Litoralia 1 1 65-82 New York Summer 1984

Marine Drilling Exploration

Technical and Environmental Criteria for Rig Selection

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ABSTRACT

The appropriate rig for offshore drilling is not necessarily the Glomar Challenger or the Discoverer Seven Seas, but rather the combination of equipment that best fits the budget and requirements of the project under consideration.

Four categories of drilling and sampling application are discussed: (1) engineering-geological investigations to assess the foundation conditions for large offshore structures, (2) mineral exploration to determine the economic value of potential mining deposits, (3) geological mapping of the ocean floor and (4) petroleum exploration.

Within these four major areas, variables are considered that influence the rationale for selection of a particular rig. Selection criteria include sampling, coring and dynamic testing capability, limiting target drilling depths, operating-basis environmental conditions, necessary support vessels and personnel. The tabulations, flow diagrams and discussion of this hierarchy of options are not intended to be exhaustive, but rather to assist the marine scientist in designing a structured decision analysis for selecting the most cost-effective rig for his or her project.

Key Words: Offshore Foundations, Offshore Drilling Rigs, Offshore Exploration, Offshore Mapping, Offshore Mining, Offshore Petroleum, Offshore Sampling.

Because of the broad scope of the present topic, discussion is restricted to commonly-used equipment and techniques with which the authors are familiar, and believe will become more widely used in the future. The text is further limited to rigs capable of retrieving soil samples and/or rock cores from a minimum depth of 12m beneath the sea floor. Thus the piston corer (Almagor 1982), and many other devices (Hopkins 1964) suitable for obtaining shallow-penetration samples, are excluded from the text. Also excluded are a variety of hybrid or less-frequently used diver-operated rigs such as the Wirth type underwater drill (Le Tirant 1979), submerged, remote-controlled rigs like the Maricor (Le Tirant 1979), and automatic underwater rigs such as the Seacore 50 developed by Texas A & M University (Bailey et al. 1971).

Although geophysical exploration is not

discussed, it is important to stress that offshore drilling programs are most cost-effectively planned on the basis of geophysical information. Thus the initial objective of the drilling program is generally to resolve geophysical anomalies for the purpose of interpreting these data in a meaningful geological or engineering-geological way. Furthermore, in petroleum exploration and in some cases of engineering-geological investigation, geophysical borehole logging provides additional highly valuable information pertaining to porosity, modulus of elasticity, the presence of gas and so on (e.g., LeRoy et al. 1977).

In comparing marine and land-based drilling, an attempt is made to show that the far greater costs associated with offshore drilling stem primarily from the more severe and diverse environmental conditions that must be confronted in the ocean.

To help establish a valid set of criteria for selecting the appropriate rig, drilling-program objectives are discussed as these apply to the following four main areas of application. (1) Engineering geological investigations to assess the potential foundation conditions for large proposed offshore structures such as breakwaters. Here emphasis is on delineating in considerable detail variations in the engineering behavior of materials. Detailed drilling exploration generally does not exceed 100m and seldom exceeds 350m below the sea bed. A primary concern relates to obtaining representative undisturbed samples for specialized engineering testing. (2) Mineral exploration where the main consideration is not sample disturbance, but rather one of obtaining representative bulk samples to assess the economic value of potential mining deposits. (3) Offshore geological mapping of the ocean floor. In this area drilling depth and continuity of soil samples and rock cores are generally the most important factors to ensure that time-stratigraphic changes are accurately interpreted, correlated and extrapolated over the area of investigation, and; (4) petroleum exploration. Although selective undisturbed sampling and coring often provide valuable information, a far greater proportion of relevant data is furnished by the lithological and foraminiferal identification of cuttings and down-the-hole geophysical logging.

The tabulations and decision-analysis flow diagrams presented (Figs. 1, 2, 7, and 8) are not intended to cover all contingencies, but are offered instead as a guideline for the prospective investigator faced with establishing more detailed site-specific criteria for rig selection.

The photographs (Figs. 4, 5, and 9) and case-history references quoted are drawn from the collective experience of the authors and again are not intended to be exhaustive, but rather to provide useful examples of appropriate drilling application. The overall objective of the paper is to stress that the selection of a particular rig is of critical importance, not only to the ultimate success of the overall project, but to the cost of the exploration program itself. Because of this, the selection process merits careful attention.

OFFSHORE VS. LAND-BASED DRILLING

In presenting information on offshore drilling and sampling methods, it is useful to remember that offshore techniques have evolved from those pioneered on land, and that many procedures, such as the use of casing and/or rotary wash with mud to advance holes, are similar onshore and offshore. Furthermore, since the sediment samples retrieved on land are generally taken below the water table, and in view of the fact that the excess hydrostatic pressure (pore water pressure) in offshore sediments is unaffected by the water depth of the ocean, soil sampling and rock-coring procedures on shore and offshore are similar.

However, in spite of these similarities the comparative cost of drilling offshore is most often several orders of magnitude greater than for drilling onshore. This is primarily a function of the more severe environmental constraints offshore. Mobilization costs are higher, the needs in terms of support equipment (especially vessels) and personnel are greater, and downtime, particularly delays resulting from poor weather, is higher.

Drilling Rig (length of barge or ship or ship in meters)	Common Usage	Soil Sampling Capability Undisturbed (U) Moderate-disturbance (M) Cuttings or dredged sample (D)	Rock Coring Capability Yes (Y) No (N)	Standard Penetration Test Capability Yes (Y) No (N)	Environmental Criteria Impacted Moderate levels of: WAVE	WIND	CURRENT	SEISMICITY	ICE	Operating Water Depth (m)	Practical Drilling Depth (m)	Manpower (drill and support vessel personnel)	Mobilization (moving or towing speed in knots)	Limiting Sea Conditions (waves/swell height in m)	Support Vessels
					Yes (Y) No (N)										
Barrel Float Wire-Line Sampler (5 m)	Interval soil samples in protected waters	U	N	Y	Y	Y	Y	Y	Y	3.5–6.0	20	3	2	0	Small tender (5 m)
Barge/Ship Vibratory Corer (30 m)	Rapid continuous soil sampling	M	N	N	Y	Y	Y	N	Y	2–35	12	10 for live-ashore. 16 for live-aboard.	Ship 12 Barge 5	1–5	Small ship (30 m), or barge (30 m) and tug tender (18 m)
Small Jack-up Sampler/Corer	High-quality samples	U	Y	Y	N	N	N	Y	Y	5–35	350	5 on rig (one shift) 5 on tug	4	5	Tug tender (30 m)
Small Drill Ship Dredge Sampler (50–80 m)	Bulk samples	D	N	N	Y	N	Y	N	Y	5–35	15	15	12	1.5–2	None
Small Drill Ship Sampler/Corer (50–80 m)	High-quality samples	U	Y	Y	Y	Y	Y	N	Y	5–200	450	15	12	1.5–2	None
Large drill ship Sampler/Corer (100–180 m)	Interval or continuous samples	M	Y	N	N	N	N	N	N	5–2,500	8,500	20	12	3	None

FIG. 1
Criteria Influencing Rig Selection for Geotechnical, Mineral and Geological Exploration.

Perhaps not so obvious in comparing costs is the fact that offshore rigs and support equipment are not nearly as versatile as their land-based counterparts, and that the operating cost differentials between fairly similar offshore rigs may be significant.

Therefore, in planning a drilling program in estuarine, nearshore or offshore waters, a careful assessment of the objectives of the study is critical. The selection of a rig that falls short of the technical requirements of the project must be avoided at all cost, yet careful consideration must be given to the fact that the trend of incremental cost of rigs that exceed the project requirements is exponential.

DRILLING APPLICATIONS

It may be appropriate to stress that the acquisition of field data constitutes the most important phase of any exploration program, regardless of its purpose. An accurately compiled borehole log ensures, in general, that meaningful data are interpreted and analyzed. The actual content of the field log naturally varies in accordance with the subsurface materials encountered and the purpose of the investigation.

Engineering Geological Investigation

In designing foundation investigations for marine structures, it is important to remember that (1) marine structures are most often founded on soil rather than on rock and, (2) that in addition to static analyses, the design must be based also on such dynamic forces as horizontal wave loading and wave-induced liquefaction.

Drilling exploration for offshore construction is generally undertaken for four categories of structures:

1. Piled platforms such as those used for offshore petroleum exploration/production/storage (LeTirant 1979). These require the deepest (up to 300m) site-investigation borings.
2. Modular or caisson-type concrete structures, which because of their low (spread) loading, require relatively shallow borings (less than 100m). However, because of the sensitivity of these structures to differential settlement and scour-induced bearing capacity failure, investigations need to be undertaken in considerable detail.
3. Rubble-mound structures such as breakwaters and coastal-protection works (Watson et al. 1975). These structures, although sometimes loading subsurface soils to slightly greater depths than caissons, generally require less intensive investigations, because their inherent flexibility immunizes them from catastrophic failure, and
4. Extended projects such as offshore pipe lines, transmission lines (Watson 1984), and sediment borrow investigations. Here rapid continuous samples are required for shallow (12m) stratigraphic correlation.

Selection of the appropriate rig is in part a function of the purpose of the investigation, since this in turn influences the necessary drilling depth, the length of time the rig must remain on station, and the type of sample and/or in situ tests that are required (Fig. 2). These last two considerations are the most important technical criteria influencing rig selection for offshore geotechnical investigations and are discussed further in the paragraphs that follow.

The general objectives of all sampling and testing are to: classify subsurface materials in engineering-geological terms and evaluate their engineering behavior (e.g., for foundation purposes in terms of strength, compressibility and liquefaction potential, under both static and dynamic conditions).

It is strongly recommended that the geotechnical classification of soils be based on the Unified Soil Classification System (Casagrande 1948). In using this system, visual identification is supported by laboratory index tests. Disturbed samples are sufficient for this purpose and may be conveniently furnished by the "split spoon" used in the Standard Penetration Test (Terzaghi et al. 1967). The Standard Penetration Test (SPT), in its turn, is a most useful test in that it furnishes results which may be correlated with both static (e.g., relative density of cohesionless soils, consistency of cohesive soils) and dynamic engineering behavior (e.g., liquefaction potential under seismic loading). These correlations may be found in most text books on soil mechanics (e.g., Terzaghi et al. 1967). As indicated in Figs. 1 and 2, the capability of equipment to perform the SPT is a most important criterion in the selection of a rig for foundation investigations.

A second important rig selection factor relates to the capability of retrieving "undisturbed" samples. Since tests to determine such soil properties as bearing capacity and settlement may be significantly affected by any remolding of the test specimen, it is desirable to achieve the smallest practical degree of sample disturbance.

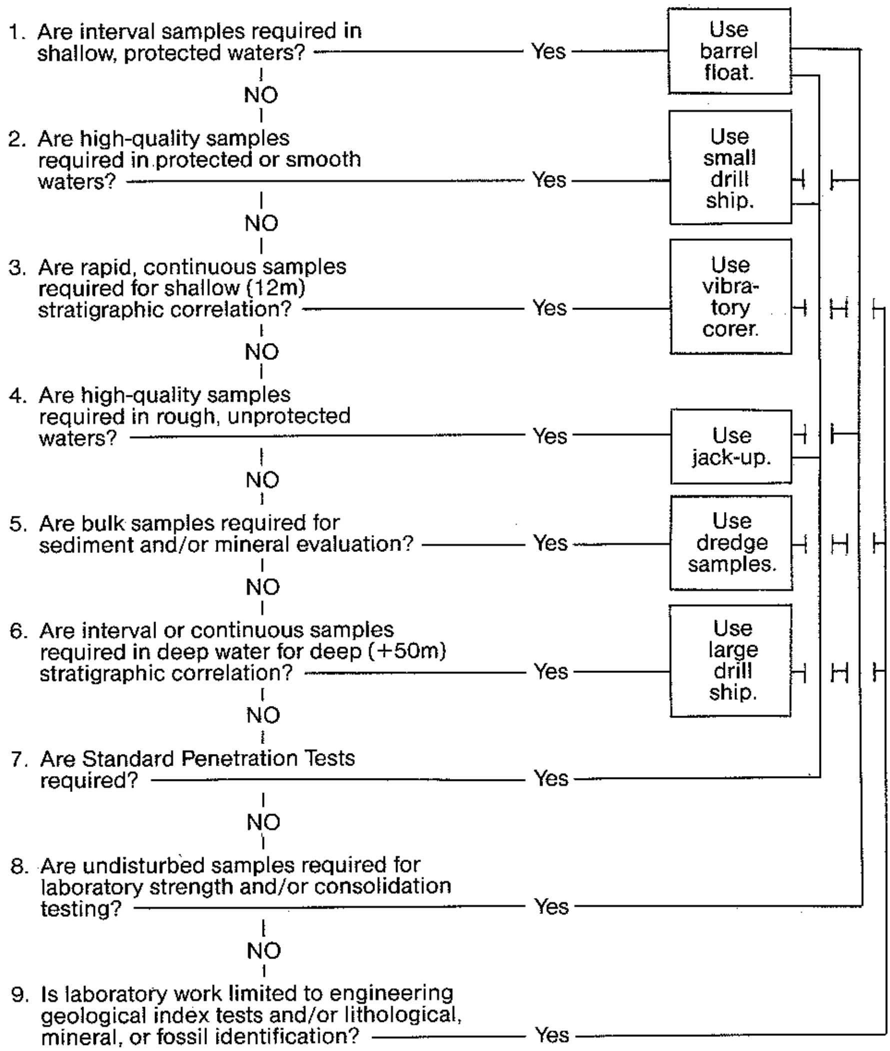

FIG. 2
Simplified Decision-Analysis Diagram for Selection of a Rig for Geotechnical, Mineral or Geological Exploration.

Sample disturbance is primarily a function of the thickness of the sampler (ratio of internal to external diameter) and the method of driving the sampler (e.g., hammer blows, hydraulic push). A thin-walled sampler pushed gently into the soil represents the ideal case. However, in materials such as very dense sands, the only procedure suitable may necessitate the use of a fairly substantial sampler such as the Dames & Moore Underwater Sampler (Fig. 3*a*). This very strong sampler must be driven by a relatively heavy hammer (300 lb., 136.1 kg). Conversely, in materials such as soft clays and peats, a thin-walled sampler (Fig. 3*b*) may be readily pushed or jacked into the soil.

Fig. 3 also illustrates two additional widely-used samplers, the Denison and the Pitcher. The Denison sampler (Fig. 3*c*) is frequently more suitable than the Dames & Moore underwater-type sampler (Fig. 3*a*) in homogeneous, hard and very stiff clays, or in very dense sands. The Denison sampler which works on the principle of the double tube rock-core barrel, has a carbide or diamond bit attached to the outer barrel and a sharp cutting edge on the inner barrel. This double-cutting action, together with the jetting assistance of drilling fluid which circulates between the inner and outer barrel, tends to minimize sample disturbance. The Pitcher sampler (Fig. 3*d*) is best suited to soils containing hard and soft layers, since a spring-loaded sample barrel adjusts automatically to the relative density or consistency of the soil. As shown in Figs. 1 and 2 and illustrated in Fig. 4, commonly-used drilling rigs capable of retrieving relatively undisturbed samples are the small jack-up sampler/corer (Fig. 4*a*), the barrel float (Fig. 4*b*) and the small drill ship sampler/corer.

The authors' experience with jackups and drill ships has been mainly with the rotary-wash method using a Failing 1500-type rig and employing samplers attached either to the drill string, or to a wire line within the drill string. This combination of equipment and technique

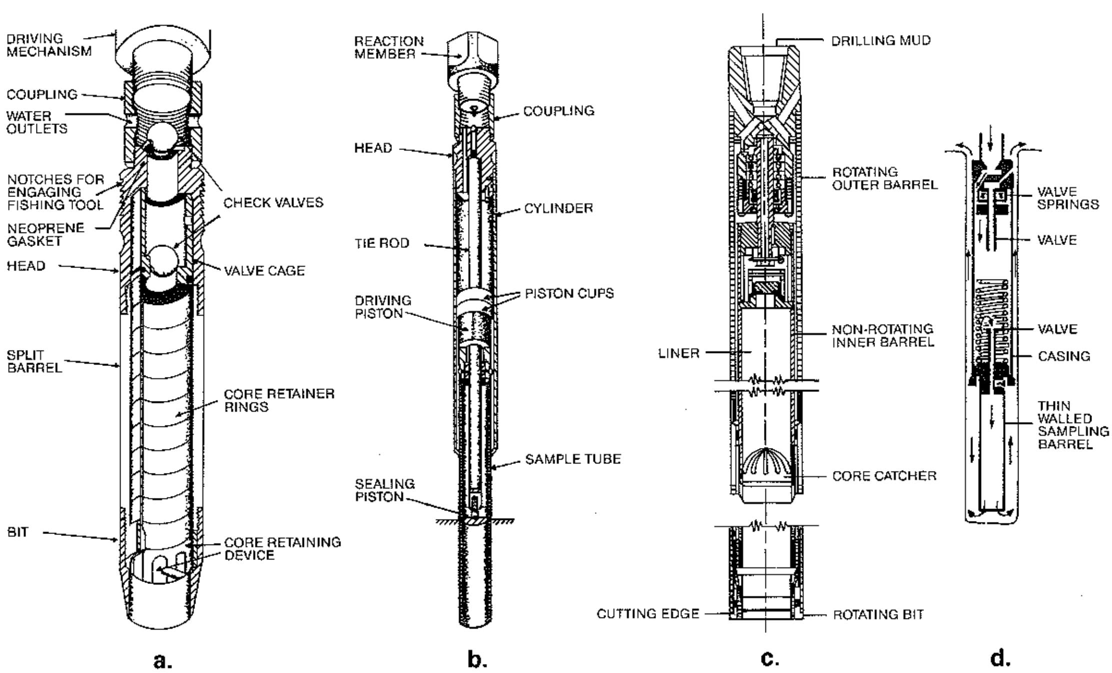

FIG. 3
Some Commonly-Used Soil Samplers.

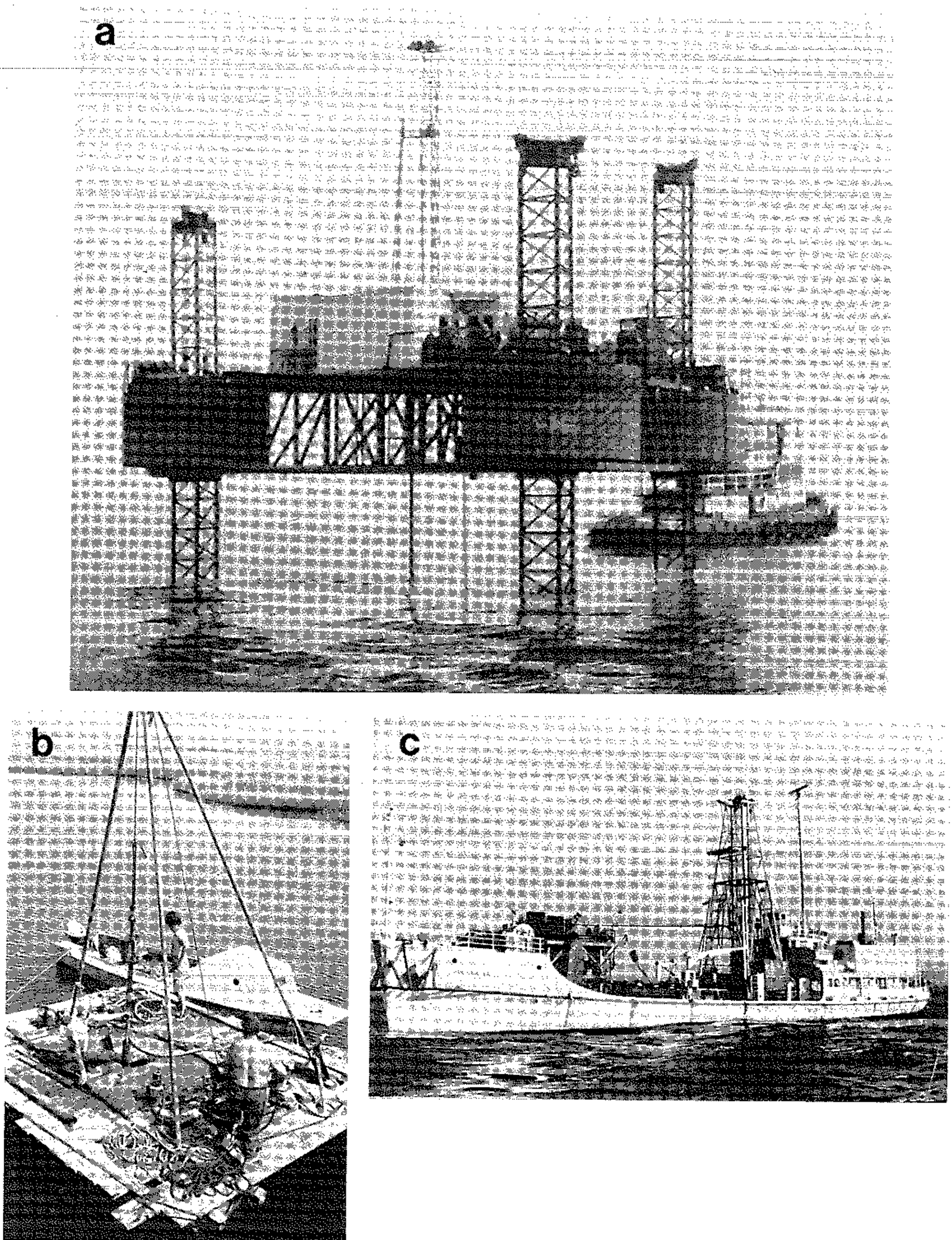

FIG. 4
Typical Rigs Used for Geotechnical and Mineral Exploration.

is recommended as the most versatile for geotechnical exploration, and has been used to sample and core almost all types of soil and rock.

As suggested in Figs. 1 and 2, the choice between jackup and drill ships is largely a function of water depth, wave height and remoteness of station.

The barrel float (Fig. 4*b*) supports a small percussion wire line rig and may be economi-

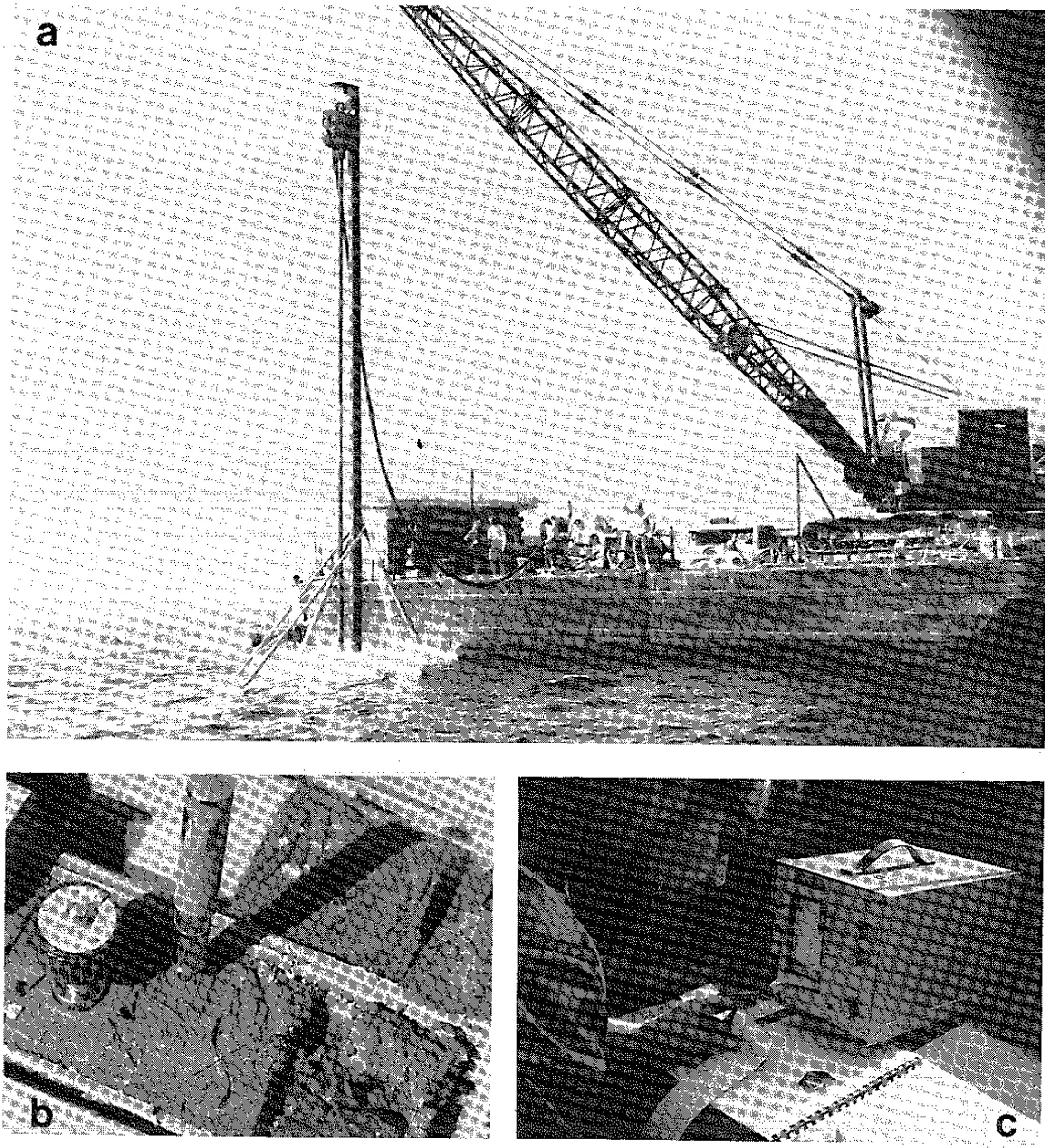

FIG. 5
The Large Vibratory Corer Provides Useful Geotechnical Data in Areas of Stratigraphic Complexity.

cally used in shallow protected water.

An additional rig which has been very usefully used by the authors is the large vibratory corer (Fig. 5*a*). This rig which may be operated either from a small ship (30m) or barge (Fig. 1) provides large continuous samples that are essential for mapping areas of stratigraphic complexity. Such samples facilitate ready visual identification and engineering index testing (Fig. 5*b*). These data set the basis for the economical planning of a more sophisticated follow-up program. The closing paragraphs of this subsection relate to the vibratory corer.

The principal disadvantage of the system is that the vibrating motion and long drive cause the sample to be disturbed to some extent (Fig. 1). Loose sands tend to consolidate, in which case less than 100 percent recovery may be achieved. On the other hand, dense sands may dilate with consequent bulking of the sample. Clays also compress and expand according to their mineralogy and depositional history. The common problem of retaining "running sands" also applies to this system. Dense sands or coarse granular materials also occasionally block the sampler, thus impeding advance. In order to obtain satisfactory results, therefore, stringent geotechnical control is required during the coring operation (Watson 1984).

An important aspect of performing efficient core logging is provided by penetration rates. The number of seconds per foot (30.48cm) of advance should be recorded during borings (Fig. 5*c*) and noted on logs. In instances of substantial bulking or compaction of samples, changes in penetration rates assist in establishing the thickness of lithologic horizons.

Only a coring unit designed to enable successive coring runs to be made from predetermined depths should be used. This may be achieved by hydrojetting the corer to a desired depth prior to sampling.

As indicated in Fig. 1, the maximum practical depth of penetration for the type of vibratory corer discussed is about 12m. Although in theory the rig may be used in very deep water, in practice the working depth is controlled by the support equipment used to handle bulky air hose and water-jetting lines. Again, as shown in Fig. 1, this is generally less than 35m.

Mineral Exploration Investigations

To date, successful large-scale offshore mining ventures have been confined to placer deposits of marine diamonds off the coast of South West Africa (Namibia) and the longstanding recovery of offshore tin in Southeast Asia. Other economically viable placers that may be mined in the future include those of gold and platinum off the coast of Alaska (Friedrich 1982), tin off the coast of Cornwall in England, and heavy minerals such as garnet, zircon, rutile, and ilmenite off the east and west coasts of Australia and the east coast of South Africa (fossil beach-dune deposits have been economically mined). The commercial extraction of salt, magnesium, and bromine from sea water (Barton 1977) is not regarded as offshore mining in the present context, and the much-written-about manganese nodule (e.g., Barton 1977) cannot be cost-effectively recovered at the present time.

Thus, the present discussion on suitable rigs for exploration is restricted to placer deposits, and to the similar but less rigorous investigations required for locating potential offshore sources of sand and gravel used for construction fill, concrete aggregate, and beach-nourishment.

Several years of experience were gained on the Namibian marine diamond project and that venture furnishes the case history for the text in this subsection.

Offshore placers may be described in general as accumulations of heavy minerals concentrated within marine sediments by the mechanical action of waves and currents. In Namibia concentration was found to be controlled to a large degree by the underlying bedrock topography; high-grade deposits were often associated with fairly small-scale depressions such as discontinuity-controlled gullies. Thus drilling and sampling-based prospecting had to be carefully supported by, (1) the mapping of bedrock exposed along the shoreline to establish the pattern of discontinuities (joints, faults, fractures), and (2) by high-resolution continuous seismic reflection surveys to map both the thickness of sediment and the elevation trend of the bedrock surface.

Trial-and-error prospecting showed that to reliably locate and evaluate deposits, bulk samples were necessary. Vibratory-cored samples, considered large by engineering standards, were found to be inadequate, and the most suitable rig evolved in the shape of the small drill ship (Fig. 1) illustrated in Fig. 4*c*. This rig, equipped with a 3-m telescoping ocean swell compensator on the drill string, achieves penetration by an oscillatory (rather than continuous rotary) action, combined with water jetting which "loosens" subbottom sediments for air-lifting through the center of the drill string (15-cm diameter), to the processing plant aboard the vessel. Since a typical exploratory excavation in a sediment thickness of 5m yields a sample on the order of 6 cubic meters, the need for a processing plant aboard the vessel is essential for many reasons. These include: the difficulty of storing large, individual samples on board, the remote setting of prospecting areas away from sample-transshipping ports, and the harsh environment in terms of both steady-state and storm waves causing excessive downtime; diamond-count results and/or concentrate evaluations in the field ensure more efficient day-to-day planning of the prospecting cruise.

Suitable processing equipment consists of scalping and washing screens to isolate the required pay size and heavy-media cyclones and/or bobbin jigs to retrieve heavy minerals. Diamonds are taken from the concentrate by hand sorting. Prior to the use of the small drill ship dredge sampler, a converted tug employing a 15-cm diameter flexible hose off the side of the vessel was used to obtain an air-lifted sample. Again, sampled material was processed aboard. The latter procedure results in a trench rather than a conical excavation and, although successful in retrieving diamonds, is extremely tedious and slow, amounting to small-scale mining rather than prospecting. It has the advantage, however, of being a jury rig which may be cost-effectively used in the feasibility stage of exploration.

The dredge sampler may also be used to evaluate sand and gravel deposits (Fig. 2), particularly where dredged materials are to be used as fill, and where a large representative sample is important for assessing the gradation and compaction characteristics of the material. The evaluation of potential fill deposits containing predominately sand-sized material may be usefully supplemented by taking vibratory-cored samples.

Geological Mapping

Drilling to facilitate offshore geological mapping relates, in the present context, to the type of program embraced by the Deep Sea Drilling Project. This project, which frequently calls for deep coring (+ 1000 m beneath the sea) in water depths of more than 4,000 m in such remote places as the Philippine Sea (Ingle et al. 1975), required the construction of a large, specially-designed drill ship—the Glomar Challenger (Fig. 6). Earlier drillships, like many of the smaller rigs used today for geotechnical exploration, were converted vessels of one type or another.

The main objectives of large-scale, geologically-oriented drilling exploration are: (1) to establish the time-stratigraphic/lithologic relationship of ocean-floor sediments and rocks and (2) to interpret the formational evolution of the exploration area, particularly with respect to plate-tectonic origin. The latter objective can only be met by integrating a host of relevant information including, for example, bio-stratigraphic evidence relating to paleo-oceanographic and paleoclimatic history, structural features pertaining to deformational characteristics, igneous petrology, paleomagnetic anomalies, etc.

With the successful completion of 96 scientific cruises, the commissioning of the Glomar Challenger represents an important technological milestone in meeting such demanding geological objectives. She and larger and more recent drillships are the most versatile of rigs, capable, as inferred, of drilling to considerable depths in a wide range of ocean soundings, self-contained and sufficiently seaworthy to voyage to the most remote locations and hold station in relatively severe weather conditions (Fig. 1).

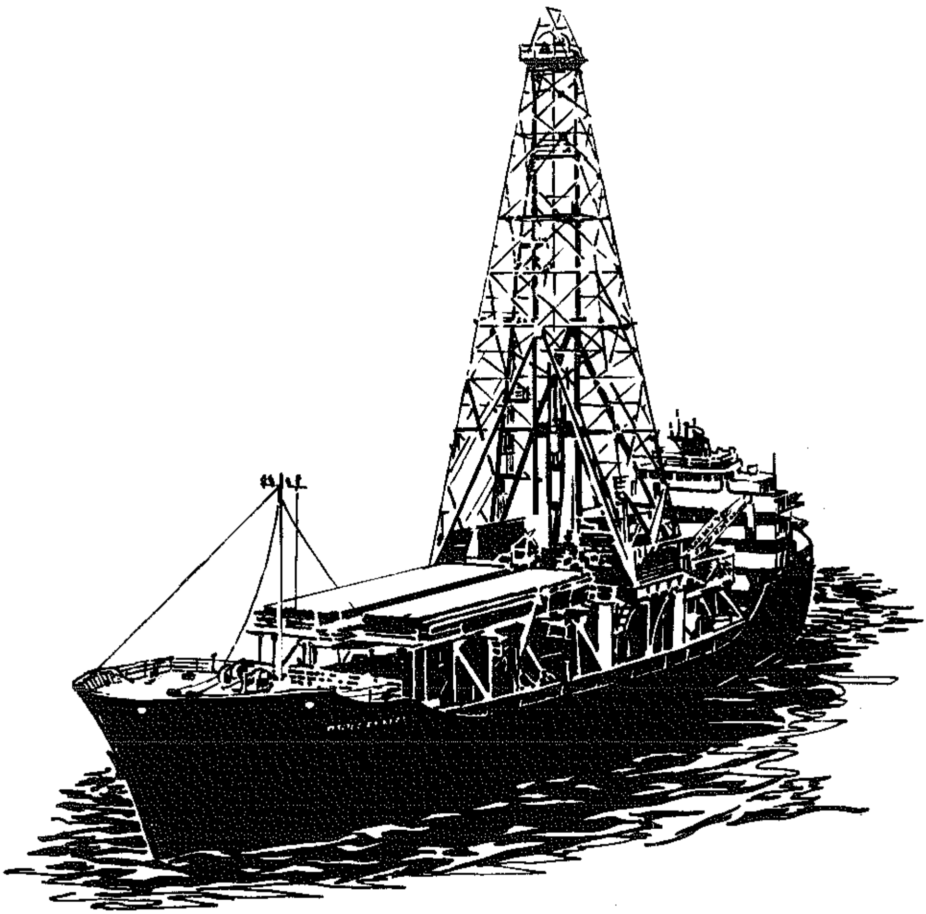

FIG. 6
The Glomar Challenger, a Milestone in Design for Geological Exploration.

With regard to drilling, the principle advantage of the Glomar Challenger design lies in a rig which combines rotary drilling with wire line sampling. This enables long samples (9.28m) to be retrieved in a very rapid manner. Like vibratory-core samples, these are conveniently retained in a plastic liner inside the core barrel. The liner is retrieved in one piece on deck, and sections of sample and liner may be cut out and sealed for detailed analysis ashore (e.g., organic geochemical analysis, triaxial strength testing). The remaining liner and sediment are split longitudinally. Representative samples of the working half are taken for still further laboratory analysis (e.g., mass spectrograph, x-ray mineralogy) and the remaining materials are logged in terms of both a sedimentological classification and paleontological age dating. In addition, the working sample is subjected to a comprehensive bank of index tests including sheer strength (Fig. 5*b*) bulk density, sonic velocity and thermal conductivity. Field logging is supplemented by shipboard observations of smear slides made under a petrographic microscope. The "archive" half of the sample is photographed. Finally, following field processing, both halves are held in cold storage aboard the ship.

An inherent disadvantage of the Glomar Challenger is that, like any other floating vessel, it develops a large heave response to swell (compared to the semisubmersible). Thus, although the dynamic positioning equipment may continue to hold the vessel on station, drilling may have to be halted when the heave approaches the compensation limit of the bumper-sub system (4.6m). Furthermore, despite the design merits of the drilling and sampling system in terms of speed and the length of the sampling barrel, an unfortunate trade-off relates to sample disturbance associated with the long drive. This disturbance ranges from relatively minor, in response to the frictional contact of the sample with the liner, to total liquefaction of a sensitive horizon. The latter condition is considered to be most often caused by the pounding of the drill string in swell. In addition, logging difficulties similar to those noted with the vibratory coring rig apply to this system (i.e., samples tend to consolidate or dilate and it is difficult to reconstruct from where exactly in the boreholes the sample was retrieved). Again, as with the help of penetration rates in logging vibracores, drilling characteristics (i.e., torque applied to the top of the drill string, weight on the bit, rate of advancement) are recorded and assist in logging these cores. This assistance is critical in the case of a design like that of the Glomar Challenger, since unlike most oil rigs, wash circulation down the hole is open ended, and no drilling cuttings are retrieved for identification.

On the question of sample disturbance, it may be interesting to note that a new hydraulic piston coring device was tested on Leg 64 of the Deep Sea Drilling Project and was successful in retrieving relatively undisturbed samples (Storms et al. 1983).

Finally, it is stressed that although the station keeping of large dynamically-positioned drill ships is not impacted by moderate levels of current velocity (Fig. 1), where surface velocities reach or exceed four knots, a number of special design modifications need to be taken into account (Gardner et al. 1982).

Petroleum Exploration

The broad-based objectives of the offshore drilling-exploration program are to address the basic geological criteria necessary for petroleum to occur. These include the presence of a favorable source rock, the potential for hydrocarbon migration into a suitable reservoir, and the existence of three-dimensional structural, strati-structural, or stratigraphic entrapment conditions.

In most instances of petroleum exploration, however, drilling is undertaken adjacent to producing fields or in areas where at least some knowledge exists about the stratigraphy and structural style of the region. Furthermore, exploration wells are seldom sited without considerable prior geophysical investigations. Thus, while some stratigraphic exploration wells are drilled which approach the intensity of geological observations described in the previous subsection, most wildcat and confirmation well logging relies almost exclusively on the lithological and paleontological identification of wash cuttings, supplemented by mudlogging-hydrocarbon detection, and down-the-hole geophysical data. Conventional soil samples or rock cores and/or side-wall ram samples are taken generally only in anticipated production zones.

In the Gulf of Mexico, an area where the authors have offshore field experience, the exploration objective is frequently restricted to sedimentological correlation to facilitate the extrapolation of a known producer. For example, the Frio Formation of Oligocene-Miocene age on the Texas Gulf Coastal Plain contains major hydrocarbon-producing plays and has already yielded nearly 6 billion bbl of oil and 60 tcf of gas (Galloway et al. 1982). Thus drilling to extrapolate the identification characteristics of this formation to new lease areas would constitute a most important exploration target.

Commonly-used drilling rigs available for offshore petroleum exploration are listed in Fig. 7. It may be noted that directional exploration wells are also drilled from production rigs (Fig. 9*a*) but these are not considered to fall into the present classification of exploration rigs and are therefore excluded from the tabulation (Fig. 7).

In examining the data in Fig. 7, it is apparent that the selection of a particular rig is in large measure a function of the water depth at the site. However, the choice depends also to a

Exploraatory Drilling Rigs	Usage	Foundation Data Required Yes (Y) No (N)	Working Water Depth (m)	Rated Drilling Depth (m)	Environmental Criteria* Yes (Y) No (N): WAVE	WIND	CURRENT	SEISMICITY	ICE	Limiting Sea Conditions (Wave-swell height in m)	Mobilization Towed (T) Self-Propelled (S) (speed in knots)	Support Vessels	Manpower (Drilling Rig)	Diver Supported Yes (Y) No (N)	Motion Compensation (Need for) Yes (Y) No (N)	Station Keeping
Drill Barge	Estuarine and Nearshore	N	2–35	800	Y	Y	Y	Y	N	3	T (4)	Work Boat (1)	20-30	N	N	Seafloor and anchor
Sub-mersible	Estuarine and Nearshore	N	2–10	10,000	Y	N	N	Y	Y	4	T (5)	Work Boat (1)	20–40	N	N	Seafloor
Jackup (Matted)	Nearshore to Offshore	N	17–150	10,000	N	N	N	Y	Y	5	T (4)	Work Boat (1) Crew Boat (1) Heli-copter (1)	40–80	N	N	Seafloor through mat
Jackup (Spud Can)	Nearshore to Offshore	Y	17–150	10,000	N	N	N	Y	Y	5	T (9)	Work Boat (1) Crew Boat (1) Heli-copter (1)	40–80	N	N	Seafloor through legs
Semisub-mersible	Offshore	N	234–1,500	10,000	N	N	N	Y	N	5	T:S. (9)	Work Boat (2) Crew Boat (1) Heli-copter (1)	60–140	Y	Y	Dynamic Position-ing and anchoring
Drill Ship	Offshore	N	100–2,500	8,400	N	N	N	N	N	5	S (14)	Work Boat (2) Crew Boat (1) Heli-copter (1)	60–140	Y	Y	Dynamic Position-ing and anchoring

**Is drilling operation adversely affected by moderate levels of . . . . Yes (Y) No (N).*

FIG. 7

Criteria Influencing Rig Selection for Petroleum Exploration.

large extent on environmental criteria, including projected wave, wind, current, ice and seismic conditions. Thus, exploration in the North Sea (Bruun 1976) poses environmental constraints that significantly change the range of rigs that might be considered, for example, in the Gulf of Mexico.

Fig. 8 provides a simple example of the format for a rig-selection analysis. It is emphasized, however, that an actual decision analysis would almost inevitably need to be case-specific. For example, although it may be inferred from Fig. 8 that a matted-leg jackup is a viable rig for an offshore site exposed to hazardous wave and wind conditions and showing relatively poor foundation materials, the actual choice of the rig may be premised on as simple a factor as a tight deadline for the completion of a drilling program. Once on site the jackup (Fig. 9*b*) can continue to work throughout relatively severe storm conditions. It would have to be borne in mind, nevertheless, that

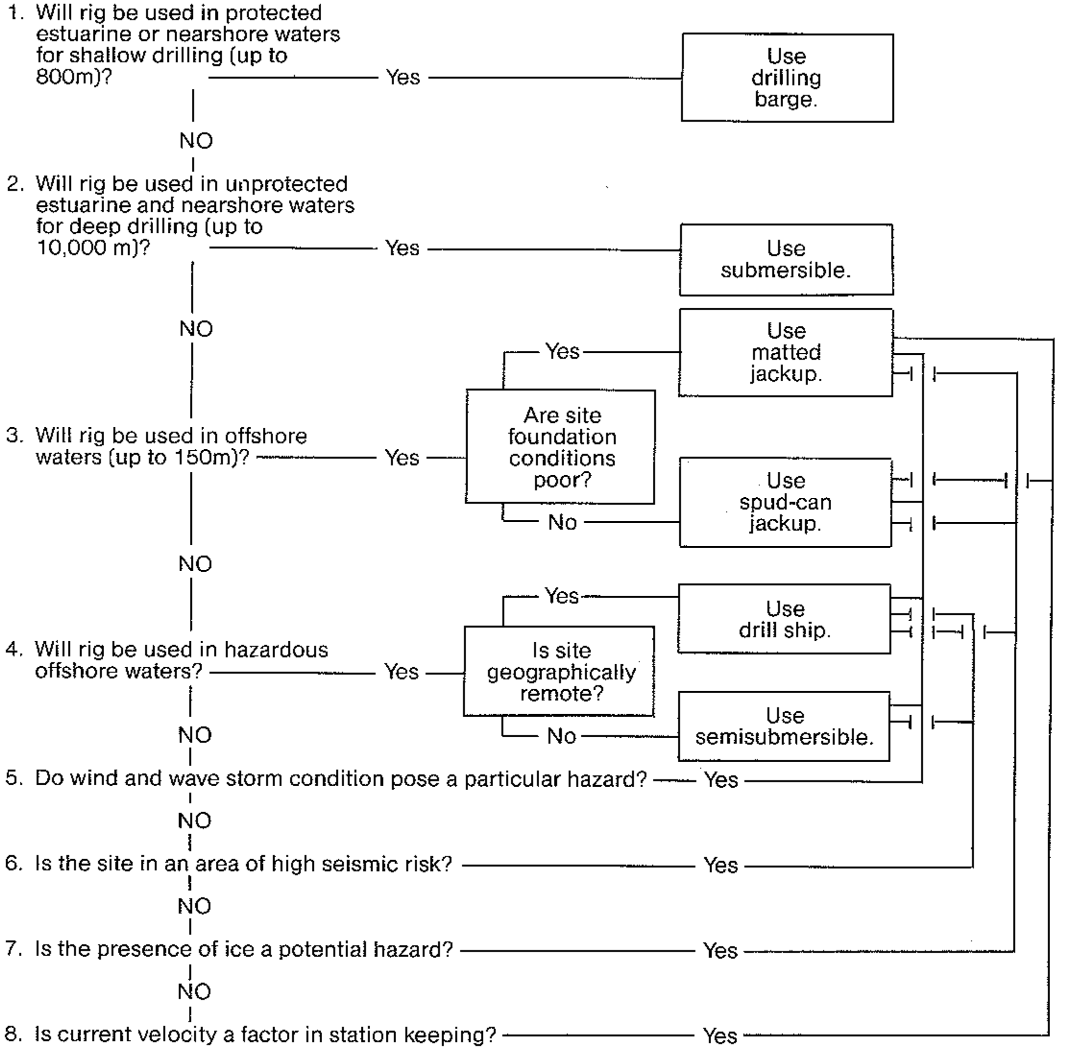

FIG. 8

Simplified Decision-Analysis Diagram for Selection of a Rig for Petroleum Exploration.

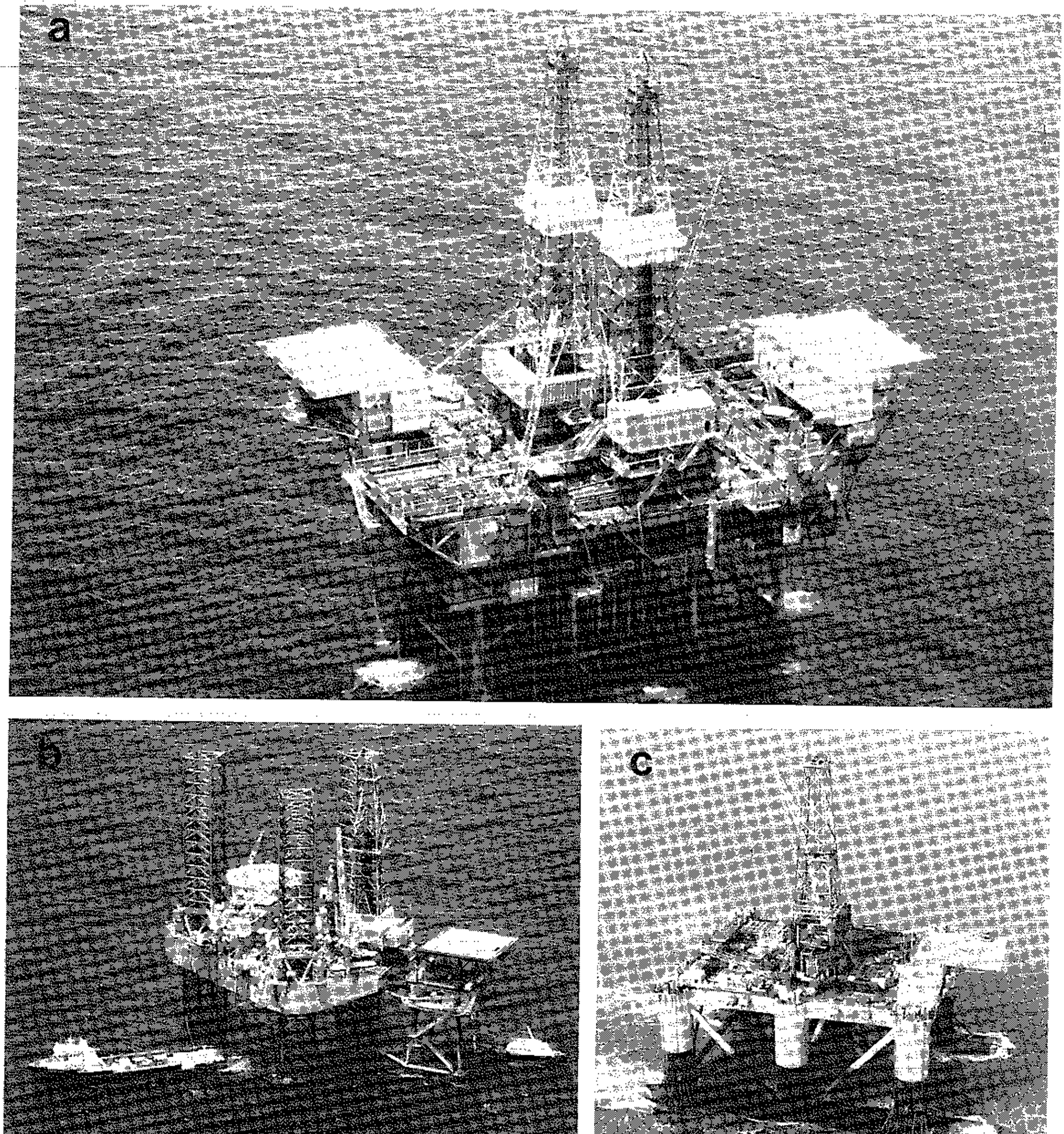

FIG. 9
Typical Rigs Used for Petroleum Exploration and Production/Exploration.

jackups are associated with more accidents than other exploration rigs (McTaggart 1976). Thus, the trade-off in choosing between a jackup and a semisubmersible (Fig. 9*c*) might hinge on just how poor the foundation conditions are judged to be.

Other less-subtle factors may, naturally, also play a big part in rig selection. The simple question of rig availability is often a critical issue, both in terms of potential costs associated with mobilization delay and mobilization distance. In the case of remote stations, discussion in the previous subsection relative to the versatility of drill ships, applies equally here. Innovative ideas in transport, however, do create viable options. For example, the semisubmersible High Seas Driller was recently transported a distance of more than 20,000 Km aboard the deck of a cargo ship at the average speed of approximately 13.5 knots (Ocean Industry 1983).

In extreme environmental conditions, such as those experienced on the Alaskan OCS, the investigator may expect ice of up to 2m thickness to persist from October to May in some areas, water depths in certain leases to reach almost 200m, storm (100-year) waves on the order of 33m, currents of up to 5 knots, tidal ranges in open water of up to 9m and ocean-floor sediments that pose severe problems in terms of earthquake-induced liquefaction. In such areas recent work in predicting environmental constraints (e.g., Hayes et al. 1983; Wang Qin-jian 1983; Shibata et al. 1983; Kopaigorodsky et al. 1983) and the rig designs based on such predictions (e.g., Bruce et al. 1982; Houmb et al. 1983; Boaz et al. 1981; Croasdale 1983) represent the state of the art of petroleum-related exploration.

Drill ships will certainly play a major exploration role in the Arctic environment. For example, the Kulluk, which is designed to operate in ice more than a meter thick, was recently commissioned for petroleum exploration in the Beaufort Sea (Buslov et al. 1983). Even in extreme environments, however, the drillship is far from the only option. The world's first harsh-environment jackup is presently under construction in Texas (Ocean Industry 1983).

With regard to the use of production-exploration rigs in Arctic conditions, the artificial island concept has been successfully used for a number of years in the Canadian Beaufort Sea (e.g., Galloway et al. 1982; Offshore 1984) and the first tension leg platform (TLP), another viable alternative for the harsh environment, will commence operations late in 1984 in the North Sea.

CONCLUSION

An attempt has been made to show that regardless of the application of drilling exploration, rig selection must be based on a careful, integrated analysis of both the particular objectives of the investigation and the environmental constraints of the proposed working location. Cost savings may be realized by selecting drilling, sampling and support equipment that are neither underdesigned nor overdesigned for the project in mind.

ACKNOWLEDGMENTS *The authors acknowledge the help of their colleagues at Florida Atlantic University, in particular, Dr. Roy R. Lemon, Dr. David L. Warburton, Dr. Charles W. Finkl, Jr., and Mrs. C. N. Mischler. Also Rio Tinto-Zinc, Amoco, Dames & Moore, the Anglo American Corporation, the Marine Diamond Corporation, and the Coastal Education and Research Foundation (CERF). Many of the facts published were gathered in employment with, or as a result of, research support by these institutions.*

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