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The field assessment of effects of dumping wastes at sea: 5 The disposal of solid wastes off the north-east coast of England.

R.A. EAGLE, P.A. HARDIMAN,
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The authors:

R A Eagle, BSc PhD, and R S Nunny, BSc, at the time of investigations were Higher Scientific Officers at the MAFF Fisheries Laboratory, Burnham-on-Crouch; they have now left the Ministry.

P A Hardiman is a Scientific Officer at the MAFF Fisheries Laboratory, Lowestoft (at the time of the investigations he was stationed at the Fisheries Laboratory, Burnham-on-Crouch).

M G Norton, BSc PhD is a Principal Scientific Officer and M S Rolfe, BSc is a Higher Scientific Officer, in the Aquatic Environment Protection Division of the Directorate of Fisheries Research and both are stationed at the Fisheries Laboratory, Burnham-on-Crouch.

Enquiries on the subject matter of this report should be sent to Dr M G Norton.

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THE FIELD ASSESSMENT OF EFFECTS OF DUMPING WASTES AT SEA: 5. THE DISPOSAL OF SOLID WASTES OFF THE NORTH-EAST COAST OF ENGLAND

by

R A Eagle, P A Hardiman, M G Norton, R S Nunny and M S Rolfe

1 Introduction

1.1 Background and aims of the survey

Large quantities of solid wastes from a number of sources have been dumped for many years either directly onto the shore or some miles off the north-east coast of England (Figure 1). Wastes from some coastal collieries in Durham and Northumberland have been tipped directly onto the foreshore where they have been dispersed by wave action while wastes from other collieries, fly ash from coal-fired power stations, and harbour dredgings have been dumped offshore from dumping vessels. Dumping started in most cases well before statutory controls, based on the protection of the marine environment, entered into force in the United Kingdom in June 1974 with the enactment of the Dumping at Sea (DAS) Act 1974 (GREAT BRITAIN, 1974). Since that date, disposal of these wastes has been regulated under licences issued by the Ministry of Agriculture, Fisheries and Food (MAFF).

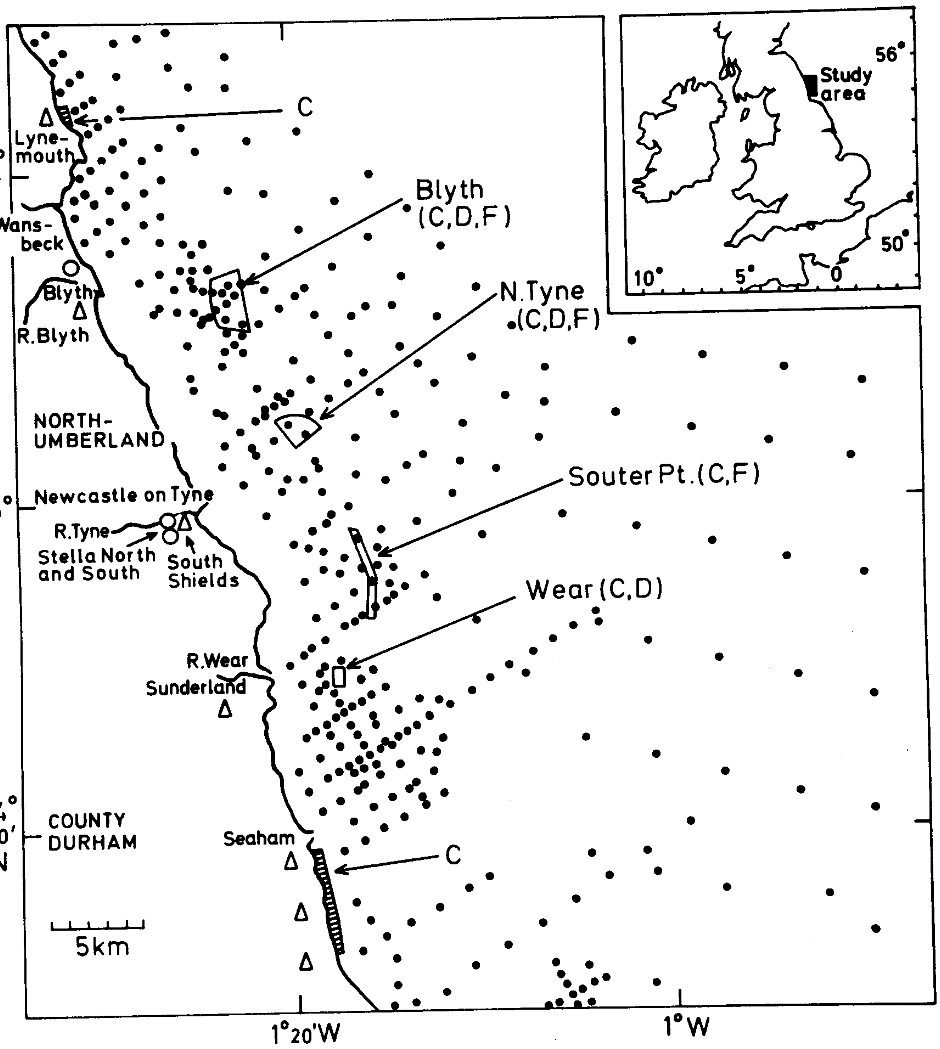


Figure 1 Location of dumping sites, sources of waste and sampling stations.

Dumping sites; (C) Colliery waste (D) Dredge spoil (F) Fly ash

□ Dumping grounds ▤ Shore tipping sites

Waste sources; △ Colliery ○ Power station ● Sampling stations

As part of the Ministry's responsibilities under the DAS Act to protect fisheries and the marine environment, periodic monitoring surveys are undertaken in areas where the disposal of wastes takes place to determine the effect that dumping may have on the receiving area and its biota. This report presents the results of surveys of the offshore dumping grounds off the Northumberland and Durham coasts, carried out during 1975, 1976 and 1977. The Ministry's policy and approach to the monitoring of dumping grounds has been described earlier in this series of reports (Norton and Rolfe, 1978) and the methods generally applied have also been described (Eagle *et al*, 1978). A report on the dispersal of colliery waste from the foreshore tipping site at Lynemouth Bay has also been published (Nunny, 1978).

The specific aims of these surveys were: (i) to characterise the area in physical, chemical and biological terms so as to provide a reference point or 'bench-mark' against which the results of future surveys can be compared; (ii) to identify the sites of deposit and subsequent dispersal pathways of the dumped waste and (iii) to identify effects on the physical and chemical characteristics of the sediments attributable to dumping and to define the resulting biological effects.

The wastes disposed of in this sea area are inert solids, and there is little likelihood of the dumping having significant effects upon the water column; studies have therefore been restricted to the sediments and biota of the sea bed. The impact of these wastes is liable to be felt primarily on the 'physical' environment, and attention has therefore been directed towards the sources, distributions and dynamics of the natural sediments along the whole coast, in order to understand the dispersion of the solid wastes. Studies of the benthos have been confined to the vicinity of the Blyth dumping ground (fly ash, colliery waste and harbour dredgings) and the Wear dumping ground (colliery waste and dredgings).

1.2 Types of wastes dumped and the location of disposal

The wastes dumped in the study area arise from the highly industrialised section of the Northumberland and Durham coast, from Lynemouth Bay to just north of Hartlepool. Throughout this coastal zone coal mining is a very important industry with many pits in south Durham and near to the coastal towns of Sunderland, South Shields, Blyth and Lynemouth; as a result, large quantities of solid waste need to be disposed of locally. In addition to the wastes produced by coal mining, three coal-fired power stations, one sited at Blyth and two at Newcastle produce large quantities of fly ash for disposal. Finally, the ports of Sunderland, Newcastle and Blyth produce dredge spoils either from maintenance dredging or from constructional activities.

These industries have used the coast or the offshore sea bed as the depository for much of their solid waste for many years. The minestone discarded from some colliery washeries has been tipped onto adjacent beaches since the start of the 20th century, while others have barged the waste out to designated dumping sites. Likewise, fly ash has been dumped at sea since the construction of the Stella South and North and Blyth power stations (1952 and 1959 respectively).

The origins and disposal sites of these wastes are shown in Figure 1. A summary of the quantities of waste currently licensed for disposal is given in Table 1, together with a record of the quantities of waste dumped in 1976.

Table 1 Waste disposal off the north-east coast

Dumping Area	Waste licensed	Quantity dumped in 1976 (t 10^6)	Quantity licensed in 1977 (t 10^6)
Lynemouth (foreshore)	Colliery waste	1.18	1.2
Blyth	Dredgings	0.282	0.6
	Colliery waste	0.21	0.3
	Fly ash	0.61	0.65
N Tyne (bad weather only)	) Harbour dredgings	0.165	0.75
	) Fly ash	0.2	0.236
S Tyne (Souter Pt)	) Colliery waste	0.57	0.85
Wear	Colliery waste	0.629	0.85
	Harbour dredgings	0.487	0.75
S Durham (foreshore)	Colliery waste	1.21	2.5

During the years of the survey (1975/77) only these wastes were dumped in the area under consideration. Subsequently, liquid industrial waste has been dumped off Blyth and it is expected that sewage sludge arising from a new treatment works on the River Tyne will be dumped at a site approximately 6 miles off the mouth of the Tyne. The results of these surveys thus provide a baseline against which the effects of disposal of several different types of waste can be assessed.

1.3 Detailed description of the wastes

Colliery waste (Minestone). This material originates from the coal washery and is comprised mostly of an angular grey shale with some sandstone. The waste is predominantly gravel-sized (approximately 90% coarser than 2 mm), with a maximum diameter of about 30 cm, and contains very little material finer than 100 μm. A typical particle size distribution is shown in Figure 2. The carbon content of the waste is approximately 20%, coal being present as inclusions in the shale fragments of the gravel-sized fraction, with some free coal among the finer particles. The coal particles have a density of approximately 1.3 g ml^{-1} compared with the density of shale of 2.65 g ml^{-1}. As a result of the inclusion of coal particles, the colliery waste contains quite high levels of trace metals; the results of a typical analysis are shown in Table 2.

Table 2 Typical metal concentrations in dumped waste (mg/kg dry solids)

Waste	Cu	Cr	Zn	Cd	Pb	Ni	Hg
Dredgings							
ex Blyth	30	20	80	<2	50	N.D.	<1
ex Tyne	40	20	140	<2	100	N.D.	<1
ex Wear	40	<10	280	<2	100	N.D.	<1
Fly ash							
Blyth Power Station	56	19	40	<2	20	N.D.	<1
Stella North Power Station	30	18	36	<2	60	N.D.	<1
Colliery Waste							
Particle size (μm) : 90-500	120	5	540	<2	230	43	N.D.
Particle size (μm) : <90	90	13	100	<2	110	52	1

N.D. = not determined

Fly ash. This material is the residue from the combustion of pulverised coal fuel and is basically comprised of alumino-silicates with a specific gravity of between 2.15 and 2.32 g ml^{-1}. The particle size of true fly ash (ie the 'dust' carried up the stack for extraction by air pollution control equipment) ranges from 2-200 μm, but the coarser boiler ash which is also dumped at sea comprises approximately 20% of the total waste, and has a size range of 60 μm-30 mm. An estimate of the particle size of the combined ashes is plotted in Figure 2. The fly ash itself is composed of a mixture of spherical, fibrous and amorphous particles, most of the spheres containing gas-filled chambers which makes them very light. Trace metals are associated with the ash (see Table 2). A fuller description of the physical and chemical characteristics of fly ash can be found elsewhere (Harwood and Wilson, 1957; Fisher *et al*, 1976).

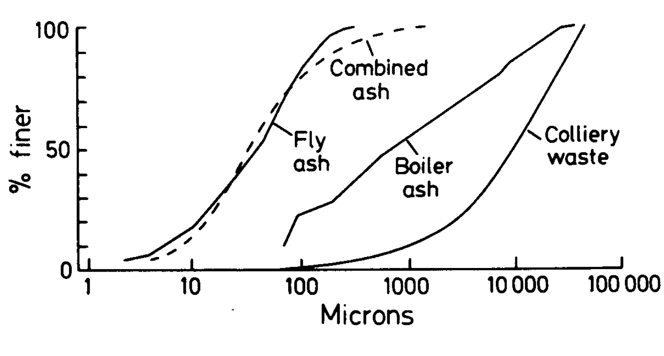


Figure 2 Particle-size distributions of fly ash and colliery waste

Dredgings. Dredging occurs in Blyth harbour and in the Rivers Tyne and Wear. Dredged spoils generally contain organic-rich sands, silts and clays, and can vary between a mud slurry with a high water content to a highly compacted sediment. Various organic and inorganic pollutants are often associated with the dredgings; typical trace metal concentrations are shown in Table 2.

1.4 Sampling

The surveys which form the basis of this report were carried out from two of the Ministry's research vessels, R V CORELLA and R V CLIONE. Sea bed samples and other field data were collected during five cruises over the period March 1974 to April 1977. The positions of the sampling stations worked during these cruises are shown in Figure 1. At the majority of stations three sea bed samples were collected using a 0.1 m^2 Day grab. From one of these hauls samples of the upper centimetre of sediment were collected for particle size, carbon and metal analysis. The other two samples were sieved to collect the macrobenthos using a 2 mm, 1 mm or 0.5 mm sieve. Samples of biota were preserved in 5% formalin and returned to the laboratory for identification. Details of the methods employed in the analysis of sediment and identification of fauna have been published (Eagle *et al*, 1978).

In addition to the information gathered from the Ministry's own surveys, data from other sources have also been considered in order to provide a picture, as detailed as possible, of the nature of the sea bed and its biota.

2 Factors influencing the dispersal of the waste

2.1 The initial behaviour of dumped wastes

All the solid wastes are dumped from large (500-1000t capacity) vessels via bottom opening doors while the vessel is stationary or slowly under-way. Thus the bulk of the cargo falls as one mass through the water column and settles on the sea bed within a few minutes of discharge; only a small fraction of the waste is likely to be dispersed into the surrounding water during the fall. Density variations within the water column and tidal movements during the period immediately following dumping will thus not significantly affect the site of initial settlement of these wastes. Subsequently, dispersion of fractions of the dumped waste may be effected by tidal or wave-induced currents; the existing data on these are briefly described in this section in order to provide a basis for the discussion of the longer-term dispersal pathways away from the dump sites (Section 3).

2.2 Tidal streams

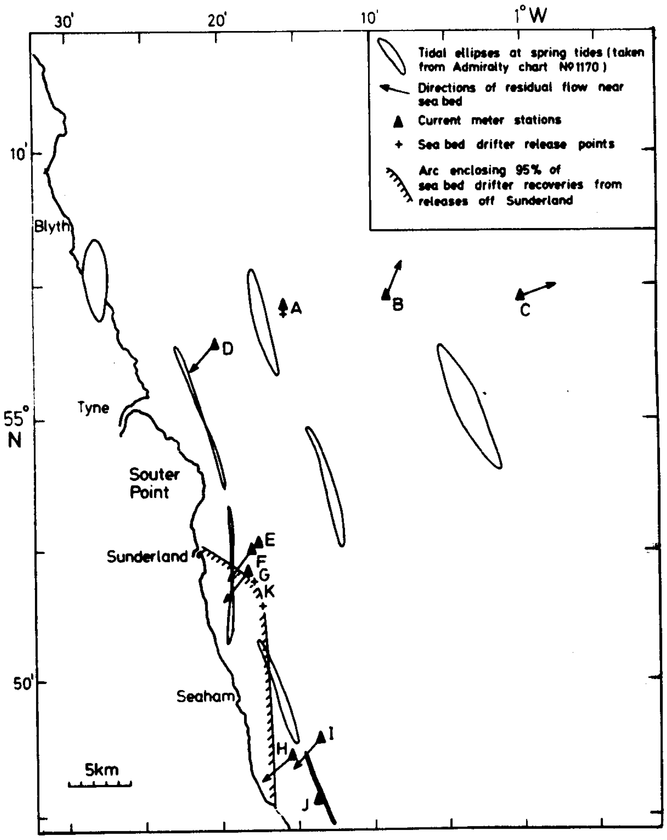


Figure 3 Water movements off the NE coast

A number of observations have been made by direct reading current meters (DRCM's) at positions shown in Figure 3, to supplement the information available from Admiralty Charts. These are:

Stations B & C	7-11 March 1975, 8 m above the bed and 8 m below the surface.
Station D	28-29 April 1976, 1 m above the bed ($\bar{U}_{100}$).
Station E	26 April 1976, 1 m above the bed ($\bar{U}_{100}$).
Station J	30 June 1968, 0.7 m above the bed. (These observations were made by the Hydraulics Research Station.)

Additionally, moored recording current meters have provided data at the following stations:

Station A (current meter 5 m above the bed). Several months of records were produced by this station which formed part of an on-going MAFF programme investigating the hydrographic characteristics of the proposed Tyneside sewage sludge dumping ground.

Stations F, G, H, I (current meters 1 m above bed) giving data for the period 3 August – 5 September 1976. (Marine Environmental Services, marine site investigation off the Durham coast 1976, pers. comm.).

Sea-bed drifters have also been released from two stations: from Station A by MAFF from 1975 onwards, and from Station K off Sunderland in 1971 (Watson and Watson, 1971).

From the above information (summarised in Figure 3) it is apparent that tidal streams are aligned parallel to the coast during the periods of strongest flow. On the north-going tide the fastest currents lie off Souter Point and Tynemouth, attaining values of 50 cm s^{-1}. This pattern is repeated on the south-going tide, with the additional development of stronger currents offshore (south of station B) where flows of 60 cm s^{-1} are recorded. Inshore, the tidal ellipse is very narrow with little flow normal to the main axis; flood and ebb currents run for equal periods of time with similar velocities. Off-shore the ellipse has a greater east-west component (see Figure 3).

The maximum tidal velocities 1 m above the bed (at spring tides) range from 28 cm s^{-1} in the south of the area (station H) and increase northwards, through 30 cm s^{-1} (stations I & G) to 35-40 cm s^{-1} (station F). The DRCM data of stations D and E (Figure 4) were collected midway between neap and spring tides, and the maximum values observed at these stations (25 cm s^{-1} at E and 30 cm s^{-1} at D) suggest that at springs velocities 1 m above the bed could reach 35-40 cm s^{-1}, consistent with the recording current meter data of station F. Surface tidal velocities increase northwards towards St. Abbs Head (90 km north of Blyth); thus, it is likely that maximum current velocities near the bed continue to increase northwards along the coast, and may exceed 40 cm s^{-1} in the northern parts of the survey area.

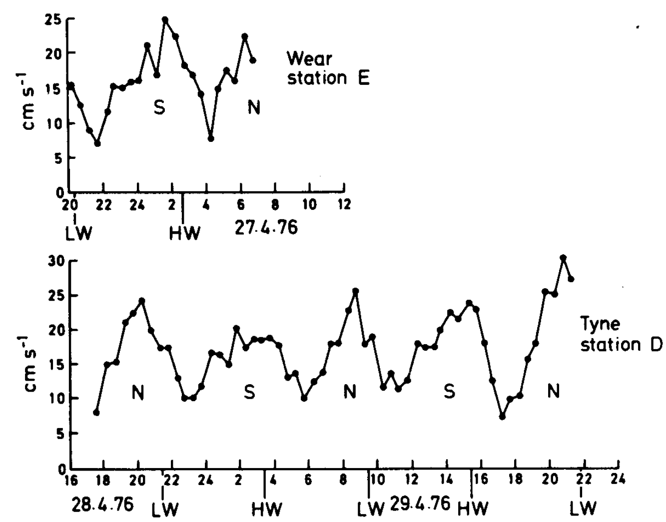


Figure 4 Current velocities 1 m above the seabed ($\bar{U}_{100}$) from direct reading current meters over the period 27-29 April 1976; Tyne and Wear stations (see figure 3 for positions). Two minute averages. S = Southgoing stream N = Northgoing stream.

2.3 Wave-induced water movements

Information on wave climate off the east coast of Britain is available from the Smith's Knoll and North Carr light vessels whose positions are shown in Figure 5A. The wave conditions along the Northumberland and Durham shore are assumed to be between those at the two sites, but are probably closer to those at the North Carr light vessel.

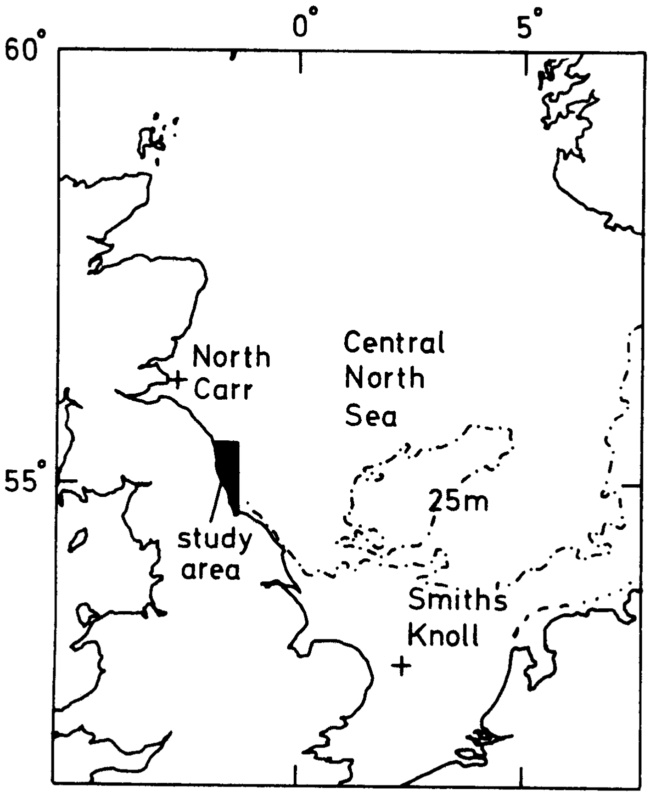


Figure 5 A. Location of Smith's Knoll and North Carr light vessels.

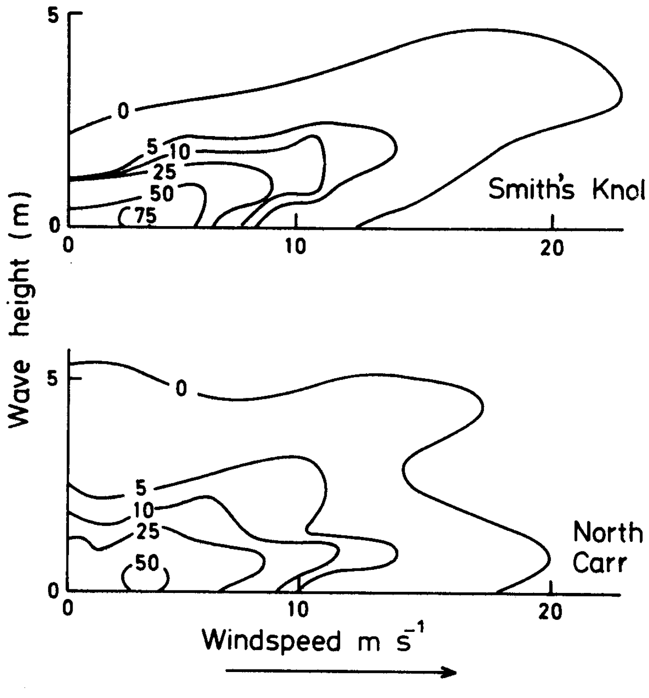


Figure 5 B. Relationship between wave height and wind-speed at the Smith's Knoll and North Carr light vessels over one year (frequencies contoured in parts per 1000).

The relationship between the wave heights and the simultaneous hourly mean wind speeds observed from these vessels (Shellard and Draper, 1975) has been redrawn in Figure 5B. At Smith's Knoll a simple relationship seems to exist, with increasing wind speeds producing higher waves. The North Carr records, however, show two marked differences. Firstly, large waves can exist at low wind speeds, probably because the north-east coast is subject to a heavier swell from the north and east than is evident at Smith's Knoll. Secondly, there is a bifurcation of contours of the wind/wave relationship which is due to the marked difference in the effect of winds with an easterly, as opposed to westerly, component. At North Carr the prevailing south-westerlies produce hardly any sea at all, even in gales, whereas storms from the north and east generate higher waves for a given windforce than at Smith's Knoll.

Draper (1967) has used the data collected at several light vessels to calculate the magnitude and duration of wave-induced flows at the sea bed in several areas around the British Isles. Unfortunately, sites off the north-east coast are not included, the Smith's Knoll light vessel being the nearest site considered. Data derived from the Smith's Knoll records have thus been extrapolated to the North Carr light vessel using the variations in wave height between the two sites shown in Figure 5B. The frequency of a range of significant peak particle speeds at the sea bed (the velocity attained during the passage of a wave of the significant height) for a water depth of 30 m at both sites is shown in Figure 6.

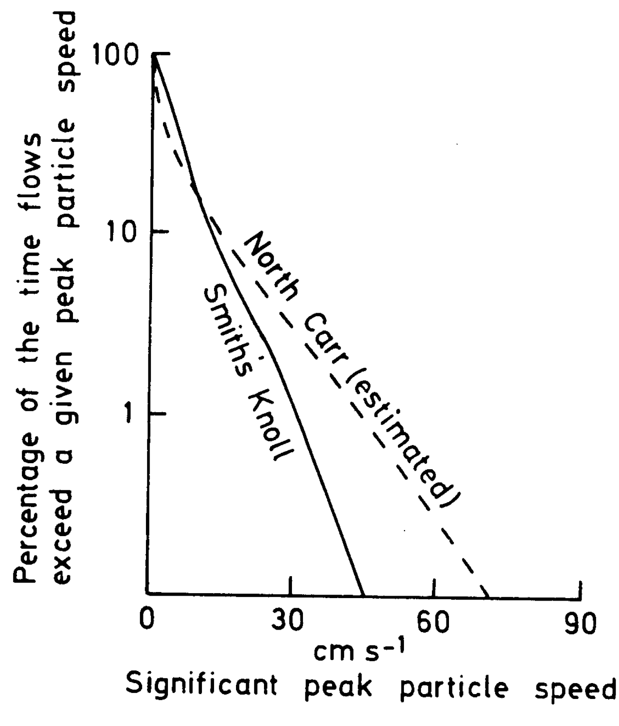


Figure 6 Percentage of the time during which near-bed wave-induced flows exceed any given value at 30 m depth (see text for explanation of signicant peak particle speed).

In shallower depths wave characteristics are modified by the frictional effects of the sea bed, and the predictions based on the light vessel observations over-estimate the strength of near-bed flows. Nevertheless it is apparent that in depths of around 30 m or less wave-induced flows will exceed tidal currents during storms.

2.4 Residual water movements

Drogue movements between Tynemouth and Blyth, one to two miles offshore, indicate that there is no underlying surface residual current system, only variable wind-driven currents (Evans, 1957). This has been supported by a recent study of short-term (up to 20 days) water movements in depths of 10-30 m, measured at six localities along the north-east coast (Riddle, 1976). Analysis of the correlation between residual flows and wind and pressure gradients suggested that the longshore component of the midwater drift is most dependent on the longshore wind component. Trends are less well defined for the component of drift normal to the shoreline.

Consistent residual water movements close to the sea bed, however, do appear to be present. Within 15 km of the coast data collected at varying times of the year by DRCM, moored current meters and sea-bed drifters consistently indicate an onshore south-westerly residual drift. In contrast, DRCM data from 20-30 km offshore suggest the direction of drift is away from the coastal area, north-eastwards into the Farne Deeps (Figure 3). A study in 1976 of residual drifts further (80 km) offshore (Ramster, 1977) showed the direction of drift to vary seasonally, however.

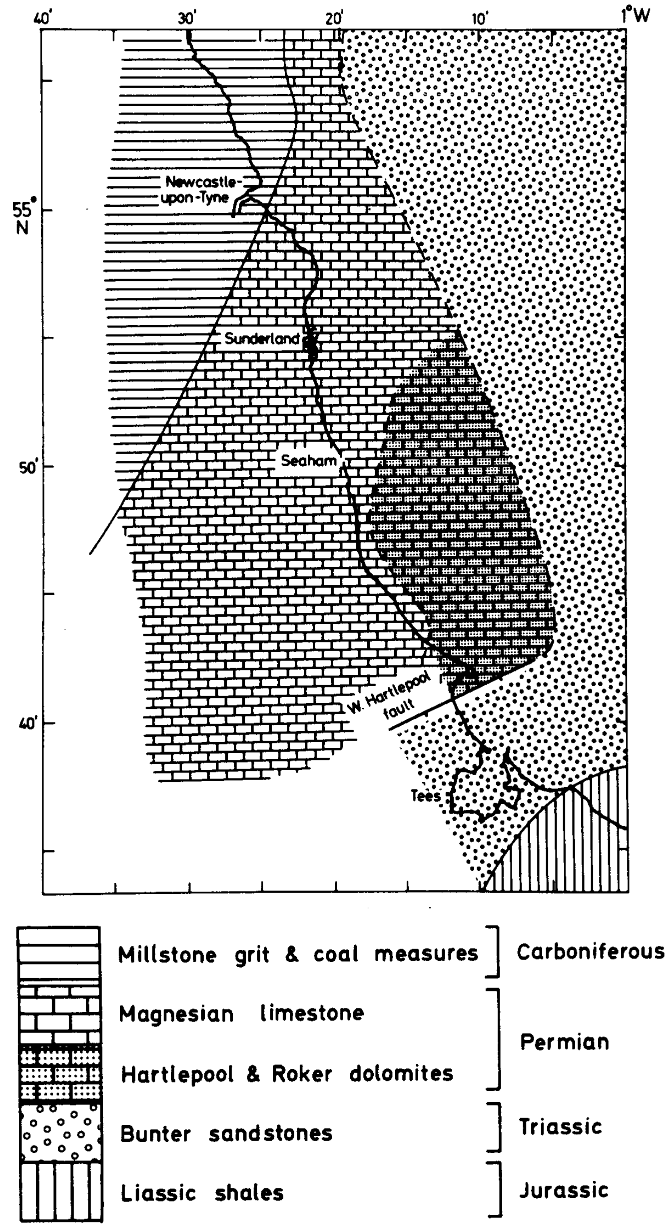


Figure 7 Geology of the Northumberland and Durham dumping area.

3 The Sediments

3.1 Natural sediments

3.1.1 *General description*

The underlying rocks of this coastal area and their distributions are shown in Figure 7. Carboniferous sandstones, shales and coal seams are exposed north-west of a line running NNE/SSW through Tynemouth (Clarke *et al*, 1961). Eastward dipping Permian strata, dominated by the Magnesian limestone and the Hartlepool and Roker dolomites, occupy the coastal area south of the Tyne. They are faulted against the underlying Bunter sandstones to the south in Tees Bay and 10-15 km offshore to the east (McGraw *et al*, 1963). All the rocks inland are covered by glacial drift deposits (predominantly boulder clays with extensive fluvio-glacial deposits further north) which cap the cliff-lines and are exposed to the waves in many of the bays.

The distribution of surface sediment types and the bathymetry of the sea bed are shown in Figure 8. A general relationship exists between the water depth and sediment type. In water shallower than 10 m fine sands predominate, especially within the bays. These flat sands extend offshore to the hard ground areas where gravels and sands infill the sheltered areas between rock outcrops. Silt accumulates at the outer edge of the hard grounds, producing muddy gravel areas which grade seawards into fine sands and silts. The silt content then decreases with increasing distance from the shore. This pattern is complicated in the northern part of the area with the development of a trough feature, the southern extension of the Farne Deeps, where increased depths favour the deposition of fine sediment, the silt and clay content of the sediments being higher down the western slope of the trough where the maximum thickness (15 m) of superficial sediments is found (Buchanan, 1964).

3.1.2 *The distribution of rock outcrops and gravel deposits*

The extent of submarine rock outcrops shown in Figure 9 has been mapped using echo-sounder and side-scan sonar records, and Admiralty Chart notations or has been inferred when repeated grabbing has failed to collect a sample. Outcrops of rock are much more numerous than is shown in Figure 9, where only the major rock platforms are identified; isolated rock exposures occur at many localities within those areas containing >5% gravel.

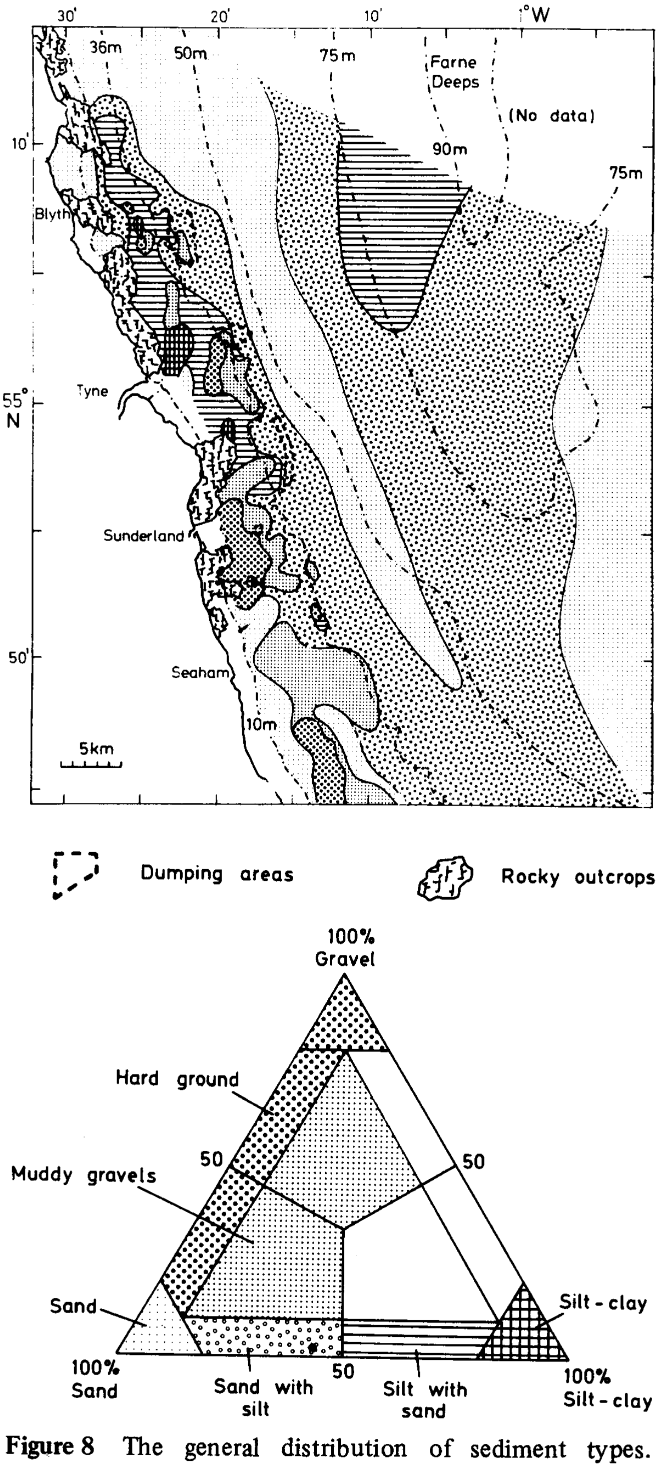


Figure 8 The general distribution of sediment types.

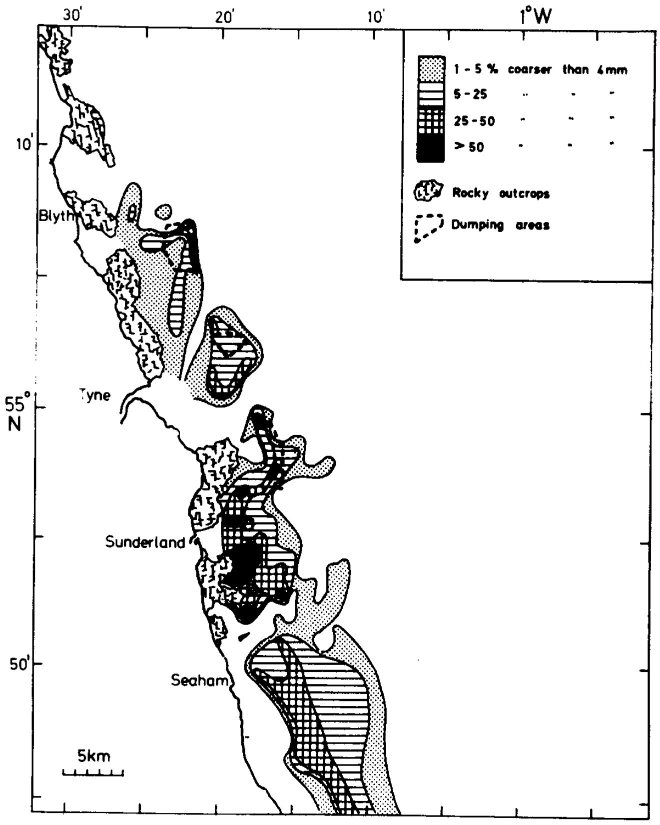


Figure 9 The distribution of rock and gravel deposits (material >4 mm).

Extensive deposits of gravel (defined as material coarser than 4 mm) occur inshore of the 50 m isobath between Blyth and the southern extremity of the survey area, tending to encompass the rock outcrops. As there are no satisfactory methods of sampling these deposits, the gravel fraction of samples has only been analysed qualitatively, through a visual description of mean and maximum dimensions, the major lithologies and the degree of encrustation.

The approximate percentages of gravel in the sediments of the area are shown in Figure 9. (Contours drawn for any variable between stations in the hard ground areas should be interpreted with caution as sediment variability is much greater than the density of grab samples. Contouring is undertaken in such circumstances to emphasize a general trend rather than to predict conditions on the sea floor between sample points.)

In the shallower areas of hard ground the gravels are well rounded and free from encrustation due to abrasion, while in the muddier areas seaward they are stained and encrusted. A wide variety of lithologies are present, suggesting that the gravels have been largely derived from the erosion of glacial material.

In contrast to these deposits the gravels of some areas are composed of un-weathered, un-encrusted angular grey shales and mudstones containing an appreciable amount of coal. The amount of this material within the gravel fraction is plotted in Figure 10. The proximity of the deposits to the waste disposal grounds confirms that they are derived from dumping activities; dumped 'minestone' accounts for a considerable proportion of the gravel deposits of this area.

3.1.3 *The distribution of sands*

The term sand is used to describe particles in the range 0.063 mm to 4 mm ('very fine sand' to 'granules'). In addition to the simple determination of the amount of sand present on the sea floor, the component normal populations (Curray, 1961) have been identified. The spatial distribution of sands with different population means is shown in Figure 11. Particle-size distributions and the component normal populations of samples from selected stations are shown in Figure 12. The characteristics of the medium/coarse (250-2000 μm) and fine/very fine (63-250 μm) sand distributions are described below.

Medium and coarse sands. There are extensive sheets of medium sands within the area comprised of quartz grains, fragments of local rock types, including coal, and smaller amounts of shell debris. In the nearshore zone they encompass the rock outcrops and gravel areas and extend seawards (Figure 9), often accompanied by, and sometimes replaced by, coarse sand and granule (2-4 mm) populations. Medium sand deposits composed largely of quartz grains also occur in deeper water in a patch offshore of Blyth and in an extensive sheet stretching south from the latitude of Souter Point and down the eastern slope of the offshore trough.

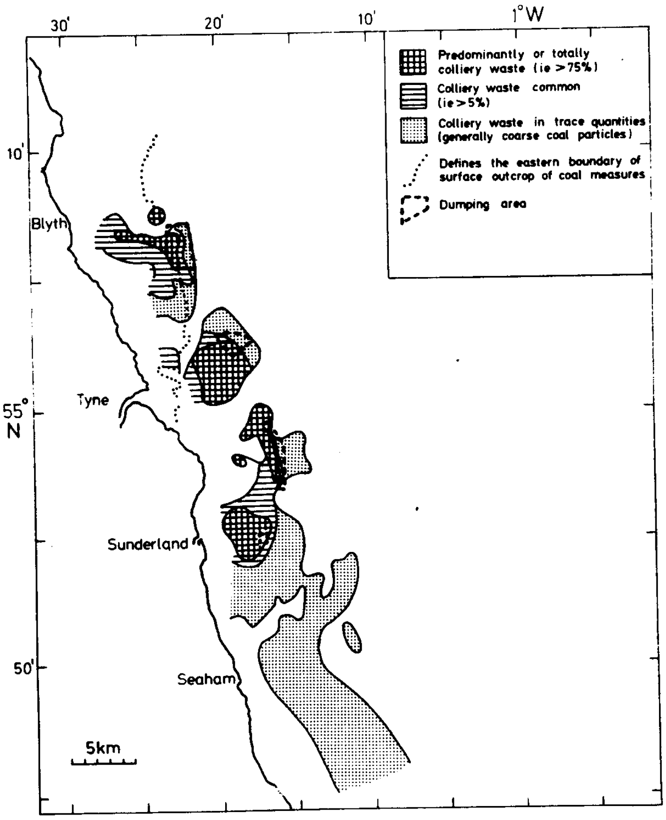


Figure 10 The colliery waste content of the gravel fraction of the sediment.

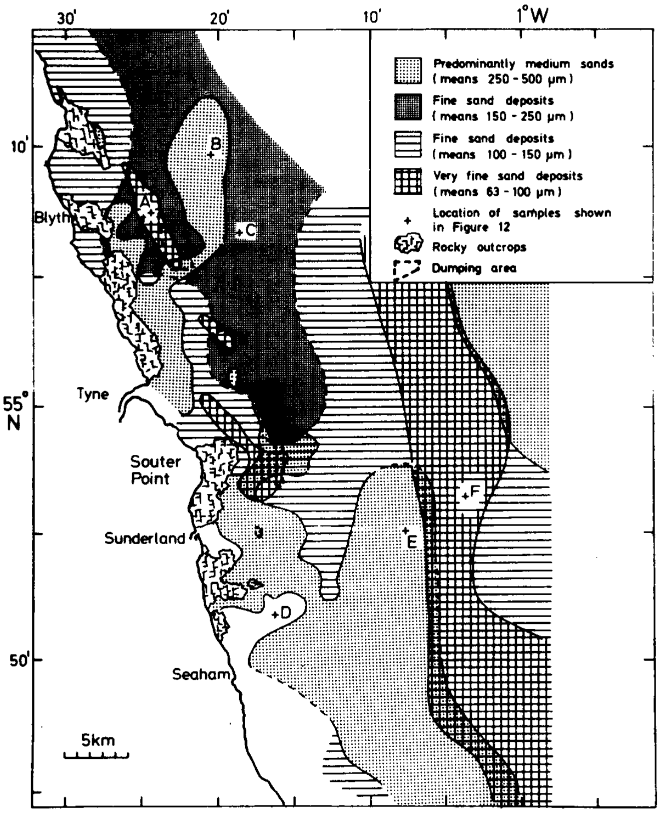


Figure 11 The distribution of sand populations.

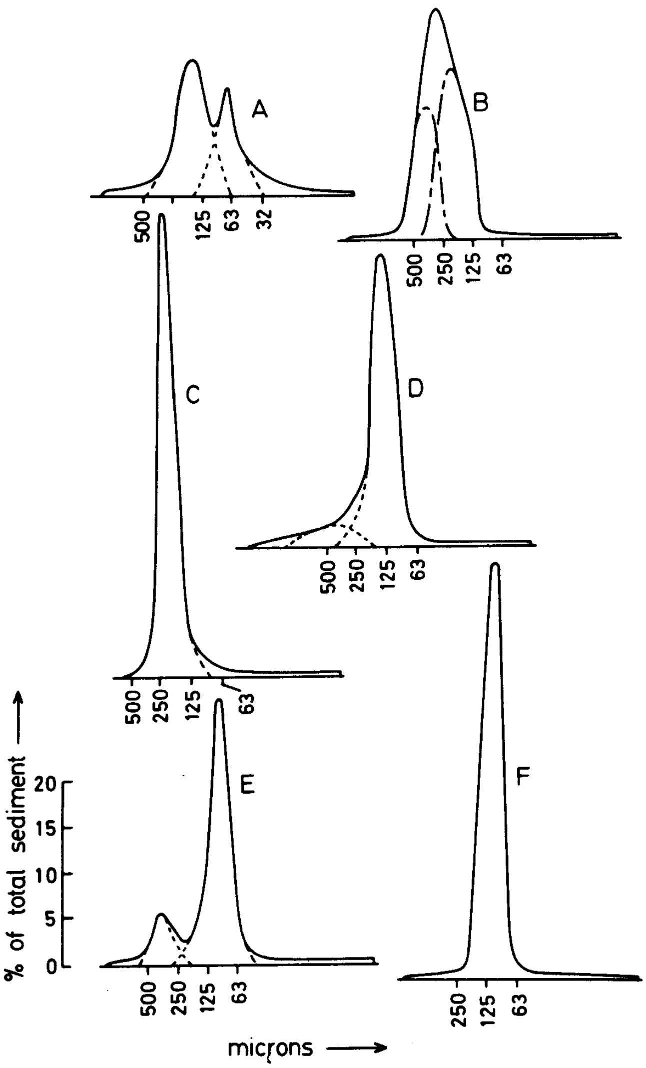


Figure 12 Particle-size distributions of sediments at selected stations showing component lognormal sand populations.

—— Particle-size distribution
---- Component sand populations (lognormal)
(See Figure 11 for locations).

Fine and very fine sands. The distribution of sands with modes within this size range are shown in Figure 11 for the 63-100 μm, 100-150 μm and 150-250 μm size fractions. All the sands immediately seaward of the surf zone have mean sizes in the range 100-150 μm, as they contain material which has escaped the surf zone in suspension. In the south of the area the mean size of this population becomes progressively finer seawards, reaching 63-100 μm about 15 km offshore. In the north this gradation is interrupted by a tongue of slightly coarser sands (means 150-250 μm) extending into the area from further north and reaching as far south as the mouth of the Tyne. The overall distribution of fine and very fine sands thus suggests that recent coastal erosion is an active source of very fine sand, with some incursion of slightly coarser sands from an area to the north. There is, however, a recurrence of sands with means in the range 100-150 μm along the eastern extremity of the survey area, suggesting increased activity at the sea bed and a possible seaward source of fine sand. A full discussion of the dynamics of these sediments is given later (Section 3.2).

The overall simplicity of this distribution of fine and very fine sand is upset by the occurrence of three isolated patches of very fine sands (means 63-100 μm) 3-7 km offshore between Blyth and Souter Point (Figure 11). Inspection of this material under the microscope showed it to be composed of fly ash and/or harbour dredgings. The three patches are thus caused by dumping activity in the Blyth, North Tyne and Souter Point disposal grounds.

3.1.4 *The distribution of silt and clay*

The distribution of silt and clay (material finer than 63 μm) in the total sediment is shown in Figure 13. The western slope of the deep water trough extending south from the Farne Deeps is the major zone of accumulation for fine material. The fact that this deposit occurs on the western side of the trough suggests a landward source of this material. This is also indicated by the elevated concentrations of silt and clay in a narrow zone parallel to the coast, in water depths of 20-40 m, within which localised areas of very high mud content are found. The latter may be due to areas of shelter provided by rock outcrops (where accumulation can take place unhindered by storm activity), the discharge of the River Tyne, or the dumping of harbour dredgings as demonstrated by the presence of terrestrial debris in the grab samples shown in Figure 13. Within this nearshore zone, silt and clay levels vary temporally as well as spatially (J Buchanan, pers. comm.) due to periodic reworking by storm waves of material which has accumulated during the more quiescent periods of the year.

The percentage of clay (<4 μm) in the sediment was determined only in those samples taken from

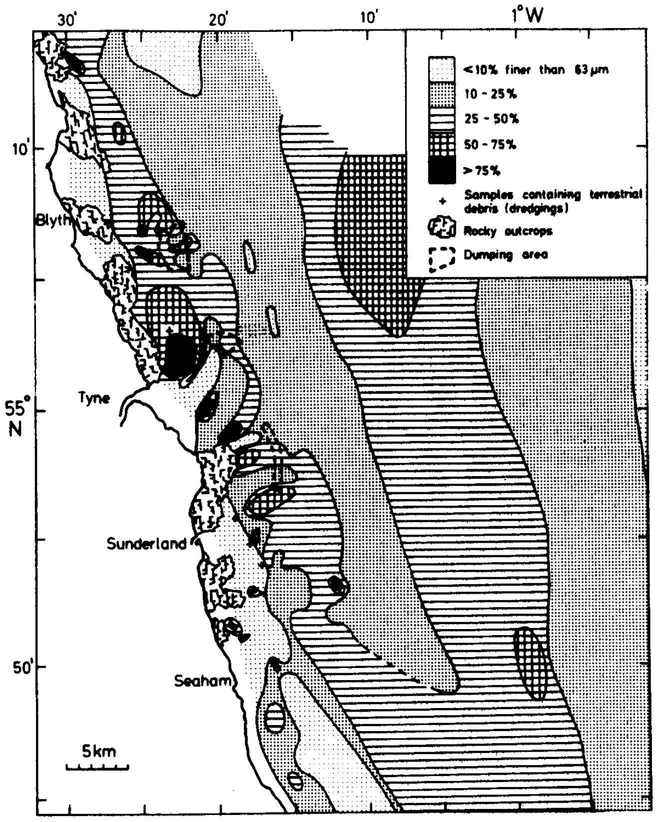


Figure 13 The distribution of silt and clay (material <63 μm).

CLIONE in 1976. Clay did not comprise more than 80% and was usually 50 to 80% of the material finer than 63 μm, the percentage appearing to vary quite randomly between localities. In some areas, however, the clay content was considerably less, being below 10% at some stations. This proved to be due to the presence of fly ash in the sediment, the ash being composed largely of silt and very fine sand-sized particles (Section 2.4.2).

3.2 Sediment dynamics

3.2.1 *The mechanisms of bedload transport*

Bedload movement is effected by tidal currents and by wave-induced oscillatory currents either acting separately or together. Whether sediment particles are transported in suspension or as bedload depends upon the degree of turbulence. When velocities just exceed the threshold of grain motion material coarser than approximately 150 μm is transported as bed load (Bagnold, 1966), and the bedload dispersive processes could therefore affect fine, medium and coarse sands and gravels.

As shown in Section 2, maximum spring tide velocities 1 m above the bed ($\bar{U}_{100}$) are near 30 cm s^{-1} south of Seaham rising to 40 cm s^{-1} between Sunderland and the Tyne and probably exceed 40 cm s^{-1} off Lynemouth. Current speeds ($\bar{U}_{100}$)

of 35 cm s^{-1} are capable of initiating motion in cohesionless medium/fine sands, and speeds of only 26 cm s^{-1} are required to maintain transport once the sand grains are in motion (Sternberg, 1971). However, with cohesive sediments (particles finer than 100 μm) a greater stress is required to initiate movement. The degree of cohesiveness (and resistance to erosion) exhibited by a fine sediment is dependent upon the composition of the sediment and its degree of compaction. Thus, it is impossible to predict a threshold velocity above which sediments with an appreciable silt/clay content will become mobile. Only in the extreme north of the survey area and close inshore, where the silt/clay content of the sediments is very low, is the 'cohesionless' threshold likely to be applicable. Thus, south of Sunderland, where tidal currents are weaker, peak tidal currents alone are not likely to be powerful enough to transport sediment; north of Sunderland tidally-induced transport may take place during periods of strongest flow in those areas where the sediments have a low mud content.

Wave-induced oscillatory flows near the sea bed occur only at intervals, especially in deeper water, but in shallow water waves are at times capable of producing flows stronger than tidal currents (see Section 2). Although shoaling waves are capable of producing a net landward movement of bed material because of the asymmetry of their orbital motions, the main significance of wave-induced currents is in providing the energy to set bed material in motion. Once this has been achieved tidal currents, however weak, can effect a net transport of the sediment in addition to the oscillatory motion imparted by the waves.

The frequencies with which oscillatory flows of various magnitudes can be generated has been predicted by Draper (1967) from records at the Smith's Knoll light vessel (Section 2.3). In addition, wave data from the North Carr light vessel have been used to calculate the strength of near-bed wave activity at that locality, using the procedure described by Komar and Miller (1973). These results are combined in Table 3 and expressed as the proportion of time during which near-bed velocities exceed 10 cm s^{-1}, this being the approximate velocity at the bed required to initiate motion in quartz-density cohesionless fine sands (Allen, 1970).

Table 3 Water depths in which oscillatory velocities exceeding 10 cm s^{-1} occur (m)

% of time conditions are exceeded	Smith's Knoll	North Carr
1%	N.D.	80
10%	45	45
50%	25	12

N.D. = no data

If it is assumed that conditions in the survey area fall between those occurring at Smith's Knoll and the North Carr light vessels, it would appear that during long periods of the year there is liable to be no significant wave disturbance below depths of 10-20 m off this coast. This is due to the shelter provided by the land from the prevailing south-west winds. For 10% of the year storms can generate near-bed flows in excess of 10 cm s^{-1} down to depths of 45 m. During the worst storms of the year such flows are experienced down to depths of 80 m or more; wave-induced velocities at the shallower depths associated with the dumping areas (20 m) could reach 100 cm s^{-1}.

As previously discussed, a greater shear stress is required to erode cohesive sediments, which occupy the greatest area of the sea floor in this region. Although a near-bed velocity of 10 cm s^{-1} will initiate motion in cohesionless fine sands it is not likely to be effective on a sediment composed of organically-bound fine sands, silts and clays. Cohesive sediments in deeper water are thus unlikely to be significantly disturbed by wave action, but the powerful near-bed currents generated by storm waves in shallow water are capable of moving gravel particles and eroding well-compacted muds.

A final factor affecting bedload transport is suspended sediment, since the stress exerted upon the sea bed by a given flow is much diminished if there is an appreciable amount of sediment in suspension (Komar, 1976). Thus, not only does the presence of cohesive silt and clay increase the threshold of erosion, but once in suspension it absorbs some of the energy of the water flow, so reducing bedload movements. This is especially important in the inshore region where there is a blanketing deposit of very fine sand which has escaped from the breaker zone. Thus, during storms the onshore movements of coarse bed material beneath the shoaling waves is likely to be reduced by the high levels of very fine sand suspended in the lower parts of the water column.

It is evident therefore that it is not possible to predict from wave and tidal stream data alone the degree and pattern of bedload movement in this area. As it has not been feasible to directly measure bedload transport, indirect evidence has been sought.

3.2.2 *Evidence of bedload movement*

The occurrence of bedload movement may be inferred from surface features of the sediment (eg ripples) as well as from any structures the passage of such bedforms will produce within the sediment. Surface features have been identified using underwater photography and side-scan sonar. Internal structures have been identified by making peels (sections) of sediment cores taken at selected stations (Ostler and Martini, 1973).

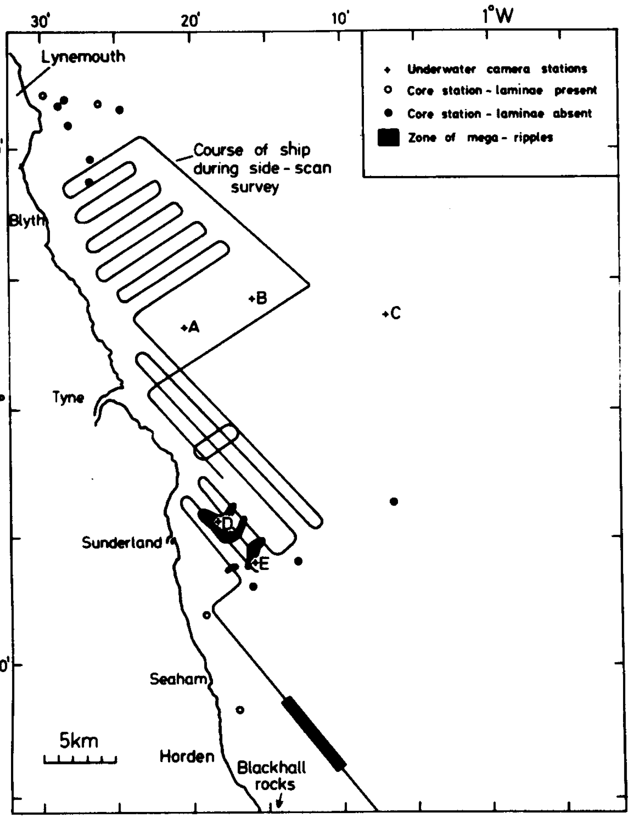


Figure 14 Sea bed photograph stations, coring stations and side-scan survey track.

The locations of the stations at which sediment cores were taken are shown in Figure 14 in which the four samples showing traces of internal bedding are marked as open circles. Three of these samples originated from the inshore zone off Seaham, Lynemouth and Horden in water depths of less than 10 m, while the fourth core was collected in 40 m of water off Lynemouth Bay. The presence of laminae preserved in these cores demonstrates that bedload movement occurs, with erosional and depositional cycles, probably associated with the formation of ripples on the sea bed.

The track of the 1977 sonar survey is also shown in Figure 14. Large structures on the sea bed were identified only in two localities, off Sunderland and Blackhall Rocks. These features consisted of a series of megaripples with wavelengths of around 20 m and heights of about 1 m, the crests running approximately east-west. There was insufficient information to determine the degree and direction of any asymmetry exhibited by the waves.

Underwater photographs were taken at the five sites shown in Figure 14. At site A the substrate was either fine sand with degraded ripples or coarse angular gravel which was presumably dumped minestone. At site B photographs showed a featureless sandy bottom. The most striking feature of the sea bed at site C was the presence of numerous open burrows which suggested that bed movement was not frequent at this site. The sea bed at station D showed considerable variation between featureless sands, sandy gravel and coarse minestone. At station E the substrate was rippled sand, with patches of sandy gravel.

Relating the above observations to the sediment composition and water depth at each locality, the following conclusions can be drawn:

(i) evidence of internal structures resulting from bedload transport was found only in sediments with less than 10% silt/clay content;

(ii) megaripples were found only in medium sands in zones where less than 25% of the sediment was silt/clay and where the water depth was 25 m or less;

(iii) only very faint ripple marks were apparent in the underwater photographs; these occurred at two stations, both with sediments comprising less than 25% silt and clay and in water shallower than 40 m.

From these conclusions it is possible to identify areas where bedload movement may occur.

In the north of the area where the mud content of the sediments is less and tidal stream velocities are slightly greater, the tongue of coarser fine sand (population means of 150-250 μm) that extends as far south as the mouth of the Tyne (Figure 11) may be due to the movement southward of sand from the northern part of the survey area during storms, when sediment put into motion by wave action is transported southwards by the residual tidal flow.

In water depths of less than 40 m and in areas where silt and clay form less than 25% of the sediment, storm waves commonly effect bedload movement. In most areas this only results in the passage of fine material into suspension, but where there is a plentiful supply of coarser material, eg the inshore edges of the hard ground areas and the minestone dumping grounds, bedload transport due to combined tidal and wave action takes place. Gravels and coarse sands probably undergo a degree of transport and abrasion, but medium sands appear to undergo much more intensive transport, forming megaripples along the inshore edges of the extensive deposits of medium sands that occur south of Souter Point (Figure 11). The ripple crests were orientated approximately east-west indicating that movement is along a north-south axis. Evidence from the dispersion of coal particles from the dumping sites (Section 3.3.2) suggests that the residual movement is southwards.

Elsewhere, the presence of sediments with a high silt and clay content which resist the scouring action of the currents makes extensive bedload transport unlikely except for loose surface floccules of silt and clay, organic matter, faecal material etc which are likely to be transported on the sea bed in all areas, being dispersed north and south along the axis of strongest tidal flow.

3.2.3 *Movement of sediment in suspension*

The distribution of mud in the sea bed sediments (Section 3.1.4) indicates that silt and clay discharged from rivers and eroded from the boulder clay deposits along the coast accumulates initially in water depths of 20-40 m. Indeed, these mud zones depend upon this constant landward source of material, as the mud is depleted during storms when wave action re-suspends fine material and disperses it much more widely. The ability of waves to mobilise sea-bed sediments has already been discussed (Section 3.2.1 and 3.2.2), from which it was concluded that there was little evidence for disturbance of the sediment in water depths greater than 40-50 m and that the mud zone on the western slopes of the deep-water trough may be the ultimate sink for much of the fine suspended matter generated in this area (this is discussed further in Section 3.3.3).

Material entering suspension in the nearshore zone is carried offshore by eddy diffusion and by the residual drift associated with water flows in the area. The latter exhibits an inshore component near the bed up to approximately 15 km offshore, with an offshore component further away from land (Figure 3). A two-celled system of the probable suspended sediment circulation is shown schematically in Figure 15; fine material trapped temporarily in the inshore zone where near-bed residual currents have an onshore component can only escape seawards in suspension through eddy diffusion and wind-driven currents acting in the upper part of the water column.

An estimate of the spatial and temporal variations which occur in the concentrations of suspended sediment within this system may be made from the following limited water quality measurements:

(i) Moore (1972) found that the seston concentrations in the immediate sublittoral zone (5 m depth) varied between 8 and 25 mg l^{-1} through the summer months at four localities off the north-east coast. North of the survey area these levels persisted throughout the year of Moore's study but concentrations south of Lynemouth were elevated during the remaining two thirds of the year and rose to a maximum of 150 mg l^{-1}.

(ii) Seston concentrations in surface and midwaters 1.6 and 3.2 km offshore of Robin Hoods Bay (60 km south-east of the study area) varied between 20 and 100 mg l^{-1} over a two-year period (Newton and Gray, 1972) with the higher concentrations during the winter months.

(iii) Seston concentrations ranged from 4 to 15 mg l^{-1} up to 2 km off the south Durham coast in June and July 1969 (Hydraulics Research Station, 1970).

Unfortunately the concentrations of suspended matter in waters further than 15 km offshore are not known, ie in the outer cell of the system shown in Figure 15. From the data inshore, however, it would appear that concentrations are unlikely to exceed 5 mg l^{-1}.

3.3 The effects of colliery waste dumping on sediment composition

3.3.1 *The distribution of coarse colliery waste*

Colliery waste is predominantly composed of angular fragments of sandstone and shale with inclusions of coal (Section 1.3), and is mostly of gravel size (60% coarser than 1 cm) with blocks of up to 30 cm in diameter. Coal measures only occur as outcrops on

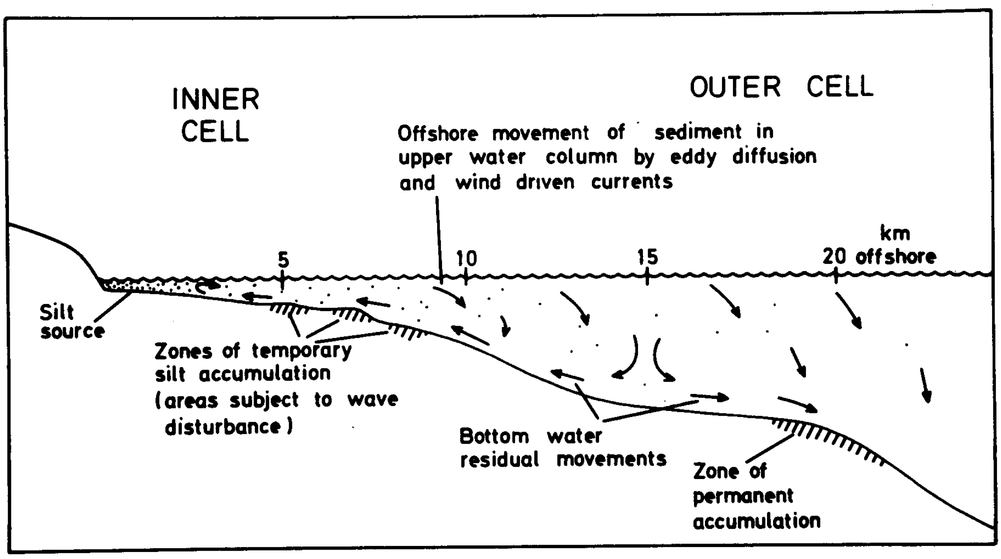


Figure 15 Diagrammatic section normal to the coast showing probable suspended sediment circulation.

the sea bed west of a line that runs approximately north-south through the mouth of the Tyne (Figure 10). Thus 'natural' sources of minestone contribute only to minestone found on the sea bed in parts of the Blyth dumping ground.

As described in Section 2.2, discharge is by instantaneous release through the bottom of the ship and there is little chance of even the finest particles becoming dispersed before the material reaches the sea bed. The areas where coarse waste is 'predominant' in Figure 10 therefore reveal the sites of dumping. The areas where waste is 'common' in the gravel fraction may receive dumped waste less frequently but the distribution may also be due to the limited dispersion of waste fragments of up to 4 mm diameter by the combined action of tidal currents and storm waves. Where material of colliery origin is found in trace quantities, however, it is generally represented by isolated coarse coal particles which due to their lower density have been transported well away from the tipping zone.

The distribution of coarse waste shown in Figure 10 suggests that dumping has often taken place well short of the designated dumping sites prior to these surveys.

3.3.2 *The dispersion of sand-sized coal*

When dumped, only approximately 22% of the waste is smaller than 4 mm diameter. However, all the dump sites are in water shallower than 45 m (the Wear ground is in only 20 m of water) and thus storm waves are capable of producing the near-bed oscillatory flows necessary to cause attrition (Section 3.2.1). Once the waste is abraded to particles finer than about 1 mm, the coal content exists as discrete particles rather than as inclusions in the 'minestone'. As it is impossible to distinguish between minestone-derived and natural sand, only the dispersion of coal particles away from the dumping ground can be studied.

Because of their lower density ($1.4\ g\,ml^{-1}$) coal particles are set in motion by much lower flows than are required for quartz sands. The threshold of movement of coal under uni-directional flows was ascertained using the formula (Shields, 1936):

$$\Theta = \frac{\tau o}{(p_s - p) g\, D}$$

where Θ is the dimensionless relative stress, τo is the stress exerted by the fluid flow on the bed, p_s and p are the grain and water densities respectively, g is the acceleration due to gravity ($981\ cm\,s^{-2}$) and D is the grain diameter.

τo was related to the current velocity 1 m above the bed ($\bar{U}_{100}$) through the quadratic stress law

$$\tau o = 3.1 \times 10^{-3} . p . (\bar{U}_{100})^2$$

This relationship is known to hold over wide ranges of bed roughness (Sternberg, 1972). In this way, it was calculated that a coal particle of 600 μm diameter would be set in motion by a flow ($\bar{U}_{100}$) of 15 $cm\,s^{-1}$, and coal of 200 μm diameter by flows of only 11 $cm\,s^{-1}$, compared with a velocity of 35 $cm\,s^{-1}$ required for quartz-density 200 μm sands. It is difficult to calculate the stress needed to initiate motion in coal finer than this diameter as the particles begin to behave cohesively.

As sand-sized coal particles appear liable to be set in motion by currents ($\bar{U}_{100}$) only a little in excess of 10 $cm\,s^{-1}$, wide dispersion of the coal particles is to be expected in this area where spring tidal stream velocities attain 30 $cm\,s^{-1}$. However, where coal particles move across a muddy substrate, they are liable to become incorporated in it and the cohesive properties of the natural muds will inhibit further movement of the coal.

The amount of sand-sized coal in sediment samples was determined using simple loss-on-ignition techniques (550°C for 8 h); two sand fractions (90-500 μm, 500-4000 μm) were tested in order to determine the size of the coal particles. Naturally-occurring organic substances are also present in the sand fraction, but as experience from coal-free areas suggests that these seldom exceed 2% weight loss this concentration may be taken as indicating a negligible contribution from coal. The distribution of coal as

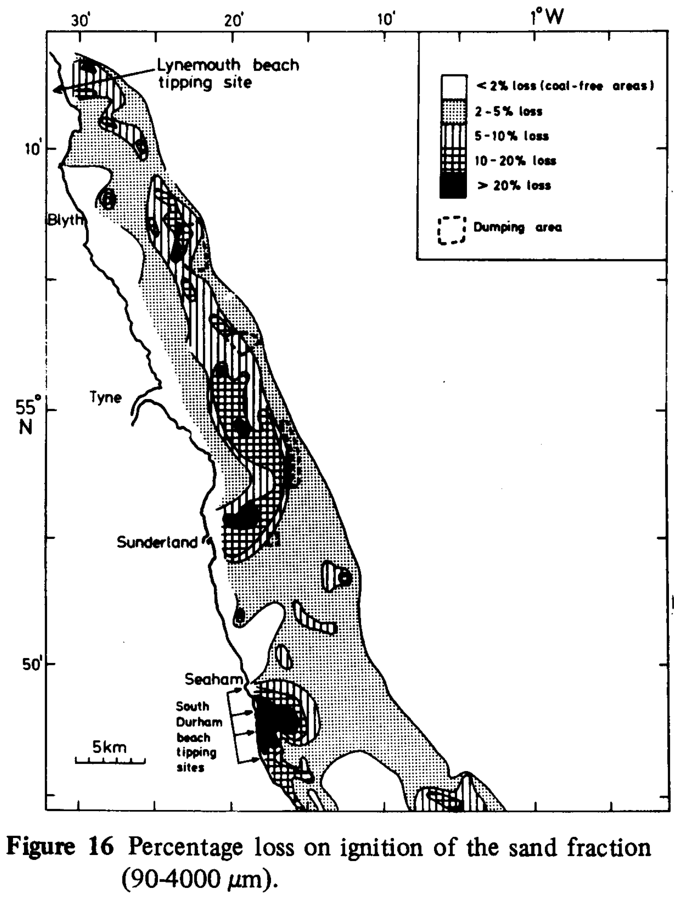


Figure 16 Percentage loss on ignition of the sand fraction (90-4000 μm).

indicated in Figure 16 shows that dispersion from the offshore dumping sites is taking place parallel to the coast, in the directions of strongest tidal flow, with very little transport occurring normal to the shore. The absence of coal in the sediments north of Lynemouth (the northernmost waste disposal site) indicates that dispersion is predominantly southwards. Available near-bed current meter data (Figure 4) shows that tidal velocities exceeding 10-15 cm s^{-1} have a longer duration on the south-going streams than on the north-going. This, together with the dispersal caused by the approach of large waves from the north and north-east, results in the southward residual transport.

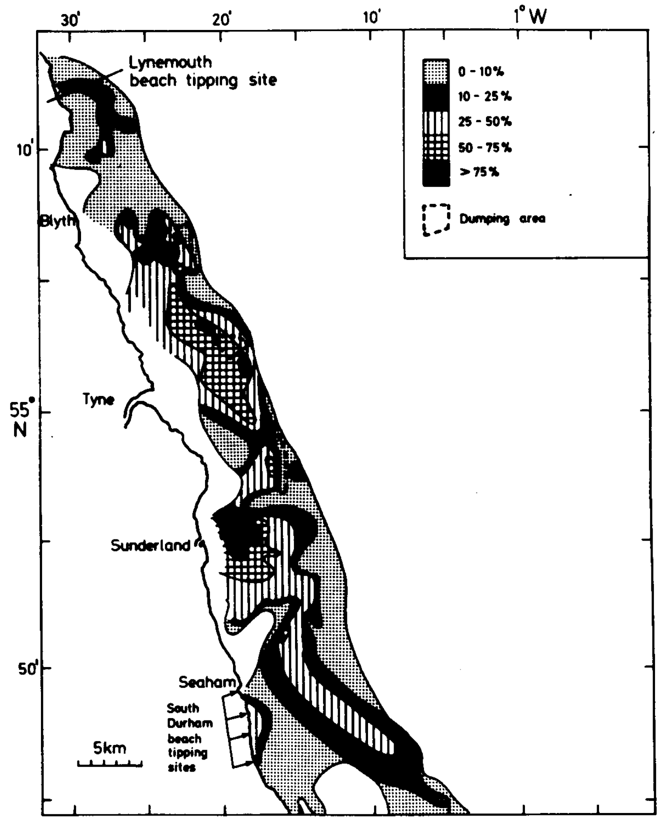


Figure 17 Percentage of the sand-sized coal coarser than 500 μm.

The percentage of the sand-sized coal coarser than 500 μm has been calculated and the results plotted in Figure 17. This indicates considerable transport of material coarser than 500 μm away from the offshore tipping sites, but very little away from the shore tipping sites. It appears therefore that very little coal coarser than 500 μm is able to escape seawards of the surf zone. Most of the coarse particles dispersed away from the offshore tipping sites appear to be restricted to well-defined pathways running parallel to the coast, with the coal populations becoming finer both inshore and offshore of these pathways. Coal particles coarser than 500 μm are transported as bedload, rather than in suspension near the bottom, and this accounts for their more restricted distribution. South of Sunderland megaripples are known to exist on the sea bed in these zones of coarse coal transport (Figure 14), confirming that bedload transport processes are operating.

Coal particles coarser than 500 μm are theoretically capable of being moved inshore under the influence of shoaling waves, to appear on the beaches as sea coal. In reality this does not happen, at least not to any significant extent, which is demonstrated by the absence of coal from the inshore zones of fine sand away from the beach tipping sites (Figure 16). A possible mechanism whereby the onshore movement of coal is checked has been mentioned at the end of Section 3.2.1.

Even the finest sand-sized coal particles do not appear to penetrate further than 10 km offshore. This is not surprising as net water movements produced by wave action at the sea bed will be directed southwards, and the near-bed residual tidal flow is to the south-west. Only particles capable of long periods of suspension in the upper water column could become dispersed further offshore.

3.3.3 *The dispersion of very fine coal particles (<90 μm)*

It is difficult to estimate the amount of coal in the finest fraction of the sediment due to the presence of significant amounts of natural organic material. The following procedure was thus adopted to give an estimate of the amount of coal present. After first removing carbonates by treatment with sulphurous acid, the carbon and nitrogen contents of the fine sediment fraction were determined using a Carlo Erba C/H/N analyser. In natural sediments the carbon:nitrogen ratio is generally 10:1 (range 7:1 to 12:1) (Degens and Mopper, 1976). Thus, for each sample the nitrogen level was determined and multiplied by a factor of 10 to give an estimate of the amount of organic carbon present. This value was subtracted from the total amount of carbon determined and so provided an estimate of the coal content.

Samples collected during the 1976 CLIONE survey were subjected to this analysis and the results are shown in Figure 18. As the data are rather sparse, contours suggest only overall trends and should not be used to indicate levels of fine coal on the sea bed between sampling points. In general, the concentrations of coal in the fine sediments away from the source zones are approximately the same as those in the sand fraction (1-3%). However, the coal contents of the sand-sized fraction exceed 20% in the vicinity of the dumping sites, whereas the concentrations of coal in the <90 μm fraction of the sediment rarely exceed 5%. This presumably reflects the lack of fine material in the waste as dumped (<1% in finer than 90 μm). Fine particles are thus mainly generated by abrasion on the beach face and on the sea bed after

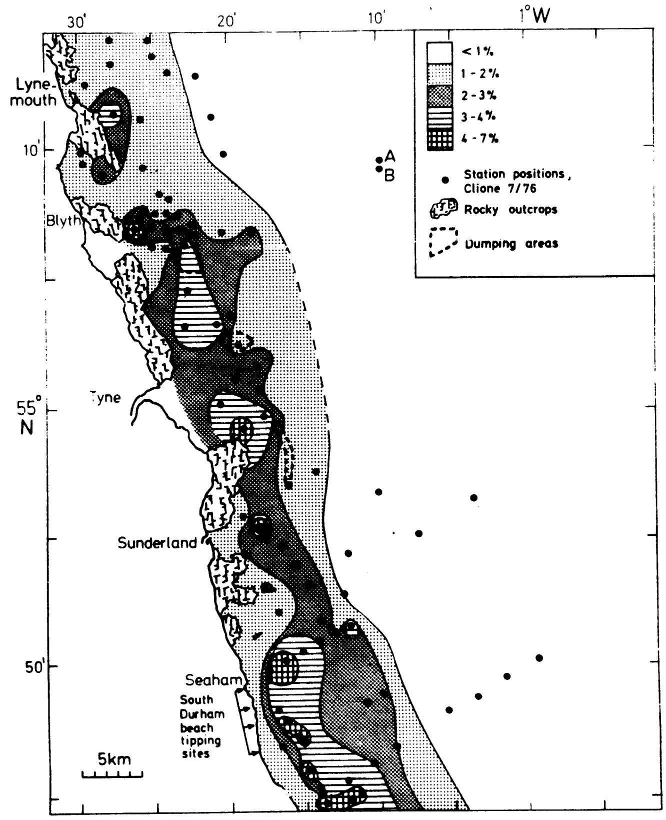


Figure 18 Percentage of coal in the fine (<90 µm) fraction of the sediment.

dumping. Attrition is likely to be greatest in shallow water where there is greater wave activity, and on hard substrates where there is no mud to restrict the movement of particles. However, these areas are unsuitable for the accumulation of the fine abraded material which settles in sheltered, muddy areas. Indeed, a comparison of Figures 18 and 13 shows that most of the zones where the concentrations of coal in the fine fraction exceed 3% are areas where silt and clay form more than 25% of the substrate.

Perhaps one of the most interesting features of the distribution of very fine coal particles is that this material does not seem to escape seawards in any significant quantities. The two samples collected from the zone of accumulated silt and very fine sand on the western slope of the offshore trough (samples A and B in Figure 18) had normal C:N ratios (10:1 and 7:1), suggesting that there is little or no fine coal in the sediments 20 km offshore. This implies that negligible quantities of suspended sediment are moving into the offshore cell of suspended sediment circulation (see Section 3.2.3) from the landward zone, and that the silt deposit of the trough area may not be a result of present-day processes.

3.3.4 *The dispersion of quartz-density waste*

As waste-derived sands and silts are indistinguishable from natural sediments, it is impossible to trace their dispersion away from the dumping sites. The dynamics of natural sands and silts have already been discussed (Section 3.2) and the conclusions drawn apply also to waste-derived materials. In comparison with the movement of coal particles, quartz-density materials move along similar pathways, but the degree of transport is much more limited. Only fine and medium sands are likely to be transported any appreciable distance, and then only during periods of storm wave activity.

3.4 The effects of fly ash dumping on the sediment composition

Fly ash is a light grey powder composed of fine sand and silt-sized particles. A full description of its physical and chemical characteristics has been given in Section 1.3. The ash is dumped into the Blyth, Souter Point and Tyne disposal grounds using vessels with instantaneous discharge through bottom doors. As parts of the waste are fine and light (density is approximately 2.2 g ml^{-1}) some dispersion may take place before the waste reaches the sea bed. Subsequent dispersion may occur during periods of peak tidal flows or storm activity.

3.4.1 *Dispersal whilst in the water column*

The bulk of the fly ash probably reaches the sea bed in less than one minute, the waste load behaving as a single body and settling close to the site of dumping. However, because of turbulence during the fall, some of the ash may be dispersed into the water column, particles settling at rates dependent upon their individual characteristics. The mean particle diameter of the fly ash which forms the bulk of the waste (as opposed to the coarser boiler ash) is about 40 µm and such particles settle at a rate of approximately 4 mm s^{-1}, reaching the sea bed in just over two hours in water depths of 30 m. Thus, it is very unlikely that significant quantities of the waste will remain in suspension for longer than a tidal cycle.

3.4.2 *Dispersion away from the dump sites*

The degree to which fly ash has been dispersed away from the dumping ground has been determined from the distribution of ash in the sea-bed sediments over the area as a whole. Density separation of fly ash in the sediment using triethyl orthophosphate was discarded because it proved too time consuming for dealing with the large number of samples. Two methods were finally adopted. In the first fly ash spheres were identified under the microscope, providing an index of the amount of ash present. In the second the particle-size characteristics of contaminated sediments showed the probable amounts of ash present, by either identifying an ash 'population' (with a mean size in the coarse silt—very fine sand range, see Section 3.1.3), or by measurement of the silt:silt and clay ratio, which is 95% for fly ash but only 50% for the natural sediments of the area.

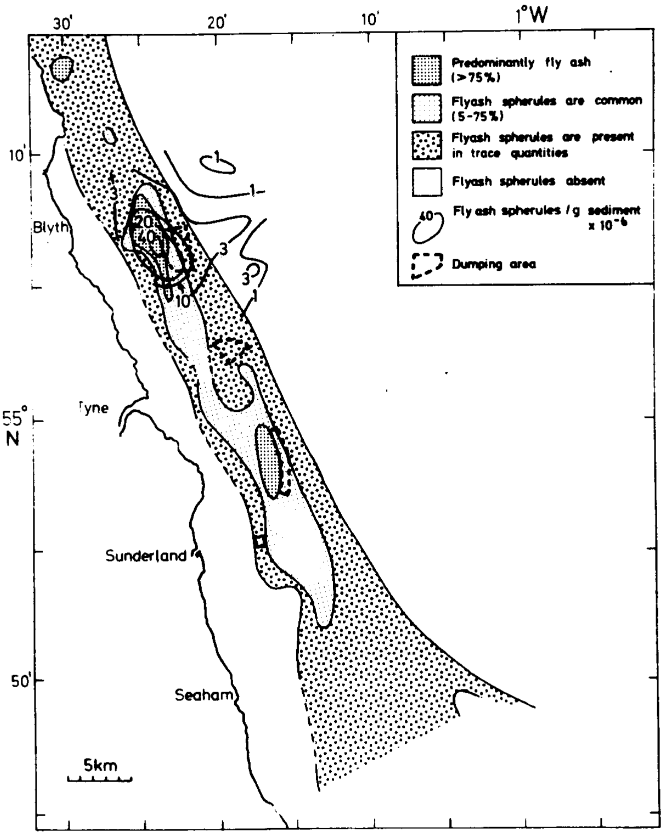


Figure 19 A. The distribution of fly ash spherules in the very fine sand fraction. Contours relate to the distribution of fly ash in 1975 (R.Bamber, pers. comm.). Figures indicate numbers of fly ash spherules in the sediment (10^6 particles/g).

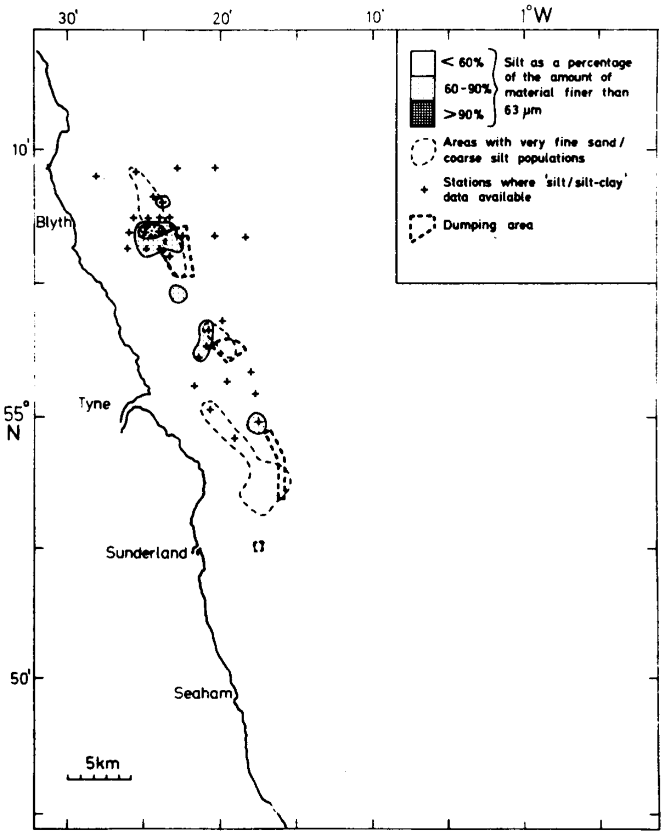


Figure 19 B. The distribution of fly ash inferred from particle-size characteristics of the sediments.

Of the latter two methods, the identification of sediments with particle-size populations consistent with those of fly ash was least successful, as dumped harbour dredgings often had a similar size distribution. There was, however, a reasonable correlation between the numbers of ash spherules counted under the microscope and the silt:silt and clay ratio.

The distribution of fly ash in the sea-bed sediments shown by microscope counts (Figure 19A) proves that there is wide dispersal of some of the ash. The distribution may overestimate the dispersion of all components of the ash since only spherules, which are liable to be partially gas-filled and more readily transported in suspension, have been identified. As expected from a knowledge of the tidal and wave regimes and from the study of coal dispersal, transport of the fly ash takes place parallel to the coast with little dispersion normal to the shore. Movement appears to be predominantly southwards.

The zone within which the sea-bed sediments have been severely modified by the presence of fly ash is best shown by the silt:silt and clay index (Figure 19B). At the Blyth dumping ground, where the greatest amounts of ash are dumped, a large area of the sea bed has been blanketed by fly ash deposits. This area, known locally as the 'cement pit', is situated inshore of the dumping ground, a situation which can only be attributed to short dumping. Boulder (>25 cm) sized concretions of fly ash are found in this area, probably standing proud of the sea bed as they have been picked up in Aggassiz trawls. It is believed that these concretions were present in the fly ash prior to dumping.

3.5 Organic matter in sediments

Levels of organic matter in sediments are usually established by using oxidation techniques, such as the determination of loss on ignition, or, where more precision is required, by measuring the carbon content of the sediments. Unfortunately coal is also oxidised by these methods, so organic matter has been estimated through the measurement of proteinaceous matter determined by nitrogen analysis of the <90 μm fraction. The fine fraction of the sediment was chosen because organic matter in the fine fraction is more likely to be available to the benthos as food, and because the ability of organic material to become associated with a sediment is largely dependent upon the sediment's specific surface area, ie grain size. Thus, analysis of a specific fraction reduces variability due to differing particle sizes and simplifies recognition of sources and sinks of organic matter.

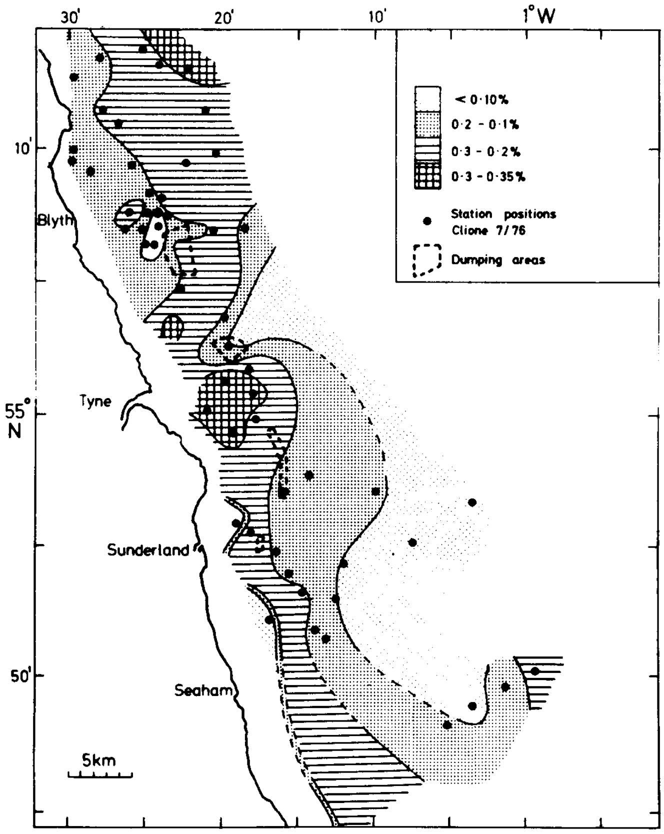


Figure 20 The distribution of nitrogen in the fine (<90 μm) fraction of the sediments.

The nitrogen content of the <90 μm fractions determined for the samples collected in 1976 is shown in Figure 20. The levels of total organic matter are approximately 16 times the nitrogen values shown. From Figure 20, the impact of the River Tyne as a major source of organic detritus in the area is evident, although the enriched zone off the mouth of the Tyne may also be due to the disposal of harbour dredgings. Indeed, two of the sediment samples containing nitrogen concentrations in excess of 0.3% (approximately 5% organic matter) also contained brick and china fragments etc, indicating that the dumping of dredgings is at least partly responsible.

3.6 Trace metals in sediments

Trace metal analyses have been carried out on all sediment samples collected for copper, zinc, lead, chromium, nickel, cadmium and mercury concentrations in two specific fractions of the sediment (0-90 μm, 90-500 μm). Full details of the analytical procedure have been described elsewhere (Eagle *et al*, 1978). The results are shown in Figures 21-29. The cadmium concentrations in both sediment fractions were below the detection limit employed (0.5 mg/kg).

The concentrations of trace metals in the sediments are dependent upon a complex interaction of variables. The most important of these are:

(i) the potential of the sediment to become associated with trace metals (ie its specific surface area and organic content);

(ii) the coal content; because coal which is widespread in the area contains substantial concentrations of trace metals (see Section 1.3);

(iii) the localised influences of other pollutant inputs, eg coastal sewage discharges; harbour dredgings.

Although the distribution of trace metals in the sediments has been severely modified by the dumping of coal, the coal-derived metals are generally considered to be in an inert form, and not available biologically. In the present study, no attempt has been made to identify the relative contributions of the various sources of metals to the overall distribution. The data are simply presented as a baseline, against which future results can be compared.

4 The macrobenthos

Surveys to determine the effects of waste disposal on the macrobenthos were carried out in and around two of the dumping areas covered by the sediment survey. One of these, the Wear dumping site, receives only colliery waste and smaller quantities of dredge spoil. The other, the Blyth dumping site, receives fly ash with smaller quantities of colliery waste and dredge spoils. As each of the two areas was surveyed in different years and different techniques of identification and data work-up were employed the results of each survey will be presented and discussed separately.

4.1 The macrobenthos of the Wear dumping ground

4.1.1 *Sampling*

The Surveys were carried out in 1975 and 1976. The 1975 survey covered a grid of 90 sampling stations from off Seaham in the south to Souter Point in the north. A minimum of two sea-bed samples was taken at each station with a 0.1 m^2 Day grab, except where the hardness of the substrate prevented effective sampling. In the latter situation the contents of up to 5 grab hauls were bulked to enable at least a qualitative faunal assessment to be made. Sub-samples for sediment analysis were collected from one grab sample at each station, the sediment remaining and the contents of the other grab samples were carefully washed through a 2 mm mesh sieve. The separated fauna were then identified to genus or species level and recorded. Those specimens which could not be immediately identified were preserved in formalin for subsequent examination in the laboratory. This 'rapid assessment' technique has been described in more detail elsewhere (White *et al*, 1974).

Since the 1975 survey, however, a more quantitative approach to benthos sampling has been employed and 16 stations were revisited in 1976 (Figure 30). At each station three samples were collected with a 0.1 m^2 Day grab. One sample was used for sediment analysis and the other two were sieved through a 1 mm sieve and the residue preserved in 5% formalin. The animals were subsequently removed from the sediment and wherever possible identified to species level and counted. Nomenclature followed that of the Plymouth Marine Fauna (Marine Biological Association, 1957).

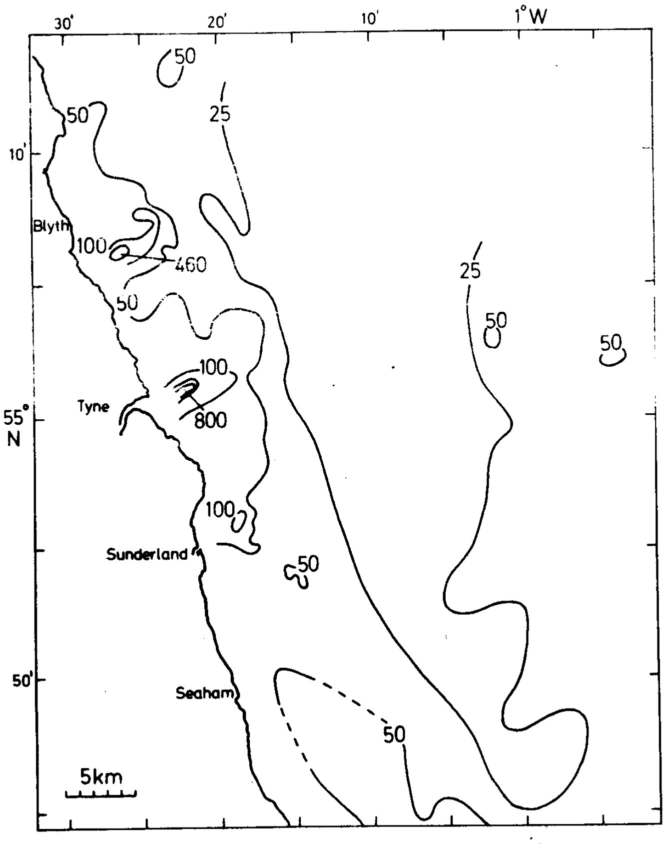


Figure 21 The concentration of copper in the <90 μm fraction of the sediments (mg/kg).

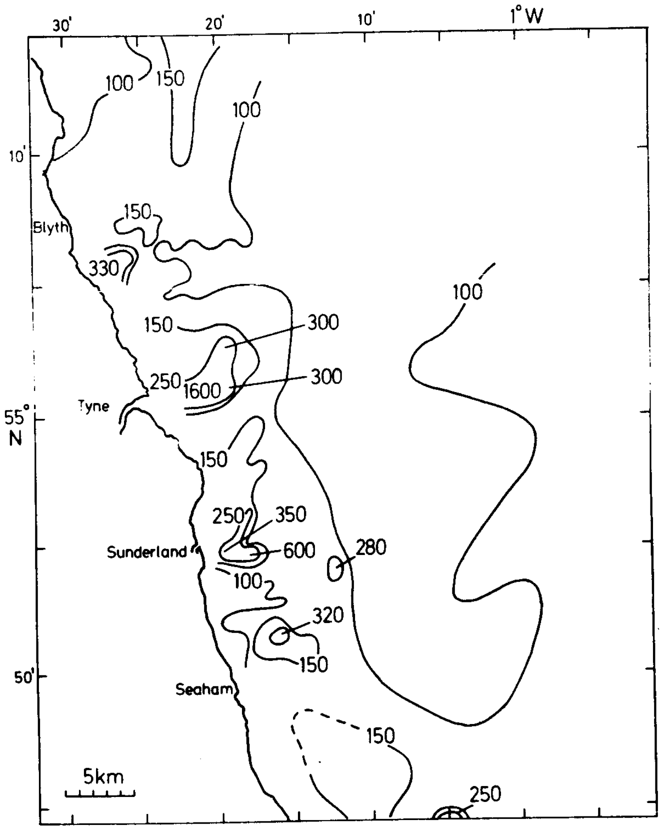


Figure 23 The concentration of zinc in the <90 μm fraction of the sediments (mg/kg).

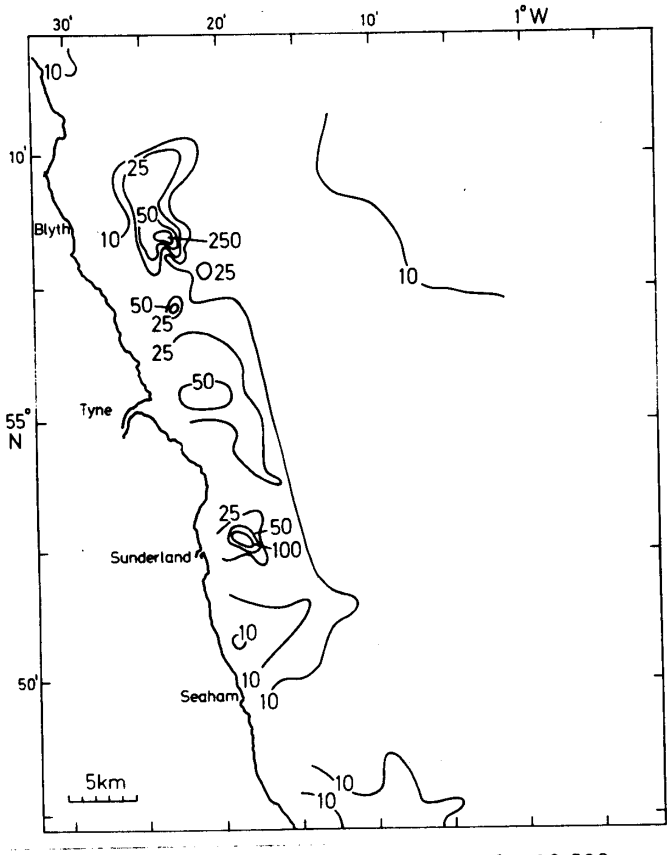


Figure 22 The concentration of copper in the 90-500 μm fraction of the sediments (mg/kg).

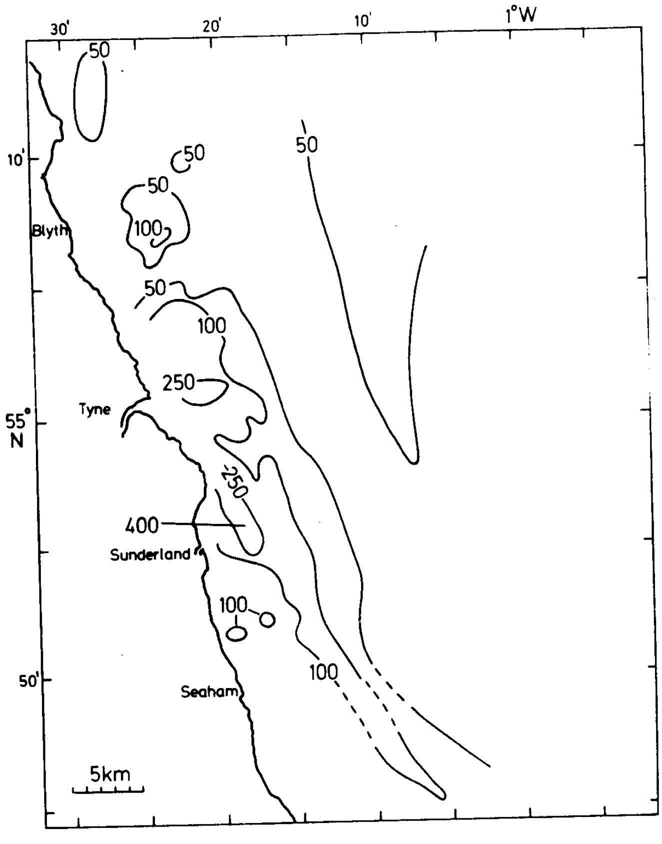


Figure 24 The concentration of zinc in the 90-500 μm fraction of the sediments (mg/kg).

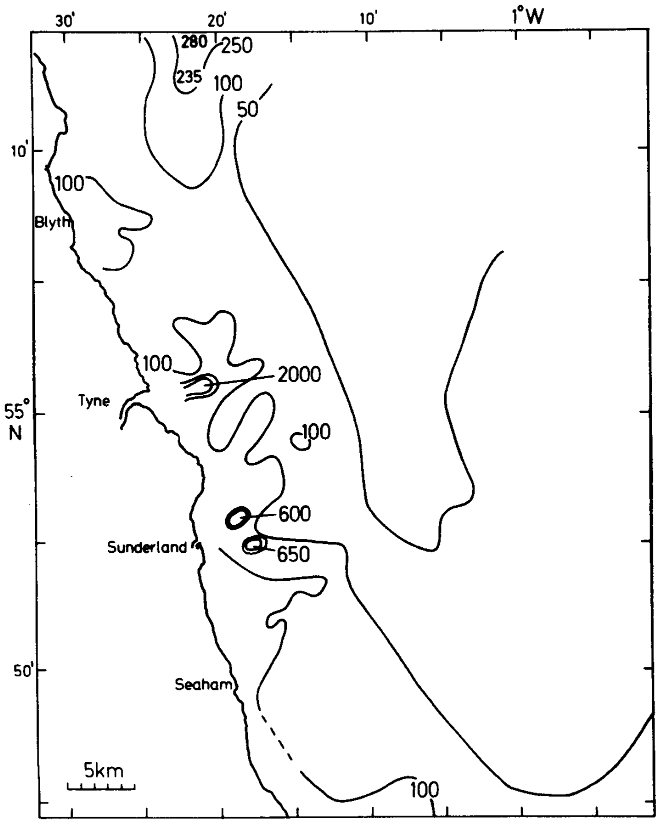


Figure 25 The concentration of lead in the <90 μm fraction of the sediments (mg/kg).

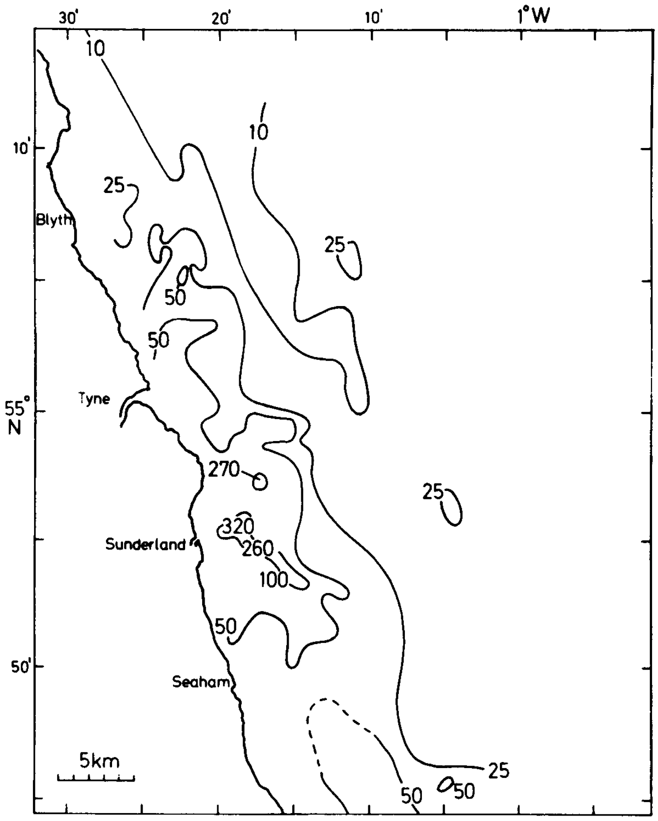


Figure 26 The concentration of lead in the 90-500 μm fraction of the sediments (mg/kg).

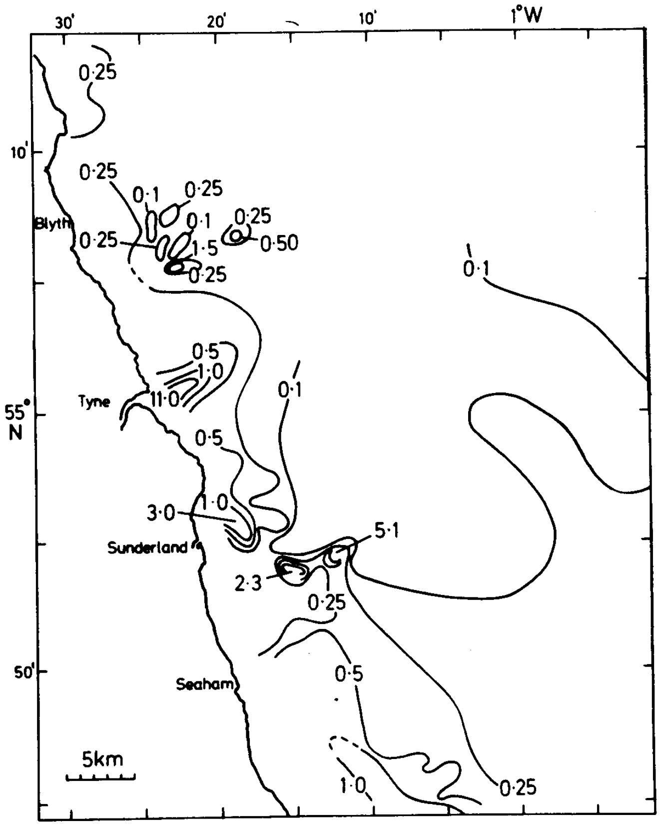


Figure 27 The concentration of mercury in the <90 μm fraction of the sediments (mg/kg).

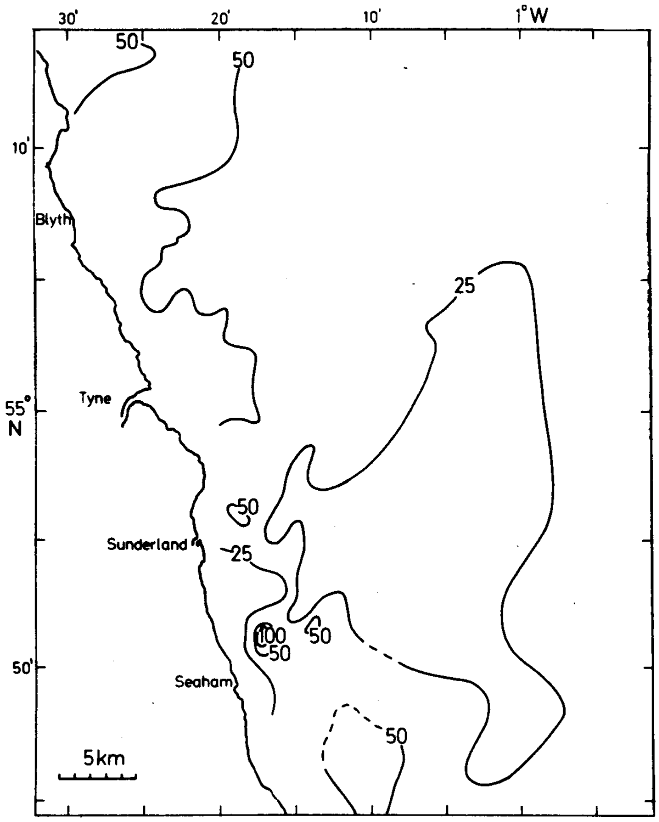


Figure 28 The concentration of nickel in the <90 μm fraction of the sediments (mg/kg).

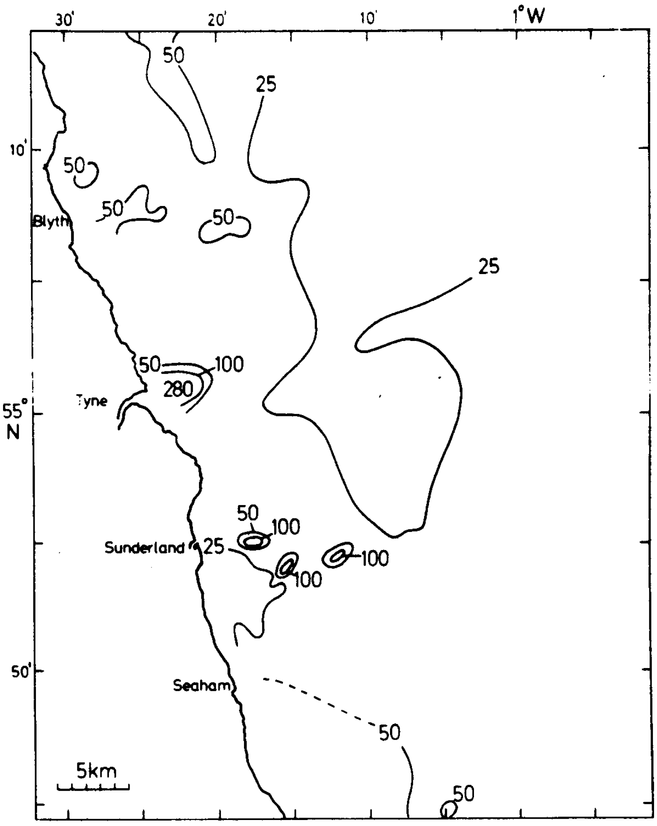


Figure 29 The concentration of chromium in the <90 µm fraction of the sediments (mg/kg).

The fauna from the two 0.1 m^2 sub-samples collected at each station were summed, there not being any marked difference between them. The data were analysed with the aim of distinguishing different associations of animals and the reasons for their distribution, and to examine any gradients of distribution. The techniques used were group-average clustering (Lance and Williams, 1967) with the Bray Curtis index of similarity (Bray and Curtis, 1957) and the reciprocal averaging method of ordination (Hill, 1973a). The distributions of some of the more abundant species were mapped out and compared to the distributions of station clusers, diversity (Hill, 1973b) and to the ordinations. The fauna were also compared with the distributions of silt, sand and gravel in the sediment and of dumped material. (For further details of these techniques see Eagle *et al*, 1978.)

Of the 16 stations visited in 1976, because of the hardness of the ground, no sample could be obtained from station 99, only a sediment sample was obtained from station 100 and only small samples were collected at two other stations. By using a percentage transformation of the data it was ascertained that classification of the data was not substantially affected by the small volume of some samples. In order that differences in the absolute abundances of animals should not be obscured, the observed numerical abundance data have been used throughout.

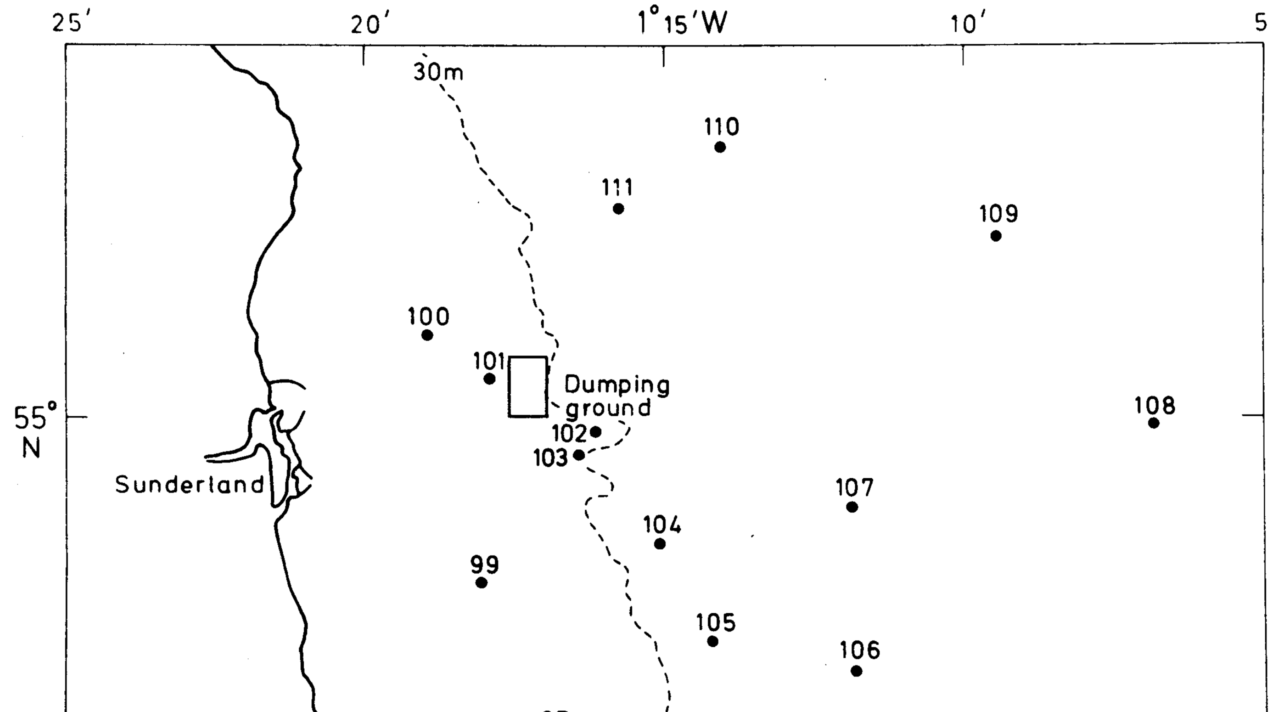
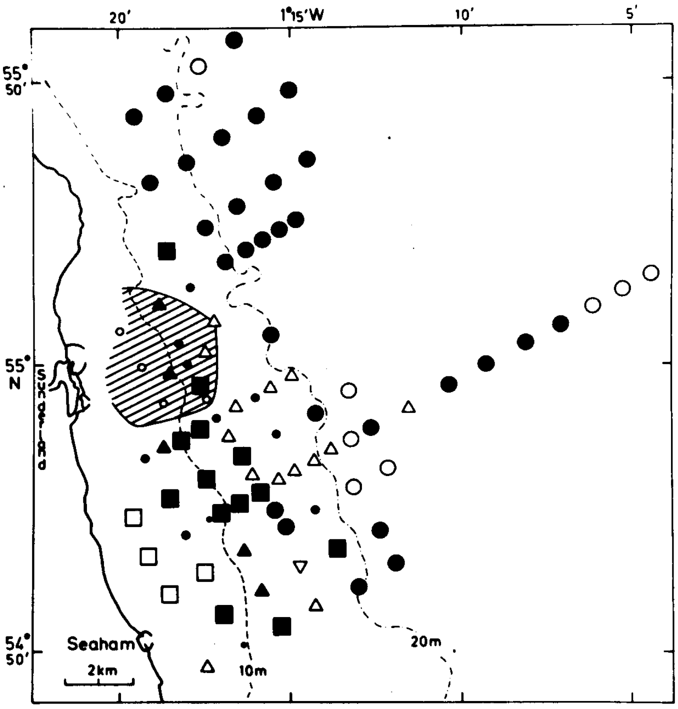


Figure 30 Positions of stations sampled during the Wear dumping ground survey, 1976.



Association	Symbol	Common species
A	■	*Ophiothrix fragilis*
B	□	*Nucula turgida*
C	●	*Amphiura filiformis, Turritella communis (Glycera* sp., *Nucula* sp.)*(Cucumaria* sp., *Owenia fusiformis)*
	○	*Amphiura filiformis* (low density) *(Abra alba, Virgularia mirabilis)*
D	▲	*Ophiura albida* (low density), very little else
E	△	Tube worm, *Ophiura albida*
F	▽	*Melinna* sp.
G	•	Virtually no fauna found
	∘	No fauna found - minestone
	·	No fauna found - rocky
	▨	Zone of main concentration of dumped minestone in 1975. (See figure 10)

Figure 31 Faunal associations identified by classification of data collected on the Wear survey in 1975 (2 mm sieve)

4.1.2 *Results*

(a) 1975 Survey

In the qualitative survey of 1975 a 2 mm sieve was used and identification of the animals was not as exhaustive as in the 1976 survey. Nevertheless, the data collected have been subsequently analysed by classification to identify similar associations of fauna. These are shown in Figure 31 although, due to the relative sparseness of the fauna collected, the similarity between the associations identified was low (below a 0.2 level of similarity). This survey revealed severe depletion of the benthos at the stations where the substrate was comprised of coarse minestone, indicative of the zone of most active tipping.

(b) 1976 Survey

The 1976 survey grid (Figure 30) was designed to examine in more detail results of the 1975 survey and included stations typical of the main faunal associations.

The classification dendrogram for the 16 stations is shown in Figure 32. Three small but very different groups (stations 97 and 98; 101; 102 and 104) were distinguished from the bulk of stations. Additionally, station 105 contained several species not found at the remaining stations. These distinctions were verified by ordination: stations 102/104 and 97/98 being isolated on the first two axes and stations 105 and 101 on the third axis of major variation. Station 101 was separated from all others because of its lack of a unique, distinctive fauna. On the fourth axis, stations 96 and 111 were separated, but as they had many species in common with the remaining stations, and as this axis of variation was very weak, they have been included with them in a single association. The distributions of the groups are shown in Figure 33, together with the species richness, total faunal density and diversity at each station. In Table 4 these attributes are averaged for each group of stations and the characteristic species found in each are listed.

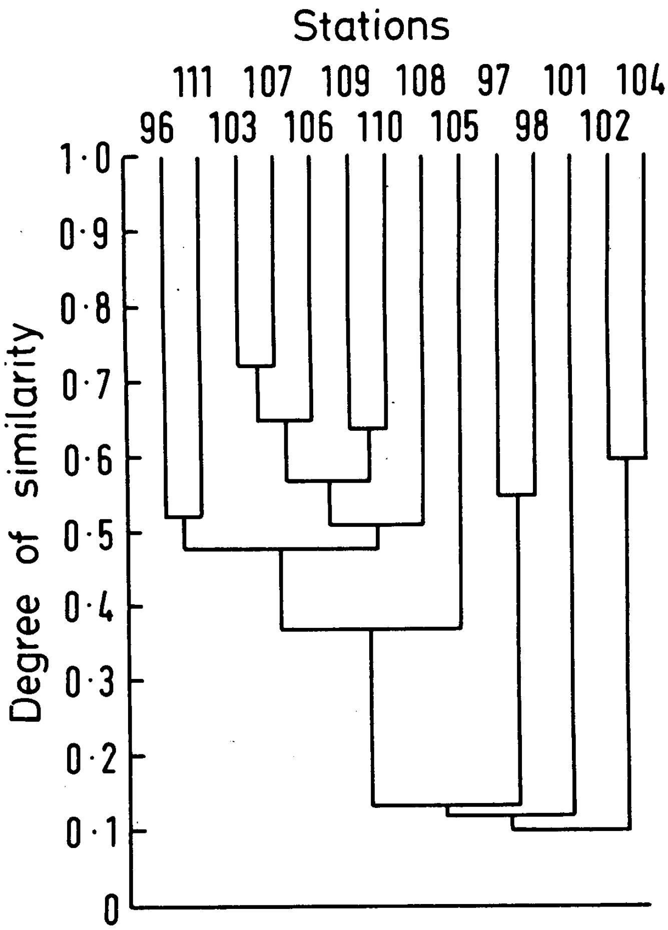


Figure 32 Dendrogram of station similarity (1 mm sieve, 0.2 m^2 sample area). 1976 Wear survey. For location of stations see Figure 30.

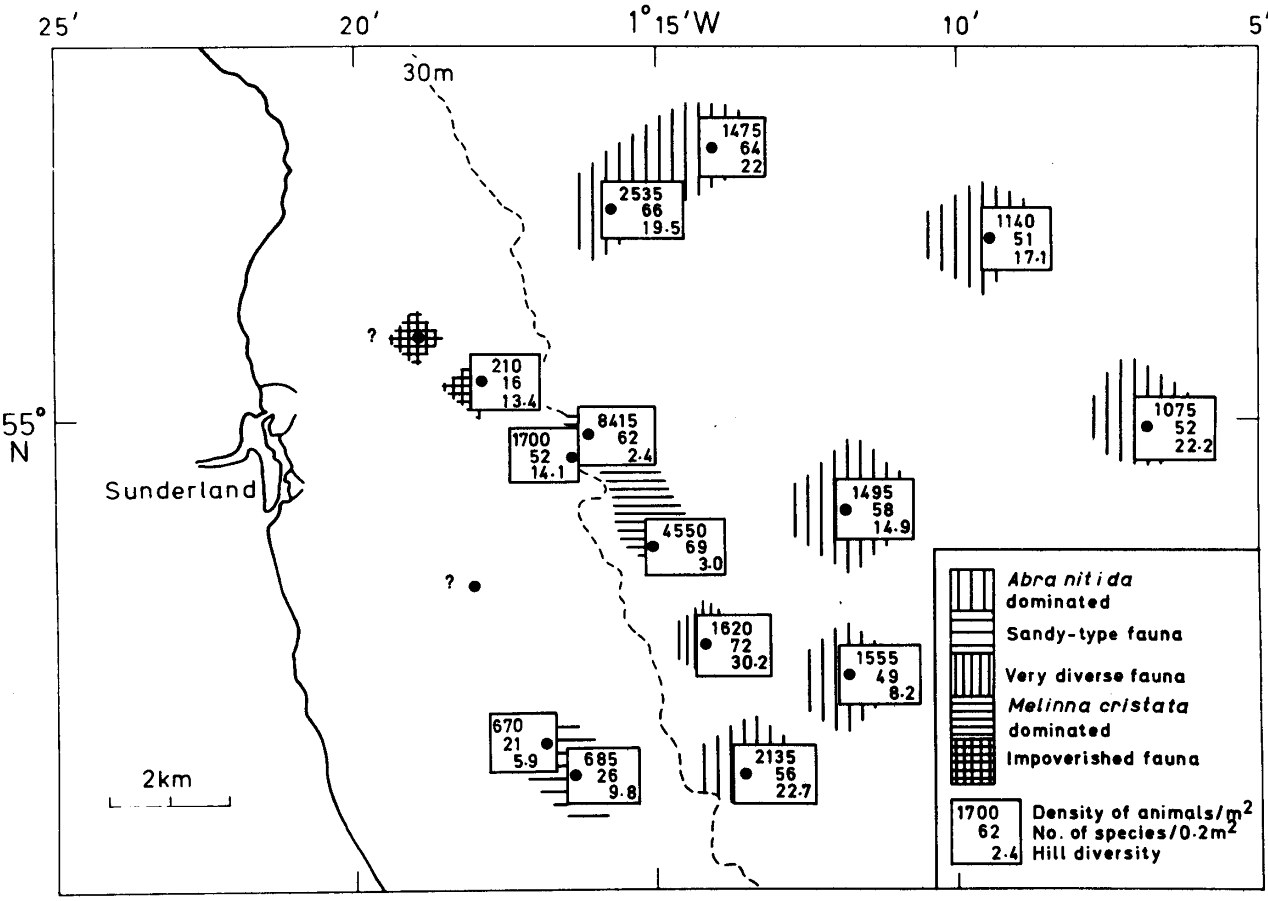


Figure 33. Distribution of animal associations, faunal density, number of species and diversity; 1976 Wear survey.

Table 4 Faunal characteristics of the groups of stations (1976 Wear survey).

Stations	96, 103, 106, 107, 108, 109, 110, 111.	105	97, 98	101	102, 104
Average No. of animals/m^2	1640	1620	680	210	6485
Average No. of species/0.2 m^2	58	73	24.5	16.0	65.5
Average diversity	17.6	30.2	7.9	13.4	2.7
Characteristic species. (Those in brackets are of secondary importance.)	*Abra nitida* very abundant *Magelona filiformis* *Nephthys hombergi* *Pectinaria koreni* *Thyasira flexuosa* *Nucula tenuis* (*Lumbriconereis gracilis*) (*Prionospio malmgreni*)	Nematoda *Glycera lapidum* *Pista cristata* *Praegeria remota*	*Spiophanes bombyx* *Magelona papillicornis* *Bathyporeia* sp. *Tellina fabula* *Nucula turgida*	Nothing characteristic	*Lumbriconereis gracilis* very abundant *Melinna cristata* very abundant *Exogene verruga* *Ampelisca* spp. (*Hiatella arctica*) (*Ampharete grubei*) No *Abra nitida*

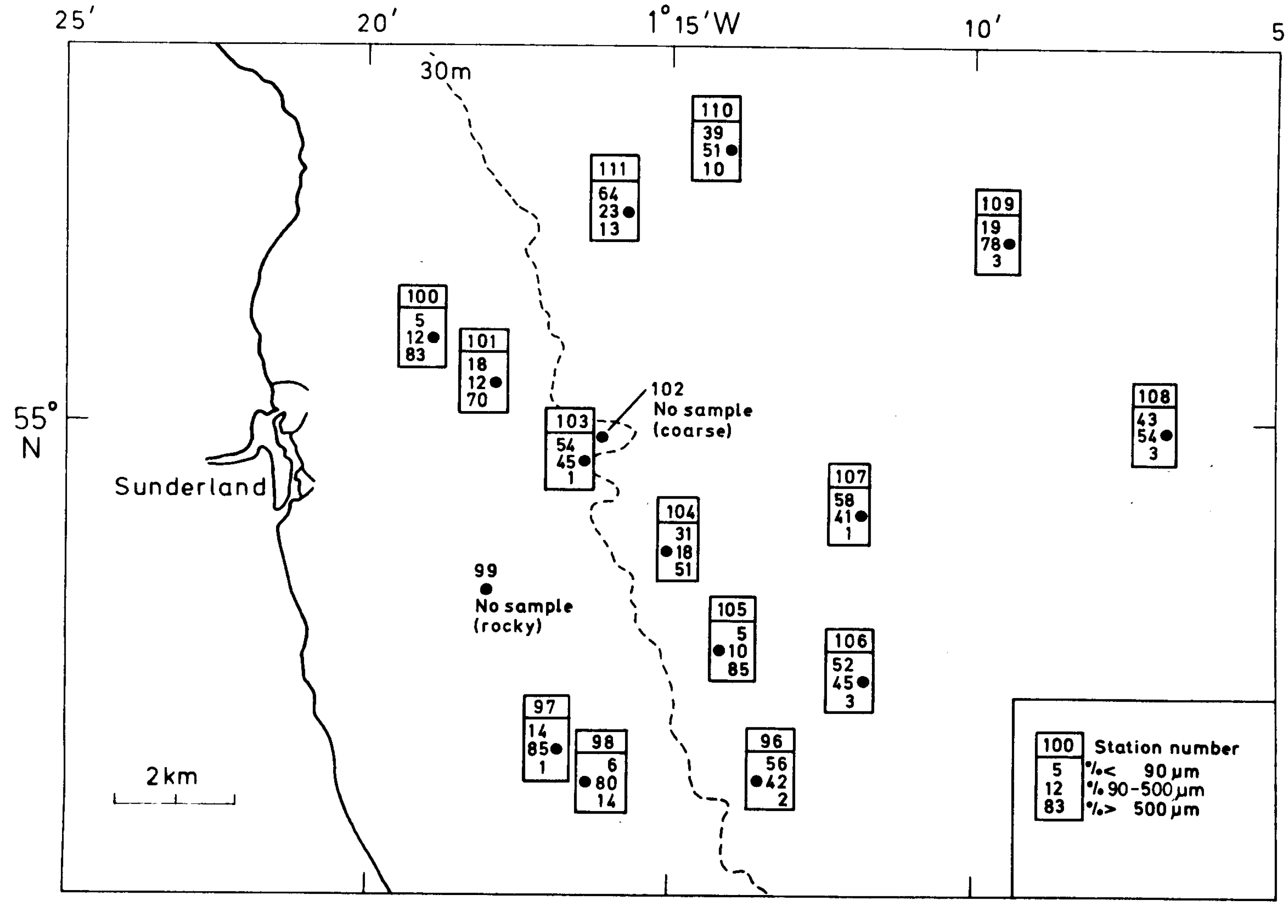


Figure 34 Sediment particle-size characteristics, 1976 Wear survey

The proportions of the sediment in the three size ranges <90 µm, 90-500 µm and >500 µm are presented in Figure 34. From comparison of this with Figure 33 it is evident that the cleaner sand stations were inhabited by the fairly low-density fauna dominated by *Spiophanes bombyx*, *Bathyporeia* spp. and *Nucula turgida*. The *Melinna cristata* and *Lumbriconereis gracilis* dominated fauna and the very diverse association at station 105 were present in sediments with substantial quantities of gravel. No sediment sample was collected at station 102 but notes made at sea recorded a coarse sediment. Examination of this gravel has revealed that it was of natural origin, unlike that at stations 101 and 100 where minestone (shales, coal, sandstone, etc) was predominant. At the latter stations the fauna was composed of species which were present elsewhere, but at much reduced densities. The sediment of the largest group of stations was silt-like fine sand with very little coarse material.

4.1.3 *Discussion*

Due to the qualitative nature of the 1975 survey, most attention here will be paid to the results of the 1976 survey.

The fauna of the muddy fine sediments at depths below 30 m (Figure 33) closely resembled that of the *Amphiura filiformis* community of Thorson (1957) and the equivalent boreal offshore muddy sand association of Jones (1950), except that *Abra nitida* was the dominant species in the association which averaged 1640 individuals/m^2. Inshore of this fine, muddy sand facies, the other faunas occurred in discrete areas. At station 101 the fauna appeared to be impoverished, with only 16 species from the mud-preferring *Amphiura filiformis* community present at a total density of 210/m^2. On the sparse evidence obtained from the small volume of sea bed sampled at station 100, the fauna there was more impoverished than at station 101. From Figure 34 it can be seen that 70% or more of the sediment at these two stations was comprised of coarse pieces of minestone, but typical gravel epifaunal species (eg *Alcyonium*, *Ophiothrix*, *Flustra*) were not found. Their absence was probably due to the frequent deposition of minestone. High suspended solids concentrations immediately following dumping may also be particularly detrimental to the filter-feeding epifauna. The data in Section 3 indicated that station 101 was near the fringe of the most intensively used dumping area; less frequent dumping at this station seems to have allowed species more typical of the offshore *A. filiformis* community to inhabit the muddy interstices between the minestone pieces.

Material from the Wear dumping ground moves predominantly southwards as bedload and southwards and offshore in suspension (Section 3.2). Thus the effects of this transport on the fauna should be most evident at stations 102, 103 and stations further south near the 30 m line. Observations showed that station 103 supported a diverse fauna similar to the muddy, fine sands further offshore. At stations 102 and 104 *Melinna cristata*, a tubicolous worm which collects food from the surface of the sediment, was strongly dominant in an association of animals very rich in species, most of which were also present in the *Abra nitida* association. The high abundance and great variety of species present here, encompassing suspension feeders, selective surface deposit feeders and non-selective deposit feeders, indicated an undisturbed community in a muddy gravel sediment. Buchanan (1963) has found a similar association in mixed sediments just offshore of rocky submarine outcrops to the north of the Tyne which are not affected by any dumped wastes. No specific reason for the very high abundance of *Melinna* and resultant low diversity of the association can be identified. Further south than stations 102 and 104 the gravel contained less mud. At station 105 *Melinna* was still present, but an exceptionally rich collection of animals (73 species in $0.2m^2$) was found with no single dominant species (diversity 30.2). Again, the minestone dumping had no apparent effects, and at stations surrounding this gravelly area the fauna was typical of the offshore muddy, fine sand areas, although some sand-sized particles derived from dumping are thought to move over these areas (Section 3.2).

In the south-west part of the survey area much cleaner sand supported animals at an average density of $680/m^2$. This relatively low density is usual in sandy sediments where hydrodynamic conditions are unsuitable for the deposition of organic food matter. Species such as *Magelona papillicornis, Spiophanes bombyx, Bathyporeia* spp., and *Tellina fabula* seem to be especially adapted to such conditions and were dominant here.

In conclusion therefore, the biological surveys suggest that the effect of minestone dumping on the benthos is restricted to the zone of initial settlement, ie to an area of approximately 10-15 km^2 which is centred just inshore of the Wear dumping site, where severe depletion of the bottom fauna results. It has not been possible to detect any effects on surrounding areas although they have been shown to be subject to some degree of sediment transport including particles of waste origin.

4.2 The macrobenthos of the Blyth dumping ground

4.2.1 *Sampling*

The survey, carried out in April 1976, covered the sampling stations shown in Figure 35. Techniques of sample collection and data work-up were identical to those employed in the second (1976) Wear survey (Section 4.1.1). Because of the hardness of the ground, no sample could be obtained from station 60 and the volumes of samples collected at four other stations were low. By using a percentage transformation of the data it was ascertained that classification was not substantially affected by the small volume of some samples. In order that differences in the absolute abundances of animals should not be obscured the actual numerical abundances have been used throughout.

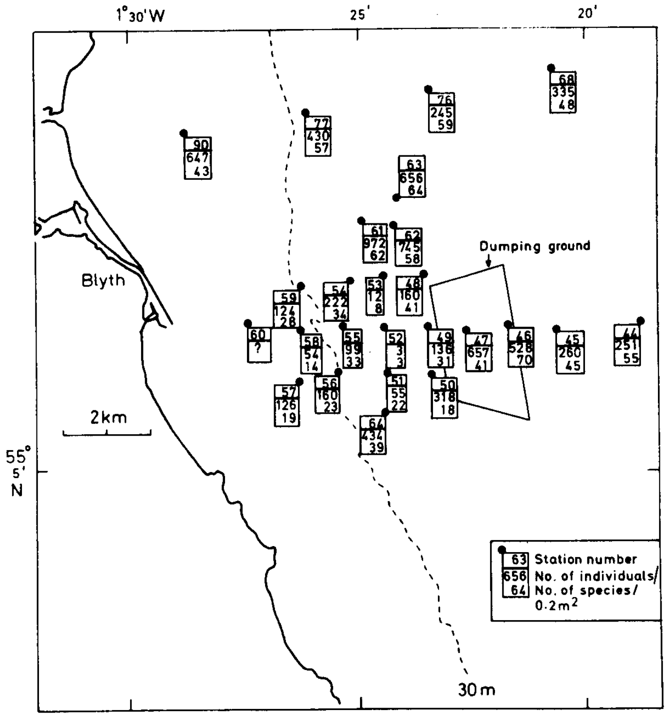


Figure 35 Station positions, faunal density and species richness for samples collected during the Blyth dumping ground survey, 1976.

4.2.2 *Results*

The faunal density (Figure 35) showed that very few animals were found just to the west of the dumping ground, with only 3 and 12 animals/0.2 m^2 found at stations 52 and 53 respectively, but concentrations were between 50-200/0.2 m^2 at nearby stations and up to 745/0.2 m^2 further northwards and offshore. The number of species was also depleted in the same area: only 3 species/0.2 m^2 occurred at station 52 and 8/0.2 m^2 at station 53, but towards the north and offshore the number rose to 50-60 and above/ 0.2 m^2. To the south and west of station 52 the number of species in each sample increased to about 20-30/ 0.2 m^2, though two of the inshore stations (57 and 58) each supported less than 20 species/ 0.2 m^2.

Classification of the stations on the basis of their faunal similarities revealed six clusters of stations

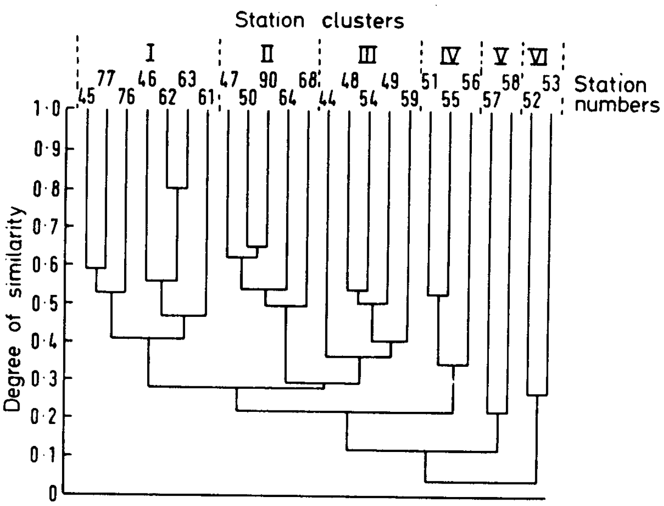


Figure 36 Dendrogram of station similarity (1 mm sieve, 0.2 m^2 sample area) 1976 Blyth survey.

(Figure 36), although the separate status of groups V and VI may be uncertain due to the low level of clustering (levels of similarity were 0.22 and 0.27 respectively). Examination of the species composition of the six clusters confirmed that several species occurred in all clusters. In general terms they could all be included within the same boreal offshore muddy sand association (Jones, 1950) which is equivalent to the *Amphiura filiformis* community of Thorson (1957). A list of the more common species found is presented in Table 5. The differences between the groups were due to differences between the proportions of the species present, the total density and the number of species present. Thus, the diversity also varied between the groups. Table 6 summarises these attributes for each cluster and the characteristic species are also listed.

Table 5 Some of the more common species found in the Blyth survey area. Abundances are the maxima observed (numbers/0.2 m^2).

POLYCHAETA	
Diplocirrus sp.	23
Chaetozone setosa	30
Goniada maculata	32
Lumbriconereis gracilis	103
Magelona filiformis	65
Nephthys hombergi	13
Owenia fusiformis	18
Paraonis gracilis	124
Pectinaria auricoma	9
P. koreni	23
Pholoe minuta	72
Prionospio malmgreni	76
Scalibregma inflatum	10
Scoloplos armiger	42
Terebellides stroemi	8
Trichobranchus glacialis	23
AMPHIPODA	
Ampelisca spp.	10
MOLLUSCA	
Abra nitida	56
Cyprina islandica	12
Dentalium entalis	14
Dosinia lupinus	19
Mysella bidentata	176
Nucula tenuis	39
Nucula turgida	117
Thyasira flexuosa	78
Turritella communis	7
Venus striatula	44
ECHINODERMATA	
Amphiura chiajei	2
A. filiformis	184
Echinocardium cordatum	17
Ophiura albida	30

Table 6 Faunal characteristics of each station cluster.

Group	I	II	III	IV	V	VI
Density (m^2)	2740	2390	895	575	450	37.5
Average no. of species/0.2 m^2	64.6	37.2	37.8	26	15.5	5.5
Average diversity/ (0.2 m^2)	14.6	6.2	16.3	11.0	8.4	4.5
Characteristic species (those in brackets of secondary importance)	*Magelona filiformis* *Abra nitida* *Thyasira flexuosa* (*Lumbriconereis gracilis* very abundant) (*Pectinaria koreni*) (*Paraonis gracilis*) (*Ampharete grubei*) (*Chaetozone setosa*) (*Goniada maculata*)	*Mysella bidentata* very abundant *Amphiura filiformis* very abundant *Dosinia lupinus*	No characteristic species	No characteristic species	(*Amaea trilobata*) (*Pseudocuma gilsoni*)	Virtually no fauna

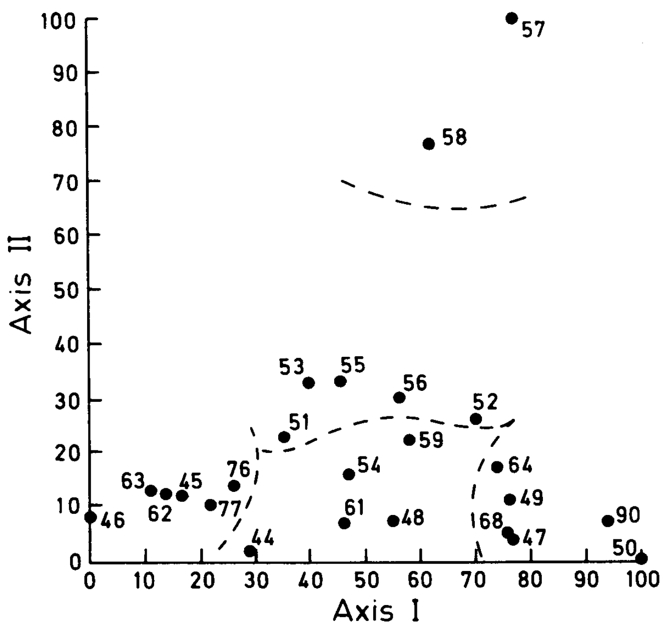


Figure 37 Ordination of Blyth stations on Axes I and II (1 mm sieve, 0.2 m^2 samples).

The ordination of stations on the first two major axes of variation is shown in Figure 37. The first axis graded the stations between the largest of the classification groups (I) where the highest densities were found, and the strongly clustered group II stations where the degree of dominance was greatest. Stations of groups III, IV, V and VI, which had no typical species, were ordinated between the extremes on axis 1. On axis 2 stations 57 and 58 (group IV) were clearly separated from other stations, indicating that they both had the same distinctive type of fauna. The stations of groups VI and IV were ordinated slightly higher on axis 2 than those of groups I, II and III, but were not clearly isolated on any axes due to their lack of characteristic species.

In order to assess the relationship between the fauna and the nature of the sediment, at each station, correlation coefficients were calculated between the faunal density, diversity and species richness and the following sediment variables: % clay (<4 μm); % silt (4-90 μm); % sand (90-500 μm); % coarse particles (>500 μm); relative amounts of fly ash, scaled 0-4.

The results are summarised in Table 7. The only correlation to be significant at the 95% probability level was between the fly ash content of the sediment and the number of species per sample.

4.2.3 *Discussion*

It was suggested in Section 4.2.2 that all the six groups identified by cluster analyses could be placed within a single community, despite the wide variation in the proportions of mud, gravel and sand between the stations. The only major variations from the community described by Jones (1950) and Thorson (1957) were the substitution of *Lumbriconereis gracilis* for *L. impatiens*, the frequent high densities of *Paraonis gracilis* and *Mysella bidentata*, and the low densities of *Turritella communis* and *Amphiura chiajei*. All stations, even the most sparsely populated, contained some of the species listed in Table 6, one or more of which were dominant.

The fauna of Group I was the typical community of the area, judging by its distribution and its species richness and diversity. Several species were found in this association which did not occur in any other group, although none was very common. In group II the total density was somewhat lower but the high abundance of *Mysella bidentata, Amphiura filiformis* and, to a lesser extent, *Dosinia lupinus* substantially reduced the diversity of the fauna; the average number of species present in each sample was about 40% less than in group I. Group III was similar to group II in this respect, but here the total density was also lower and this, together with the relatively low degree of dominance of any species, resulted in a higher diversity; the animal density within this group was more than 60% less than in groups I and II.

Groups IV, V and VI had very low faunal densities and the number of species and diversity also declined progressively. It was observed that species different from those in groups I to III were not present in these groups: the faunas simply represented a progressive impoverishment of the typical community with elimination of many species. At station 52 in group VI only 1 *Lumbriconereis gracilis,* 1 *Amphiura filiformis* and 1 *Ophiura albida* were present.

To determine the extent to which the dumping of fly ash and colliery waste had caused the reduced faunal abundance at several stations, it is necessary first to establish the relationship between the groups and the substrata identified by sediment analysis at each station. The proportion of sediment in the size ranges <4 μm, 4-90 μm, 90-500 μm, >500 μm is shown in Figure 38. Nine stations in the centre of the survey area contained more than 50% fine material attributable to fly ash dumping (Section 3.4). Elsewhere this proportion dropped to about 10-30%, the fine material generally being replaced by medium-fine sand. At Station 57, 89% of the sediment was sand with only 1.8% of fine material present. Stations 47 and 51 were predominantly of material >4 mm which has been identified as mainly minestone, sandstone and clinker. There was no natural gravel at any of the stations.

Consideration of the distribution of the faunal groups (Figure 39) shows that the fauna did not follow precisely the same pattern of distribution as the sediments. Five different faunal groups were found in the

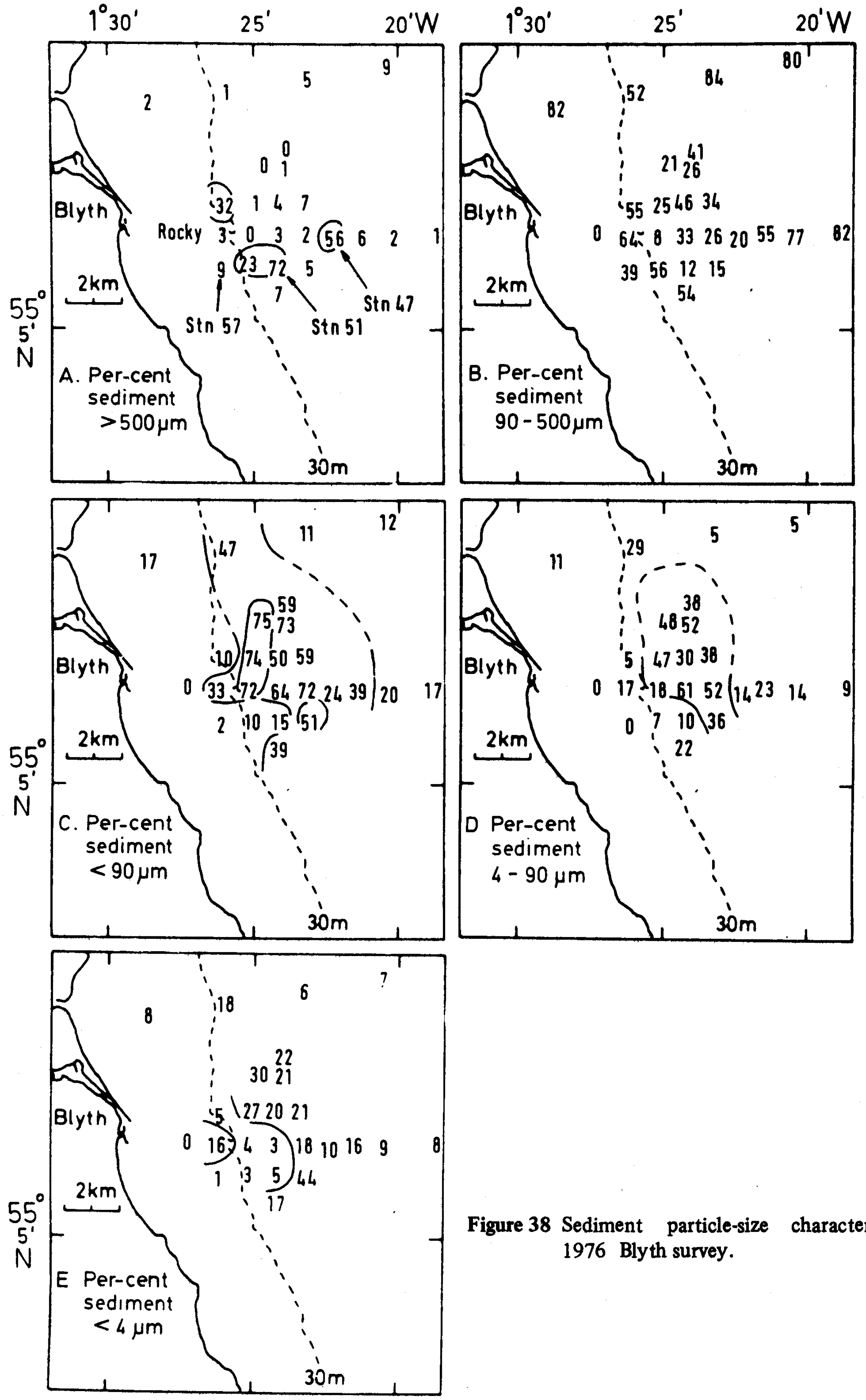


Figure 38 Sediment particle-size characteristics, 1976 Blyth survey.

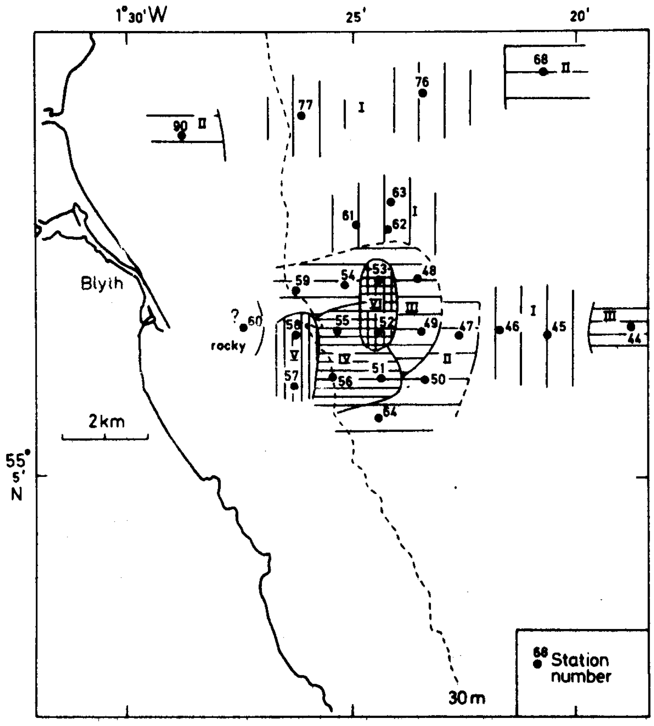


Figure 39 Distribution of groups identified by classification, 1976 Blyth survey.

area of finest sediment and the two stations (47 and 51) at which coarse material predominated supported substantially different faunas. Even at stations where an apparently natural background fauna was present, the range of sediment characteristics was very broad (eg 78%, 47% and 11% of <90 μm at stations 61, 77 and 76 respectively).

The distribution of fly ash in the sand fraction of the sediment (90-500 μm) estimated by stereo microscopic examination (Figure 19A) shows that fly ash makes up a large proportion of the sand-sized sediment where finer material predominates. However, although the area of maximal faunal depletion was close to the area of maximal fly ash accumulation, it was apparent that the distribution of the fauna did not follow the fly ash distribution exactly. The correlation coefficients between the fauna and either the fly ash content or the grain size of the sediment are shown in Table 7. The correlations between the distribution of fly ash and the faunal density, species richness and diversity were all negative but only that between fly ash and the species richness was significant at the 95% level. This relatively poor statistical correlation between the major sediment characteristics and faunal indices may be due to a number of

Table 7 Correlation coefficients between the fauna and sediment

Variable 1 Total density of animals (0.2 m^2 sample)
2 Number of species/0.2 m^2 sample
3 Diversity per sample:
4 % clay (<4 μm) in sediment;
5 % silt (4-90 μm) in sediment;
6 % sand (90–500 μm) in sediment;
7 % coarser material (>500 μm) in sediment;
8 Fly ash in sediment (scaled 0-4: based on microscope counts of number of fly ash spherules in very fine sand fraction in Figure 19A).

Variable	4	5	6	7	8	Mean	SD	n
1	0.38	0.05	–0.10	–0.13	–0.19	317.9	261.9	24
2	0.12	–0.06	0.17	–0.23	–0.41	38.0	18.91	24
3	–0.03	–0.02	0.22	–0.25	–0.29	11.58	5.34	24
Mean	14.0	27.6	47.5	10.8	1.88			
SD	10.28	22.30	25.52	18.75	1.48			
n	24	24	24	24	24			

τ = 0.406 for P = 0.05 with 22 degrees of freedom.

factors. First, the sediment samples were not collected from the same grab hauls as the benthos samples, and it is possible that the fauna was taken from a different substrate than that analysed. Second, the two wastes (fly ash and minestone) dumped in this area may have affected the sediment composition in different ways, and a single correlation would occur only if the effect of one waste totally dominated that of the other, which is clearly not the case since, although fly ash appears to be the cause of depletion around stations 52 and 53 (Figure 35), the large quantities of colliery waste at other stations (eg at stations 51 and 58) may be the dominant factor. Finally, the sedimentological analysis cannot determine the age or origin of the waste deposit. Where recovery takes place after dumping or where fly ash transported to the area by dispersive processes has a different effect relative to that from direct dumping, waste deposits with similar physical characteristics may contain different faunas. Having regard for these uncertainties, any detailed interpretation of the factors determining the distribution of the benthos has to be to some extent speculative. Nevertheless, some general comments on these factors can be made with some confidence.

The typical community for the whole of this area of muddy sands appears to be that of Group I. The other groups contain fewer species or numbers than the typical association, reflecting the varying conditions throughout the study area. Some indication of the species more tolerant of the changes in sediment that result from dumping can be gained from Table 8 where the frequencies of occurrence of the more common species throughout the survey area are given. The distribution of some species (eg *Lumbriconereis gracilis*) covers the whole area, including the area most affected by dumping (Figure 40). In other cases (eg *Amaea trilobata*) the species is absent from the main tipping area. Others show an intermediate distribution. The statistically significant correlation of the fly ash content of the sediment with the number of species present rather than with the faunal density would support the hypothesis that there are certain species which are better able to accommodate sediment changes due to dumping. In the zones away from regular tipping, where the age of the waste deposit may be greater or where accumulation has been due to transport from the main tipping area, the faunal density is greater due to the increasing abundance of these 'resistant' species, rather than through a re-colonisation by the other species present in the surrounding community.

The area of the severest impoverishment (Group VI; stations 52, 53 in Figure 39) was situated in the centre of the area subjected to daily additions of fly ash. It is clear that frequent deposition of fly ash leads to near total depletion of the benthos. Away from the centre of dumping, however, the degree of depletion became less, even though the sediment still contained a large proportion of fly ash. Thus, at stations having a community group IV to the south and west of station 52, where the fly ash content was still high, the faunal density and species richness were greater than at stations 52 and 53, although still low relative to groups I-III. It is possible that this increased faunal density relative to stations 52 and 53 may have resulted either from less frequent direct deposition of fly ash or from the fly ash having been derived from the adjoining area through secondary processes (movement in suspension or as bedload).

Table 8 Frequency of occurrence of species present in at least 9 of the 24 stations sampled. Species shown in brackets occurred with relatively greater frequency in the impoverished groups than did other species.

Common species are indicated by:-

X $> 50/m^2$ in at least 2 samples
XX $> 250/m^2$ in at least 2 samples
XXX $> 500/m^2$ in at least 2 samples

No. of occurrences/24	*Species*	*"Commonness"*
22	*Lumbriconereis gracilis*	XX
21	*Pholoe minuta*	X
	Mysella bidentata	XXX
	Amphiura filiformis	XXX
19	*Goniada maculata*	X
	Nucula tenuis	X
	Nucula turgida	X
18	(*Scoloplos armiger*)	X
	Venus striatula	X
17	*Ampharete grubei*	X
	Prionospio malmgreni	XX
16	*Chaetozone setosa*	X
	Nephthys hombergi	X
15	*Cerebratulus fuscus*	
	Nemertine	
	Glycera convoluta	
	Pectinaria auricoma	
	Trichobranchus glacialis	X
	Thyasira flexuosa	XX
14	*Abra nitida*	X
	Cylichna cylindracea	
	Cyprina islandica	X
13	*Owenia fusiformis*	X
	Spiophanes bombyx	
	Ampelisca spp.	
	Eudorella truncatula	
	Echinocardium cordatum	
	(*Ophiura albida*)	X
12	*Diplocirrus* sp.	X
	Paraonis gracilis	XX
	Pectinaria koreni	X
11	(*Amaea trilobata*)	
10	(*Myriochele heeri*)	
	Dosinia lupinus	X
9	*Magelona filiformis*	XX
	(*Scalibregma inflatum*)	
	Terebellides stroemi	

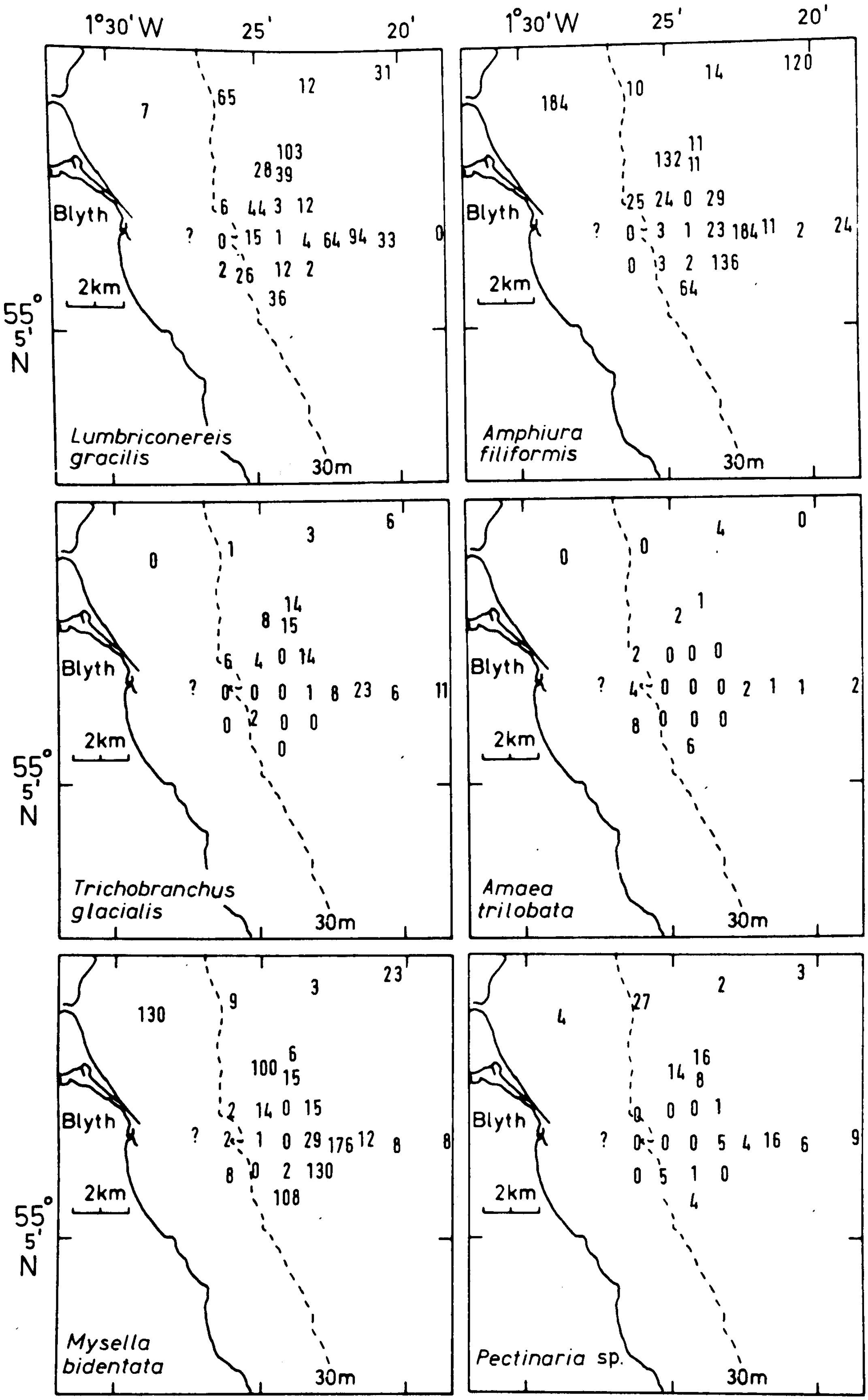


Figure 40 Distributions of selected species (numbers/0.2 m^2). 1976 Blyth survey.

The fact that both deposit and suspension feeders were among the species excluded from this area suggests that the high rate of deposition may have more effect than material in suspension. Similarly, the group III fauna found to the east and west of the main area of deposition (Figure 39) lacked several suspension and bottom feeders common in the background fauna. However, the number of species in this area was larger than in group IV, perhaps indicating a lower rate of fly ash deposition either directly from dumping or by dispersion from the area of dumping.

Further away from the heaviest accumulations of fly ash, at stations having a group II population (Figure 39), the abundances of *Mysella* and *Amphiura* (Figure 40) and the total density of animals (Figure 35) were much higher, although the number of species was still appreciably less than at stations even further away from the site of dumping. Fly ash is unlikely to have been an important influence at these stations, since they include two stations situated in the transect north of the dumping ground away from sites of deposition.

Although the group I fauna was the typical animal association for the area, it showed some peculiarities in its distribution, being present in sediments in which fly ash was common (up to 78% fine material) and in sediments without fly ash (only 11% fine material). Yet within this range the fauna maintained a moderately-high degree of homogeneity (>0.4 similarity). If sampling differences between grab hauls did not account for this, it is possible that the fly ash accumulations were not recent, having become stabilized and having developed a diverse association of animals over a long period of time.

Finally, the group V fauna at stations 57 and 58 to the west of the dumping area (Figure 39) consisted of few species and had a low total density despite the presence of very little fly ash and relatively small amounts of fine sediment. It is possible that these shallower stations, situated near the rocky inshore grounds, were subject to more severe hydrodynamic conditions and that the resulting sediment instability resulted in a species diversity at a lower level. However, very few species characteristic of inshore mobile sediments were present, and impoverishment is more likely to have been due to the dumping of colliery waste.

In 1961-2, shortly after the commencement of fly ash dumping from Blyth in 1959, Buchanan (1963) surveyed an area of 2000 km^2 of the sea bed from Cullernose Point in the north to Souter Point in the south. The sediment type and faunal associations found by Buchanan in the area of our current survey are shown in Figures 41 and 42 respectively. Comparison of Figures 13 and 41 shows that the sediments were much finer in 1976 than in 1961-2, thus fly ash dumping has reduced the particle size of the sediment both in and around the dumping area, and may have buried rocky outcrops, thereby making the habitat less suitable for crabs and lobsters.

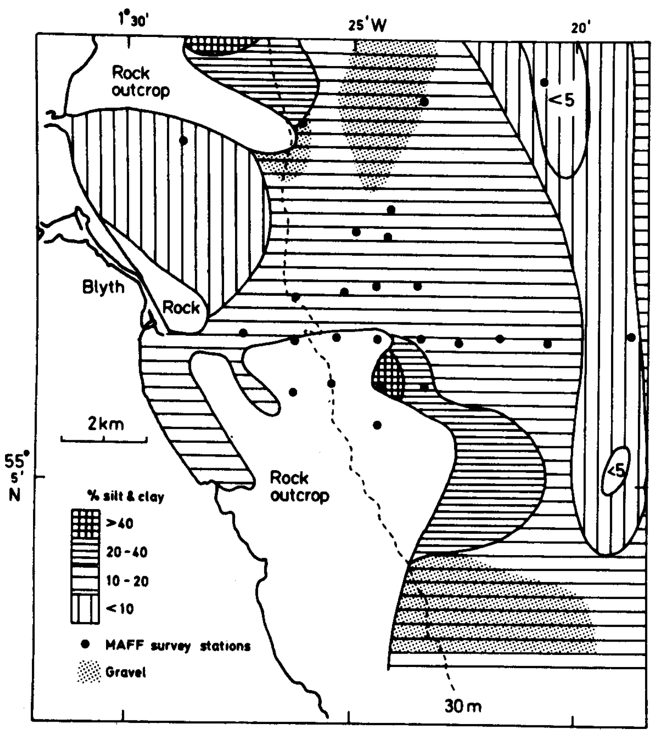


Figure 41 Percentage of silt and clay (<63 μm) in the sediments off Blyth in 1962. Redrawn from Buchanan (1963).

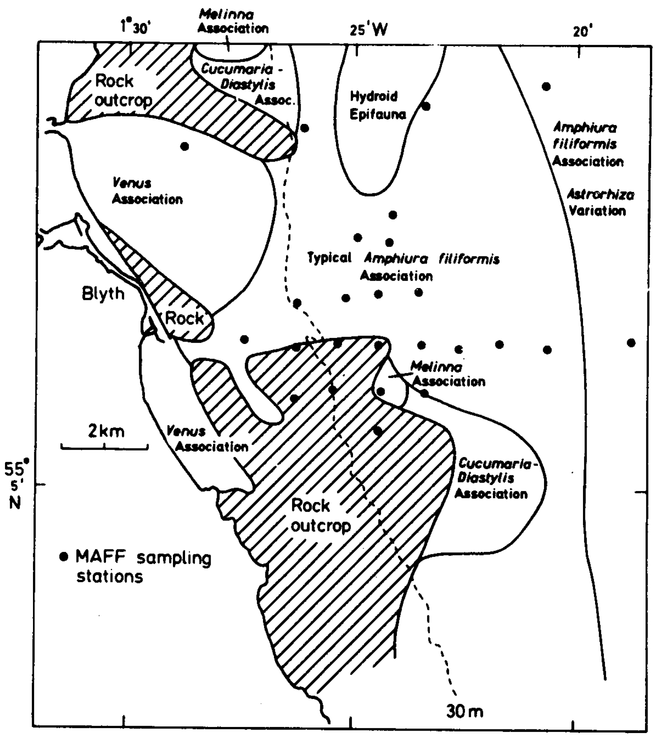


Figure 42 Benthic faunal associations in 1962. Redrawn from Buchanan (1963).

In 1961-2 Buchanan found an *Amphiura filiformis* association in most of the soft sediments in the area. *Turritella communis*, which occurred in patches within the widespread *Amphiura* community, was listed as one of the characterising species but this species was uncommon in 1976. *Paraonis gracilis*, *Lumbriconereis gracilis* and *Mysella bidentata* were very abundant in 1976 but, because he used only a 2 mm sieve size to retain the animals, the density of animals found by Buchanan was only about 10% of that found recently. Some sub-communities found in 1962 were, however, not present in 1976, *Astrorhiza* not being recorded. Six species of *Diastylis* were found in 1976 but none was common.

From the foregoing it may be concluded that, as in the case of the Wear tipping ground, severe depletion of the benthos has occurred in the zone off Blyth most extensively used for the dumping of fly ash and colliery waste. In view of the much larger quantity of fly ash dumped off Blyth relative to colliery waste, fly ash would appear to be the dominant factor in determining the extent of depletion. There is some evidence that in the areas surrounding the active tipping zone partial re-colonisation of soft fly ash deposits may take place by some species, but it is not possible to estimate the time scale of the process.

5 Effects of dumping on commercial fisheries

The waters off the north-east coast of England provide some of the most productive commercial inshore fisheries off the United Kingdom. The inshore zone is trawled or potted by vessels from Hartlepool, Seaham, Sunderland, Newcastle, Blyth and from ports further north. The total value of landings at these ports of fish taken within 12 miles from the coast in 1976 was approximately £3 million of which £1.1 million was from pelagic fisheries (mostly sprats and herring with some salmon), £1 million was from demersal fisheries (cod, haddock and whiting), and £0.9 million was from fisheries for shellfish (crabs, lobsters, *Nephrops*). The dumping areas themselves are thus located in areas which are potentially good trawling or potting grounds. The inshore edges of the Wear and Blyth dumping grounds are sited over the rocky areas formerly suitable for crabs and lobsters while the remaining areas would, in the absence of dumping, be part of the area trawled for whitefish. Pelagic and *Nephrops* fisheries are generally found further offshore than the dumping areas.

The disposal of solid wastes such as those described in this report can affect commercial fisheries in a number of ways. First, there is direct interference with bottom trawling arising from the presence of uneven piles of spoil on the sea bed. Second, the regular deposit of spoil is incompatible with crab and lobster potting. Third, the in-filling of the natural sea bed features (rocky shelters in particular) destroys the habitat of crabs and lobsters. Fourth, the depletion of the benthos that results in the zone of active tipping may reduce the productivity of demersal and crustacea fisheries by reducing the available food supply.

Although it is difficult to make a precise estimate of the total area involved, the main areas of waste deposit identified in this survey which interfere with the productivity of the fishery amount to the following:

Dumping ground	*Area*
Wear	12 km^2
Souter Point	10 km^2
Tyne	6 km^2
Blyth	12 km^2
Total	40 km^2

These are the areas in which bottom trawling and potting are restricted to some extent. They are also the areas which are likely to encompass the main zone of benthos depletion. The total area of sea bed spoiled by dumping thus amounts to 40 km^2 or 2% of the inshore fishing zone from Tees Bay to Blyth (2000 km^2). Within these affected areas the degree of interference ranges from near total depletion of the benthos and avoidance by commercial trawlers of the zones of active present-day tipping to relatively minor depletion of the benthos and little direct interference with fishing and potting towards the edges of the areas. The loss to fisheries due to dumping is likely therefore to be less than would be predicted from the area of the inshore zone affected. It is worthy of note, however, that the area of sea bed over which dumping has taken place (40 km^2) is more than three times the area licensed for dumping. The effect of dumping has thus been greatly increased due to inadequate observance of the conditions of the disposal licence which require dumping to take place in certain limited areas.

6 Conclusions

Surveys have allowed the distribution of dumped colliery waste and fly ash to be determined in an area extending from south of the Wear dumping ground to north of the Blyth dumping ground.

The primary areas affected by tipping are those where deposition of the waste occurs immediately after dumping. These are found, in most cases, inshore of the areas designated for dumping.

Although the waste reaches the sea bed very soon after dumping, subsequently some dispersion of a proportion of it takes place by movement in suspension and as bedload. Thus sediments surrounding the zones of active tipping also contain particles of waste origin. The most readily defined dispersion pathways for these wastes are those arising from the southward movement of sand-sized particles as bedload.

The effects of waste disposal on the benthos have been investigated in two of the four dumping areas. Fly ash and colliery waste dumping has caused severe depletion of the benthos (both in terms of species and abundance) in the areas where the waste is tipped with greatest intensity. There is evidence that some recovery has taken place on older and weathered waste deposits. Thus, the productivity of the areas currently affected could increase following a cessation in tipping.

Dumping has caused direct interference with commercial trawling and potting in the primary areas of tipping. The productivity of the fishery may have been reduced through depletion of the benthos in all areas and through the smothering of areas formerly sutiable as crab and lobster habitat in the inshore zones of the Wear and Blyth dumping areas.

The area over which dumping has taken place (40 km^2) is more than three times the area licensed for dumping. The effect of dumping on fisheries has thus been greatly increased by dumping outside the licensed areas.

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