sediment distribution over the past 120,000 years, (Ruddiman, 1977). The distributions mapped by this method to date are shown in Figure 1. Based upon the above information the Pleistocene parts of sediment columns on the ocean floor north of 40°N or even 30°N are expected to be both laterally and vertically inhomogeneous.

With regard to the disposal of radioactive wastes, the presence of sediment surfaces strewn with pebble and boulder material would be an obvious hazard for methods involving dropping of waste cannisters either onto or into the seabed. Dropped cannisters could break open or projectiles could fail to penetrate the seabed. The latter could also happen if pebble or coarse sand layers made up part of the sediment column. Furthermore, the lateral and vertical inhomogeneity of such sediment columns and the characteristic poor size sorting of glacial debris itself make them unattractive media for subseabed waste emplacement merely because of their complexity for later modelling of pore water movement and radionuclide diffusion. Moreover, layers of pebbles, even if buried under relatively impermeable sediments, might provide paths for rapid movement of pore water away from a disposal site, possibly to locations where it could easily reach the sea-floor.

Clearly areas in which ice-rafted material makes up a significant part of the sediment sequence are unlikely to prove suitable for disposal of high-level radioactive waste. Equally clear, however, is that distributions of such material on or under the ocean seabed are very imperfectly known, (Institute of Oceanographic Sciences, 1979). Little is known, for example, of surface distributions on open abyssal plains which have not been dredged and where disposal sites might well be located. The presently inferred latitudinal limits of Pleistocene ice-rafted sand and other erratics are based upon a very limited, and possibly biased, data base. Only thirty-two cores form the basis of Ruddiman's maps of ice-rafted sand distributions. Erratic boulders recovered during rock dredging aimed at sampling Neogene and older rock formations on upstanding ridges and seamounts may be a biased sample. Boulders may be unusually concentrated here because of iceberg grounding or melting caused by water column circulation effects around topographic highs. Similarly boulders could be widely distributed on abyssal plains or on the other hand be concentrated along distinct iceberg pathways, whose location is controlled by movements of the polar front.

A latitudinal limit of 30 °N (see Figure 1), if established as a site selection criterion, would confine exploration for shallow subseabed and on-the-seabed disposal areas to subtropical and equatorial regions and thus exclude large areas of seafloor which might in other respects be suitable for investigation. For this reason the Institute of Oceanographic Sciences has begun a two-year commissioned project to investigate this distribution of ice-rafted material on the Northeast Atlantic seafloor.

BIOLOGICAL SAMPLING ON ABYSSAL PLAINS

Benthic net sampling by biological research groups provides an obvious source of data on pebble distributions on open abyssal plains. The benthic biology group at IOS, Wormley have conducted extensive sampling surveys using epibenthic dredges and otter trawls over the deep seafloor of the Northeast Atlantic and have in more recent cruises simultaneously conducted bottom photographic surveys. The samples examined in this study were obtained on cruises of "RRS Discovery" that took place between October 1970 and April 1978. 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. These sub-samples presently make up part of the "Discovery Collections" at Wormley.

Most of the hauls examined here were recovered using the acoustically monitored opening and closing epibenthic sledge developed at IOS (Aldred et al, 1976). It consists of a steel frame on skids to the rear of which is a net bag of 45 mm terylene mesh (Figure 2). Its rectangular mouth is 2.3m wide by 0.6m high and is designed to remain closed by a blind while the system is clear of the seabed. This blind is pushed upwards and forwards clearing the mouth when the gear is on the bottom. The design is aimed at skimming the seabed to collect organisms living within the few centimetres on either side of the water-sediment interface. A double "tickler chain" is mounted between the skids to disturb animals living within the sediment. The behaviour of the sledge is monitored by a precision pinger which signals when the sledge is in contact with the bottom and in the 'fishing' position. An odometer wheel records the distance travelled across the seabed.

Hauls taken after 1976 were also monitored by a simultaneous photographic survey using a 35 mm deep sea camera and electronic flash unit mounted on the forward part of the sledge, (Rice et al, 1979). This is capable of taking up to 400 frames per haul usually at frequencies of 15 or 30 second intervals. By means of a switch on the closure unit of the sledge mouth the camera is operated only when the sledge is in contact with the seabed. 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).

SAMPLE ANALYSIS

Because we were interested in rapidly determining rock types as well as size distribution from the sorted material in the "Discovery Collections", no pebbles were included of less than 1.5 cm maximum diameter. Samples were studied from both residues and specimen jars containing pebbles and associated benthic faunas.

The first samples studied were all from stations in water depths greater than 2500m. A total of forty-three stations were examined here, twenty of which yielded pebble material greater than 1.5 cms in size. These pebbles were measured for their maximum, median and minimum dimensions. Rock type, surface features and thickness of manganese coating were also recorded for each. The rock types were categorised into: ashfall pumice, igneous, metamorphic, sedimentary and "clinker" (including coal and coal shale). From this data two diagrams were drawn: one to show grain size distribution (maximum pebble diameter being taken as "grain size") (Figure 3), and the other to show percentages of each rock type category for each station, illustrated as a pie diagram (Figure 4). Note that no attempt was made to determine whether the igenous, metamorphic or sedimentary pebbles were glacial erratics. It is tacitly assumed that any non-volcanic or clinker material found on abyssal sediment surfaces is likely to be of ice-rafted origin. Sedimentary rocks associated with clinker and probably Carboniferous in age such as shales, sandstones and coal were taken to be unburnt material dumped with the clinker. Also, a check was carried out on the samples from station 9638#2 by comparing the estimated total volume (by measurement of maximum, median and minimum dimensions) with the volume measured by fluid displacement. Assuming that the volume by displacement is the true volume, then the estimated volume was 54% in excess of the true volume. This should not however affect the findings we present here which examine relative volume changes between stations.

After the above data had been collected and analysed, a sample of 18 stations, (five yielding suitable material) from water depths less than 2500m was examined using the same procedures, in order to establish whether the patterns observed in the deeper hauls were continued into shallower regions. The results of this analysis were plotted onto a single diagram (Figure 5).

Finally, of the twenty-five stations which showed pebble material (>1.5 cm grain size) four had been dredged using the benthic sledge with a deep sea camera attached. A total of 200 prints were examined from these four stations in order to establish whether there is a correlation between the amount and type of pebble material found and the material visible by photography on the seafloor.

RESULTS

Figure 3 shows pebble size distributions for hauls below 2500m water depth. From this diagram it is clear that there is no appreciable latitudinal change in the size distributions over the area and that pebble material recovered is generally small, in most cases being around 2cm (maximum pebble diameter). Note should be made of station 9638#2 where the large number of pebbles found require the ordinate of the histogram to be on a larger scale. More pebbles were retrieved from the Northern stations, however this is not reflected in changes in grain size.

Figure 4 shows the percentage of total volume of each rock type at individual stations greater than 2500m water depth. Distributions are fairly predictable. Near recently active volcanic islands like the Azores and Canaries, hauls are dominated by pumice and tephra. Mixed rock assemblages are most frequent north of 40°N. However the most striking feature of this figure is the high proportion of clinker recorded.

It appears in all but one of the stations below 2500m.

Figure 5 was drawn from a selection of stations above 2500m and displays both size distribution and pebble type. Both parameters show similar trends to those seen in the stations below 2500m.

Figure 6 indicates the stations from which photographs were examined. Only a qualitative analysis may be carried out on these because of the small number of photographs available. In some cases one can see a clear relationship between the number of pebbles collected and the nature of the sediment surface. Station 9756#9 collected a total of 152 pebbles and here the photographs show pebbles clearly visible on the seabed. Station 9128#6 yielded only 15 pebbles and the photographs at that station showed no pebbles. At other locations the photographic evidence is deceptive. One of the photographs from station 9775#3 shows pebbles being unearthed by the towing cable. The rest of the photographs from that station show a remarkably smooth bottom considering that 91 pebbles had been retrieved from the haul. This would suggest that much of the recent material (including clinker) may be masked by recent sedimentation and biogenic activity.

DISCUSSION

The discovery from this sampling of presently available benthic biology hauls that clinker from coal burning ships is more abundant on abyssal plains than any pebble material deposited by geologic agents, suggests that the search for a latitudinal limit for use as a disposal site selection criterion is something of a half-measure. However, this statement must be qualified by the fact that clinker must primarily be a surface feature since it derives only from the days of coal powered ships, from the early 1800's to the period spanning the two World Wars. Similarly, it should be possible to predict both its occurrence and its grain size characteristics from historical shipping records. Some modification may be necessary to the site criterion which suggests avoidance of major shipping lanes, (Searle, 1979) to take account of historical route changes and knowledge of likely dumping areas for clinker (Figure 7).

The fact that the largest numbers of pebbles recorded occur in hauls from stations near the Porcupine Seabight (about 50°N) is clearly a function of both its closeness to likely source areas for glacial materials, and its location on transatlantic shipping lanes into ports in Western Europe. All are dominated by clinker but also have mixed rock assemblages made up primarily of igneous and sedimentary rocks.

Nowhere do the hauls or photographs show evidence of material on the seafloor larger than 14 cm (maximum pebble diameter) even though the sledge mouth could accommodate boulders with maximum volume of around 1 cubic metre. This may be a reflection however, of the behaviour of the sledge on the seafloor. It may be, that the sledge is forced to ride over large boulders whereas smaller material is less obstructive and therefore more readily collected. Large boulders have been recovered by these methods close to the UK shelf edge (M.H. Thurston & N.R. Merrett, personal communication). Here their occurrence is most likely to be due to concentration related to grounding of icebergs. That grounding has been a common occurrence on the outer shelf of the British Isles is evidenced by plough marks detected by sidescan sonar surveys (Belderson, R.H., Kenyon, N.H. & Wilson, 1973). In deeper northern areas high sedimentation rates may have buried large boulders; certainly we have photographic evidence of pebble material having been buried at station 9775#3. Nevertheless size ranges of material recovered in these hauls rarely extend beyond 6 cm maximum pebble diameter and we consider that boulders may indeed be rare on abyssal plains south of the present day polar regions.

Our comparisons of the materials sampled with visual evidence from simultaneous photographic surveys concur to some extent with the finding of Rice et al (1979) for macrobenthos sampling. Pebble materials within a few centimetres of the sediment surface may be masked sufficiently in some areas that little confidence can be placed on photographic surveys alone as a way of assessing hazards to disposal operations. The use of a camera on the sledge capable of providing overlapping coverage of photographic frames would be a considerable advantage in determining how representative are hauls, or indeed the photographs themselves. Previous photographic surveys which cover larger areas of seafloor could provide a check for the occurrence of isolated boulders. A modified version of the IOS epibenthic sledge with a net bag more similar to that used in geological dredging and fitted with a high capacity deep sea camera should now be towed over abyssal plains selected for their isolation from former steam shipping lanes and location between latitudes 40°N to 50°N where there is a considerable gap in our data.

CONCLUSIONS

The major conclusions of this report can be listed as follows:-

1. The combined use of sampling gear similar to the present IOS epibenthic sledge along with deep sea photography is likely to provide the most useful and reliable quantitative data on surface hazards to deep ocean high-level radioactive waste disposal. Photographic or sidescan sonar surveys alone would be insufficent.

2. Numbers of pebbles are significantly greater on the abyssal seabed in areas north of 45°N than in those to the south, but their sizes are generally small and boulder material is rarely present.

3. Clinker from coal-burning ships occurs in greater abundance in these epibenthic hauls than pebble material supplied by any of the natural geologic agents. Besides clinker the limited spread of stations examined suggest that distributions of glacial and volcanic debris would be as expected from earlier studies.

4. Further studies related to those reported here should include: (a) comparisons of photographic coverage in high versus low sedimentation rate areas to examine further aspects of pebble burial and representativeness of bottom photographs; (b) historical studies of steam shipping routes and dumping practices; (c) comparisons of provenance of boulder material obtained by conventional rock dredging with that found as pebbles on abyssal plains to examine aspects of iceberg concentration, grounding and pathways; and (d) further sampling with a modified epibenthic sledge/deep sea camera system in a north-south series of abyssal plain surveys in the eastern North Atlantic; (e) box coring to examine buried pebble material, especially clinker, which may provide a good control for the study of the mechanisms and rate of burial of pebble material.

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FIGURE CAPTIONS

Figure 1. Occurrence of ice rafted material in dredge hauls and Deep Sea Drilling Project cores (black dots, from Davies & Laughton, 1971) together with contours of maximum rate of deposition of glacial sands in milligrams per square centimetre per thousand years (from Ruddiman, 1977) and inferred limits of rafted ice.

Figure 2. The epibenthic sledge used by the IOS Marine Biology group: (A) in the mid-water attitude with its quadrant levers lowered and the blind closed, and (B) in the sampling attitude with the levers raised and the blind open.

Figure 3. Part (a) shows the station positions for stations $>$ 2500m water depth with the total number of pebbles collected at each station. Part (b) shows the size distribution for each of the stations in part (a).

Figure 4. Rock type and total volume of pebble material collected at each station $>$ 2500m water depth.

Figure 5. Selected stations $<$ 2500m water depth, rock type and size distribution.

Figure 6. Stations from which photographs were examined for this study.

Figure 7. Present day major shipping routes in the Northeast Atlantic. (Source, The Edinburgh World Atlas, Bartholomew, 1970)

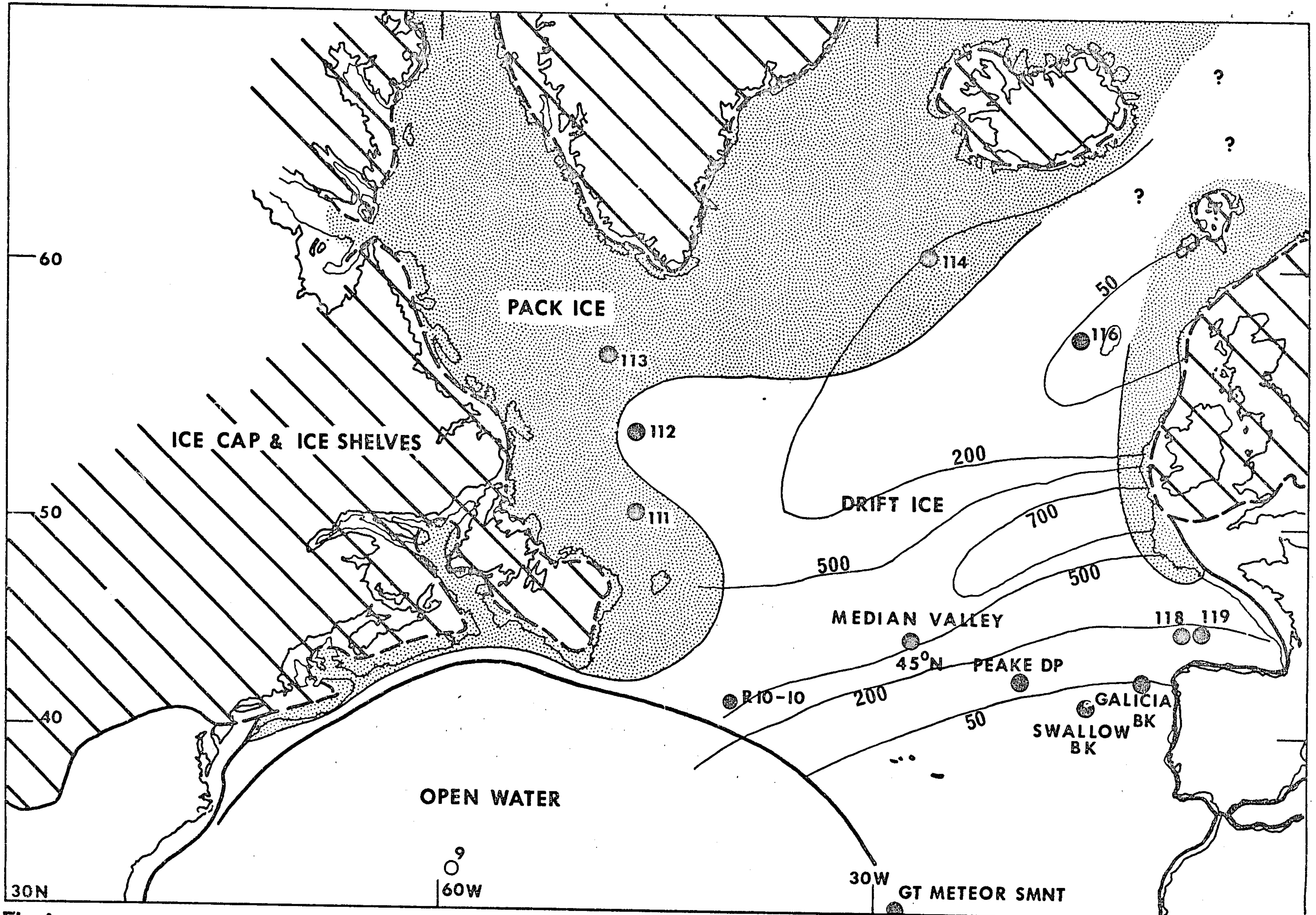


Fig.1 *Suggested ice limits at maximum extent of glaciation.*

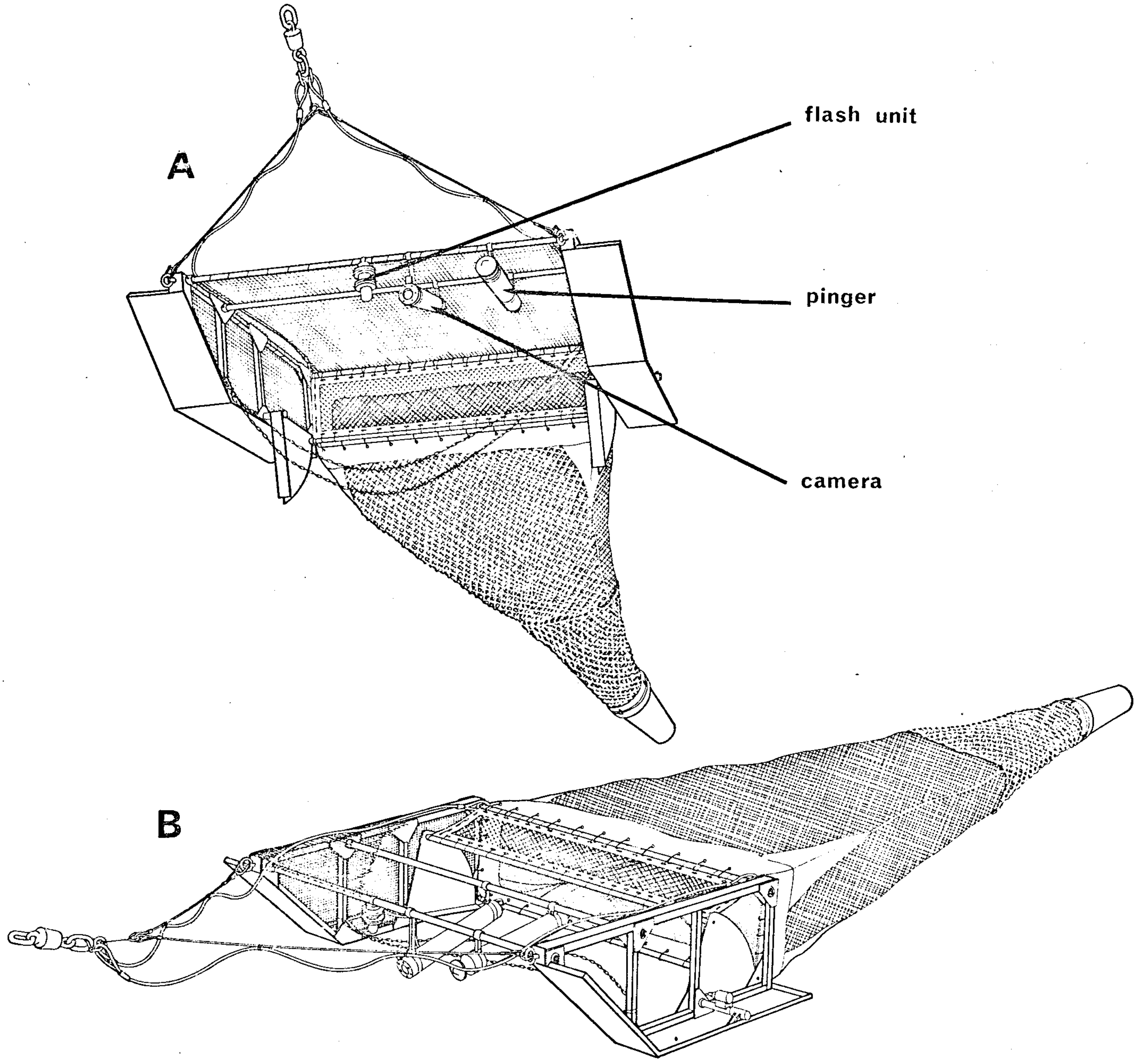


Fig.2 Epibenthic Sledge used by I.O.S. Marine Biology Group

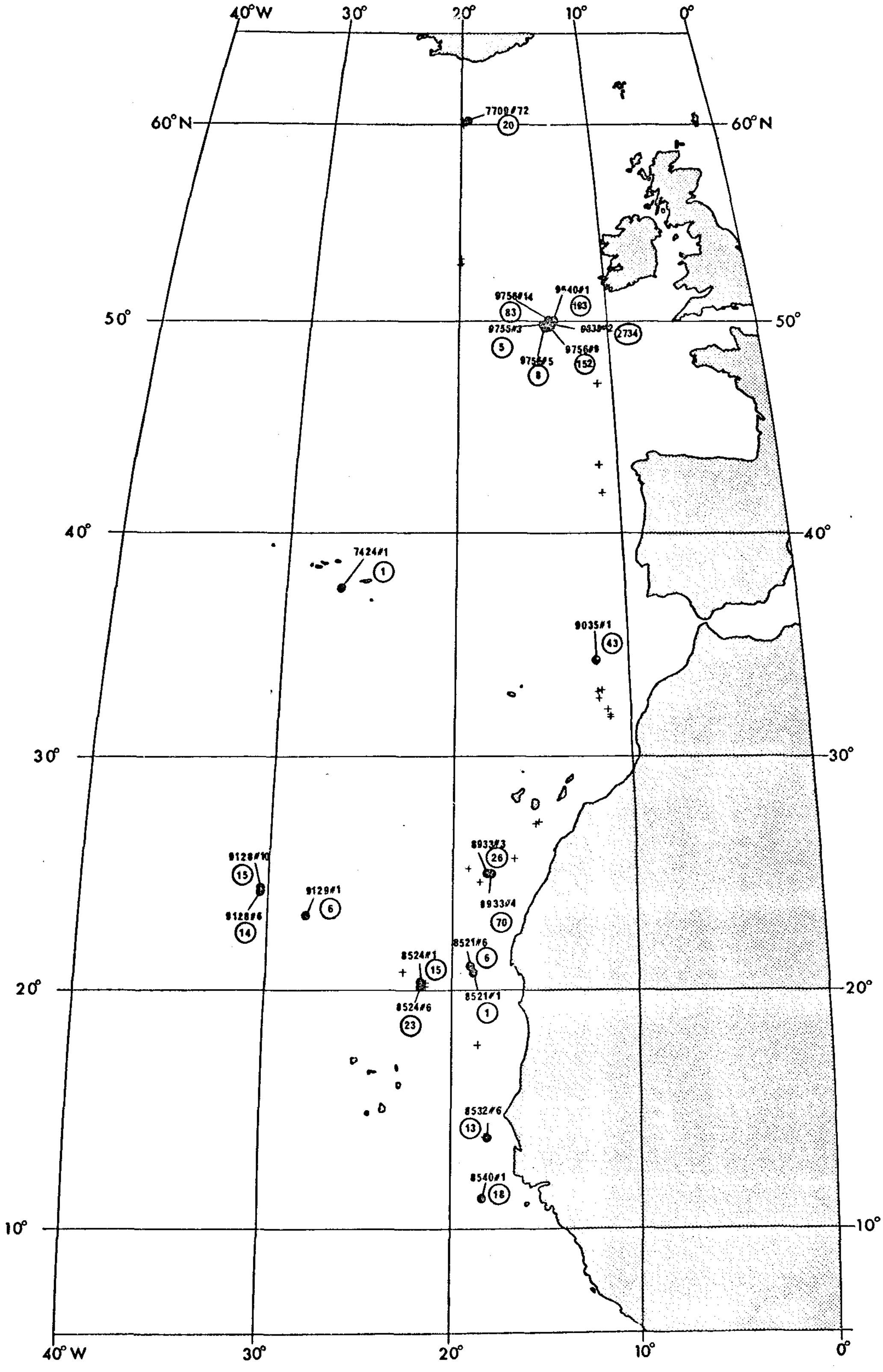
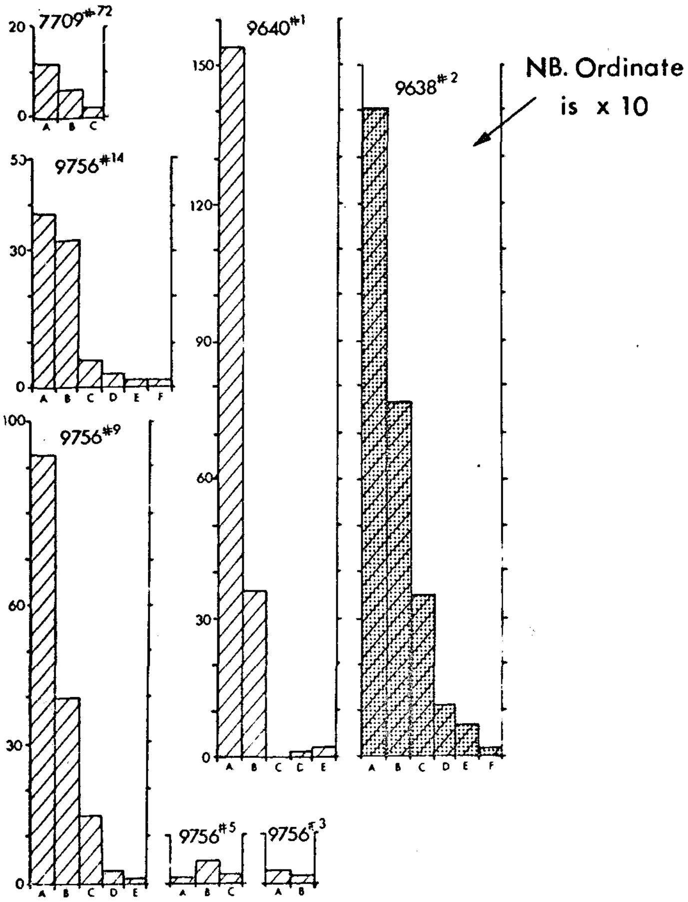


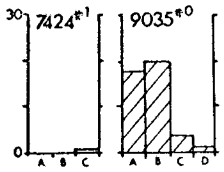
Figure 3 (a) Stations > 2500m

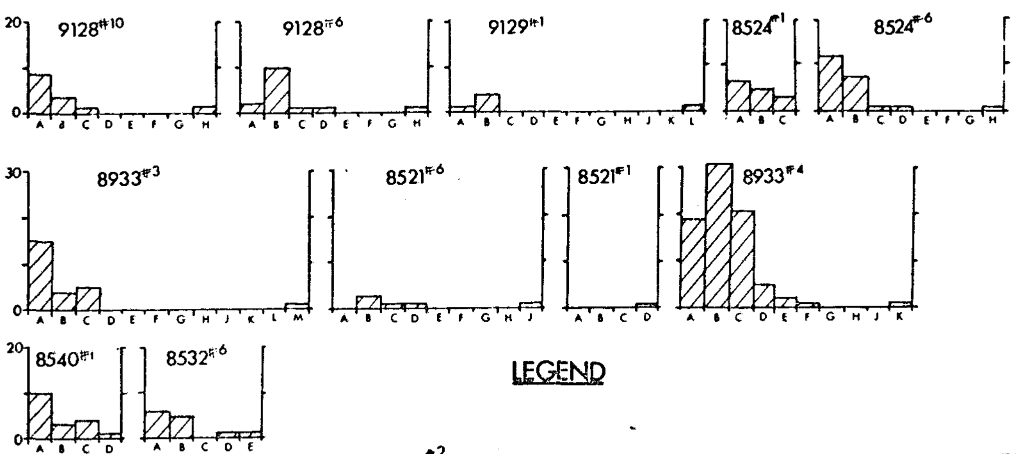


PEBBLE MATERIAL IN I.O.S. BENTHIC BIOLOGY HAULS

all stations > 2500m : until 14·8·1979

Fig.3(b) SIZE DISTRIBUTION





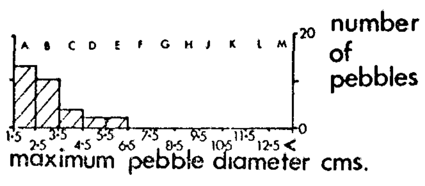
LEGEND

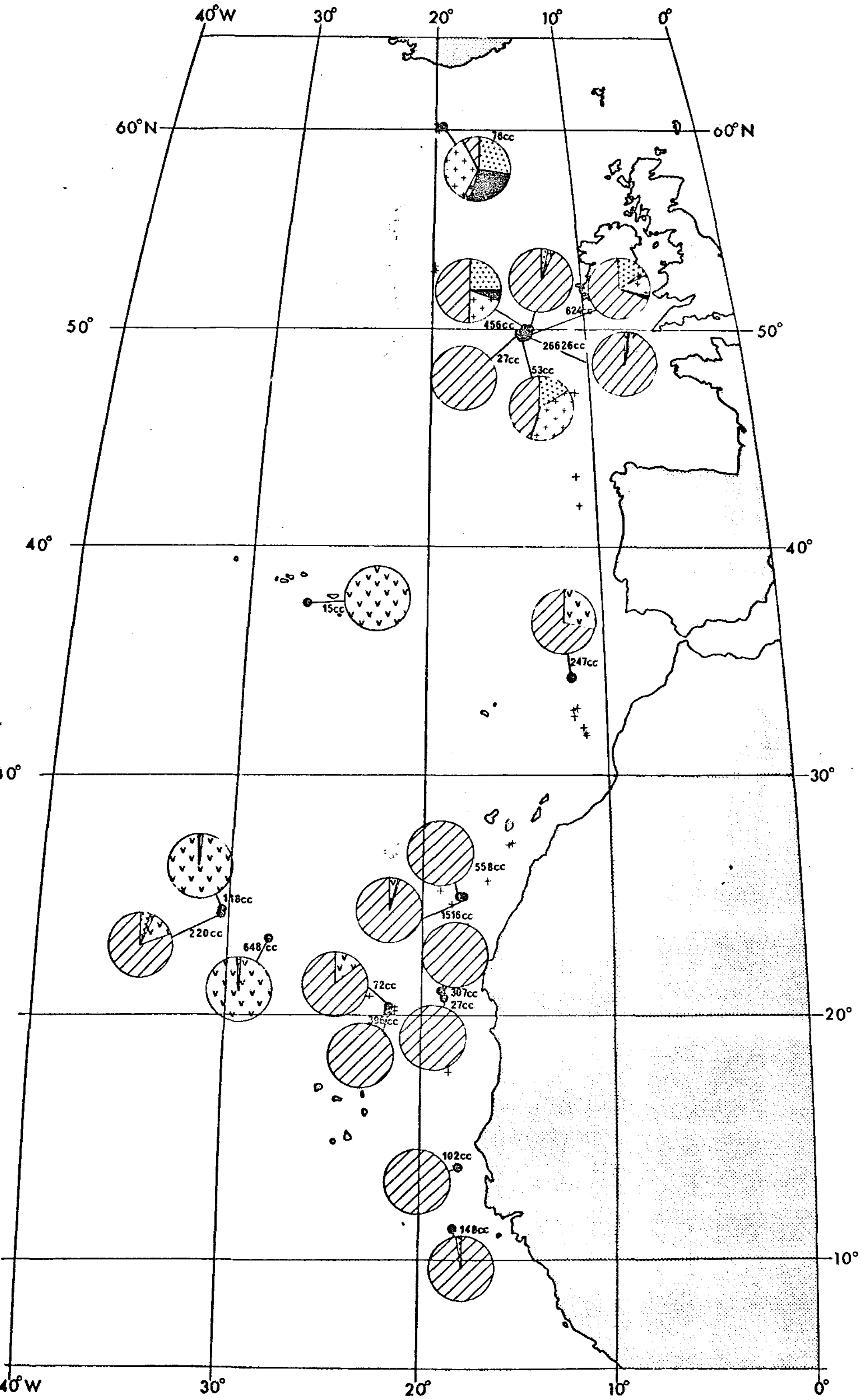
8933#2

Station location number

Total number of pebbles/station (34)

No pebbles > 1·5cms in residue +





PEBBLE MATERIAL IN I.O.S BENTHIC BIOLOGY HAULS.

All stations > 2500m: to 14/8/1979.

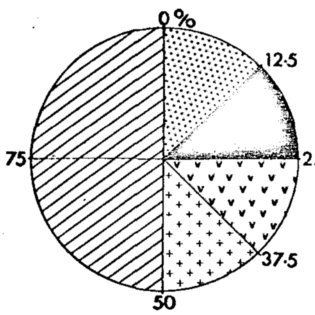
ROCK TYPES

Fig. 4

LEGEND

Total volume (cubic centimetres) 220 cc

Rock type percentages of total volume.



Rock Types.

Sedimentary

Metamorphic

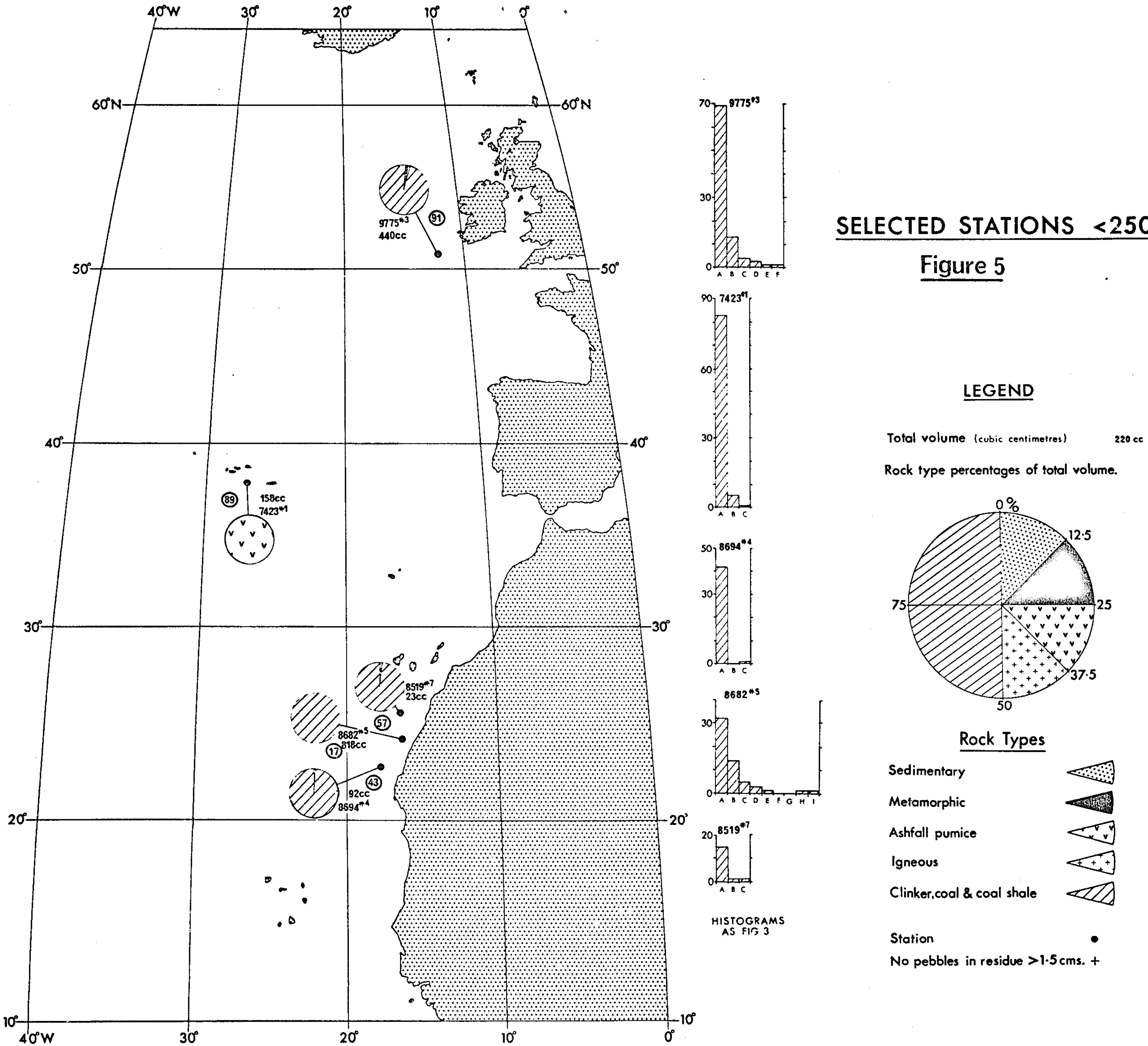
Ashfall pumice

Igneous

Clinker, coal & coal shale

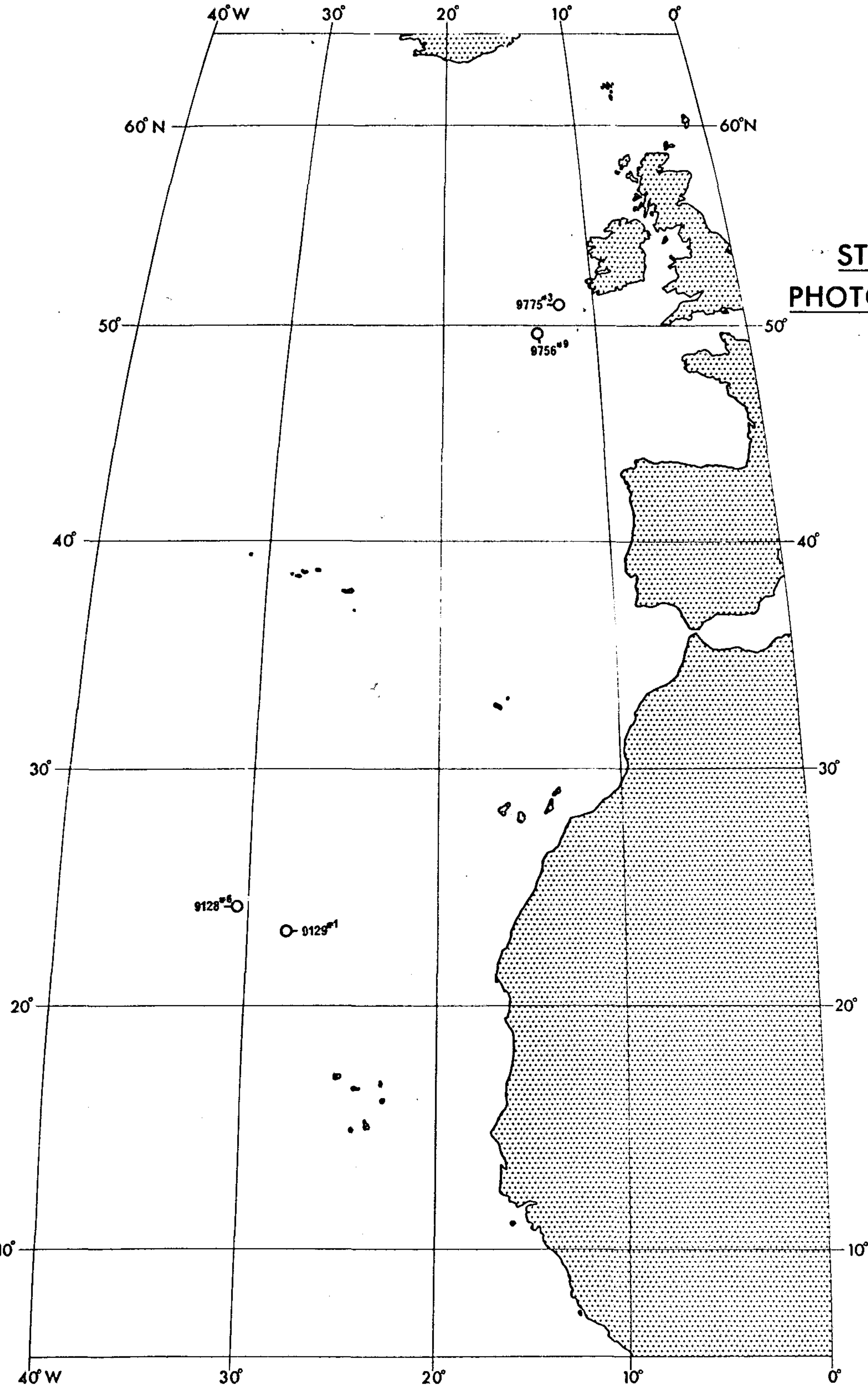
Station ●

No pebbles in residue > 1·5 cms. +



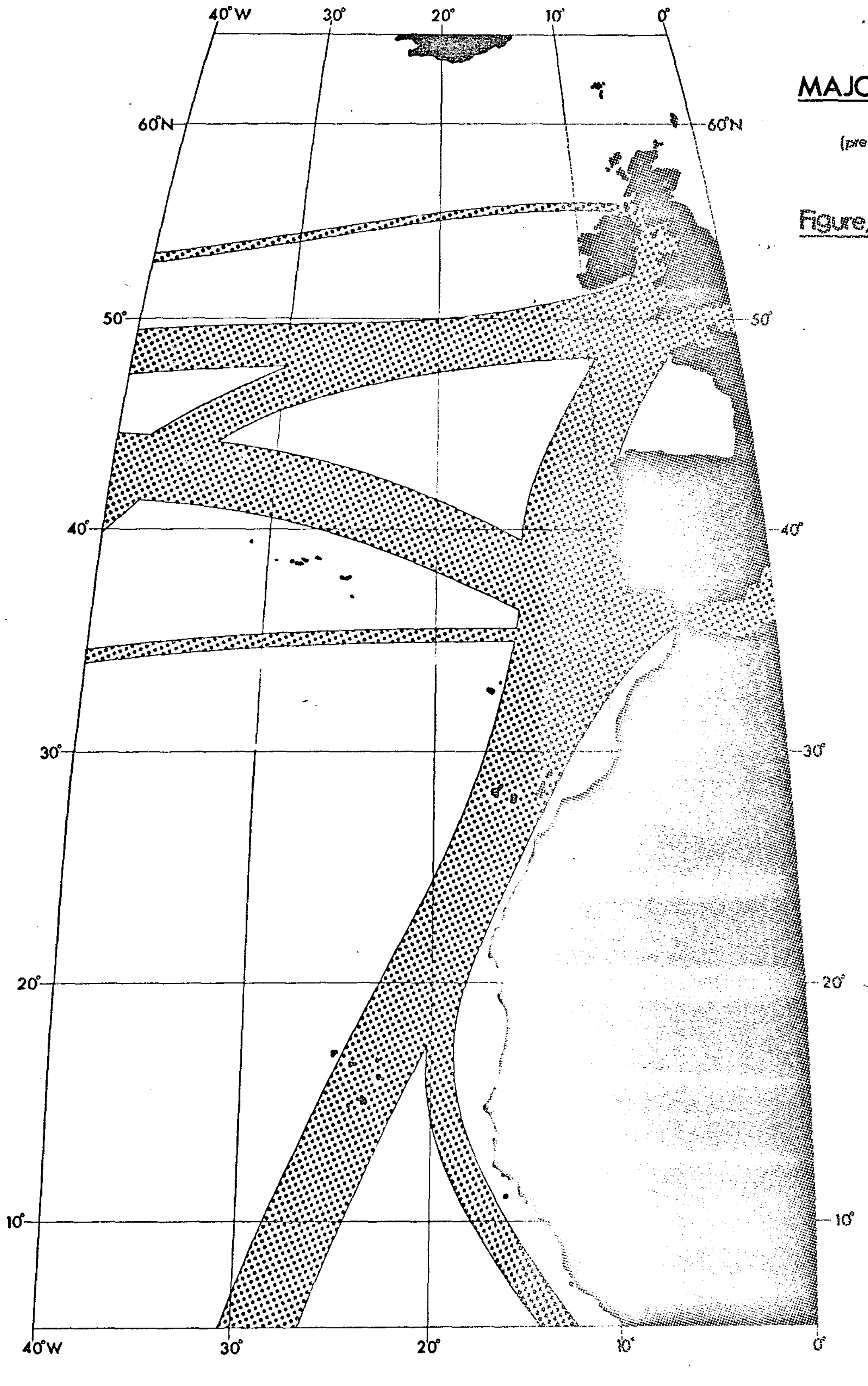
SELECTED STATIONS <2500m

Figure 5



STATIONS AT WHICH PHOTOGRAPHS WERE TAKEN

Figure 6



MAJOR SHIPPING LANES
(present day)

Figure.7