BN 252 Vera Van Lancker

SEDIMENT MOBILITY STUDIES & *IN-SITU* MEASUREMENTS OF SHINGLE MOVEMENT, USING AN INSTRUMENTED PLATFORM (TOSCA)

G. VOULGARIS and M.B. COLLINS

Department of Oceanography, The University, Southampton, SO17 1BJ, U.K.

INTRODUCTION

Coarse clastic (gravel/shingle) deposits are found throughout the world, but especially in formerly glaciated regions or along tectonically - controlled coastlines where high gradient streams deliver bedload material to the shore; they are presented also in wave-dominated areas, subject to rock cliff erosion. Nevertheless, despite their worldwide occurrence they are nowhere of more significance to coastal engineers than in Britain (Carr, 1983), in terms of coastal defence and the construction industry. Shingle deposits may be classified as coarse clastic shorelines or offshore deposits.

Coarse clastic shorelines are divided into barriers (free-standing or fringing) and beaches (natural or artificial) (Figure 1). Each of these categories displays a number of distinctive morphodynamic attributes (Carter and Orford, 1993).

Offshore clastic deposits are classified, likewise, according to their origin and hydrodynamic environment into (Figure 1): ancient (relict) shingle shorelines; buried palaeovalleys; gravel sheets and offshore gravel banks or tidal ebb deltas.

Although these environments are governed by different hydrodynamic conditions (i.e breaking waves, tidal currents etc), sediment movement is not confined between rigidly set boundaries. Exchange of material takes place, as shown by the two arrows on Figure 1. Dominance of one of the two directions will result in an erosional or accretional coastline.

In the present contribution, experience gained in participation in the South Coast Mobility Study (HR Wallingford, 1993) is described. The detailed parameters required for such a study are identified, whilst a method for in-situ monitoring of flow structure and sediment movement details is presented.

SEDIMENT MOBILITY

Although the predominant direction of shingle transport in barriers is to landward (due to overtopping processes), offshore movement can be observed after the breaching of such a structure. The shingle on beaches is transported alongshore and/or in the onshore-offshore direction.

Changes are rapid and at times visually dramatic within the surf zone, especially during extreme storm events. For example, Seymour (1985) has demonstrated that 50% of the gross longshore sediment transport occurs over only 10% of the time, during extreme events. Although these data are the result of long-term wave monitoring along the West Coast of the USA for sandy beaches, a similar value is likely to be valid for UK coastal waters. Such an observation was confirmed during winter storms along the south coast of the UK, during 1989-90, where significant amounts of shingle material were removed from the beaches.

During such events, material is removed from the beach/barrier system; it is transported initially offshore over the inner (<60m) continental shelf. Here, this material will be subject to wave and current forces under normal and storm conditions. Along the southern coastline of England, for example, Hurst Spit, (a large sedimentary structure consisting of gravel), faces serious erosional problems. During severe gales (in December, 1989), the beach face receded by some 80m in a single day. As a consequence, much material is being lost to the sea: 50000 tonnes of gravel is a typical value for a storm event (Velegrakis and Collins, 1992).

Coastal management plans should be able to predict: the result of extreme events on the shoreface; and the long-term effect of waves and currents on the inner shelf. Such predictions should be able to identify the transport pathways and areas of erosion and deposition.

Sediment Transport on the Beachface (inside the surf zone)

Sediment movement on the beachface results in a continuous alteration of the beach profile. This movement may be classified into longshore (drift) and cross-shore sediment transport. The former is considered to be the major factor affecting long-term erosion or accretion; the latter is considered to be associated to short-term erosional events.

Longshore Sediment Transport

The energy flux approach (CERC, 1984) as developed for sandy beaches, has been used also for the prediction of longshore sediment transport on shingle beaches:

$$Q = k \cdot P \cdot \cos(\alpha_b) \cdot \sin(\alpha_b) \qquad (1)$$

where Q is the volumetric transport rate, P is the wave power at the breaking point and α_b is the angle of wave approach at the breaking point. In the equation, various values have been proposed for the constant, k. Thus, Hattori and Suzuki (1978) suggested 0.0025, whilst a similar value (k=0.002) was proposed by Brampton and Motyka (1987). For comparison, a series of gravel tracing experiments has revealed k values ranging from 0.002 to 0.0059 (Nicholls and Wright, 1991). Commonly the coefficient for shingle beaches is about 3 orders of magnitude smaller than that suggested for sandy beaches; this reflects the difference in size and hydraulic behaviour of the two sediment types.

The values of k presented above are the result of tracing experiments. Although different material (i.e radioactive, painted, aluminium pebbles) have been used as tracers, a fundamental problem in such experiments is the recovery rate and the depth of detection.

Both parameters are important in the definition of sediment transport rates. Therefore, a new technique (an electronically transmitting pebble) is under investigation for use as a tracer. Such a technique promises high recovery rates and detection depths of up to 1m (Voulgaris et al., 1994c)

Cross-shore Sediment Transport

Beach profile changes are due, in general, to movement of sediment in a cross-shore direction. Profile models can be classified as either morphodynamic or parametric. The former attempt to predict the development of the beach from a description of the relevant physical processes (i.e current flow and flow-sediment interaction); the latter ignore physical processes and relate features on the beach to parameters which include (mainly) wave incident conditions, initial beach slope and sediment size. A review of the performance of such models for sandy beaches can be found in Seymour and King (1982), Seymour and Castel (1989), and Horikawa (1988).

Nowadays, most shingle beach models are parametric (e.g. Powell, 1990); this is because of a general lack of knowledge concerning the controlling physical processes (velocity field, perculation etc). No cross-shore sediment transport equations exist for shingle transport along the beach profile, which would relate grain movement to fluid velocities.

Sediment Transport on the Shoreface (outside the breaker zone)

Farther offshore, gravel deposits are subject to forces induced by both waves and currents. Although a number of models have been developed for the study of the wave-current interaction (Grant and Madsen, 1979; Christoffersen and Jonsson, 1985; Sleath, 1991), major uncertainties are included in the use of threshold criterion and empirical sediment transport formulae. In such approaches, the direction of transport is determined by the resultant vector of bed shear stress of the waves and currents.

In addition to the quantitative techniques outlined above, there are also a number of qualitative approaches to the problem: sediment size analysis; and geophysical and bathymetric surveys (i.e shallow seismic profiling, side-scan sonar, echo-sounding etc).

A combination of both approaches leads to the derivation of sediment transport pathways, such that the natural environment is simulated and facilitates coastal management studies. This procedure is demonstrated by the South Coast Mobility Study.

The above investigation was concerned with the mobility of the seabed sediments (sand and gravel) in the area extending from the Isle of Wight to Shoreham, for water depths ranging from 5 to 50m (Figure 2). Sediment transport pathways were determined on the basis of: assessment of the sea bed character, using sea bed sampling; and geophysical surveys (shallow seismic profiles and side-scan sonar imagery). These data, were integrated with the output of numerical modelling work undertaken by HR Wallingford (1993). In these models, the hydraulic climate was presented by establishing a detailed pattern of waves and currents across the study region. Wave climate data (H, T, direction) were converted into near-bed ocities and then used, together with tidal currents, for the derivation of comparison with the threshold of movement of sea bed material permitted of sea bed mobility and sediment transport pathways (Figure 2).

ant aspect of this study, was the selection of the appropriate threshold criterion, for tion of the percentage of the time that shear stress exceeds threshold. Mainly, any s were due to absence of *in-situ* data for gravel beds, for use in the modelling.

MEASUREMENTS OF SHINGLE MOVEMENT (TOSCA)

uth Coast Mobility Study, outlined above, involved the definition of the threshold on for shingle movement. In general, however any numerical model investigations a sediment transport formula to be used in conjunction with the hydrodynamic conditions. Although there are a number of hydrodynamic models available of sufficient accuracy, the sediment transport formulae available (especially for shingle particles) are somewhat limited and based mainly on riverine research (Einstein, 1950; Kallinske, 1947; and Meyer-Peter and Muller, 1948). Information is not available on shingle transport under the combined action of waves and currents; this is due mainly to the absence of any approach for measuring sediment transport, at time-scales comparable to the wave period.

In an attempt to fulfil the above requirements, a Research and Development study was awarded to Southampton University by the Ministry of Agriculture Fisheries and Food (Coastal and Flood Defence Division) for the *in-situ* monitoring of shingle movement, under the combined action of waves and currents. An objective of the study was to obtain flow parameters and sediment threshold values for use in studies such as the South Coast Mobility Study.

An underwater tripod was constructed which was equipped with electromagnetic current meters, measuring horizontal and vertical currents together with wave-induced pressures and sediment transport rates. The concept of the Self-Generated Noise (SGN) was used for monitoring the sediment transport rates. The tripod was connected to a surface buoy used for power supply provision and data transmission to the shoreline in "almost" real time. The operation of TOSCA is shown schematically, as a flow diagram, on Figure 3. [More details on the tripod and its characteristics can be found in Voulgaris et al (1994a)].

SGN is a passive non-intrusive acoustic method, for shingle transport estimations in the field. The approach is based upon the assumption that when individual particles are in motion, noise is generated due to their intercollision. Such noise (SGN), is proportional to the amount of material in motion and, hence, to the shingle transport rate. Extensive theoretical work on SGN has been undertaken by Thorne (1990), whilst the method has been used previously for measuring gravel transport within a tidally-dominated environment (West Solent, (Williams et al., 1989)).

Extensive laboratory work was undertaken, prior to the deployment, to:

(i) define the frequency of the Generated Noise from the collision of shingle particles - this was necessary in order to construct the processing unit required for the conversion of the raw noise signal, into an rms level which was more easily comparable with the hydrodynamic parameters;

(ii) define a relationship between the SGN and sediment transport rates (Fig. 5); and

(iii) determine the error introduced by noise created from water flow around the body of the sensor (hydrophone).

A first-order approximation technique was utilised for the conversion of the laboratory calibration, for use in the field.

The systems was deployed along the southern coastline of England, in Christchurch Bay (Figure 5) during the period 20th April to 8th May, 1993, in a mean water depth of 8m. The sea bed was consisted of loose shingle, with a mean particle size of 1.70cm. Bursts of data were collected every 2 hours, for 10min and at 5Hz. Some 130 bursts of hydrodynamic and sediment transport data were collected during the deployment period. A schematic diagram of the tripod and its mode of operation is shown as Figure 5 .

The tripod was located near the edge of a gravel wave field. Hence, flow characteristics over the bedforms were recorded during ebb flow: in contrast, flows over a flat bed were recorded during flood phase. Analysis of the hydrodynamic data has identified roughness lengths which should be used in the modelling of flow and sediment transport over gravel bed as (Voulgaris et al., 1994b):

$$k_s = 2 \cdot D_{50} \tag{2}$$

for flow over bedforms, and

$$k_s = 2 \cdot D_{50} + 4.4 \eta \cdot \frac{\eta}{\lambda} \tag{3}$$

for flow over a flat gravel bed; where (D_{50} is the mean particle diameter; η is the gravel wave height and λ is the wave length).

Sediment transport rates derived from the SGN method are related to shear stress, due to both waves and currents. A relationship has been found (Figure 6), which expressed the immersed weight shingle transport (I_b) as a function of the 3rd power of the shear stress (τ_{wc}) (Voulgaris et al., 1994b):

$$I_b = 4.44 \cdot 10^{-3} \cdot \tau_{wc}^3 \tag{4}$$

No definite threshold condition has been identified in this relationship; this is not in contradiction with existing theories. A review of existing threshold conditions (Voulgaris et al., 1991) has shown that published threshold values varied by an order of magnitude, for the mean size of material found at the deployment site (Figure 7). Alternative approaches to the subject of threshold criterion suggest that threshold coincides with the energy level at which a minimum sediment transport occurs (Paintal, 1971). Such an approach to the definition, however, shifts the problem of the definition of a threshold to the establishment of a minimum sediment transport rate to be considered as significant. Two such expressions are presented on Figure 7, as straight lines. Line P1 corresponds to the value defined by Paintal (1971), whilst P2 corresponds to the minimum sediment transport defined by other published formulae (Einstein, 1950; Meyer-Peter and Muller, 1948; and Kallinske, 1947). Characteristically, these lines cross the sediment transport equation (4) line (Fig. 6) at values very close to the minimum and maximum threshold values shown on Figure 7.

CONCLUSIONS

The successful application of any sediment mobility study is based upon accurate hydrodynamic and sediment transport formulations. Although a plethora of hydrodynamic models exist, providing satisfactory results, the large number of sediment transport formulations show significant scatter in their output.

Development of the TOSCA tripod has contributed towards an improved formulation of both the above aspects, in terms of the hydrodynamics and for gravel transport. Application of the results should improve significantly the reliability of mobility studies, based upon modelling.

Gravel transport should be considered as a continuous process. Such an approach reduces the uncertainty in the application of a shingle threshold criterion, leading to the derivation of more accurate results.

ACKNOWLEDGEMENTS

The TOSCA study was supported by MAFF Research Contract CSA 1839. The South Coast Mobility Study was undertaken by HR Wallingford (together with the University of Southampton), funded jointly by the Crown Estate and SCOPAC (Standing Conference on Problems Associated with the Coastline). However, the views expressed here are solely those of the authors.

REFERENCES

BRAMPTON, A. and J.M. MOTYKA (1987) Recent Examples of Mathematical Models on UK Beaches. *Proceedings of Coastal Sediments '87 (ASCE)*, 515-530.

CARR, A.P. (1983) Shingle Beaches: Aspects of their Structure and Stability. In: *Shoreline Prediction*, Thomas Telford Ltd, London, 97-104.

CARTER, R.W.G. and J.D. ORFORD (1993) The Morphodynamics of Coarse Clastic Beaches and Barriers: A Short- and Long-term Perspective. *Journal of Coastal Research*, **15**, 158-179.

CERC (1984) Shore Protection Manual, Vol. I., 4th edition. Coastal Engineering Research Center. U.S. Army Corps of Engineers, Washington D.C.

CHRISTOFFERSEN, J.B and I.G. JONSSON (1985) Bed Friction and Dissipation in a Combined Current and Wave Motion. *Ocean Engineering,* **12**, 387-423.

EINSTEIN, H.A. (1950) The Bedload Function for Sediment Transportation in Open Channel Flows, U.S. Department of Agriculture, Tech. Bull. 1026.

GRANT, W.D. and O.S. MADSEN (1979) Combined Wave and Current Interaction with a Rough Bottom. *Journal of Geophysical Research,* **84**, 1797-1808.

HATTORI, M. and T. SUZUKI, 1978. Filed Experiment on Beach Gravel Transport. *Proceedings of the 16th Conference on Coastal Engineering,* 1688-1704.

HORIKAWA, K. (1988) Nearshore Dynamics and Coastal Processes. University of Tokyo Press, Japan, 522pp.

HR WALLINGFORD (1993) South Coast Seabed Mobility Study. Report EX 2795, 24pp plus Tables and Figures.

KALLINSKE, A.A. (1947) Movement of Sediment as Bed-Load in Rivers. *Trans. Am. Geophys. Union*, **28**, 615-620.

MEYER-PETER, E. and R. MULLER (1948) Formulas for Bed-Load Transport. *Proc. 2nd Congress IAHR,* Stockholm, Sweden, **2**, 39-64.

NICHOLLS, R.J. and WRIGHT,P.W. (1991) Longshore Transport of Pebbles: Experimental Estimates of k. *Proceedings of Coastal Sediments '91, (ASCE),* 920-933

PAINTAL, A.S. (1971) Concept of Critical Shear Stress in Loose Boundary Open Channels. *Journal of Hydraulic Research*, **9**, 91-113.

POWELL, K.A. (1990) Prediction of the Short Term Profile Response for Shingle Beaches/ Hydraulics Research, Report SR219.

SEYMOUR, R.J. and D. CASTEL (1985) Epicodicity in Longshore Sediment Transport. *Journal of Waterway, Port, Coastal & Ocean Engineering, ASCE,* **111(3)**, 542-551.

SLEATH J.F.A. (1991) Velocities and Shear Stresses in Wave-Current Flows. *Journal of Geophysical Research,* **96**, 15237-15244.

THORNE P.D. (1990) Seabed Saltation Noise. In: B. Kerman (ed.) *Natural Physical Sources of Underwater Sound.* Kluwer Academic Publishers.

VELEGRAKIS, A.F. and M.B. COLLINS (1992) Marine Aggregate Evaluation of Shingles Bank, Christchurch Bay. Technical Report SUDO/TEC/92/14/C, Southampton University, Oceanography Department, 33pp plus Plates, Figures and Appendices

VOULGARIS, G., M.P. WILKIN and M.B. COLLINS (1991) Storm Damage - South Coast Shingle Study. Technical Report SUDO/TEC/93/8/C. Department of Oceanography, University of Southampton, 44p plus Figures.

VOULGARIS, G., M.P. WILKIN and M.B. COLLINS (1994a) The in-situ Passive Acoustic Measurement of Shingle Movement under Waves and Currents (TOSCA) Development and Preliminary Results. *Continental Shelf Research* (in press)

VOULGARIS, G., M.P. WILKIN and M.B. COLLINS (1994b) Shingle Movement under Waves and Currents: An Instrumented Platform for Field Data Collection. *Proceeding of Coastal Dynamics '94 (ASCE)* (in press)

VOULGARIS, G., M. WORKMAN and M.B. COLLINS (1994c) New Techniques for the Measurement of Shingle Transport Rates in the Nearshore Zone. *2nd Int. Conf on the Geology of Siliclastic Shelf Seas*, 24-28 May, Gent, (accepted for presentation)

WILLIAMS, J.J., P.D. THORNE and A.D. HEATHERSHAW (1988) Comparisons between Acoustic Measurements and Predictions of the Bedload Transport of Marine Gravels. *Sedimentology*, **36**, 973-979.

LIST OF FIGURES

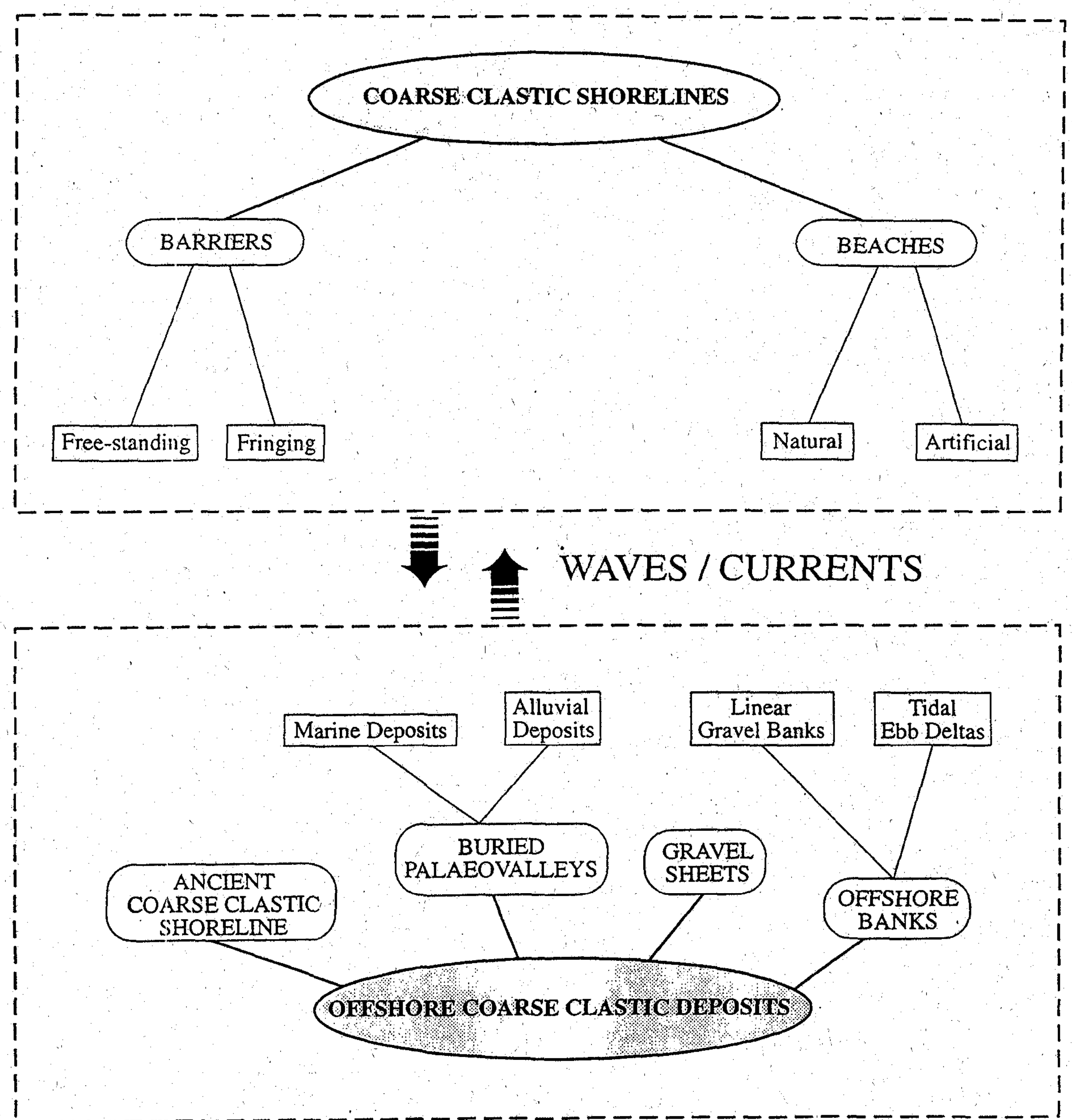

Figure 1. Classification of coastal (*after* Carter and Orford, 1983) and offshore clastic deposits.

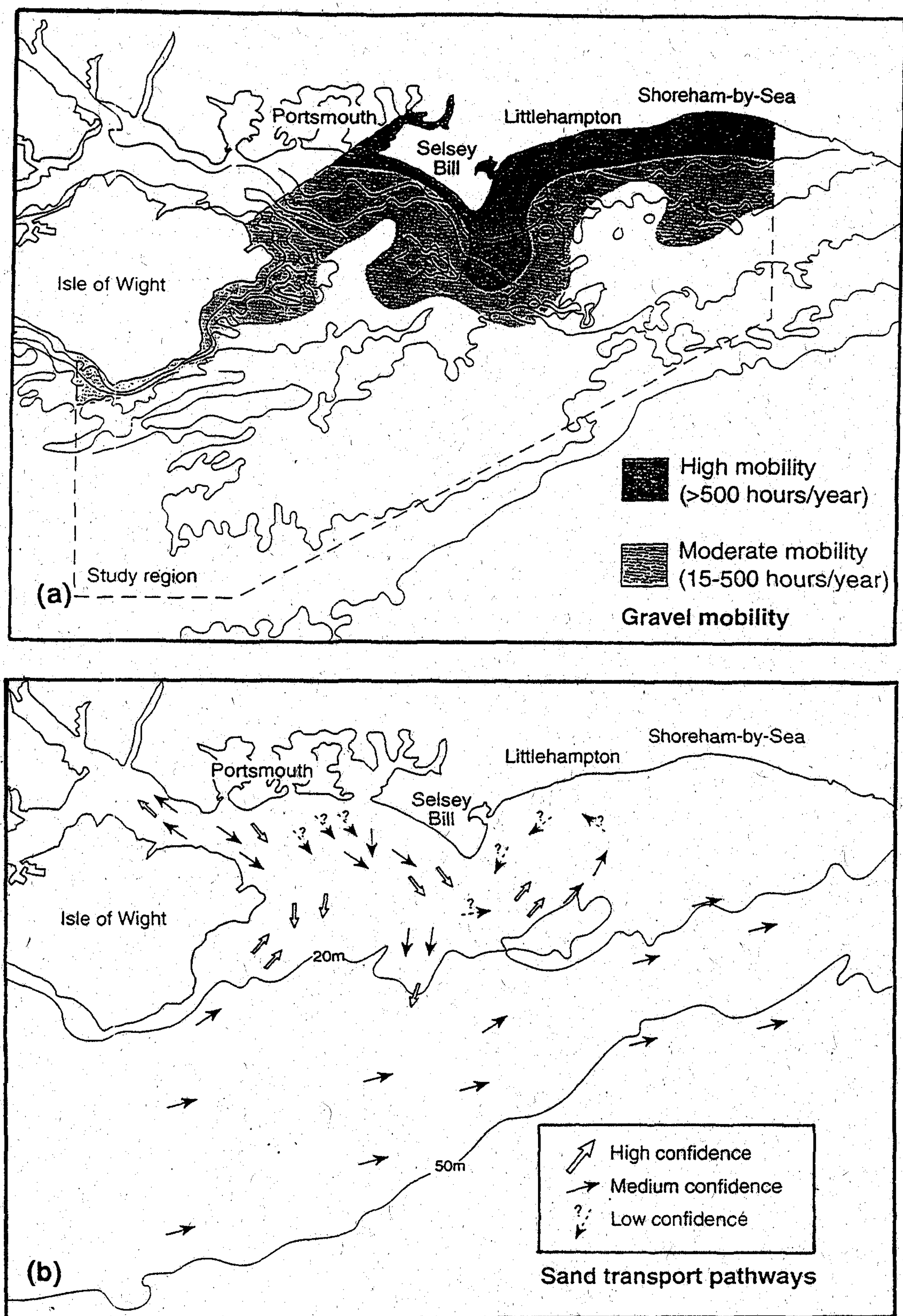

Figure 2. South Coast Mobility Study: (a) gravel mobility over the study area, based upon sea bed sediment distribution, combined with wave- and tidally-induced near-bed currents; and (b) sand transport pathways over the study area (*from* HR Wallingford, 1993).

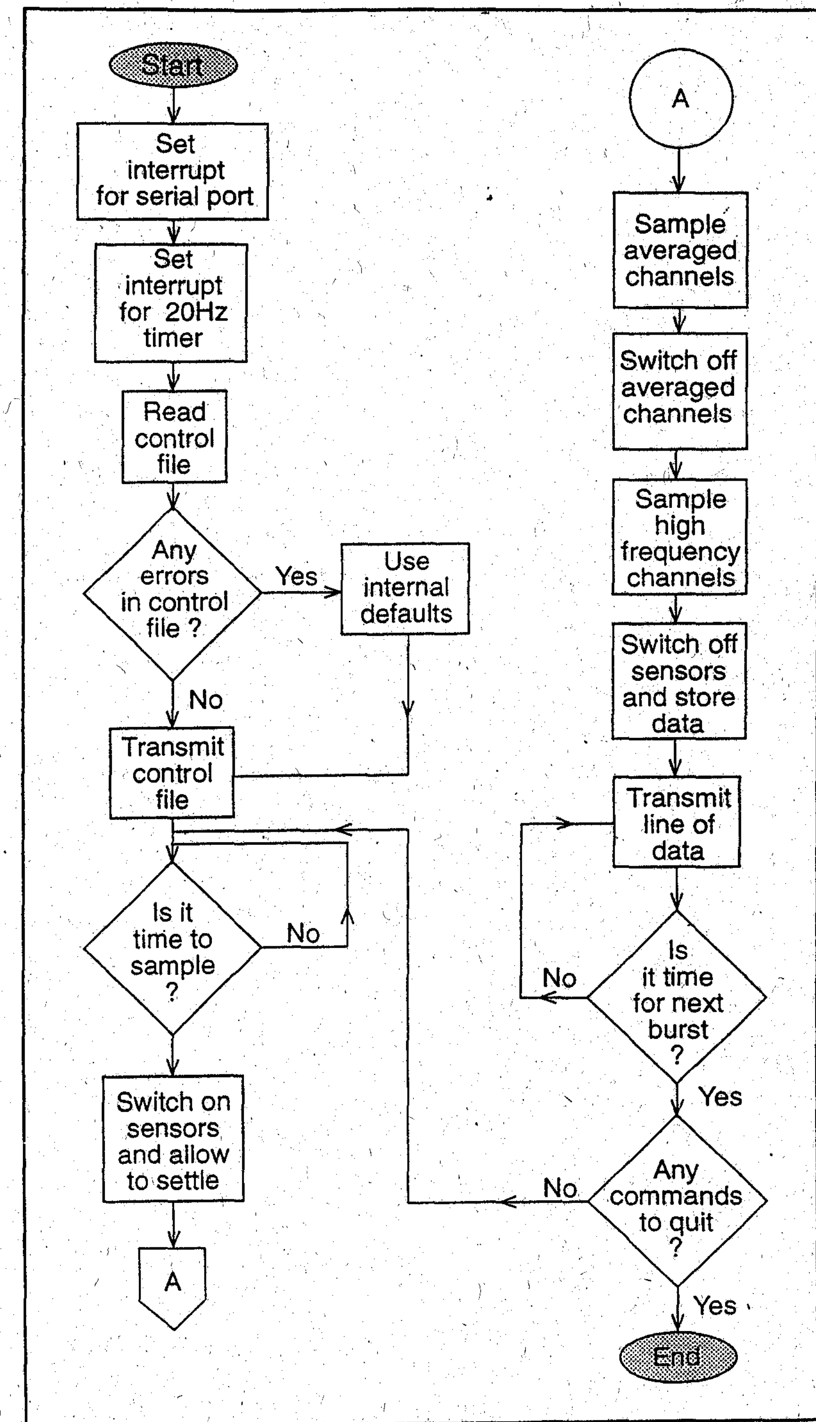

Figure 3. Flow chart representing TOSCA operation during data collection and transmission.

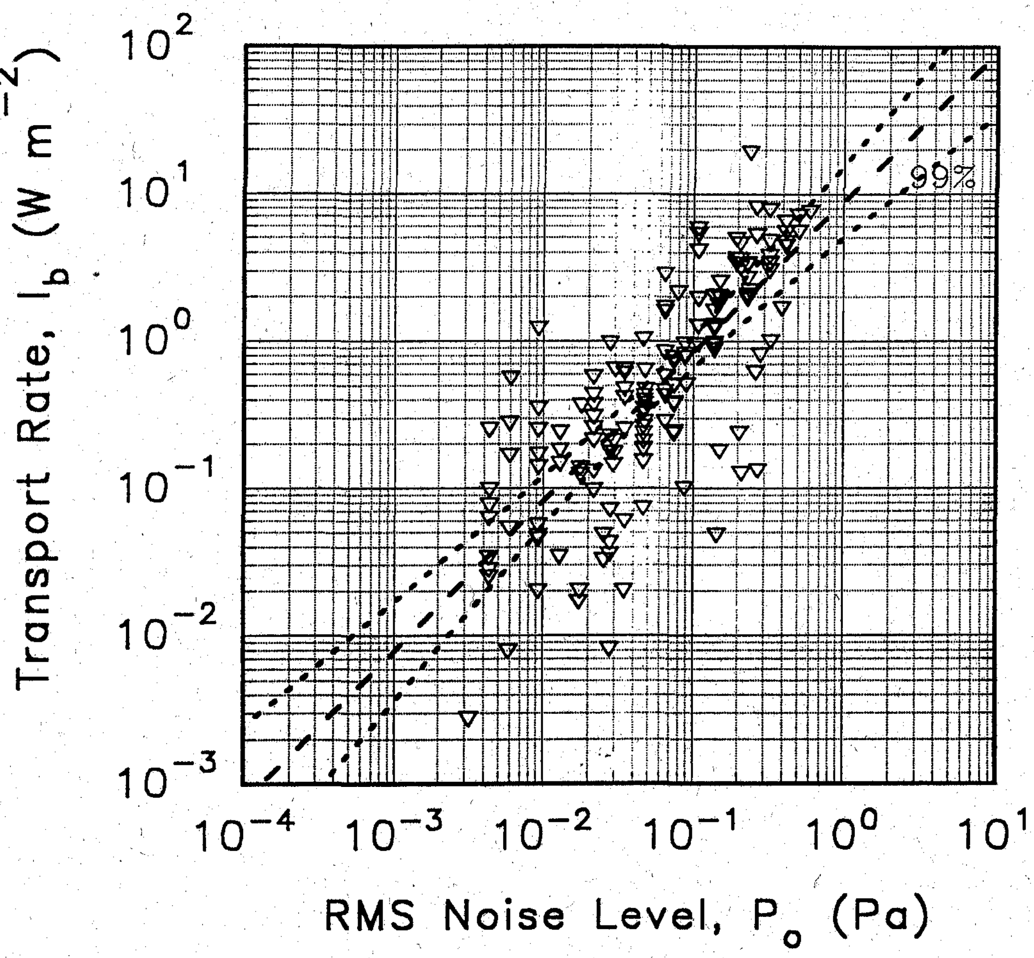

Figure 4. SGN laboratory calibration diagram

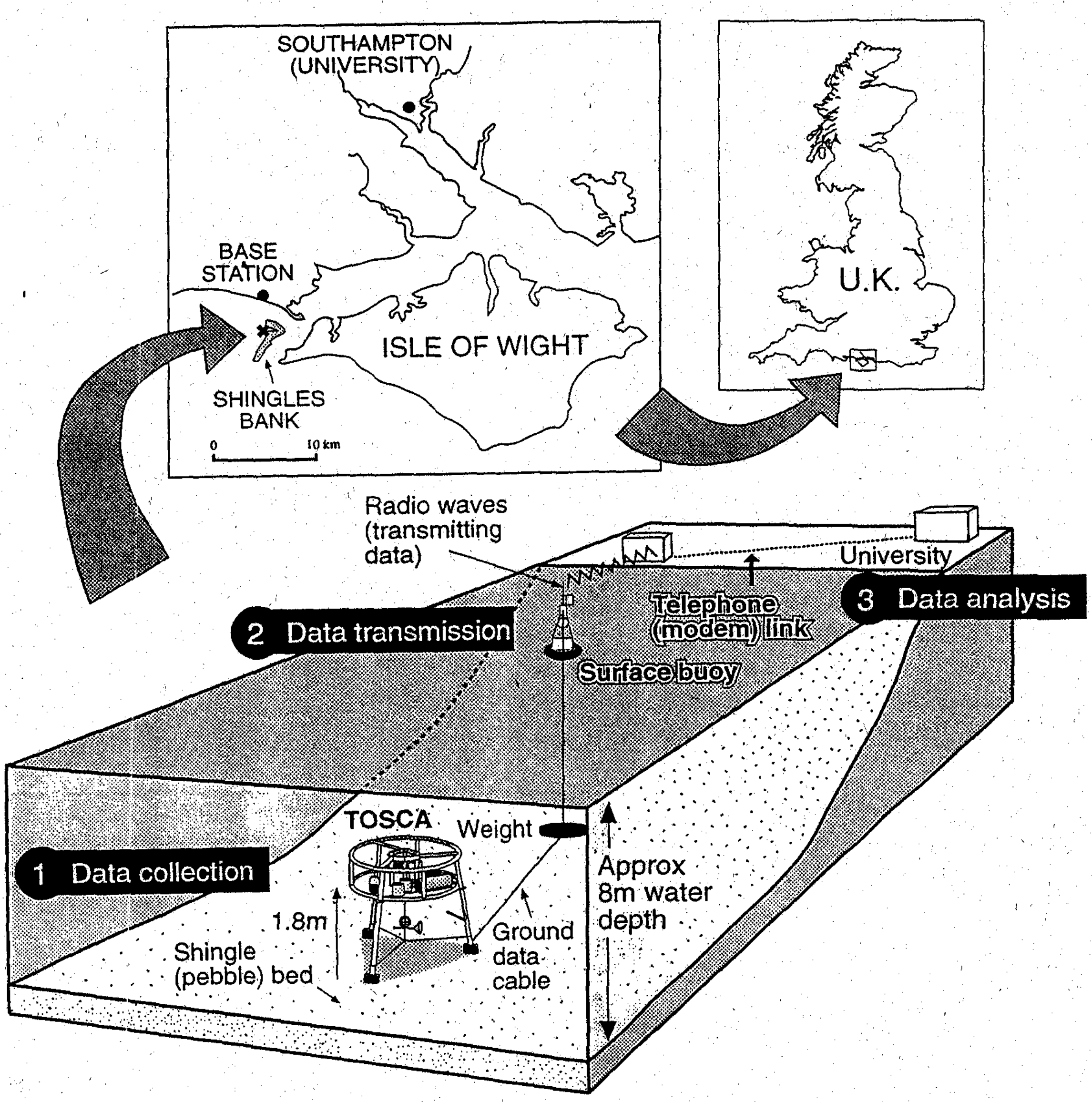

Figure 5. TOSCA deployment location, together with an artist's impression of data collection and transmission modes.

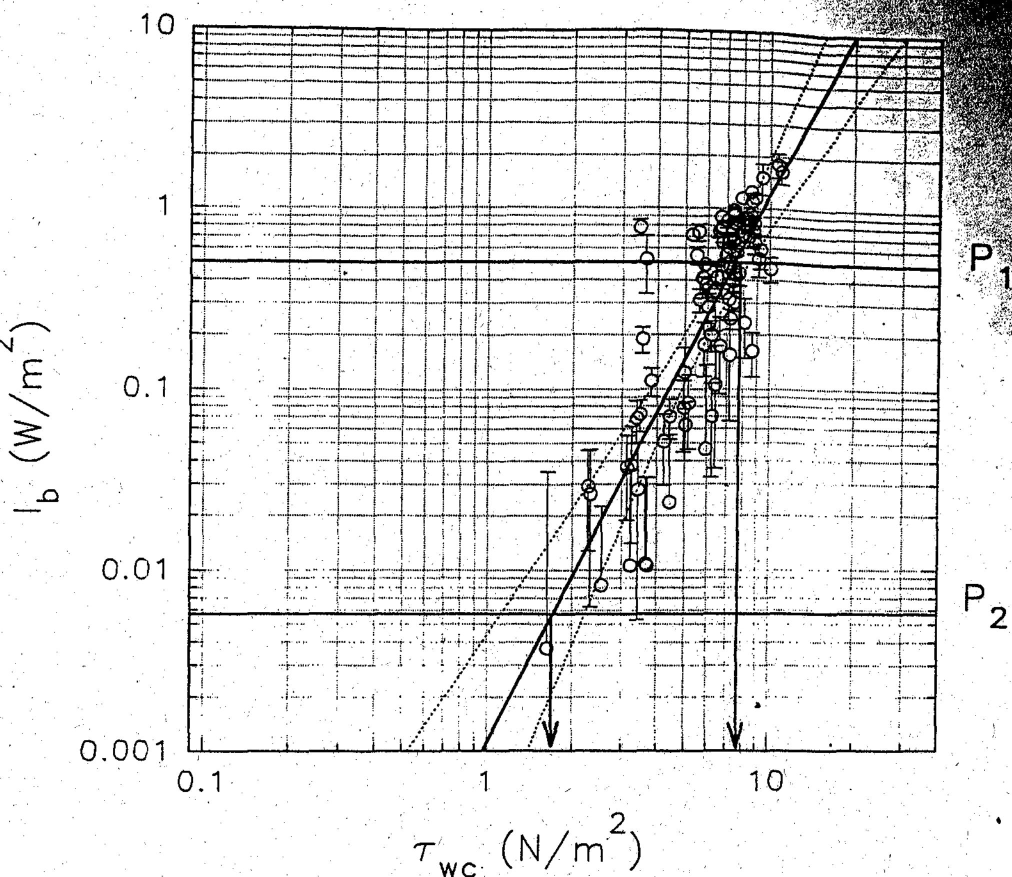

Figure 6. Sediment transport relationship, based upon the analysis of data collected in Christchurch Bay (for explanation, see text).

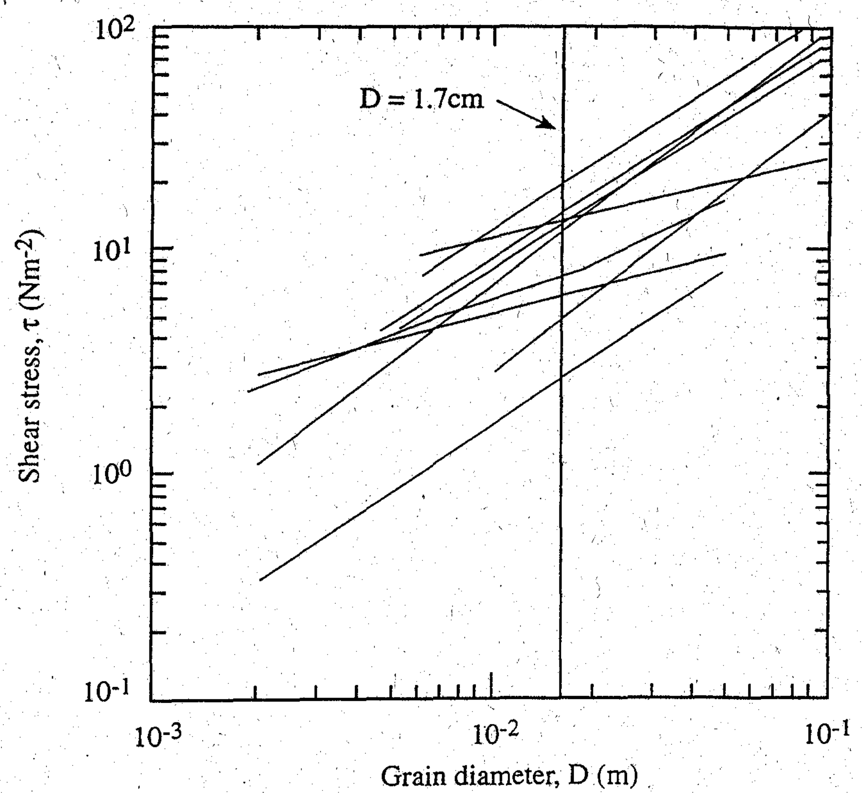

Figure 7. Critical shear stress values for gravel, derived by various investigators (*after* Voulgaris et al., 1991)