INTERNATIONAL WORKSHOP ON COHESIVE SEDIMENTS

TOWARDS A DEFINITION OF "MUD"

ABSTRACT VOLUME

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(editor)

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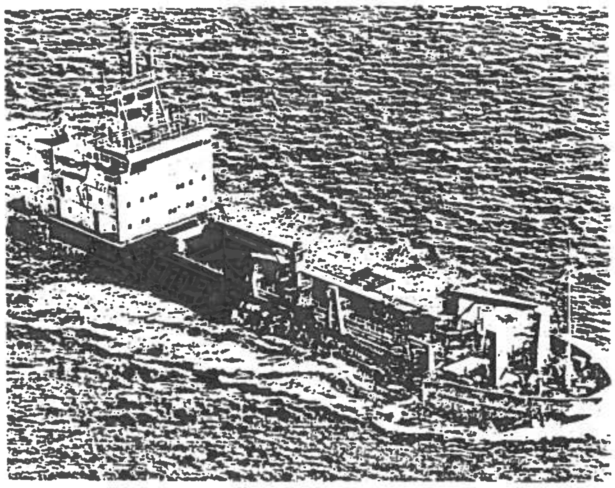
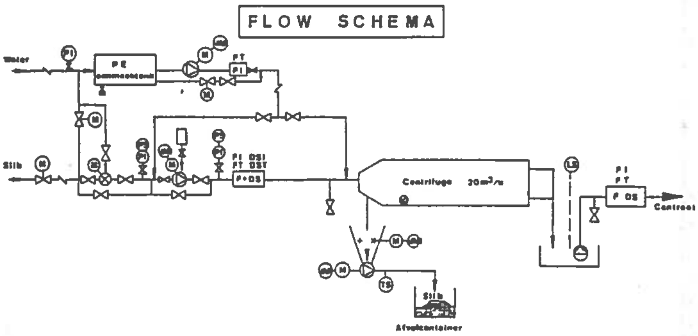
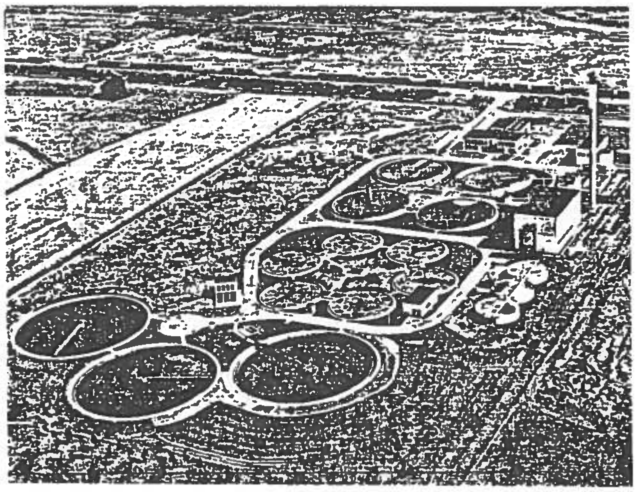




Sludge treatment.
Mobile decating centrifuge

engineering and
construction of
turn-key projects



Waste Water Purification
plant at Bruges,
300.000 I.E.

engineering and
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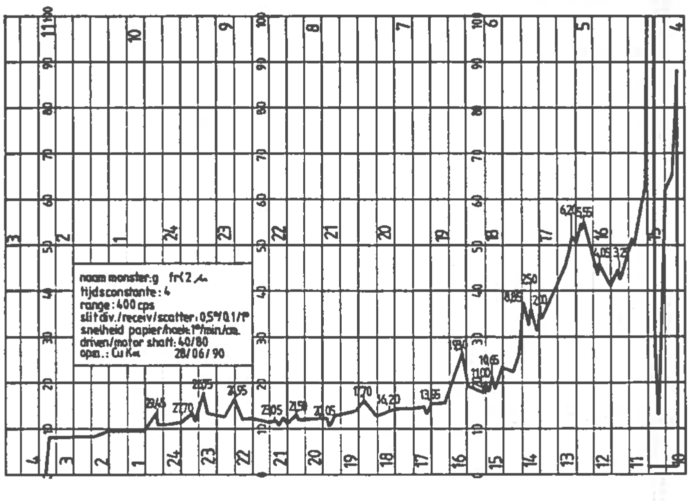

Caracterisation of dredged
materials and development of
treatment techniques
X-ray diffractogram of Scheldt silt

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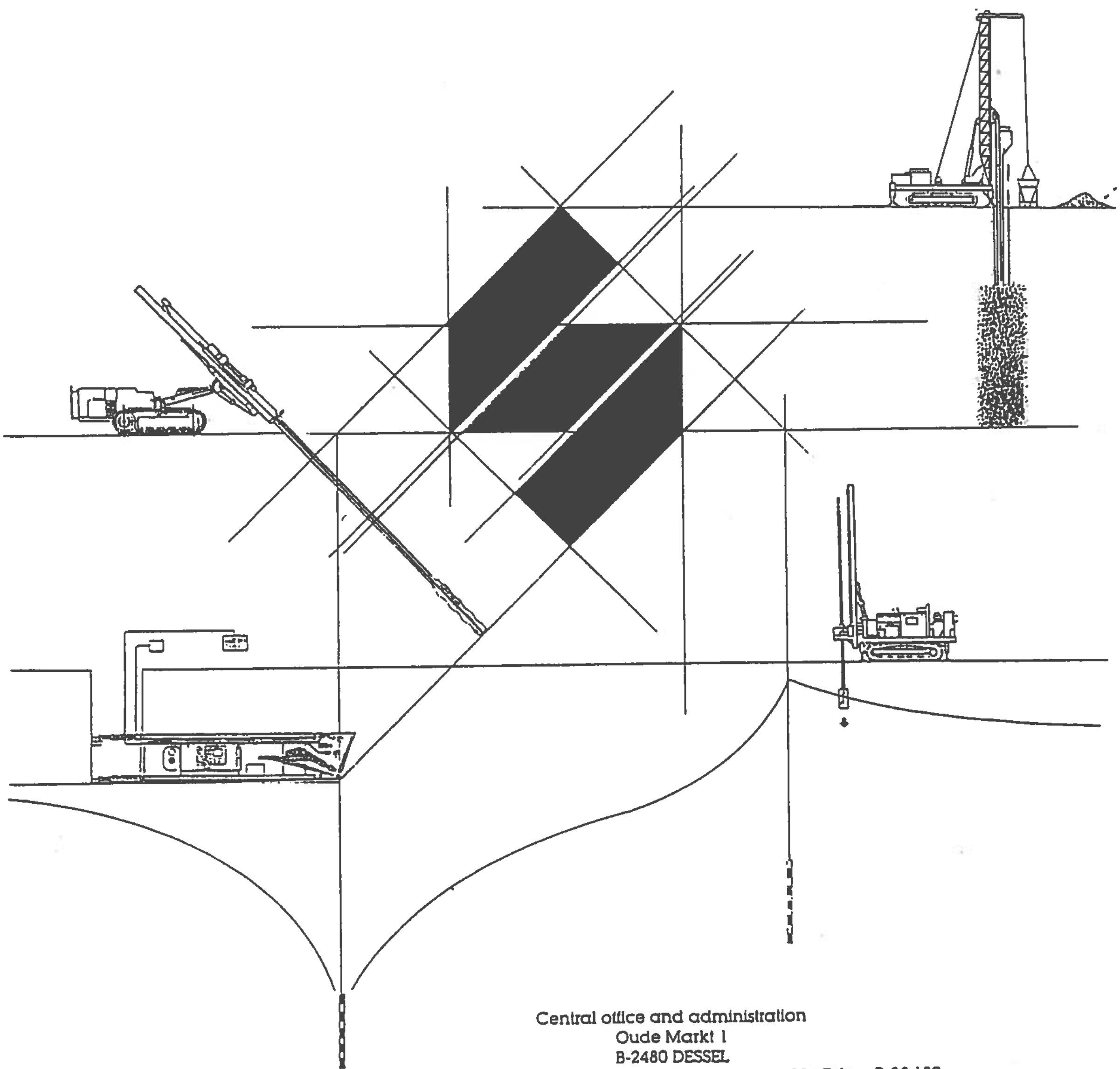

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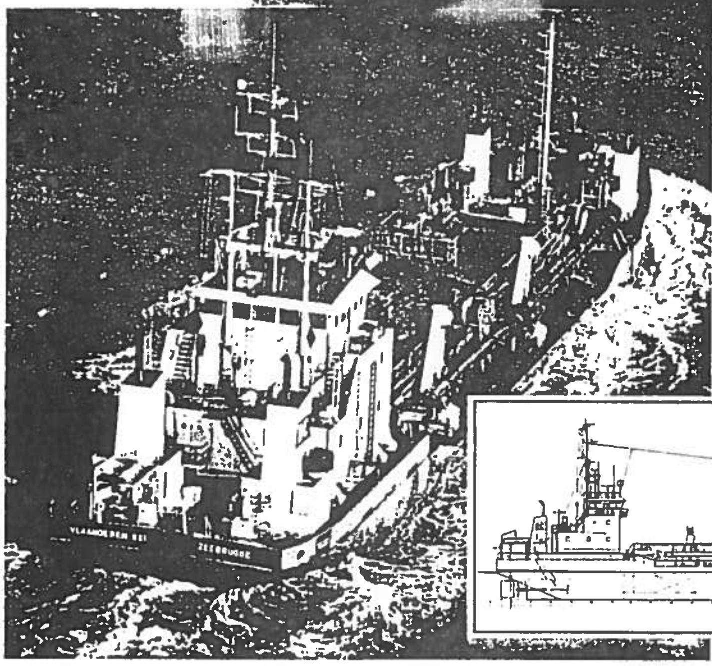

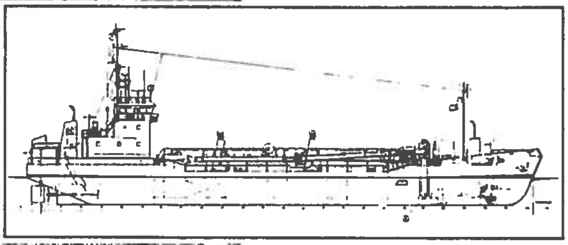

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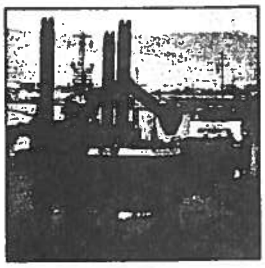

Backhoe dredge BIG BOSS in Izmir (Turquie).

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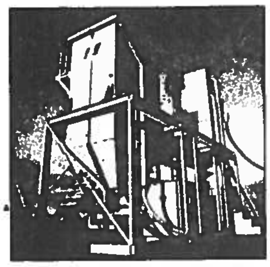

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Geochemical processes in mud and sandy sediments.

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Introduction:

Sediments play an important role in the functioning of aquatic systems. In shallow waters such as estuaries, coastal and shelf seas, a large fraction of the particulate biogenic material accumulates at the bottom. Through the action of heterotrophic bacteria the organic material is partially recycled into inorganic nutrients which diffuse back into the overlying water, where they stimulate new productivity. Simultaneously with the organic matter, major and trace elements are deposited at the bottom where they generally follow pathways which are completely different from those of the nutrients.

Considering now a typical sandy and mud sediment only differentiated on the basis of their granulometry. The sand sediment has a high content of particles larger than 63µm and the muddy sediment a low content. The rather simple pathways followed by organic matter and nutrients (production of bicarbonate, ammonia, phosphate, etc..., and the consumption of appropriate oxydants, see e.g. Froelich et al., 1979) are not substantially different in both types of sediment.

That is, however, not the case for major and trace metals, resulting not only in a different granulometry for sandy and mud sediments but also in a different chemical and mineralogical composition and a different biological habitat. When in addition to the natural variables, an anthropogenic (pollution) vector is added to the ecosystem, then this vector will further accentuate the differences between both types of sediments.

In this paper we will demonstrate the quite different behaviour of metals (major and trace) in a sand and a mud core, sampled on the same intertidal flat in the Scheldt estuary, only a few hundreds of meters distant from each other. The sedimentation pattern causes a granulometric gradient on the flat, resulting in a variety of sediment types if only based on this parameter. The bad quality of the Scheldt water, which is similar at both sampling sites, accentuates the difference in geochemical behaviour between the sandy and mud sediments.

Sampling area and analyzed parameters:

The Ballastplaat, an intertidal flat of approximately 250 hectares is located at about 60 km from the mouth of the Scheldt estuary. The flat is separated into two parts by a dike which also influences the sedimentation pattern: especially at ebb tide higher (lower) current velocities are observed upstream (downstream) the dike. The hydrodynamical pattern thus favours deposition of fine sediments downstream the dike, the muddy area, and erosion upstream the dike, the sandy area. Such a sedimentation pattern was yet demonstrated whith a mathematical model (Baeyens et al.,1981). In both areas sediment cores were sampled: station A in the sandy area, station B in the mud.

The sampling and analyses procedures are described in a related paper (Panutrakul and Baeyens, 1990). In each core ten slices were subsampled (1 cm slices from the top to 5 cm depth, 2.5 cm slices up to 10 cm depth and 5 cm slices up to 25 cm depth). In the interstitial water Eh, alcalinity, Cd and Pb were analyzed.

In the solid sediment Si, Al,Ti, Fe, Mn, Mg, Ca, K, Na, P, Cd, Pb, Y, La, Ce, Cu, Zn, V, Ba, Cr, Co, Ni and ignition loss at 550°C (organic matter) were determined. In addition sequential extraction of Al, Fe, Mn, Pb and Cd from the solid phase with appropriate reagents (Baeyens et al.,1988; Kersten and Förstner, 1987) allow to distinguish between the following fractions: (1) exchangeable and carbonate; (2) reducible; (3) acid soluble not yet destroyed in (1) and (2); (4) oxidizable; (5) residual. The same elements were determined in the sediment fraction < 63 µm.

Results and discussion:

The vertical major and trace metal concentration profiles in the bulk sediment at station A and B are qualitatively and quantitatively different. At a given station, however, most metals show a similar trend. At station A, the highest metal concentrations are found in the deepest layers (10 to 25 cm) except a few trace and major elements (SiO_2, Al_2O_3, CaO and K_2O, ignition loss and Fe are present in concentrations above 1%). At station B maximum concentrations are observed at 3 to 4 and 5 to 7.5 cm depth for most metals .

The difference in the bulk metal contents between stations A and B may be explained by the dilution effect of the fine contaminated silt/mud component through the coarse, sandy and non-contaminated component at station A. If this is the case, we expect the same range of metal contents in the sediment size fraction < 63µm at both stations as well as similar enrichment factors. This is, however, not the case. In the bulk sediment of station B, EF-values of Fe are slightly higher than at station A, EF-values of Mn and Pb are two times higher at station B and EF-values of Cd are up to 10 times higher at station B. So, despite the correction for the difference in Al content between both stations, Al is often chosen as reference element for the small particle size fraction, it appears that station B is more enriched in several trace metals. The EF-values of Fe, Mn, Cd and Pb at station A are fairly homogeneous with depth and are only enhanced in the deeper layers. Station B shows enhanced EF-values at the top for Fe, Mn and Cd (somewhat lesser for Cd), and in the 4 to 5 cm layer, but for Cd especially in the 5 to 7.5 cm layer. In the sediment size fraction < 63 µm the metal contents are still lower at station A than at station B up to about 15 cm, but then they come close to each other, or even higher at station A (for Al, Fe and Pb).

The explanation for this different geochemical behaviour is given by the redox potential profiles and is confirmed by the sequential extraction results (Panutrakul and Baeyens,1990). At station B the redox profile drops steeply from the first cm depth and tends to stabilize at - 210 mV from 6 cm depth on (this indicates a shallow switch at the sediment surface from oxic to anoxic) while at station A the oxic/anoxic interface is situated at about 8-10 cm depth.Why do we find such a different redox situation: (1) the amount of POM entering into the sediment at station B is much higher than at station A. Fine particles, containing high amounts of organic matter (between 8 at 10% ignition loss at the top of station B, only 2% at station A) preferentially settle down at station B. 93.5% of the sediment at station A, but only 39.8% at station B has a granulometric size larger than 63 µm; (2) the high amount of organic matter at station B, rapidly exhausts the total amount of oxygen, while the renewal through diffusion from the overlying water is limited, due to the small grain size and hence the compaction of sediment B.

Oxygen is only exhausted in the deeper sediment layers (above 10 cm depth) of station A. At 15 to 20 cm sulphate reduction may occur and precipitate the metals, leading to the enhanced metal levels in the deepest layers at station A. At station B, an intermediate redox zone (between 1 and 5 cm) where Fe and Mn reduction and dissolution occur, exists: hence other metals linked to Fe/Mn minerals are also liberated, the sediment showing depletion in this zone. At the surface reoxydation of Fe/Mn by oxygen reprecipitates these metals together with associated metals (this process leads to high EF-values at the sediment top). Once the sulphate reduction zone is reached (from about 5 cm depth), metal precipitation through sulphide formation occurs, like in the deepest layers of station A.

Conclusion:

Sandy and mud sediments do not only differ in grain size distribution and organic matter content. As a result of a higher oxygen consumption and a decreased oxygen intrusion, mud sediments show much lower redox values. Geochemical processes which control the metal distribution in sediments such as Fe/Mn oxyhydroxides dissolution in the suboxic sediment layer (at reduced redox values), reprecipitation at the oxic top layer, and metal-sulphide formation in the deeper anoxic layer, are much more pronounced in mud sediments.

In-Situ Studies of the Transport Properties of Fine-Grained Sediments in Estuarine and Coastal Systems : Review and Evaluation

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The development of numerical models providing quantitative estimates of the mass transport of fine grained sediments and associated contaminants in estuarine systems requires comprehensive data detailing transport factors under a variety of field conditions for model calibration and verification. In contrast to the majority of natural systems where abundant data were collected prior to the availability of adequate numerical modeling schemes, modeling of cohesive sediment transport in coastal systems has been impeded by field data limitations. Review indicates that the ability of available numerical modeling schemes far exceeds the quality and quantity of the field data supplied for calibration and verification. These limitations appear to be the result of the complexity of two-phase transport in marine waters and difficulties associated with the in-situ measurement of transport. System complexity results primarily from the moderate to high degree of spatial and/or temporal variability associated with fine-grained cohesive sediment transport in shallow waters. Measurements indicate that this variability extends from mm spatial scales on the vertical to km scales on the horizontal and from second to seasonal time scales. Such variability establishes some particular constrains on sampling and tends to confine model application to a well defined range in time and space. A single model is typically unable to encompass the entire range of conditions found in the system. In-situ measurements are complicated by the need for time series observation and the range of factors governing transport. To date, time series observations sufficient to satisfy the required sampling protocols have been limited to a relatively small number of parameters such as suspended material concentrations and the gross characteristics of the near-surface sediment column including benthic infaunal densities, sediment grain-size, bulk density and selected Atterberg limits. The majority of these latter observations are characterized by limited spatial and temporal resolution and are typically constrained by lack of suitable in-situ instrumentation sufficient to provide time-series measurements. Given these constrains it is not surprising that laboratory results detailing transport characteristics are difficult to reproduce in the field. Such difficulties lead to doubts of the utility of the lab data within models intended to simulate field conditions. A variety of laboratory and field data are reviewed to demonstrate these characteristics and to provide a basis for the evaluation of the present state of field measurements as input to system modeling and the requirements for future work. The results point clearly to the need for increased study of synergistic effects, a range of factors often difficult to detail in the laboratory.

Determining Resuspension Rates

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The resuspension rate of fine-grained sediments remains an empirical parameter relying on difficult, direct measurements. Lacking a standard method, investigators use a variety of approaches. Qualified estimates have been made by (a) empirical relationships to the bed shear velocity derived from flume studies, (b) measuring changes in the integrated concentration of suspended sediment, and (c) intercepting the settling flux. Flume studies can be done on either reconstituted sediments or undisturbed samples. In-situ flumes have also been constructed and, recently, a simple, particle-entrainment simulator has been applied to several environments using an oscillating grid to entrain sediment from an undisturbed sample. The vertically integrated concentration of suspended sediment has been determined from time-series of the concentration profiles which may be measured by filtering water samples, by optical or acoustic devices. Where the resuspension rate is very large compared to the rate of long-term accumulation, near-bottom sediment traps intercept the entrained particles as they resettle. Rates determined by different methods (and investigators) in Long Island Sound (CT/NY, USA) were comparable but provide little discrimination among sediment types or conditions.

AMELIORATION OF THE VENICE LAGOON THROUGH MORPHOLOGICAL INTERVENTIONS

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INTRODUCTION AND BACKGROUND

A number of major projects to ameliorate the lagoon, the historical City of Venice and the coastal areas are either currently being assessed or are being implemented. The present general approach to solving these problems is closely connected with the efforts to prevent the flooding of the City of Venice during excessively high tides. The Consorzio Venezia Nuova has been charged with co-ordinating the research, design and implementation of activities; its mandate includes also the construction of these projects.
The main project is the system of mobile gates at the inlets.
The Consorzio Venezia Nuova in 1989 presented a new, comprehensive approach which focusses on the links between the construction of the mobile gates, the general action of reestablishing the equilibrium of the environment of the Venice Lagoon and regulating the economic activities within the lagoon. The major projects are:

a) the design of a system of mobile gates for the complete control of flooding generated by storm surges;

b) the restoration of the lagoon morphology counteracting the on going erosion of wetlands and the sedimentation in the canals by means of dredging and reconstructions of wetlands using the same material;

c) the stopping and reversal of environmental decay of the lagoon's ecosystems, (sedimentation of sludge inside the city of Venice, algae blooms, etc.);

d) undertaking research and special projects, aimed at verifying the environmental and socio-economic impacts of the reopening of the fish farms within the lagoon and the development of aquaculture.

e) the design of an environmental management system for the major landfills built during the 1960 from the construction of the main navigation channel Canale dei Petroli;

f) the design of passive systems for the local defence of the urban centers against flooding;

g) the design and reinforcement of coastal protection works.

After a short description of the present status of the lagoon the paper takes into account the projects b), c), and d). The essential knowledge on sediments and related disciplines produced during the last four years is presented (almost one hundred studies and synthesis of previous investigations of various institutions such as Universities, National Research Centers, etc.).
Looking at the results, it is evident that, according to the objective of the studies, the description of the bottom of the lagoon is different:

- a solid or moveable geometric surface rispectively for current models and sediment transport models;

- a sink and source of pollutants for water quality models;

- a polluted mud to be dredged, transported and contained in an acceptable disposal site for Port Authority and Public Health Administration decision makers;

- a inorganic matrix of silica, alumina, and carbonates, which is coated with organic matter containing bacteria attached to its surface. The inorganic matrix contains also organic detritus and living organisms. Geochemical and biological processes modify the physical properties of the matrix.

From the experience on the studies on the Venice Lagoon the paper points out the incompleteness of current criteria for the definition of bottom sediment : there is a clear tendency of staying under the umbrella of a main discipline asking to the other disciplines to provide either "usual" parameters or "unusual" specific tests.
This problem oriented approach can contribute to the solution of specific practical problems, but it does not help in assessing a clear and comprehensive definition of bottom sediment.
This multidisciplinary approach "distorted" by the main discipline usually produces an increase in the number of tables of data included in the average technical report not used in the analysis; the extra data which do not influence the report conclusions are misleading and they contribute to increase the distance between research and practice.

The complexity of problems and the international awareness on the restoration and conservation of Venice and its lagoon have been stimulating Consorzio Venezia Nuova, who acts on behalf of the State, to strive for a better interface between research and practice; a significant improvement in transferability of environmental technology (such as the one developed by the U. S. Army Corps of Engineers on beneficial or accepted uses of dredged material) can be acquired establishing a standard interdisciplinary multipurpose criteria for the definition of sediment and bottom characteristics of coastal waters.

THE LAGOON OF VENICE

The hystorical boundary of the lagoon of Venice defines an area of some 550 km^2 (420 of which are covered by water, 90 by fish farms and 40 by embankments, coastal barriers, islands and land); the lagoon is connected to the Adriatic Sea by the port entrances of Lido, Malamocco and Chioggia and three hydrographic sub-basins may be defined, with surface area respectively of 276, 162 and 110 km^2 (Fig. 1). Daily water exchange between the sea and the lagoon is about 3 x 10^8 m^3 (the fresh water input is two order magnitude smaller). The lagoon has an average depth of 0.6 m and a salinity in the range 28-36‰ . Many natural channels cross the entire area.
Two main artificial canals, i.e.: Vittorio Emanuele (4 km long and 10-12 m deep) and Malamocco-Marghera (15 km long and 12-14 m deep) were dredged in 1926 and 1968, respectively, in order to allow the passage of large vessels to the industrial zone of Marghera (Fig. 1). At present, some 28.000 persons are employed in steel, chemical and other industries of Porto Marghera. Agricultural drainage (a maximum of 650 m^3/s and an average of 30 m^3/s of fresh water from 1.800 km^2 of heavily cultivated land) enters the lagoon at twenty points located along the inner border.
In addition to industrial and agricultural wastes, the lagoon has being receiving for several decades urban wastes from Venice (80.000 inhabitants), Mestre (240.000 inhabitants) and visitors (30.000 tourists in the average day).

The lagoon has a morphological system crossed by a network of canals which gradually diminish in section from the inlets towards the interior. There are two large channels dug in recent times to carry shipping to the industrial port of Marghera.
It is along these natural and man-made channels that the tide propagates inside.
Part of the lagoon is permanently submerged in water (shallows), part is permanently above water (islands) and part is submerged only by high spring tides (wetlands which constitute an important habitat for the characteristic lagoon flora and fauna).

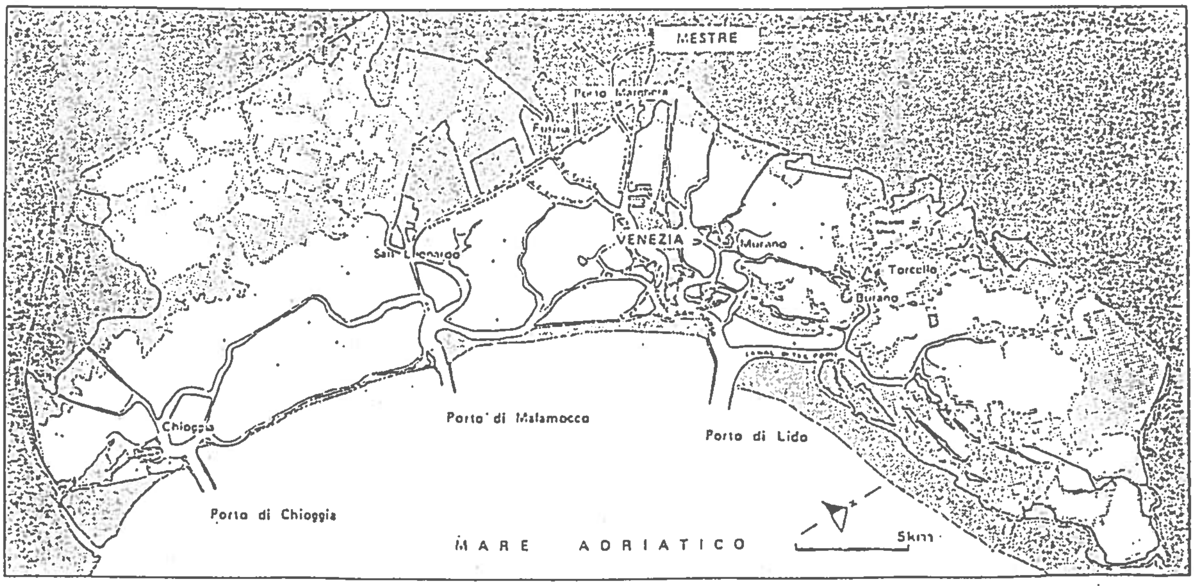

Fig. 1 Venice Lagoon

The history of Venice and its lagoon is the history of the difficult relationship between an environment under evolution and the continual efforts of man to adapt the some to his changing needs. From its first existance the city has had to fight the tendency to become filled with sediments brought by the rivers discharging into the lagoon.
The Venetian carried out, between the 16th and 17th centuries, a complex series of works to make lagoon accessible to shipping of ever - increasing tonnage (for military and commercial reasons), as well as to extirpate the malaria caused by stagnant water. The course of rivers such Brenta, Piave and Sile were redirected directly in to the open sea rather than the lagoon.

Because of its low altitude the historical centre of Venice is exposed and vulnerable to flooding. From the beginning of the century the relative sea level rise in Venice has been about 23cm (the sea has risen by about 11 cm, the land has sunk by 12cm because of subsidence mainly due to the intense extraction of groundwater from 1950 to 1970).
This comparable small relative sea level rise brings about serious risks for Venice if we consider that the average spring tide excursion is about 1 m and in the very first decades of this century St. Mark's Square was flooded 7 times per year while today flooding occurs, on average, more than 40 times a year.
While the antropic subsidence has been stopped in 1970 prohibiting the extraction of water, it has been agreed to design taking into account a scenario of 30-60 cm of global sea level rise over the next century.

The existance of a large harbor constitues the principal reason for many of the man-made transformations, such as the construction of the jetties and dredging of navigation channels.
The lagoon of Venice is one of the most important lagoon systems of the Mediterranean Sea. Throughout the centuries its size, shape and structures have evolved significantly due to natural and human actions (Fig. 2).

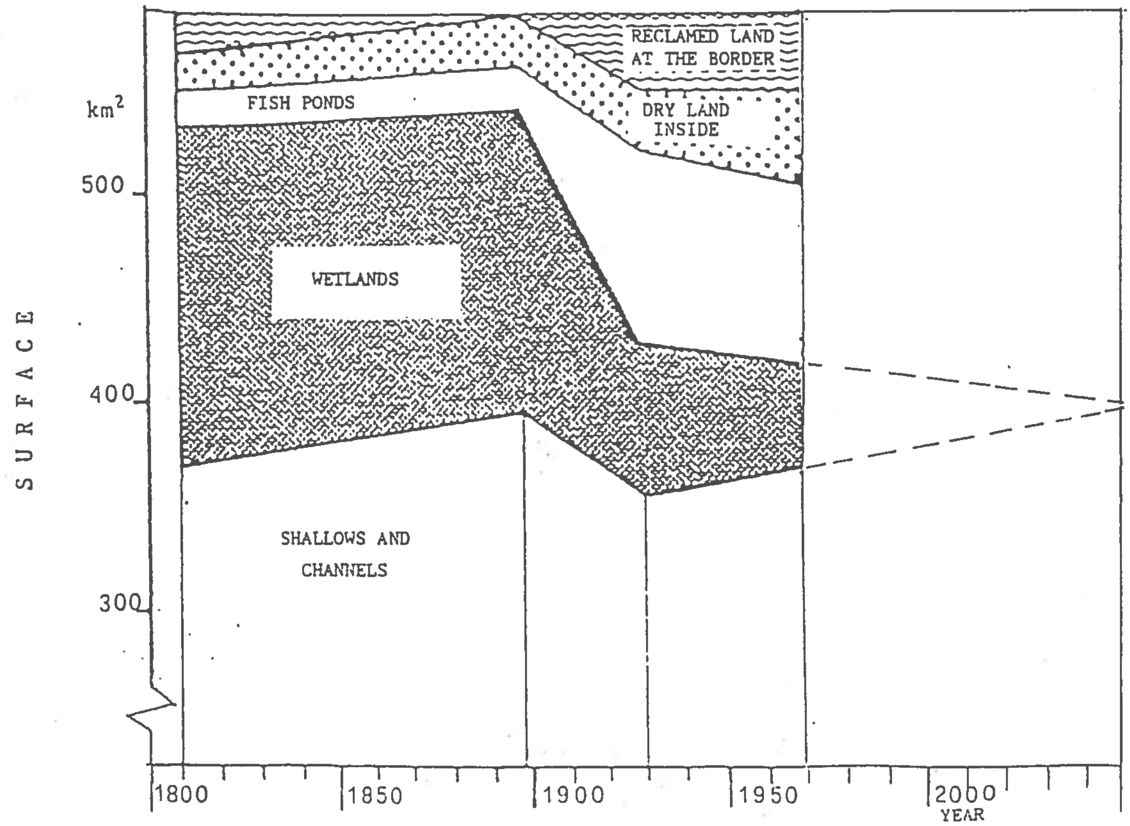

Fig. 2 Morphological evolution of the Venice Lagoon

SEDIMENT CHARACTERISTICS

The textural and mineralogical composition of the surface sediments in the entire Lagoon of Venice have been reported in the works of Barillari, Rosso, 1976; Barillari, 1978, 1981; Hieke Merlin et al. 1979; these authors have shown that, according to the lithological classification of Shepard, sandy silts (29%) and clayey silts (26%) are more abundant than silty sands (15%), sands (11%) silty clays (10%) and silts (9%). Sands were observed only in restricted areas near the three port entrances where strong tidal currents do not permit the settling of fine particles. There is a general decrease of particle size from these areas towards the inner parts of the lagoon.
In the entire lagoon, the average concentration of the pelitic fraction (d<63 μm) is 67%. Pelite is present in the largest part of the lagoon (Fig. 3). In the channels and the more confined shallows the concentration of the pelitic fraction is higher (80%-90% along the navigation channel; 70% in the channels inside the city of Venice which collect all the antropic waste).

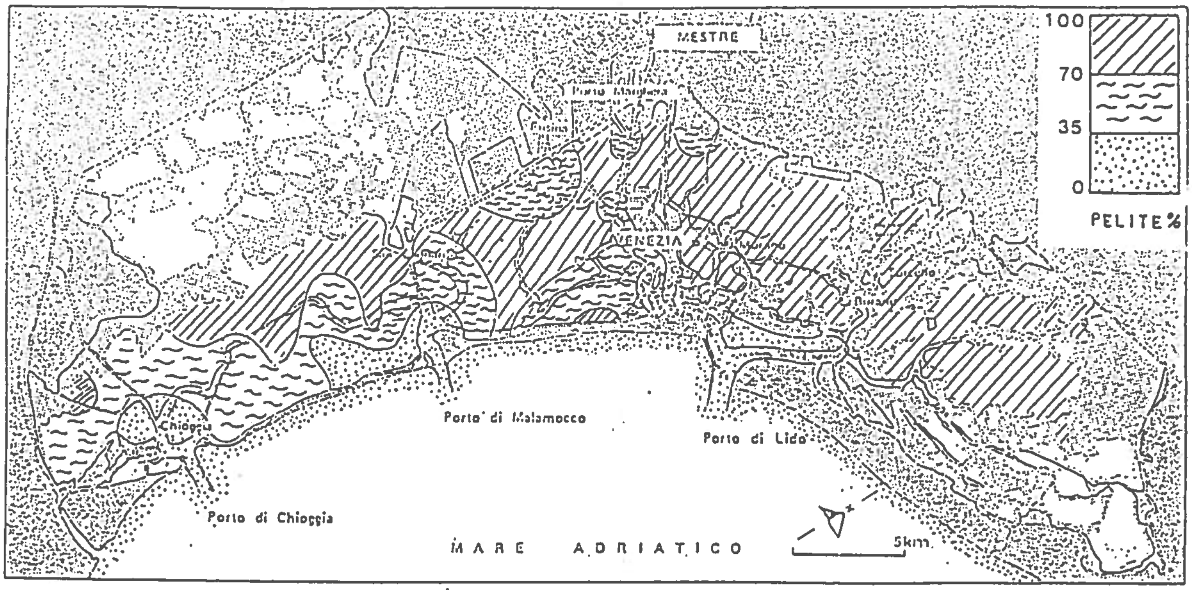

Fig. 3 Distribution of pelitic fraction (d < 63 μm). Drawn using data form Barillari, Rosso (1976), Barillari (1978; 1981).

Carbonates are the most abundant minerals (46%) with dolomite prevailing over calcite. Other identified minerals include quartz, clay minerals (illite, kaolinite and chlorite) and feldspars.

Comparing the sediment characteristics of Adriatic Sea and of the three lagoon sub-bacins of Lido, Malamocco and Chioggia, the pelitic fraction shows an increase in the content of silt relative to clay (Fig. 4). This result can contribute to explain why the shallows of Malamocco and Chioggia are more affected by the erosion process.

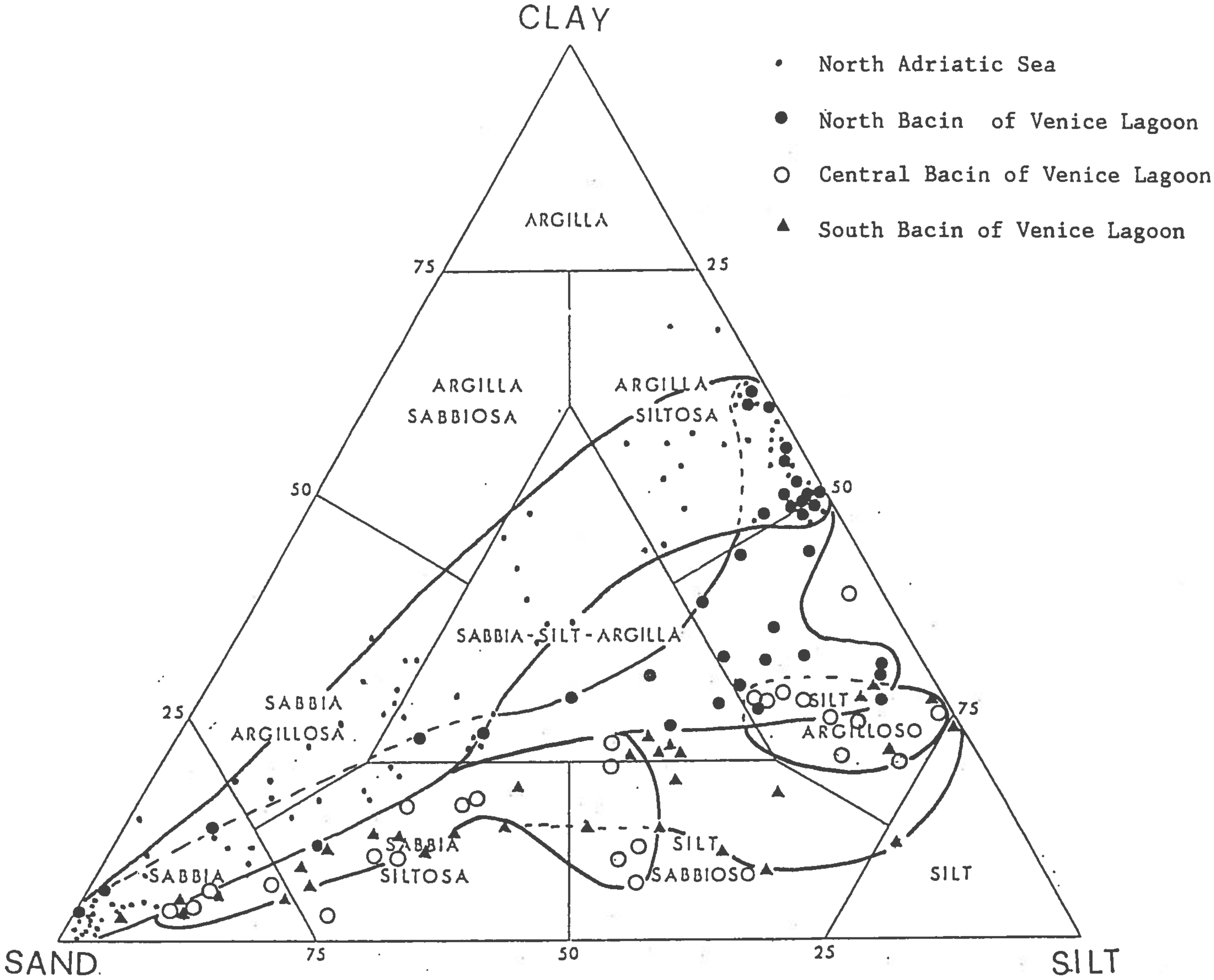

Fig. 4 Comparison of bottom sediment of Venice Lagoon and Adriatic Sea.

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IN-SITU TREATMENT OF CONTAMINATED DREDGED MATERIAL

The knowledge about the behaviour of contaminated dredged material has improved tremendously during the last few years. Also the number of techniques particularly developed for separation, sanitation and isolation have increased simultaneously. However, such techniques often have proven to be rather unsuccessful due to lack of scientific back up. SILT always tries to combine results of scientific research and technical feasibility into operational solutions.
An example of this is the treatment of harbour sludge in Zeebrugge.

In the inner harbour of Zeebrugge two heavily contaminated sites have been identified. High concentrations of PAH's have been located and identified, as have TBT (TriButylTin), from protective anti-fouling paints, and purgative organic pollutants.

The nature of these pollutants suggested the potentially most promising cleansing process to be an in-situ microbiological one. The technique opted for is a combination of Augmented Bio Restoration and Conditioning In-Situ (ABR/CIS), which consists mainly in adding cultures of selected microbiological populations together with certain chemical additives in order to condition the sediment. From preliminary experiments these cultures have proven to be fully compatible with those already present in the sediment.

Within the harbour, an area of about 1000 m^2 has been screened off by a turbidity curtain to be used as the site for experimentation. Using the chosen cleansing method on the sludge/silt within the isolated area, comparison can be made easily over time between the treated sludge laying within the isolated area and that in the surrounding harbour area.

Using a cutterdredger the sludge contained within the screened area has been mixed or inoculated with micro-organisms (ABR), nutrients and conditioning products (CIS) to a depth of about one meter below the harbour bed.

While the experiment is running regular sampling and testing is being conducted to determine and compare results between the treated and untreated area. In particular the following will be analysed and compared :

- microbial degradation of the organic pollutants
- microbial activity, using total plate count and respiratory tests
- identification of degrading microbial species
- intoxification (if any) by sediment-bound heavy metals.

In this way the efficiency of the cleansing process will be evaluated. The evaluation of the overall process implements technical and economical considerations for real scale projects.

Cohesive sediments in Scottish freshwater lochs and reservoirs.

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Studies of cohesive sediments in the natural environment have almost entirely been directed towards those materials deposited in marine and estuarine settings. Cohesive 'muds' are not, however, confined to these systems but are also characteristic of many freshwater lakes and impoundments. In this contribution we draw attention to the physical properties of such sediments which typify the freshwater lochs and reservoirs of Scotland. These water bodies range in scale from large (5-10 km long), deep (50-150 m) lochs occupying glacially-scoured rock basins to small, drift-dammed lochans and artificial, water supply reservoirs. In general, below surface water wave base, fine cohesive silts and clays are the dominant deposits. These charcteristically have both high water contents (65-75% by weight) and high concentrations of oxidisable organic matter (>20% by weight).

Examination by light microscopy and S.E.M. of suspended sediments collected from the water columns and surficial bed materials demonstrates the almost universal occurrence of aggregate bodies comprising mineral grains, diatom tests and organic matter. This texture is reflected by sediment settling experiments.

Whereas in the presence of a chemical dispersant the sediment particles fall as individuals (Stokesian), when resuspended in native lake water (ionic strength = 5 x 10^{-4} to 2 x 10^{-3} mole l^{-1}) aggregates form in suspension with the onset of settling. These are up to 2 mm in diameter and are clearly visible with the naked eye. Settling velocity grading curves, derived via the pipette method, reveal that median settling velocities are usually about one order of magnitude greater in the 'natural' mode compared with the 'dispersed' mode. Further experiments in native lake water using sediments from which the organic matter had been removed (by H_2O_2 treatment) demonstrate settling velocity grading curves closely comparable with the latter. The organic materials adsorbed onto grain surfaces undoubtedly play a major role in aggregate formation, possibly through the creation of polymer bridges between particles. This will be explored further in the paper.

The deployment of the seismic reflection technique of sidescan sonar in the Scottish lochs and reservoirs has enabled recognition of low relief (0.25 to 0.5 m), blister - like slides in the cohesive deposits on basin slopes. In the major lochs studied these underwater mass movements of sediment occur discontinuously, but in regularly distributed zones, at the level of the summer thermocline. Internal waves (seiches) on the thermocline lead to circulation patterns dominated by periodically reversing horizontal currents in nodal positions, and vertical motion at antinodes. Although the currents (<7 cm s^{-1}) are too weak to entrain the deposited cohesive sediments, we believe that they exert sufficient shear stresses at nodal regions to cause breakdown of aggregate structures. This leads to shear thinning of the surficial sediments and a consequent deepening of the weakened, near-bed concentrated suspensions which begin to move down the often steep (up to 20°) basin slopes. As water escapes, shear strength is regained and the sediment ceases to move, leaving zones of blister-like slides centred on the nodal regions. At the antinodes no slides are normally developed. Simple viscometry experiments have confirmed the shear thinning behaviour of the deposits, the thixotropic behaviour of which is demonstrated by hysteresis loops for readings of shear stress taken at increasing and decreasing shear rates. Where lake bed sediments have undergone failure, differences in internal texture are detected by low frequency sub-bottom profilers.

Field and laboratory measurements of floc properties

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Laboratory measurements have been carried out on flocculated mud from the Tamar Estuary at a number of concentrations and salinities. Results show that floc density reaches a maximum between 10 and 15 $^{o}/_{oo}$ over a wide range of concentrations. Floc strength measurement in a calibrated vibrating column shows that the binding force per unit cross sectional area of the floc increases with floc diameter. However, strength of the individual particle bonds decreases with the increasing floc size. These results are at variance with the commonly observed breakup on sampling of the larger flocs, and this implies that flocs produced under laboratory conditions may have a more uniform structure than those produced in the field.
Field measurements of floc size in the Tamar Estuary show an abrupt decrease within the turbidity maximum, showing that floc disruption through collision may be a dominant process.

Abstract

Particle size analysis of suspended material

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At present chiefly four types of particle size analysis have been carried out on particulate material in suspension: a) in-situ measurements, b) with a Coulter counter, pipet, microscope or other methods after sampling, c) the same methods after ultrasonic treatment, and d) the same methods after removal of the organic matter by oxidation. Recent developments of in-situ measurement now allow measuring a size range from ca 3-4 µm up to maximum size, whereas the other methods have been in use already for decades or longer. The in-situ measurements give the particle size (floc size) as it is in the water, while the particle size measured after sampling is an indication for floc-strength. The particle size after removal of the organic matter gives the size of the unflocculated mineral particles, which can be compared directly to the grainsize of bottom sediments and soils. The interpretation of the different types of particle size is discussed more in detail and some future lines of research are indicated.

Microbial activity in sandy and muddy sediments.

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Muddy sediments generally differ from sandy sediments by a higher content of organic matter. This probably does not result only from an organic matter input, but also could depend on the rate and extent of particulate organic matter (POM) degradation. In muddy sediments pollutants like heavy metals might show an inhibitory effect on microbial POM degradation (in any way a stronger effect than in sandy sediments) while conversely, organic compounds present in the system could have a significant effect on the solubility and mobility of these heavy metals by chemical and microbiological action. The partitioning of metals between the particulate and dissolved phase mainly results from adsorption - desorption processes (Balls, 1989). The behaviour of metals depends on their chemical speciation which is a consequence of their source, but also on the physico-chemical conditions of the environment such as maximum turbidity zone, salinity gradients, ionic strength, pH. Microorganisms also play a leading role in the dissolution of metal oxides by direct or indirect action (Francis Dodge, 1988). Direct action involves enzymatic reductive dissolution of the metal oxide, by which the oxide can be used as the terminal electron acceptor, whereas indirect action involves dissolution due to production of metabolites such as organic acids, chelating agents and lowering of the pH of the medium. Today, only a few studies deal with the relationship between microbial activities and mobilization of pollutants in the bulk sediment of the Scheldt estuary. Since data on benthic macrofauna (Vanhooren, 1989) and concentration of heavy metals in the sediment (Panutrakul, 1989) of the mudflat 'Ballastplaat' in the Westerschelde suggest that varying concentrations of metals in the sediment could result in a different colonisation of macrofauna, we suspect that microbial communities could also play an important role in these processes. Therefore, a study of bacterial activities in relation to polluant mobilization has been undertaken at the same place for two station, A and B, corresponding respectively to a sandy and a muddy sediment. Let us consider a simple model based on our preliminary results for the oxidation of organic matter in both kinds of sediments:

- In the upper layer of sandy sediment (St. A), oxygen is apparently the terminal electron acceptor. Substantial numbers of aerobic chemoheterotrophic bacteria (most of which were gram-negative) can be enumerated by a classical plate count method. As oxygen is consumed, conditions may become locally anaerobic and fermentative organisms will develop. The products of fermentation then diffuse to regions in which oxygen is still

present or they may be oxidized anaerobically by organisms able to reduce nitrates, sulphates or carbonates. Reduction of iron and sulphate is already detected near to the subsurface of the sediment. The FeS (+ FeS_2) profile increases slowly with the depth under the 1 cm level, but most of the iron remains in the ferric form. Small concentrations of reduced sulphur are detected in the interstial water. Eventually, the organic compounds will be completely converted into CO_2 or assimilated and the condition will again become fully aerobic. Metals initially bound to the particulate organic matter (POM) may be transfered into the dissolved phase during this process. The mobilized pollutants may return back to the water column or continue their internal cycle in the sediment through adsorption on certain specific mineralogical phases or precipitation of an authigenic phase
- The higher organic matter content of muddy sediment (St. B) results in a rapid exhaustion of the dissolved oxygen. For this reason, POM degradation is most probably first mediated by Clostridia and other fermentative anaerobes with the formation of CO_2, H_2, NH_3, organic acids and alcohols. Other electron acceptors are then involved in the oxidation of the fermentative products : successively nitrate, iron (and manganese) and sulphate are solicited and reduced. The activity of sulphate reducing bacteria is particulary apparent in station B. Signs of the process are the odor of H_2S and the pitch-black color of the mud. The sulphate concentration profile decreases rapidly with depth over the 3 cm level and then remains constant. In incubated sediments, sulphate reduction is most active in the 0-0.5 cm depth interval, but a stimulation can be observed even in lower depths in spiking experiments. When incubations are done in the presence of light, a complete sulphur cycle is observed with the development of the photosynthetic purple and green sulphur bacteria. In obscurity, a methane production in the 0-0.5 and 1-3 cm depth intervals is detected when sulphate was exhausted from the medium. Methanogenesis can, therefore, be considered as the terminal process of organic matter oxidation since present information suggests that methane cannot be further metabolized under anaerobic conditions. In natural environment, much methane escapes and this loss constitutes the only significant leak from the anaerobic cycle of organic matter. The iron concentration profile increases over the 8 cm level and then declines slowly with depth, but most of the iron is in ferrous form. It is possible that part of the iron reduction results from a bacterial activity, since an enrichment culture has shown that some bacteria are able to metabolize glucose or a mixture of amino acids with a concomittant reduction of Fe (III). It is not demonstrated, however, whether these bacteria could obtain energy for growth from an iron reduction. The reduction of Mn (IV) and Fe (III) has direct influence on the heavy metals partitioning between the dissolved and particulate phases. Mn and Fe oxy-hydroxides are known to be efficient heavy metals scavengers and their reduction remobilizes these pollutants. Since the pore water content of H_2S in the muddy sediment is astonishingly low and, the FeS (+ FeS_2) concentration in the bulk sediment rather high

(10 times higher than in St. A), it is probable that the sulphate reduction could precipitate a number of metals as sulphides.

To summarize, although degradation processes of organic matter appears different in both kinds of sediments, their influence on heavy metals mobilization could be more or less similar. Inhibition of certain biological processes by pollution , especially in the muddy sediment where the contamination by heavy metal is high, could alter the rate of POM degradation and, consequently, modify the structure of the sediment by making it more viscous. To what extent microbiological processes coud be effectively inhibited by pollutants is as yet unknow and further research work along these lines is in progress.

References :

- Francis, A.J. & Dodge (1988). Anaerobic microbial dissolution of transition and heavy metal oxides. Appl. Environ. Microbiol., **54**, 1009-1014.
- Panutrakul, S. (1989). The contamination and mobilization of metals in the sediments of an intertidal mud flat of the Scheldt Estuary, Belgium. FAME thesis. Laboratorium voor Analytische Scheikunde, Vrije Universiteit Brussel.
- Vanhooren, H. (1989). Verspreiding van macrozoobenthos in de Westerschelde : Invloed van abiotische factoren en pollutie. Licentiaatsverhandeling, Rijksuniversteit Gent.

Rheological Boundaries of "Mud" - Where are the Limits ?

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Abstract

"Mud", a complex mixture of inorganic particles smaller than 63 μm, usually combined with a variety of organic compounds, occurs in numerous depositional settings and environments, and exhibits a broad range of responses to stresses generated within the environment. The complex behavior of "mud" makes it necessary to study each occurrence individually as it has not yet been possible to develop satisfactory generalizations which describe its behavior with great precision.

"Mud" can be visualized as a member of a continuum of a multi-phase system composed of sediment particles and water (in which both organic and inorganic substances may dissolved), the end members of which are **dispersions** and **shales**. During lithogenesis, the water content of the mixture is reduced, causing it to pass through a consistency state defined as **liquid** (possessing no measurable shear strength and behaving as a viscous fluid). The end of this state may be specified by the **liquid limit** of the material, defined as the water content at which the material ceases to exhibit liquid properties. "Mud" occupies a position in the continuum within the liquid state (e.g., fluid mud), but appears to extend significantly into the plastic state (e.g., settled mud). Here its lower boundary can be defined by its **plastic limit**, i.e., the water content of a sediment sample at which the mixture ceases to exhibit plastic (e.g., deformable) behavior. This limit is quite variable and depends to a large extent on the mineralogy of the fine-grained constituents and the nature and amount of organic matter found in the material.

The rheological properties of these "muds" are both time- and density-dependent phenomena, enhanced by the geochemical properties of the particles. Consequently, complex mineralogical mixtures, generally composed of small particles possessing large surface areas, high cation exchange capacities (CEC's), tend to flocculate and settle slowly and develop time-dependent properties slowly (e.g., yield stress, shear thinning flow behavior). "Muds" possessing these characteristics (e.g., smeetites) have been analyzed from microtidal environments (Newport River, Neuse River, Mississippi Sound, Chesapeake Bay). Other "muds" composed of less active minerals (quartz, feldspar, illite and chlorite) flocculate and settle rapidly, quickly develop yield stress, and usually

display shear-thickening (dilatant) flow behavior. Such deposits have been analyzed from macrotidal environments (Scheldt Estuary, Belgium; Cornwallis Estuary, Nova Scotia).

The rheological properties of "mud" may be responsible for determining the ultimate preservability of the material as a recognizable geologic unit. The concept of "preservation potential" of mudrocks has previously been expressed with reference to depositional sites. A more fundamental approach to "preservation potential" would be concerned with the rheological behavior of the suspension under hydrological stresses. Thus, a suspension that responds to shear stresses in a **dilatant** fashion (shear thickening) would demonstrate a greater preservation potential than a suspension which responds in a **pseudoplastic** fashion (shear-thinning). The former behavior tends to reduce resuspension and increase bed retention; the latter behavior tends to favor resuspension and sediment loss from the bed.

During lithogenesis, the changes in solid-liquid relationships involved in the transformation of the **dispersion** to **shale** involves understanding the physical behavioral changes that accompany the removal of the water phase and the concentration of the solid phase (particles plus organic matter). Overprinting these changes are the chemical reactions associated with interstitial waters of oceanic/estuarine chemical composition. These complex interactions manifest themselves in the time-dependant rheological behavior of these particulate systems as they proceed from one consistency state (e.g., liquid) to another (e.g., plastic). Thus, the transition from "mud" to shale is recorded by changes in the plasticity and compressibility of the material until finally a condition is reached at which the material no longer deforms but acquires the properties of a brittle solid. This condition, determined by the arrangement of the sedimentary particles, is permanently recorded in the sediment as a **fabric** and may take many geometric configurations. The essential feature involves the destruction and breakdown of the flocculent structure associated with the "mud" consistency state and the conversion to an oriented "face-to-face" particle configuration. Dewatering, void ratio reduction, and densification due to mass enhacement characterize the end of the "mud" phase and the beginning of the rock phase.

Time dependent changes of deposited cohesive sediments in Northern Chesapeake Bay, U.S.A.

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Navigation channels in the Northern Chesapeake Bay are routinely dredged to permit vessel passage. Annual maintenance dredging requires the removal of approximately one million cubic meters of predominantly fine grained sediments in which silt and clay sized particles average 60 and 40 percent respectively. Sand sized materials average less than 5 percent of the sediment by weight. A large proportion of these sediments are deposited overboard at designated disposal sites via hydraulic pipeline in the late fall to early winter period. The disposal sites are located within the turbidity maximum zone of the Chesapeake Bay in water depths ranging from a minimum of 3 meters to a maximum of 17 meters. Minimum suspended sediment concentrations in the turbidity maximum average 15-20 milligrams/liter, but concentrations commonly exceed 200 mg/l during periods of high fresh water input and during resuspension events. Current velocities are characteristically low in the Chesapeake with maximum tidal velocities on the order of 50 cm/sec.

Repetitive, multiple years' deposition at these designated sites has permitted the examination of the deposits through time as they alter from a hydraulically pumped high water content fluid nature to a more consolidated deposit similar in character to naturally deposited cohesive sediments. The changing bulk properties of the sediments, their thickness and volume, repopulation by benthic infauna, and the potential for resuspension by tidal currents have been evaluated. In most cases repeated surveys have been conducted over a period of one year, until the subsequent depositional event occurs. However, at certain sites, the absence of yearly depositional events has permitted identification of changes in deposit characteristics over periods in excess of 36 months.

The majority of the sediment discharged at the distal end of the hydraulic pipe descends rapidly to the bottom as a density flow. Turbidity plumes generated in the water column during the disposal operations have been found to only extend a maximum of 1 kilometer from the point of discharge during times of maximum tidal current velocities. Turbidity flows along the bottom have not been observed either during or immediately following deposition. However, the location of the deposited sediment on the bottom relative to the discharge point and the known turbidity plume distributions strongly suggests that density flows along the bottom account for much of the final placement of sediment.

On acoustic reflection surveys conducted immediately following the disposal operations, the deposited sediments are internally reflection free and overlay a clearly defined strong reflector which represents the pre-disposal bottom. Sediment thicknesses of up to several meters are often attained. Gravity cores collected from the deposit return muddy sediments with high water contents, and calculated average bulk densities of 1.13 g/cc. On Xeroradiographs the cores exhibit fine laminations representing grain size variations which occur during the disposal operations. The sediment surface is flat and benthic infauna are lacking.

The pre-disposal sediment-water interface can be clearly identified on both the acoustic reflection profiles and in the gravity cores. Burrow traces produced by benthic infauna provide distinctive markers of former sediment-water interfaces, as does the strong character of the acoustic reflection from that interface. Often multiple years of deposition can be observed within a sediment core.

Acoustic surveys conducted at periodic intervals following each depositional event clearly reveal that the deposit thins and that the total volume decreases over time. This is due to the combined effects of autocompaction, as the sediment pile dewaters, and resuspension and removal of material from the surface under the influence of currents. On average, these deposited fine grained sediments undergo a reduction in volume of 20% within the first 3 months, 35% after 6 months, 50% after 9 months, and 65% after 18 months. The rate of change in reduction of sediment volume decreases with time as the material becomes more compacted, both slowing the expulsion of water and producing a greater resistance to erosion.

Sediment water contents and calculated porosities and bulk densities have been determined from sediment cores collected at the times of the acoustic surveys. These indicate that, for example, average bulk densities increase from the 1.13 g/cc observed within a few days following the completion of disposal operations to between 1.25 and 1.35 g/cc a year later. Bulk density changes of this magnitude would account for approximately 10% of the total reduction in volume of the deposit. Comparison of this value with the total volume reduction determined from the acoustic surveys indicates that the remainder of the volume reduction should be due to resuspension from the sediment surface.

Tidal resuspension experiments have been carried out at a site in 3.4 meters of water depth immediately following deposition. Estimates of bottom shear stress have been made using a quadratic drag law modified to account for the intense near bottom stratification observed. Tidal resuspension appeared to follow a linear relationship between erosion rate and the excess of estimated bottom shear stress over some critical value, but both the constant of proportionality ($M = 0.5$ mg/cm^2/h) and the critical shear stress ($\tau_c = 0.16$ dynes/cm^2) were much less than many previously reported results. In addition, the total resuspended sediment load observed during maximum tidal resuspension events only requires the erosion of 0.28 mm of surficial sediments (at the observed bulk densities immediately following deposition). Thus normal tidal erosion apparently cannot account for the decrease in volume of deposited sediment in the period following deposition. Although confirmatory evidence is lacking it is more likely that the decrease in volume observed is due to the superposition of tidal and wind driven currents with wave induced velocities and pressure fluctuations during storms. Preliminary results from a deployment during a minor storm event support this contention.

CHARACTERIZATION OF MUDS PROPERTIES FOR ENGINEERING PURPOSES

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1. INTRODUCTION

Typical engineering studies involving mud carried out for 30 years by the french laboratories SOGREAH (Grenoble) and Laboratoire Central d'Hydraulique de France (Maisons -Alfort) have covered the following fields :

. Maintenance of depths (harbour basins, navigation channels, water intakes and dam reservoirs)

. Navigation in muddy waters

. Evolution of waste disposal sites (dredged material in the coastal zone, sewerage sludges, industrial wastes).

In order to describe adequately the properties and dynamics of cohesive sediments, specific methods have been developed. Their review is the aim of this paper which will cover laboratory tests and field measurements.

2. LABORATORY TEST

The parameters regularly determined in the laboratory to characterize the behaviour of mud are :

- Dry sediment density
- Particle size grading
- Mineralogy
- Organic matter content

- Settling velocity Ws (C,S) :
function of suspended sediment concentration and water salinity (Andreassen's method)

- Yield value τy(Ts):
function of the dry sediment density
(viscosimeter Brookfield LVT with a rotation speed of 0.3 revs/mn)

- Viscosity η(Ts):
function of the dry sediment density
(viscosimeter Brookfield LVT with different rotation speeds)

- Consolidation : Tsmean (Ci, Hi, t):
mean value of the dry sediment density
function of initial concentration, initial height of the deposit and time, (Settling columns 0.2 to 4m high and 100mm of diameter)
: Ts(z,t,Ci,Hi)
vertical profile of Ts in the deposit
(Settling columns + Gamma densimeter)

- Critical shear stress for erosion τce(Ts):
function of the dry sediment density (Flume tests)

- Equilibrium slope of immerged and emerged deposits tgα(Ts): function of the dry sediment density (Flume tests)

It should be noted in this list that we consider that the knowledge of the dry density profile of a mud deposit is not enough to characterize its mechanical properties in presence of hydrodymanic factors (currents, waves). The erodability of cohesive sediments is primarily function of its rheological properties which are not simply related to the dry density (Migniot and Hamm, 1990).

3. FIELD MEASUREMENTS

Comprehension of the dynamics of mud transport, erosion and deposition requires detailed field measurements including :

- hydrodynamic conditions (levels, current profiles, waves)
- water properties (salinity, temperature, ph)
- suspended sediment concentration profiles
- radioactive tracers experiments
- detection of the fluid mud (echo soundings)
- fluid mud properties (dry density profile, viscosity profile)

The measurement of fluid mud properties in the field has required the development of devices and methods for measuring the physical characteristics of fluid muds, such as the JTD 3 gamma densimetric fixed point probe (CEA - ORIS - Caillot et al, 1984), JTD 4 gamma densimetric probe (CEA - ORIS), SD 105 continuous operation ultrasonic densimetric probe (Port of Bordeaux Authority) and SR 10 rheological probe (LCHF - SOGREAH - Galichon et al, 1990) these are now fully operational.

Radioactive tracers experiments are used to follow the evolution of dredged material discharges (Tola et al, 1984).

4.A PRACTICAL APPLICATION : NAVIGATION IN MUDDY WATERS

One recent application of the methods described above deals with the navigation in muddy waters. Extensive laboratory and in-situ measurements in the navigation channels of two main estuaries (Loire and Gironde estuaries) linked with scale model experiments (Brossard et al, 1990) have enabled to define more precisely the navigable depths in the turbidity maximum. Results of tests and measurements will be presented in the paper.

5.REFERENCES

. Brossard C. Delouis A, Galichon P., Granboulan J, Monadier P. (1990)
"Navigability of mud silted channels - scale model experiments"
Abstracts of 22nd ICCE, Delft, 95-96.

. Caillot A, Meyer G., Chambellan D, Tanguy J.C. (1984)
"A new nuclear density gauge to measure directly high turbidities in muddy areas".
Proc. 19th ICCE, ASCE, 3172-3179

. Galichon P., Feral A, Granboulan J, Viguier J (1990)
"Rheological properties of muds in the Gironde Estuary - spatio- temporal variations in rigidity"
Abstracts of 22nd ICCE, Delft, 369-370

. Migniot C, Hamm L. (1990)
"Consolidation and rheological properties of mud deposits"
Abstracts of 22nd ICCE, Delft, 371-372

. Tola F, Caillot A, Courtois G, Gourlez P, Hoslin R., Massias J, Quesney M, Sauzay G (1984)
"Study of the evolution of dredged material discharges by means of radioactive tracers".
Proc 19th ICCE, ASCE, 2042-2062

Comparison of field yield stress measurements and rheological yield stress measurements.

by
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Introduction.

The present study investigates the relationship between a common field method for determining the yield stress of cohesive sediment, and a more detailed laboratory rheological analysis. Samples of cohesive sediment were collected from several sites were located in the intertidal zone of the Severn Estuary during the summer months of 1989. At each site samples were collected along a line extending seawards from the high water mark, different sampling methods were examined. Field vane shear measurements were recorded at each station. Rheological investigations show that care must be taken when using a field vane instrument. The time dependency of the vane shear apparatus has been investigated.

Methods.

In the collection of cohesive sediment samples for rheological testing it must be recognised that any meaningful study must consider the role of changing structural levels within samples occasioned by mechanical disruption on collection and subsequent recovery after collection. Two methods of sample collection were tested.

The first method consisted of the retention of bulk samples of the surficial sediment to the depth of the measurement vane. These samples were stored in sealed containers to preserve moisture content until required for analysis.The second method involved collection of samples in specially designed containers that allow access for laboratory testing in the rheometer with minimal mechanical disruption of the sample. Samples obtained using both methods were stored at 4^0C prior to laboratory analysis.

At each sampling site, a series of geotechnical vane shear measurements were made. The instrument employed (Pilcon DRI-240) is typical of this type of device and measures yield stresses in the range 0-120 kPa. At least 25 vane shear readings were taken in $1m^2$ quadrats, the mean value is reported.

The rheological measurements appropriate to discussion herein where made with a modified Carri-Med CS100 Rheometer, fitted with the miniature vane geometry discussed in detail by James and co-workers(1987). In the present study five miniature vanes were used and the quasi-static yield stresses of the sediments were determined following the methodology established by these authors.

Prior to determination of the quasi-static yield stress it is necessary to establish the equilibration time of the sediment sample. In the present study the equilibration time was determined using oscillatory shear measurements, which involved the kinetic measurement of the stress response of the sediment to oscillatory strains at a fixed frequency. The stress response was analysed to obtain the storage modulus, G',as a function of time. The equilibrium time is identified when a quasi-constant value of the storage modulus is detected. These tests were carried out using a Carri-Med CS100 rheometer with a parallel plate testing assemblage, an oscillation amplitude of 1 milliradian and a oscillation frequency of 10 Hz. A vapour trap was used to ensure that the water content of the sample did not change during the experiment. Equilibration times of around 300 seconds were observed.

Samples of cohesive sediment collected by the first method described above were rehomogenised before analysis. This technique was found to produce consistent results when the sample was allowed to relax for its equilibrium time prior to the quasi-static yield stress determination. This observation is consistent with the assumption that the sample had recovered its internal micro-structure and as such was representative in some manner of cohesive sediments found in the vicinity of the sample site.

In practice the second method of sample collection was troublesome and failed to produce consistent results. Problems centred around the passive restructuring of the sediment by drainage of interstitial waters. The internal drainage within the sample introduces an unpredictable time dependent effect. It is surmised that if the samples were analysed immediately after collection then more consistent results would be possible. It was not possible to test this condition in the present study.

<u>Results</u>

All rheological results quoted herein were determined on remixed sediments. Field samples exhibited bulk densities in the range 1300 kg m^{-3} < ρ < 1500 kg m^{-3}. The yield stresses of the cohesive sediments obtained using the field vane shear have an approximately linear relationship with density irrespective of site. In general the higher density samples were found at landward stations. The results of rheological analysis are similar in that a near linear trend is seen in the density-yield stress relationship. A near linear relationship is seen to exist between the field vane yield stress and the rheological quasi-static yield stress over the range of densities of samples obtained in the field. That the regression line does not pass through the origin is probably an indication of non-linear response in the field vane in low density mechanically weak sediments.

The bulk density-yield stress relationship is non-linear over a wider range of sample density. There is a region of rapid change of yield stress with density at around 1200kg m^{-3}. This region of bulk density is of obvious importance in erosional processes.

It is clear that the quasi-static yield stress measured under creep conditions is much smaller in magnitude than the corresponding field vane measurement. Further tests were carried out on sediment samples; the yield stress was measured as a function of the time taken for sediments to fail. Significant time dependency was found in the field vane measurements. In further investigations the rheometer was operated at high stresses and the time to failure of samples was monitored. Time dependency of failure was also seen in the rheometer measurements. The quasi-static yield stress, obtained at low strain levels under creep conditions is approached as time increases. The near exponential relationship between yield stress and time suggests a simple kinetic relationship between yield stress, τ, quasi-static yield stress, τ_y, and time, t.

$$\tau = \tau_y + A*\exp(-kt)$$

Severn Estuary sediments are characterised by $0.020s^{-1} < k < 0.106\ s^{-1}$.

Cohesive sediments from different sites in the Severn Estuary show a similar density-yield stress relationship. Time dependency of the yield stress is seen to follow a simple kinetic relationship that is related to the structure of the sediments. Rheological investigations are an important means of characterising cohesive sediments.

GEOCHEMICAL CHARACTERIZATION OF POLLUTANT MOBILITY IN COHESIVE SEDIMENTS

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The accumulations of various trace metals in fine-grained sediments are thought to reflect patterns of productivity and anthropogenic pollution at the time of burial, because most metals of environmental relevance are predominantly bound to organic matter. However, trace metal accumulation in sediments is not solely dependent on the detrital metal flux. Many pore water studies have provided evidence for the release of metals associated with degradation of biogenic detritus at the sea floor as well as from dredged material (Förstner & Kersten, 1988). The rates of these degradation processes as well as associated processes such as sediment-water exchange and flux of nutrients and pollutants are directly coupled to the concentration and chemical nature of the metabolizable fraction of the sedimentary organic matter. High concentrations of organic matter is a typical feature of "mud".

Biogeochemical processes involving trace metal cycling in cohesive sediments have been studied thoroughly by the "FOAM" group of Dr. Berner and his coworkers (Berner, 1980; and citations therein). The funny term "FOAM" ("Friends of Anoxic Mud") points to another typical feature most frequently encountered in near-coastal and estuarine sediments which is a compression of the depth of oxygen penetration. An increase in productivity within the overlying water column will increase the detrital flux of biogenic material, while compressing sediment redox boundaries (Reeburgh, 1983). However, metals must be preserved more efficiently than their biogenic carrier phase to be accumulated in the sediment record. The most efficient fixation process within anoxic mud for trace metals is production of free sulfide during anaerobic organic matter degradation to form the acid volatile sulfide (AVS) concentration of the sediment. AVS is the actual reactive pool of solid phase sulfide that is available to bind metals and in turn render that metal portion unavailable to the sediment-water exchange flux and non-toxic to epibenthic biota.

While the ability of the sediment to produce free sulfide is determined by the sulfate reduction rates, the ability to remove all produced free ΣH_2S can be termed the Reduced Sulfide Capacity (RSC: Williamson and Bella, 1980), and is given by the reactive metal (predominantly Fe) fraction available to form metal sulfides. RSC and ASV can provide a good means to characterize mud, because the concentrations of both parameters are much lower in coarse than in fine-grained sediments. One problem with this criteria is that only a portion of sedimentary iron is available to form ferrous sulfides and this portion may vary considerably. Salt marsh sediments, e.g., may have a very high ASV but low RSC due to high POC and low Fe concentrations.

Any short-term flushing and physical disruption of bottom mud deposits by, e.g., dredging activities result in oxidation of the AVS. Recent evidence indicate that such relatively short oxidation events followed by resettling of material does not totally shift the early diagenetic succession back to a much earlier stage, i.e. from free sulfide to sulfate. The oxidation of ferrous sulfide during oxidation events results in the formation of elemental sulfur. With redeposition, e.g., on land sulphur is buried within the deposit and chemically react with ferrous sulfide to form pyrite (Berner, 1984). Though this reaction is relatively slow, pyrite sulfur concentrations with estuarine and marine mud typically exceed the AVS. A long reoxidation period such as occurs during final deposition of mud on land, however, would significantly shift succession back to sulfate formation. The ability of the sediment to release thereby acid can be termed the Acid Producing Potential (APP), and the ability of that sediment to buffer the acid released the Acid Consuming Capacity (ACC; Förstner et al., 1990). Regarding the potential release of toxic metals from sediments, changing of pH is of prime importance. In practice, the APP is subtracted from ACC - a negative value indicates a potential long-term pH decrease. The characterization of bottom deposits with respect to their APP and ACC is therefore a first step in the prognosis of middle- and long-term processes of metal mobilization.

In conclusion, the metal and sulfur biogeochemistry of cohesive sediments provides criteria which are able not only to characterize that material but also to set up sediment quality criteria with regard to pollution assessment. RSC defines the total metal-binding capacity, ASV the boundary of acutely toxic concentration of trace metals, and APP and ACC the potential release of that metals in freshwater and marine sediments. The intend of this paper is therefore twofold: to present these criteria for characterization of cohesive sediments and to discuss their value for sediment quality criteria.

Literature cited:

Berner R.A. (1980): Early Diagenesis - A Theoretical Approach. Princeton University Press, Princeton

Berner R.A. (1984): Sedimentary pyrite formation: An update. Geochim. Cosmochim. Acta 48, 605-615.

Förstner U., Ahlf W., Calmano W. & Kersten M. (1990): Sediment criteria development. In: D. Heling et al., Sediments and Environmental Chemistry, Springer, Berlin, Heidelberg, pp. 311-338.

Reeburgh W.S. (1983): Rates of biogeochemical processes in anoxic sediments. Ann. Rev. Earth Planet. Sci. 11, 269-298.

Williamson K.J. & Bella D.A. (1980): Estuarine sediments: Successional model. J. Environ. Engineering Div., ASCE, Vol. 106, No. EE4, Proc. Paper 15595, pp. 695-710.

TOWARDS A DEFINITION OF THE NAUTICAL BED IN MUD DEPOSITS : THE CONCEPT OF RHEOLOGIC TRANSITION , RT.

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ABSTRACT

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1. BACKGROUND

The presence of loose cohesive sediment deposits has been identified in several places of the world (Bertois 1954, Wartel, 1972, Bastin 1974, Galenne 1978, Faas, 1986). The most common denomination for these deposits is "mud" since this provides a macroscopic, a lithological and a granulometric description.

The accumulation mechanism of these loose deposits is described elsewhere (Migniot, 1968, De Meyer and Malherbe, 1987).More specifically, can the dynamics of these loose mud deposits be associated to estuarine and marine turbidity maximum areas : TMA's (Faas, 1986, Malherbe, 1989).

In estuaries, waterways and harbours these mud deposits cause problems for the definition of the the nautical bottom and they cause problems in the programmation of maintenance dredging works.

The most widely used concept of nautical bottom relies on bulk density or concentration values which can be directly measured in-situ (Kirby and Parker, 1974, Van Bochove, 1979, Caillot, 1986, Granboulan et al., 1986, De Vlieger and De Cloedt, 1987).

The density-profile of a mud deposit is time-dependent and gives no description of fundamental structural changes within the sediment. Therefore several researchers have been looking for significant transition levels enabling a description of the transition between a suspension and a sediment supported by its own framework (flocs and/or individual grains).

As mentioned earlier (Migniot 1976, Malherbe 1984), shear strength behaviour is the most typical property of mud, differentiating it from other sediments ; it is therefore indicated to consider the rheology of mud in the definition of mud and the characteristics of the deposit.

2. RHEOMETRY OF MUD

Mud is not a fluid but can be a suspension or a sediment deposit with definite soil characteristics. The transition from the first to the second state can not rely on the concept of dry volumetric weight (or density) alone, but must essentially be based on the shear strength properties. This is indeed common practice in geotechnics.

Because of the low shear strength range of loose mud deposits, classical geotechnical investigation methods fail. Thorough rheological research on mud can be achieved using viscosimetric methods allowing the definition of shear strength properties such as initial rigidity, yield stress, dynamic viscosity and thixotropy (Migniot, 1968, Malherbe, 1982, Faas, 1986, Metha, 1986).

For a given mud type under given testing conditions (stress-history, temperature, salinity, etc...), our investigations showed that initial rigidity and yield stress (both defined at low shear rates) and dynamic viscosity (defined at higher shear rates) vary with increasing dry volumetric weight of the supension (or bulk density), corresponding to a power-law relationship. This is illustrated for some mud-sediments, i.e. from Zeebrugge-harbour (fig 1), Rotterdam-harbour (fig 2), Ymuiden-harbour (fig 2), Antwerp-harbour (fig 2) and Scheldt River near Kallo (fig 2).

FIGURE 1 RHEOLOGY OF NORTH SEA MUD
INITIAL RIGIDITY OF ZEEBRUGGE MUD

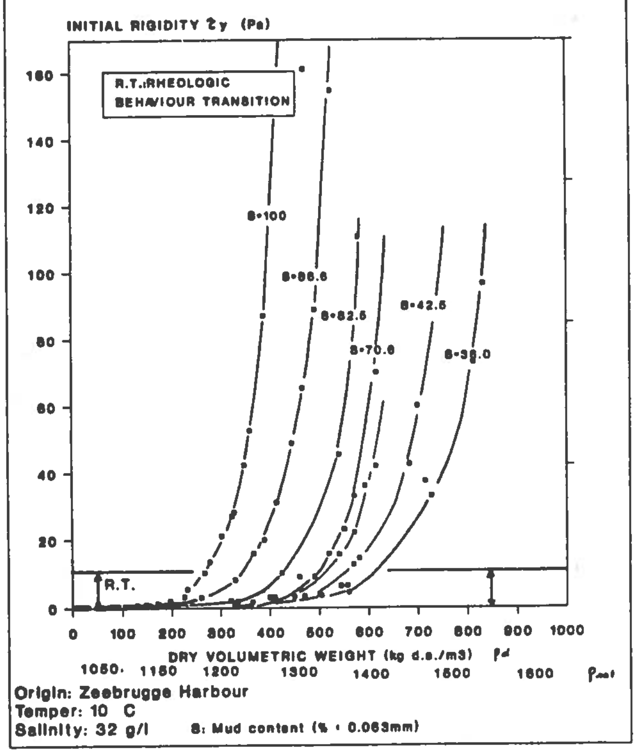
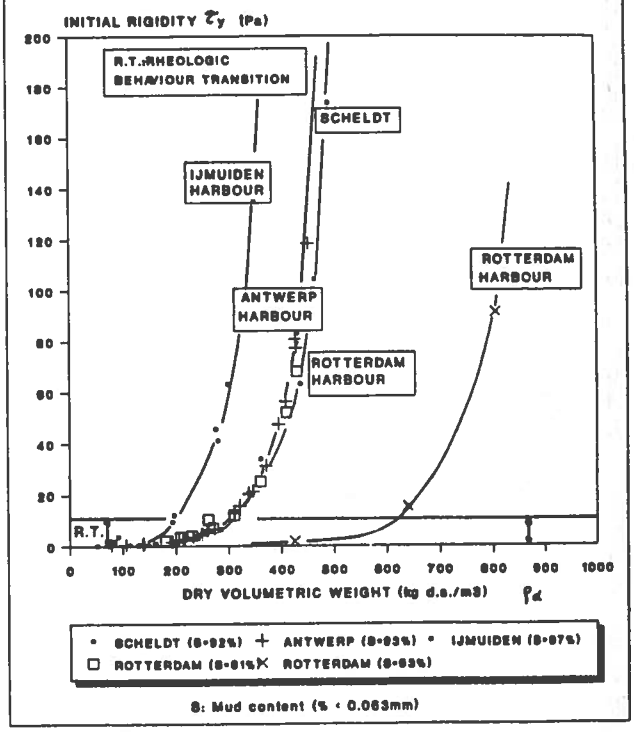


FIGURE 2 RHEOLOGY OF MUD-SEDIMENTS
INITIAL RIGIDITY IN FUNCTION OF DRY VOLUMETRIC WEIGHT AND MUD CONTENT



These different investigations showed that the rheological properties :

a) are very dependent upon volumetric weight and sand-content or granulometry (Migniot, 1968 ; LCHF, 1978 ; Malherbe 1986) ;
b) are dependent upon stress-history ;
c) are only slightly dependent upon the utilised testing method.

Most important is the fact that these relationships between rheologic parameters defining the shear strength and the dry volumetric weight and the sand content show the existence of a "rheologic behaviour transition " where the mud transits :

a) from a loose suspension similar to water and where shear strength is not, or only slightly, dependent upon dry volumetric weight variations (at lower concentrations) ;
b) to a sediment deposit with a well-measurable shear strength wich is strongly dependent upon dry volumetric weight variations (at higher concentrations of dry solids).

This "rheologic behaviour transition" (RT), detected for both low and high shear rates at the same volumetric weight, suggests a fundamental structural transition in the sediment.

From the engineering point of view one can assume that the RT in the mud deposit defines the level at wich mud transits from a suspension with minor shear forces acting on navigation ship hulls to a soil where definite shear forces are increasing rapidly with volumetric weight (and thus with depth).

A field viscosimeter called Rheometer has been developed in order to measure the "rheologic behaviour transition" (Malherbe , 1987). The rheometer measures the exerted shear forces on a rotor operating continuously at high shear rates.

3. RHEOLOGIC AND DENSITY PROFILES IN LOOSE MUD DEPOSITS

Figure 3 illustrates typical rheologic and density profiles in loose mud deposits defined with the Rheometer and with a radio-active backscatter density gauge.

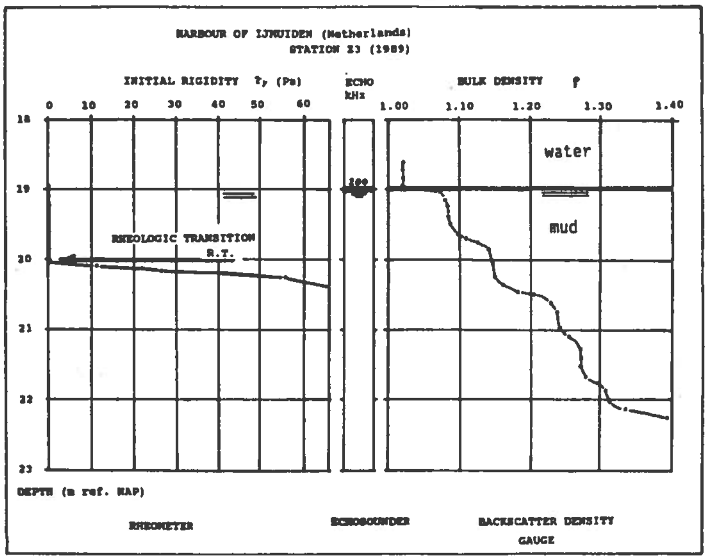
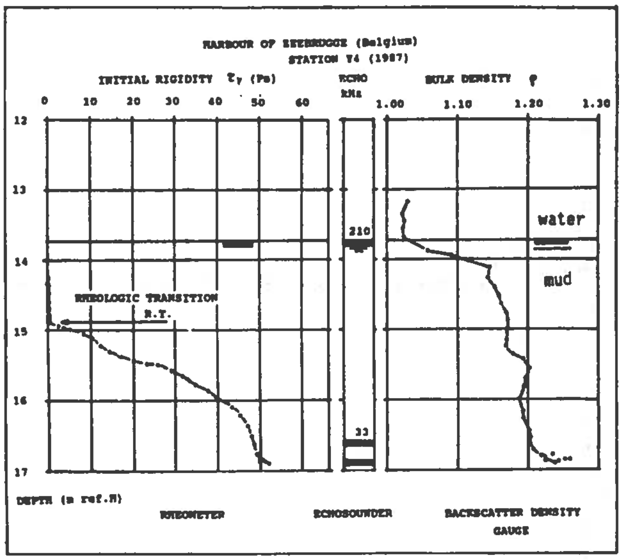


FIGURE 3 : EXAMPLES OF RHEOLOGIC AND BULK DENSITY PROFILES IN LOOSE MUD DEPOSITS. THE RHEOLOGIC PROFILE INDICATES THE SHARP RHEOLOGIC BEHAVIOUR TRANSITION, R.T.,AND CAN BE USED FOR THE DEFINITION OF THE NAUTICAL BED. THE DENSITY PROFILE REFLECTS THE CONSOLIDATION STATE OF THE DEPOSIT AND CAN BE USED FOR PRODUCTION ESTIMATES.



The profiles show how the "rheologic behaviour transition" (RT) can clearly and accurately be detected in the mud deposit by the sudden increase in shear strength. This detection technique allows a good depth resolution.

The density profiles show typical "steps" in which density is hardly increasing over several meters depth. This means that the assocation of a structural transition or the nautical bed to a single value of the volumetric weight can lead to major uncertainties regarding the depth of this transition or the bed.

4. DEFINING THE NAUTICAL BED IN THE FIELD

To ascertain the above mentioned approach of the nautical bed by a rheologic behaviour transition, prototype navigation and measuring tests were conducted with a trailing suction hopper dredger loaded to different keel-clearances with respect to the mud-water interface (Kerckaert et al., 1989).

The decrease of relative advancing and manoeuvring speed of the ship is set out as a function of the keel-clearance with respect to the RT (fig 4).

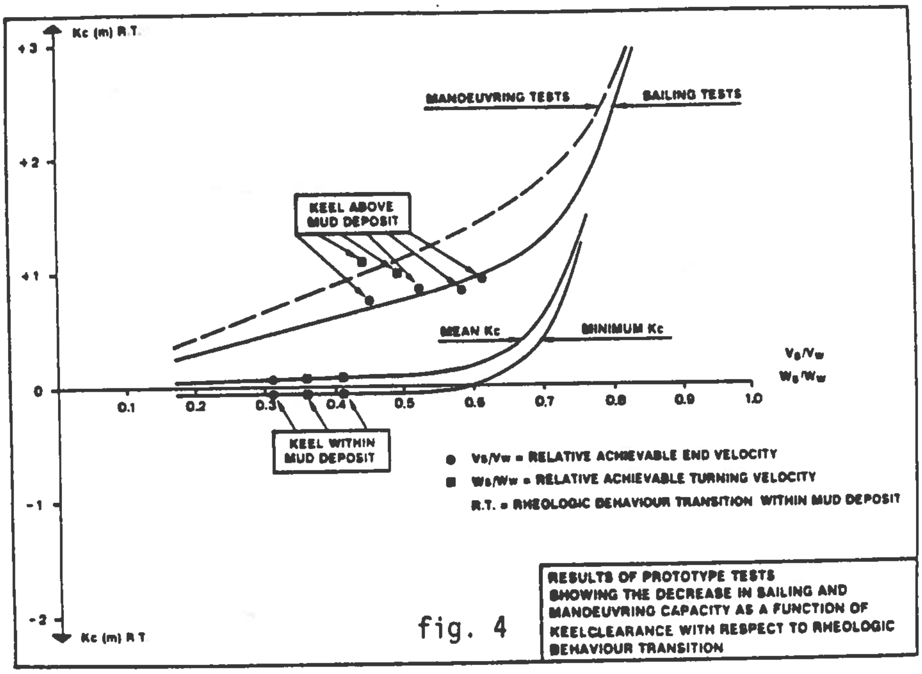


fig. 4

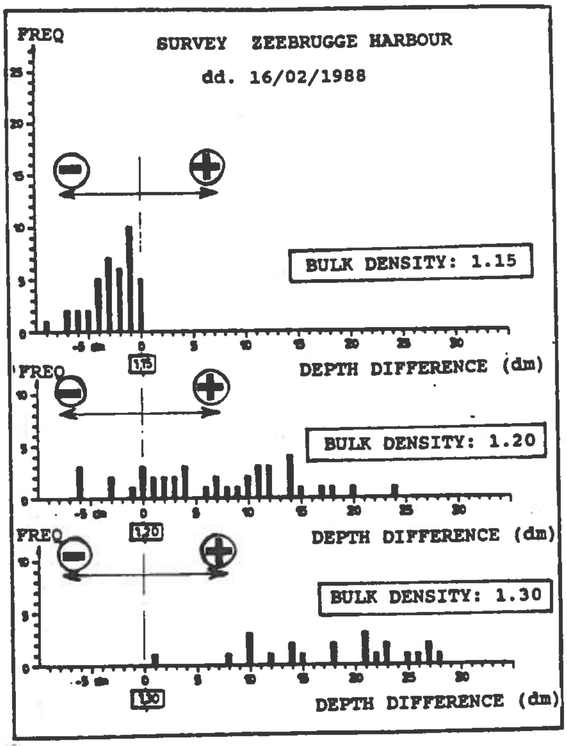
RESULTS OF PROTOTYPE TESTS SHOWING THE DECREASE IN SAILING AND MANOEUVRING CAPACITY AS A FUNCTION OF KEELCLEARANCE WITH RESPECT TO RHEOLOGIC BEHAVIOUR TRANSITION

The figure shows indeed that manoeuvring and navigation capacity is tending to 0 when approaching the rheologic behaviour transition.

In figure 5 the depth-dispersion of 3 different density-levels with respect to the RT is given ; the dispersion pattern illustrates again the difficulties in defining characteristic levels in the mud deposit, such as the nautical bed, by one single density value.

From the rheological investigation of the Zeebrugge-mud and the full-scale trials, it was concluded that the 1,15 density- horizon represents the safest choice for the definition of the nautical bed in Zeebrugge ; the 1,15 density corresponds to the R.T. for the worst case , i.e. sandless mud (see also fig.1).

FIGURE 5: COMPARISON OF THE DEPTH LEVEL OF THE BULK DENSITY HORIZONS COMPARED TO THE DEPTH LEVEL OF THE RHEOLOGICAL BEHAVIOUR TRANSITION , R.T. DISPERSION HISTOGRAMS ARE DRAWN FOR 0.10m INTERVALS (- = R.T. IS DEEPER THAN CONCERNED BULK DENSITY; + = R.T. IS SHALLOWER THAN CONCERNED BULK DENSITY)



DEFINING FLUID MUD IN A DYNAMIC ENVIRONMENT

By

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ABSTRACT

The physical state of mud; i.e. whether it is in the form of a dilute suspension, a fluid supported slurry or a porous solid; is obviously of critical significance to matters related to the integrated effects of accumulation or scour of bottom materials in the coastal and estuarine areas as well as lakes. With regard to advective motion, the contribution of fluid mud to the rate of mass transport is typically of overwhelming importance to sedimentation problems in general; hence it is essential to focus on the complex nature of fluid mud and its motion in particular hydrodynamical environments characterized by currents and waves.

Reviewing the dynamic nature of the vertical structure of the sediment density profile, it becomes apparent that density alone can not parameterize the concentration range over which the hyperpycnal layer containing fluidized mud occurs. The mode and character of hydrodynamic forcing is clearly important as well; hence for example a distinction must be made between fluid mud and stationary mud. The latter may or may not be a wholly fluid-supported slurry, depending upon the stress history. In turn this distinction has a critical bearing on the issue of mud susceptibility to eroding forces, since the manner in which fluid mud erodes seems to differ qualitatively from the way in which a bed, i.e. a particle supported matrix, undergoes erosion.

Defining, hence identifying, the fluid mud layer and its evolution raises questions concerning the mode of occurrence of fluid mud in a particular

environment, since fluid mud can be formed and dissipated in more than one way. Reviewing different modes of formation and dissipation highlights the fact that identification of the fluid mud layer under typically ephemeral circumstances poses difficult definitional problems, both theoretical and operational. Given these constraints, however, some insight apropos the question of identification can be gained by choosing a simple, operational framework which allows tracking the fluid mud layer through time in a very approximate way. Illustrations from a lacustrine environment in Florida highlight some unique features of fluid mud response to wave action, and indicate sediment composition to be an additional parameter of much significance in this particular environment.

Laboratory testing of muds and the application of results

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Abstract

This paper describes the equipment and techniques being used at Hydraulics Research Limited (HR) for testing the properties of estuarine muds. Erosion under uni-directional currents and under waves, self-weight consolidation, entrainment tests, sedimentological and rheological tests are described. Typical results are presented for mud from a British estuary, and some recent applications are stated.

Introduction

The ability to predict the movement of cohesive sediment (mud) within coastal, estuarine and inland waters is of great importance in the development and maintenance of engineering works. Many numerical models of flow and sediment transport have been developed to assist in such engineering studies. The behaviour of the mud in these models has generally been based on algorithms which have been derived from laboratory tests. Many physico-chemical and hydrodynamic parameters govern the behaviour of the mud, so these algorithms are based on the parameters which are currently conceived to be most important. At Hydraulics Research (HR) the laboratory mud tests determine these parameters and seek to improve our understanding of the processes.

Sedimentological tests

The Sedimentological Laboratory at HR is equipped to conduct a wide range of analyses on mud. These include bulk density, cation exchange capacity and organic content. A laser particle sizer is used to determine the size grading of a sample in the range 0.1 - 1200 microns.

The mineralogy of the mud is determined by a specialist laboratory outside HR.

Erosion by uni-directional currents

The erosion properties of a deposited mud bed under uni-directional currents are measured in the HR Carousel. The carousel flume (Fig 1) is an annular flume with an outer diameter of 6m, a channel width of 0.4m and depth of 0.35m, and has a detachable roof.

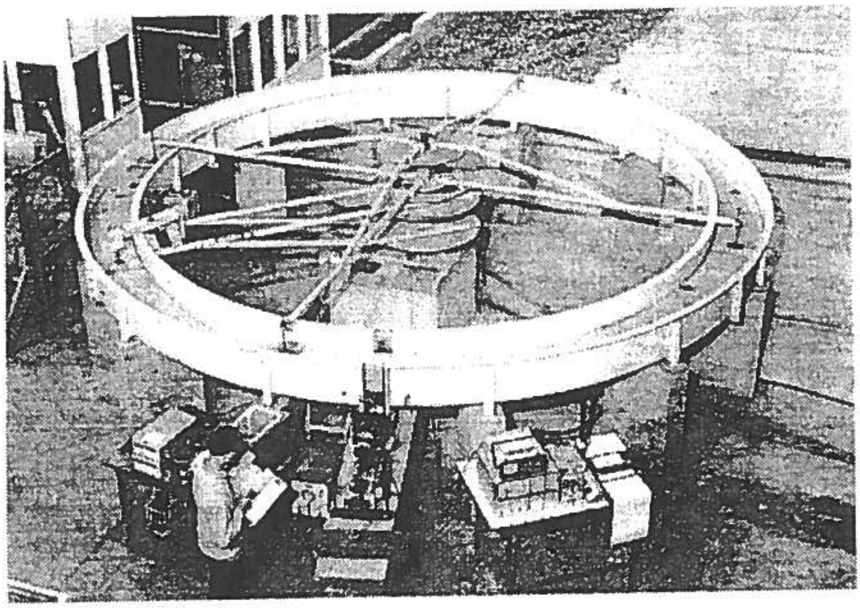

Fig 1

The Carousel

The roof fits into the channel, and floats on the fluid. Fluid motion in the carousel flume is induced and continued by the drag between the roof and the fluid surface as the roof rotates. The roof speed is controlled by a micro computer. The average shear stress exerted by the fluid on the bed has been measured and calculated in several studies (Ref 1). Both different roof rotational speeds and different flow depths have been investigated.

A mud bed is prepared by mixing a suspension of mud at the desired salinity and concentration, pumping it into the Carousel and allowing it to settle and consolidate for a prescribed period. The bed is then eroded in stages by increasing the speed of rotation of the roof in steps. Erosion occurs quickly at first, then more slowly and finally stops when the bed has eroded down to a density which is sufficient to resist the applied shear stress. The concentration of mud in suspension is continuously measured during a test by extracting a sample from the Carousel using a peristaltic pump, passing it through a densiometer and returning it to the flume. The thickness of the bed is measured from below the flume using an ultrasonic probe.

The objectives of the uni-directional current erosion tests are to determine the shear strength of a mud as a function of its dry density, and to determine the rate of erosion with applied shear stress. These are site-specific. The relationship between shear strength, τ_e, and dry density, ρ_d, can generally be expressed in the form

$$\tau_e = a \rho_d^b \tag{1}$$

where a, b are constants determined by laboratory tests.

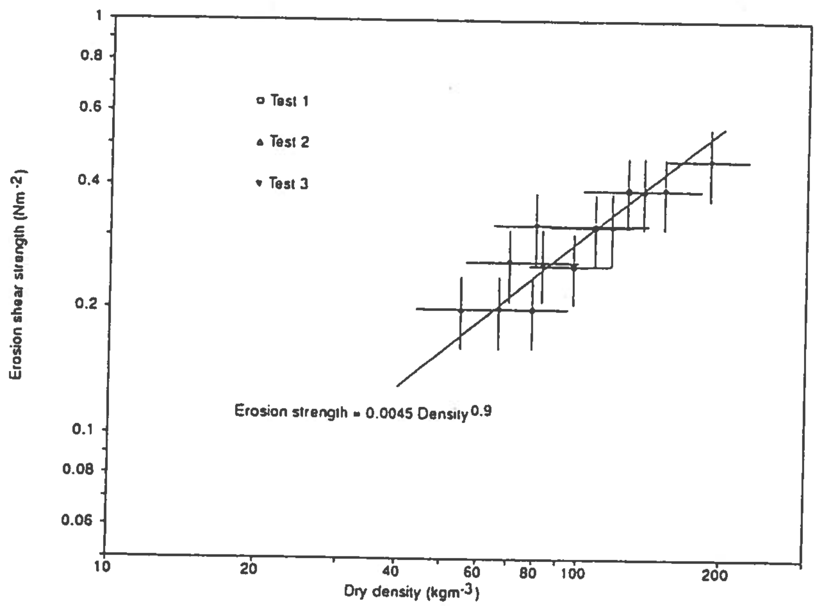

Fig 2

Shear strength against density

Figure 2 shows this relationship for a recently tested mud from a UK estuary. All the results shown in this paper are for the same mud. The relationship between erosion rate per unit area, dm/dt, and applied shear stress, τ, is often expressed as

$$dm/dt = m_e(\tau - \tau_e) \quad , \text{ for } \tau \geq \tau_e \qquad (2)$$

$$dm/dt = 0 \quad , \text{ for } \tau < \tau_e$$

where

m_e = erosion constant ($kgN^{-1}s^{-1}$) , determined by laboratory tests.

By assuming that the shear strength of the bed at any time is proportional to the eroded mass, a value for this erosion constant may be determined by fitting an exponential curve to the suspended solids concentration with time for each increase in applied shear stress, with the concentration tending to equilibrium for large times, as observed. Figure 3 shows the values of m_e as determined for one recent test.

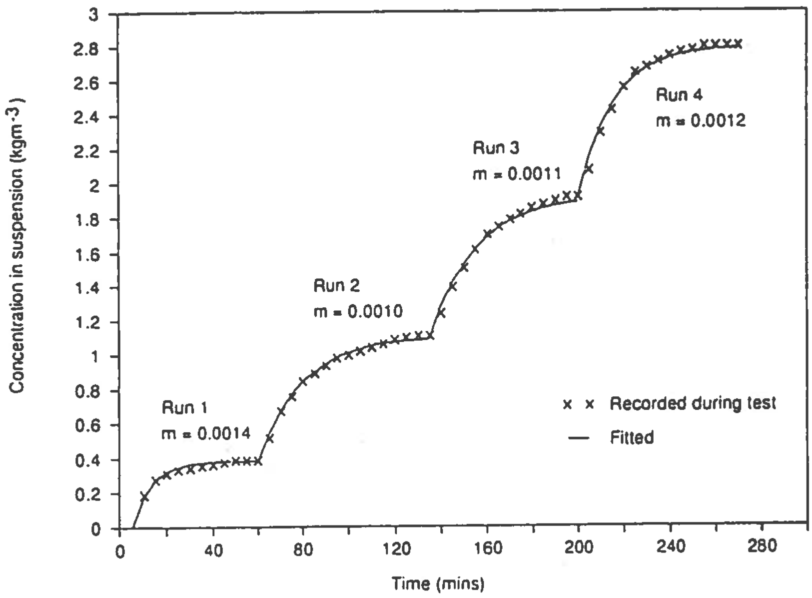

Fig 3 Concentration with time - showing calculated values of the erosion constant

Erosion by waves

To determine the behaviour of mud under the influence of waves, tests are carried out in a wave flume 23m long and 0.3m wide, with a maximum water depth of 0.55m. A trough in the floor of the flume holds the test bed. At one end of the flume are two wave generators, which can be set for monochromatic or random waves. For monochromatic waves, the user controls the wave frequency and wave height manually. The random wave generator is controlled by a micro-computer. For random waves, the user inputs a zero crossing period and a significant wave height; the program generates a random wave spectrum which satisfies these input conditions. The wave spectrum generated in this case is the JONSWAP spectrum.

An ultrasonic probe mounted on a moving platform above the bed is used to monitor the surface level of the mud bed along its length. The results from a water pressure transducer are used to determine the wave spectrum. The vertical bed density profile is measured in situ using a conductivity probe. A turbidity sensor is used to measure suspended sediment concentrations at various depths and positions along the flume, at time intervals throughout each test.

A uniform slurry is made up from the collected mud sample by dilution with saline water, and poured into the test section of the flume. The mud is then subjected to a pattern of waves, either monochromatic or random waves. The wave generating equipment is capable of generating higher peak bed shear stresses with monochromatic waves. The peak bed shear stress on the bed is increased in steps by changing the input parameters at hourly intervals.

The objective of the wave erosion tests is to determine a threshold bed shear stress for erosion of mud of a known density and to calculate erosion rates above this critical shear stress. The erosion rates are calculated from both the depths of erosion along the test bed and the concentration in suspension. An erosion constant under waves, m_{ew}, may be found from a relationship between the excess bed shear stress and the rate of entrainment, dm/dt, which is given by:

$$dm/dt = m_{ew} (\tau_{bw}-\tau_{ew}) \quad (3)$$

where

τ_{bw} = applied bed shear stress under waves (Nm^{-2})

τ_{ew} = critical bed shear stress under waves (Nm^{-2})

Self-weight consolidation

An experimental system has been developed at HR for determining the properties of mud during formation and consolidation (Fig 4).

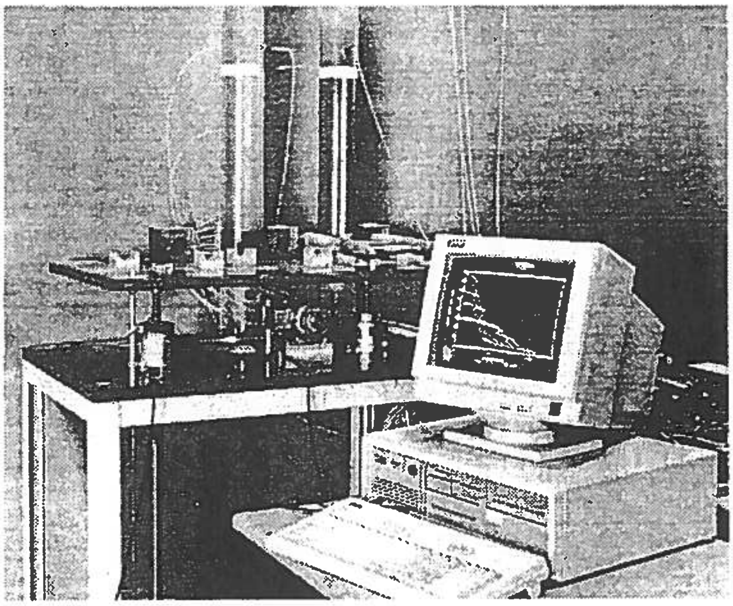

Fig 4 Settling column apparatus

This consists of three 2 metre settling columns of 0.092m internal diameter with a pumped sediment injection system. Density profiles of the consolidating bed are measured with a Harwell gamma-ray transmission probe and logged on to a micro-computer. Pore pressures are measured at various points through the bed. The input conditions for the column are chosen to be representative of conditions at the site of interest. Different final bed thicknesses and resulting densities are obtained by changes in the input rate and duration of input. A constant rate of input over a set period of time is chosen for each test. Density profiles, excess pore pressures and bed thicknesses are recorded regularly during the first day of the test. Subsequent readings are made at approximately 24 hour intervals until the excess pore pressures have dissipated and the decrease in bed thickness has stabilised.

The objective of the consolidation tests is to determine two relationships, specific to the mud under investigation, which can be used in a computer model to simulate the consolidation of a bed of that particular mud. The first relationship is between effective stress, σ', and dry density, ρ, and may be expressed in the form

$$\sigma' = a_0 + a_1\rho + a_2\rho^2 \qquad (4)$$

with $\sigma' = 0$ at $\rho = \rho_0$ for some $\rho_0 \geq 0$

where

ρ_0 = dry density at the surface of the bed (kgm^{-3})

a_0, a_1, a_2 = constants

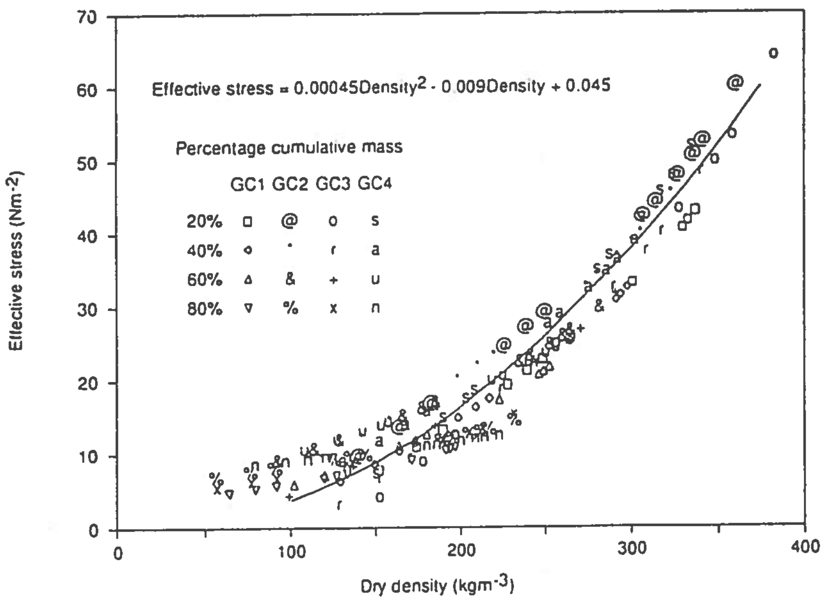

Fig 5 Effective stress with density relationship

Figure 5 shows the relationship which was determined for the mud being considered here. Each set of symbols represents the change in density (and effective stress) for a fixed mass point in the bed (defined by some fixed percentage of the total mass being below that point).

The second relationship is between permeability and dry density. This may be expressed as

$$\log(k) = c_0 + c_1\rho \qquad (5)$$

where c_0, c_1 = constants

Figure 6 shows the relationship that was determined for this mud. Again each set of symbols represents the time-varying change in density (and permeability) for a fixed mass point.

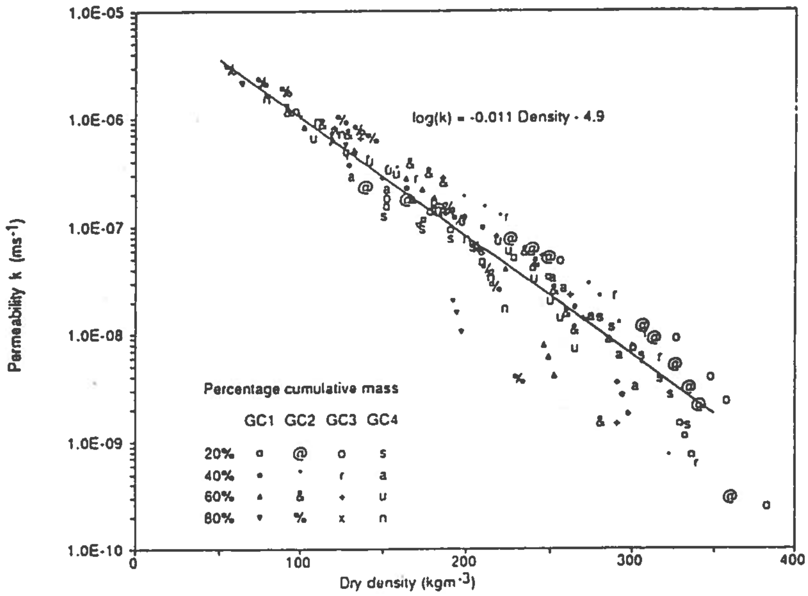

Fig 6 Permeability with density relationship

Entrainment of fluid mud

The Carousel is used for testing the entrainment of fluid mud. The objectives of the tests are to determine the critical shear stress for entrainment of a fluid mud layer which has settled out of suspension, and to determine the density near the surface of the layer at the onset of erosion. After a chosen settling period, the roof of the carousel is rotated with increasing speed, therefore applying an increasing shear stress to the surface of the fluid mud. Entrainment is observed and measured by the increase in suspended solids concentration.

The applied shear stress at the onset of erosion is calculated from a numerical model of shear stresses in the carousel, recently developed and tested by Polytechnic South West (Ref 1). This indicated that the shear stress in the carousel can be related to the roof rotational speed (rpm) as a power law. This law varied for different depths of flow and for the position across the width of the flume. The density of the fluid mud at the onset of erosion is measured by conducting a simultaneous consolidation test in a settling column and measuring the bed density with the transmission probe.

Rheology

Yield stress, viscosity and shear modulus are determined in rheological studies by a specialist research centre outside HR. This is done using a controlled stress double concentric cylinder rheometer. This enables more meaningful low shear data to be produced for non-Newtonian materials as the instrument does not force the material to move as it does with a controlled shear rate instrument. Recent studies at HR have included rheological tests on fluid mud.

Application of results

Hydraulics Research regularly uses many different numerical models to simulate a variety of hydraulic situations. The laboratory experiments aim to provide useful parameters for these models, both for use within HR and elsewhere. Recent studies in which such parameters have been used have included the possible siltation in a man-made lagoon, scour potential from a reservoir drain-down, siltation in and around new ship berths, and siltation and fluid mud in an approach channel to a port.

References

1. Besley P, Delo E A. "The hydrodynamics of the Carousel", Hydraulics Research, Wallingford. Report SR 223, Jan 1990.

TITLE: ***SOME SOFT MUD PROPERTIES EVALUATION BY ACOUSTICS***

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I. INTRODUCTION.

By mud is ment an unconsolidated mixture of water with clay, with or without silt and less common larger particles, occurring in the sea floor or fresh water receptacles floor. The term has no composicional restrictions and embraces the entire spectrum of organic and inorganic chemical and mineralogic material occurring in particulate form.

Mud is a complex medium with, generally, a very complicated structure due to its randomly located particles imbeded in a continuous fluid such as water.

Mud is becomming an important problem in close sites such as harbours, rivers, or open sites with predominence of fluid fluxes, or estuaries. The mud can become a burden and for example economic expenses will be derived from dredging in harbours; a close look at the growing of the mud layer thickness is then, very important. Mud is also a messenger of meteo, physical, chemical, even biological phemomena ocurred at places in relation with those under concern.

Not always the mud lies in a place or region easy to reach. In these instances it is necessary to extract samples to be studied afterwards. Those samples, unfortunately, can reach the surface of the water "destroyed" by the change of environmental conditions. To keep the sample undisturbed implies to use techniques never simples but always very expensive.

Acoustics is particularly suitable to study the uppermost part of the sedimentary layers of rivers harbours, beaches, bays, open sea, etc... The atractive look of acoustics is that the exploration does not disturb the environment, is a rapid method, and is relatively cheap. The problem arises when modelling the mud as a medium through which the acoustic wave is passing. The mud forms a medium in which the solid particles are "discontinuities" in the field and as such the sound wave will be reflected, refracted, scattered, and will interact with the particle (some kind of induced vibration will surely be originated in the solid particle).

Because it is not realistic to introduce or control all the variables involved in the process of interaction (acoustive wave-mud medium), it is more pactical to consider the composite medium characterized by its propagation constant.

The two quantities which are fundamental to all measurements are the sound velocity, C_c , and the attenuation coefficient α_c . They describe the propagation of waves in a medium that absorbs energy, in the form

$$P_c = P_o \exp j\, w \left[t - \frac{r}{C_c}\right] \exp\left[-\alpha_c r\right]$$

Both quantities can be combined into a simple propagation constant K_c.

$$K_c = \frac{\omega}{C_c} - j\alpha_c = \left| K_c \right| \exp(-j\varphi)$$

The problem will be to show the relationship between the value of C_c and α_c (or φ) and the properties of the mud interface: density, percentage of particles in the unit volume, elasticity of the solid. Also the ratio beween wavelength λ and the mean radius of the solid particle is of importance.

II. ABSORPTION ESTIMATION.

When a wave is propagated through real materials, the common esperience is that energy decays as a result of a variety of processes. Such processes include frictional dissipation due to relative motion between grains and frame, relaxation losses owing to shear displacements at pore-fluid boundaries, partial saturation effects, heat conversion of elastic energy, bulk scattering at small inhomogeneities, surface scattering at interfaces, and others. Hamilton (1987) called each of these processes intrinsic attenuation, as different to the effective attenuacion measured in practice.

Absorption includes attenuation as well as phase distorsion. The incluence of the absorption on a propagating perfectly known pulse includes: attenuation, pulse spreading, and change in travel time.

Atenuation is usually taken into account by introducing a zero-phase low-pass filter

$$A\,(f) = \exp\,[-\alpha_c\, Z]$$

where α_c, the so called attenuation coefficient, is an increasing function of frequency, and Z is the travel distance.

Time delaying and pulse spreading are due to the distorsion of the phase spectrum. Attenuation amplitude always imply phase distorsion, if the propagating pulse has to be casual. In this case, the real and imaginary parts of the wavenumber must be related by Hilbert transform. Furthermore, if the phase spectrum has to be minimum, then both phase and log-amplitude spectra must be related by Hilbert transform.

Time delaying is produced by the linear component of the phase, as a consequence of the modified velocity, while pulse spreading is caused by the non linear component, as a consequence of the group velocity being a function of frequency. Constant-Q absorption produces a spreading of the pulse waveform that varies roughly linearly with the travel distance.

Although attenuation should produce phase distorsion if the phase spectrum has to be minimum, most of the collected subbottom profiling measurements don't appear to show any evidence on it. Hamilton (1971, 1987) has gathered most of the available acoustic measurements on marine sediments, both in laboratory and in situ, and he concludes that velocity dispersion is negligible from a few Hz to the MHz range. But, if the phase spectrum is almost linear it is possible to have some delay of the arrival time of the pulse, without any spreading. Thus, phase distorsion might be considered even though velocity dispersion is not evident.

Because we can experience with known pulse , we have control on the wave shape. By conparaison of both signals we can get the filter parameters that will characterize the mud layer: modulus and phase spectrum.

III. VELOCITY.

It is always possible to irradiate the mud layer with sound of low and high frecuency which allows to write C_c as a function of the speed of sound in water and the ratio of the propagation constants of water and the composite medium (Urick 1949).

IV. CONCLUSIONS.

In some circustances the parameters that characterize the mud layer are found by definig a filter that covers the two more important effects on the propagation of a sound pulse of perfectly known characteristics.

V. REFERENCES.

Hamilton, E.L., 1971. "Compressional-wave attenuation in marine sediments". Geophysics, 37 (4), p.620-

Hamilton, E.L., 1987. "Acoustic properties of sediments". **In Acoustics and Ocean Bottom.**(Lara, Ranz and Carbo, Eds.) CSIC Publ., Madrid.

Urick, R.J., J.A.S.A. V.21, nº2. March 1949.

QUANTITATIVE PALYNOLOGY, A TOOL FOR CHARACTERIZING MUD.

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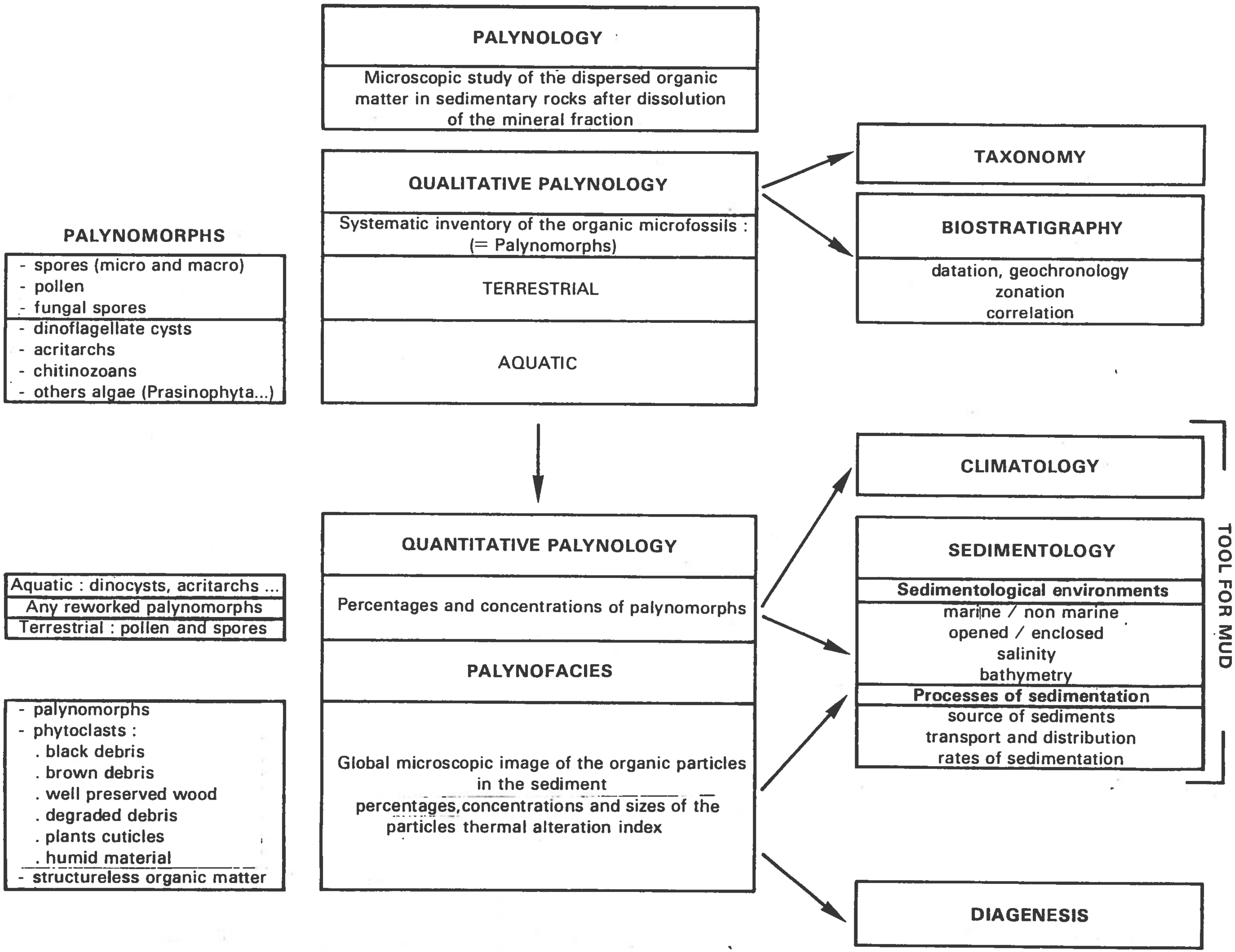
Mud, because often anoxic, are rich in organic matter.
After physical and / or chemical separation from the mineral fraction, the organic matter (kerogen sensu lato) is observed, in routine, with optical or, occasionnaly, scanning electron microscopes by Palynologists.
Qualitative Palynology, often used alone in Taxonomy and Biostratigraphy, is a prerequisite for Quantitative Palynology, the tool that we want to emphasize in this paper.
Palynomorphs are diversified in aspect and origin. Some come from the land like Miospores and Phytoclasts. Some like Acritarchs or Dinoflagellates originate from the sea, on the bottom or inside the surface sediment itself, or in suspension in the water, the cysts falling on the bottom of the sediment. Others like Structureless humic Material may have both origines.
Together they constitute the Palynofacies which may be defined by the concentration (Amount of Palynomorphs, Phytoclasts and Structureless Material by unit of weight or volume) and by the proportions of the constituents.
The analysis of the Palynofacies is often carried on in order to determine the Thermal Alteration Index, a measure of the diagenesis of the sediment after deep burial or occasionnal heating but this is outside of the scope of the present paper.

The signature of mud by Palynofacies is twofold: climatological and sedimentological ones.
Variation of climate and sedimentological environment are recorded in mud through the variation in proportion of several climatic versus sedimentological indexes.
1) Pollen of gymnospermic cold forest of moderate altitude carried on to the sedimentary basin by wind and fluvial system reflects through its variation of abundance the progression or the regression of cold climate on the continent.
2) Shift in abundance of specific population of Dinoflagellate cysts also reflects changes in marine water temperature versus salinity.
3) Ratio Terrestrial versus Marine originating Palynomorphs are good parameters to evaluate the distance to the shoreline.
4) Specific diversity of Dinoflagellate cysts is a index of isolation of the environment.
5) Terrestrial originating palynomorphs, which are carried on and sorted by fluvial and marine currents along with the light sediment particles, are used as tracers in the elucidation of the source area of sediments, the characteristics of their transport and of the sedimentary pattern. Even recycled palynomorphs are good tracers.
6) When the land vegetation cover is stable and bioturbation absent in the mud, pollen concentration and pollen influx allow to reconstruct the sedimentation rates.


PALYNOLOGY
Microscopic study of the dispersed organic matter in sedimentary rocks after dissolution of the mineral fraction
QUALITATIVE PALYNOLOGY
Systematic inventory of the organic microfossils : (= Palynomorphs)
TERRESTRIAL
AQUATIC
PALYNOMORPHS
- spores (micro and macro)
- pollen
- fungal spores
- dinoflagellate cysts
- acritarchs
- chitinozoans
- others algae (Prasinophyta...)
TAXONOMY
BIOSTRATIGRAPHY
datation, geochronology
zonation
correlation
QUANTITATIVE PALYNOLOGY
Percentages and concentrations of palynomorphs
PALYNOFACIES
Global microscopic image of the organic particles in the sediment
percentages,concentrations and sizes of the particles thermal alteration index
Aquatic : dinocysts, acritarchs ...
Any reworked palynomorphs
Terrestrial : pollen and spores
- palynomorphs
- phytoclasts :
. black debris
. brown debris
. well preserved wood
. degraded debris
. plants cuticles
. humid material
- structureless organic matter
CLIMATOLOGY
SEDIMENTOLOGY
Sedimentological environments
marine / non marine
opened / enclosed
salinity
bathymetry
Processes of sedimentation
source of sediments
transport and distribution
rates of sedimentation
TOOL FOR MUD
DIAGENESIS

CONSOLIDATION OF MUD: A HINDERED SETTLING MODEL VERSUS A SOIL MECHANICS APPROACH

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ABSTRACT

The disposal of dredged material is of major importance for the port of Antwerp. Therefore several large scale pilot projects were started to evaluate different disposal techniques (on land, hydrocyclone, under water, pellets) and to set up a dredged material management plan.
Beside the pilot projects a research program was started, in which the examination of the consolidation behaviour of fine cohesive material (mud) was a major topic.
The succesful calculation of the progress of consolidation in a field situation requires a suitable model and accurate material properties.
In laboratory collumns the consolidation process was simulated, using comparable densities, flow rates and drainage systems as in the field.
A mathematical model (CONSOL), was developed to calculate one-dimensional consolidation of fine grained dredged material.
A module on the prediction of evaporation and shrinkage characteristics has been included. Based on a mathematical formulation of the different silt characteristics, such as porosity-permeability and porosity-internal stress, CONSOL calculates the following items:
- evolution of the layer thickness versus time
- evolution of the density versus depth and time
- water outflow at the surface and bottom of the silt layer
- generation of cracks caused by evapotranspiration
- pore water pressure versus depth and time

The model has been calibrated based on the laboratory experiments and has been applied to predict the behaviour of different mud depositions in the Antwerp region.

The soil mechanics approach has two major disadvantages:
- it requires a lot of parameters which are often difficult to measure and therefore makes calibration of the model complex;
- below a certain density other physical behaviour occurs (hindered settling).

Therefore another simple mathematical model (DEPOS) has been developed, based on the hindered settling theory by Kynch.
A mathematical characteristic of the mass conservation equation for settling is that density propagates as a kinematic wave. This can be used to calculate the density and fall velocity at the interface.
A simple semi-empirical law for the fall velocity as a function of the density has been found. A quick result can be obtained by solving the characteristic lines (iso-density lines). This model introduces only a few parameters with a clear physical meaning: equivalent Stokes fall velocity, and 3 density limits. Calibration of the model is performed using the data of a simple settling collumn experiment.

Refined modelling is possible by solving the 1-dimensional mass transport equation, with diffusion and settling (without convection). A numerical method (finite elements) is used. It also allows to take into account two fractions, fine, cohesive particles and a coarser non-cohesive fraction. In this way an accurate prediction of density profiles is possible and allows the simulation of layered dumping. It has been found through calculations that the diffusive flux has to be multiplied with the same hindrance factor as the settling flux.
As there is a lower density limit for the validity of the soil mechanics approach, similarly it is likely that the hindered settling model is no longer valid beyond a certain density, where mud has to be considered as a soil. Both methods are therefore only comparable within a certain range of densities.

COMPARATIVE GRAIN SIZE MEASUREMENT METHODOLOGY

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Earlier analyses revealed the laserdiffractometer (type MALVERN 2602 Lc) to generate grain size values in some cases to differ considerably from sedigraphy results. Therefore a series of experiments was set up to control the reliability of the MALVERN laserdiffractometer and to compare the grain size distributions with curves resulting from grain size measurements with sieving columns, sedigraph and photo-extinction settling tube.

In a first series of experiments the laserdiffractometer was tested on his gauge suitability by means of detailed grain size distribution measurements on testing materials. Nearly perfect spherical glass spheres were separated in 1/4 phi intervals by fraction sieving and hand sieving, making this material very suitable for comparative grain size measurements with different techniques and equipments. This very high sphericity degree supposes at least 80 to 90% of the sieved material to fall within sieving limits. Comparison of results from settling tube and MALVERN laserdiffractometer (fig. 1) displays a greater spread of distributions with the laserdiffractometer for coarser testing materials because the resolution for this coarser sand classes is not fine enough to reconstruct the given 1/4 phi distribution. On the other hand, in the finer sand classes laserdiffractometer results are more accurate than settling tube ones.

A second series of tests dealt with measurements on standard samples with a grain size exceeding the measurement range of one lens but completely within the range of another lens, in order to compare in an accurate way the influence of the grain size distribution on reproducibility. If more than 20% of the fine fraction exceeds the measurement range, the grain size distribution lacks reliability, as it does for a part of the coarse fraction. Analyses should therefore be performed with all coarse fraction material within lens measurement range, and with no more than 20% of the fine fraction material outside range.

Earlier grain size analyses with sedigraphy also revealed samples containing practically no fraction greater than 2 micron to consist of an essentially greater than 2 micron fraction with laserdiffractometry (fig. 2). A third experiment series was thus set up to elucidate whether this anomaly is induced by the material nature or is characteristic for the fine fraction. Standard testing garnet particles with an average diameter of 3 micron were analyzed with both sedigraph (type MICROMERITICS 5000) and MALVERN. As both

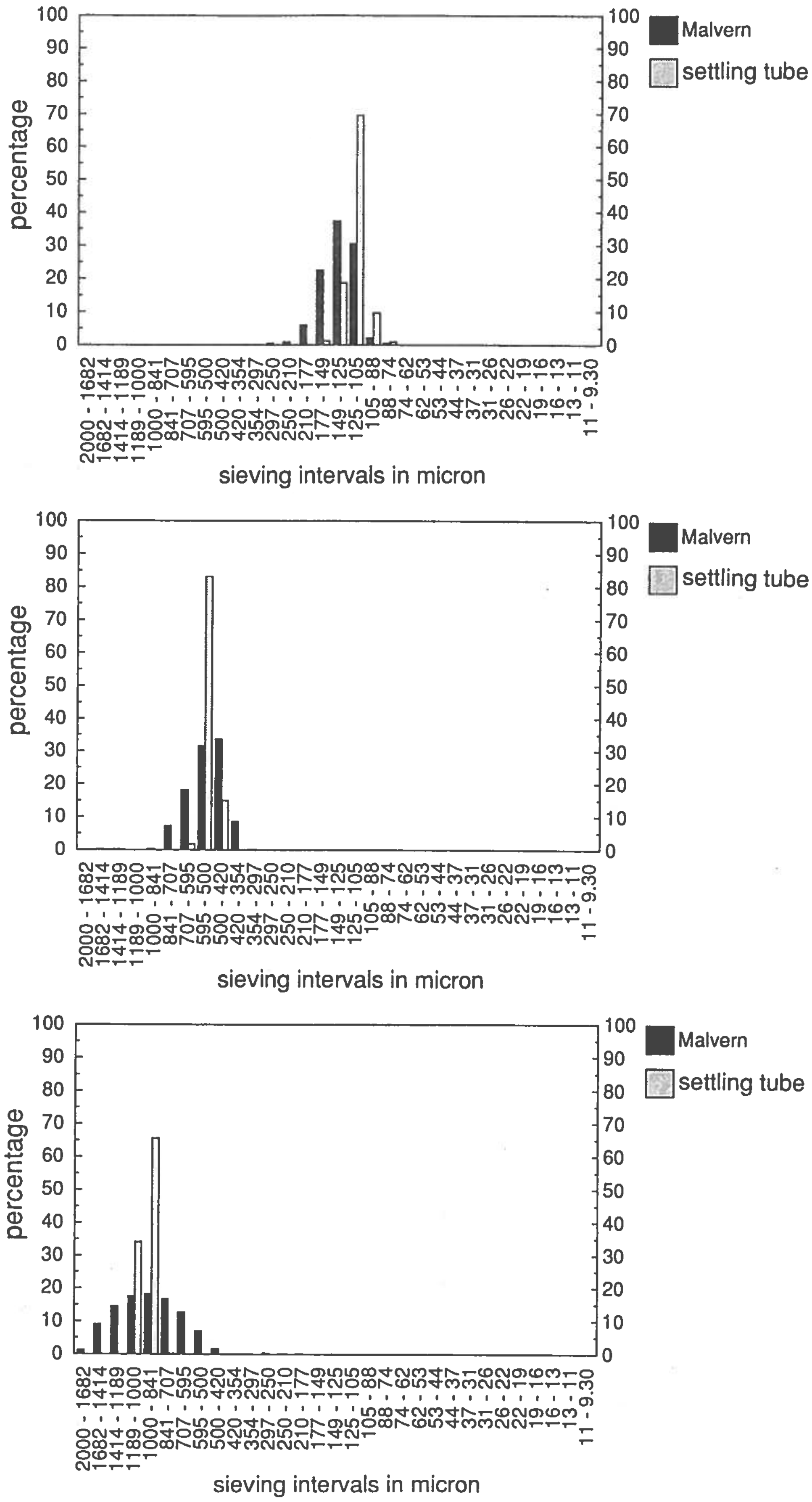


Fig. 1 - Grain size distribution spread of different grain size classes with laserdiffractometry versus settling tube

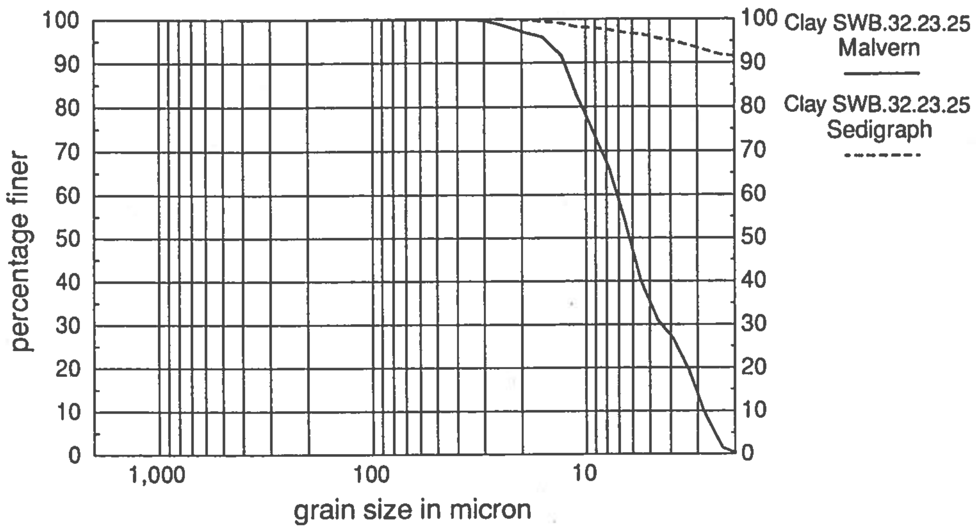


Fig. 2 - Laserdiffractometry versus sedigraphy grain size measurements of clay particles

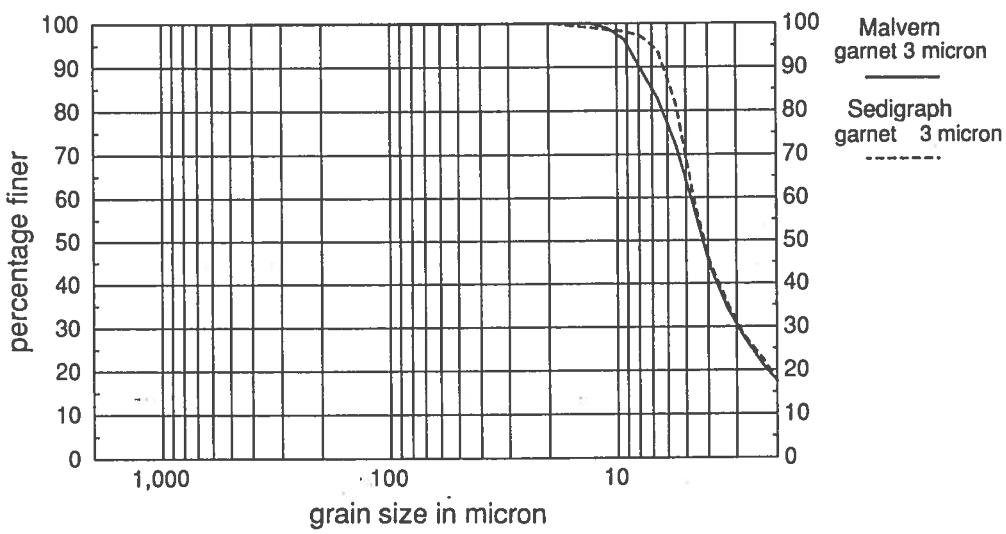


Fig. 3 - Laserdiffractometry versus sedigraphy grain size measurements of garnet particles

measurement series were in agreement with each other (fig. 3), the anomaly in measurement results can only be explained by the nature of the components constituing the clay. This abnormally great anomaly for clay minerals might be interpreted as non fulfilment of the Stokes'law exigence of sphericity as applied in sedigraphy, sedimentation balance and Atterberg sedimentation. On the other hand it might be also possible that clay minerals are not detected by laserdiffractometry. Hence grain size distributions only reflect detected grain sizes in this case. From a grain size point of view sedimentation analysis results of clay mineral samples are of no value. From a sedimentological point of view they are nevertheless valuable because they show distributions of hydrologically equivalent diameters.

In a last series of experiments two sandy samples already analyzed with fraction sieving and sedigraphy were analyzed with laserdiffractometry. The grain size curves showed parallel trends, but the MALVERN modus shifted a 1/4 phi unit to coarser values. A possible explanation might be found in the divergence of the supposed sphericity of the particles. The sieving method reflects the grain size distribution of the most narrow particle diameter, while the laserdiffractometry takes into account the grain size distribution of the average particle diameter.

In general, laserdiffractometer grain size analysis results of clays will show strong divergence with all published results based on sedimentation methods. The grain size distribution of clays measured with laserdiffractometry might within certain limits match more accurately the real grain size distribution, but for sedimentological purposes settling velocities are more important than real grain sizes.

MALVERN laserdiffractometer grain size distributions of samples with ellipsoidal or spherical particles with a maximum grain size not exceeding 600 micron, are comparable to distributions obtained by sieving and sedimentation methods.

"MUD, MUD, GLORIOUS MUD,

NOTHING QUITE LIKE IT FOR COOLING THE BLOOD".

Sisk Henry B

The title of this paper is taken from the comic "Hippopotamus Song" by the English duo, Flanders and Swan. The "blood cooling" criterion is perhaps not the easiest to use when we want positively to define mud and register its presence. In this paper, I will attempt to make a contribution to certain practical aspects of the definition of mud, refer to some linguistic connotations and describe a technique for the remote sensing of mud as an in situ marine soil. In particular, I will be showing results of trials of this new equipment carried out by Rijkswaterstaat Zeeland Survey Service.

I submit that our need and capacity to define mud is dependent on three primary factors:

1. By which physical properties do we define mud?

2. How do we sense its properties?

3. How do we use the information?

Taking two extremes: a female prawn creating a burrow will require a very specific consistency of mud and an esturial harbour authority will consider mud only as it affects his annual dredging costs. The now well established yardstick for navigable water depth of liquid mud with a specific gravity of 1.2 is easy to state but the sensing of the level at which this occurs is not a straightforward subject. Because liquid mud is frequently associated with a high level of suspended particles in the water column, the conventional use of hydroacoustics as the near universal underwater remote sensing and communication medium is naturally inhibited. Thus the liquid mud problem illustrates how we should address the three primary issues, not necessarily in the order listed.

My interest in this field is commercial rather than academic. Our company Marine Microsystems Ltd's principal product is an ultrasonic signal processing unit, USP RoxAnn, which automatically outputs numerical seabed identification. Thus we have a direct interest in the classification of all types of marine soils, including mud. Both the physical phenomena we process and the format of the USP RoxAnn output are different to conventional hydroacoustic equipment. We have found it difficult to describe the significance of USP RoxAnn since there are no comparable products. In replying to interested parties when they ask: "What are you actually sensing and with what level of discrimination?", we can refer them to military clients who can detect sand ripples, to dredgers who can routinely detect differences between coarse and fine sand and to commercial fishermen who use it most effectively to precisely identify the preferred environment of a target species. While validated by trials, by direct comparison with side scan sonar in the case of sand ripples and by continuous use by marine aggregate trailer suction dredgers, in most cases the descriptions tend to be expressed in a non quantative format, indeed as subjective as the interpretation by operators of visual displays of most sophisticated hydroacoustic tools.

Therefore it is with mud as it is with so many observable phenomena,

"First we measure, then we know".

In quoting Lord Kelvin, I am highlighting the need to achieve numerical descriptors of the properties of marine soils. The use of the English word "reduce" in this context has acquired derogatory connotations but our collective target should be to reduce the definition of mud to specific numbers.

In this context we should be conscious of the need to use those numerical parameters which are capable of being sensed reliably and inexpensively. So there should be feedback from the users' needs and the means of sensing to the choice of the parameters.

The medium grain size of a (granular) sample is just such a parameter which can be quickly determined once the sample is acquired (and dried). Since this is the dominant yardstick in marine engineering, dredging and construction, it has been readily adopted. (See Fig. 1.) Within such national norms as we can find for construction aggregates there appears to be general consensus of three main dividing lines:

2mm between gravel and sand,

60 micron between sand and silt, and

2 micron between silt and clay.

This appears to satisfy the needs of the construction industry and its associated suppliers of aggregates. The net contents in the hold of a marine aggregate mining vessel may be quite different to the undisturbed marine soil. So we arrive at the need to define more precisely the undisturbed marine soils.

Perhaps we should preface such consideration by restricting it to relatively homogeneous material. Obviously a multiplicity of sedimentary layers in marine soils cannot be characterised except, where discontinuities occur, by the use of such shallow geophysical tools as sub bottom profilers. However we can say that almost invariably mud is both a superficial and consistent, i.e. non layered, phenomenon. Therefore the high powered sub bottom profilers will routinely pierce the surface layers and with low frequency and considerable energy output, "punch through" to the underlying layers but give little or no information on the surface of the seabed.

The dual frequency echo sounder is a standard tool for detecting the presence of a mud layer. By noting the differences on the echogram between the soundings using 33 and 210 kHz, an operator can visually deduce the registration of a mud layer, i.e. the presence on a yes/no basis. It is not generally possible to make a good assessment of the depth or consistency of the mud layer from such data.

This was the problem experienced by the Rijkswaterstaat Zeeland Survey Service in routine siltation studies. The interpretation of the DESO 20 dual frequency echogram inevitably led to labour intensive manual work. Charts had to be marked up and of course frequent bottom samples are required to determine the thickness of the silt layer (after registration).

In the context of Dutch siltation studies of tidal waters I translate the Dutch word "slib" as directly equivalent to "silt" and only approximately the more general word "mud". "Slib/silt" may be understood to relate more to recent, relatively shallow deposits of fine suspended material, while the word "mud" may have the association with areas of more stable and deeper layers of very soft fine material, not necessarily related to estuarial or even coastal processes e.g. abyssmal ooze might also be described as mud but not as silt. Similarly such marine soils as localised areas of clay or peat with cohesive properties and/or organic constituents might also colloquially be described as "mud" in English. I mention these aspects of the word "mud" simply in order to highlight the associated meanings the word may have and to recommend to those who are compiling the physical parameters to take this into account.

Before going on to describe the remote sensing of mud in the Dutch trials, we may remind ourselves of the basic range of descriptors which can be used to characterise marine soils:

- size classification of soil
- maximum grain size
- dominant type of soil, i.e. gravel, sand, clay, etc.
- modifiers top the dominant soil type to indicate gradation
- plasticity (of cohesive soils, of fines in granular soils)
- grain shape and hardness (granular soils)
- compactness - relative density (granular soils)
- unconfined compressive strength (cohesive soils)
- colour and odour (if any)
- in situ density
- structure of intact soil
- presence of peat, other organics, cementation, debris

(Sources: PIANC 1984-Permanent International Association of Dredging Congresses & Spigolon S.J., Fowler J.: "Geotechnical Descriptors for Soils to be Dredged", XIIth World Dredging Congress, Orlando, Florida, 1989)

From this list we can see that only a number of these descriptors can be sensed quickly and effectively. We should not forget the third question I posed at the beginning: How do we use the information? Putting it differently, the needs of the user may be fulfilled by one simple descriptor and in this context I could add one more not listed above: taste!.

Moving from possible descriptors to classification, the British Geological Survey uses a modified Folk scheme of 1954. (See Fig. 2.) I am not aware that this has gained international acceptance but it is a rare example of an attempt to classify in situ marine soils in great detail. Unfortunately it may be very difficult to sense the difference between:

(g)sM - slightly gravelly sandy mud and

(g)mS - slightly gravelly muddy sand.

And we should again ask ourselves : who needs to tell the difference?

Staying with the English speaking world, the U.K. Hydrographic Office has provided good verbal descriptions of their traditional coarse classification of marine soils. Originally devised for both navigation (identification of material adhering to the tallow of a lead line) and anchor holding ground, it reflects the wide range of sedimentary marine soils found around the British Isles, including descriptions of cobbles as being of a clenched fist size.

Our USP RoxAnn equipment is capable of sensing at least this broad or coarse classification of the Hydrographic Office. We have a keen interest in stimulating an international consensus of definitions for such marine soils. Ideally through a European standard, this could allow calibration of sensing techniques and is, I submit, a logical extension of the objective of this Workshop. Obviously we believe that we have an excellent means of simply and effectively outputting USP RoxAnn values directly equivalent to such standards. Returning to the specific task of defining mud I can now show slides of the results of the trials by Rijkswaterstaat Zeeland. As previously mentioned, in their siltation studies they currently can only remotely register the presence of mud.

Trials USP RoxAnn by Rijkswaterstaat

Zeeland Survey Service

- Project Leader: W. de Leeuw
- Locations: Ooster and Westerschelde
- Date: May/June 1990

- Vessel: M.V. "Pluympot"

- Positioning: Trident II

- Echosounder: Krupp Atlas DESO 20

- Water depths: 3 to 50m

- Sampling: Grab

- Seabed conditions:Mainly sand and silt with some manmade materials e.g. ballast, wreck, etc.

- Silt/sand seabed combinations defined as percentage of silt i.e. less than 53 micron.

- Seabed samples ranging from 3.1 to 60.7% silt

- USP RoxAnn data defined in terms of combination of two numerical semi independent variables:

  E1: seabed roughness

  E2: seabed hardness

(E1,E2) values shown as single point on cartesian display (RoxAnn Square). Rectangles or "boxes" created in square to delineate those combinations of E1 and E2 values which correspond with specific seabed material e.g. 20-30% silt or gravel. Detection of seabed material similar to that calibrated by cursor's presence in box triggers display of alphanumeric description of material on screen together with colour infill corresponding with box of repeat of depthprofile from echo sounder.

- In combination with navigational positioning data, the colour of survey tracks are automatically linked to the seabed type.

- Realtime data during surveys allows targeted selection of locations for bottom sampling.

- Level of discrimination permits description of system as "remote ground truthing".

Summarising Rijkswaterstaat's conclusions:

- Despite the very limited number of bottom samples used to calibrate the system, it proved capable of not only automatically registering the presence of silt but also the relative concentration, e.g. 10-20%, 50-60%, etc.

- Temporal and spatial repeatability achieved. (Surveys repeated after 3-4 days over 7 no. tracks of 2km with perpendicular tracks as additional control.)

- Registration of silt by USP RoxAnn when none detected from interpretation of DESO 20 on dual frequency. Presence of silt confirmed by bottom samples.

- Siltation surveys with USP RoxAnn can be carried out in half the time compared with surveys using existing techniques.

How was this achieved?

If time permits, I will give a more detailed description of the principles underlying the processing system. For those interested, I can provide reprints of the April '90 Hydrographic Journal article "New Acoustic Processing For Underway Surveying".

In conclusion I would like to revert to the three primary questions I posed:

1. **BY WHICH PROPERTIES DO WE DEFINE MUD?**

   I submit that in arriving at these we should adopt the American "KISS" principle (Keep It Simple, Stupid) and as far as possible select those properties which relate to the 2nd and 3rd questions.

2. **HOW DO WE SENSE THESE PROPERTIES?**

   I submit that we should seek to eliminate or, at the very least, minimise the element of subjective operator judgment. For many reasons but primarily now for electronic data acquisition, we should keep to Lord Kelvin's dictum. While analysis of samples will always be necessary, if only for calibration and verification, an accurate and continuous remote ground truthing system should be the preferred survey technique.

3. HOW DO WE USE THE INFORMATION?

I submit that we should keep uppermost in our considerations the ultimate benefit which the data provides. Perhaps the fine detail of, for example, the BGS modified Folk scheme is simply too refined for practical use, both in acquisition, recording and end user application?

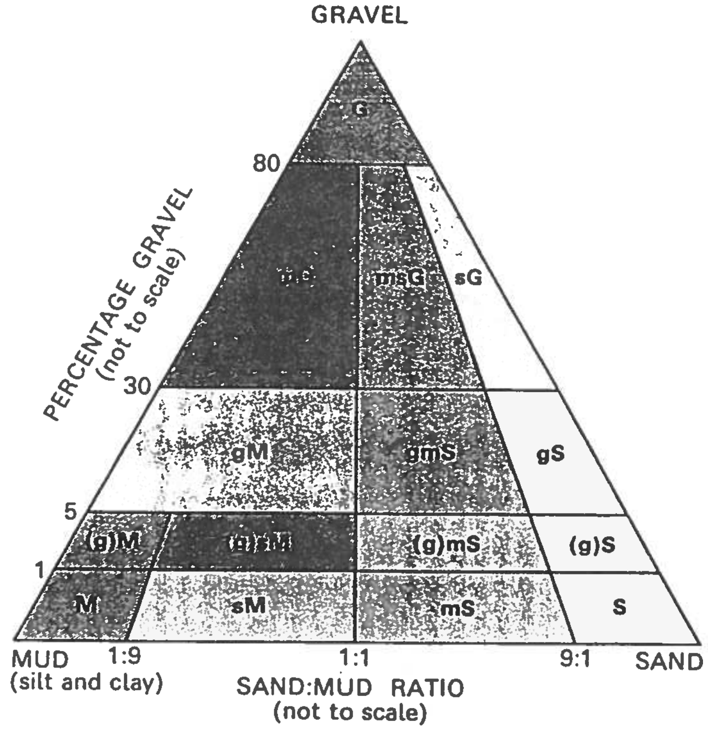
Finally, the complete chorus of the song:

"Mud, mud glorious mud,
Nothing quite like it for cooling the blood,
So follow me, follow,
Down to the hollow,
And there let us wallow,
In glorious mud!"

Specific diameter = 10/U	Netherlands Standard N 209/N 210	German Standard DIN 4023	American Standard M.I.T.	British Standard B.S. 1377
	Clay	Clay	Clay	Clay
2 µ	Silt	Silt	Silt	Fine Silt 6 µ
				Medium Silt 20 µ
16 µ	extremely fine / Fine sand	60 µ	60 µ	Coarse Silt 60 µ
63 µ	very fine	fine sand 200 µ	Sand	Fine sand 200 µ
83 µ	medium fine			
125 µ	moderately fine			
200 µ	moderately coarse	medium sand 600 µ		Medium sand 600 µ
333 µ	medium coarse			
500 µ	very coarse			
1 mm	extremely coarse / coarse sand	coarse sand 2 mm	2 mm	Coarse sand 2 mm
2 mm	Fine gravel / gravel	Fine gravel 6 mm	gravel	Fine gravel 6 mm
		Medium gravel 20 mm		Medium gravel 20 mm
16 mm	Coarse gravel	Coarse gravel 63 mm		Coarse gravel 60 mm
64 mm	Stone	Stone/Blocks		Cobbles 200 mm
100 mm	Rock			
500 mm	Blocks			

Fig. 1.

KEY TO COLOURS & SYMBOLS



M..Mud
sM..Sandy mud
(g)M..Slightly gravelly mud
(g)sM..Slightly gravelly sandy mud
gM..Gravelly mud
S..Sand
mS..Muddy sand
(g)S..Slightly gravelly sand
(g)mS..Slightly gravelly muddy sand
gmS..Gravelly muddy sand
gS..Gravelly sand
G..Gravel
mG..Muddy gravel
msG..Muddy sandy gravel
sG..Sandy gravel

Outcrop of bedrock on the sea bed

• 175 *Sample station with I.G.S. registration number*

Geophysical traverse line

Boundary between sediment types

— 60 — *Bathymetric contour, depth in metres below O.D.*

Fig. 2.

Microstructural Classification of Clayey Sediments

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Electron microscopy has shown that the structure of clayey sediments consists of elements such as domains, card-houses, etc., with voids both within and between these elements, and occasional silt particles; but recognition and analysis of these elements has been on a subjective and qualitative basis. The paper will discuss the progress which is being achieved in developing automatic methods of image analysis of electron micrographs for measuring the strength and direction of local preferred orientation, recognition of random areas, measuring local variations in void ratio and other parameters, in order to provide a better microstructural classification of these sediments.

CONSOL, A MODEL FOR THE CALCULATION OF THE CONSOLIDATION OF DREDGED MATERIAL

by : F. SMEDT - Free University of Brussels, Department of Applied Sciences, Brussels (B)
K. VAN CRAENENBROECK - Silt N.V., Antwerpen (B)

Keywords : Settling and consolidation modelling, deposit dimensioning

For an optimal dimensioning of mud deposits, it is necessary to understand and to be able to predict the consolidation of the deposited material.

Because of our rather empirical knowledge of floculation - settlement- and consolidation-phenomena, a flexibel model was conceived to enable to establish the theoretical relations between parameters depending on local situations.

The poster presents a summary of :

- the input parameters : a.o.
  - project specific parameters;
  - mud specific parameters;
  - model specific parameters.
- the output : a.o.
  - settlement as a function of time;
  - porosity and void ratio as a function of time;
  - pore pressure;
  - water content;
  - shrinkage;
  - evaporation;
  - infiltration;
  - hydraulic conductivity;
  - dewatering;
  - drainage;
  - .....

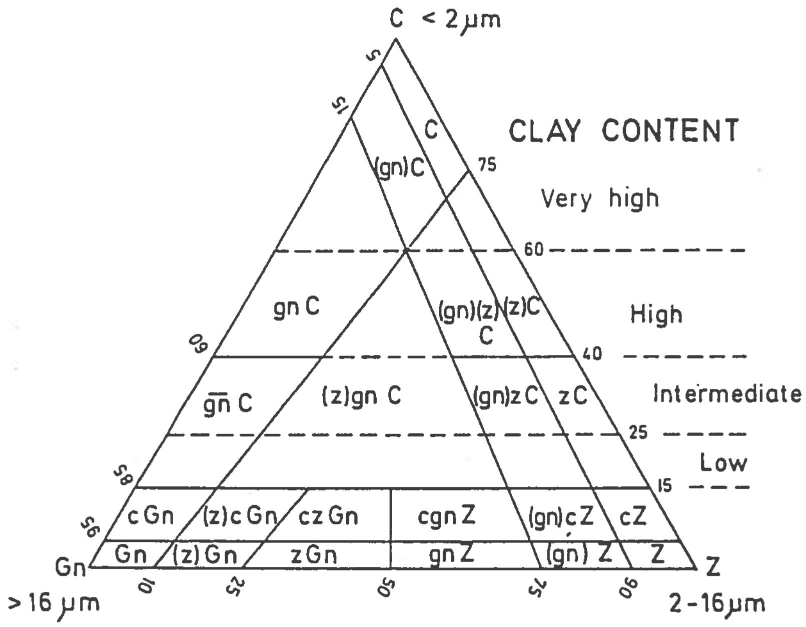
This model is one of the first of its kind to study the consolidation-phenomena with a pragmatic scientific approach. The model can further be calibrated by laboratory and in situ measurements.

A COARSE–SILT—FINE–SILT—CLAY TRIANGLE FOR TEXTURAL NOMENCLATURE OF MUDDY SEDIMENTS

Rodney L. Stevens

Department of Geology, Chalmers University of Technology and University of Göteborg, S–412 96 Sweden.

The usefulness of sand–silt–clay triangles is often limited by the near–linear plot of muddy textures along the clay–silt side. A logical improvement is to split the silt fraction into two end–members which are plotted together with the clay content on a new triangle classification scheme. Significant changes in the grain–size statistics of muddy sediments are observed at approximately 16 μm and are suggested to be largely due to the greater influence of aggregation processes upon smaller particles during sedimentation. The 16–μm boundary has a significance in applied studies since fine silts have high capillary capacities and coarse silts provide root–sized pores and greater permeability. The importance of relative low clay contents for sediment cohesiveness, plasticity and geochemical responsiveness is reflected by internal subdivisions of the triangle for different textural classes of muddy sediments. These subdivisions are also sensitive to the occurrences of small amounts of each end–member which can have value for sedimentological interpretations in fine–grained deposits. The proposed nomenclature attempts to make field and laboratory descriptions more continuous with each other. The effective separation of textural variations and their interpretative significance is illustrated by glaciomarine sediments from southwestern Sweden.



The proposed classification scheme for fine–grained sediments. Optional modifiers for clay content are shown to the right. The adjectives are used in order of increasing stress, i.e. (gn) before z, and when equal in stress, in order of increasing grain size, e.g. (z)gnC–h.

ABBREVIATIONS

Gn grains˝	**gn** grainy	**(gn)** slightly grainy	**gn** very grainy
(˝grains˝ = >16 μm)			
Z zilt	**z** zilt	**(z)** slightly zilty (zilt= >2 μm)	
C clay	**c** clayey	**(c)** slightly clayey (3–5% clay, not shown)	

Optional modifiers:

–vh very high clay content
–h high clay content
–i intermediate clay content
–l low clay content

SIZE DISTRIBUTION OF QUARTZ AND FELDSPARS IN GLACIOMARINE SILTY CLAYS AND IMPLICATIONS FOR FLOCCULATION PROCESSES

Rodney L. Stevens

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Quartz and feldspar extracts, obtained by chemical dissolution of the clay minerals, were studied for insight into their size distribution. The mineralogical influences upon texture are further considered by comparison plots of statistical parameters of the particle−size distributions of the total samples and the graphically partitioned coarse and fine subpopulations. The Quaternary, glaciomarine setting of these fine−grained deposits may have allowed for well developed, inorganic flocculation with limited disturbance by pelletization and other aggregation processes. Glacial comminution explains the relatively high contents of quartz and feldspars. Quartz and feldspar are better sorted and were apparently less influenced by flocculation than were phyllosilicates, except for particles less than approximately 16 μm which are poorly sorted due to their inclusion in flocs. Up to 30% of the total sediment was deposited as unflocculated single particles, primarily in the well sorted, coarse subpopulation which is dominated by quartz and feldspar. Increased quartz and feldspar contents in the samples with varying texture reflect an increase in the proportion of the coarse subpopulation and are, therefore, associated with coarser total mean values, coarser grain modes upon dispersion and lower total standard deviation values. The 16−μm boundary is suggested to be useful for separating fines that were essentially always involved in flocculation and coarse silt and larger grains that were less influenced.

THE "CLAY INTEGRON" OR THE NECESSARY INTEGRATION OF THE MULTISCALE ARCHITECTURAL CONCEPT AND APPARAISAL OF PROPERTIES OF MUDDY SUSPENSIONS, COHESIVE CLAYEY SEDIMENTS AND RELATED BUT LITHIFIED SEDIMENTS

by J.Thorez, Clay Geology Laboratory, Liège University, Belgium.

During this symposium, several questions will be of direct concern to all those who study the earthy material called mud. This contribution attempts to present within a series of **didactic illustration** what is fundamentally a mud in order to (re)conciliate the **observational scales**, ways and means of **characterization**, the interrelated **architectural (multiscale structural) properties**, and the **genetic meanings** attached to this material; it will refer, too, to the **variability of interests** by and for various mud researchers. Attention will be particularly drawn on the necessity to reach an **integrated concept** about "muds" by emphasizing the **criteria for their definition and knowledge**.

Nobody will contest that the term "mud" is firmy entrenched in the geological literature. The term is still , and has for long, been used to depict in reality a "pigeon-holes" state related to the **kaleidoscopic occurrences** of different kinds of "earthy" or "rubbish" material called, for the sake of simplicity or as an universal appeal , broadly a "mud". This term should better be normally **restricted to all kinds of natural materials predominantly built up by clay minerals**. However, in practice and by extension, any loose silt or even a sand which, because of its natural or artificial admixture with organic matters, may **mimetically** exhibiting the mechanical and hydrological properties of the corresponding "clayey" mud is also called a mud whether in suspension or already accumulated. Finally, through its highly **variable chemical composition** and other characteristic properties, but also at the level of **processes and modes of formation**, any geologically generated mud reflects the large fan of sedimentological or pedological settings and the later conditions of its occurrence as "muds" in suspension in continental or marine waters. Any mud, or its related clayey material, as both coprresponding tothe very "dust" of the Earth, remains intimetly interrelated all the way throughout from the very moment and site of its occurrence.

These occurrences link the **uphill formation** (at the surface of the Earth) to thre**downhill deposition and possible burial conversion** into a mudstone or a later slate (when this "dust" returns to the depths of the lithosphere).

Hence the necessity to definitively try to **bridge the interests** of those who study all kinds of muddy suspensions, those who analyse the birth of "mud" at the locality of their formation (through weathering of parent rocks), those who focus on the fate of the muds throughout erosion, transport and deposition, and finally those who analyse the transformation of these muds into hard rocks.

Different meanings - descriptive as well as genetic - are nowadays too widely but separately used; they all reflect the real antagonism existing about the very concept of a mud , or better reveal the "pigeon-holes" and the azimuthal fundamental or applied characterization of the large set of "muds" accordingly to the scientific background and interest but without the "normal" links joining the different ways of approach and study.

Under the heading of "mud" is, consequently, here considered fine-grained materials, composed predominantly by a large variety of **clay minerals** .

Mud can be referred toeither actual or recent **suspended matters** in river or marine waters, but also as recent but somewhat evolved **sediment** accumulated at the bottom of a variety of sedimentary basins, or as former muddy material nowadays more or less deeply transformed (lithified) into a **consolidated, muddy or clayey geological material** either outcropping at the surface or crosscuted by boreholes.

A **variety of descriptive terms** refers to the muddy substances: i.e. muds, clays, claystone , mudstone , shale or slate, depending on the degree of compaction, lithifaction and diagenesis. Because of the kind of technical approach and interest developed in the study of such a material, many discrepancies still arise in the choice of descriptive criteria, methods of analysis and , hence, about the appropriated genetic meanings. One could say that the "mud" problem is (still) in a kind of "babel tower" for which everybody vaguely or quickly refer to without really trying to reach a common but universally accepted definition or consensus in the methodology of appraisal.

If one accepts to exclude here the varieties of "mud" made of anything else than true but predominantly clay minerals, a muddy or clayey material would naturally be built up by the intimate association of a **variety of minerals.** Any definition of a clayey or of a muddy material should involve at least **six interrelated levels or facets** of observation and their subsequent genetic appraisal:

1) a **geological sense** by referring to all geological (or pedological) material predominantly composed of clay minerals s.s..

2) a **specific grain -size** with all or the majority of the mineral particles being concentrated around or below 2 microns

3) a **mineralogical sense** which refers to an admixture of various minerals and of organic substances at both the level of the composition and quantitative content :

The mineralogical characterization will encompass that of the **clay mineral** themselves and their fine-grained (micrometric) related **phyllosilicates** , but also all the other possible associated **non-clayey silicates** (i.e. quartz, feldpars, ferromagnesians), and/or **non silicates** ones (i.e. sulphates carbonates, salts), as well as any **organic and/or inorganic but amorphous compounds**, and finally a certain amount of **inter- and intra-particular water** (moisture content).

4) specific **geomechanical characteristics** better related to the aggregation mode (i. e. the **microstructural properties**) of all the micrometric particles or components ; here the evolution of a clay substance towards the avcquisition of a **fissility** state when consolidated is of an increasing importance to the geological sciences

5) the **rheological properties** : any mud or clayey substance in **suspension** also beasr an increasing importance in characterizing the properties of a mud still in suspension; this characterization relies on the detailled mineralogy, crystallography, organic and inorganic chemistry and hydromechanical behaviour of the "muds".

6) the **mutual integration of dimensions, structural arrangement, compositions and modes of occurrerence- what is her referred to as the Clay Integron-embodies the description of the mud** from the **atomic level** (arrangement of atomic planes) throughout the **landscapewhere** which muds and clays occur as in situ by-products or as accumulated geological material. In other words, the concept of the Clay Integron stresses the **multiscale study of muds from the Angström scale to the cubic Kilometer one** by encompassing a true global approach,that may or is to be itself enlarged to the plate tectonics.

In order to raise the attention on what is or has to be called correctly "mud", and in trying to reconciliate the **different meanings and scales** as well as to precise the better choice of **technical observational tools** in depicting and fully qualifying all the matters referred to the "mud realm", a set of synthetic illustrations is presented which emphasizes such a need through a **multiscale integration** of the different fundamental and applied facets. This **multiscale approach** makes structurally and genetically speaking any naturally occurring muddy or clayey substance appearing as a real but still difficult enjoyable subject of study for all of us in touch with the muds providing that a kind of mutual concensus develops amongst the interested researchers.

The concept of the **Clay Integron** is here proposed as to precisely try to bridge the **different but mutually integrated scales** and **structural parameters** which, at the standpoint of any clayey material, essentially yield the **architectural organization** from the **Angström** scale (of the **atomic planes, sheets, layers and structural units)** up to the **field occurrence** (in **samples, profiles** and **clayey bodies**) where clays accumulate within a **plurikilometric** scale. The intermediate steps or phases within the concept of the Clay Integron concern the existence and the interrelationship of **primary particles, morphological units** , **micrometric clay particles** and **clay domains** with increasing sizes of construction (between the ten of hundreds of Angströms up to the micron in size). In parallel, the appropriate **investigational techniques** are emphasized, which are part of the **different disciplines** interested in the knowledge of muds or clays. The **genetic informations** take into account the variable and even contrasted conditions of **occurrence, accumulation (in situ formation), erosion, transport, sedimentation and burial**. Associated **geochemical processes and pathways** closely connected with the **birth** and **fate of muds and clayey substances** are graphically illustrated within the **argillogenetic cycle which links the lithosphere to the hydrosphere,** and thus incorporate in the genetic model the impact of **internal** (composition, texture, structrure, porosity, granulometry, rheololgy) and of **external "stimuli'** (geomorpohology, vegetation, climate, geological duration of the argillogenesis, etc.) ; all theseparameters are displayed from the **local sites of claygenesis** towards the final setting of these materials within the framework of the **plate tectonics and in close relation with the facets of the classic geological cycle.**

Acoustic Remote Sensing of Marine Environments

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Abstract: The acoustic reflectometry is an appropriate method to solve some of the problems stated in a marine environment. One is only interested here in the study of the sediment layers and the near subbottom, and not in a geological prospecting of the underground of seas and rivers. This means that information up to a few meters of depth via a non-destructive or non-disturbing technique is envisaged, i.e. without having the composition and location of the sediment layers altered while measuring. This implies that the use of probes towed along the seabottom is excluded. The acoustic echosounding method is for this remote sensing task a far better candidate then the techniques based on seismics. This is due to the fact that it is possible to generate emitted pulses with a high power content electronically (up to a few kW) and to the short duration of an experiment, since only a low penetration is aimed, so that with a high repetition frequency the bottom can be scanned (e.g. 5 records/second).
Although from metrological point of view, the acoustic reflectometry seems to be a good measurement method, it follows from practice that the interpretation of the echograms is not a simple nor a trivial task! Several arguments can be used to explain this statement: the definition of mud (but also other sediments), the used instrumentation and the physical environment where the experiments have to be carried out. The definition of mud is certainly one of the most difficult tasks because it is a very heterogeneous, cohesive sediment composed of a small fraction of sand and an important fraction of clay and organic material. This paper will treat the automated acquisition and interpretation of echosounding measurements. A new technique based on modelling and parameter estimation will be proposed.

ABSTRACT

FINE SEDIMENT TRANSPORT UNDER TIDAL ACTION

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Characteristic properties of fine sediment behaviour are obtained when cohesive sediment dynamics is studied under tidal action. In the cycle of sedimentation, consolidation, resuspension and flocculation, there are two aspects of utmost importance. Firstly the clustering of fine particles to relatively large flocs in the water column, and secondly the role of the top layer of the bed. Attention will be given to both the flocculation process during a tidal cycle and the development of the top layer of the bed under unsteady flow conditions.

In estuaries and coastal waters, the transports of fine-grained particles are largely governed by the interaction of accelerating and decelerating tidal flows with topography. Especially tidal asymmetries are very important in the total sediment transport. The processes are further complicated by river inflow, density gradients, waves and meteorological forcing. Generally these processes result in a turbidity maximum, which is characteristic for many estuaries.

Besides the processes during the tidal cycle also subtidal variations can be important. Episodic events such as high river discharge and stormy conditions are recognized more and more as important elements in the fine sediment transport over long periods.

The behaviour of fine sediment transport under tidal action will be illustrated from results of recent field measurements in the Ems Estuary in the northern part of the Netherlands.

On the classification of marine and estuarine muds.

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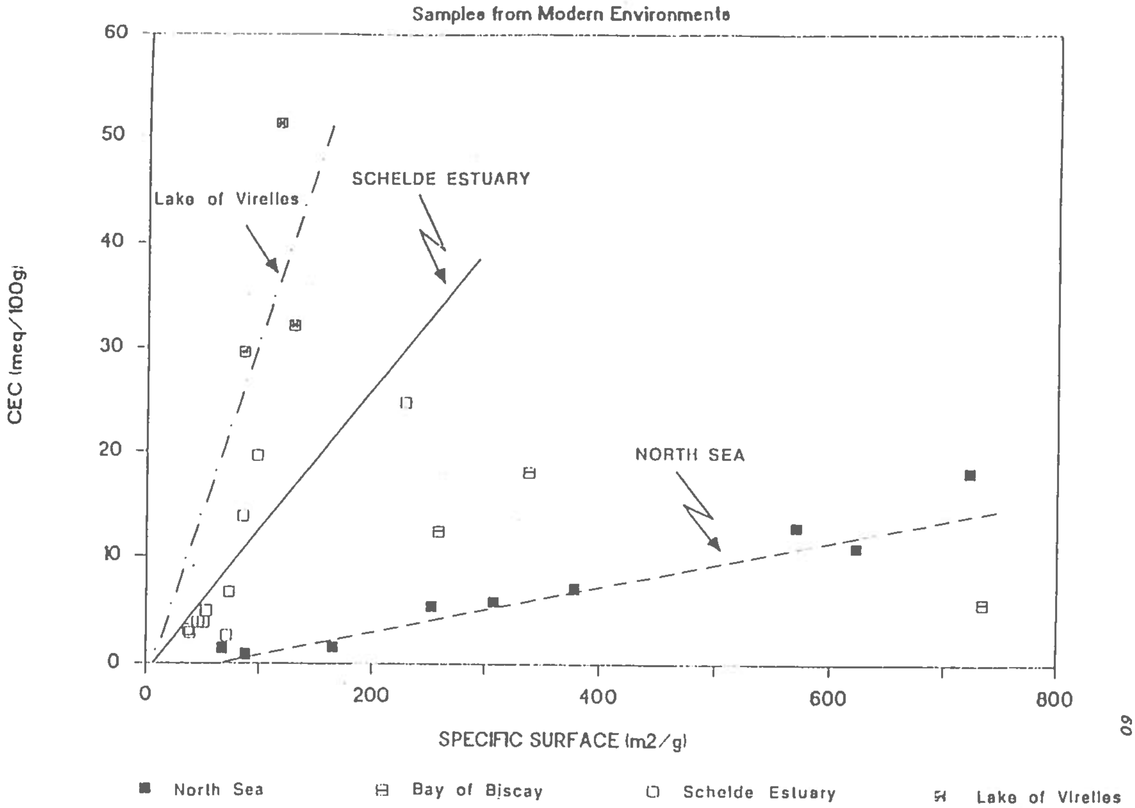
Cohesive, very fine marine or estuarine sediments, generally called "mud" or "fluid mud" occur on many continental shelves and in many cases constitute the main sediment deposited within the area of the turbidity maximum in coastal plain estuaries. Also a considerable progress has been made in the understanding of the sedimentological setting of these sediments. However, it is surprising to ascertain that in contradistinction to the soundness of the scientific analysis of the "mud" a clear description and classification of "mud"-sediments is still lacking. Not only many different names are used (mud, slingmud, hedoro, fluff) but also the given descriptions (stationary suspension, mobile suspension, particles finer than 2, 50 or 63 microns transported in suspension) doesn't say very much about the sediment itself. The incompleteness of such a description not only is confusing but also hinders a comparison of the published data of different environments. This is why an attempt is made here to arrive at an acceptable description and classification of these sediments inspired by a classification of deep-sea sediments proposed by Dean W.E., Leinen M. & Stow D.A. in 1985, and using data of Schelde-estuary and North Sea muds and also data taken from literature.

Because of its general use the name "mud" should be maintained. However, major and minor modifiers can be added. The major modifier must relate to the clay content, which in the case of mud is more relevant than the mean grain size. The first minor modifier can give the ratio between the silt fractions and the clay content. This parameter is correlated with the degree of flocculation of the suspended sediment and thus may hold information on the hydrodynamical conditions prevailing before deposition. As far as the Schelde estuary is concerned the ratio has also an environmental meaning and can thus be of interest for the interpretation of older clay deposits.
However, a descriptive parameter probably more important than any grain-size term, can be found in the relationship between cation-exchange-capacity (CEC) and specific surface (SS) of the sediment (see figure).



Analyses of modern and ancient (Pleistocene) sediments has demonstrated the environmental sensitivity of this relationship.

Another minor modifier can be found in the nature of the bedding and some internal structures as clay fabric and gas bubbles. Gas bubbles are observed in radiograms and SEM-analyses. From observations in North Sea muds it has been assumed that expanding and migrating gas bubbles, due to changes in hydrostatic pressure, induce changes in the properties of the clay.

International Workshop on Cohesive Sediments: <<Towards a Definition of "Mud">>

Parameters to characterise natural muds.

Johan C. Winterwerp, John M. Cornelisse, Cees Kuijper
Delft Hydraulics, The Netherlands

Abstract:

At Delft Hydraulics various physico-chemical bulk parameters are currently being measured to characterise the properties of natural muds, including pore water, and the properties of the overflowing fluid. These parameters were selected after a preliminary study, involving a concise literature survey and additional laboratory experiments, and compromising between completeness and economics, i.e. costs.
This paper describes the results of this preliminary study. Where appropriate, definitions are given, the measuring methods and their accuracy discussed, and the mutual relations between various bulk parameters is elaborated.

Physico-chemical properties of the overflowing fluid:

Parameter	Unit
Chlorinity	kg/m^3
Temperature	$^\circ C$
Oxygen content	kg/m^3
Redox potential	mV
pH	-
Na-, K-, Mg-, Ca-, Fe-, Al-ions	kg/m^3
Sodium Adsorption Ratio	$(meq/l)^{½}$

Physico-chemical properties of the mud:

Parameter	Unit
Chlorinity	mg/kg dry sediment
Temperature	°C
Oxygen content	kg/m^3
Redox potential	mV
pH	-
Sand and organic content	kg/kg dry sediment
Na-, Mg-, K-, Ca-, Fe-, Al-ions	meq/100 gram dry sediment
Cation Exchange Capacity	meq/100 gram dry sediment
Bulk density	-
Specific surface area	m^2/g
Mineralogical composition, for instance:	
smectite	% by weight
chlorite	% by weight
illite	% by weight
kaolinite	% by weight
montmorillonite	% by weight
quartz	% by weight
feldspar	% by weight
calcite	% by weight
dolomite	% by weight
Grain size distribution of deflocculated sediment	m
Settling velocity distribution at various concentrations	m/s
Viscosity at various concentrations	Pas
Bingham strength, yield strength at various concentrations	Pa
Variation of dry density profile during small scale consolidation test	kg/m^3
Pore pressure variation during small scale consolidation test	Pa

Accuracy of measurements:

Several measurements and their interpretations are very sensitive to the experimental procedure. This is discussed and quantified in the paper:

1. Is it possible to determine the mineralogical composition in an unambiguous way from the spectrum analysis?

2. Methods to determine concentrations of dilute suspensions of sediments and organic compounds, and their accuracy (filter techniques and optical methods).

3. Measurements of the distribution in grain size and settling velocity using a sedigraph, a sedimentation balance and Malvern particle sizer, their accuracy, and the sensitivity of the results to utlra-sonic stirring, to the addition of a de-flocculant, and to the removal of organic material.

4. Measurements of viscosity, yield strength and Bingham strength, the effects of experimental procedure on the results and comparison of "applied shear rate" and "applied stress" rheometers.

Several of these bulk parameters are related mutually. This is elaborated for some cases in the paper.

The use of sediments as a monitoring tool

R. WOLLAST. University of Brussels.

The sediments present several advantages for monitoring contaminants in aquatic systems. Heavy metals, pesticides, hydrocarbons show a high affinity to particulate matter and are consequently enriched in bottom sediments of estuaries and coastal areas adjacent to industrial and urban areas . They are however preferentially associated with fine grained suspended solids and colloidal organic and inorganic particules. It is therefore essential to understand and normalize for the effect of grain size distribution before the effect of anthropogenic inputs can be realistically evaluated.

The aim of this talk is to pesent a tentative normalization technique to evaluate the concentrations of contaminants in sediments with respect to backgroung or natural levels expected for similar non contaminated deposits. Excess levels above backgroung values could then be used to establish sediment quality criteria. The proposed methodology results from the discussions of the working group on "Marine Sediments in Relation to Pollution" and of the "Advisory Committee on Marine Pollution" of the International Council for the Exploration of the Sea (ICES).

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