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Sediment fluxes in the Bristol Channel

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Difficulties encountered in the derivation of sediment fluxes for continental shelf environments are outlined. Reference is made to various attempts, using conventional oceanographic and sedimentological techniques, at defining sediment transport paths and rates in the Bristol Channel. Finally, some unique approaches to the problem are introduced: the integration of results from empirical transport equations, for wave/current interaction; the interpretation of output from 3-D numerical models; and the detailed statistical analysis of grain size data. These developments may be of broader applicability to geologists examining the movement of modern sediments.

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Introduction

Sedimentologists and physical oceanographers are becoming involved increasingly in investigations which attempt to quantify the transport of sediment within, or between, various environments of deposition. Hence, consideration has been given to: the supply of riverine sediment to adjacent continental shelves (Milkman and Meade 1983); the storage of muds within estuarine systems (Postma 1980); various patterns of mud deposition over shelf areas (McCave 1972); and, more recently, the transfer of sedimentary material between the shelf break and the adjacent continental slope. Studies into the latter have examined, for example, shelf edge exchange processes of the mid-Atlantic Bight (Walsh 1988), processes and resources of the Bering Sea Shelf (PROBES) (Hood 1986) and, within Europe, ECOMARGE (Monaco 1987). Each of the investigations has involved an integrated approach to the problem of sediment dynamics, involving measurements of water characteristics/ movement and the nature and concentration of sedimentary material in transit.

On a smaller scale, the study of sediment movement in the Bristol Channel exemplifies the problem of quantifying sediment flux, of material moving in suspension or as bed load. The results of a wide variety of investigations in the Channel have been reviewed recently (Collins 1987); nonetheless, new data and approaches to the problem of sediment sources and transport paths have now become available. These studies range from a detailed analysis of sedimentary deposits in the Bristol Channel, to the application of 3-D numerical models to the explanation of sediment dynamics. The approaches may be of interest to geologists, coastal engineers and oceanographers.

Previous investigations

The Bristol Channel is bounded by Wales, to the north, and south-west England, to the south (Fig. 1). Water depths in the Channel range from 50 to 60m at the mouth, to around 5m or less (as intertidal flats) within its inner part. For convenience, this 'estuarine-type' system has been divided up into Outer,

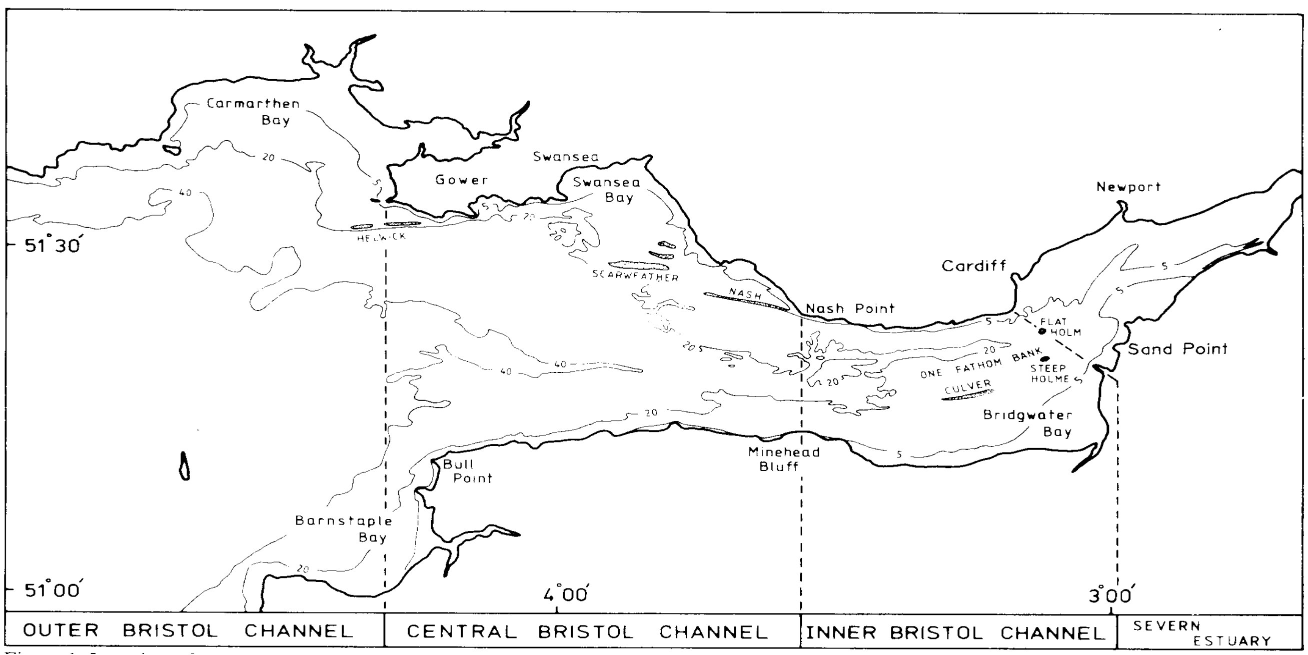

Figure 1. Location of the study area and bathymetry (in metres). The division of the Channel/Estuarine system is that adopted by IMER (UK).

Central and Inner segments (of the Channel) and the adjoining Severn Estuary. Although tidal ranges are large (with mean springs of 11m at Avonmouth, in the Estuary) and the tidal excursion of water particles extensive (up to 22km over a single tidal cycle), the retention time for river runoff in the various compartments of the Bristol Channel is high. Hence, for quasisynoptic cruises carried out in 1973 (May and July) and 1974 (January) mean retention times vary as follows (IMER 1974): 160 to 300 days (Outer Channel); 150 to 240 days (Central Channel); 90 to 150 days (Inner Channel); and 20 to 90 days (Outer Estuary). These extended mixing periods have important implications in the computation of fluxes, against a background of extensive sediment resuspension.

Tides in the Channel generate tidal currents of the order of 1 to $2ms^{-1}$ in the sea bed area around Swansea Bay. For the Channel as a whole, various investigators have drawn attention to the fact that there is correlation between the near-bed stresses and the nature of the surficial sediment cover: areas of exposed bedrock coincide with those of high bottom stresses. Waves, with fetches of up to 6000km extending out into the Atlantic Ocean, also generate near-bed currents of the order of $1ms^{-1}$. Similarly, wave heights of up to 7m have been observed at Port Talbot, during extreme storms; they are 4m in height at the entrance to the Severn Estuary.

It is against the dynamic background outlined above that flux computations have been attempted, or transport paths identified. Previous investigations into sediment transport paths in the region are reviewed extensively elsewhere (see Collins 1987 for full reference listing) and include studies which relate to:

(i) the use of side-scan sonar, to identify ‘bed-load parting zones’ (and, more recently, to provide information on the areal distribution of megaripples, sandwaves and sand ribbons);

(ii) the identification of foraminifera and heavy mineral assemblages;

(iii) the application of 2-D depth and tidally-averaged numerical models, to compute near-bed currents/shear stresses and sand transport paths and rates; (iv) the interpretation of airborne and satellite imagery; and (v) the use of conventional oceanographic instrumentation to obtain Lagrangian (surface and sea bed drifters) and Eulerian (self-recording current meters) observations of water movement.

Over a period of 25 years, involving a large number of man years of effort, various conceptual models of sediment movement within the Bristol Channel/Severn Estuary system have been described. A differential two-way transport pattern was proposed by Culver (1980), with up-channel movement due to wind action taking place in the upper part of the water column and the underlying waters being associated with downchannel transport as bed load. In an attempt to incorporate more recent data sets, Collins and Ferentinos (1984) have suggested that a laterally-varying transport pattern is more appropriate (Fig. 2), with flood-dominated coastal boundary zones and an ebb-dominant axial flow along the centre of the channel. This hypothesis has been examined recently on the basis of field observations (see below).

Recent studies

Bed load transport computations

Mid-depth and near-bed self-recording current meter data were obtained along a cross section of the Channel, between Nash Point and Minehead Bluff (Fig. 1). These data were used subsequently in empirically-derived sediment transport formulae, for the computation of the rates under tidally- and wave-induced currents (separately, and in combination) in sediment flux determinations (Harris and Collins 1988). Taking into account areas of the seabed not covered with loosely consolidated recent sediments and the frequency of

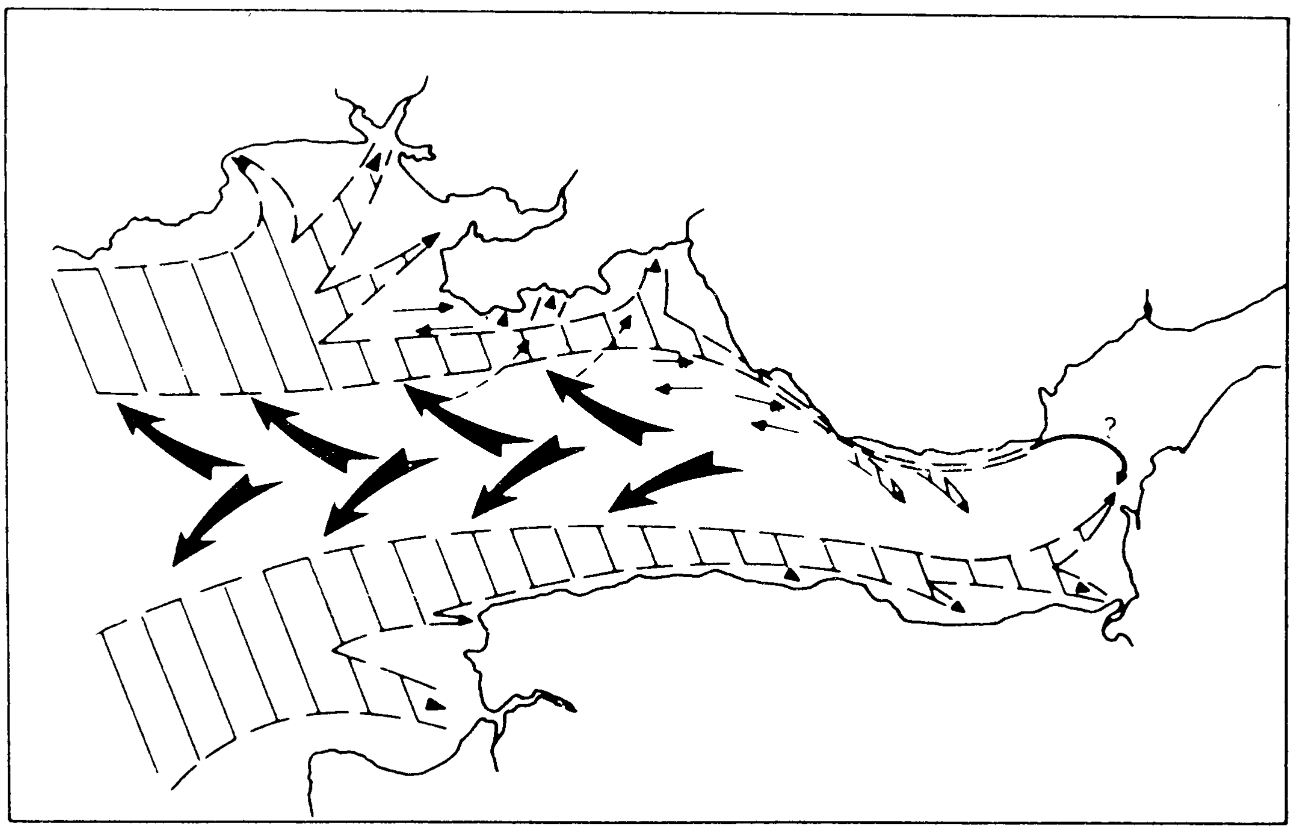

Figure 2. Conjectural near-bed sediment drift pattern, based upon the results of Woodhead drifter recovery patterns and confirmed, in places, by the movement of heavy mineral grains (from Collins and Ferentinos 1984).

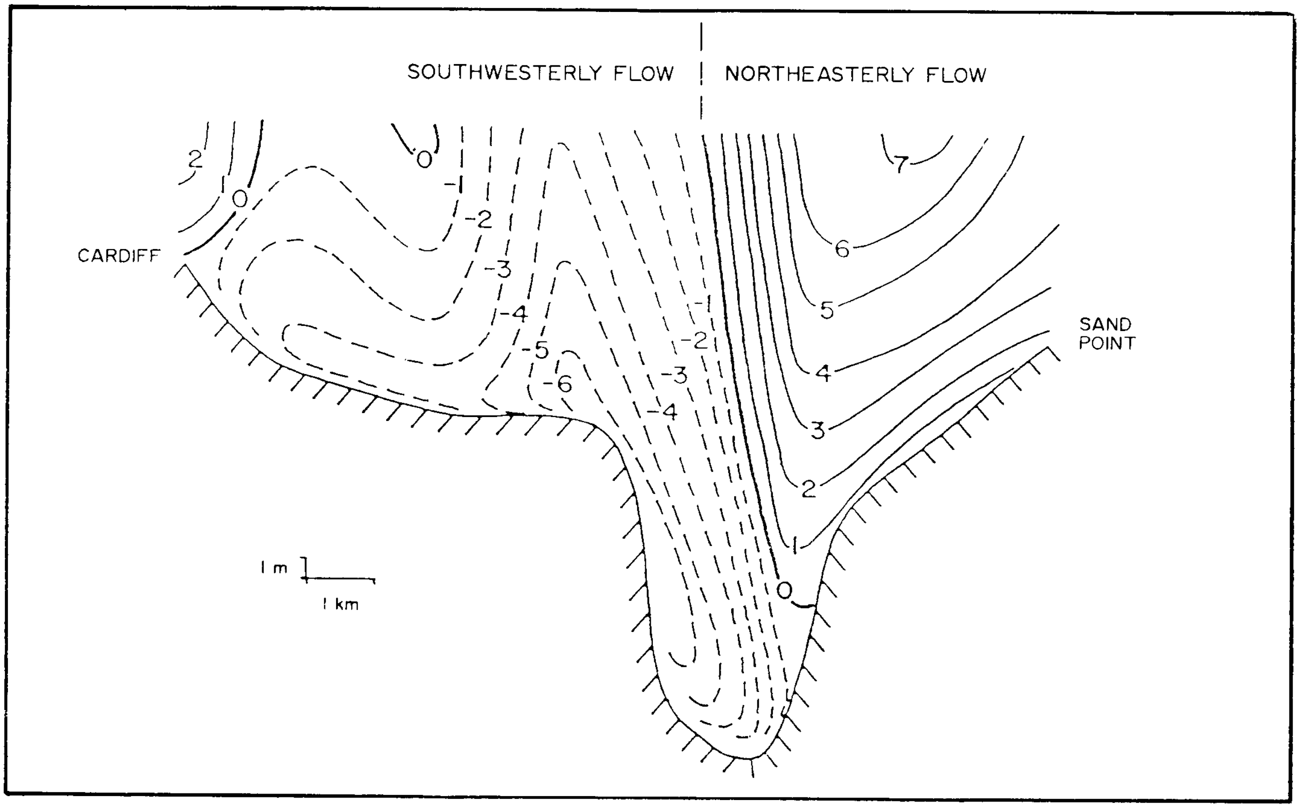

Figure 3. Typical output from the Wolf (1987) 3-D Model of the Inner Bristol Channel/Severn Estuary, showing residual water movement along the channel axis, in cross section.

occurrence of storm events, annual transport rates (sand flux) through the section were calculated as follows: F (in), southern flood zone and Breaksea Valley - $6.45 \times 10^6 t yr^{-1}$ F (out), ebb-dominant part of the Channel - $6.37 \times 10^6 t yr^{-1}$ These results could be interpreted as being indicative of a `balanced' sand flux within the system but, likewise, emphasise the extreme difficulty in establishing *net* fluxes using conventional instrumentation and analytical techniques.

Use of 3-D numerical models

A new generation of numerical models is under development in the UK, whose potential for use in sediment transport investigations has not yet been exploited fully. Following on from the work of Owen (1980) in the Bristol Channel, who demonstrated excellent correlation between the Eulerian residual current output from a 2-D model of the M_2 tides and the presence of linear sandbanks, Wolf (1987) has developed a 3-D model. The Owen model had a grid spacing of 1.29km east by 1.37km north; it was depth-integrated and had a uniform coefficient of bottom friction of 0.0026. Wolf (1987) applied a semi-implicit alternating direction finite difference scheme, on a grid size of approximately 1km, to a 3-D model of the Channel and has presented some representative output of up, down and across channel residuals.

Interestingly, along the cross section between Cardiff (Wales) and Sand Point (England) (Fig. 1), there appeared in the model output a change in the direction of the along-channel residual (Fig. 3), from southwest to northeast. This change in direction represents a ‘shear zone’ which appears to coincide with the position of a suspended sediment front, identified from field observations of turbidity (Parker and Kirby 1982) (Fig. 4). Although mechanisms for the formation and maintenance of this `suspended sediment front' are not yet fully understood (Kirby and Parker 1987), it would appear that the secondary flow circulation patterns shown in the 3-D model outputs may assist considerably in the understanding of such processes. This approach to the application of numerical model outputs to sediment dynamics research has now been extended by McLaren and Collins (1989).

Sedimentological analyses

Sediment transport paths in the Severn Estuary have been interpreted also from a transport model developed by McLaren and Bowles (1985). The model demands specific changes in the three grain size statistical parameters (mean, sorting and skewness) to suggest a transport direction, on the basis of the recognition of trends in simple statistical characteristics.

900 samples were collected from the bed of the estuary and grain size distributions were determined using a laser particle size analysis system and dry sieving. On the basis of the analysis of these results, sedimentary environments and transport paths have been identified (McLaren and Collins 1989). The selection of the environments was based on three criteria:

(i) the sediment type (sand, sand and mud, or mud);

(ii) the mode of sediment transport; and

(iii) the status of the regime, in terms of net accretion, dynamic equilibrium, net erosion or total deposition. Fig. 5 shows a representative section of the above interpretation and includes:

(a) beach and nearshore sands in eastern Bridgwater Bay;

(b) possible recirculatory sand transport around the offshore Culver Bank;

(c) radial movement, to seawards of mixed material in Bridgwater Bay.

The latter may be indicative of delta formation at the mouth of the River Parrett, which is unusual in an area of such strong tidal currents (McLaren and Collins 1989).

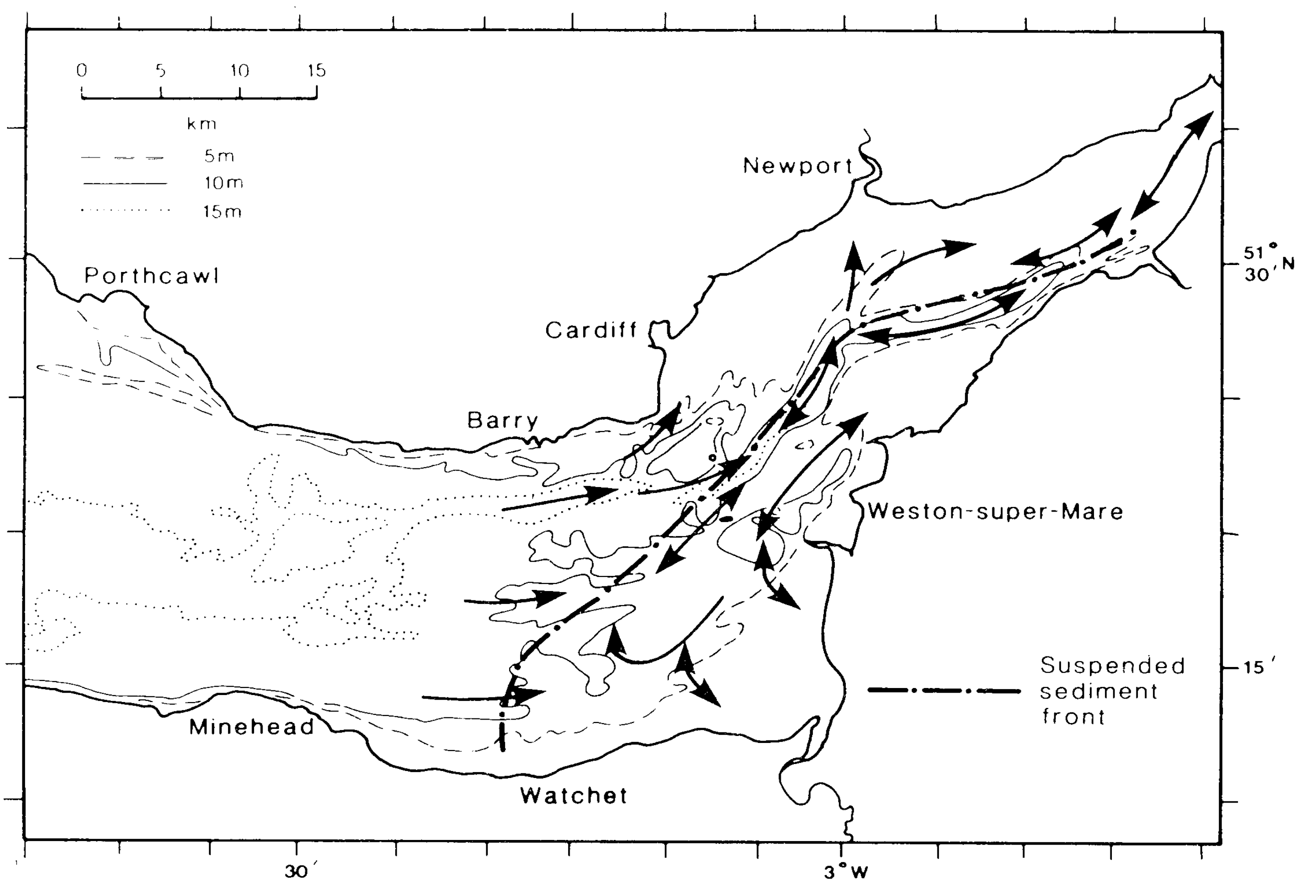

Figure 4. Schematised circulation of fine-grained sediment in the Inner Bristol Channel and Severn Estuary, based upon data from various sources (from Parker and Kirby 1982).

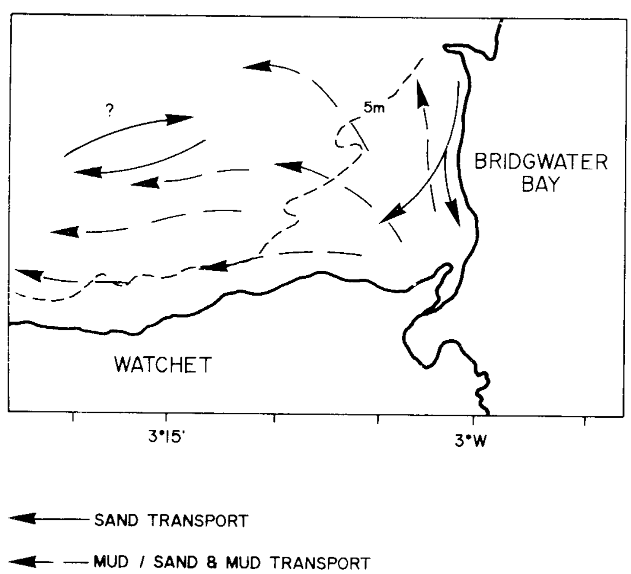

Figure 5. Section of the sediment trend analysis, showing transport paths for sand and mud/sand and mud material (abstracted from McLaren and Collins 1989).

Concluding remarks

The approaches to the interpretation of sediment movement in the Bristol Channel, described above, represent techniques which could be equally applicable to other areas of the continental shelf. As such, they require further investigation and, in particular, understanding of the processes involved.

The results of the sediment trend analysis, to determine the source or origin of the Bristol Channel/Severn Estuary muds, demonstrate a clear relationship between the small river estuaries (e.g. the Parrett) and the mud deposits found in the main estuary. Interestingly, these conclusions concur entirely with those arrived at some hundred years ago by Sollas (1883); however, the depositional processes are not fully understood. Certainly, the transport paths suggest that the rivers, if not the entire source for the muds in the Estuary, are instrumental in their deposition.

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