



## Application of the 'Pejrup Approach' for the Classification of the Sediments in the Microtidal Dyfi Estuary, West Wales, U.K.

Zhong Shi

Institute of Earth Studies  
University College of Wales, Aberystwyth  
Dyfed SY23 3DB, U.K.

### ABSTRACT

SHI, Z., 1992. Application of the 'Pejrup Approach' for the classification of the sediments in the microtidal Dyfi Estuary, West Wales, U.K. *Journal of Coastal Research*, 8(2), 482-491. Fort Lauderdale, Florida. ISSN 0749-0208.



The classification, texture and distribution of the estuarine intertidal sediments in the microtidal Dyfi Estuary, West Wales, were studied. Evaluation of 72 surficial sediment samples shows that the estuarine intertidal sediments are mostly fine-grained silt and fine-grained sand. By testing Pejrup's triangle diagram for the classification of estuarine sediments, five sub-facies were distinguished from the estuarine intertidal sediments of the estuary. Proceeding seaward, these are saltmarsh, high mud zone, low mud zone and sand flat. Cutting them is an extensive tidal creek network. Textural patterns within the study area show an upward-fining sequence typical of intertidal environments described elsewhere. Most of the investigated sediments fall within the field of deposition controlled by unidirectional currents, which are mainly represented by tidal currents.

**ADDITIONAL INDEX WORDS:** *Estuarine sediments, grain size, classification, sub-facies, texture, hydrodynamic, Wales.*

### INTRODUCTION

Sedimentary sub-environments in estuarine intertidal sediments may be identified qualitatively in the field based on, for example, the degree or type of vegetation, topographic variations, bed-form types and such characteristics of the deposits as cohesiveness, cavernous nature or the presence of shell lag deposits (CARLING, 1979). Estuarine sediments are often classified and distinguished by means of statistical parameters which are derived from grain size analyses (e.g. EVANS, 1965; EDWARDS and FREY, 1977; YEO and RISK, 1981). That is, percentages of sand, silt and clay in the samples were plotted on a triangular diagram proposed by SHEPARD (1954) and the sed-

iments are classified. PEJRUP (1988) discussed this classification, which can be troublesome for estuarine sediments because a large amount of clay in the samples hampers computation (PEJRUP, 1986). He therefore proposed a new triangular diagram for classification of estuarine sediments.

According to his classification (PEJRUP, 1988: Figure 2, p. 291), lines of constant clay content of the mud fraction (smaller than 4 phi) are drawn to divide the triangle. The finest part (smaller than 6 phi) of the mud fraction (smaller than 4 phi) of estuarine sediments very often has a constant textural composition, because these small grain sizes occur in the water as part of sediment flocs. EDWARDS and FREY (1977) found that relative proportions of clay and silt tend to remain more or less constant. Therefore, they cannot be subject to internal hydraulic sorting. Such sediment flocs are fragile and easily broken by water turbulence. The percentage of this flocculated

91004 received 7 March; accepted in revision 27 September 1991.  
Contribution No. 184, Institute of Earth Studies, U.C.W., Aberystwyth.  
Present address: Institute of Estuarine and Coastal Studies, University  
of Hull, Hull HU6 7RX, U.K.

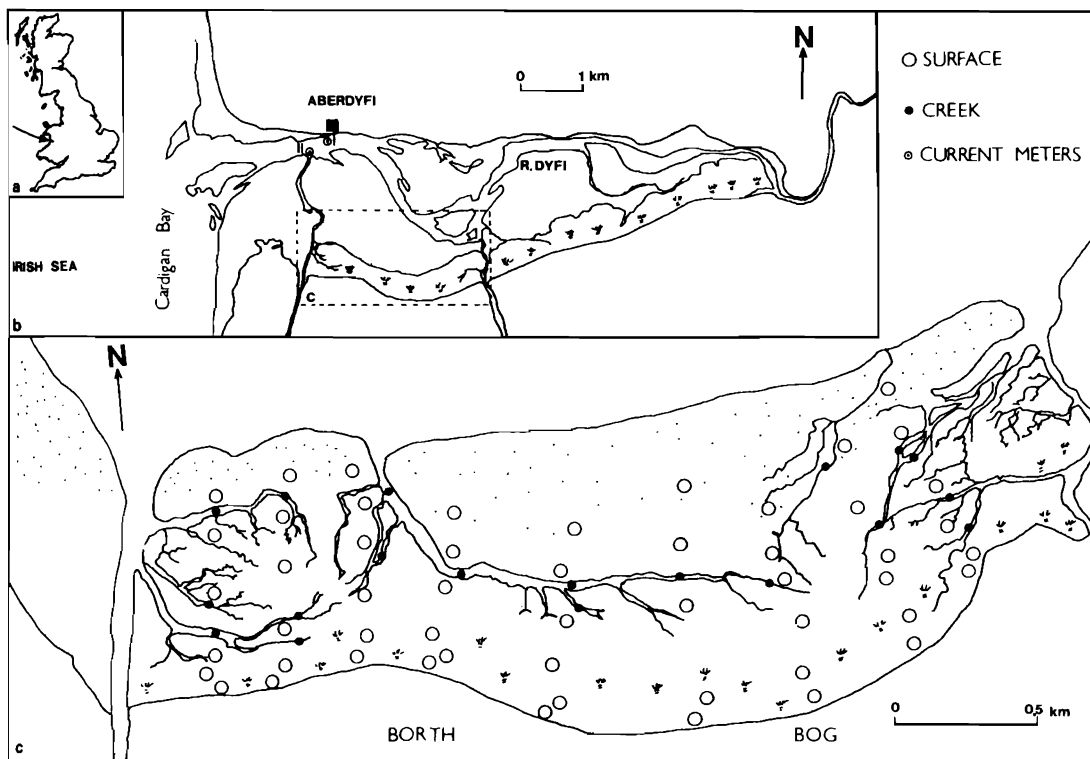


Figure 1. (a) Regional map, (b) physiography and locations of current meters, (c) locations of surface samples.

grain size population in the mud fraction of an estuarine sediment can therefore be used as a simple indicator of the hydrodynamic conditions under which deposition took place. The greater the percentage of the flocculated population, the less the flocs have been broken and the calmer the hydrodynamic conditions. Because of the constant textural composition of the finest part of the mud fraction, its percentage of the mud fraction can be described by the percentage of clay in the same sediment. Lines of constant clay content of the mud fraction separate different facies characterized by differences in hydrodynamic conditions; these "clay lines" have been used to subdivide the triangle. Because estuarine sediments with a clay content of more than 80% in the mud fraction are rarely found, the line reflecting this content level has therefore been chosen to divide the triangle. For reasons of symmetry the lines of 50% clay and the line of 20% were chosen, thus dividing the triangle into four sections labelled I to IV, which indicate increasingly high energy hydrodynamic conditions. The sedi-

ments are classified according to their sand content into four sections, A to D. The triangle is thusly divided into 16 sections, each of which can be named by a letter indicating the type of sediment and a number indicating the hydrodynamic conditions during deposition.

This approach has not been widely applied to shallow estuarine sediments and no classification of sediments has been attempted for the Dyfi Estuary. It is the aim of this paper to apply Pejrup's approach to classification of estuarine sediments in the Dyfi Estuary. Emphasis is placed on examination of the various sedimentary sub-facies in the estuarine intertidal zone and the interpretation of each facies, and the discussion of the environmental factors which control the sediment characteristics.

## STUDY AREA

### Physiography

The Dyfi Estuary is located on the west coast, Cardigan Bay, Wales, U.K. (Figure 1a and b); its

total wet surface area is ca. 17.3 km<sup>2</sup> (SHI and LAMB, 1991). The estuary is funnel-shaped, but is restricted at the mouth by a beach-spit which extends from the southern side of the estuary. Behind the beach-spit on the southern landward side is an extensive area of supratidal and intertidal flats traversed by tidal channels and a creek network (Figure 1b and c). The present study area is restricted to a limited intertidal zone at the southern margin of the Dyfi Estuary (Figure 1b and c). Gales with a velocity of 38 miles per hour and upwards, are common over the Irish Sea and are known to be the cause of heavy seas along the Welsh coast (MOORE, 1968). The present study area experiences moderately heavy rainfall (MOORE, 1968).

### Tide and Wave Characteristics

The pronounced landward shallowing of Cardigan Bay produces a strongly asymmetrical tidal wave with the mean spring rise occurring at Aberdyfi in only 5.5 hours (HAYNES and DOBSON, 1969). Within the study area, tides are mixed, predominantly semidiurnal (SHI, 1991). Predicted high tides are shown in Figure 2a.

Tidal current velocities in the study area (Figure 1b) have been summarized in Figure 3 (based on JARVIS, 1970). It was found that a kinetic dominance of the flood tide, which on spring tides is at least 0.5 m/sec (JARVIS, 1970). Tidal current velocities fluctuate through neap-spring tidal cycle. The maximum current speeds are high at spring tides with values of approximately 1.5 m/sec (Figure 3A). The turbulent nature of the flow (Figure 3A) has also been noted (JARVIS, 1970). The average current speeds decrease gradually toward the limit of tidal influence. The flood-current speeds exceed those of ebb (on average) throughout most of the estuary. In the intertidal zone, during spring tides, flood currents range between 0.15 and 0.61 m/sec, and ebb currents range between 0.36 and 0.50 m/sec (HAYNES and DOBSON, 1969).

Waves also have a strong hydrodynamic influence on the Dyfi intertidal sediments. High wave amplitudes mainly correlate with high wind speed and certain wind directions—those which originate from the SW quadrant 41%, 29% from NW, 30% from W according to MOORE (1968). The characteristics of waves in the Aberdyfi have been shown in Figure 2b.

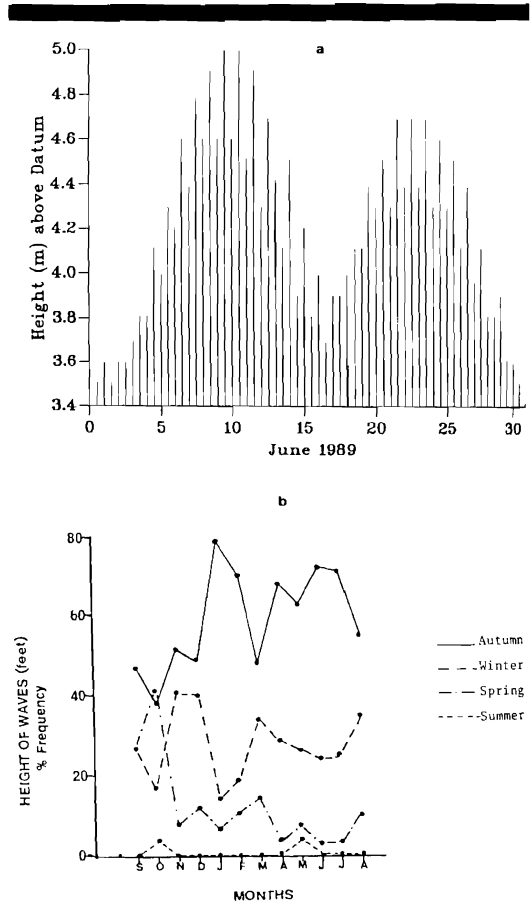


Figure 2. (a) Predicted high tide water for June 1989. (b) Wave characteristics in the Aberdyfi (based on Penner, 1984).

### METHODS

A total of 72 surface samples (Figure 1c) were collected in June 1989 from the uppermost layer (less than 2.0 cm), with care being taken to prevent mixing of material from different laminae. Grain size analysis of surficial sediments was performed by standard sieve and pipette techniques (FOLK, 1974). To prepare coarser samples for grain size analysis of only clastic components, approximately 5–20 g of sediment was first treated with standard reagents (HCl and H<sub>2</sub>O<sub>2</sub>) for the removal of carbonates and organic matter. Sand and mud fractions (*i.e.* silt and clay) were separated by sieving with a 4 phi mesh; the sand fraction was sieved at 0.5 phi intervals, using a set of British Standard sieves on a Ro-Tap shaker. The mud fraction was dispersed in a 0.1% sodium hexametaphosphate solution before analysis. Finally, sand, silt and

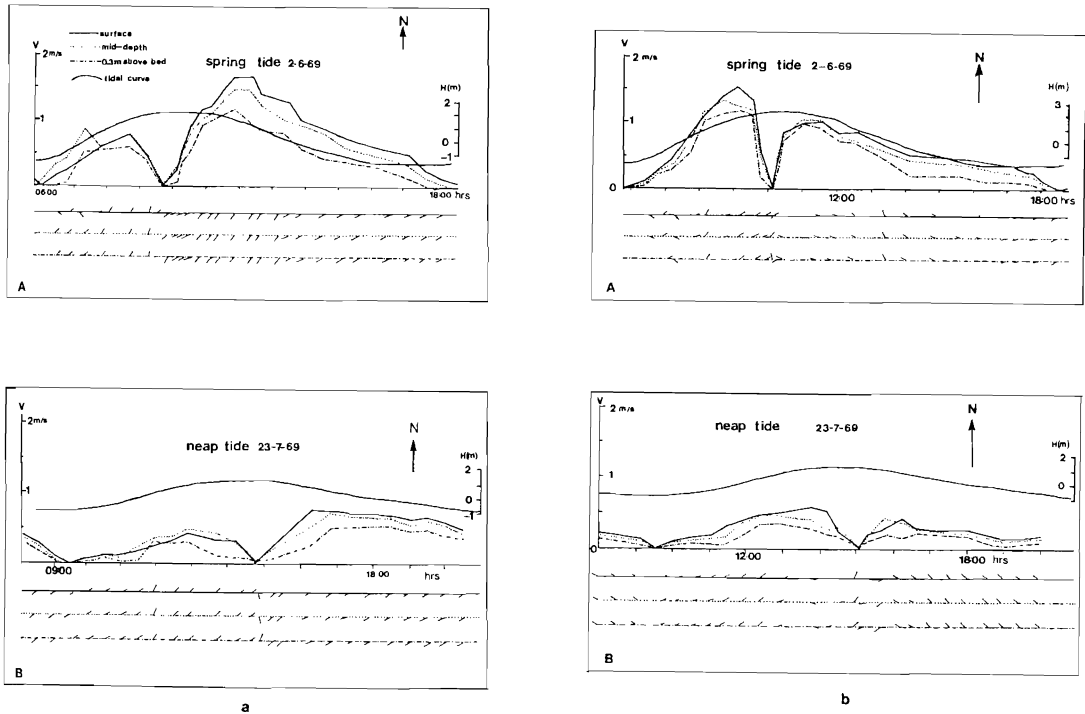


Figure 3. (a) Tidal current velocities curves for site 1. (b) Tidal current velocities curves for site 2 (based on Jarvis, 1970).

clay fraction data were then combined, and sedimentary parameters were calculated by BBC computer (SHI, 1990).

**RESULTS**

**Separation of the Sub-Facies**

Sand, silt and clay content values of each sample were plotted in Pejrup's triangle diagram. Surprisingly, they fell into 4 different sections (Figure

4). The samples from the high marsh as defined by HAYNES and DOBSON (1969) mostly fell into group (D, II). The samples from the upper part of the low marsh are associated with group (C, II). The samples from the lower part of the low marsh can be associated with group (B, II). The different sand sediments, taken from the sand flat and creek bottoms, fell into groups (A, I), (A, II), (A, III), (A, IV). Thus, the Dyfi intertidal sediments can be texturally classified into five sub-facies. Proceeding seaward, these are: saltmarsh,

Table 1. Grain size characteristics of each sub-facies in the intertidal zone.

Facies	Medium (Md)	Sorting	Skewness	Kurtosis	Sand (%)	Silt (%)	Clay (%)
Saltmarsh	5.5-7.0	1.16-2.04	(-0.22)-0.69 to	0.79-1.15	1.3-8.4	56.6-80.0	16.3-42.0
High mud zone	4.3-6.1	1.76-2.37	(-0.44)-1.10 to	0.89-1.03	10.7-40.0	44.0-72.0	7.6-32.0
Low mud zone	3.1-3.8	0.70-2.04	(-0.74)-0.96 to	0.99-2.11	56.5-88.9	11.1-40.0	0.5-16.0
Sand flat	2.5-3.1	0.34-0.42	0.34-0.54	(-0.07)-0.08 to	88.0-99.9	0.1-11.8	0.1-0.5
Creek	2.2-3.5	0.33-1.95	(-0.09)-1.14	0.86-3.09	64.0-99.0	0.1-35.0	0.1-14.0

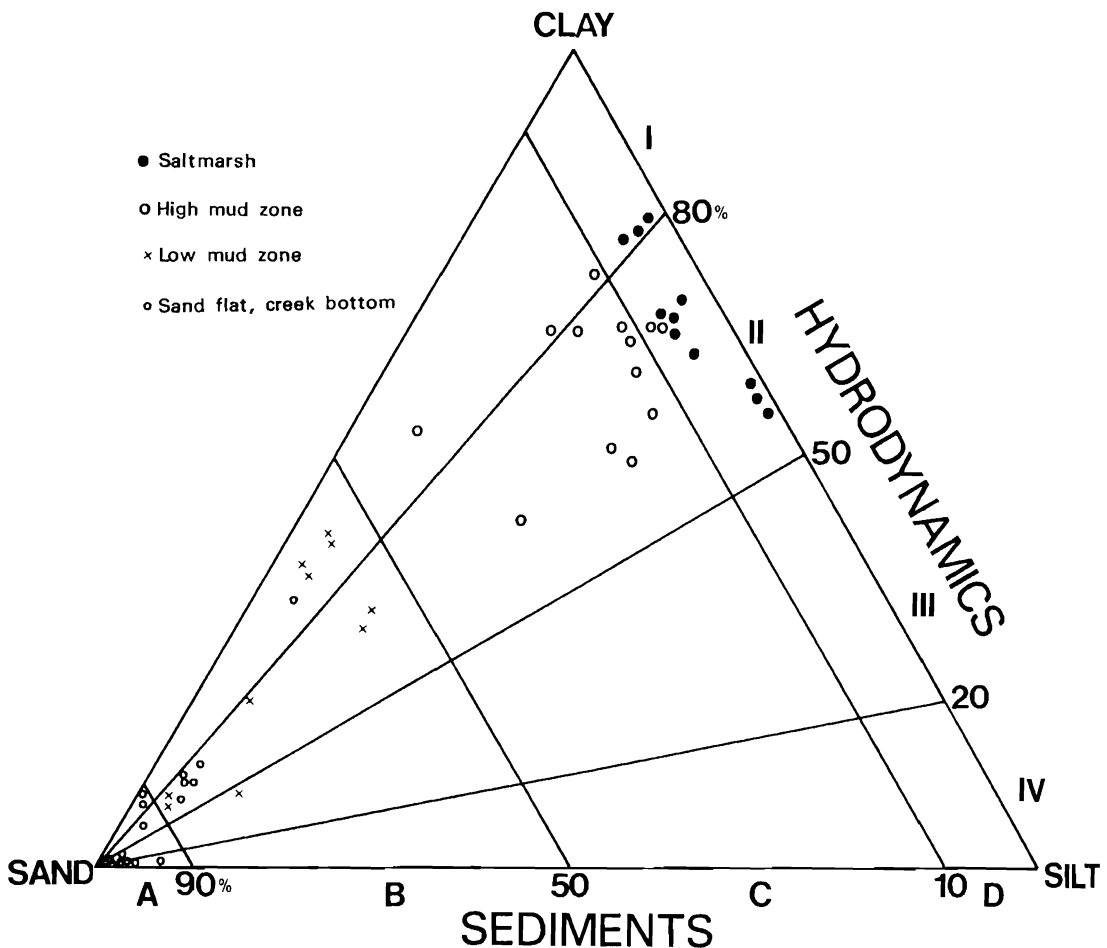


Figure 4. Triangle diagram for classification of Dyfi estuarine sediments, based on Pejrup (1988).

high mud zone, low mud zone, sand flat and creek. Apparently, the low mud zone is a transitional zone between the sand flat and the high mud zone.

#### Textural Characteristics

Most of the Dyfi intertidal sediments are fine-grained silts to fine-grained sands. The cumulative curves of grain size of the various sub-environments are shown in Figure 5. The grain size characteristics of intertidal sub-facies are summarized in Table 1.

**Sand Flat:** The sediments are fine sands containing abundant shell fragments. The grains fall in the 2.5–3.0 phi range.

**Low Mud Zone:** The sediments are fine sands

but containing 5–50% of the portion of the grain size less than 4.0 phi, which are composed of silt and clay (content scale 2:1). It is called muddy sand or sandy mud.

**High Mud Zone:** The sediment grain size is more than 4.0 phi.

**Saltmarsh:** The grain sizes fall into the 5.0–9.0 phi range. They are homogenized silt to clay.

#### DISCUSSION

The results of sedimentary parameters derived from the grain size have been applied to many environmental situations. By separating each of the modes and considering them individually, FOLK and WARD (1957) applied their statistical

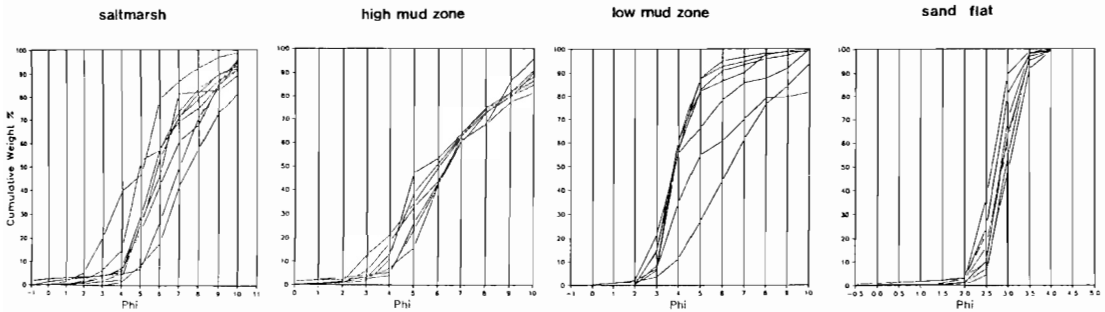


Figure 5. Cumulative curves for grain sizes of different sub-facies sediments.

procedures to polymodal distributions. Moss (1963) recognized three main populations based on the slope of the grain size cumulative curves: (a) suspension, (b) saltation, (c) drag or bedload of the coarser fraction. VISHNER (1969) related sedimentary processes to the textural properties of the sediment.

#### Hydrodynamic Interpretation of Each Facies

Because the samples from the saltmarsh have the highest content of clay in the mud fraction (Table 1), they represent the quiet hydrodynamic conditions, shown in the diagram (Figure 4) as (D, I) and (D, II). The difference between the samples from the high mud zone and the low mud zone is caused by different hydrodynamic conditions. The clay content of the samples from the low mud zone is lower than for those from the high mud zone. The difference between samples from the sandflat and creek bottom is not caused by different sand content but a difference in sorting caused by different topographic position and hydrodynamics.

In Figure 4, most of the samples plot in the hydrodynamic section I while some samples plot along the boundary of hydrodynamic section II. This indicates rather calm hydrodynamic conditions within this estuarine intertidal environment. Hydrodynamic conditions in this connection reflect the total effect of current velocity, wave turbulence and depth, and should not be associated with specific values of Reynold or Froude numbers (PEJRUP, 1988).

The rather calm hydrodynamic conditions inferred from the ternary diagram is evident by the interpretation of sedimentary processes from the scatter plot of sorting versus skewness (Figure 6a,

see next section for detail), and by the hydrodynamic data (Figures 2 and 3). The former (Figure 6a) suggests that the mechanism of deposition is influenced by the effect of unidirectional currents.

#### Textural Properties Related to Depositional Processes

Primary depositional processes that act on any sediment sample within this estuarine intertidal sedimentary environment may be inferred with a fairly high degree of probability from the size characteristics of that sample alone. Of the diagrams showing the interrelationships between median (Md), sorting and skewness, Md against standard deviation (sorting) is the most important. This relationship was used by several investigators (*e.g.* STEWARD, 1958; AL-GHADBAN, 1990) for the reconstruction of the depositional processes of ancient sediments.

In Figure 6b, it can be seen that there is probably a linear relationship between the two variables found within the various sub-environments. On the saltmarsh and high mud zone where the sediments are finest, the sorting becomes poorer. On the high mud zone, this trend is more clear than on the saltmarsh. The finer the sediments become, the poorer is the sorting. There is an increase in sorting with increase in the grain size from the saltmarsh, high mud zone to low mud zone and sand flat. A similar relationship is also reported from the Wash (AMOS, 1974). Here Amos suggested that the increase in grain size and associated improvement in sorting results from an increase in exposure to various oceanographic processes, and that the progression is comparable to the subenvironments occurring successively from high to low water mark. Another similar

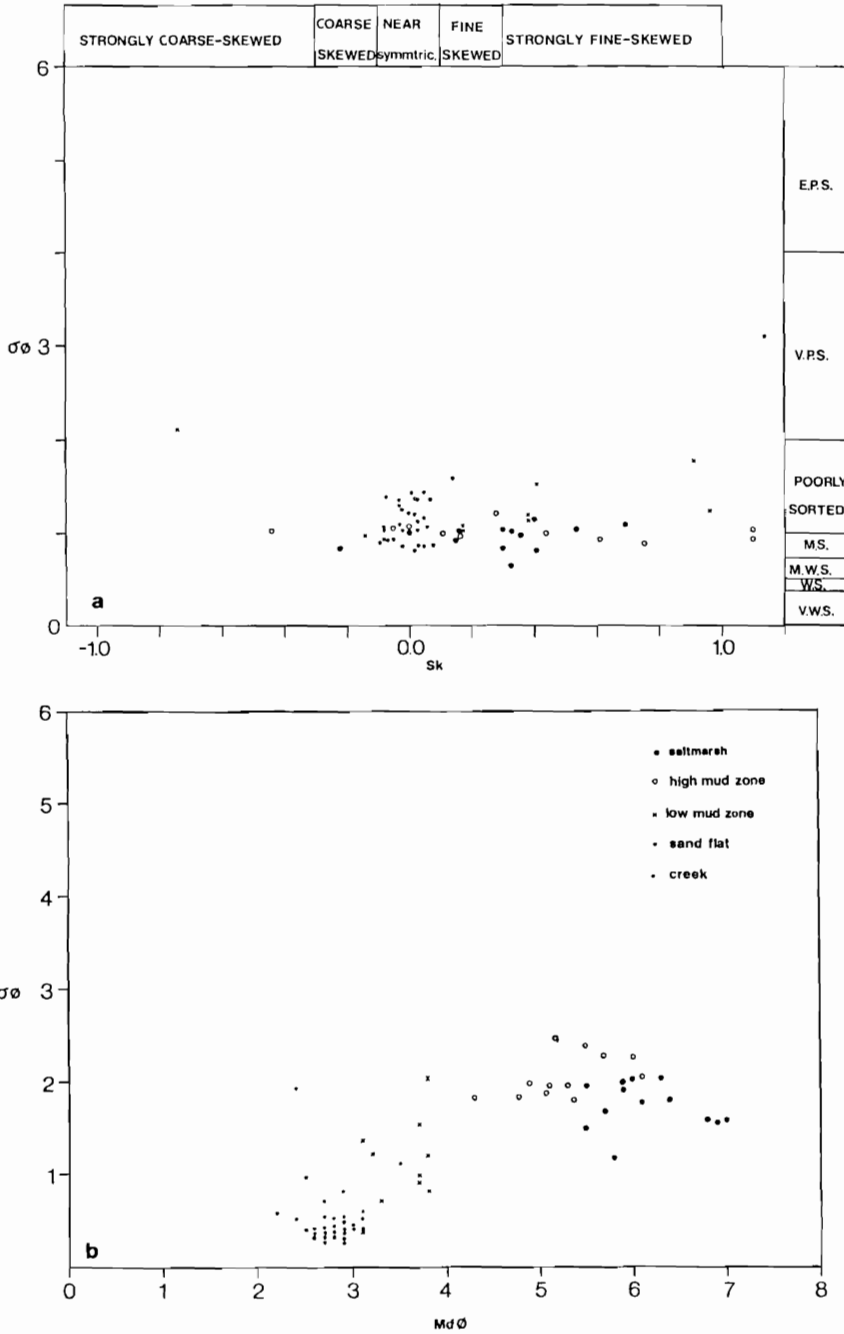


Figure 6. (a) Scatter diagram of kurtosis versus skewness. (b) Scatter diagram of kurtosis versus median diameter ( $Md$ ).

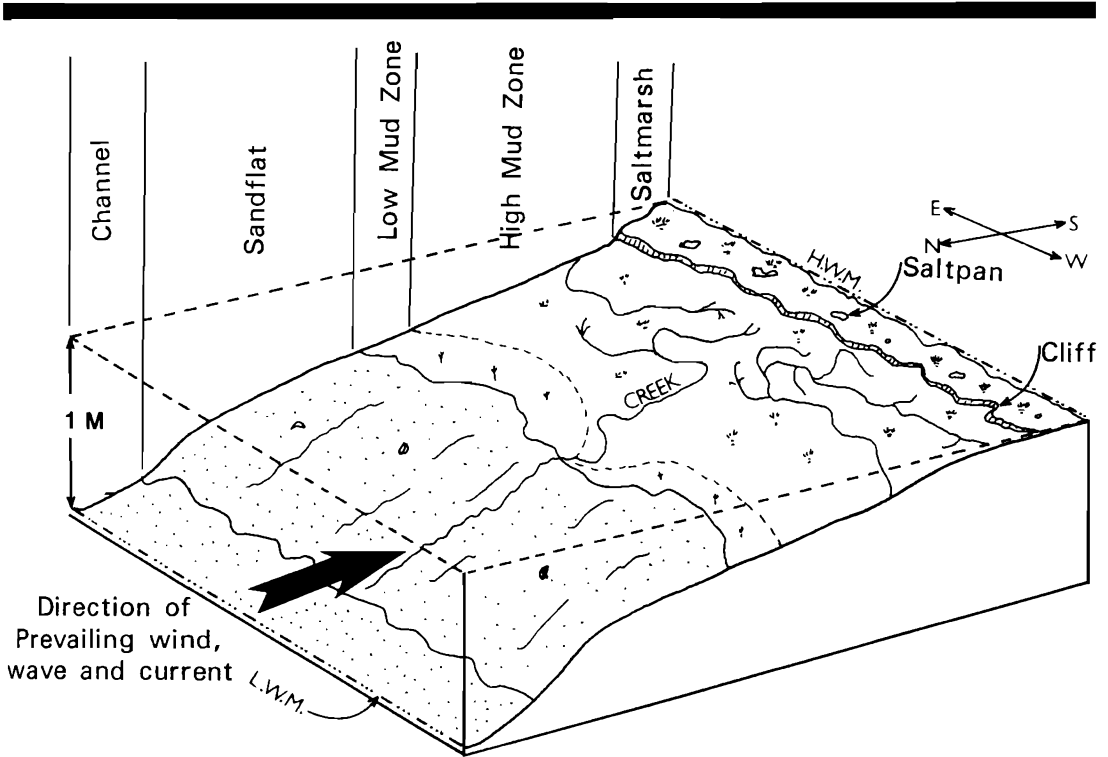


Figure 7. Block diagram showing the relative distribution of sub-facies in the study area in Dyfi intertidal zone.

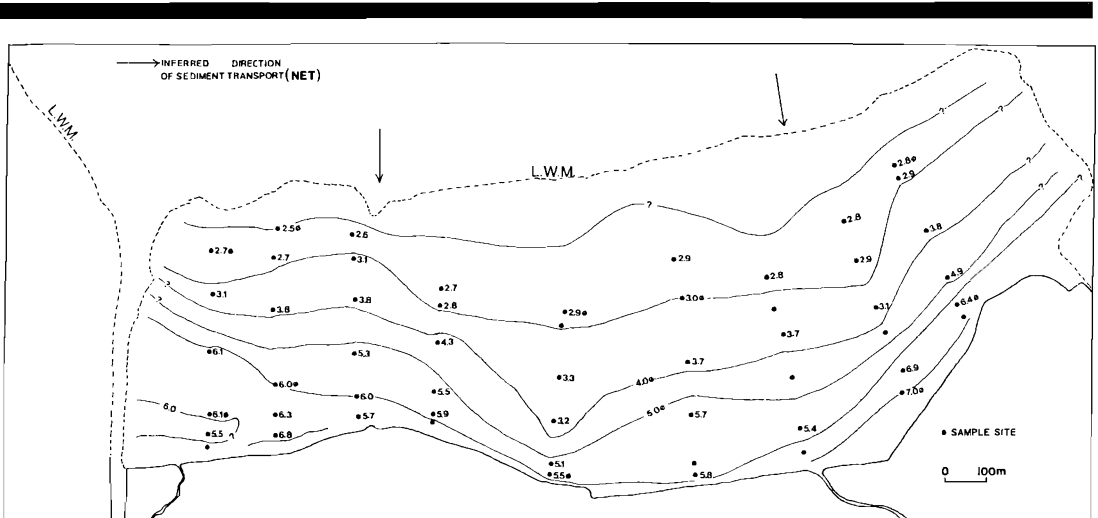


Figure 8. A regional distribution of median diameter (Md). Inferred direction of net sediment transport is indicated by arrow. L.W.M. = Low Water Mark.



result which is reported in the present study is that the creek samples show an unpredictable distribution in the ratio of sorting to median grain size.

FRIEDMAN (1961) and AL-GHADBAN (1990) showed that sorting versus skewness is also a useful parameter. This relationship for this study environment (Figure 6a) shows that most of the sediments are grouped in a well-defined field, which suggests that the mechanism of deposition is influenced by the effect of unidirectional currents.

#### Distribution of Sub-Facies

Clearly, by using Pejrup's triangle diagram, five sub-facies are distinguished in the Dyfi intertidal zone. The relative distributions of these sub-environments are shown in Figure 7. The terms 'high mud zone' and 'low mud zone' are terms based on mud composition, and on location and physiography in the field. Other terms are after EVANS (1965, p. 83), REINECK and SINGH (1986, p. 430).

The regional distribution of the median (Md) indicates that the sediment become coarser in a seaward direction and finer in a landward direction (Figure 8). This pattern is related to the modern facies distribution in this area (Figure 7). The direction of net sediment transport is also inferred (Figure 8). The textural distribution of sediments (Figure 8) showed that sediments transported and deposited within this low-energy intertidal environment are distributed in accordance with a principle of *scour and settling lag* proposed for sediments in the North Sea (POSTMA, 1967; VAN STRAATEN and KUENEN, 1958). The pattern of the textural distribution of the Dyfi intertidal sediments is very similar to that of the Wash for which COLLINS *et al.* (1985) concluded that the decrease in grain size, from low- to high-water mark, of the intertidal flat sediments records the decrease in tidal current speed in that direction.

#### CONCLUSIONS

The intertidal zone in the Dyfi estuary can be texturally divided into five depositional sub-environments (from high to low tide): Saltmarsh, High Mud Zone, Low Mud Zone, Sand Flat and Creeks.

Most sediments are fine grained silt to fine grained sands. The textural characteristics of the sediments show that most of the investigated sediments fall within the field of deposition by uni-

directional currents, which are mainly represented by tidal currents. Sediments are derived primarily from areas seaward of the estuary.

From this study, it is demonstrated that certain hydrodynamic conditions are represented on Pejrup's diagram and that the sediments can be texturally classified into several groups that are responsive to hydrodynamic conditions.

#### ACKNOWLEDGEMENTS

I would like to thank the British Council and the Chinese Embassy for financial support. Thanks are due to Dr. H.F. Lamb for his support. The quality of the manuscript has been improved by the critical readings by Dr. A. Wintle and by two anonymous reviewers.

#### LITERATURE CITED

- AL-GHADBAN, A.N., 1990. Holocene sediments in a shallow bay, southern coast of Kuwait, Arabian Gulf. *Marine Geology*, 92, 237-254.
- AMOS, C.L., 1974. Intertidal Flat Sedimentation of the Wash-E.England. Unpublished Ph.D. Thesis. University of London, 404p.
- CARLING, P.A., 1979. The Influence of Creek Systems in Intertidal Flat Sedimentation. Unpublished Ph.D. Thesis. University of Wales.
- COLLINS, M.B.; AMOS, C.L., and EVANS, G., 1985. Observation of some sediment-transport processes over intertidal flats, the Wash, U.K. In: NIO, S.-D. *et al.* (eds.), *Holocene Marine Sedimentation in the North Sea Basin*, Special Publication No. 5 (International Association of Sedimentology), pp. 65-80.
- EDWARDS, J.M. and FREY, R.W., 1977. Substrate characteristics within a Holocene saltmarsh, Sapelo Island, Georgia. *Senckenbergiana Maritimo*, 9, 215-259.
- EVANS, G., 1965. Intertidal flat sediments and their depositional environments in the Wash. *Quarterly Journal Geological Society London*, 121(482), 209-241.
- FOLK, R.L., 1974. *Petrology of Sedimentary Rock*. Hemphill Publishing Co., pp. 16-44.
- FOLK, R.L. and WARD, W.C., 1957. Brazos river bar. A study in the significance of grain size parameters. *Journal of Sedimentary Petrology*, 27, 3-26.
- FRIEDMAN, G.M., 1961. Distinction between dune, beach, and river sands from their textural characteristics. *Journal of Sedimentary Petrology*, 31(4), 514-529.
- HAYNES, J. and DOBSON, M.R., 1969. Physiography, foraminifera, and sedimentation in the Dyfi estuary (Wales). *Geological Journal* 6, 217-256.
- JARVIS, J., 1970. A Physical Investigation of Tidal Phenomena in the Dyfi Estuary: With Particular Reference to Channel Development and Sediment Movement. Unpublished Ph.D. Thesis. Aberystwyth, U.C.W.
- MOORE, J.R., 1968. Recent sedimentation in Northern Cardigan Bay, Wales. *Bulletin British Museum (Natural History)*, 2(2), 40-46.
- MOSS, A.J., 1963. The physical nature of common sandy

- and pebbly deposits. Part II. *American Journal Science*, 261, 337-373.
- PEJRUP, M., 1986. Parameters affecting fine-grained suspended sediment concentrations in a shallow microtidal estuary, Ho Bugt, Denmark. *Estuarine, Coastal and Shelf Science*, 22, 241-254.
- PEJRUP, M., 1988. The triangular diagram used for classification of estuarine sediments: A new approach. In: DE BOER, P.L. *et al.* (eds.), *Tide-Influenced Sedimentary Environments and Facies*. Dordrecht: Reidel, pp. 289-300.
- PENNER, S., 1984. The Ecology and Seasonal Distribution of Foraminifera on the Dyfi Estuary. M.Sc. Thesis. U.C.W., Aberystwyth.
- POSTMA, H., 1967. Sediment and sedimentation in the estuarine environment. In: LAUFF, G.H. (ed.), *Estuaries*. Washington, D.C.: American Association Advancement Science Publication 83, pp. 158-179.
- REINECK, H.E. and SINGH, I.B., 1986. *Depositional Sedimentary Environments*. New York: Springer-Verlag, 430p.
- SHEPARD, F.P., 1954. Nomenclature based on sand-silt clay ratios. *Journal of Sedimentary Petrology*, 24, 151-158.
- SHI, Z., 1990. Recent sedimentation in the Dyfi Estuary, west Wales. *Abstracts 13th International Sedimentological Congress (Nottingham)*, p. 238.
- SHI, Z., 1991. Tidal bedding and tidal cyclicities within the intertidal sediments of the microtidal estuary, Dyfi River estuary, West Wales, U.K. *Sedimentary Geology*, 73, in press.
- SHI, Z. and LAMB, H.F., 1991. Post-glacial sedimentary evolution of a microtidal estuary, Dyfi River estuary, West Wales, U.K. *Sedimentary Geology*, in press.
- STEWART, H.B., 1958. Sedimentary reflections of depositional environment in San Miguel Lagoon, Baja California, Mexico. *Bulletin of the American Association of Petroleum Geologists*, 42(11), 2567-2618.
- VAN STRAATEN, J.M.J.U. and KUENEN, P.H.H., 1958. Tidal action as a cause of clay accumulation. *Journal of Sedimentary Petrology*, 16, 25-47.
- VISHER, G.S., 1969. Grain size distribution and depositional processes. *Journal of Sedimentary Petrology*, 39, 1077-1106.
- YEO, R.K. and RISK, M.J., 1981. The sedimentology, stratigraphy and preservation of intertidal deposits in the Minas Basin system, Bay of Fundy. *Journal of Sedimentary Petrology*, 51, 245-260.