ANNEX VII

FINAL REPORT - WORKING GROUP 61

SEDIMENTATION AT CONTINENTAL MARGINS

INTRODUCTION

This Working Group was set up by SCOR in 1978 and was asked to undertake the following tasks:

To review existing knowledge of sedimentation processes at continental slopes and margins, to recommend long term measurement devices for currents, turbidity, accumulation rates and other relevant parameters; to recommend coordinated quantitative determinations of suspended and accumulated materials; to define a few experiments in key areas on both eastern and western sides of oceans.

Members of the group have met from time to time at conferences, particularly the IUGG in Canberra (1979) and latterly at JOA in Halifax and the International Sedimentological Congress in Hamilton, Ontario during August 1982. Unfortunately, at no single meeting was it possible to get all the members of the WG together. We feel it is highly desirable for initial meetings of a WG to be organized so that a cohesive and more effective group is formed. This would require SCOR funds for at least two meetings of any given working group.

RECOMMENDATIONS FOR LONG-TERM MEASUREMENT DEVICES

1. Currents:

Engineers working with deep-sea current meter moorings have to be very conservative because experience has shown that even small changes to successful systems can result in the loss of whole moorings. At present the Vector Averaging or Measuring Current Meter (VACM or VMCM) using a savonius rotor and a vane is the preferred instrument for long-term deep ocean deployment. Microprocessors can now be added to these to allow them to sample at higher frequency when an event of interest (such as higher current speed) occurs. There is an increase in the use of acoustic current meters both for high-frequency turbulence measurements and for longer term measurements. An advantage of these devices is the absence of moving parts and low power consumption. While most instruments have been specially constructed at research institutions, one company (Neil Brown Inc.) now manufactures a deep ocean acoustic current meter. This type of device we suspect will be increasingly preferred as the older VACM's reach the end of their operating life. For boundary layer work the BASS (Benthic Acoustic Stress Sensor) of A.J. Williams at Woods Hole has proved highly successful in both shallow water (Coastal Ocean Dynamics Experiment CODE) and deep water (High Energy Benthic Boundary Layer Experiment HEBBLE). It has the advantage over electromagnetic meters of low power consumption permitting measurements of relatively long duration. At present the limiting condition is 8 hours of tape in the recorder. A move to *in situ* processing and compression of the data will allow much longer continuous records to be obtained. Event triggering allows high frequency data to be taken in relatively rare events of high energy, thereby conserving data storage capacity for times of interest.

2. Turbidity:

The continuous measurements of turbidity has hitherto been mainly by use of light-scattering measurments. Such measurements show quite good correlation with measured turbidity but are very sensitive to instrumental parameters. Different laboratories use different designs and their results are not easy to compare. Recently, a new generation of 0.25 and 1 m path length transmissometers have been designed for the deep-sea, the shorter one being in commercial production by Sea Tech Inc. The results from transmissometers are far less dependent on instrumental variation and a simple optical parameter, the attenuation coefficient, correlates very well with particle concentration. These instruments can operate in deep and shallow water and can be made to record in the pressure case of an associated current meter, thereby giving a record of the two parameters needed for estimates of sediment transport.

For the very high concentrations that may be encountered in some estuaries, (fluid mud with $C > 10$ kg m^{-3}) optical devices will not work. In these cases X-ray densitometry of the type undertaken by the Institute of Oceanographic Sciences (U.K.) in the Severn estuary may represent a viable technique. Long-term recording devices employing this principle have not been made.

Acoustic back-scattering particle measurement systems are currently being developed for deep and shallow water. They appear to detect suspended sand quite well and may also be satisfactory for muds. The advantage of these systems is that by range-gating measurements may be made up to 100 m away from the sound source. When combined with acoustic-doppler current meters also being developed, it may be possible to sense sediment transport rate remotely and obtain its vertical and horizontal profile. We can anticipate successful systems of this type before the end of the decade. Here again the possibility of event triggering with buffer storage gives us a means of studying episodic sediment transport. At present the frequency of events examined is of the order of one per month, but in principle much more rare events could be examined.

3. Equipment Loss:

An acute problem in shelf and upper slope depths (down to about 800 m) is loss of equipment to fishermens trawls. The two possible ways to combat this are to maintain close contact with fishermen and keep them informed of our activities or to develop cheap sensors that can telemeter data back to shore. Unfortunately, we see little chance that oceanographic sensors for sediment transport work are likely to be in sufficient demand to bring the price down through mass-production as with the XBT.

4. Accumulation and Particle Mixing Rates:

There have been many reviews of radioactive geochronologies for sediments. In determining the rate of accumulation in the uppermost part of the sediment column, the Holocene for the deep sea, results are made more difficult to interpret by biological mixing of the sediments. Material is moved into the bed both by advection - net sedimentation - and by mixing. For laminated sediments advection is dominant and isotopic data are more easy to interpret. Bioturbation effectively diffuses sediments downwards amd may be parameterised in the form of an eddy diffusivity. However, because there is more food near the surface there is a decrease in the biological activity with depth, and the biological diffusivity is higher in the top of the biologically mixed layer than it is lower down. The significance of this is that the portion of radionuclide profiles below the uniform mixed layer, where a decline of radioactivity with depth is found, may contain both an advective and a diffusive component. In the past it has (in the case of some ^{210}Pb data) been interpreted as entirely due to advection and decay. The inferred accumulation rate may be high by a factor or two. Thus, a suite of radionuclides should be determined in conjunction with a multilayer model such as that of Olsen and others (J. Geophys. Res., 86, 11020-11028). The radionuclides most commonly used and their half-lives are ^{234}Th (24 d,), ^{210}Po (138d), ^{210}Pb (22y), ^{32}Si (280y) and ^{14}C (5600y). In addition the bomb-produced nuclides ^{137}Cs and $^{239,\,240}Pu$ with a peak in 1962 are also used for dating

For the upper Pleistocene, oxygen isotope stratigraphy gives the best resolution and is to be preferred to the older WXYZ biostratigraphic zonation, though that may still be useful for quick estimates. Also useful for some situations are pollen zones. Tephrochronology frequently gives excellent local correlation and dating if within K-Ar range or constrained by ^{14}C dates or O-isotope stratigraphy. A note of caution must be sounded for both ^{14}C dates and ^{18}O stratigraphy because they may be contaminated by reworked older material and give anomalous results.

Direct assessment of sedimentation by sediment traps gives satisfactory results in quiescent conditions such as some fjords, lakes and oceanic mid-depths. As current velocity past traps increases the behaviour of particles in relation to the trap becomes less and less well known. There appears to be a component concentration or horizontal flux rather than vertical flux to their behaviour, but in a non-linear manner. In the frequently active current regime of continental margins they produce results that cannot yet be properly interpreted and are not recommended for use in the nepheloid layer by the working group.

5. Problems of Episodic, Powerful Events:

An important aspect of sedimentation at continental margins is the episodic occurrence of powerful, gravity-driven sediment movement in slumps, debris flows and turbidity currents. Very few measurements have ever been taken of such movements in the sea, and those in lakes have been of comparatively slow low-density underflows. The major problem is being in the right place at the right time with suitable instruments. We have to be able to predict when a slide that may develop into a turbidity current is going to occur. The problem is not unlike that of earthquake prediction. In recent years much emphasis has been placed on measuring active processes of current transport and on measuring geotechnical properties of deposited sediments. The latter allow the conditions for slope failure to be evaluated. What is now needed is an effort to instrument areas where failure is expected soon so that measurements may be made of flow velocities and concentrations in turbidity currents.

Two strategies are suggested. One is repeated monitoring of a region of known instability using side-scan sonar and multi-beam echo sounding with accurate position fixing so as to be able to detect movements. Such an approach has been used by the group at Louisiana State University to reveal several slump scars and debris flows on the upper prodelta slope off the Mississippi, and by the French CNEXO on the Var delta slope failure near Nice. The second approach is to install *in situ* piezometers (to measure pore pressure) at depth. These would periodically be interrogated and with knowledge of the local slope an assessment of slope stability would be made. The systems used could be similar to those used in conjunction with oil platforms to keep track of their site stability. With approach of critical conditions a programme of instrument deployment would be initiated. Specially designed current meters and turbidity sensors would be emplaced along the probable path of a current. Downward-looking acoustic-doppler meters with event triggering could be moored above the probable path of such a flow. These would yield both flow speed and concentration profiles. The precise requirement of a site for such studies is that it should have very high rates of accumulation and secondly it should be close to an oceanographic institution to permit regular servicing and interrogation of monitoring devices. It would also be useful to find an area where there was the possibility of sandy turbidities being generated because this is the type most commonly studies in the geological record. Unstable areas of muddy bottom are most common however.

KEY EXPERIMENTS TO BE CONDUCTED

1. Laboratory Studies:

Several dynamics and sediment transport studies are currently being undertaken or have just concluded. Among these are the Coastal Ocean Dynamics Experiment (CODE) off California though this does not have a large sediment transport component, the studies of the shelf in the New York Bight by the NOAA labs in Miami, the joint U.S.-China programme in the east China Sea, studies of wave and tidal current sand transport on the shelves around U.K. by staff of the Institute of Oceanographic Sciences, and in deep water the High Energy Benthic Boundary Layer Experiment (HEBBLE) conducted by U.S. investigators from several institutions. It is becoming increasingly apparent from HEBBLE and other studies that biological mediation in sediment transport processes can not be neglected. Mucus coatings on both silt/clay and sand beds can and does significantly alter and control initial motion conditions, and aggregation with biological substrates is important in controlling suspended sediment settling velocity distributions. Thus, there is a need for a programme of controlled laboratory experiments to examine and define these effects. As a component of these efforts a renewed attack must be made on all aspects of cohesive sediment dynamics, particularly erosion, deposition and aggregation.

2. Sites for Mass Movement Studies:

Areas that might conform to the outline specification made above (rapid deposition rate, near oceanographic institute, relatively sandy) are the prodelta slopes of the Rhone and Ebro, the Danube, the Frazer in Canada, and because they are unstable though not sandy, the Mississippi and the Magdalena in Venezuela. Some submarine canyons such as La Jolla may also be suitable for examining the possibility of instability with instruments wired right into the laboratory. Other canyons with known instability and recorded mass movement are the area below Nice Airport on the Var Delta/Canyon system and the canyons of the Congo and Magdalena (Venezuela).

3. Sites for Studies of Modern Redistribution:

HEBBLE is conducting studies of sediment transport under deep western boundary currents with significant eddy contribution to the velocity field. Other studies of sediment redistribution in regions of current activity and sediment supply would be valuable. In the Pacific the Okinawa trough under the Kuroshio is a suitable target. In the S.W. Indian Ocean the Limpopo and Tugela Cones are fed with a substantial amount of sediment and have some reworking from AADW flows in the Transkei Basin/Natal Valley. In the North Atlantic, Rockall Trough has both a western boundary current constructing the Feni Drift on one side and deep sea fans (Barra and Donegal) and eastern boundary currents on the other side, with an abyssal turbidite plain in between. Here, however, there is little modern sediment input whereas the S.E. African cones and Okinawa Trough do have modern supply.

Upwelling areas have been targets principally for geochemical and biological studies of bottom sediments. However, the upwelling system off Walvis Bay in southwest Africa is associated with the Benguela Current and the reworking of the products of upwelling would be best carried out here.

These suggestions are by no means exhaustive. The working group has not sought to provide suggestions for everyone's own back yard. The cases we have mentioned are worth serious attention, at least a reconaissance study after gathering existing information together.

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