

frequently viewed as leading to the degradation of the dune system and prompting a need for management action. However, Thomas (1999) cautions that patchy development of blowouts is a natural feature of most dune systems and that although disturbance of the vegetation can undoubtedly lead to increased turbulence this should not simply trigger efforts at revegetation. Rather a detailed understanding of the vegetation surface conditions must be used to project the implications of the apparent disturbance and plan any remedial action. This call for a more holistic recognition of vegetated coastal environments as biogeomorphic systems recognizes that management actions must appreciate the natural dynamics of the system as well as its form and surficial characteristics.

Future issues for vegetated coasts

The importance of plant growth and survival to the sustainability of both landforms and ecosystems of vegetated coasts means that environmental changes that alter vegetative structure can have important implications. Two factors that threaten vegetated coasts are the massive increases in coastal populations, and the associated development pressures, and future climate changes.

The coastal population of the United States is currently growing faster than the nation's population as a whole, a trend that is projected to continue. By 2010, 75% of the US population is expected to live within 50 miles of the coast. Nicholls and Small (2002) identify 23% of the global population as living in coastal areas and note that most of the near-coastal population does not live in large cities but in smaller towns and in rural areas. The growing coastal population, increasing economic development, and expanding coastal communities exert pressure on vegetated coasts through recreational pressures, direct damage due to filling or development, and lowered water tables. Pinder and Witherick (1990) point to the loss of coastal wetlands associated with growth of ports and urbanization in the second half of the 20th century, and dunes and other intertidal vegetated habitats have been similarly consumed. The societal need for development space at the coast, especially for industries and port facilities that are directly functionally related to the coastal ocean, combined with the diminishing area of land available and the recognition of the ecological, recreational, and esthetic value of vegetated coasts, has led to increasing examination of the potential for creating new land specifically to support development. However, while this approach may relieve development pressure on existing systems, it has consequences for coastal sedimentary and hydrodynamics. Arens *et al.* (2001) examined the potential environmental impacts of offshore island development in the Netherlands and noted effects associated with construction and to the marine ecosystem based on the footprint of the island and the direct loss of habitat. Coastal dunes and higher plants were largely unaffected and Arens *et al.* projected only local alterations in the sediment budgets and wave climates that support the adjacent vegetated coasts.

While vegetated coasts are often characterized by plants adapted to living in stressful conditions, changes in climate may increase stresses beyond their tolerance range resulting in shifts to nonvegetated coastal systems and potentially dramatic geomorphic transitions. Scavia *et al.* (2002) note that projected increases in sea level are unlikely to have near-term catastrophic impacts on coastal wetlands and mangroves, but when combined with other stresses such as alterations to local hydrology or sediment movement patterns associated with development pressures, the long-term consequences may be severe. For vegetated coastal forms to survive they must increase elevation in place (e.g., accrete soil), or migrate inland to keep pace with the rising sea. However, coastal structures and river management alter sediment supplies, and thus limit vertical building, and developed coastlines limit migration. Management approaches for vegetated coasts during climate change must be focused on alleviating the stresses imposed by human alteration of coastal systems, and allowing transitions in form and ecology to cope with the changing sea level, temperature, and precipitation regimes. Vegetated coasts are among our most valued, and highly pressured systems. By their very nature they can survive change and harsh conditions. Our management actions must allow the natural cycles that have sustained them in the past to continue long into the future.

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Cross-references

Bioengineered Shore Protection
 Dune ridges
 Mangroves, Coastal Ecology
 Salt Marsh
 Tidal Creeks
 Tidal Environments
 Wetlands

VIBRACORE

Vibracoring is a state-of-the-art sediment sampling methodology for retrieving continuous, undisturbed cores. Also referred to as *vibrocoreing*, this mechanical drilling technique is used to collect core samples (referred to as either *vibracores* or *vibrocores*) from unconsolidated, loosely compacted, or semi-lithified materials by driving a tube with a vibrating device. Large, heavy-duty vibracores can work in water up to 5,000 m deep and can retrieve core samples up to 13 m in length. In coastal shallow-water environments where use of heavy equipment is limited by trafficability and ground support on land and high-energy conditions alongshore, cores are shorter, usually about 6 m in length.

The coastal/marine environment presents specialized conditions that are not encountered on *terra firma* or in deeper oceanic waters. Because many onshore areas are characterized by coastal wetlands with extensive areas of organic soils in marshy or swampy conditions, tidal sand and muds, or lacustrine and lagoonal facies, beach sands, or chenier-type materials, access for conventional drilling equipment and personnel is often limited, if not by biophysical conditions, then at least economically. Financial considerations are often limiting when costs of sediment retrieval are very high on a per-sample basis. Large multinational corporations involved in petroleum exploration can go almost anywhere to penetrate the most inhospitable environments while sparing no expense to obtain conventional long-drill cores. Most coastal/marine research, however, operates on a reduced cost basis that must be efficient and cost-effective. There are also numerous subaqueous environments that are normally hostile to the positioning of conventional drilling equipment and so alternative sediment-sampling methods are sought. Retrieval of shallow-water sediments using conventional cylindrical coring methods (e.g., those that employ gravity or piston cores) is limited by shallow water depth as well as the nature and habit of the materials requiring undisturbed collection. Resistance of the sediment restricts penetration of gravity cores and core-lengths typically obtained are less than 3–5 m, depending upon the firmness of the sediment.

Sediment cores obtained from a vibracore system are invaluable because they permit direct, detailed examination of composition and layering in sequences of subsurface sediment (Lanesky *et al.*, 1979; Watson and Krupa, 1984). Examination of material sequences in vibracores provides information regarding the history of depositional environments (e.g., Brooks *et al.*, 1995) and the physical processes that were operative during sedimentation. Vibracores and subsamples derived from them find almost limitless applications in scientific geological research, engineering and geotechnical pre- and re-design, and environmental investigations. The versatility of the vibracore technique is illustrated by its utilization in sampling riverine sediments, lacustrine deposits, organic accumulations in marshes and bogs, as well as nearshore shallow water coring. Although examples of applications are legion, of primary interest to most coastal specialists are results that are relevant to the scientific study of coastal zone morphodynamics, evolutionary sequences, and exploratory searches for beach-quality sand that is suitable for beach renourishment.

The utility of vibracores, as seen in these few examples from a huge literature, has been demonstrated in: (1) subsurface exploratory sampling for geotechnical purposes (e.g., Meisburger, 1990; Larson *et al.*, 1997), (2) determination of depositional stratigraphy and geomorphological history in marine, estuarine, fresh water, or wetland environments including marshes, swamps, and peat bogs (e.g., Snowden *et al.*, 1977; Amos, 1978; Kraft *et al.*, 1979; Stevenson *et al.*, 1986; Morang *et al.*, 1993; Kirby *et al.*, 1994), (3) glacioeustatic sea-level changes (e.g., Gehrels, 1994; Harvey *et al.*, 1999), (4) integrating studies of barrier island evolution, bars, lithofacies, and sediment-stratigraphy (e.g., Davis and Kuhn, 1985; Davis *et al.*, 1993; Brooks *et al.*, 1995), (5) offshore sand searches to locate beach-quality sands for beach restoration (e.g., Finkl *et al.*, 1997; Freedenberg *et al.*, 2000), (6) environmental studies of pollution or contamination by hydrocarbons or heavy metals (e.g., Varekamp, 1991), (7) investigations to determine seafloor environments or bottom types (e.g., Barnhardt *et al.*, 1998; Knebel and Poppe, 2000), (8) deltaic and sedimentary shelf processes (e.g., Delaune *et al.*, 1983; Brooks *et al.*, 1995; Levitan *et al.*, 2000; Toldo *et al.*, 2000), (8) collection of samples for chemical, biological, and physical analyses (e.g., Kadlec and Robbins, 1984; Gehrels, 1994), (9) verification of seismic stratigraphy or seismic stratigraphic sequences (e.g., Shipp *et al.*, 1991; Knebel and Poppe, 2000), (10) preliminary investigations for the purpose of determining the presence and positions of paleoshorelines (e.g., Gayes and Bokuniewicz, 1991; Shipp *et al.*, 1991), and (7) stratigraphic and mineral surveys (e.g., Barousseau *et al.*, 1988; Brooks *et al.*, 1995). Use of vibracores to substantiate seismic interpretations (e.g., sidescan sonar, Uniboom seismic reflection—sub-bottom boomer profiles) is a major application that integrates geological and geophysical methodologies to advantage in many studies. Marine or subaerial unconformities, seismic reflectors, stratigraphic units, internal structures of morphodynamic units, sediment textural properties, and even geomorphic features can be identified in vibracores. Although vibracores find use in many diverse applications, the overall setup of coring systems is an important consideration.

Early attempts to obtain (undisturbed) samples in coastal/marine environments

Retrieval of marine sediments is nearly as old as the science of oceanography itself. Initial interest focused on getting an idea of what kinds of

sediments were deposited on the seafloor but, then, as technological advancements assisted the desire for more complete information, new methods of bottom sampling were developed. The purposes of sampling marine sediments varied among professionals as the pioneering biologist, petrographer, sedimentologist, and civil engineer had different demands. Reviews of some historical efforts in bottom sampling are summarized, for example, by Trask (1939), Sanders (1960), Rossfelder and Marshall (1967), and Watson and Krupa (1984) who note the pros and cons of numerous platforms, rigs, and devices such as the Ström coring tube, Twenhofel coring tube, Varney pile-driver sampler, Trask suction sampler, Renn sampler, Piggot coring apparatus, Kudinov vibro-piston core sampler, etc. These early devices suffered from a variety of shortcomings that were eventually overcome by improved sampling methods. Modern methods of coring are not without problems, but they have been reduced to the greatest possible extent to satisfy the purpose of a particular analysis.

Terrestrial deposits in coastal marshes and on coastal plains were initially sampled using hand augers, which are still in use today for special applications (see discussion in Soil Survey Division Staff, 1993). Screw or worm augers do not provide undisturbed samples, but they can bring up materials from several meters depth by adding extra lengths to the shaft. Barrel augers, core augers, bucket augers, on the other hand, have a cylinder or barrel to hold the soil, which is forced into the barrel by cutting lips at the lower end. The upper end of the cylinder is attached to a length of pipe with a crosspiece for turning by hand at the top. Although both ends of the cylinder are open, the soil generally packs so that it stays in place while the auger is removed from the hole. Barrel augers disturb the soil less than screw augers. Soil structure, porosity, consistence, and color can be better observed. Barrel augers work well in loose or sandy soils and in compact soils. They are not well suited for use in wet or clayey soils, though an open-sided barrel is available that works well. They also work poorly in stony and gravelly soils. Barrel augers bore more slowly than screw augers or probes, but they are easy to pull from the hole.

The Dutch auger is a modified barrel auger having two connected straps with lips. The cylinder is about 5–10 cm in diameter. The Dutch mud auger works well in moist or wet soils of moderately fine or fine texture, but poorly in other moist or wet soils and in all dry soil.

Although soil augers are simple in design and somewhat crude in appearance, considerable skill is required to use them effectively and safely. They must be pulled from the soil by using a technique that puts stress on the leg muscles, rather than the back muscles, to avoid serious back injury. Twisting the auger firmly while pulling takes advantage of the inclined plane of the screw to break the soil loose. A pair of pipe wrenches is needed to add and remove lengths of shafts and bits.

Examinations of deep deposits of peat are made with special tubelike samplers. A peat sampler designed by the Macaulay Institute for Soil Research (Aberdeen, Scotland), for example, takes a relatively undisturbed volume that can be used for measurement of bulk density. The Davis peat sampler, consists of 10 or more sections of steel rods, each 60–120 cm in length, and a cylinder of brass or Duralumin, approximately 35 cm long with an inside diameter of about 1.9 cm. The cylinder has a plunger, cone-shaped, at the lower end and a spring catch near the upper end. The sampler is pressed into the peat until the desired depth for taking the sample is needed. Then the spring catch is released, allowing the plunger to be withdrawn from the cylinder. With the plunger withdrawn, forcing it further downward fills the cylinder. The cylinder protects the sample from contamination and preserves its structure when the sample is removed. With this instrument, one can avoid the error of thinking that firm bottom has been hit when actually a buried log is encountered.

Probes consist of a small-bore tube that has a tempered sharp cutting edge slightly smaller in bore but larger in outside diameter than the barrel. Approximately one-third of the tube is cut away above the cutting edges so that the soil can be observed and removed. Probes are about 2.5 cm in diameter and about 20–40 cm in length. The tube is attached to a shaft with a "T" handle at the opposite end. Adding or removing sections can vary shaft length. Probes can be used to examine the soil to a depth of 2 m. Rubber or plastic mallets can be used to drive the tube into the soil; a pair of pipe wrenches is needed to add and remove lengths of shaft.

Probes work well in moist, medium textured soils that are free of gravel, stones, and dense layers. Under these conditions, the soil can be examined faster than with an auger. Probes are very difficult to use in dry, dense, or poorly graded soil, and in soil containing gravel or stones. Probes disturb the soil less than augers, but they retrieve less soil for examination. Probes are light and easily carried, and they pull from the hole more easily than screw augers. Use of a soil probe is the fastest method to collect samples of surface layers for analysis. Probes used

with power equipment have wide applications in surveys of surficial sediments. Coastal specialists are increasing turning to mechanical sampling devices as the need increases for longer cores of undisturbed samples. Vibracores meet these needs in many different types of environmental situations, but there are still limitations to collection of coastal/marine sediments. The essentials of vibracoring systems, which supplement hand sampling in terrestrial coastal environments and partially replace other types of marine bottom samplers, are briefly summarized in what follows.

Vibratory coring systems

These relatively simple devices, referred to as vibracorer, consist of three essential components: frame, core barrel, and vibrator (Hoyt and Demarest, 1981). The frame, which allows the corer to stand free on the seafloor, consists of a quadrapod or tripod arrangement with legs attached to a vertical beam that in turn supports and guides the core barrel and vibrator (Figure V1). The core barrel and vibrator slide on the beam for coring and retraction. The core barrel assembly consists of 7.5 or 10 cm diameter (thin walled) aluminum pipe fitted with a cutter head and core catcher (which holds the sediment inside the barrel when it is withdrawn from the sediments), and a plastic tube inner liner that contains the core material (cf. Figure V11). There are many different kinds of innovative assemblies that can include, for example, an electronic penetrometer to record time and depth of penetration of the core pipe into the sediments (Smith, 1992). Deploying and retrieving the corer usually

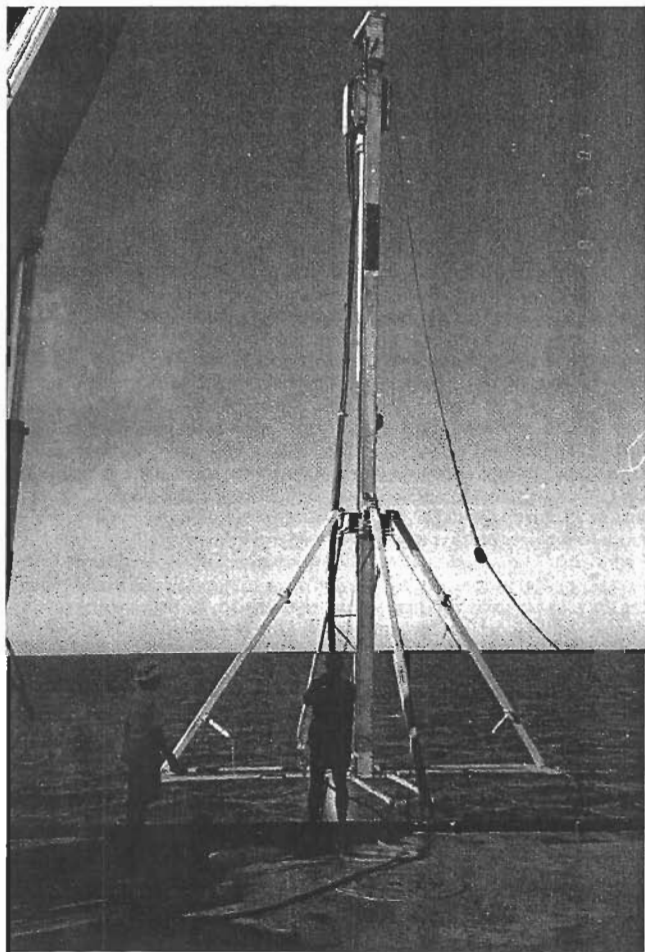


Figure V1 A 10-m vibracore (Alpine rig) being raised from the Gulf of Mexico seafloor offshore from Louisiana. The quadrapod stand stabilizes the vibracore frame, which sits on the seabed and allows the pneumatic vibrahead to slide downwards with core penetration. The entire apparatus is lifted aboard the research vessel using a hydraulic crane that reaches over the stern (photo courtesy of Coastal Planning & Engineering, Boca Raton, Florida).

requires a hydraulic crane (Figure V2), A-frame, or similar winch or hoisting equipment with a lifting capacity of at least 10–15 tons (Meisburger, 1990). Shallow protected waters may allow use of small barges, often of simple construction from polystyrene blocks wrapped in heavy-duty industrial plastic and encased in a wooden frame, mounted with a superstructure from which the vibracoring device can be deployed (e.g., Wright *et al.*, 1999). A marine Kiel Vibracorer can, for example, be adapted for deployment from a well in the barge.

Smaller, lightweight, hand-carried units are used to advantage in coastal environments on marshland or in very shallow water. Figure V3, for example, shows a small backpack power unit that is deployed in shallow water to obtain marsh sediments. Once driven into the marsh sediments, the core is retrieved by various methods for pullout but in this case a hand-operated come-along is used to extract the core (Figure V4). After the core is extracted, it can be transported to the laboratory or split in the field as shown here (Figure V5). Because there was easy access to a grassy work area near the sample site, the core barrel was carried to dry land and split using a skill saw. Splitting in the field provides opportunity for immediate inspection of the core and assessment of environmental conditions, as shown in Figure V6. Other advantages accrue from splitting a core in the field because it can be immediately determined whether the core is short due to loss of sediment or compaction, or whether there are other abnormalities such as coarse materials that plug the core causing gaps in sediment retrieval, etc. The sampling program can be modified on the basis of what is observed in the recovered materials. This flexibility in the field is important because deployment and setup are often significant costs in sample retrieval.

Equipment, design, and function

The main consideration in developing vibracoring systems, often referred to as the “Rule of Deployment,” that most researchers learn by experience is that “the cost of an operation is related to the size of the

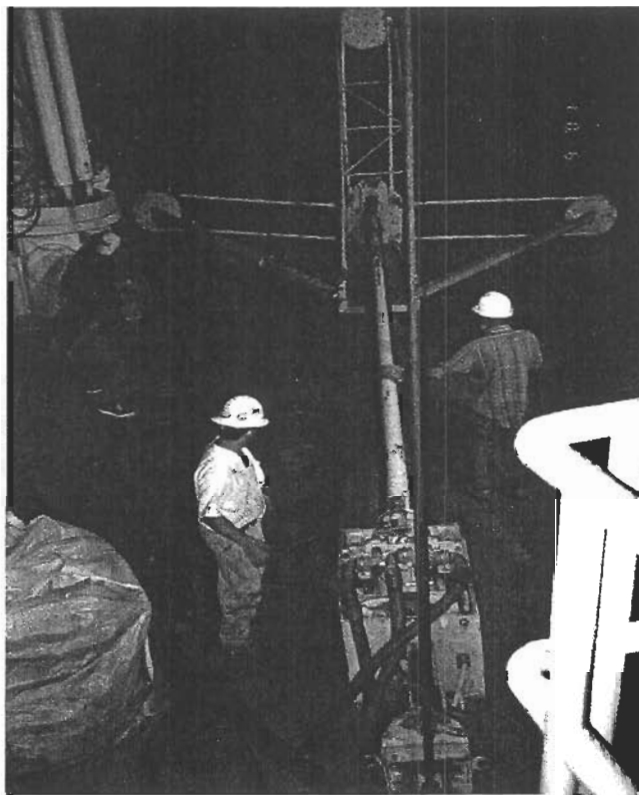


Figure V2 Same vibracore assembly unit shown in Figure V1 being laid down on the deck. The long core inside the 10-cm-diameter core barrel will provide valuable undisturbed sediment data from the seabed on the continental shelf off Louisiana. Operations such as this one require experienced crew to handle these large vibracoring units (photo courtesy of Coastal Planning & Engineering, Boca Raton, Florida).



Figure V3 Small, portable vibracore. A backpack power unit operates this pneumatic vibracore; the core barrel is stabilized by hand as the unit penetrates the marsh sediments. The lightweight aluminum A-frame is carried to the site and waits for use in retrieval of the core (photo courtesy of Steve Krupa, South Florida Water Management District, West Palm Beach, Florida).



Figure V4 Retrieval of vibracore using a portable aluminum A-frame. The lightweight A-frame has pads on the feet so the unit does not sink into the sediment when load is applied. One leg of the A-frame has steps so the driller can extract the core barrel with a hand-operated come along. The A-frame must be placed vertically over the core barrel to ensure easy extraction without flexure or bending of the core. The A-frame collapses into a compact unit for transporting (Photo courtesy of Steve Krupa, South Florida Water Management District, West Palm Beach, Florida).

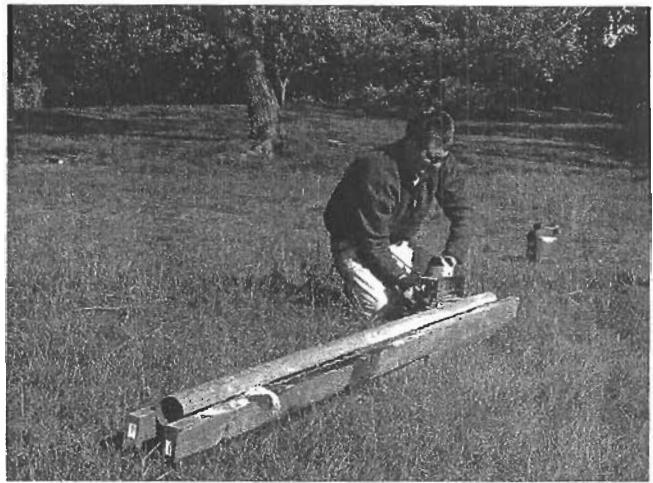


Figure V5 Splitting a vibracore. As shown here, the core barrel is laid in a wooden frame and an electric circular saw uses the frame as a guide to cut the flight lengthwise. The upper half is then rotated away from the frame and placed on the ground for observation and sampling (Photo courtesy of Steve Krupa, South Florida Water Management District, West Palm Beach, Florida).

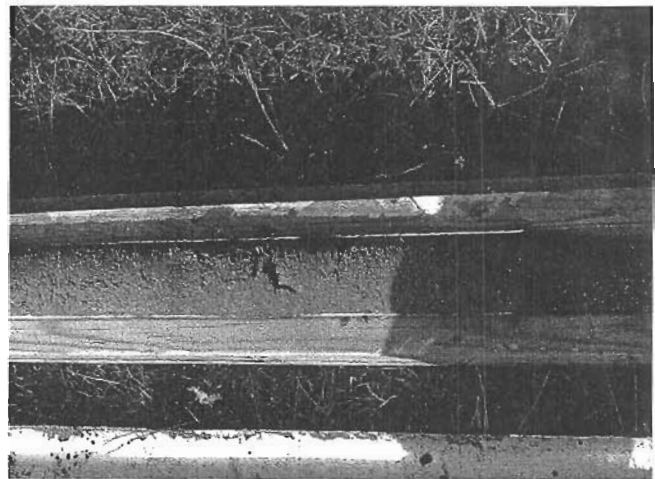


Figure V6 Split core. After cutting the core barrel lengthwise, the contents are visually inspected for a range of physical parameters such as sediment grain size, color, stratigraphic discontinuities, coarse fragments, etc. Shown here is a fine-grained marsh sediment from the south coast of Long Island, New York (photo courtesy of Steve Krupa, South Florida Water Management District, West Palm Beach, Florida).

vessel which is related to the size of the draw works which is related to whatever hangs at the end of the cable." These concerns are especially important to boggy onshore sites where access is limited and in shallow-water work where vessel size and equipment load is restricted. Realizing the need to minimize the weight of individual parts while maximizing the overall force/weight ratio, it becomes obvious to select equipment that can be handled with limited manpower from all-terrain vehicles, small vessels, and even inflatable barges (e.g., Hoyt and Demarest, 1981). A variety of vibracore units are commercially available. Some are small, lightweight, and portable, whereas others are large heavy units that can only be deployed from large vessels. There are various types of bottom-standing rigid frames that are ordinarily used for stabilizing and guiding vibracores (cf. Figures V1 and V2 for heavy-duty marine examples and Figures V3 and V4 for light-duty terrestrial setups).

The principle behind a vibracore is the development of high-frequency, low-amplitude vibration that is transferred from the vibracore head (vibrahead) down through the attached barrel or core tube (Figure V7).

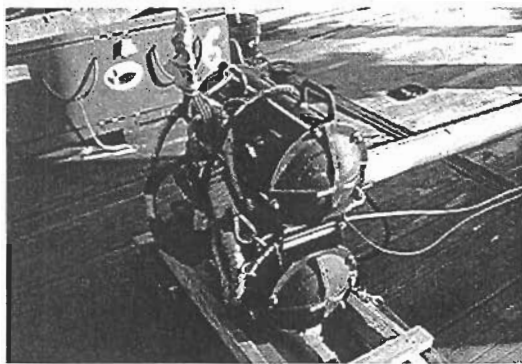


Figure V7 Detail of the parallel mount of electric vibrator heads, showing extension of the core barrel below the vibrahead (photo courtesy of Coastal Planning & Engineering, Boca Raton, Florida).

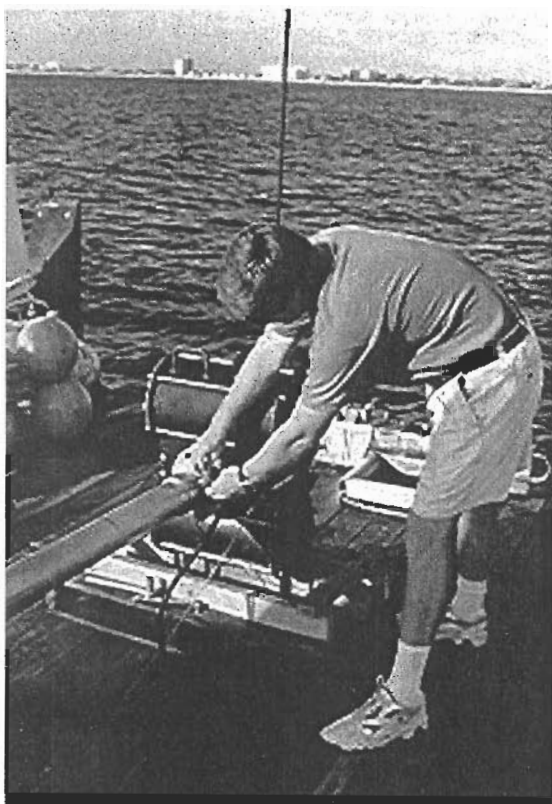


Figure V8 The 7.5-cm-diameter core barrel is attached to the electric vibrahead assembly prior to being lowered overboard into the Atlantic Ocean as part of an offshore sand search near Miami, Florida. Although the unit is of medium size, the weight of the vibracore assembly requires crane winching from the deck (photo courtesy of Coastal Planning & Engineering, Boca Raton, Florida).

The vibrator generates sufficient vibrations by means of pneumatic/hydraulic/electric motors that are sealed in a submersible housing. Vibrations combined with instrument weight drive the core barrel into the sediment/substrate. The vibrational energy delivered to the core tube (Figure V8; cf. Figures V1 and V2) induces vertical penetration by temporarily displacing sediment particles to overcome frontal resistance and wall friction. The technique is thus most efficient in water-saturated sediments because vibration increases the pore pressure along the wall of the core tube by generating a thin layer of liquefaction. As the vibrating tube penetrates the sediment, it displaces the bedded particles on both sides of the wall. This results in the collection of a largely undisturbed core of sediment within the vibrocore tube. Although useful in

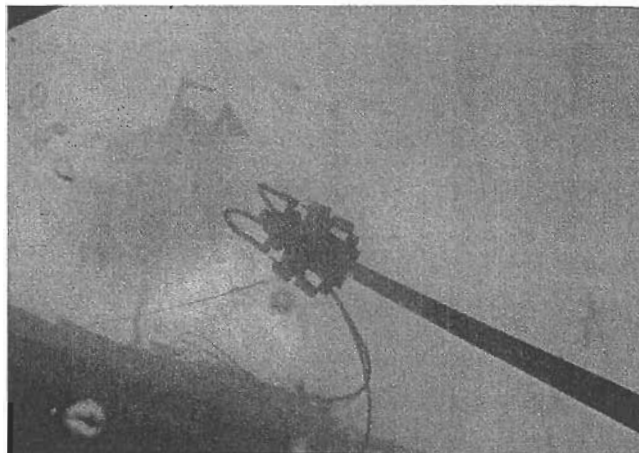


Figure V9 Diver's view of vibracore being lowered over the side of the research vessel. The dark area in the upper left of the photo is the bottom of the vessel's hull. Cables to power the vibrahead and a lifting cable are visible to the left of the diver near the water surface (photo courtesy of Coastal Planning & Engineering, Boca Raton, Florida).

water-saturated subaerial environments, such as in marshes, underwater sediments present the optimum medium of application. Starting in the 1950s, vibracoring became increasingly accepted as an efficient and useful method for collecting underwater core samples. The technique was initially slow to gain acceptance because vibrators could not be easily outfitted for underwater use; the problem was soon overcome and a variety of vibrators are now available. Figure V9 shows a typical medium-sized vibracore assembly being lowered over the side of a research vessel.

Among the three basic types of vibrators (i.e., pneumatic, hydraulic, and electric), pneumatic piston vibrators were preferred in early research because they worked underwater and did not involve the undersea use of electrical current. Although still deployed in many surveys, this type of vibracoring setup requires an air compressor and the hoses that sometimes become an impediment in swift or choppy waters. Hydraulic vibrators use fluid flows in a closed circuit in balance with the ambient environment. A hydraulic power plant and an umbilical hose are required, presenting similar drawbacks to pneumatic vibracores. All things considered, including the force/weight ratio from the power source to the vibrahead, electric vibrators become an attractive choice, particularly when the power source is already part of the vessel system. Many researchers conclude that electric vibracores are good choices for work in shallow waters viz. those characterized by surf or spray zones. There are two main types of electric vibracores, electromagnetic vibrators and rotating-eccentric vibrators. The second type is often preferred because the dynamics of the overall spring-like system soil-core-tube-vibrohead, the contra-rotating eccentric vibrators mounted in parallel (cf. Figure V7), does not require mechanical linkage or special gear for establishing synchronized motion for delivering oscillatory force along a vertical axis. Many combinations of vibracore assembly are available for a variety of environmental conditions. Lightweight parallel-mount twin vibrators that, for example, run at 8,000 V/m on standard 110 V AC current, can be operated with a 5 kW camping-type generator. Heavier models often run at 2,800–3,400 V/m on 3-phase, 50 or 60 Hz, 220–440 V power sources. There are also vibracores, operating in the medium-frequency range, based on a single vibrator that delivers an oscillatory force to the vertical axis, also often operating on 3-phase 220–440 V. Other variations of basic setups include a "vibro-torsional" operating mode where the two contra-rotating vibrators are mounted along the same axis instead of being in parallel. This coaxial configuration or arrangement synchronizes spontaneously, as in a parallel mount, while adding a horizontal oscillatory torque of small amplitude to the main vertical oscillation. Above the medium range, there is a domain of vibracoring known as "resonant drive" with frequencies on the order of 200–360 Hz (12,000–22,000 V/m) and amplitudes down to a fraction of a millimeter. In this resonant drive mode, the core tube vibrates like a musical string with stationary nodes and antinodes that help to efficiently overcome wall friction, but these units lack force and amplitude for frontal penetration. There is thus a range of vibracore types that can be deployed to specific use.

Advantages and disadvantages of vibracoring

Classical problems associated with coring in general include, for example, flow of external sediment into the core barrel due to increased or reduced stress below the core nose, wall friction, sediment deflection below the cutter, shear failures, thinning or compression of softer strata, thixotropic liquefaction, and textural rearrangement (e.g., Rossfelder and Marshall, 1967; Smith, 1984; Crusius and Anderson, 1991; Morton and White, 1997). Withdrawal disturbances may take place in response to decrease in hydrostatic pressure below the sample, increase in pressure over the sample, lack of wall friction, and adhesion between the sample and the core wall. The sampler may inadvertently be tipped over and dragged along the bottom because of improper retrieval. Even though modern sampling methods have been overcome, there are still sampling problems associated with state-of-the-art core retrieval using vibracore samplers. Some of these difficulties are briefly outlined as precautionary observations for a system of bottom sediment sampling that is generally reliable (e.g., Blomqvist, 1985).

Vibracores 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 (Larson *et al.*, 1997). Vibracores are not very effective in either very compact (dense) or very loose sediment; they are not suitable for sediments containing large clasts that can block penetration of the core barrel.

While common vibratory corers are capable of penetrating 6 m or more in unconsolidated sediment, actual performance depends on the nature of the sub-bottom sediment. Under unfavorable circumstances (viz. rough seas, rocky bottom) very little sediment may be recovered. Limited recovery may be primarily due to lack of penetration of the core barrel, blockage of the bit by rock, or loss of sediment during recovery. Core penetration is measured both visually and with an electronic penetrometer. Core recovery is determined by measuring the total length of sediment in the core barrel immediately following retrieval, and the percent recovery calculated as follows (Brooks *et al.*, 1999):

$$\% \text{ Recovery} = (\text{length recovered} / \text{length penetrated}) \times 100$$

In certain instances, penetration refusal is met before full penetration of sediment is achieved (Anders and Hansen, 1990; Morton and White, 1997). In such cases the vibracore is removed, and the short core is extracted and stored. A new core liner is installed and the vibracore is again deployed. The core barrel is hydraulically jetted down to the depth of the refusal and then the regular vibracoring is resumed to the targeted depth. In other cases, refusal means that the vibracore cannot be driven any further into the sediment and the borehole is terminated. Coarse fragments such as diamictite, scree, lag, or carbonate/coral rubble may, for example, be larger than the core barrel or the deposit may be so densely packed, if containing smaller diameter clasts, that vibracoring into these materials becomes problematic. Core barrels sometimes get stuck in the sediment and removal requires patience, strength, and some ingenuity.

Vibratory corers are capable of penetrating up to 12 m of unconsolidated sediment, but actual performance depends on the nature of the sub-bottom material. Under unfavorable conditions, however, less than 1 m may be recovered; no coring device has been developed that eliminates the potential for core shortening. There are, however, practical solutions to problems associated with vibracore sample loss or compaction (Smith, 1992). Core shortening may result from several factors that include, for example, physical compaction, sediment thinning, or sediment bypassing (Morton and White, 1997). Limited recovery occurs in response to lack of penetration where stiff clays, gravel, and hard-packed fine to very fine sand are usually most difficult to penetrate. "Freezing" of material in the core liner, which is an age-old coring problem due to skin friction before full penetration is reached (e.g., Rossfelder and Marshall, 1967), stops new material from entering the sampler while the core barrel continues to penetrate; this process may result in exclusion of underlying sediments so that some strata are bypassed and not recovered in the core barrel. Lubrication of the inner wall of the core barrel can reduce friction and prevent plugging as additional sediments enter the core barrel. Choice of lubricant to reduce friction is recommended as long as the chemical additives do not interfere with chemical analyses planned for the cores (Morton and White, 1997). Compaction and loss of material during recovery can also cause discrepancy between penetration and recovery, but occurs less frequently. It is sometimes not possible to correct for shortening when it is not certain whether the shrinkage was due to dewatering or loss of core out of the bottom (Wright *et al.*, 1999). Harvey *et al.* (1999) found, for example, that

compaction may range from negligible in clay-rich cores up to 40% for organic-rich mangrove-dominated cores. The coring technique, including setup and deploying the corer, coring and recovery is quite rapid compared with standard soil boring operations. Usually, a 6-m-long core can be obtained in a matter of minutes under ideal conditions.

In some areas where vibracoring is difficult, rough ideas of sediment composition can be obtained by alternative sampling procedures. Wash borings, for example, can sometimes provide estimates of grain size and composition by flushing out sediments using compressed air (Figure V10). Jet probes (*q.v.*) also provide rough estimates of bottom sediment types but, like wash borings, they do not provide undisturbed samples that are recoverable for further offsite analysis.



Figure V10 A "wash boring" that is operated by jetting down a pipe within a pipe at intervals of 1–2 m and "washing" up a sample with a blast of compressed air between the pipes. This exploratory technique was previously used to provide preliminary information on the quality of sand in a potential borrow area before engaging more expensive vibracoring operations. Although surface sand samples can be easily obtained, it is necessary to know what type of material lies at depth. This method of sampling provided an inexpensive way to sample sediment at depth, which would be "washed up" the pipe and trapped in cloth bags that were used to catch the samples. The heavier materials (gravel, etc.) could not be lifted in the pipe, but divers could "hear" gravel and rocks banging against the casing to establish the presence of unusable coarse materials. Fines could not be trapped because the material would pass through the cloth bags used to trap sediment samples; the "cloudiness" of the water, however, provided experienced divers with a rough indication of how much silt plus clay was present in the sediment. The penetration of the pipe was similar to jet probes that are now used in order to test the depth of unconsolidated sediment. Although crude, this method provided useful information for refining sand searches. The limitations of disintegrated wash borings compared to undisturbed vibracores emphasize the value of cores that can be subsampled, analyzed, and archived. Wash borings today find specialized applications by most researchers (photo courtesy of Coastal Planning & Engineering, Boca Raton, Florida).

Core logging and sample analysis

During the field data collection phase in large surveys, a preliminary analysis of the cores and samples from the cores is made on a daily basis to obtain information for making advantageous modifications to the survey plan. In addition, when the specific site surveys of high-potential borrow sources are undertaken immediately following the general survey; the preliminary analysis must suffice for selection of these sites, and needs to be as complete as possible. The scope of preliminary core and sample analyses in the field is limited by: (1) only partial visual and physical access to the cores for preliminary logging and sampling; (2) the type and extent of sample analyses that are possible in the field, which in many respects are not comparable to laboratory analysis; and (3) the field analysis for each core that must be completed in a limited time frame in order to keep pace with the progress of the survey.

After each core is taken, the liner containing the cored materials is removed and replaced by a fresh liner. Liners may be clear acrylic plastic tubes that allow observation through the wall. Heavy scratching by granular material or silt and clay particles may smear the inner wall obscuring the contents. Where the cored material is visible, logging and selection of samples can be made. Some corers use aluminum or opaque plastic tubing as core barrels without liners and use the core barrel themselves as the containers using a fresh core barrel for each core run.

Access to cores is best obtained by splitting the cores lengthwise to expose the cored section (Figures V6 and V11). Prior to sampling or disturbance, the core materials are usually photographed next to a scale. Prior to sampling for laboratory analysis, cores are examined visually to determine pertinent characteristics such as size distribution and composition in terms of relatively broad categories. For this purpose, a hand lens and size comparison charts are useful aids. In addition, samples that appear on visual examination to be possibly suitable as fill material should be further analyzed to obtain data on their size distribution characteristics by more accurate means than visual inspection. This can be done using small-diameter sieves to separate small samples into appropriate size fractions, which are then weighed to determine the percent weight of each size fraction. Minimal equipment needed for this procedure is a drying oven, small-diameter sieves covering the Wentworth sand size ranges at $\frac{1}{2}$ phi intervals, and a small top-loading electronic balance with a precision of at least 0.01 g (Meisburger, 1990).



Figure V11 Split core liners from vibracore that penetrated sandy bottom sediments in an inter-reefal area offshore from Miami, Florida. The vibracores are split longitudinally, one half is retained for archival purposes and the other is logged and analyzed in the laboratory for grain-size parameters, organic content, coarse fragments (e.g., loose shell hash, pieces of coral, chunks of coquina), mineral composition (e.g., silicates versus carbonates), etc. Note: Core barrels are generally cut into sections that are about 2 m in length. Depending on the length of core obtained, there may be a small section left over that would be difficult to split lengthwise. These small leftover sections also tend to be disturbed because they are at the end of the core. The two PVC ends shown here are used to store "bit samples" because the core-cutting bit does not have a liner. Typically, when a core is being recovered, the material in the bit falls out because it is below the core catcher. Sometimes the sample stays in the bit and it is saved as shown in the photo. The two piled samples sitting on paper in the center of the photograph are plugs of rock, cut from the subsurface, that were lodged in the bit (photo courtesy of Coastal Planning & Engineering, Boca Raton, Florida).

Usually, cores are opened in the laboratory, logged, photographed, and portions are then sampled for various purposes. The presence of carbonate shelly debris or shell layers, bioturbation clasts and infills, gravels, (de)oxygenated surfaces, color changes, and other notable features are recorded prior to sample removal (Figures V12 and V13). Notations are also made for the presence of epifauna, abraded foraminifera tests, coproliths, or any other unusual biological feature such as insect carapaces and appendages. Molluscan assemblages (including microfossils) are, for example, often removed from the core prior to subsampling for other types of analyses (e.g., Barusseau *et al.*, 1988; Wright *et al.*, 1999). Standard laboratory sediment analysis may be conducted following the sieving methods proposed by Wentworth (1929), by using a rapid sediment analyzer (sand fraction) (e.g., Schlee, 1966), or a Coulter Counter (silt and clay fractions) (e.g., Shideler, 1976). In addition to standard particle-size analyses, there are numerous other kinds of analysis that can be performed on core materials, depending on their nature and composition. Organic-rich deposits such as peat, for example, can be vibracored taking care to make corrections for compaction (usually -10%) by making stratigraphic comparisons with an uncompacted Eijkelkamp core from the same site (Gehrels, 1994). Detrital plant fragments are often selected for dating by the accelerator mass spectrometer (AMS) ^{14}C method (e.g., Gehrels and Belknap, 1993), in preference to bulk samples that can be contaminated by humic acids and younger roots (Belknap *et al.*, 1989). Methods for foraminifera sampling and sample preparation are similar to those described by Scott and Medioli (1980).

Bottom sampling for coastal sand searchers

Samples of seafloor sediments are required for numerous purposes, the least ambitious of which is to gain a rough idea of sediment types. Different kinds of sampling devices are usually geared for the collection of fine or coarse-grained surficial sediments or continuous cores to specified depths. There are a variety of grab-type samplers of different sizes and design that are used for obtaining surficial samples. Most consist of a set of opposing, articulated, scoop-shaped jaws that are lowered to the bottom in an open position and closed by some mechanism. In this process, a sample is retrieved between the closed jaws. Many grab samplers can be deployed by hand while others require lifting gear. Dredge samplers, which can be dragged a short distance along the bottom to dredge up a sample, are sometimes used in place of grab samplers that are subject to losing finer material during recovery when shells or gravel prevent complete closure of grab samplers. Jet probes (*q.v.*) and wash bores are sometimes used on a reconnaissance basis to gain general information on sediment types. While obtaining surficial samples is helpful, it is of limited value because vertical projection of surface data is highly unreliable. Also, the expense of running tracklines for the sole purpose of sampling surficial sediments is not economically justified by the value of the data obtained (Meisburger, 1990).

Direct sampling of sub-bottom materials is essential for borrow source identification and evaluation. This is usually accomplished by means of a continuous coring apparatus that can obtain cores 7–13 m in length (cf. Figure V1). In the types of sediment usually encountered in borrow site exploration, gravity corers are not suitable for obtaining cores of the requisite length, and some form of powered corers must be used. In most cases, vibrator-driven coring devices have been used for this purpose (Meisburger and Williams, 1981).

Collection of surface samples is not useful for most geological and geotechnical applications because depth parameters are required for various purposes. Although surficial samples (e.g., those obtained from grab samplers or jet probes) may provide rough ideas about recent submarine processes, they do not provide at-depth information about sediment thickness, structure, composition, and stratigraphic information. Jet probes (*q.v.*) provide useful information on a reconnaissance basis because large areas of seafloor can be covered relatively quickly at modest costs. Even though jet probes provide a rough idea of sediment types, specialized information is required to prove out potential borrow areas. Because vibracores provide the kind of detailed information that is required, vibracore surveys are often conducted in tandem with geophysical investigations. Geophysical surveys and geotechnical work is thus able to definitely establish deposit geometry, and the quality and quantity of sand. Vibracores are thus commonly deployed in the final stages of sand search investigations, that is, after evaluation of all available bathymetric, seismic, and jet probe data (e.g., Finkl *et al.*, 1997). Closely spaced (e.g., about 300 m apart) vibracores thus help to minimize uncertainty factors related to sediment quantification and type, thereby maximizing confidence in selection of offshore borrows. Figure V14 shows an east-west, cross-shore seismic reflection profile

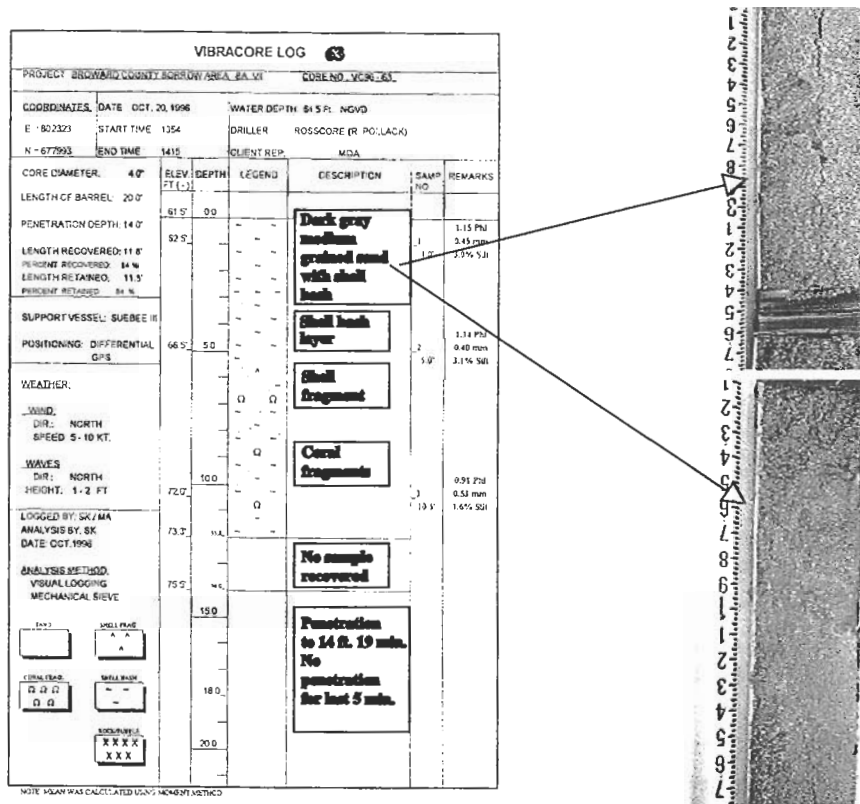


Figure V12 Example of a vibracore log showing uniform sands. This standardized summary format brings together many different kinds of data that are used to help characterize the materials contained in the cores. In addition to photographs of the core section (right side of diagram) with numbers inverted for easy determination of depth, the core log provides visual description, results of mechanical sieve analyses, notable features of the cored materials, penetration rates, and depth at refusal. The arrows point to relatively uniform dark gray, medium-grained sand with sparse inclusions of shell hash (courtesy of Coastal Planning & Engineering, Boca Raton, Florida).

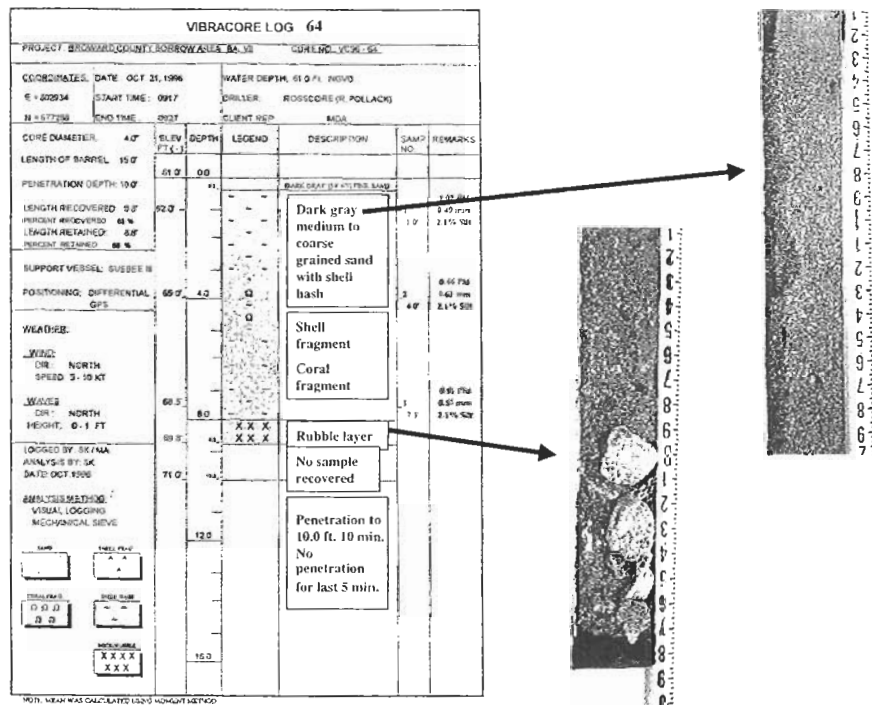


Figure V13 Example of a vibracore log showing a marked discontinuity in a basal rubble layer. Photographs of the split core (right side of diagram) show medium to coarse-grained sand interspersed with shell hash inclusions that terminate in a very coarse carbonate rubble layer. Sediment loss and refusal of the core barrel occur in the rubble layer that cannot be penetrated. The value of composite vibracore logs, as displayed here, is immediately apparent because they red flag potential problems when dredging for beach-quality sands that will be mined offshore and pumped onshore for beach replenishment (courtesy of Coastal Planning & Engineering, Boca Raton, Florida).

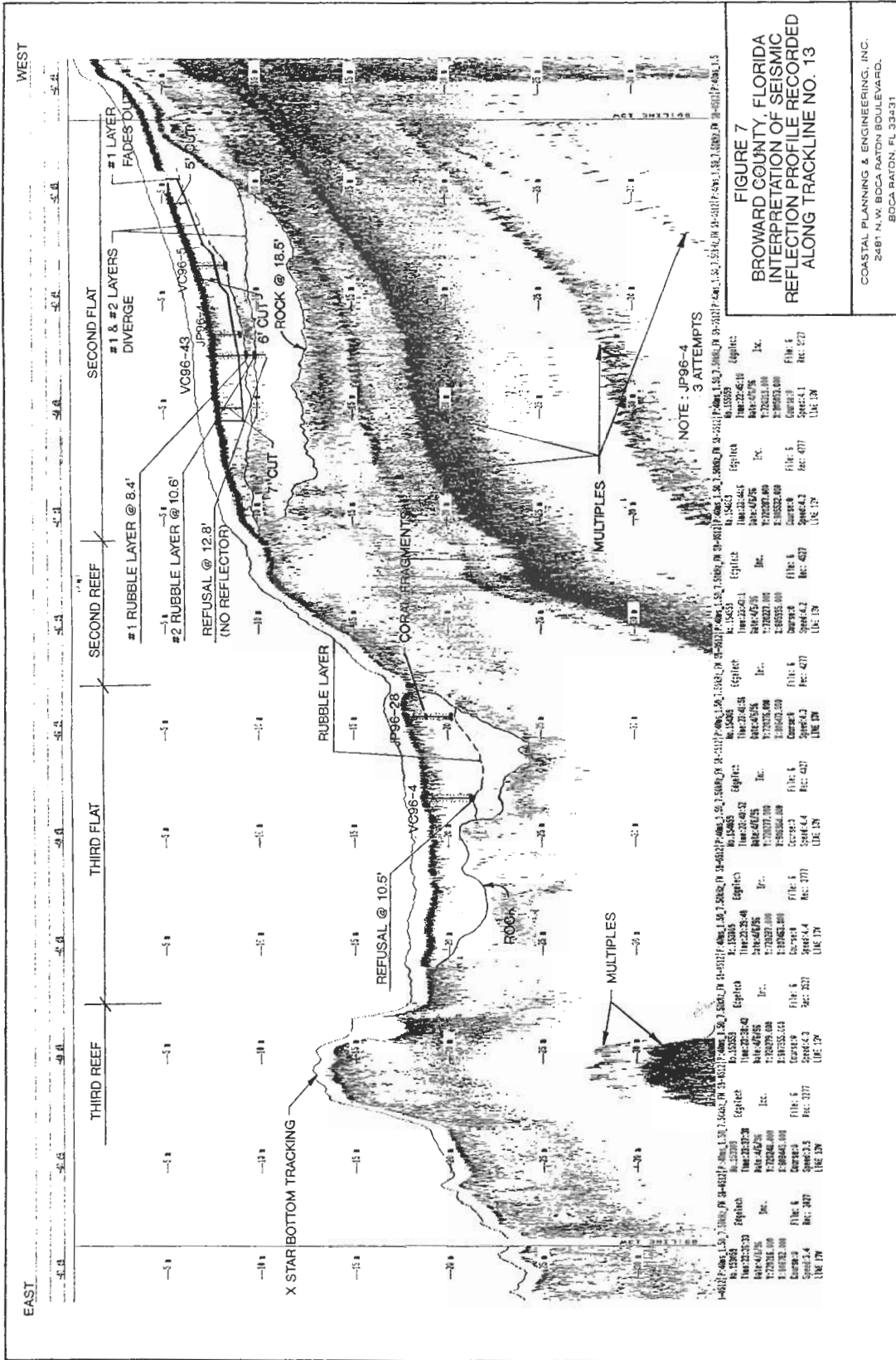


Figure V14 Cross-shore seismic reflection profile and vibracore locations, southeast coast of Florida in Broward County. This north to south view transects the shore-parallel Florida Reef Tract (so that the east or left side of the diagram leads to deeper offshore water). Depressions between parabolic coral reefs fronting the southeast Florida Peninsula contain sedimentary deposits that range from areas of silt plus clay to coarse rubble accumulations, but most areas supply sandy deposits. The second sand flat lies at about 5 m depth whereas the deeper third flat lies under approximately 17 m of water. The vibracores groundtruth the seismic reflection record by verifying the thickness of inter-reefal sandy sediments. Note the presence of carbonate rubble layers at depth in the second and third sand flats (shore is to the west, right side of diagram). Information obtained from the vibracores is essential to complete interpretation of seismic data. The presence of carbonate rubble and coral fragments delimits dredging operations to areas within inter-reefal sand flats that are devoid of materials that are unsuitable for beach renourishment. Offshore sand searches often rely on vibracore data for detailed analysis of sedimentary deposits and interpretation of geophysical surveys (courtesy of Coastal Planning & Engineering, Boca Raton, Florida).

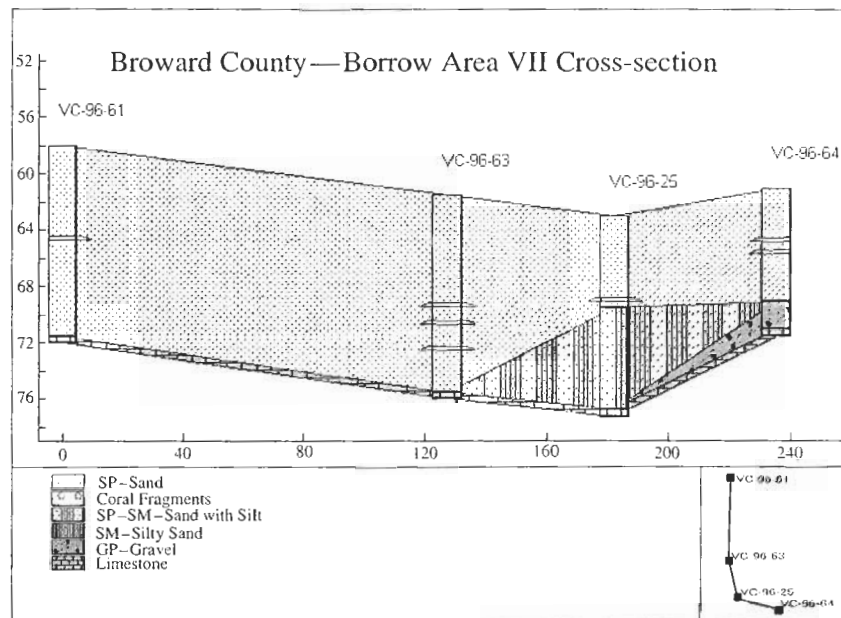


Figure V15 Example of a typical cross-section constructed from vibracore logs for a borrow area offshore southeast Florida in Broward County. The section shows the presence of inter-reefal sands overlying a limestone base (left side of section) and highlights unsuitable fine-grained (silty) materials and coarse gravels (right side of section) as in core VC-96-25. Fine-grained and coarse-grained materials are unsuitable for beach renourishment projects and must be identified prior to dredging so they are not placed on the beach. Because such materials are not compatible with native beach sands, their presence reduces the potential of borrow areas and becomes an important factor in estimating offshore reserves of extractable beach-quality sands (courtesy of Coastal Planning & Engineering, Boca Raton, Florida).

(based on a CHIRP X-Star sonar) on the inner continental shelf of southeast Florida in Broward County. The interpreted and annotated sub-bottom profile shows the sedimentary cover that overlies and partially infills inter-reefal troughs, identified as the second and third flats. Even though the seismic survey results can identify rock surfaces of the coral reefs (and buried reef), some carbonate rubble layers are not shown on the trace if they do not present a reflector. Examination of vibracores precisely locates the depth and thickness of coral fragments present in the sandy inter-reefal infills. Summary cross-sections, as shown in the example of Figure V15, although based on seismic and geotechnical data, are confidently constructed using closely spaced vibracore logs. As shown in Figure V15, materials that are unsuitable for beach renourishment (i.e., should not be dredged) are indicated (by a warning red color in the original diagram) as sand with silt, silty sand, gravel, coral fragments, and limestone. Vibracore locations are noted in this fence diagram by a simple coded annotation such as VC-96-61, which indicates a vibracore borehole (VC) that was collected in 1996 (96) as borehole number 61 in a sequence. The strategic role of vibracores as verification or searuthing of geophysical survey data and as key indicators of actual sedimentary conditions in their own right is patently obvious.

Conclusion

Vibracores are specialized sampling procedures for obtaining continuous, undisturbed cores. Although limited by the maximum length of retrievable core (about 7–10 m for most purposes), vibracores find application in many different kinds of coastal studies where undisturbed samples need to be collected from surficial sediments on land or under water. Vibracores can provide invaluable physical, chemical, and biological information that is otherwise unobtainable. Vibracoring systems range from portable, inexpensive setups to more complicated assemblies that require elaborate service platforms on ships or barges fitted with powerful hoisting equipment. Vibracores are an essential component of multifaceted surveys, such as offshore sand searches that attempt to locate potential borrow areas containing large volumes of beach-quality sands. Although vibracores have a number of limitations that preclude their use under a range of conditions, they are deployed to advantage in many different kinds of scientific and engineering applications. In many respects, vibracores are the unsung heroes of coastal research that depends on acquisition of information posited in the sedimentary record. Collection of unbiased reference information

concerning vibracores is somewhat difficult because few papers focus on the vibracoring methodology *per se*. Vibracoring is a sample collection technique that usually only finds mention in the “methods” section of research reports, often as a backup to broader topics such as geophysical or engineering survey. Nevertheless, information obtained from vibracores should not be minimized, as ancillary when in fact in many cases it is primary, even though it is often collected last.

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Cross-references

Beach and Nearshore Instrumentation
 Beach Stratigraphy
 Coastal Sedimentary Facies
 Coastal Soils
 Jet Probes
 Mining of Coastal Materials
 Monitoring, Coastal Geomorphology
 Nearshore Geomorphological Mapping
 Offshore Sand Sheets
 Sequence Stratigraphy
 Shoreface

VORTICITY

Vorticity is the tendency for spin or rotation in a fluid (i.e., vortex flow). As such it is a vector and can be separated into components of spin about the vertical axis and either or both of the horizontal axes. Eddies observed as water moves past obstacles such as bridge pilings is an example of relative vorticity flow about the vertical axis.

Figure V16 shows a Cartesian coordinate system with the x -axis pointing eastward, the y -axis pointing northward, the z -axis pointing upward in the opposite direction to the gravity vector \vec{g} . The x - y plane is parallel to a level surface, and relative vorticity (ζ) about the z -axis is defined as $\zeta = (\partial v/\partial x) - (\partial u/\partial y)$. In this equation $+v$ is the flow in the northward direction and $+u$ is the flow in the eastward direction, relative to the fluid in which the eddy is imbedded. Components of relative vorticity can be defined about the other two axes, but the most important one in mesoscale oceanography and meteorology is the vertical component ζ .