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SEDIMENT DISTRIBUTION IN THE INTERTIDAL ZONE OF THE TAY ESTUARY

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ABSTRACT

The paper describes granulometric analyses of the sediments accumulating today in the intertidal zone of the Tay estuary. The significance of the grain size distribution is discussed and the composition of sediments are examined.

INTRODUCTION

Granulometric analysis of the sediments accumulating in the various intertidal sub-zones of the Tay estuary (Fig. 1) have been made in order to examine their areal distributions and to establish whether detectable changes had occured since similar studies were carried out in 1969–72 by Buller and McManus (1975).

A study of grain size characteristics of the bed load sediments collected during sediment transport investigations has also been made to compare the mobile material sediments with the deposited sediments (Alizai, 1980).

METHODOLOGY

The surface sediments of the intertidal zone were sampled by skiming the uppermost layer of the surface sediments especially when dealing with the fine grained cohesive sediments of the upper zone and salt marsh (Alizai and McManus, 1980). These techniques allowed collection of most recently deposited materials. On the sand flats a skim from an area $0.5m^2$ of the sediment surface was assumed to be the representative of the sampling site. About 500 sediments samples were collected from the upper and lower sand flats and another 500 from the salt marshes.

The grain size analysis was undertaken using a combination of pipette analysis and sieving at intervals of 0.25 phi (Folk, 1974). The pipette techniques were used to enable percentage of silt and clay size particles to be determined (Alizai, 1980).

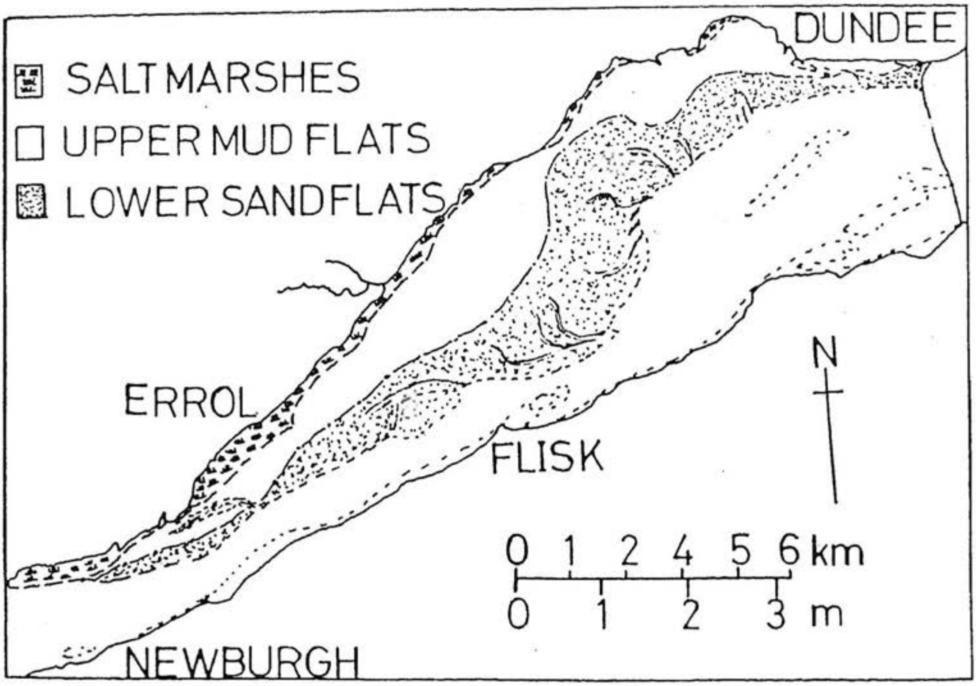

Fig. 1. The intertidal zone of upper Tay estuary.

All the samples were dominated by particles which fell within the sieve size range. Virtually all had some fines in them, so statistical characterisation using moment statistics was not possible and graphic techniques of Inman (1952), Folk and Ward (1957) and Buller and McManus (1975, 1979) have been applied. The statistical measures were calculated using the method of Inman (1957), which were well suited for describing open ended grain size distributions of sediments.

THE RESULTS

Some of the characteristic cummulative frequency distribution curves of the intertidal zone are presented in Fig. 2 and 3. They have revealed a normal unimodal curve with modification in tails due to presence of excess coarse often shelly material or fine grains.

Median distribution

Although there has been much controversy over the relative attributes of the median and mean (Koldjik, 1968), the median was chosen because it can be directly taken from commulative frequency curve without extrapolation.

The intertidal zone of the Tay estuary is characterised by fine sand to silt sized sediments ranging from an average of 2.2 Ø on the lower part of the sand flats to 5.6 Ø on the salt marshes. Medium sand of 1.45 median diameter occurs in the seaward limit of the tidal flats.

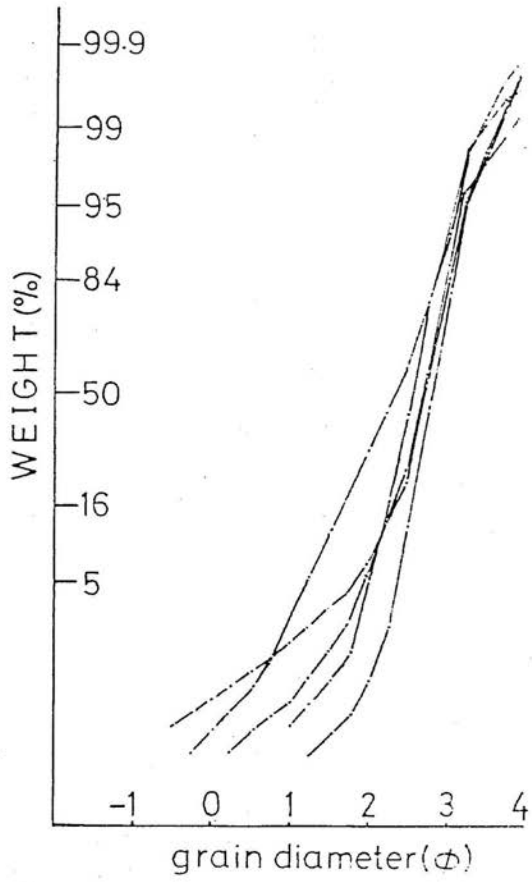

Fig. 2. The cumulative frequency curves of sediment samples from the intertidal zone.

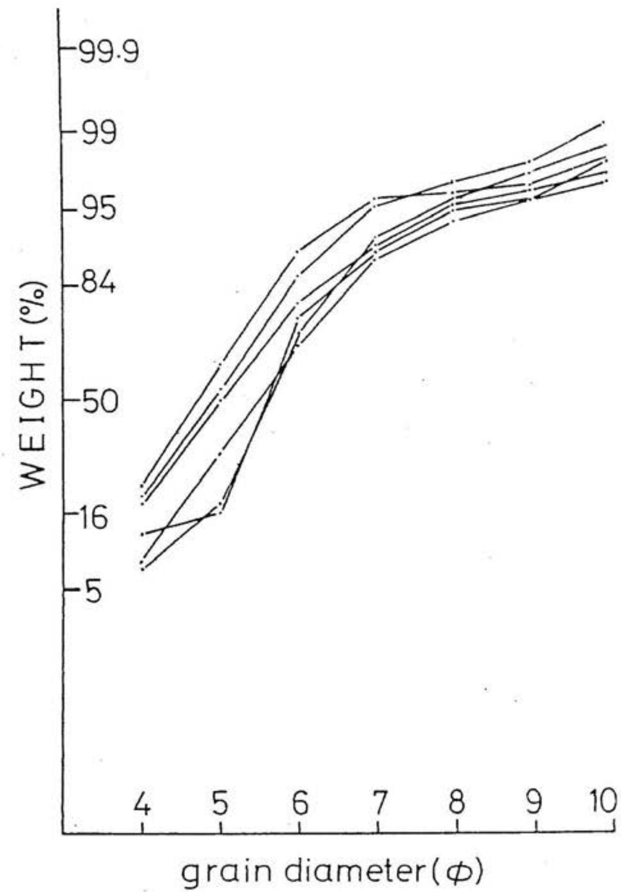

Fig. 3. The cumulative frequency curves of sediment samples from the salt marshes.

The salt marshes are characterised by very fine sands to silts ranging from 4.0 Ø to 6.0 Ø. The reed beds (Phragmites) are characterised by fine to coarse silts ranging between 4.0 and 5.0 in the outer sections but the marsh sediments become finer landward to range between 5.0 Ø and 6.0 Ø. However, the sediments of the Juncus marsh zone at Kingoodie are of fine silt ranging between 5.0 Ø and 6.0 Ø and still finer sediments occur on landward zone of the marsh (Fig. 4).

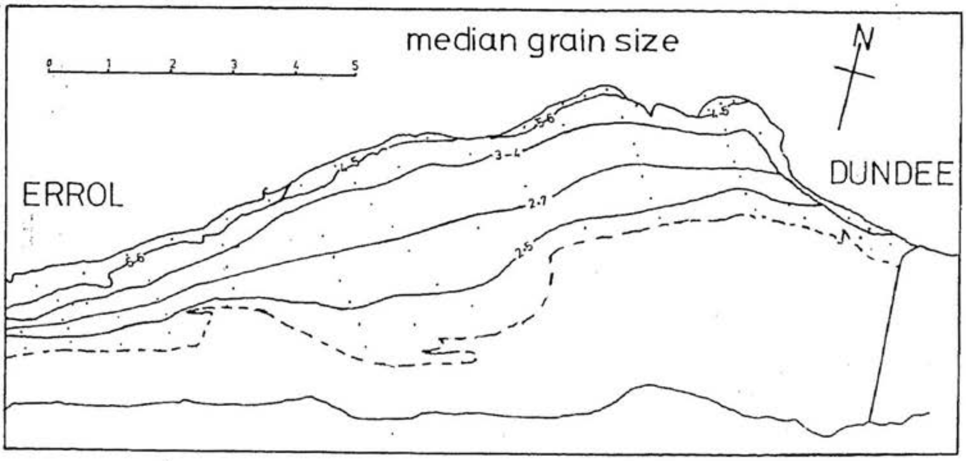

Fig. 4. The areal distribution of median grain size.

The upper tidal flats are characterised by coarsening away from the salt marshes (4.2 Ø to 3.1 Ø) but they are dominated by very fine sands. The change in grain size from coarse silts to very fine sand coincides with the edge of the marshes (Alizai and McManus, 1980).

A change in grain size from very fine sand to fine sand coincides with junction of the cohesive sediment dominating upper flats and the non-cohesive sand flats sediments further towards channel. The fine sands of the lower sand flats coarsen channelwards from 2.9 Ø in the upper part to 2.2 Ø near low water mark. The general rate of coarsening channelwards was 0.2 Ø per 500m.

Sorting distribution

The salt marsh sediments were moderately sorted in landward areas to poorly sorted (0.80–1.50 Ø, standard deviation) at their junction with the upper tidal flats (Fig. 5). At the border of the salt marsh with the upper flats, there is sharp improvement of sediment to sorting (0.75 Ø). This may be due to the tendency of sediment to be better sorted within the fine sand grade (Folk and Ward, 1957; Inman, 1949).

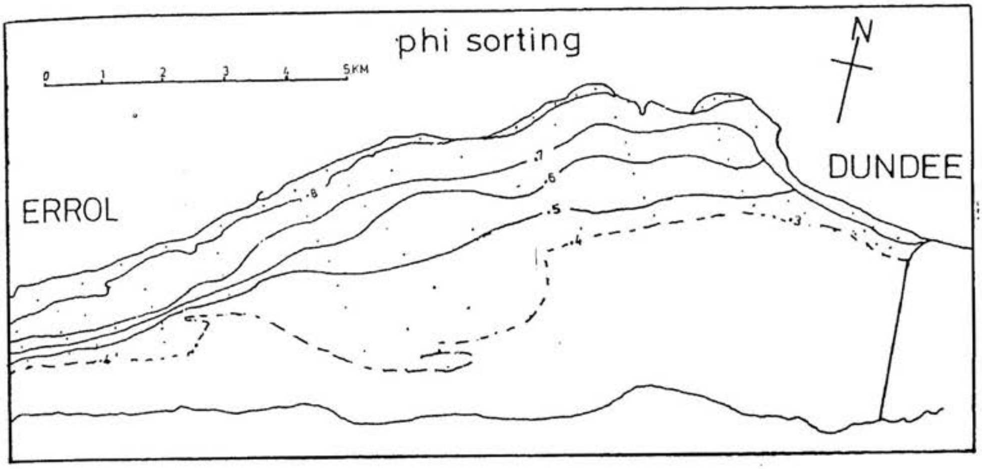

Fig. 5. The areal distribution of sorting.

The sediments of the upper flats were moderately sorted (0.7 Ø) and sorting rapidly improved on to the lower sandflats. The upper part of the lower sand flats is moderately sorted, while the lower part is composed of fine sand which had the best sorted sediments (0.3–0.4 Ø, well sorted). This pattern confirms that of Buller and McManus (1975).

Skewness distribution

The phi-skewness measure dimensionless and independent of phi sorting. Positive values indicate distributions skewed towards finer grades and conversely negative values indicate skewness towards the coarse grades.

The sediments of the salt marshes are strongly fine skewed (0.7 to 1.5). Seawards the skewness values gradually decrease to +0.4 on the upper flats, falling to +0.3 and +0.2 in the fine sediments of the lower flats. The outerpart of the lower tidal flats near the main channel consist of sediments, which are generally negatively skewed (–0.2) but the skewness values fluctuate considerably (Fig. 6). The distribution of the skewness is very similar to that of Buller and McManus (1975), who also reported the fluctuations of skewness near the main channel.

Bedload sediment distribution

The median, sorting and skewness of the populations of bed load sediments contained in the coffee jar traps during one tide were very similar to those of deposited sediments in the sampling sites. No major differences between mobile and deposited sediment were detected.

The statistical parameters calculated for the populations of 50 bed load sediment samples retained by VUV sampler (Fig. 7 and 8) during spring and

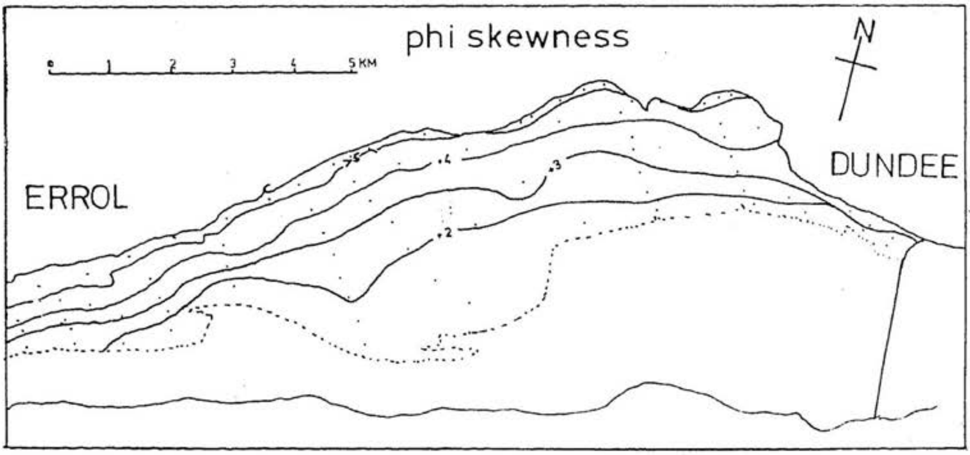

Fig. 6. The areal distribution of skewness.

neap tide revealed an interesting pattern of sediments size variation during sediment motion. Median grain size of the samples collected during the ebb phases of the spring tide over the outer flats varied between 1.45 Ø and 2.3 Ø, the coarser material was detected only in the last two hours before the emergence of the tidal flats. The median size of sediment in motion during the flood tide was finer than during the ebb and ranged between 2.5 Ø and 2.7 Ø on the same tide. The sediment was well sorted during ebb (0.42–0.5 Ø, standard deviation) and moderately to well sorted (0.67–0.5 Ø) during the flood phase of the spring tide, and was positively skewed (+ 0.10 to + 0.20) during the flood phase of the tide. During the neap tide sediment in motion over the lower flats was coarser (median between 2.6 Ø and 2.7 Ø) during the ebb than during the flood phases (2.7 –2.8 Ø) but no grains coarser than 2.6 were detected. The sediments were well sorted during both ebb (0.3–0.35 Ø) and flood (0.35–4.0 Ø) phases of the neap tide and were positively skewed (+0.14 to +0.33) during ebb and (+0.14 to +0.25) during flood phase of the same tide.

Over the inner flats on spring tide the median grain size of the sediments in motion ranged between 2.1 Ø and 2.5 Ø during the ebb, and were coarser than during the flood phases (2.7–2.8 Ø). The sediments were well sorted during the ebb (0.4–0.5 Ø) and moderately to well sorted (0.42–0.6 Ø) during flood, were positively skewed during both ebb (+0.16 to +0.35) and flood (+ 0.2 to + 0.4). During the neap very similar median values (2.6 –2.7 Ø) were detected during both ebb and flood tide. Although, the sediments were well sorted during ebb (0.45 –0.50 Ø) and moderately to well sorted (0.5 –0.65 Ø) during flood, there was no systematic difference in skewness (+0.11–+0.35).

The percentage of organic matter in the sediments retained in both the VUV samplers and coffee jar traps ranged between 2.67 on the outer flats and 6.76 on the inner flats.

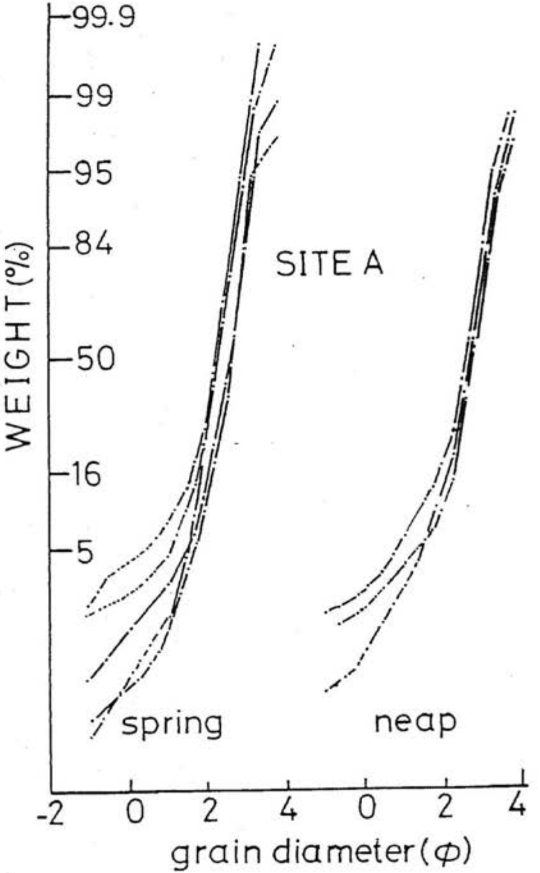

Fig. 7. The cumulative frequency curves of sediment samples collected from the bed load during sediment transport on the inner flats.

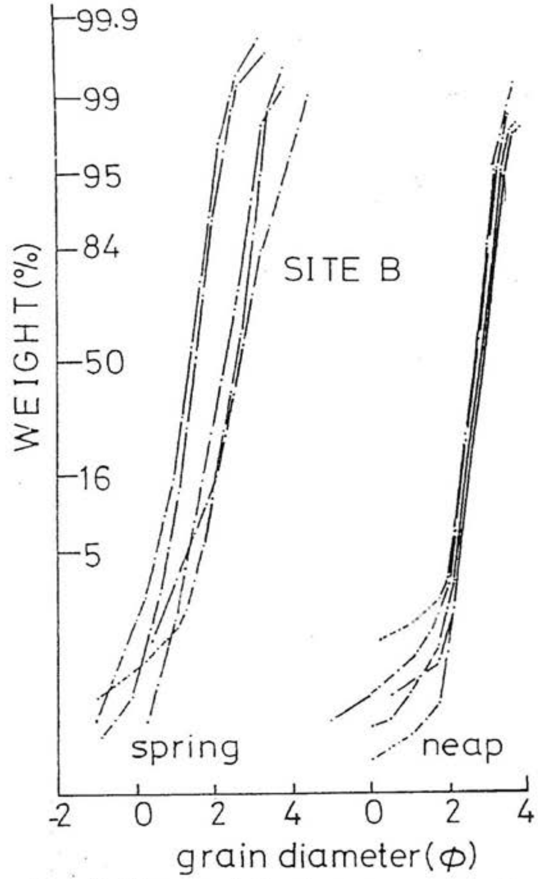

Fig. 8. The cumulaitve frequency curves of sediment samples collected from the bed load during sediment transport on the outer flats.

Silt and clay distribution

The silt and clay contents determined by pipetting are given in Figs. 9 and 10. The sediments of salt marshes contained more than 20% of silt and over 10% of clay (Alizai and McManus, 1986). Locally over 7% of silt has been recorded. The sediments of the upper flats showed 20% silt and up to 7% clay, but the content of both silt and clay fall towards lower sand flats, where no more than 2% silt and 1% of clay were recorded in the lowermost channel margin zone.

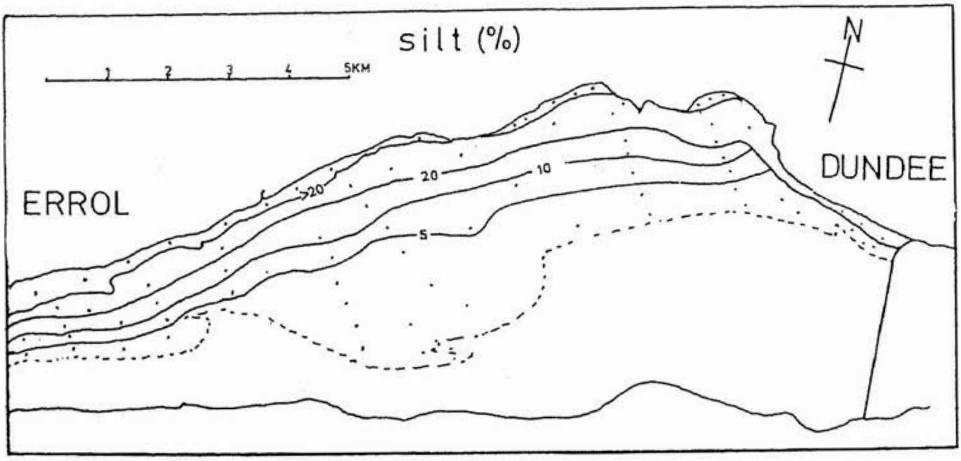

Fig. 9. The areal distribution of the silt content of the sediments of the intertidal zone.

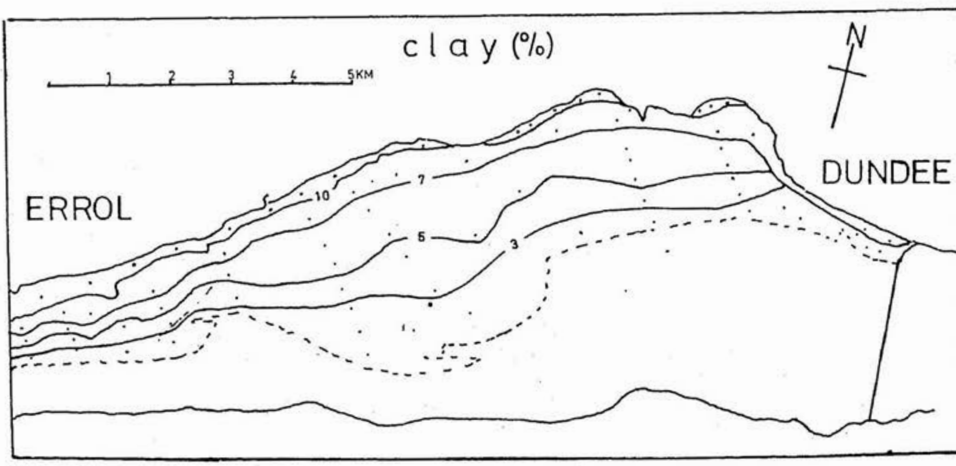

Fig. 10. The areal distribution of the clay content of the sediments of the intertidal zone.

The high proportion of fine particles in the uppermost sections suggests that deposition in those areas is largely from suspension. The importance of setting from suspension decreases towards the channel (Alizai and McManus, 1980).

Composition of sediments

As a compliment to the granulometric analysis of the sediments of the intertidal zone, three aspects of the sediment composition have been considered: (i) the light mineral composition of the five sand (2–3 Ø) fractions, (ii) calcium carbonate content, and (iii) organic matter content.

Light minerals

The light minerals of the five sand fractions (2–3 Ø) were principally of quartz, orthoclase and plagioclase with some additional lithic fragments. A total of 100 samples were analysed with representative from each sector of the intertidal zone. Grain counts were made using a 2 mm square grid placed over the mount (Carver, 1971). Consistent percentage for each mineral were obtained by counting a few as 300 grains (Table 1). Counting of all grains in alternate squares resulted in a variety in the total number of grains counted per sample but none was fewer than 300 and it was considered that the results for all the samples analysed were comparable.

TABLE 1. COMPOSITION OF THE FINE SAND-SIZE FRACTIONS FROM THE INTERTIDAL ZONE.

Sample	Grains Counted	Qtz %	ORTH %	PLAG %	LITH. F. %
1	339	70.21	11.71	4.97	3.11
2	399	75.10	14.00	6.12	4.88
3	310	71.95	10.37	3.96	13.72
4	410	69.23	18.10	8.90	3.73
5	500	78.97	9.32	5.58	6.12
6	470	77.19	7.20	8.59	7.01
7	450	68.85	9.48	10.11	11.55
8	310	80.39	11.19	4.22	4.10
9	418	73.49	10.69	7.88	7.62
10	390	67.57	13.23	12.19	7.00
Average		73.29	11.52	7.25	6.88

Quartz is the major detrital component (67.57%–80.39%), with orthoclase and plagioclase feldspars present in sub-equal amounts (Table 1). Within the feldspar group, the orthoclase is generally more abundant than is plagioclase. Lithic fragments varied from 3.11% to 13.72% of the sand. The quartz grains were sub-rounded to well rounded with sphericity varying from compact to elongate (Folk, 1974).

Carbonate content

When substantial quantities of carbonate fragments are present in a sediment, the problem arises of whether or not this material should be included in the size analysis. The hydrodynamics (settling behaviour) of carbonate (shells) fragments is very different from that of quartz particles (Maiklem, 1968; Braithwaite, 1973), and it cannot be inferred that all particles present in a sediment were necessarily transported and deposited along with the lithic components.

Braithwaite's (1973) experimental results on the settling behaviour of skeletal partciles suggested that bivalve shell fragments, which are important in the carbonate fractions here (Al–Dabbas, 1980), and quartz grains with diameter of less than 0.6 mm (0.73 Ø) were relatively uniform in their fall velocities. If it is assumed on this basis that small quartz particles and shell fragments respond in a like manner to a set of hydrodynamic conditions, it may then be possible to include carbonate particles of sieve diameter less than 300 microns in the grain size frequency distribution, which are used as a basis for the hydrodynamic interpretation of a sediment.

Bivalve fragments and quartz particles of intermediate diameter greater than 0.6 mm diverge in their fall valocities because of influence of the shell factor. Relative to quartz the bivalve fragments settle much more slowly and hydrodynamic equivalency may not be assumed. The carbonate fragments could have a fall velocity equal to a quartz particle of smaller intermediate diameter.

There is no generally agreed procedure for dealing with the carbonate fractions in the analysis of clastic sediments. Some workers retain all carbonate, while others remove it. In this study the carbonate finer than coarse lithic material was retained, while larger particles were excluded from the size analysis, as advocated by Frank and Friedamn (1973).

The calcium carbonate content was determined from sub-samples of each size fraction and involved acid digestion of a known weight of sample, and the measurement of weight loss. An areal distribution of the carbonates present in the area (Fig. 11) has revealed that the sediments of the salt marshes have very little carbonate (1%) compared with the sediments of lower tidal flats. Many of the landward salt marsh sediments showed no carbonate at all. This contrasts with the results reported by Evans (1960, 1965) for Wash salt marshes, which had a greater carbonate content than the tidal flat sediments. This many have been a results of the immaturity of the marshes in the Wash, or could be a consequence of reclamation.

The carbonate content of sediment rises to 4% on the upper flats and 10% on the lower flats near areas of shell beds (Alizai, 1980). As the principal source of carbonate within the area is molluscan shell debris, variation of densities of shell communities may be partly responsible for variation in the amount of carbonate present in the sediments. The relationship between the calcium carbonate content of the sediments and living molluscs is difficult to establish because of burrowing nature of many of life forms, however, substantial shell beds largely of Mya, were observed in the area (Alizai, 1980). Detailed identification of shell fragments was attempted by Al-Dabbas (1980) but the quantity of material suitable for analysis was found to be too small for reliable results to be obtained (Al-Dabbas and McManus, 1986).

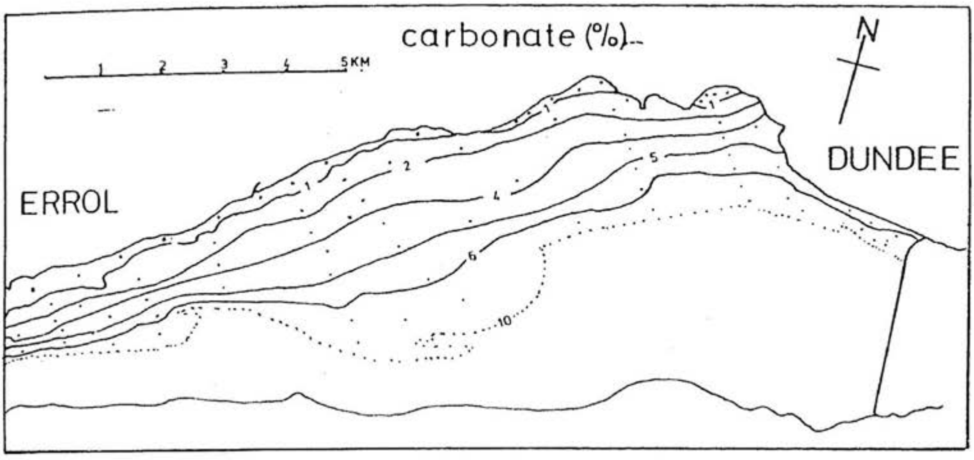

Fig. 11. The areal distribution of calcium carbonate content of the intertidal zone.

Organic matter

The percentage of organic matter in each sample was determined during the pre-treatment for size analysis. The technique used is weight loss on low temperature oxidization by 20% hydrogen peroxide (Jackson *et al.*, 1949). This did not effect the mineral assemblages present in the samples.

The distribution plot of organic content (Fig. 12) shows that the lower tidal flats are virtually devoided of oxidisable material (>1%). In the upper sand

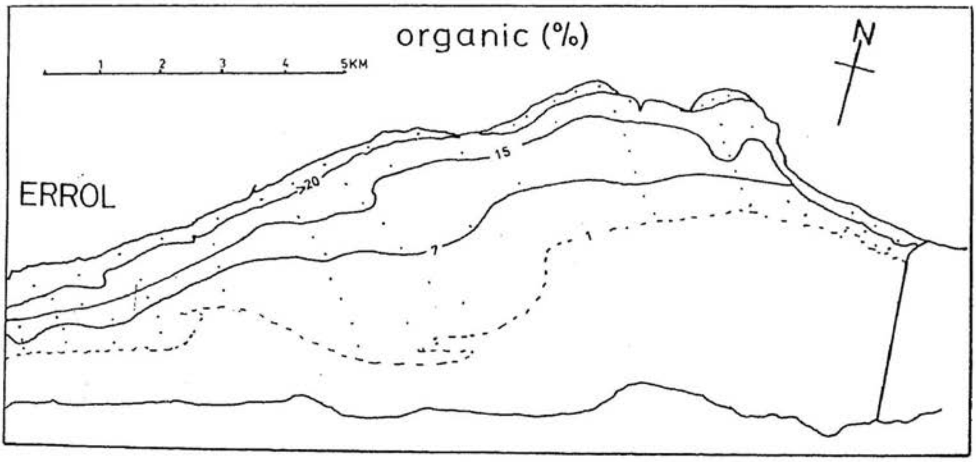

Fig. 12. The areal ditsribution of the organic content within the sediments of the intertidal zone.

flats the organic content increases up to a maximum of 7% by weight, but in the fine grained sediments of the upper flats it rises to 15% by weight, and more than 20% by weight of organic matter has been recorded in the sediments of salt marshes.

High organic content is related to sediments with less than 50% sand content such as silty sands and muds. It is difficult to determine the main source of organic matters of the sediments of the intertidal zone, but the indigenous marsh plants and local concentrations of algae are probably the most important sources.

CONCLUSION

The sediment measures reflect the prevailing hydrodynamic conditions at the time of deposition in intertidal zone. The median grain size decreases towards the stable edges of the marshes, where the currents are less strong than near the main channel. Local sites with coarser sediments are related to the proximity of small tidal channels and creeks crossing the tidal flats.

The best sorting or lowest standard deviation is thought to reflect the competency of the current and the sorting bands lie approximately parallel to the main channel. The sediments in the lower corner near the channel are best sorted and the sorting decreases away from the main channel towards areas with the most stable sediment masses. This decrease in sorting in the area of plant concentrations is mainly due to the salt marsh trapping, a wide range of sediment, which would normally stay in suspension. The sediments of the outer margin of the tidal flats near the Railway Bridge were moderately sorted and were less well sorted than sediments of the lower intertidal zone. This may result from the high flux of sediment through areas near the channel being greater than the capacity of the dispersing mechanisms of waves and current action which leads to burial of material out of equilibrium with hydrodynamic conditions.

Sediment with nearly symmetrical to negatively skewed distributions are concentrated near the main channel, while positively skewed sediments occur mainly in the upper sheltered area flooded for a small part of the tides and are little affected by currents, while those near the channels are almost continuously swept by strong currents and wave actions. This tends to support Ellis (1962) hypothesis that the sign of skewness differentiates between relatively erosional (negative) and depositional (positive) environments.

It is possible to delineate the three sub-zones based on the graphic measures and the tidal current patterns of the interidal zone;

Lower sand flats

Nearly continuous current action, wave action important, medium to fine sand, very well sorted to well sorted, near symmetrical to negatively skewed. Silt and clay less than 2%.

Upper Sand flats

Submerged for half the tide and subjected to current and wave activity. Fine sand, well to moderately sorted, positively skewed. Silt and clay less than 10% of sediments.

Upper mud flats

Submerged for one third of the tidal cycle. Very fine sand, moderately sorted, positively to very positively skewed. Silts up to 20% and clays up to 7% of the sediments, organics 15% of the sediments.

Salt marshes

Rarely flooded. Very fine sand and silt, moderately to poorly sorted. Very strongly positively skewed. Silts always over 20% and clays over 10% of the sediment. Organics always over 20% of the sediments.

The sediment in motion was coarser, well sorted and positively skewed during the ebb phases of both spring and neap tides, whereas it was finer, moderately sorted and positively skewed during the flood phases of similar tides.

The sediments of the intertidal zone are dominated by quartz with lesser quantities of orthoclase and plagioclase feldspars and still less lithic fragments. The calcium carbonate content of the sediment is purely related to the areas of shell beds. The organic matter content of the sediments is greatest near the salt marsh zone, which is the major source of organics in intertidal zone sediments.

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