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Monitoring the Coastal Environment; Part II: Sediment Sampling and Geotechnical Methods

Robert Larson†, Andrew Morang‡ and Laurel Gorman§

†U.S. Army Engineer Waterways Experiment Station
Geotechnical Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199, U.S.A.

‡U.S Army Engineer Waterways Experiment Station
Coastal Engineering Research Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199, U.S.A.

§U.S. Army Engineer Waterways Experiment Station
Information Technology Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199, U.S.A.

ABSTRACT

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The successful application of a variety of subaqueous sediment sampling devices depends upon several criteria. These criteria include an understanding of the depth and purpose of sampling, the anticipated character of the material to be sampled, and the depositional energy environments of the sample zone. Samples provide geologic information on the mineralogic content and condition. Proxmity, sequence and magnitude of sediment units or zones provide energy system change rates, source areas variations, and mechanisms of sediment emplacement. Dynamic conditions during and after sediment deposition produce features and bed forms such as ripples, dunes, and bedding. Using techniques that no not disturb or cause only minimal disturbance of the target sediment zones is important in the ultimate analysis of the subaqueous system. Description of commonly-available samplers, standard operating procedures, and methods of analysis are provided to give guidance for the successful collection and interpretation of subaqueous sediment environments.

ADDITIONAL INDEX WORDS: *Coring methods, vibratory corers, grain-size analyses, sieves, sediment statistics, coring logs.*

INTRODUCTION

This is the second in a series of four papers describing procedures and techniques for monitoring and studying the coastal environment. Here, we discuss sampling tools and geotechnical methods that provide tangible samples suitable for identification and grain-size analyses.

Despite the explosive development of remote sensing and geophysical technology during the last half of the Twentieth Century, there continues to be a need to collect actual samples of the sediment[1] or rock that underlie a study area. There are several reasons for this continued reliance on what is sometimes regarded as a primitive desire to touch, squeeze, and smell the sediment. First, any remote sensing technique is still "remote." It is an interpretation of what is down there, and is hopefully an accurate picture, but this interpretation (or "model") still needs field confirmation. For this reason, a seismic profiling study of a project area is often accompanied by a core boring program. Second, many sediment characteristics can still only be obtained by analysis of the actual samples. For example, sieving is still the best way to determine the distribution of grain sizes in a sample, although research is underway on visual, computerized methods. For engineering design, samples are needed to determine strength, organic content, compressibility, and crushability. Finally, many experienced geologists and engineers like to touch, squeeze, and smell the sediment. They can infer much about the geologic history and physical characteristic of a site by examining samples. We expect that collecting and testing sediment samples will continue to be among coastal researchers' tools of the trade for decades to come.

GRAB SAMPLING AND SAMPLERS

Seafloor sediments in many coastal areas show great spatial and temporal variation. Surface sediments provide information about the energy of the environment as well as the long-term processes and movement of materials, such as sediment transport pathways, sources and sinks. Bed surface sediments are typically collected with grab samplers and then analyzed using standard laboratory procedures. These tests are described in detail in other sources (*i.e.*, FREDETTE *et al.*, 1990; BULLER and MCMANUS, 1979).

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[1] Sediment means "solid fragmental material transported and deposited by wind, water, or ice, chemically precipitated from solution, or secreted by organisms, and that forms in layers in loose, unconsolidated form, e.g., sand, mud, till." (BATES and JACKSON, 1984). Soil is unconsolidated surficial sediment which supports plant life. This is a more restrictive definition than the one used in engineering texts, which generally refer to soil as any unconsolidated material (i.e., sediment), even if barren of plant life. Note that engineers often use the terms soil and sediment interchangeably.

There are a variety of grab type samplers of different sizes and design that are used for collecting surface sediment samples (described in detail in BOUMA (1969)). Most consist of a set of opposing, articulated scoop-shaped jaws that are lowered to the bottom in an open position and are then closed by various trip mechanisms to retrieve a sample. Many grab samplers are small enough to be deployed and retrieved by hand; others require some type of lifting gear. If there is gravel in the sample, many liters of sample may be needed for reliable grain size distribution testing. Quantities of sample needed for grain size analyses are discussed later in this paper.

A simple and inexpensive dredge sampler can be made of a section of pipe that is closed at one end. It is dragged a short distance across the bottom to collect a sample. Unlike grab samples, the dredged samples are not representative of a single point and may have lost finer material during recovery. However, dredge samplers are useful in areas where shells or gravel, which prevent complete closure of the jaws, are present.

Although obtaining surficial samples is helpful for assessing recent processes, it is typically of limited value in stratigraphic study because grab samplers usually recover less than 15 or 20 cm of the sediment. Generally, the expense of running tracklines in coastal waters for the sole purpose of sampling surficial sediments is not economically justified unless particularly inexpensive boats can be used. Occasionally, grab and dredge samples are taken during geophysical surveys, but the sampling operations require the vessel to stop at each station, thus losing survey time and creating interrupted data coverage. Precise offshore positioning now allows grab samples to be collected at specific locations along the boat's track after the survey has been run and the geophysical data examined.

STRATIGRAPHIC SAMPLING

Sediments and sedimentary rock sequences are a record of the history of the earth and its changing environments, including sea-level changes, paleoclimates, ocean circulation, atmospheric and ocean geochemical changes, and the history of the earth's magnetic field. By analyzing stratigraphic data, age relations of the rock strata, rock form and distribution, lithologies, fossil record, biopaleogeography, and episodes of erosion and deposition at the coast can be determined. Erosion removes part of the physical record, resulting in unconformities. Often, evidence of erosion can be interpreted using physical evidence or dating techniques.

Sediment deposits located across a zone that ranges from the maximum water level elevation to the depth of the wave base are largely indicative of recent processes. Within this zone in unconsolidated sediments, simple reconnaissance field techniques, using ordinary construction equipment or hand tools, can be used to collect data. Smaller efforts require shovels, hand augers, posthole diggers, or similar hand-operated devices. Larger-scale efforts may include trenches, pits or other large openings created for visual inspection, sample collection, and photography (Figure 1). A sedimentary peel can be taken from the exposed surface. The peel retains the original arrangement of sedimentary properties (BOUMA, 1969; HATTINGH, RUST, and REDDERING, 1990). Often, undisturbed chunk or block samples and disturbed jar or bag samples are carved from these excavations and taken back to the laboratory.

Rates and patterns of sedimentation can be determined using marker horizons. Marker horizons may occur in relation to natural events and unintentional human activities or they may be directly emplaced for the express purpose of determining rates and patterns of sedimentation. For example, NICHOLLS (1989) used columns of aluminum washers to measure the depth of disturbance in cobble beaches.

The petrology and mineralogy of rock samples can be used to identify the source of the sediment. This can indicate if river flow has changed or if coastal currents have changed directions. Mineralogy as it pertains to sediment budgets is discussed in MEISBURGER (1993) and WILDE and CASE (1977).

For many stratigraphic studies, direct sampling of subbottom materials is essential. Table 1 lists details on a number of subaqueous sediment sampling systems that do not require drill rigs. One system listed in Table 1, the vibratory corer ("vibracorer"), is commonly used by geologists to obtain samples in lacustrine, offshore marine, and coastal environments (and MEISBERGER, 1982a, 1982b; HOYT and DEMAREST, 1981; IMPERATO, 1987; LANESKY, LOGAN, and HINE, 1979; MEISBURGER and WILLIAMS, 1981). Vibracoring has even been successfully performed through the ice in the Antarctic (LOVE *et al.,* 1982). Vibratory corers consist of three main components: a frame, coring tube or barrel, and a drive head with a vibrator (Figure 2). The frame is a quadrapod or tripod whose legs are connected to a vertical beam. The beam supports and guides the core barrel and vibrator mechanism and allows the corer to be free-standing on the land or seafloor. The core may be up to 3 or 4 m long, which is adequate for borrow site investigations and many other coastal studies.

While common vibratory corers are capable of penetrating up to 5 m or more of unconsolidated sediment, actual performance depends on the nature of the subbottom material. Stiff clays, gravel, and hard-packed fine to very fine sands are usually most difficult to penetrate. Even when a corer has achieved good penetration, under unfavorable conditions very little sediment may be recovered. A discrepancy between penetration and recovery is either due to compaction of the core during coring or loss of material during recovery. Various types of core catchers have been devised to help retain samples within the core tubes, but the catchers usually score or disturb the sample as it penetrates the core tube, thereby affecting sedimentary structures such as laminations. In comparison with rotary boring operations, vibratory coring setup, deployment, operation, and recovery are rapid. Equipment can be prepared and set up in a few hours, and often a 3-m core can be obtained in a matter of minutes. Longer cores require a crane or some other means of hoisting the equipment, a procedure that consumes more time but is still comparatively rapid. Success with vibracoring depends on some prior knowledge of sediment type in the study area.

Cores can be invaluable because they allow a direct, detailed examination of the layering and sequences of the sub-

Figure 1. Trench excavated in the edge of a sand dune, Gulf of Mexico shore, Morgan Peninsula, Alabama.

surface sediment. The sequences provide information regarding the history of the depositional environment and the physical processes during the time of sedimentation. Depending upon the information required, the types of analysis that can be performed on the core include grain size, sedimentary structures, identification of shells and minerals, organic content, microfaunal identification (pollen counts), x-ray radiographs, radiometric dating, and engineering tests. If only information regarding recent processes is necessary, then a box corer, which samples up to 0.6-m depths, can provide sufficient sediment. Because of its greater width, a box corer can recover undisturbed sediment from immediately below the seafloor, allowing the examination of microstructure and lamination (Figure 3). These structures are usually destroyed by traditional vibratory or rotary coring.

Vibratory corers have the advantages of simple construction and easy mobilization, but they are sometimes unwieldy in congested commercial areas such as harbors, and their cost may be beyond the budget of small consultants or universities. To address the need for compact, inexpensive corers, various diver-operated pneumatic systems have been devised (Nichols and Eichenlaub, 1991; Martin and Miller, 1982). These have proven useful in confined areas, but divers cannot work in high currents or where sediments are contaminated (without special safety equipment).

If it is necessary to obtain deep cores, or if cemented or very hard sediments are present, rotary coring is necessary. Truck- or skid-mounted drilling rigs can be conveniently used on beaches or on barges in lagoons and shallow water. Offshore, rotary drilling becomes more complex and expensive, usually requiring jack-up drilling barges or four-point anchored drill ships (Figure 4). An experienced crew can drill and sample 100 m of the subsurface in about 24 hr. Information on drilling and sampling practice is presented in Headquarters, U.S. Army Corps of Engineers (USACE) (1972) and Hunt (1984).

SEDIMENT MOVEMENT AND SURFACE FORMS

Background

Tracing sediment movement is of great importance in investigations of geologic history. This includes identifying the locations of sediment sources and sinks, quantifying sediment transport rates, and discovering the pathways. Sedi-

Table 1. *Subaqueous sediment sampling without drill rigs and casing.*

Device	Application	Description	Penetration Depth	Comments
Petersen dredge[1]	Large, relatively intact "grab" samples of sea-floor.	Clam-shell type grab weighing about 450 kg with capacity about 0.4 ft^3 (0.11 m^3)	To about 10 cm.	Effective in water depths to 600 m (or more with additional weight).
Harpoon-type gravity corer	Cores 1.5- to 6-inch (3.8 to 15.2 cm) dia. in soft to firm sediments.	Vaned weight connected to coring tube dropped directly from boat. Tube contains liners and core retainer.	To about 10 m.	Maximum water depth depends only on weight. Undisturbed (UD) sampling possible with short, large-diameter barrels.
Free-fall gravity corer	(As above for harpoon type.)	Device suspended on wire rope over vessel side at height above seafloor of about 5 m and then released.	Soft sediment to about 5 m. Firm sediment to about 3 m.	(As above for harpoon type.)
Piston gravity corer (Ewing gravity corer)	2.5-inch (6.35 cm) sample in soft to firm sediments.	Similar to free-fall corer except that coring tube contains a piston that remains stationary on the seafloor during sampling.	Standard core barrel 10 ft (3.05 m); additional 10-ft sections can be added.	Can obtain high-quality UD samples.
Piggott explosive coring tube	Cores of soft to hard bottom sediments.	Similar to gravity corer. Drive weight serves as gun barrel and coring tube as projectile. When tube meets resistance of sea-floor, weighted gun barrel slides over trigger mechanism to fire a cartridge. The exploding gas drives tube into bottom sediments.	Cores to 1-7/8 inch (4.75 cm) and to 10-ft lengths have been recovered in stiff to hard materials.	Has been used successfully in 6,000 m of water.
Norwegian Geotechnical Institute gas-operated piston	Good-quality samples in soft clays.	Similar to the Osterberg piston sampler except that the piston on the sampling tube is activated by gas pressure.	About 10 m.	
Vibracorer[2]	High-quality samples in soft to firm sediments. Dia. 3.0 inch (7.6 cm).	Apparatus is set on seafloor. Air pressure from the vessel activates an air-powered mechanical vibrator to cause penetration of the tube, which contains a plastic liner to retain the core.	Length of 20 ft (6 m). Rate of penetration varies with material strength. Samples a 20-ft core in soft sediment in 2 min.	Maximum water depth about 60 m.
Box corer	Large, intact slice of seafloor.	Weighted box with closure of bottom for benthic biological sampling or geological microstructure.	To about 0.3 m.	Central part of sample is undisturbed.

[1]Similar grab dredges include the Ponar®, whose jaws close when the device strikes the seafloor, and the Ekman, whose jaws are activated by a messenger. A messenger is a metal plug that slides down the steel cable and strikes a spring-loaded jaw-control mechanism

[2]Vibracorers vary greatly in size. Many are custom-made at universities or consulting companies. Some are electrically- or mechanically-powered, and many use 3.0-inch (7.6 cm) thin-walled aluminum irrigation pipe as a combination core barrel and liner

Adapted from HUNT (1984) and other sources

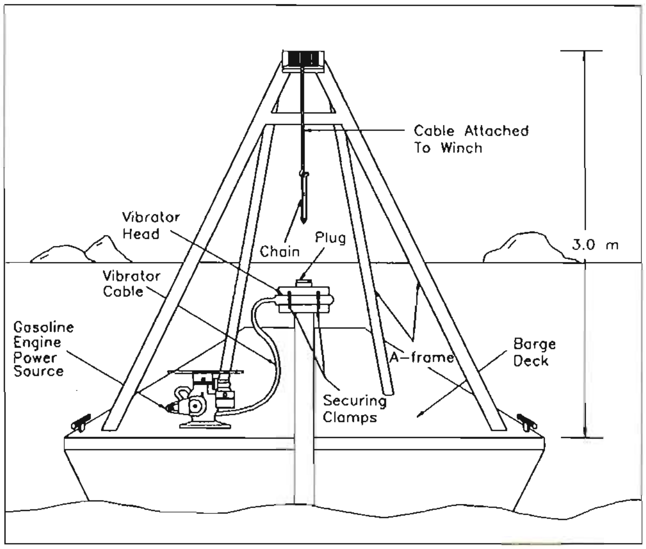


Figure 2. Lightweight vibracorer mounted on a barge.

ment transport is influenced by grain properties such as size, shape, and density, with grain size being most important. Differential transport of coarse and fine, angular and rounded, and light and heavy grains leads to grading. Repeated field visits to a project site can assess temporal variability of these phenomena. Simultaneous measurements of energy processes, such as current and waves, are often required to understand the rates and mechanisms of movement. The computation of a sediment budget is a fundamental tool needed for many coastal engineering studies, especially beach renourishments or projects where structures are likely to affect sediment movement. Unfortunately, there is still a considerable amount of "black magic" involved in calculating sediment budgets, and it is unlikely that two researchers working at the same site would generate comparable numbers. The *Shore Protection Manual* (U.S. ARMY CORPS OF ENGINEERS, 1984) discusses sediment budget methodologies, and coastal littoral transport is covered in detail in HEADQUARTERS, USACE (1992). MEISBURGER (1993) discusses data sources used in budget calculations.

Measurement of Sediment Movement

The measurement of suspended and bed load sediment movement in the surf zone is an exceedingly difficult exercise. There are a variety of sampling devices available for measuring suspended and bed load transport in the field (DUGDALE, 1981; SEYMOUR, 1989), but these devices have not performed properly under some conditions or have been expensive and difficult to use. For these reasons, new sampling procedures are being developed and tested at the Coastal Engineering Research Center (CERC) and other laboratories. Point measurements of sediment movement can be performed by two general procedures:

(1) Direct sampling and weighing of a quantity of material

(2) Detection of the fluid flow by electro-optical or acoustic instruments deployed in the water

Two general methods are available to directly sample the sediment in suspension and in bed load. First, water can be collected in hand-held bottles or can be remotely sucked into containers with siphons or pump apparatus. The samples are then dried and weighed. The second method is to trap a representative quantity of the sediment with a mesh or screen trap through which the water is allowed to flow for a fixed time. A fundamental problem shared by both methods is the question of whether the samples are truly representative of the sediment in transport. For example, how close to the seabed must the orifice be to sample bed load? If it is high enough to avoid moving bed forms, will it miss some of the bed load? Streamer traps made from mesh are inexpensive to build but difficult to use. The mesh must be small enough to trap most of the sediment but must allow water to flow freely. KRAUS (1987) deployed streamers at Duck, North Carolina, from stainless steel wire frames (Figure 5). KRAUS and DEAN (1987) obtained the distribution of longshore sand transport using sediment traps. At this time, sediment traps are still research tools and are not commonly used. A fundamental limitation of traps is that they can usually only be deployed in mild conditions. In winter and during storms, it is too hazardous for the field technicians to maintain the equipment. Perversely, it is under these harsher conditions when the greatest sediment movement occurs. Another fundamental problem is relating the instantaneous measured suspended and bedload transport to long-term sediment movement. Because of the extreme difficulty of conducting research in the surf zone, answers to these questions remain elusive.

Electronic instruments are being developed to detect or estimate sediment transport. They have some advantages over direct sampling procedures. These include the ability to measure the temporal variations of suspended or bed load sediment and the ability to be used in cold water or in harsh conditions. (Note, however, that in severe storms, essentially no man-made devices survive in the surf zone.) Their disadvantages include the difficulty of calibrating the sensors and testing their use with different types of sand and under different temperatures. In addition, many of these instruments are expensive and not yet commonly available. STERNBERG (1989) and SEYMOUR (1989) discuss ongoing research to develop and test new instruments for use in sediment transport studies in estuarine and coastal areas.

Sediment movement, both bed load or total load, can also be measured with the use of natural and artificial tracers (DUGDALE, 1981). Heavy minerals are natural tracers which have been used in studies of sediment movement (MCMASTER, 1960; WILDE and CASE, 1977). Natural sand can also be labelled using radioactive isotopes and fluorescent coatings (ARLMAN, SANTEMA, and SVAŠEK, 1958; DUANE, 1970; INMAN and CHAMBERLAIN, 1959; TELEKI, 1966). Radioactive tracers showed great promise in the 1940's and '50's, but their use is no longer possible because of health and safety concerns. When fluorescent dyes are used, different colors can be used simultaneously on different size fractions to differ-

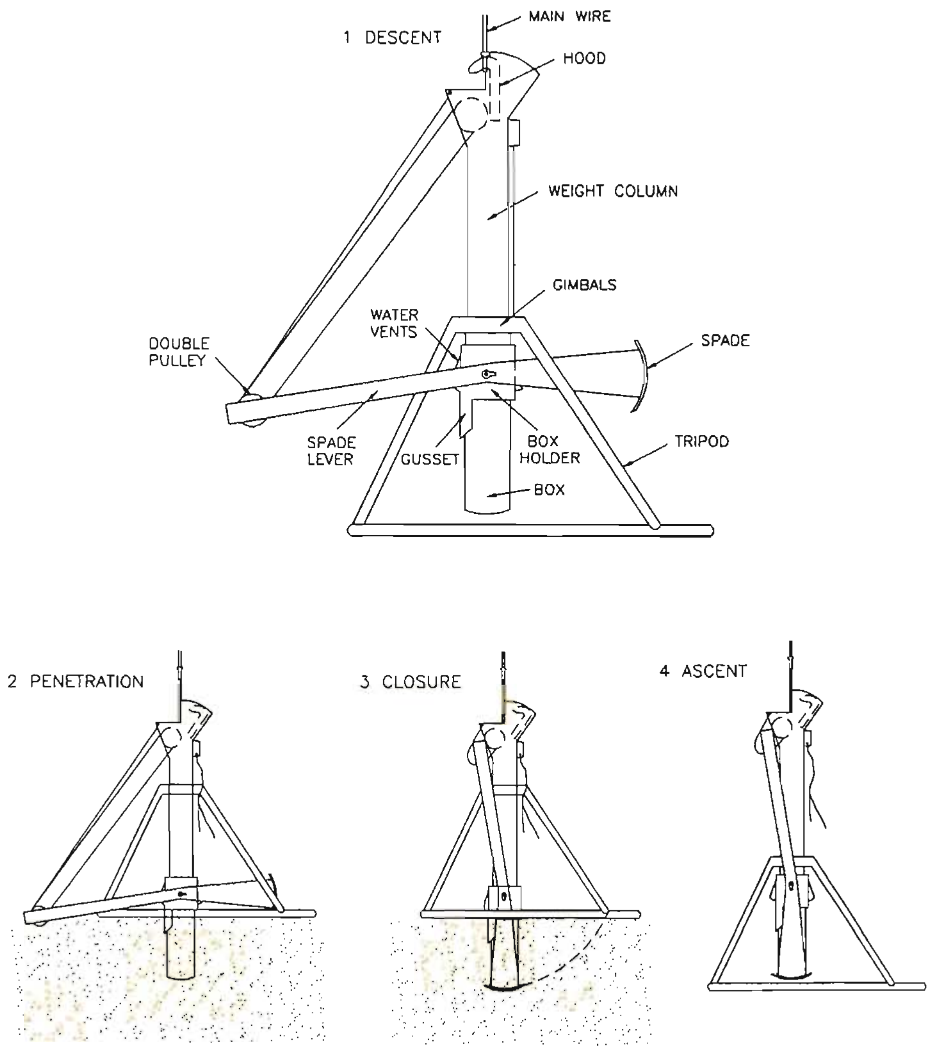


Figure 3. Box corer, commonly used for biological sampling and studies of geological micro-structure (from LEE and CLAUSNER, (1979).

entiate between successive experiments at one locality (INGLE, 1966). Artificial grains, which have the same density and hydraulic response of natural grains, can also be used in tracer studies. NICHOLLS and WEBBER (1987) used aluminum cobbles on rocky beaches in England. They located the aluminum rocks in the field using metal detectors. NELSON and COAKLEY (1974) review artificial tracer methods and concepts. Note that tracer studies are extremely labor-intensive, both for the field work and the subsequent sample examination and grain-counting. In addition, in dynamic settings, tremendous amounts of tracer may be necessary in order to be able to identify sediment pathways. Therefore, because of these logistical considerations and high labor costs, many geologists now are unable to mount tracer studies and must use other field methods.

As with other phenomena, the experimental design for tracer studies may be Eulerian or Lagrangian. For the time integration or Eulerian method, the tracer grains are injected at a constant rate over a given interval of time. For the space integration or Langrangian method, the tracers are released over an area at the same time. The choice of the method depends upon the nature of the problem. Field experiments must be designed carefully to isolate the parameter of interest that is to be measured or traced. For example, if the purpose of the study is to assess bed-load transport, then care must be taken not to introduce tracers into the suspended load in the water column.

INTRODUCTION TO BED FORMS

Introduction

When sediment is moved by flowing water, the individual grains are usually organized into morphological elements called *bed forms.* These occur in a baffling variety of shapes and scales. Some bed forms are stable only between certain values of flow strength. Often, small bed forms (ripples) are

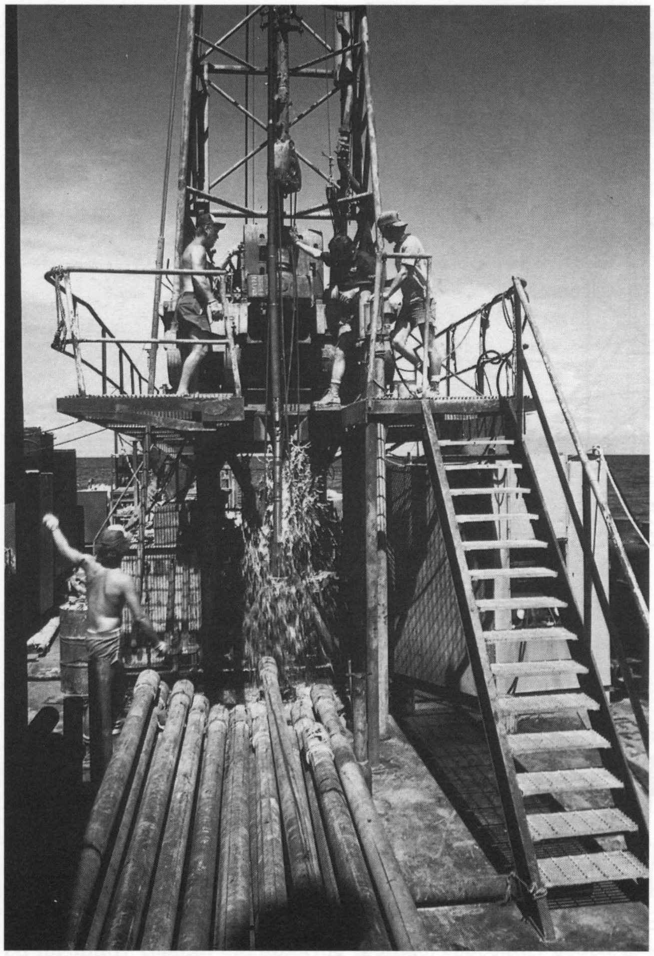


Figure 4. Rotary drilling operations underway from a 4-point anchored drill ship in the Golfo de Guayaquil, Ecuador. Drilling was conducted 24 hr using two crews.

found superimposed on larger forms (dunes), suggesting that the flow field may vary dramatically over time. Bed forms may move in the same direction as the current flow, may move against the current (antidunes), or may not move at all except under specific circumstances. The study of bed form shape and size is of great value because it can assist in making quantitative estimates of the strength of currents in modern and ancient sediments (HARMS, 1969; JOPLING, 1966). Bed form orientations are indicators of flow pathways. This introduction to a complex subject is by necessity greatly condensed. For details on interpretation of surface structures and sediment laminae, readers are referred to textbooks on sedimentology such as ALLEN (1968, 1982, 1985), KOMAR (1976), LEEDER (1982), LEWIS (1984), MIDDLETON (1965), MIDDLETON and SOUTHARD (1984), and REINECK and SINGH (1980).

Environments

In nature, bed forms are found in three environments of greatly differing characteristics:

- Rivers—unidirectional and channelized; large variety of grain sizes
- Sandy coastal bays—semi-channelized, unsteady, reversing (tidal) flows
- Continental shelves—deep, unchannelized; dominated by geostrophic flows, storms, tidal currents, wave-generated currents

Classification

Because of the diverse natural settings and the differing disciplines of researchers who have studied sedimentology, the classification and nomenclature of bed forms have been confusing and contradictory. The following classification scheme, proposed by the Society for Sedimentary Geology (SEPM) Bed forms and Bedding Structures Research Group in 1987 (ASHLEY, 1990) is suitable for all subaqueous bed forms:

Ripples. These are small bed forms with crest-to-crest spacing less than about 0.6 m and height less than about 0.03 m. It is generally agreed that ripples occur as assemblages of individuals similar in shape and scale. On the basis of crest-line trace, ALLEN (1968) distinguished five basic patterns of ripples: straight, sinuous, catenary, linguoid, and lunate (Figure 6). The straight and sinuous forms may be symmetrical in cross section if subject to primarily oscillatory motion (waves) or may be asymmetrical if influenced by unidirectional flow (rivers or tidal currents). Ripples form a population distinct from larger-scale dunes, although the two forms share a similar geometry. The division between the two populations is caused by the interaction of ripple morphology and bed, and may be shear stress. At low shear stresses, ripples are formed. As shear stress increases above a certain threshold a "jump" in behavior occurs, resulting in the appearance of the larger dunes (ALLEN, 1968).

Dunes are flow-transverse bed forms with spacings from under 1 m to over 1,000 m that develop on a sediment bed under unidirectional currents. These large bed forms are ubiquitous in sandy environments where water depths are greater than about 1 m, sand size coarser than 0.15 mm (very fine sand), and current velocities greater than about 0.4 m/sec. In nature, these flow-transverse forms exist as a continuum of sizes without natural breaks or groupings (ASHLEY, 1990). For this reason, "dune" replaces terms such as megaripple or sand wave, which were defined on the basis of arbitrary or perceived size distributions. For descriptive purposes, dunes can be subdivided as small (0.6–5 m wavelength), medium (5–10 m), large (10–100 m), and very large (> 100 m). In addition, the variation in pattern across the flow must be specified. If the flow pattern is relatively unchanged perpendicular to its overall direction and there are no eddies or vortices, the resulting bed form will be straight crested and can be termed two-dimensional (Figure 7a). If the flow structure varies significantly across the predominant direction and vortices capable of scouring the bed are present, a three-dimensional bed form is produced (Figure 7b).

A *plane bed* is a horizontal bed without elevations or depressions larger than the maximum size of the exposed sediment. The resistance to flow is small, and results from grain

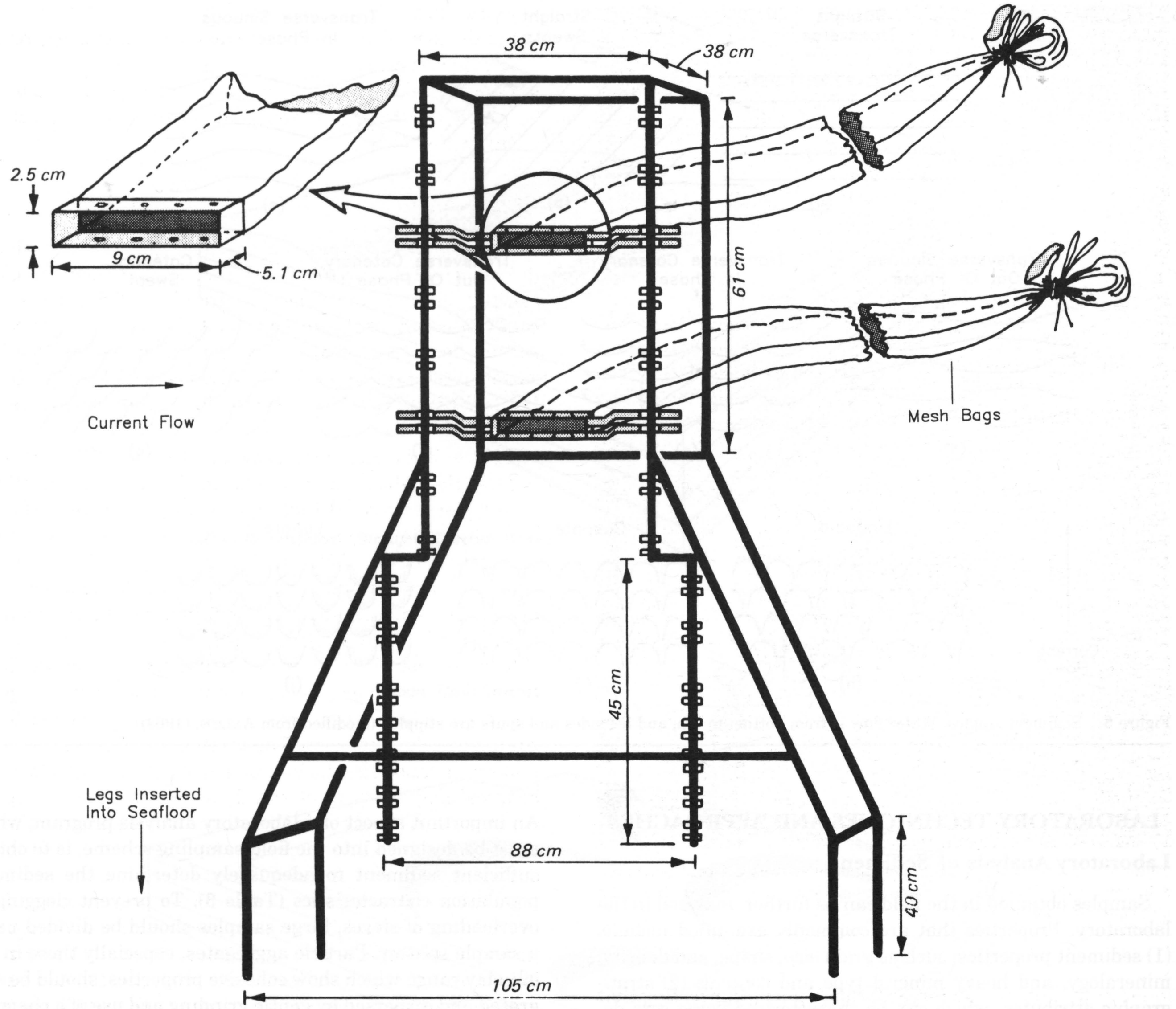


Figure 5. Side view of steel frame and polyester mesh sediment traps used at Duck, North Carolina, by KRAUS (1987) during CERC's DUCK '85 field experiments.

roughness, which is a function of grain size. Plane beds occur under two hydraulic conditions:

- The transition zone between the region of no movement and the initiation of dunes (Figure 8)
- The transition zone between ripples and antidunes, at mean flow velocities between about 1 and 2 m/sec (Figure 8)

Antidunes are bed forms that are in phase with water surface gravity waves. Height and wavelength of these waves depend on the scale of the system and characteristics of the fluid and bed material (REINECK and SINGH, 1980). Trains of antidunes gradually build up from a plane bed as water velocity increases. As the antidunes increase in size, the water surface changes from planar to wave-like. The water waves may grow until they are unstable and break. As the sediment antidunes grow, they may migrate upstream or downstream, or may remain stationary (the name "antidune" is based on early observations of upstream migration).

Velocity–Grain Size Relationships

Figure 8, from ASHLEY (1990), illustrates the zones where ripples, dunes, planar beds, and antidunes are found. The figure summarizes laboratory studies conducted by various researchers. These experiments appear to support the common belief that large flow-traverse bedforms (dunes) are a distinct entity separate from smaller current ripples. This plot is very similar to Figure 11.4 in GRAF's (1984) riverine hydraulics text, although Graf uses different axis units.

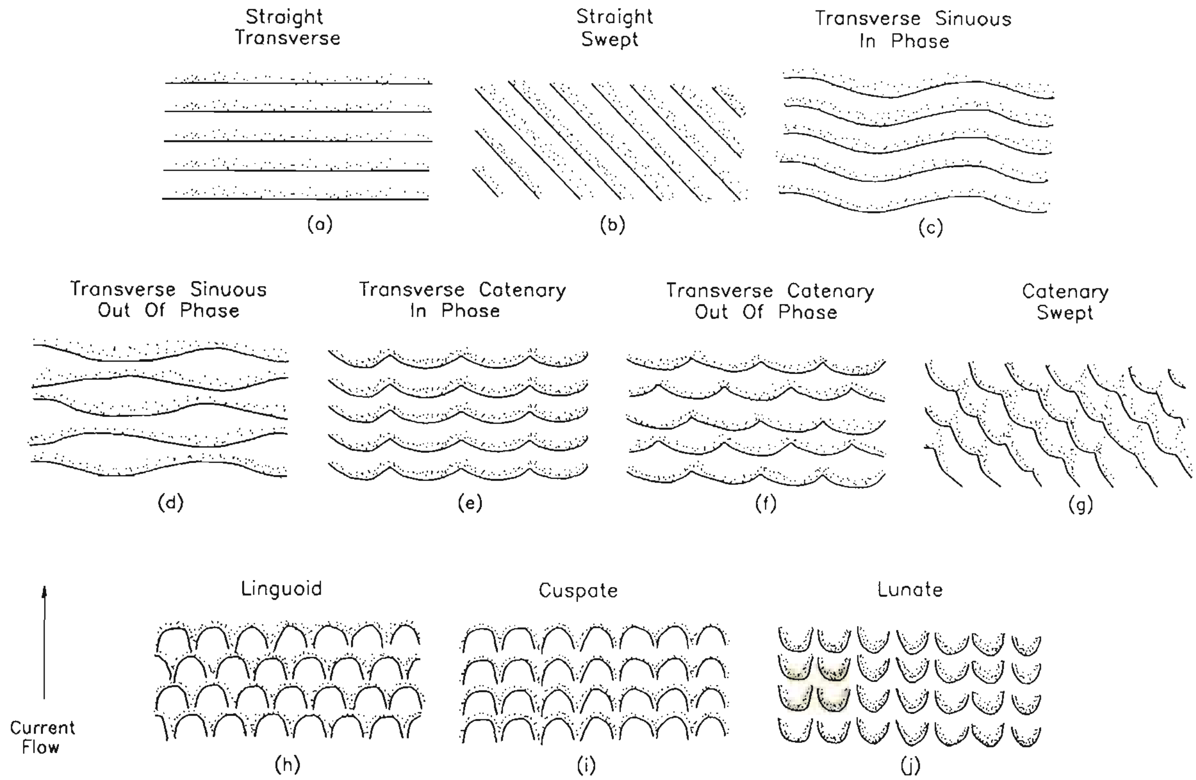


Figure 6. Sediment ripples. Water flow is from bottom to top, and lee sides and spurs are stippled (modified from ALLEN, (1968)).

LABORATORY TECHNIQUES AND APPROACHES

Laboratory Analysis of Sediment

Samples obtained in the field can be further analyzed in the laboratory. Properties that are commonly examined include: (1) sediment properties, such as grain size, shape, and density, mineralogy, and heavy mineral type and content; (2) stratigraphic attributes, which can be characterized using core description, preservation, and analysis techniques; and (3) geochronological history, obtained from radiometric dating and various relative dating approaches. In order to achieve maximum benefit from laboratory analyses, the coastal scientist must be cognizant of the limitations and variance of precision and accuracy of each test and procedure.

Sediments can be classified into size range classes. Ranked from largest to smallest, these include boulders, cobble, pebbles, granules, sand, silt, and clay (Table 2). Particle size is often expressed as d, or the diameter in millimeters, and sometimes includes a subscript, such as d_{84}, to indicate the diameter corresponding to the listed percentile. Geologists often express grain size in phi (ϕ) units, where $\phi = -\log_2 d$ (KRUMBEIN, 1934, 1938). This procedure, which tends to confuse non-geologists, normalizes the grain size distribution and allows computation of other size statistics based on the normal distribution.

Grain-size analysis involves a series of procedures to determine the distribution of sediment sizes in a given sample. An important aspect of a laboratory analysis program, which must be designed into the field sampling scheme, is to obtain sufficient sediment to adequately determine the sediment population characteristics (Table 3). To prevent clogging or overloading of sieves, large samples should be divided using a sample splitter. Particle aggregates, especially those in the silt-clay range which show cohesive properties, should be separated and dispersed by gentle grinding and use of a chemical dispersant (sodium hexametaphosphate) before analysis. Note that depending on the purpose of the study, it may be important to preserve the hydraulic characteristics of sediment aggregates (*i.e.*, clay balls, cemented sand, or shell fragments). In these circumstances, it is best to not split or mechanically grind the samples.

Laboratory techniques used to estimate sediment diameter depend in part on the grain size. Pebbles and coarser sediments can be directly measured with calipers or by coarse sieves. The grain-size distribution of sand is determined directly by sieve analysis, sedimentation tubes, or Coulter counter (Figure 9). Silt and clay-sized material is determined indirectly by hydrometer or pipette analysis, or the use of a Coulter counter. The size distribution of mixed sediments is determined by using a combination of sieve and hydrometer or pipette analyses. Practical procedures for conducting laboratory grain size and mineralogical tests on sediment samples are covered by FOLK (1980) and LEWIS (1984). Laboratory manuals more oriented towards engineering applications

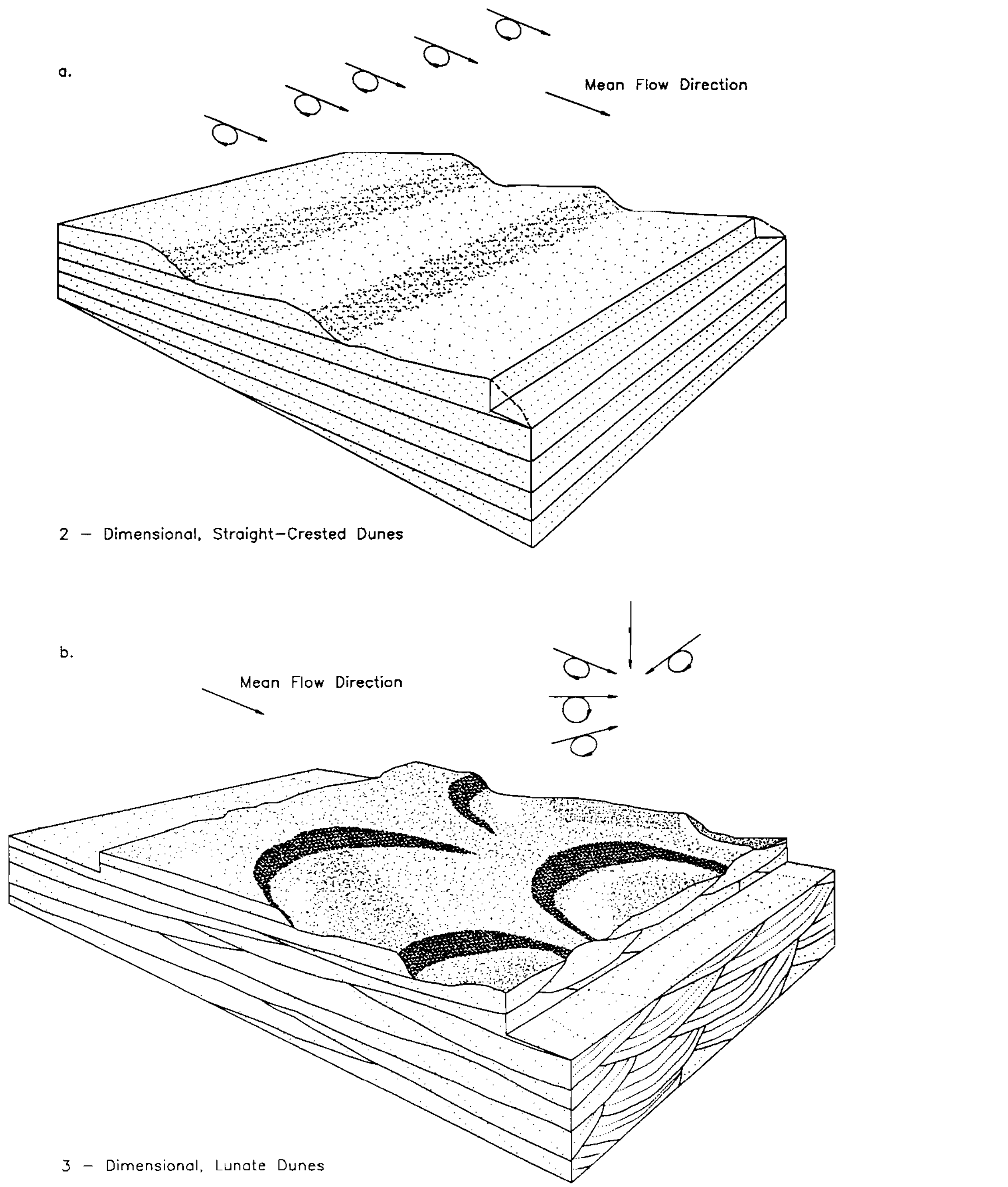


Figure 7. Two- and three-dimensional dunes. Vortices and flow patterns are shown by arrows above dunes. Adapted from REINECK and SINGH (1980).

include those produced by the AMERICAN SOCIETY FOR TESTING AND MATERIALS (1994; reprinted annually), BOWLES (1986), and HEADQUARTERS, USACE (1986).

Coastal sediments reflect the relative importance of various source areas and transport processes. Sources of coastal sediments include:

- River basins that empty into the coastal zone
- Coastal cliffs and uplands that are denuded by waves
- Wind-transported material
- Mass-wasting and slumping
- Sediments transported by longshore currents
- Material moved landward from the continental shelf
- Biologic production (shells and tests)
- Volcanic ash and debris

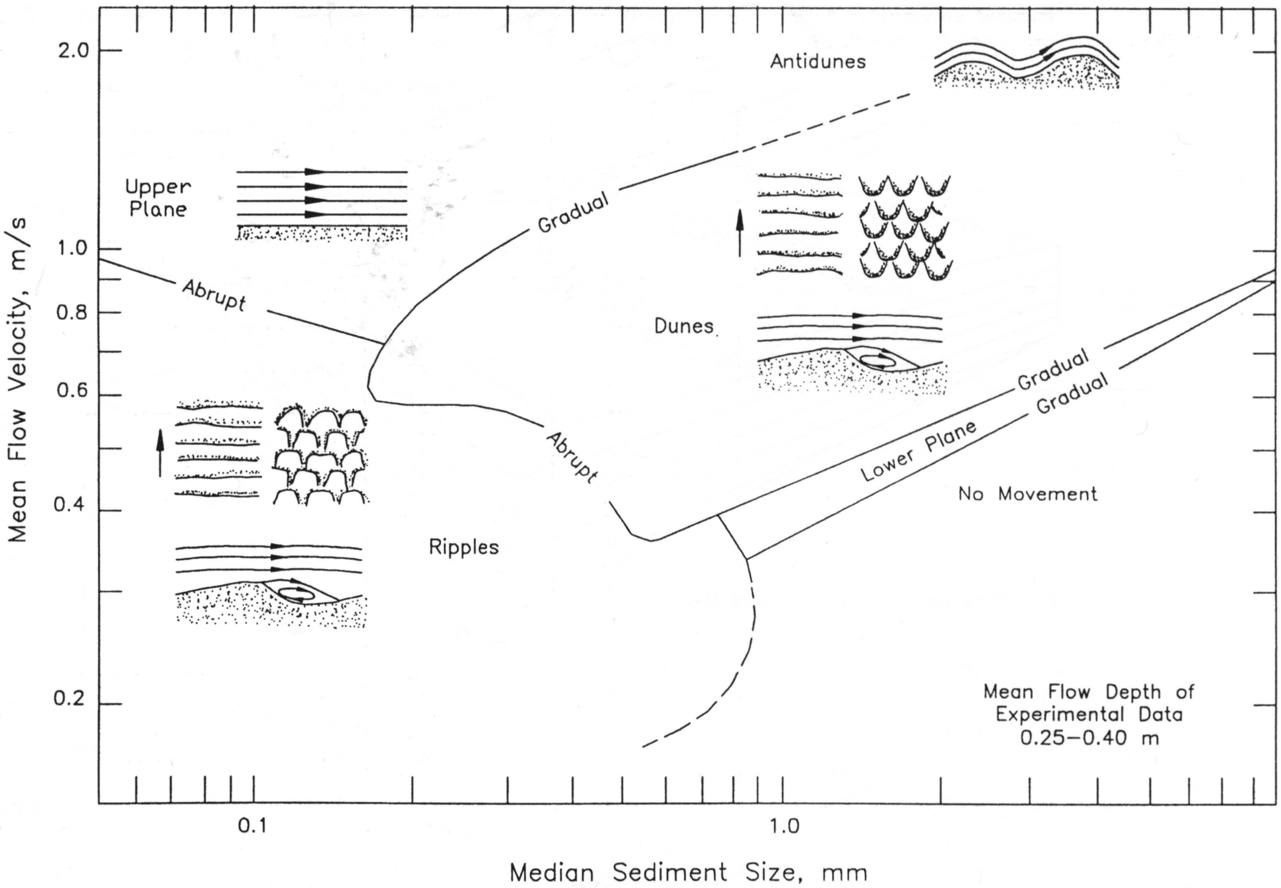


Figure 8. Plot of mean flow velocity against mean grain size, based on laboratory studies, showing stability phases of subaqueous bed forms (modified from ASHLEY (1990)). Original data from various sources, standardized to 10° C. water temperature (original data points not shown).

- Man-made activity

Because gravel and larger particles require more energy to be transported, they are typically found close to their source. In contrast, silt and clay may be transported long distances. The size fraction distribution is determined by the composition of the source rocks and weathering conditions. Variations of the mineralogy of sediments are controlled by source rocks and weathering conditions. Resistant minerals, such as quartz and feldspars, comprise most coastal deposits. However, as tracers, the least common minerals are generally the best indicators of source.

Heavy minerals can provide information regarding source and process and other aspects of geomorphic variability in the coastal zone (BRENNINKMEYER, 1978; JUDGE, 1970; MCMASTER, 1960; NEIHEISEL, 1962). Pronounced seasonal variations in heavy minerals may occur in beach and nearshore samples. Lag deposits of heavy minerals are often seen on the beach after storms.

Analysis of size and texture can also be used to distinguish among sediments that may have come from the same original source area. As an example, MASON and FOLK (1958) used size analysis to differentiate dune and beach sediments on Mustang Island, Texas.

A variety of techniques are used to identify the mineralogy of coastal sediments. Mineralogy of coarse sediments and rocks is typically assessed using laboratory microscopes. Clay mineralogy is usually assessed with X-ray diffraction methods or electron microscopy. Heavy minerals are separated from light minerals using bromoform (specific gravity of 2.87) after washing and sieving. In unconsolidated sediments, heavy mineral samples are examined under a microscope to determine or percentages of mineral types.

CORE DESCRIPTION AND ANALYSIS

Core description is widely used to characterize the features and depositional environments of sediments. After being collected in the field, core barrels are sealed to retain moisture. In the laboratory, they are cut in half lengthwise. One side of the core is used for description and the other for radiography, peels, and sampling for grain size analysis, palynology, and organic materials. Cores are often photographed soon after splitting, while the exposed surfaces are still fresh and subtle colors and textures can still be distinguished.

Table 2. *Sediment particle sizes.*

ASTM (Unified) Classification[1]	U.S. Std. Sieve[2]	Size in mm	Phi Size	Wentworth Classification[3]
Boulder		4096.	-12.0	
		1024.	-10.0	Boulder
	12 in (300. mm)	256.	-8.0	
		128.	-7.0	Large Cobble
Cobble		107.64	-6.75	
		90.51	-6.5	Small Cobble
	3 in (75. mm)	76.11	-6.25	
		64.00	-6.0	
		53.82	-5.75	
		45.26	-5.5	Very Large Pebble
Coarse Gravel		38.05	-5.25	
		32.00	-5.0	
		26.91	-4.75	
		22.63	-4.5	Large Pebble
	3/4 in (19. mm)	19.03	-4.25	
		16.00	-4.0	
		13.45	-3.75	
		11.31	-3.5	Medium Pebble
Fine Gravel		9.51	-3.25	
	2.5	8.00	-3.0	
	3	6.73	-2.75	
	3.5	5.66	-2.5	Small Pebble
	4 (4.75 mm)	4.76	-2.25	
	5	4.00	-2.0	
Coarse Sand	6	3.36	-1.75	
	7	2.83	-1.5	Granule
	8	2.38	-1.25	
	10	2.00	-1.0	
	12	1.68	-0.75	
	14	1.41	-0.5	Very Coarse Sand
	16	1.19	-0.25	
Medium Sand	18	1.00	0.0	
	20	0.84	0.25	
	25	0.71	0.5	Coarse Sand
	30	0.59	0.75	
	35	0.50	1.0	
	40 (0.425 mm)	0.420	1.25	
	45	0.354	1.5	Medium Sand
	50	0.297	1.75	
	60	0.250	2.0	
	70	0.210	2.25	
Fine Sand	80	0.177	2.5	Fine Sand
	100	0.149	2.75	
	120	0.125	3.0	
	140	0.105	3.25	
	170	0.088	3.5	Very Fine Sand
	200 (0.075 mm)	0.074	3.75	
	230	0.0625	4.0	
Fine-grained Soil:	270	0.0526	4.25	
	325	0.0442	4.5	Coarse Silt
Clay if PI ≥ 4 and plot of PI vs.	400	0.0372	4.75	
LL is on or above "A" line*		0.0312	5.0	
Silt if PI < 4 and plot of PI vs.		0.0156	6.0	Medium Silt
LL is below "A" line*		0.0078	7.0	Fine Silt
		0.0039	8.0	Very Fine Silt
*and the presence of organic		0.00195	9.0	Coarse Clay
matter does not influence LL.		0.00098	10.0	Medium Clay
(PI = plasticity limit; LL =		0.00049	11.0	Fine Clay
liquid limit)		0.00024	12.0	
		0.00012	13.0	
		0.000061	14.0	

[1]ASTM Standard D 2487-92. This is the ASTM version of the Unified Soil Classification System. Both systems are similar (from ASTM (1994))
[2]Note that British Standard, French, and German DIN mesh sizes and classifications are different
[3]Wentworth sizes (in inches) cited in KRUMBEIN and SLOSS (1963)

A USACE core drilling log is shown in Figure 10. An alternate sheet used at some universities is shown in Figure 11. Grain size variations, sedimentary structures and directions, and occurrences of cyclic bedding, such as varves, are among the important characteristics of a sedimentary sequence that need to be carefully described in the log. Evidence of plant roots and features such as color changes, mottling, discontinuities, and other variations in physical char-

Table 3
Minimum Weight of Sample Required for Sieving

Maximum Particle Size Present in Substantial Proportion (> 10%)		Weight of Sample
inches	mm	kg
2.5	64	50
2.0	50	35
1.5	40	15
1.0	25	5
0.75	20	2
0.50	12.5	1
0.38	10.0	0.5
0.25	6.3	0.2
	2.4	0.1

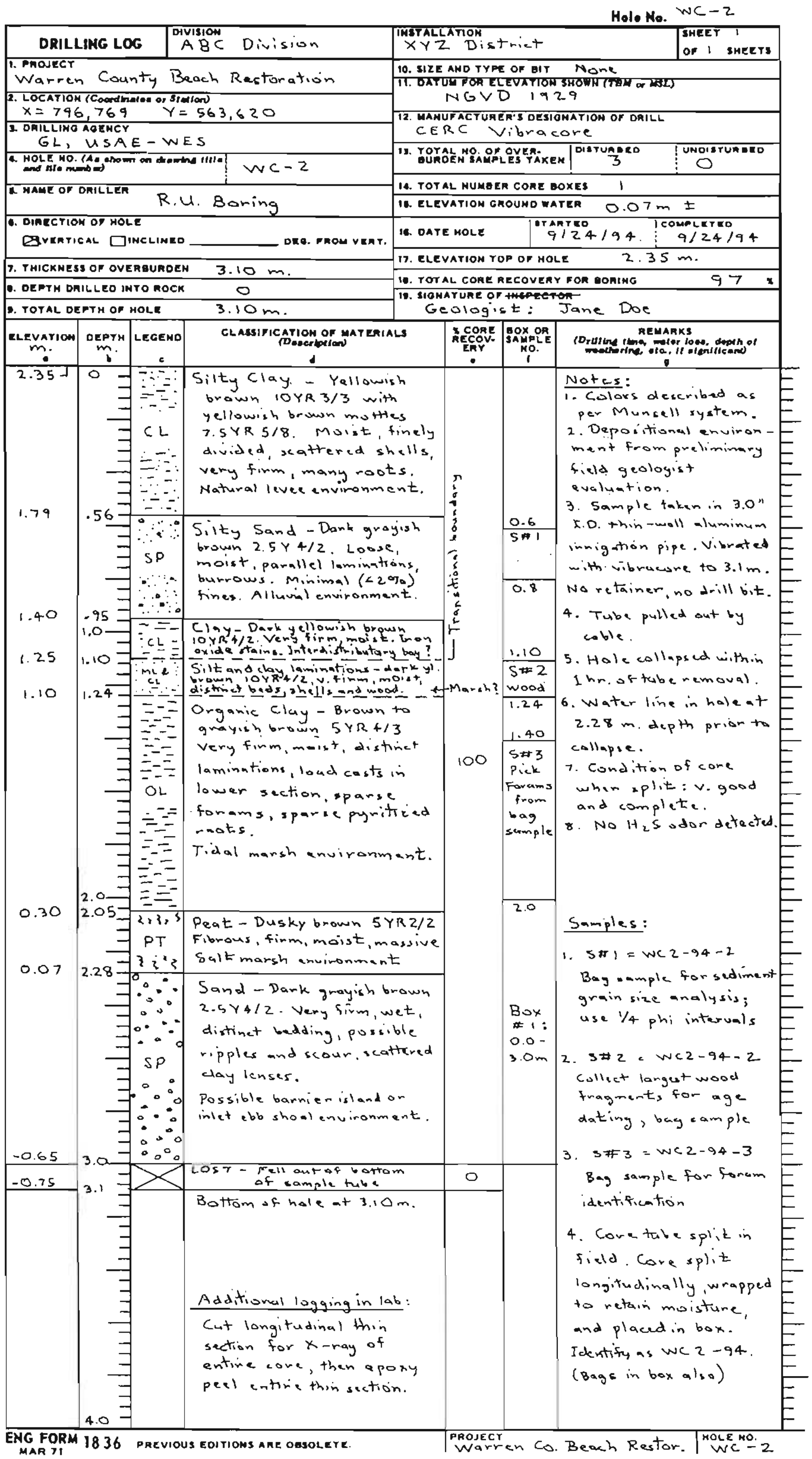
British Standards Institution (1975). Note: quantities specified in ASTM Standard D2487-92 are similar

acteristics may be indicators of key changes. Roots, for example, often represent marsh deposits in coastal sequences. Fossils and pollen in stratigraphic sequences can be used to identify paleoenvironmental characteristics and changes. Techniques for analysis and interpretation of such evidence can be found in Faegri and Iverson (1975) and Kapp (1969).

Grain size variation in cores can yield much information about the sedimentary environments and thus the geologic history of the region. Coarser fractions settle first, followed by silts and clays. This separation is a function of particle settling velocities, which vary depending upon particle size, density, shape, and the nature of the transport media. Changes in the environment of deposition can result in the clay fraction being separated from granular material both spatially and temporally. For example, silt and clay are usually deposited further from shore than granular material.

X-ray radiography is an imaging method that amplifies contrasts in grain size, mineralogical composition, packing density, water content, diagenic products, sedimentary structures and geochemical inclusions in cores that otherwise appear homogeneous (Roberts, 1981). Being able to distinguish these features may assist in understanding the sequence of geomorphic changes that occurred at that site. For

Figure 9. Gilson GilSonic sonic sifter and balance used with 1/4 ϕ sieves for grain size analyses.



Hole No. WC-2

DRILLING LOG | DIVISION: ABC Division | INSTALLATION: XYZ District | SHEET 1 OF 1 SHEETS

1. PROJECT: Warren County Beach Restoration
2. LOCATION (Coordinates or Station): X= 796,769 Y= 563,620
3. DRILLING AGENCY: GL, USAE-WES
4. HOLE NO. (As shown on drawing title and file number): WC-2
5. NAME OF DRILLER: R.U. Boring
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 3.10 m.
8. DEPTH DRILLED INTO ROCK: 0
9. TOTAL DEPTH OF HOLE: 3.10 m.
10. SIZE AND TYPE OF BIT: None
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): NGVD 1929
12. MANUFACTURER'S DESIGNATION OF DRILL: CERC Vibracore
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 3 | UNDISTURBED 0
14. TOTAL NUMBER CORE BOXES: 1
15. ELEVATION GROUND WATER: 0.07 m ±
16. DATE HOLE: STARTED 9/24/94 | COMPLETED 9/24/94
17. ELEVATION TOP OF HOLE: 2.35 m.
18. TOTAL CORE RECOVERY FOR BORING: 97 %
19. SIGNATURE OF ~~INSPECTOR~~ Geologist: Jane Doe

ELEVATION m. (a)	DEPTH m. (b)	LEGEND (c)	CLASSIFICATION OF MATERIALS (Description) (d)	% CORE RECOVERY (e)	BOX OR SAMPLE NO. (f)
2.35	0	CL	Silty Clay - Yellowish brown 10YR 3/3 with yellowish brown mottles 7.5YR 5/8. Moist, finely divided, scattered shells, very firm, many roots. Natural levee environment.		
1.79	.56	SP	Silty Sand - Dark grayish brown 2.5Y 4/2. Loose, moist, parallel laminations, burrows. Minimal (<2%) fines. Alluvial environment.		0.6 S#1 0.8
1.40	.95 / 1.0	CL	Clay - Dark yellowish brown 10YR 4/2. Very firm, moist. Iron oxide stains. Interdistributary bay?	Transitional boundary	1.10
1.25	1.10	ML & CL	Silt and clay laminations - dark yl. brown 10YR 4/2, v. firm, moist, distinct beds, shells and wood. ← Marsh?		S#2 wood
1.10	1.24	OL	Organic Clay - Brown to grayish brown 5YR 4/3 Very firm, moist, distinct laminations, load casts in lower section, sparse forams, sparse pyritized roots. Tidal marsh environment.	100	1.24 1.40 S#3 Pick Forams from bag sample
0.30	2.0 / 2.05	PT	Peat - Dusky brown 5YR 2/2 Fibrous, firm, moist, massive Salt marsh environment		2.0
0.07	2.28	SP	Sand - Dark grayish brown 2.5Y 4/2. Very firm, wet, distinct bedding, possible ripples and scour, scattered clay lenses. Possible barrier island or inlet ebb shoal environment.		Box #1: 0.0-3.0m
-0.65	3.0		LOST - Fell out of bottom of sample tube	0	
-0.75	3.1		Bottom of hole at 3.10 m.		
	4.0		Additional logging in lab: Cut longitudinal thin section for X-ray of entire core, then epoxy peel entire thin section.		

REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g)

Notes:
1. Colors described as per Munsell system.
2. Depositional environment from preliminary field geologist evaluation.
3. Sample taken in 3.0" I.D. thin-wall aluminum irrigation pipe. Vibrated with vibracore to 3.1 m. No retainer, no drill bit.
4. Tube pulled out by cable.
5. Hole collapsed within 1 hr. of tube removal.
6. Water line in hole at 2.28 m. depth prior to collapse.
7. Condition of core when split: v. good and complete.
8. No H_2S odor detected.

Samples:
1. S#1 = WC2-94-1 Bag sample for sediment grain size analysis; use 1/4 phi intervals
2. S#2 = WC2-94-2 Collect largest wood fragments for age dating, bag sample
3. S#3 = WC2-94-3 Bag sample for foram identification
4. Core tube split in field. Core split longitudinally, wrapped to retain moisture, and placed in box. Identify as WC 2-94. (Bags in box also)

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. | PROJECT: Warren Co. Beach Restor. | HOLE NO.: WC-2

Figure 10. Example of Corps of Engineers drilling log from hypothetical site. The log must be methodically and completely filled out by the field geologist.

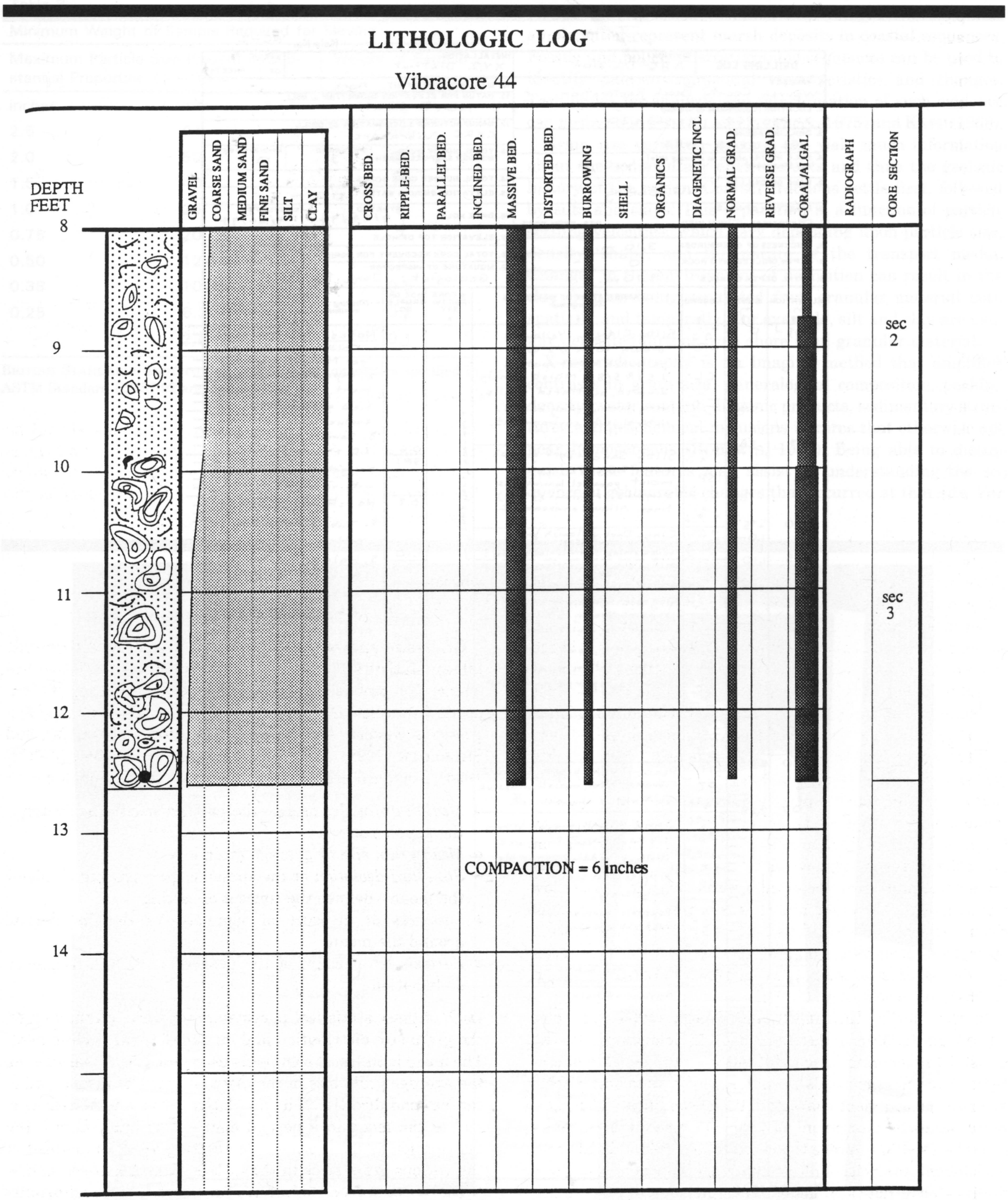


Figure 11. Example core description form used for sedimentary environments (courtesy of Dr. Harry Roberts, Louisiana State University).

example, the scale and direction of bed forms can be used to estimate paleocurrents. Marker horizons are related to a date or a significant event. Peat indicates stability and growth of marshes at or near sea level. Radiography is based on the differential transmission of X-ray radiation through a sample onto sensitized X-ray photographic film. Variations in texture as well as chemical composition throughout the sediment result in differential attenuation of the incident X-ray radiation before it reaches the underlying film. Samples of uniform thickness (about 1 cm) that are cut lengthwise with a wire knife provide the best results in radiography (ROBERTS, 1981).

SEDIMENT GRAIN SIZE ANALYSES AND STATISTICS

Introduction

The coastal zone is comprised of many dynamic morphologic features that frequently change their form and sediment distribution. Although a beach can display a large range of sizes and shapes, each beach is characterized by particular texture and composition representing the available sediment. Although temporal changes in sediment type and distribution occur at any given location on the coast, these variations are generally less spectacular than the changes due to geographic location (DAVIS, 1985). Textural trends alongshore and cross-shore are indicative of the depositional energy and the stability (or instability) of the foreshore and nearshore zones.

Because of natural variability in grain size distributions, a sampling scheme should adequately sample the native beach in both the cross-shore and alongshore directions. Sediment sampling needs to coincide with survey profile lines so that the samples can be spatially located and related to morphology and hydrodynamic zones. Consideration of shoreline variability and engineering structures should be factored into choosing sampling locations. A suggested rule of thumb is that a sampling line be spaced every half mile, but engineering judgment is required to define adequate project coverage. On each line, it is recommended that samples be collected at all major changes in morphology along the profile, such as dune base, mid-berm, mean high water, mid-tide, mean low water, trough, bar crest, and then 3-m intervals to depth of closure (Figure 12) (STAUBLE and HOEL, 1986). The concept of depth of closure is summarized in Paper 4 of this series and discussed in greater detail in HEADQUARTERS, USACE (1995) and PILKEY *et al.* (1993).

In the 1950's, KRUMBEIN and SLACK (1956) (see also KRUMBEIN (1969)) conducted pioneering field studies for the Coastal Engineering Research Center on the benefits of statistical sampling methods to enable geologists to better characterize the sediment characteristics of complicated beaches. More accurate assessment of sediment sizes and statistics could be used to improve the choice of fill used in beach renourishment projects. Unfortunately, it appears that these findings have not been generally implemented, and we are unaware of whether recent research on statistical sampling methods in other fields has been applied to beach projects. This would be an area of research with many benefits to coastal project design and management.

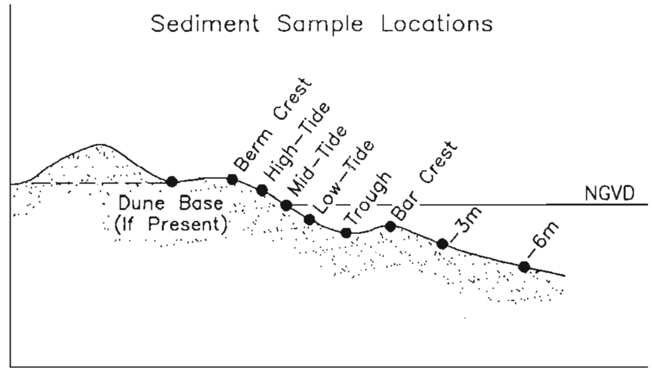


Figure 12. Recommended sampling locations at a typical profile line.

Grain Size Analysis Statistics

For projects in the United States, sediments should be sieved using U.S. Standard sieves at 1/4-phi (ϕ) unit intervals. *Phi* (ϕ) is defined as the negative logarithm of the grain dimension in millimeters to the base 2. The equation for the relationship of millimeters to phi scale is:

$$\phi = -\log_2(d_{mm}) \tag{1}$$

where

d_{mm} = particle diameter in millimeters

Grain-size analyses should include grain-size distribution tables, statistics and graphics of frequency, cumulative frequency and probability distribution (see "Calculation of Composite Grain Size Distribution" in the *Automated Coastal Engineering System* (ACES) of LEENKNECHT, SZUWALSKI, and SHERLOCK (1992) and ASTM Standard D 2487-92 (ASTM, 1994). Standard grain-size distribution statistics include:

- *Median grain size* or d_{50}—the particle size in the center of the population
- *Mean grain size* or average grain size
- *Standard deviation* or the spread of the distribution about the mean—defines the concept of sorting
- *Skewness* or measure of symmetry of the distribution around the mean
- *Kurtosis* or measure of the peakedness of the frequency distribution

Each of these statistical parameters provides information on the grain-size distribution and its depositional environment. The mean is the most commonly used statistic to characterize the average grain size of the distribution. The median value can be read directly off a cumulative curve and is near-normal to the mean in a normal distribution but differs if the distribution is non-normal. The sorting gives the spread of the various grain sizes in the distribution. A *well-sorted distribution* contains a limited range of grain sizes and usually indicates that the depositional environment contains a narrow range of sediment sizes or a narrow band of depositional energy. A *poorly sorted distribution* contains a wide range of grain sizes indicating multiple sources of sediment or a wide

Table 4
Comparison of graphic and moment procedures for calculating grain-size statistics

Method	Advantages	Disadvantages
Graphic	Can be calculated from almost all distribution data	Does not use all data from all sieves
	Resistant to sampling and laboratory errors (i.e., a single faulty sieve does not invalidate the calculated statistics)	
	Can use open-ended samples (more than 5 percent of sample weight on either tail)	
Moment	Uses formula that has a greater number of parameters	Parameters have to be established in laboratory
	Uses data from all sieves	Parameters should be important to the application; otherwise may be more than needed or useful
		Open-ended distributions (more than 5 percent of sample in either tail) must be excluded, therefore losing the geologic information that these samples might reveal

range of energies of deposition (example: glacial tills are usually poorly sorted, containing material ranging from clay to boulders). *Positive skewness* indicates an excess of fine grain sizes, whereas *negative skewness* indicates an excess of coarser grain sizes. The *kurtosis* represents the ratio between the sorting in the tails of the distribution relative to the central portion (sand size) of the distribution.

These statistical parameters are commonly calculated by two different methods. The *graphic method* uses specific percentiles of a grain-size distribution (*i.e.*, 5, 16, 25, 50, 75, 84, and 95) that are read from graphical data plots (FOLK, 1980) or can be calculated from sieve data. The values are used in simple equations to produce the approximate statistical parameters. Phi values are used to calculate these parameters, and only the mean and median should be converted to millimeter values. The *method of moments* uses the entire grain-size distribution values to mathematically produce the statistical parameters (FRIEDMAN and SANDERS, 1978). This procedure is more accurate, but was time-consuming to calculate before the use of computers; for this reason, older sediment statistical data are commonly based on the Folk graphic method. Additional consideration for the user of grain size statistics are listed below:

- The graphical and moment methods are *not* directly comparable. Because sediment statistics for many projects have historically been calculated by the graphic method, for uniformity it may be best to continue using the graphic method.
- The graphic and moment procedures have advantages and disadvantages. These are summarized in Table 4.
- Note that calculated statistical parameters are only an *indication* of the characteristics of the sediment in the field. The user must not assume that the whole population has exactly these characteristics and must remember that the statistics are critically dependent upon how the population was sampled.
- Accurate sediment grain-size statistics are dependent on adequate sample size. Recommendations for sample quantities have been listed in Table 3.

The following sections list equations and provide verbal description of sediment grain-size parameters for both the graphic method and the method of moments. The equations are identical to those used in the Corps of Engineers ACES software (LEENKNECHT, SZUWALSKI, and SHERLOCK, 1992).

Mean grain size. Table 5 lists formulas and descriptive criteria for classifying the mean grain size of a sample.

Standard deviation (sorting). The standard deviation or measure of sorting uses the equations and verbal descriptors listed in Table 6.

Skewness. The skewness or measure of symmetry shows excess fine or coarse material in the grain-size distribution. Table 7 lists equations used for the graphic method and method of moments, with the range of verbal descriptors.

Kurtosis. Kurtosis or measure of the peakedness of the grain-size distribution relates sorting of the tails compared to sorting of the central portion of the distribution. The equations listed in Table 8 are used for the graphic method, which centers around graphic kurtosis $K_G = 1.00$, and the method of moments, which centers around the moment kurtosis $k = 3.00$. The range of verbal descriptors of peakedness is based on the platykurtic (flat) curve versus the leptokurtic (peaked) curve, with a mesokurtic curve as normal.

Composite Sediments

Combining samples from across the beach can reduce the high variability in spatial grain size distributions on beaches (HOBSON, 1977). Composite samples are created by either physically combining several samples before sieving or by mathematically combining the individual sample weights to create a new composite sample on which statistical values can be calculated and sediment distribution curves generated. Samples collected along profile sub-environments can be combined into composite groups of similar depositional en-

Table 5
Mean Grain Size

Graphic Mean, M:

$$M = \frac{\phi 16 + \phi 50 + \phi 84}{3} \quad (2)$$

Where: ϕn = grain size of nth weight percentile in phi units

Moment Mean, x:

$$\bar{x} = \frac{\Sigma f m_\phi}{100} \quad (3)$$

Where: f = frequency weight percent
m_ϕ = midpoint of size class

Descriptive Criteria:

Grain size (mm)	Grain size (Phi)	Wentworth Classification
1.00 - 2.00	0.0 - -1.0	Very Coarse Sand
0.50 - 1.00	1.0 - 0.0	Coarse Sand
0.25 - 0.50	2.0 - 1.0	Medium Sand
0.125 - 0.25	3.0 - 2.0	Fine Sand
0.0625 - 0.125	4.0 - 3.0	Very Fine Sand

Table 6
Sample Standard Deviation (Sorting)

Graphic Sorting, σ:

$$\sigma = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6} \quad (4)$$

Moment Sorting, σ:

$$\sigma = \left[\frac{\Sigma f (m_\phi - \bar{x})^2}{100} \right]^{\frac{1}{2}} \quad (5)$$

Descriptive Criteria:

Sorting Range (Phi)	Description of Sorting
<0.35	Very well sorted
0.35 - 0.50	Well sorted
0.50 - 0.71	Moderately well sorted
0.71 - 1.00	Moderately sorted
1.00 - 2.00	Poorly sorted
2.00 - 4.00	Very poorly sorted
> 4.00	Extremely poorly sorted

Table 7
Sample Skewness

Graphic Skewness, Sk:

$$Sk = \frac{\phi 16 + \phi 84 - 2(\phi 50)}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2(\phi 50)}{2(\phi 95 - \phi 5)} \quad (6)$$

Moment Skewness, Sk:

$$Sk = \frac{\Sigma f\,(m_\phi - \bar{x})^3}{100\,\sigma^3} \quad (7)$$

Descriptive Criteria:

Skewness Range	Description of Skewness
+1.0 to +0.3	Very fine-skewed
+0.3 to +0.1	Fine-skewed
+0.1 to −0.1	Near-symmetrical
−0.1 to −0.3	Coarse-skewed
−0.3 to −1.0	Very coarse-skewed

Table 8
Sample Kurtosis

Graphic Kurtosis, K_G:

$$K_G = \frac{\phi 95 - \phi 5}{2.44\,(\phi 75 - \phi 25)} \quad (8)$$

Descriptive Criteria for Graphic Method:

Graphic Kurtosis Range	Description of Kurtosis
< 0.67	Very platykurtic (flat)
0.65 to 0.90	Platykurtic
0.90 to 1.11	Mesokurtic (normal distribution)
1.11 to 1.50	Leptokurtic
1.50 to 3.00	Very leptokurtic
> 3.00	Extremely leptokurtic (peaked)

Moment Kurtosis, k:

$$k = \frac{\Sigma f\,(m_\phi - \bar{x})^4}{100\,\sigma^4} \quad (9)$$

Descriptive Criteria for Moment Method:

Moment Kurtosis Range	Description of Kurtosis
< 3.00	Platykurtic (flat)
Around 3.00	Mesokurtic (normal distribution)
> 3.00	Leptokurtic

ergy levels and processes as seen in Figure 13 (STAUBLE, 1994). Intertidal and subaerial beach samples have been found to be the most usable composites to characterize the beach and nearshore environment area. After comparing several composite groups, STAUBLE and HOEL (1986) found that a composite containing the mean high water, mid-tide, and mean low water gave the best representation of the foreshore beach. They found that nearshore sample composite sediment distributions changed little over time. This suggests that active sorting and sediment transport occur on the active beach face and bar area and that nearshore sands remain uniform over time.

Seasonal Variability

There can be wide variability in grain size distribution on a native beach between winter high wave periods and summer fair weather periods. This variability can be a problem in choosing a representative native beach. The winter grain size distribution usually is coarser and more poorly sorted than the summer distribution (due to the higher frequency of storms in the winter). The concept of the seasonal beach cycle is based on the frequency of storm-induced erosion and fair weather accretion. Extreme events, such as hurricanes that occur in the summer or early fall, as well as mild winters with few extratropical storms, may cause perturbations on the seasonal cycle. A sampling strategy to characterize the seasonal variability should take into account the recent local storm climate.

Sediment Data Interpretation

Grain size distributions of beach sediment vary with both time and space. Because of the daily wave and tidal influence on sediment deposition on the beach, swash processes create an ever-changing foreshore sediment distribution. The use of composites helps to simplify the analysis and interpretation of these changes. The bar/trough area also experiences a wide variety of energy conditions and thus displays a variety of grain size distributions over time. Dune and nearshore grain size distributions have less variability due to the lower energy conditions that affect these areas. The dune is primarily influenced by wind transport, which limits change to the finer grain sizes except under extreme wave conditions, when the waves actually impact on the dune. The nearshore zone is dependant on regional and local coastal processes.

An example of composite grain size distribution curves for the beach at the Field Research Facility, Duck, North Carolina, is shown in Figure 13. Using the entire distribution from coarse to fine sizes shows the changes in size classes for various depositional regimes. The beach group composite is illustrated because it displayed the greatest variability in distribution during the study. The bimodal nature of the distribution can be seen, with increases in the coarse mode fraction after storms or when samples on the foreshore contained granule-size lag deposits. The coarsest material was present early in the study period during the winter storm period. Later, the distribution shifted to the finer mode except during July, 1985, when a coarse fraction was present. Swash processes of uprush and backwash are the principal transport mechanism in this area.

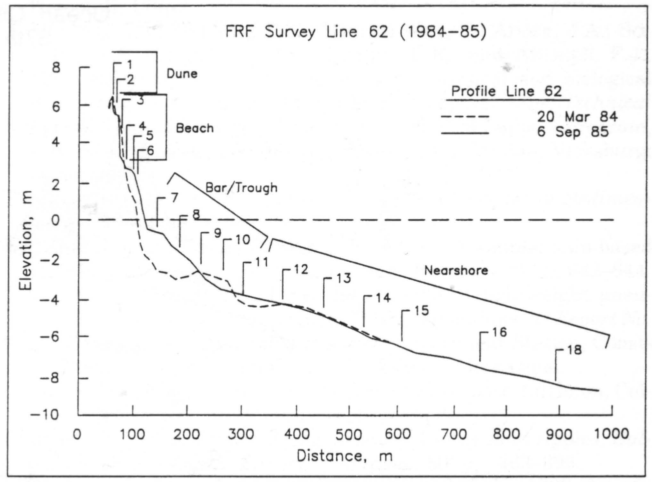


Figure 13. Combination of samples into composite groups of similar depositional energy levels and processes (example from CERC Field Research Facility, Duck, North Carolina).

Spatial variation along a beach is more complex. Analysis of grain size data from six profiles at Ocean City, Maryland, shows the influence of beach fill placement and storm processes. Figure 14 shows the change in mean grain size of the foreshore composites (high tide, mid-tide and low tide samples) for the six profiles located along the central section of the beach fill project. Between the pre- and post-fill sampling, the means became finer and the volume of the profile increased on five of the six locations as the fill was placed. Storm processes caused the foreshore means to become coarser, but a return to finer foreshore mean was found with storm recovery. From these studies, a general trend to coarser (and more poorly sorted) sediment grain size distribution occurred after high wave conditions. High wave power values and, to a lesser extent, wave steepness values correlated with times when the means became coarse. The shift to finer means occurred as the wave parameters decreased.

SUMMARY

Climatic energy systems influence rock degradation and control the erosion, transport and deposition of sediment. The products of degradation and the spatial-temporal attributes of the resulting sediment deposits can be interpreted by geoscience investigations. Both subaerial and subaqueous samples are necessary to adequately interpret coastal zone environments. Often, simple techniques such as trenching or hand-augering are adequate to investigate sediment conditions on land. Offshore, investigations are much more difficult and expensive because of the need for workboats or barges from which to deploy coring equipment or grab samplers. To investigate mineral assemblages, source area of sediments, grain size distribution, environment of deposition, sediment redistribution, and in-situ diagenesis, geoscientists need an appropriate number, variety, and volume of sedi-

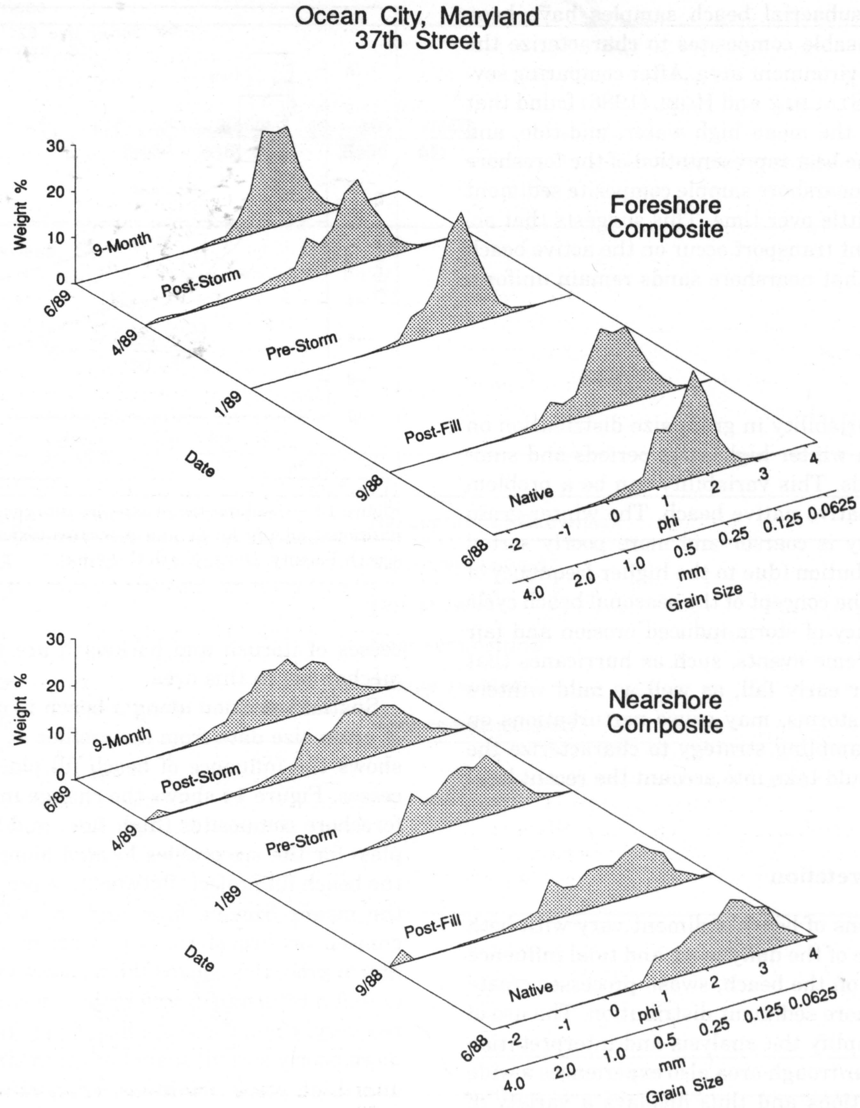


Figure 14. Change in mean grain size of the foreshore (high tide, mid-tide, and low tide samples) and nearshore composites for six profiles at Ocean City, Maryland.

ment samples. For coastal studies, geotechnical sample collection requirements are often determined from reconnaissance investigations, existing information on sediment and energy conditions, and geotechnical data gleaned from previous investigations.

Surficial and subsurface samples can be collected in *disturbed* or *undisturbed* form. Grab samples are adequate for grain size distribution analyses and mineral identification, but these samples to not preserve or convey information about stratigraphic relationships and coastal zone energy systems. In contrast, stratigraphic sampling is used to collect subsurface data indicative of changes of sediment grain attributes, depositional patterns, physical and energy regimes.

Undisturbed cores provide the most accurate interpretation of environmental dynamics and temporal/spatial variations. The undisturbed samples preserve sample fabric, ripple marks, dunal sediment features, and other indicators of geologic environments. For these reasons, many coastal researchers prefer to use coring devices (*e.g.*, piston corers, rotary drill rigs, vibracorers) that minimize disturbance as much as possible given various project considerations such as budget, weather, required depth of penetration, and field time available.

Grab, disturbed subsurface, and undisturbed subsurface samples can be analyzed by conventional visual, microscopic, and radiographic means for the determination of engineering and geologic environment data. Similarly, samples can also be analyzed by laboratory techniques to ascertain the grain size, mineralogy and micro-faunal/floral attributes. Grain size analysis data obtained from sediment fraction separation (sieving) can be interpreted statistically to evaluate geologic environments, deposition patterns, source area, and changing dynamic conditions throughout the coastal zone. Micro-faunal and age dating techniques are used to supplement the temporal interpretation of the study area.

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