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JET PROBES

Introduction

Jet probes are used for a variety of purposes (e.g., underwater cable routing, marine archaeology, coastal engineering) and are usually deployed in conjuction with other data-collection techniques such as hydrographic surveys (to determine water depths and map existing bottom conditions), subbottom profile survey (to identify near subbottom stratigraphy, 3–7 m depth), side-scan sonar survey (to identify morphological variations, and natural and man-made obstructions on the seabed), and vibratory coring (to acquire direct physical information of nearsurface sediments). Jet probe surveys acquire indirect physical information on subsurface lithology by surveying the thickness and stratigraphic layering of sedimentary covers on land or underwater. A jet of either air or water is used to penetrate the sand cover; the latter, however, is only applicable underwater (USACOE, 2002).

Most jet probe surveys, in the service of coastal engineering for shore protection via beach renourishment, provide a rapid means for determining the nature of unconsolidated sedimentary deposits that occur underwater. Because jet probes have no cutter head and depend only on the power of a water jet to penetrate bottom sediments, they are restricted to use in shallow waters (i.e., the effective range of operating depths is usually from 1 to about 30 m) that overlie unconsolidated (loose) sandy deposits. Clear water is desirable, but not essential, because it facilitates site location, maneuverability of jet probe equipment over the bottom, and visual estimation of turbidity plumes that are created by water-jetted penetration of a pipe down through the sediment (CBNP, 1995). Jet probing finds application in marine archaeology, geotechnical studies that feature searches of seabed deposits for beach-compatible sands that can be placed on degraded beaches, and geological investigations that attempt to determine the thickness of sand covers on the seafloor or on lakebeds. Although widely deployed in many different kinds of environments and for various applications by scientists and engineers, jet probing probably finds most extensive application in coastal sand searches (e.g., Meisburger and Williams, 1981; Meisburger, 1990; Keehn and Campbell, 1997; Finkl *et al.*, 1997, 2000, 2003; Andrews, 2002) that require reconnaissance surveys of bottom types or verification of geophysical survey data (e.g., subbottom profiles, side scan sonar surveys).

Grab samples provide information about surficial seafloor sediments, whereas vibracore and jet-probe samples can penetrate down into the sediment layers. Vibracore samples are relatively inexpensive to obtain and can recover the long and relatively undisturbed cores that are required to assess the composition and grain sizes of the materials, as well as to establish the stratigraphy of the deposits (e.g., Meisburger and Williams, 1981). Water jets are less expensive than cores (CBNP, 1995; USACOE, 2002), involving the water-jetted penetration of a pipe down through the sediment in order to determine the layering, as opposed to (undisturbed) core retrieval for splitting and analysis.

Marine archaeology

This tool assists marine archaeologists in determining the nature or presence of materials or features that lie within or underneath bottom sediments (Anon, 1996). On archaeological sites, the jet probe is manually driven through various nonconsolidated sediments on the seabottom where the probing pipe goes through soft strata until it hits bedrock, a cemented stratum, compacted clay, or artifact. This tool provides information regarding the location and elevation of buried ancient waterline features (indicators of previous sea-level positions) and other geomorphological data. Ultimately, the information enables the archaeologist to reconstruct shallow coastal-marine sedimentary environments, local surficial stratigraphic sequences, and other geological features that can then be dated and calibrated with archaeological finds.

Stratigraphic studies

Coastal-marine stratigraphic studies often rely on a range of techniques that are used to compile various kinds of information, that is, related to layering of different kinds of materials on the seabed (e.g., Toscano and Kerhin, 1990; Wells, 1994). Data are commonly derived from several independent studies viz. surface sediment samples, vibracores, and seismic records to compile an assessment of Quaternary stratigraphy, as, for example, in the Paranaguá Bay Estuary in southern Brazil (Lessa *et al.*, 2000). Estuarine environments often provide ideal conditions for jet probing because there is a range of unconsolidated materials related to coarse- and fine-grained facies. Fluvial- continental deposits often occur with paleo-valleys as substratum for more recent sedimentation. These kinds of estuarine environments are often characterized by the intercalation of trans- gressive–regressive mud and sand facies that can be effectively studied using jet probes in conjunction with other techniques.

Underwater surveys of lakebeds often use jet probes to assist in reconnaissance verification of sedimentary bottom types, especially where sediment samples and grain-size analyses are eventually required. Lakebed studies often combine jet probing with underwater video investigation as independent lines of inquiry. Jet probe surveys to determine the thickness of sand cover are based on differentiation of the kinds of materials that are penetrated by the jet probing. On the American Great lakes, for example, the presence of diamictites (tills) that have been eroded from truncated drumlins to produce cobble–boulder lag deposits on the lakebed can limit the effeciveness of jet probes, as would any other substantial impediment to penetration of sedimentary layers (e.g., Stewart, 2000).

Assessment of sand resources and mining

Sandy shores occur along about 13% of the world's coastline (Coleman and Murray, 1976) and it is estimated that today about 75% of these shores are eroding (Bird, 1985). Beach erosion is thus a common problem along sandy coastlines and it is necessary to artificially renourish beaches because they provide natural protection from storms and have economic value (Finkl and Walker, 2002). The location of materials that are suitable for beach renourishment becomes an issue for best management practices that have to consider environmental concerns, methods of shore protection, storminess, and impact of exploration procedures to locate sand bodies on the seafloor. Even though sand sources differ from region to region around the world, there is a commonality to the need for good-quality sand and methods of looking for adequate long-term supply, as described, for example, by Anders *et al.* (1987), Conkright *et al.* (2000), and Walker and Finkl (2002).The salient problem then, is how to best locate sand sources that are appropriate for beach nourishment. Although inland sand sources are often suitable from a textural and compositional point of view for beach replenishment, their location away from the coast requires overland transport that can pose significant placement problems along the shore. Offshore sources of beach-quality sand are thus most often sought as geotechnical and economic reserves. Inner continental shelves host a range of coastal (e.g., beach ridges, dunes, nearshore bars, flood- and ebb-tidal deltas, estuarine sands) and marine sediments (e.g., shoals, banks, ridges, terraces, blanket deposits) as well as terrestrial deposits (e.g., glaciofluvial materials on valley floors, winnowed tills, coarse-grained alluvial terraces, and plains), all of which have been drowned and modified by rising sea levels during the Holocene (e.g., Toscano and York, 1992). Offshore sands that are suitable for beach renourishment are a sought-after and coveted commodity because in many regions they are in dwindling supply (e.g., Freedenberg *et al.*, 2000).

Advanced geophysical and geotechnical procedures are often backed up or verified by low tech efforts, such as jet probing, that are essential to the efficiency and economic success of offshore sand searches. General procedures for the exploration and development of borrows were summarized by James (1975) and Meisburger (1990), for example, who emphasized the value of collaborative approaches. Figure J1 shows the main sequential steps in modern data collection that are followed in sophisticated coastal sand searches that integrate diverse techniques. As shown in the figure, jet probe surveys are typically conducted at the reconnaissance level in conjunction with a suite of independent, but related, geophysical and geotechnical survey operations that provide specific kinds of information that collectively elucidate sediment thickness, lateral continuity, structural relationships, and composition. It is important to note that the first step in sand resource assessment is the review of historical data, an effort that is essential to proper appreciation of prior efforts and conclusions. Jet probe logs (Figure J2) are archived because they contain useful information that may be required later. A typical jet probe log, as shown in Figure J2, includes the usual kinds of locational information; date acquired, water depth, top and bottom divers, start- and end-times, etc. Notes in the log include important information that is related to the length of pipe, penetration depth, jet pump capacity, weather conditions, turbidity levels, and characteristics of the sand (grain size, percentage of silt content, color).

Sand searches for beach nourishment and protection commonly employ jet probe surveys (e.g., see Meisburger and Williams, 1981; CBNP, 1995; Walther, 1995; Freedenberg *et al.*, 2000; Finkl *et al.*, 1997, 2000). Usually conducted as a reconnaissance field survey (cf. Figure J1), the procedure is often misunderstood and the least utilized tool in sand

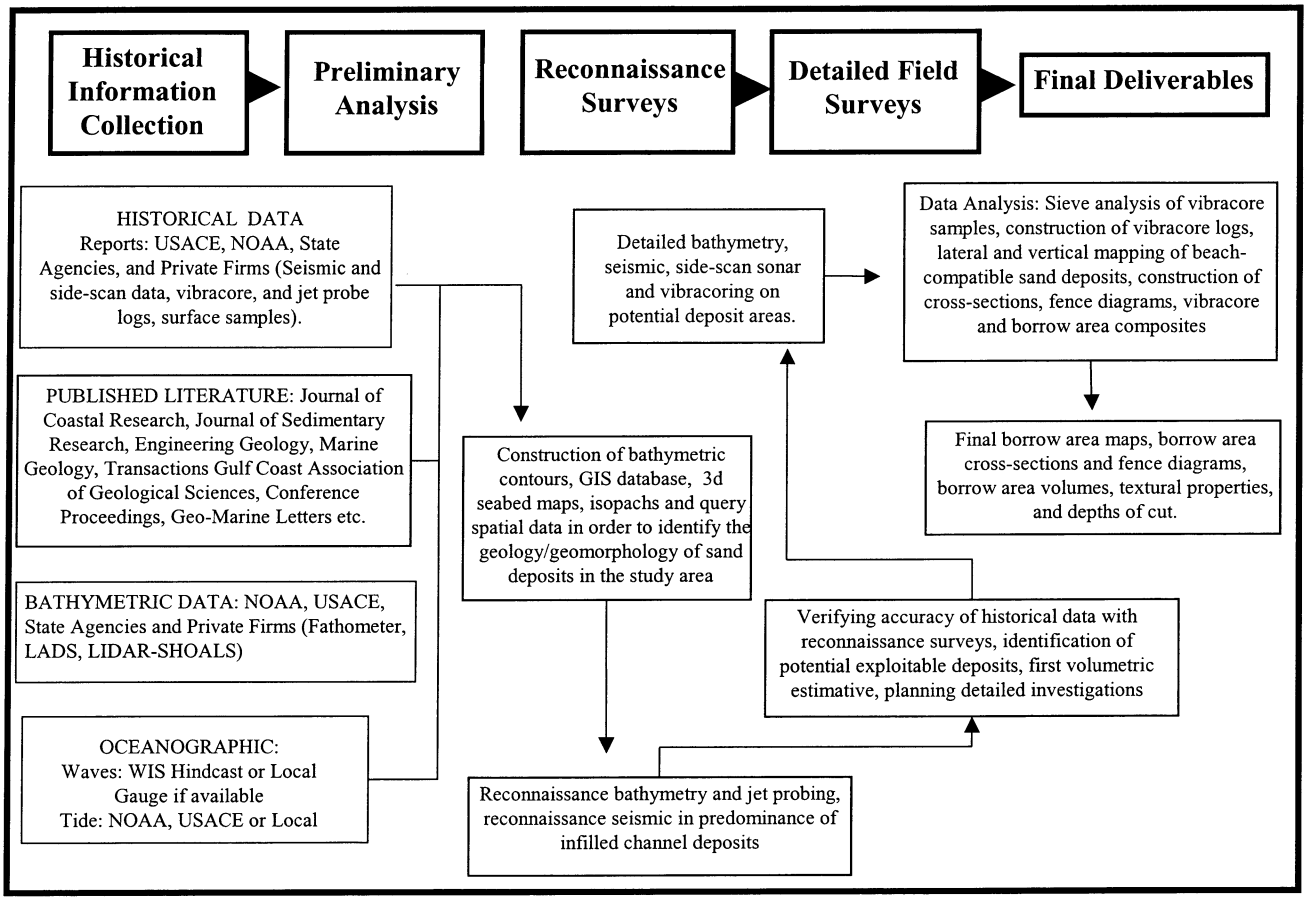
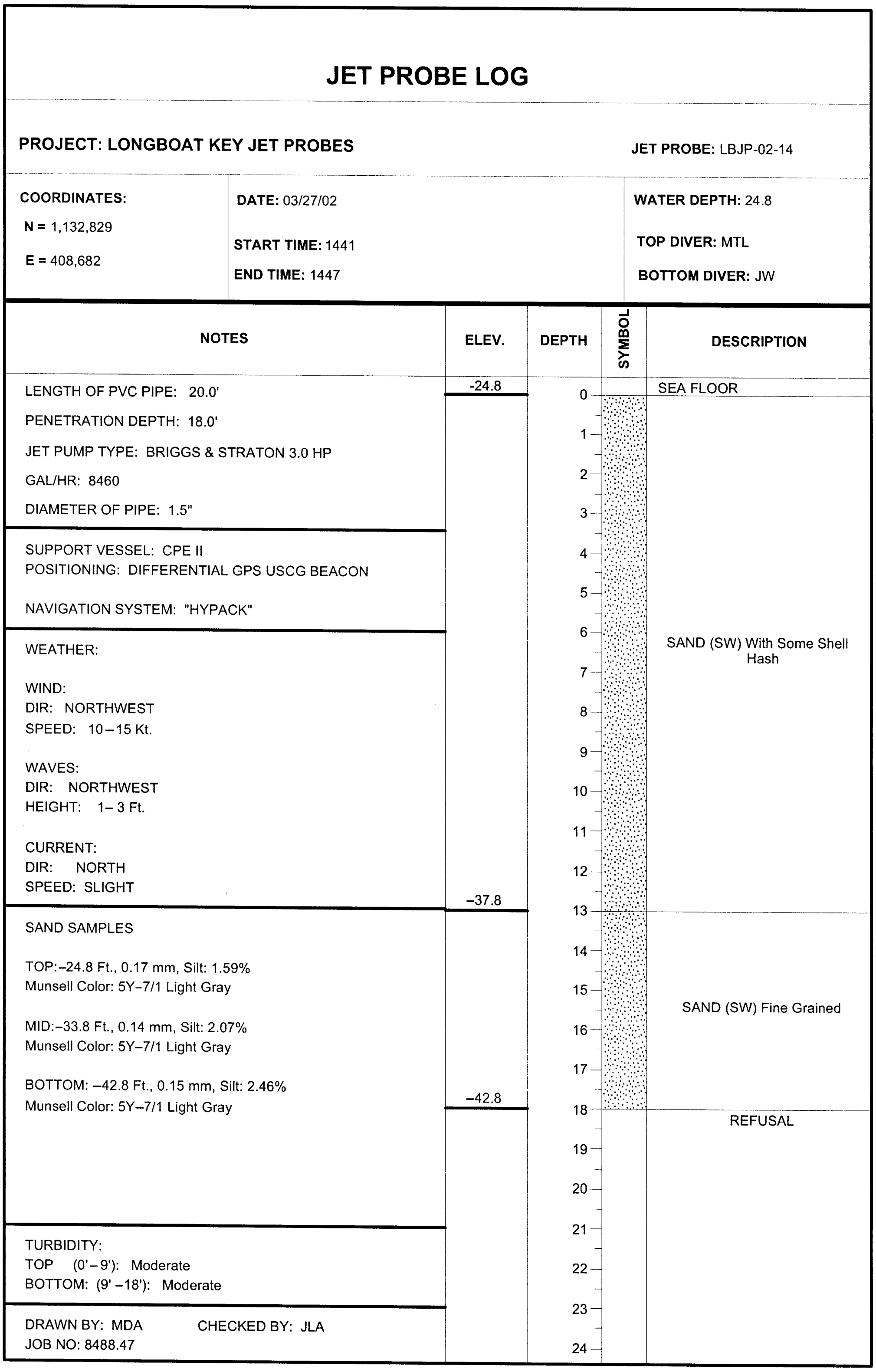


Figure J1 Flow diagram showing the organization, routing, and sequential application of coastal sand searches that are normally deployed on the inner continental shelf. Note that investigations begin with review of historical data, including proprietary reports and works in the public domain, and proceed to the construction of electronic databases that interface with GIS frameworks. Reconnaissance jet probing assists in the verification of historical data and provides focusing criteria for conducting detailed surveys. After review of historical, laboratory, and field data, sand resources with the greatest potential for use as beach sediments are identified as borrow sites. Jet probe surveys provide critical information in the evaluation of offshore sand resources and help identify which deposits are exploitable.



JET PROBE LOG

PROJECT: LONGBOAT KEY JET PROBES

JET PROBE: LBJP-02-14

COORDINATES:
N = 1,132,829
E = 408,682

DATE: 03/27/02

START TIME: 1441
END TIME: 1447

WATER DEPTH: 24.8

TOP DIVER: MTL
BOTTOM DIVER: JW

NOTES

LENGTH OF PVC PIPE: 20.0'
PENETRATION DEPTH: 18.0'
JET PUMP TYPE: BRIGGS & STRATON 3.0 HP
GAL/HR: 8460
DIAMETER OF PIPE: 1.5"

SUPPORT VESSEL: CPE II
POSITIONING: DIFFERENTIAL GPS USCG BEACON

NAVIGATION SYSTEM: "HYPACK"

WEATHER:

WIND:
DIR: NORTHWEST
SPEED: 10–15 Kt.

WAVES:
DIR: NORTHWEST
HEIGHT: 1– 3 Ft.

CURRENT:
DIR: NORTH
SPEED: SLIGHT

SAND SAMPLES

TOP:–24.8 Ft., 0.17 mm, Silt: 1.59%
Munsell Color: 5Y–7/1 Light Gray

MID:–33.8 Ft., 0.14 mm, Silt: 2.07%
Munsell Color: 5Y–7/1 Light Gray

BOTTOM: –42.8 Ft., 0.15 mm, Silt: 2.46%
Munsell Color: 5Y–7/1 Light Gray

TURBIDITY:
TOP (0'–9'): Moderate
BOTTOM: (9' –18'): Moderate

DRAWN BY: MDA CHECKED BY: JLA
JOB NO: 8488.47

ELEV.	DEPTH	SYMBOL	DESCRIPTION
-24.8	0		SEA FLOOR
	0–13	▨	SAND (SW) With Some Shell Hash
–37.8	13–18	▨	SAND (SW) Fine Grained
–42.8	18		REFUSAL

Figure J2 Example of a jet probe log showing the kind of information that is logged in verbal or numerical formats along with graphic displays of sediment composition. These digital logs are part of a GIS framework and the information contained in them can be queried for special purposes. Note that some information is back loaded into the logs because it is obtained subsequent to field logging. Granulometric analyses, for example, report median grain sizes for clasts (e.g., sand grains) and particulate matter (e.g., percent silt content).

search investigations. Usually deployed after preliminary assessment of historical data (e.g., geophysical and geotechnical information), comprehension of the regional geology and geomorphology, and computer aided analysis (including GIS summaries), jet probing should verify previously indicated field conditions. Jet probe surveys thus perform a valuable function in sand searches and their relevance and importance should not be underestimated as a time- and cost-saving effort.

Reconnaissance bathymetric and jet probe surveys are also used to verify hydrographic features with widely spaced bathymetric surveys, historical surface sand samples, jet probes, core sites, and other potential sand features in the study area. Reconnaissance bathymetric surveys groundtruth and verify the National Oceanic and Atmospheric Administration hydrographic data in selected areas of potential sand deposits. The reconnaissance bathymetry should be compared with historical bathymetry to identify areas where sand has accumulated by natural coastal processes or offshore dredge disposal. An example of reconnaissance jet-probe survey is shown in Figure J3 for a portion of the southwestern coast of Florida. Here, on the wide continental shelf of the eastern Gulf of Mexico, a range of sedimentary deposits overlie a karstified limestone peneplain that extends seaward from the Florida peninsula (Evans *et al.*, 1985). Although the karst surface is somewhat irregular due to dissolution of the carbonate rocks, drowned valleys are infilled and planar areas are covered by blanket deposits and ridges.

Inlets along this coast, which produce deltaic deposits, show no strong regional trends and are stable in terms of channel width, length, geographic position, and orientation (Vincent *et al.*, 1991; Finkl, 1994). The low wave energy regime that influences sediment accumulation at inlets in this region enhances construction of large ebb-tidal deltas, which store enormous quantities of sand (Davis *et al.*, 1993). Flood-tidal deltas along the west-central Florida coast are relatively inactive due to small tidal ranges, sheltered lagoons, and ebb-dominated inlets (Davis and Klay, 1989; Finkl, 1994). The wide Continental shelf offshore southwest Florida, described by Davis (1997) and which gently slopes seaward toward the central basin of the Gulf of Mexico, maintains shallow depths to 9 km offshore to the 10 m isobath. Shelf morphologies and coastal (inlet) morphodynamics impact spatia distributions of mineral resources (Wright, 1995), large-scale coastal behavior (Short, 1999), and barrier island evolution (Oertel, 1979).

Various types of sand ridges (linear accumulations of sand bodies) are common on inner shelves along many shores the world over (viz. Duane *et al.*, 1972; Swift and Field, 1981; McBride and Moslow, 1991). These topographically positive sedimentary accumulations on the seafloor are recognized as relict sand bodies that formed in response to prior stillstands of mean sea level (MSL) when sea levels were lower than those of today. On the shelf off southwestern Florida, for example, prominent seabed morphologies include linear sand ridges, some of

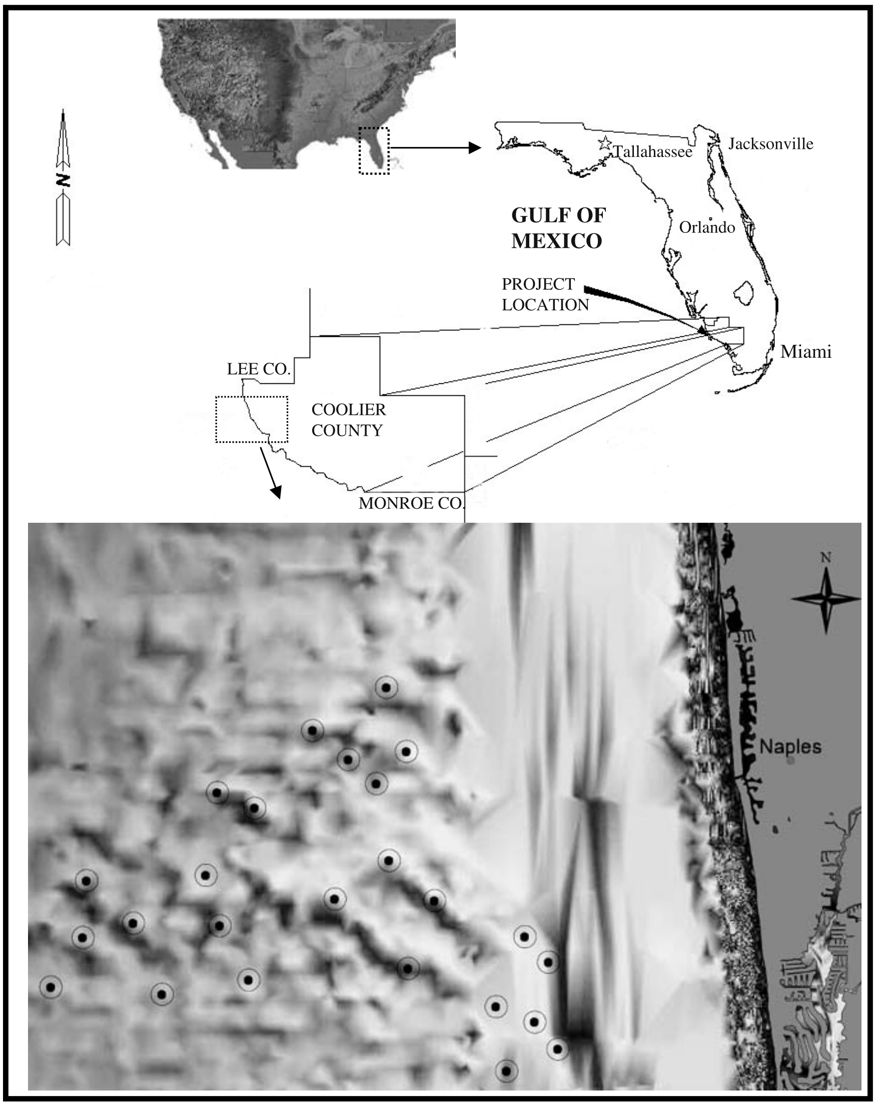


Figure J3 Jet probe location diagram showing bathymetry in terms of a graduated grayscale ramp so that sedimentary accumulations on the seafloor may be inferred from bathymetric highs. Jet probe locations, identified by the circled dots, are strategically placed to provide information related to the deposit thickness. Note the placement of jet probes on sand ridges.

which extend continuously for distances greater than 6 km. These deposits formed during the Flandrian Transgression (most recent Holocene trend in sea-level rise) (Davis, 1997). Depressional (negative topographic) features are incised into the karst surface and some surficial marls. When the continental shelf was exposed to subaerial geomorphic processes during low stands of sea level, streams cut into the karstified surface and persisted as valleys until sea level rose and they became infilled with recent marine and terrigenous sediments.

Figure J3 shows the distribution of reconnaissance jet probe locations of Naples, Florida. The jet probe locations are strategically placed on the basis of hydrographical, geophysical, geotechnical, and geological (including geomorphological) information (cf. Figure J1) that indicates the presence of sand deposits. As illustrated here by the shaded bottom relief on the lower left side of the Figure J3, caused by sedimentary accumulations on the seafloor, jet probes are sited on ridges, inter-ridge depressions, sand flats, and in other areas to verify thickness of sedimentary covers (or lack thereof). Emphasis must be placed on the fact that jet probes are not randomly sited on the seabed just to see what is there; rather, siting is intelligently coordinated with all collateral data that is related to the nature of bedrock surfaces and sedimentary accumulations on the seafloor. Reconnaissance jet probing is a strategy that is conducted as part of an overall coordinated methodology to define the presence of beach-quality sands on the seafloor.

Jet probes are thus taken in areas that show promise for sand deposits and to confirm historical vibracore logs. Jet probes and surface sand samples provide an indication of the thickness and characteristics of the unconsolidated sediment layers. With two dive teams, consisting of a geologist and a support diver, generally 8–15 jet probes can be obtained in a day depending on water depths, weather, and sea conditions (Andrews, 2002).

Geologists who are proficient in SCUBA diving, operate the jet probe by penetrating a graduated 7 m water pressure pipe into the ocean bottom and making observations as it passes through the sediment layers. The geologist is on the bottom and the support diver stays at the upper end of the probe to hold it upright against the current (Figure J4). The support diver also observes the turbidity level changes from above as silt is washed out of the probe hole (becoming suspended in the water column) during penetration of the seafloor. The geologist on the bottom observes the graduated scale on the probe and by the "feel" of the objects it encounters, makes mental notes of the depths of each change in texture, which are afterwards incorporated into the field log (cf. Figure J2). An experienced diver-geologist can distinguish layers such as shell, rubble, sand, peat, clay, and rock. The probe is jetted to the total length of the pipe (usually 7 m) or until it encounters a layer that it is unable to penetrate. On the Florida Gulf coast, karstified limestone formations on the inner continental shelf (e.g., Evans *et al.*, 1985; Hine *et al.*, 1998) usually limit jet probe penetration because sand deposits are less than 7 m thick. Nearly contiguous offshore sand ridges (described above), which are related to ebb-tidal deltas, and paleo barrier island, beach, and surf zone environments constitute the major source of beach renourishment sand on the central coast of west Florida. Jet probes, which are ideally suited to quickly and economically measure the thickness of thin sand deposits (i.e., <7 m in thickness), are therefore widely used in this geomorphic setting to determine the isopachs of shelf deposits that often occur in the form of sand sheets (shoals) or low ridges.

To obtain sediment samples from various depths, wash borings are obtained by the following methods. The geologist, who directs the jet probe into bottom sediments, takes two sample bags that are labeled "mid-depth" and "bottom of hole." The support diver, near the water surface, takes one sample bag labeled "surface sample." The probe is driven to its total depth of penetration, point of refusal (caused by hard layers, large floater, or bedrock) or maximum length of pipe. If that depth is 6 m, for example, the probe is pulled out and a second hole is

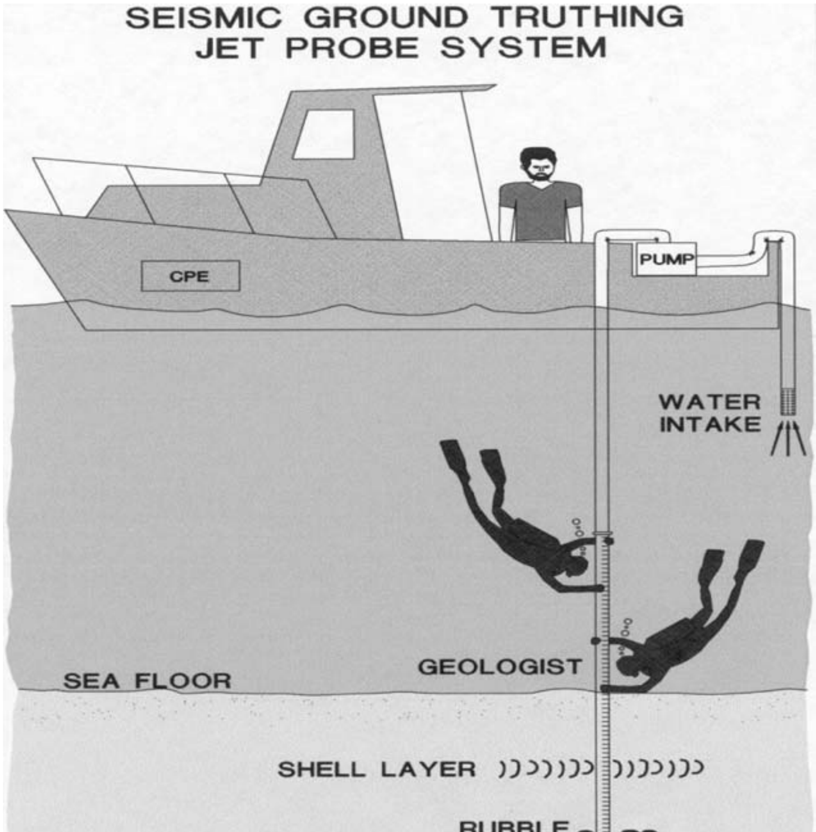


Figure J4 Schematic diagram showing the procedure for jet probing bottom sediments on the seafloor. Note that the portion of pipe that penetrates into the sediments contains graduated marks so that sediment thickness can be accurately determined. The geologist-diver works at the lower level near the seafloor and is proficient at estimating the nature of the materials probed by the "feel" of the pipe as it penetrates to refusal or reaches the end of the pipe.

probed to a depth of 3 m, 2–4 m up current from the first hole. The geologist pulls the first probe and the support diver signals the boat to haul the probe to the surface. The geologist takes a sample of the material that has formed a mound (spoil pile) around the probe hole and places it in the "bottom of hole" sample bag. A subsample of the material forming a mound around the second (shallower) hole is placed in the bag labeled "mid depth." The support diver, after the jet probe is hauled to the surface workboat, swims toward the bottom while moving against the current at about 2 m from the probed area (first two holes) and obtains an undisturbed "surface" sample from the bottom.

The subsamples removed from the washout mounds provide a representative bulk sample of the material that the probe passed through and which was jetted to the surface by the water pressure in the pipe. Materials comprising the washout mounds are deposited in the reverse order of the actual stratigraphic layers in the bottom sediments. Wash borings tend to have inherently low slit contents because the fine-grained particles, which have lower specific gravities than larger grains, tend to remain in the water column as suspensiods. The denser grains thus settle annularly in a mound around the jet probe. Suspension of fine-grained materials (typically silt plus clay and possibly organics) produces turbidity clouds in the water, which are quickly dispersed by currents. It is essential for the near-surface support diver to estimate changes in the turbidity plumes issuing from the jet probe so that the presence of fine-grained sediments is not under estimated from inspection of the heavier wash borings that quickly settle out of the water column. With experience, estimates of fines at different depths can be surprisingly accurate. Even though these samples (spoil from jet probing and estimates of fines) are extremely useful in the selection of areas for additional investigation, they are not meant to supplement or replace vibracores when defining borrow sites.

Upon returning to the surface workboat, both the diver- geologist and support diver immediately relay their underwater jet probing observations (i.e., depths of penetration, nature of the materials in different layers, and levels of turbidity that were associated with different depths) to the second onboard geologist who records this information in a permanent logbook. The descriptions relayed to the logbook should also include information that is relevant to characterization of the seafloor surface viz. sand ripples, algae, sea grass, surface rubble, or other observations. This information is often used to assist in the interpolation of sidescan sonar data. The sand samples are cataloged and notes on the texture (grain size) and color are recorded.

To prepare jet probe data for inclusion in reports, data that were recorded in the logbook are digitally entered into a jet probe log that is formatted in a manner similar to vibracore logs (see *Vibracores*). Sand samples are sieved to determine grain size and compared, in both wet and dry states, with a Munsell soil color chart. Representative samples are archived in small sample bags for presentation, reporting, and review. An example of data compilation for a jet probe survey is summarized in Table J1, which shows the classification of the jet probe, local relief of the surrounding seafloor, penetration of the probe, grain size, turbidity, and other relevant observations. Classification of the jet probe is important to interpretations of the survey because a single probe does not determine the viability of a deposit. The classification reported here is not universal, just an indication of what kind of system might be devised to show the resource potential of a probed area. Categorization of the "area of influence" for a single jet probe is comprehended by the application of "buffers," whereas multiple jet probe penetration defines a deposit. The buffer concept for jet probes represents an area that expands or contracts, depending on local sedimentary and geomorphological conditions. A sand sheet deposit will, for example, have a larger buffer zone around each jet probe because these kinds of deposits tend to be rather uniform over relatively large distances. The buffer around a probe on isolated sand ridges or in valley fills (i.e., drowned fluvial valleys, delta distributaries, tidal channels) will be a smaller zone because these kinds of deposits have limited lateral extents and conditions of sedimentation change in relatively short distances away from the probe. Local relief of the seabed in this area, increased by the presence of sedimentary bodies, is an indication of penetration depth for jet probes. Figure J5 demonstrates the observation with a fairly good correlation coefficient ($R^2 = 0.3935$). Once a survey is completed and the full range of parameters is appreciated and incorporated into an electronic database (see below), each jet probe is back classified so that it indicates the location of potential sand resources to be further investigated by refined geophysical (seismic and sidescan sonar) and geotechnical (vibracore) methods. Each jet probe is thus classified into one of five categories that range from unsuitable to a high potential for use. The categories are defined in Table J1 and it is important to note that application of the buffer concept in a spatial context on maps permits the recognition of sands (and the associated seafloor texture as seen in sidescan sonar images, three-dimensional bathymetric models, or isobathic expression of geomorphic units) that are potentially useful in beach replenishment projects. Grain size is determined by granulometric procedures from the subsamples collected by the geologist manning the jet probe. Turbidity is reported as estimated in the field and is a rough guide to the percent silt in the deposit (which is accurately determined later in the laboratory). Other observations included in Table J1 refer to the presence of rock fragments (e.g., limestone rubble, coral fragments), whether grain sizes fine or coarsen upwards or downwards, or any other property that should be noted.

Modern jet probe surveys are interfaced with advanced navigational software and differential GPS that make it possible to incorporate data into GIS database systems in such a way that reconnaissance-level surveys can be easily updated by new information and to facilitate efforts to groundtruth geophysical and geotechnical surveys. Table J1 is an example of the kind of jet probe-related information that can be extracted from GIS databases or queried for specific purposes. GIS analysis rings also facilitate querying procedures that can locate potential targets for sand mining activities and that can also point to areas where sediment texture and compositional information is insufficient to make reliable conclusions as to the presence of quality-sand sources. On the basis of jet probe data and other information, specific sand deposits are identified for detailed field surveys. Summary reports are usually prepared in a composite GIS framework, that is, in an electronic database and maps that help estimate sand volumes and approximate costs for detailed investigation of each potential borrow area, based on characteristics such as grain size and distance from the beach nourishment site on the shore and dredging suitability.

Conclusion

Jet probes are used to obtain information related to surficial sediment thickness on land and in shallow coastal waters. On land, jet probes may be powered by air or water pressure forced through a length of pipe. Jet Probes represent a good low-cost survey method for reconnaissance surveys on the sea and lakebeds. They are applicable to archaeological investigations and stratigraphic studies of thin sedimentary sequences, but it is in the search for beach-compatible sediments on the inner continental shelf that they find greatest use.

As a coastal resource tool, jet probes are often underutilized because researchers tend to use more sophisticated survey methods in the belief that greater value is received from greater expenditure. Jet probes are, however, an economical way of determining not only the thickness of sedimentary bodies but also their composition, grain size, compaction, and inclusions of rock fragments or other materials. When used collectively with a defined area as a specialized reconnaissance survey method, jet probes provide groundtruthing for geophysical, geotechnical, geological, and geomorphological interpretations of the seabed sediments. The main drawback for jet probing is that operators need to acquire sensitive skills for interpreting the "feel" of probe penetration. With some practice, however, geologist-driver operators can become proficient estimators of the various parameters that are normally associated with jet probe surveys. The most widespread application of jet probing is in coastal sand searches because increased knowledge of offshore sand resources is required for beach nourishment projects. Maximum water survey depths for jet probing are limited to about 30 m and the depth of penetration to the length of pipe that is easily handled underwater, usually about 7 m. For practical considerations, the minimum operating depth in water is about 1 m. As the search for sand resources intensifies, due to increasing erosion of beaches and coastal land loss on protective barrier islands and shoals, jet probes will increasingly serve as comparatively inexpensive procedures for evaluating seabed sediments on inner continental shelves.

Advanced geophysical and geotechnical procedures are essential for the accurate definition and location of sand resources on the inner shelf; however, these resources can be optimized if backed up or verified by low tech and less costly efforts, such as jet probing, that are essential to the efficiency and economic success of offshore sand searches. Advancements in positioning and navigation software and hardware that can be interfaced with GIS systems in the field permit analysis of spatial data associated with the jet probes in a timely fashion that increase survey efficiency and applicability. Although combinations of modern marine exploration techniques have contributed to the cost-effectiveness and success of sand search investigations, they are of reduced value if they are not accompanied by logical and rational planning of surveys in accordance with local geology and geomorphology.

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Table J1 Summary of field results for a jet probe survey off Charlotte County, southwestern Florida.

Jet Probe (#)	Category (rank)[a]	Relief (ft)	Penetration (ft)	Grain size (mm)	Turbidity (estimated)	Observations and notes
1	3	N/Av[b]	19	0.18	M to H[c]	Four feet of silty sand with clay balls on top/no refusal
2	4	N/Av	12	0.24	H; H to M	Three feet of sand with silt/clay on top
3	5	N/Av	14	0.42	L to M	Slightly fining upwards
4	5	N/Av	20	0.31	L to M	Slightly fining upwards/no refusal
5	4	5	5	0.23	L to M	Fining upwards (1 ft layer), rock on bottom
6	4	5	7	0.35	H	Two feet of silty sands on top, 1 ft rubble on bottom
7	3	3	4	0.23	M to H	Fining upwards, rock on bottom, not well-defined ridge
8	2	4	3.5	0.19	M to H	Homogeneous, rock on bottom
9	1	4	3	0.16	H	One-foot thick layer of silty sand on top
10	2	5	7	0.17	L to M	About 4% silt and very fine sand
11	3	4	3	0.33	M to H	Fining upwards, relatively thin
12	1	4	3.5	0.17	H	Silty sands, 0.5 ft of rubble
13	2	5.5	4.5	0.17	M to H	One layer of silty sand on top
14	2	4.5	7.5	0.15	L to M	Fining upwards, very fine sediments
15	3	5	4	0.71	H	Fining upward, shell fragments
16	3	4.5	5	0.19	M	Finer than 0.2
17	2	5	8	0.14	H	Silty sand, too fine and H turbidity
18	4	5	9	0.16	M to H	Finer top, 0.5 mm visual estimate of bottom sand
19	3	6	16	0.14	M to H	Finer top, coarser on bottom (0.23 visual estimate)
20	2	1	3	0.22	H	Finer silty sand in top layer
21	4	6	8	0.23	M to H	Fining upwards, 1′ silty sand on top, 0.5′ rubble bottom
22	4	4	6	0.23	M to H	Fining upwards, at least 4 ft of fine–medium sand
23	3	4.5	4	0.95	M to H	Shell fragments, some silt in top 2 ft
24	4	7	7	0.52	M to H; L to M	At least 4 feet of clean sand, silty sand in top 2 ft
25	3	4.5	6	0.17	L to M	Clean sediments but too fine
26	5	3.5	5	0.23	L to M	Five feet of clean sand
27	5	4	8	0.37	L to M	Eight feet of clean sand, fining upward
28	4	6	6	0.19	L to M; M to H	Somewhat finer-grained than neighbors
29	5	3	5	0.29	M; M to H	Four and one-half feet of clean sand
30	2	2	2	0.41	M to H	Missed the top of the ridge
31	3	3.5	3	0.28	M	Missed the top of the ridge
32	3	3	3	0.22	H	Limited penetration, high turbidity
33	3	4	4	0.19	M to H	Fine sand, M to H turbidity levels
34	1	1	0	—	—	Trough before reef gave a “false-ridge” impression
35	1	3	3	0.16	H	Fine sediments, high turbidity, limited thickness
36	1	2	2	0.22	H	Limited thickness, high turbidity
37	2	3.5	3	0.34	H	Limited thickness, high turbidity
38	2	3	5	0.2	M to H	Silty sand on top, relatively high silt %
39	3	3	4	0.54	M	Shell fragments, 3 ft of clean sand
40	3	3	3	0.6	H	High turbidity, limited thickness
41	1	1	2	0.19	H	Trough after outcrop, limited thickness and silty sediments
42	3	3	4	0.6	M to H	Limited thickness, shell fragments, 1 ft layer of rubble 3 to 4′
43	4	2.5	5	0.57	L to M	One foot of rubble from 4 to 5
44	5	3.5	6	0.5	M	Five and one-half feet of coarse gray sand
45	2	3	2	0.22	L to M	Missed depositional area
46	5	3.5	11	0.25	M	Homogeneous sediment distribution
47	4	N/Av	14	0.17	L	Coarsening upward
48	2	N/Av	15	0.13	L	Sediments <0.15, but coarsening upwards and low turbidity
49	2	N/Av	15	0.13	L	Sediments <0.15, but coarsening upwards and low turbidity
50	2	N/Av	15	0.15	L	Sediments <0.15, but coarsening upwards and low turbidity

Table lists major criteria that are useful for the interpretation of sand deposits. Information that is summarized in tubular form assists in the identification of materials that are suitable for beach replenishment.

[a] Buffers divide jet-probed sedimentary deposit thickness into four categories based on sand quality and dredging capabilities, as follows: (1) Unsuitable: Deposit is less than 0.5 m thick, or mean grain size <0.17 mm, or there are high levels of turbidity during jet probing. (2) Marginally useful: Deposit is less than 1 m thick, or mean grain size is <0.2 mm, or the deposit is thicker with larger grain sizes but there is high turbidity, or the presence of silty sands or rubble layers. (3) Conditionally usable: Deposit thickness is between 0.5 and 1 m with relatively good quality sediments containing a mean grain size greater than 0.2 mm, but there are limiting factors such as limited thickness of sand bodies, or high turbidity levels, or good penetration but sediments analyzed <0.2 mm but visual description on other layers was >0.2 mm mean diameter of sand grains. (4) Potentially useful: Deposits thicker than 1 m but less than 1.5 m and sand grain sizes are between 0.2 and 0.25 mm; there is moderate to low turbidity. (5) High potential for use: Deposit is more than 1.5 m thick and sand grain size is more than 0.25 mm, there is moderate to low turbidity.

[b] N/Av = not available.

[c] The terms low, medium, and high are relative estimates of silt content based on visual interpolation of turbidity plumes.

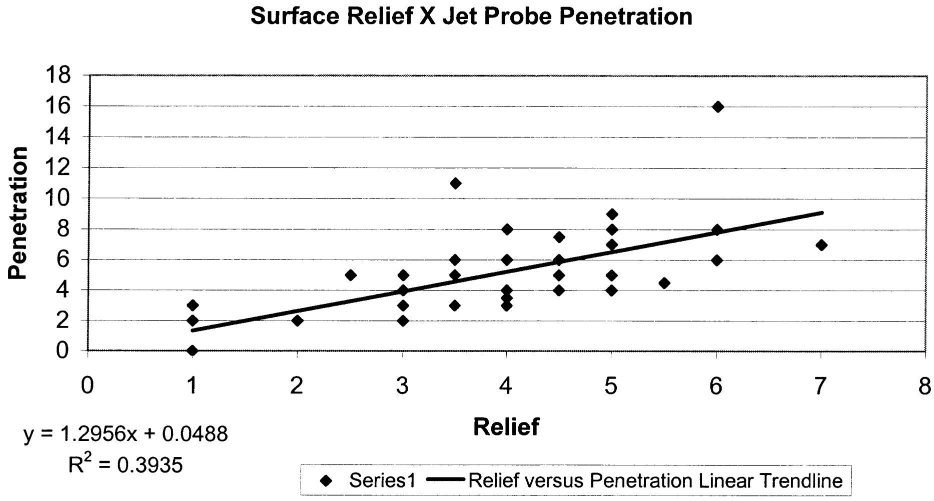

Figure J5 Linear regression analysis for a subset of jet probes collected offshore Naples, Florida, showing that jet-probe penetration increases with increasing local relief of sediments on the seafloor. The survey area included a series of sand ridges with intervening troughs. The troughs contained a thin veneer of sand (generally less than 0.5 m) over limestone bedrock whereas the sand ridges had a local relief up to at least 2.5 m (units on the graph are in feet).

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