What is Geophysics?

- Horizontal loop electromagnetic apparatus is used to locate conductive zones that may be leachate plumes.

- Data from a grid of ground penetrating radar stations is displayed in a cube. The horizontal slices indicate possible fractures in limestone bedrock.

- The sledge hammer provides a source of energy for determination of the depth to water table and bedrock.
The guiding principles of the geophysical method are based on the laws of physics that deal with gravity, electricity, magnetism, and mechanics. Geophysical tools use sensors that are reactive to one of the above physical properties. These sensors act in either a passive or active mode to measure subsurface properties within a given survey area. For instance, seismic and electrical methods are active methods that transmit energy and measure the response of the earth to this transmission. The response of the geophysical sensors is used to determine information on subsurface conditions. Although guided by principles of physics, the realities of site conditions and subsurface complexities necessitate practical approaches to survey design and interpretation. For this reason, a combination of geophysical methods are often used to provide flexibility in the field survey and to help resolve any ambiguities which might arise if only one method was applied.

The balance of this article will acquaint the reader with the use of offshore geophysics. There are any number of projects that could benefit from the use of offshore geophysical investigations, including the evaluation of routes for undersea cables, pipelines, and outfalls; the evaluation of scour around bridge piers and marine pipelines; geologic hazard surveys to evaluate seabed conditions for siting offshore platforms; the design of marine terminals and coastal facilities; or mapping fishery habitats and the distribution of shallow-water macrofauna.

Offshore geophysics provides a practical solution to these common situations. Although offshore geophysics requires a significant capital investment, the rate of data acquisition and survey coverage possible make it cost effective compared to an offshore drilling program that would attempt to obtain the same coverage.

Marine geophysical techniques were used recently on a project in Alaska, where geophysicists were tasked with the evaluation of several routes for a proposed marine high-voltage power cable crossing (see Photo 1). The primary objectives of this survey were to determine the depth to bedrock and identify areas of boulders, both surface and subsurface, that might impact the trenching or directional drilling operations for the cable installation. The tidal exchange in the area is 20 to 25 feet; therefore, in a time frame of less than six hours, the bay could go from mud flats to 25 feet deep in seawater. Because of this extreme tidal and associated current conditions, the traditional method of drilling along proposed routes would not have met the schedule or budget constraints. It would have been too difficult and uneconomical to obtain the necessary subsurface information with any type of barge-mounted drilling platform. The use of marine geophysics to map the surface and subsurface sediments and geology along the five proposed routes resulted in a significant cost savings to the client.

Another example involves a recently completed marine survey off the Island of Rota in the Northern Mariana Islands. The object of this search was the Santa Margarita, a Spanish galleon that sank in 1601. Recently acquired evidence located offshore and pieces of broken porcelain found in the beach sands were evidence that the approximate location of the wreckage had been identified. A detailed survey, using marine geophysical techniques including sub-bottom profiling, magnetometry and electromagnetics, identified a number of targets in the area of interest that are now in the process of being excavated with hydraulic dredges.

Depending on the scale and location of the investigation, offshore surveys can be conducted from vessels that range in size from rubber rafts to large research vessels. Offshore geophysical data are obtained with a suite of instruments (see Fig. 1) that can be run simultaneously as the survey vessel traverses the trackline at four to five miles per hour.

The echo sounder is a sonar devise that uses a high-frequency, narrow-beam acoustic pulse to obtain detailed water depth information for mapping the topography of the seabed. Subbottom profiling and seismic reflection are also sonar devices, but they use more energy and lower frequencies than the echo sounder. These two methods are used to obtain subsurface information such as the depth to bedrock, to measure the thickness of a surface layer of silt, or to identify areas of buried boulders. The information from these sonar systems assists in the selection of pipeline and cable routes; in identifying areas of submarine slides; in calculating quantities of dredged materials; in identifying shoal areas that are hazardous to navigation; or to assist in evaluating routes for directional drilling.

Another highly-effective method geophysicists employ in their offshore geophysical investigations is the use of side-scan sonar. Side-scan sonar provides information about the surface characteristics of the sea floor both below and to either side of the survey vessel. Targets or objects that have relief above the sea floor, such as boulders, sand waves, sunken ships, pipelines, or miscellaneous debris, usually appear as a strong reflector with a noticeable shadow. It is possible to calculate the height of the object above the sea floor based on the length of the shadow. Golder Associates, Atlanta, recently applied the side-scan sonar method off the shore of Narragansett, R.I., where in January 1996, heating fuel oil was discharged from a barge that went aground on a shoal. This spill happened in an area of unknown size and affected the associated crab and lobster habi-

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**Figure 1.** At left is a summary of marine geophysical techniques used to map sediments on and beneath the sea floor. This illustration clearly demonstrates the complexity of the geophysical techniques available for offshore investigations.
Terrestrial geophysical techniques offer an efficient, cost-effective investigative method

Just as offshore geophysics provide an efficient and cost-effective method for surveys on rivers, lakes, and marine environments, terrestrial geophysical methods allow for the rapid assessment of site conditions using non-invasive remote sensing techniques. These techniques are more cost-effective to use than conventional subsurface exploration methods.

Terrestrial geophysical surveys are used to:
- Find buried objects;
- Map subsurface sediments, bedrock, and groundwater;
- Locate areas of contaminated sediments and leachate plumes;
- Identify and map fracture zones, cavities, and voids; and
- Determine the engineering properties of soils and rock.

One of the most common techniques used for engineering geophysical investigations is ground-penetrating radar, a remote-sensing, non-intrusive survey system used for mapping subsurface soils, groundwater, and geological features, and for locating buried objects such as tanks, pipes, and utilities. The ground-penetrating radar system consists of an antenna, a processing console, a graphic display recorder, and an optional magnetic recorder. During a survey, the antenna, which is connected to the console by a 200-foot cable, is pulled along a selected route or survey trackline. As the antenna is being moved, it transmits and then receives radar impulses that have reflected from subsurface soil horizons, interfaces, or individual objects. The reflected pulses are processed and sent to a display recorder. The displayed data represent a continuous profile or cross-section of the subsurface conditions along the survey trackline.

This technique was used to locate unmarked burial caskets at a remote location in Alaska, where annual flooding was threatening to destroy a 90-year-old cemetery. Engineers feared that the spring floods would wash out graves and sweep coffins into the river. The setting was the village of Noatak, home to about 300 Eskimos. Citizens of the village of Noatak had two choices: spend seven million dollars to stabilize the river bank or move the coffins and establish another cemetery.

Eventually, villagers agreed to move the cemetery. However, because of the sanctity of the cemetery grounds, the move was conditional in that heavy machinery could not be used in any manner on the sacred ground of the cemetery. At the time, this included moving four feet of snow, which ultimately was removed by hand.

Each of the graves, many of which were unmarked, had to be located. This was accomplished using ground-penetrating radar. As explained earlier, this non-intrusive surveying system sends pulses into the ground that reflect off of subsurface features. In this case, the ground-penetrating radar pulses struck coffins and reflected back their images. Using this technique, more than 150 coffins were found, many of which were encased in ice. Workers in protective clothing manually lifted the caskets from the graves and relocated them to another site. The use of ground-penetrating radar to locate the graves eliminated the need to spend millions of dollars to stabilize the river bank and met the needs of the villagers by avoiding the desecration of sacred ground with the use of heavy machinery.

In addition to ground-penetrating radar, other terrestrial geophysical methods include:
- Magnetic surveys, which are commonly used to map regional geologic structures, to explore for economic mineral deposits, and to locate buried metallic objects. This technique makes it possible to observe small magnetic disturbances, associated either with small objects or deeply buried objects, that might otherwise be masked by the earth's relatively large magnetic field.
- Seismic refraction, which is used for subsurface mapping of structures or features such as fault zones, buried channels, weathered rock, and depth to bedrock. This technique is commonly used for engineering projects, groundwater investigations, hazardous waste site studies, and mining projects. The energy source used for seismic refraction work depends on the depth of the materials you are seeking and the properties of the near-surface materials. Explosives, mechanical vibrators, and mechanical impact are traditional energy sources.
- Electromagnetic techniques, which are conducted to map lateral variations in soil types; provide information on changes in overburden thickness; identify zones of localized contaminants; map inorganic contaminant plumes in groundwater; map buried metallic debris and utilities; and map subsurface ice lenses, thaw bulbs and permafrost. Conventional electromagnetic systems can explore depths ranging from 18 to 90 feet. Another, highly-powered transient electromagnetic system, called time-domain electromagnetic, is capable of defining the electrical properties of soil and rock to depths of 10,000 feet.

Whether using ground-penetrating radar, magnetic surveys, seismic refraction, or electromagnetic techniques, geophysical surveys provide a much greater density of measurements than is economically feasible using conventional subsurface exploration methods.

— Robert Anderson
tats. There was potential for harm to both the environment and the economy. Geophysicists obtained side-scan sonar data on a five-square-mile area of the shallow offshore area and produced a detailed map that identified all major lithologic units and possible crab and lobster habitats. The side-scan sonar data underwent preliminary analysis in the field, which enabled a video camera to calibrate the sonar images and pinpoint the area that required remediation.

Side-scan sonar is often used to assist in surveys of fish habitats in rivers and around dams and fish ladders, to map the distribution of marine plants and grasses, and to locate offshore pipelines and cables. A survey boat, such as David Evans and Associate's research vessel shown in Photo 2, can readily obtain the geophysical data necessary for fish habitat and other engineering-related surveys.

Another geophysical method, resistivity, uses probes or electrodes to induce currents in the ground. Resistivity investigations are used to detect different horizontal geological layers, map pollution plumes, locate fracture zones in rock, detect underground cavities, map groundwater, and locate sand and gravel resources. A recent development has been the use of the resistivity method to determine the integrity of plastic liners in newly developed landfills or in holding ponds. Ian Bishop, Ph.D., a senior geophysicist with Golder Associates, has successfully mapped leaks less than .5 inches in diameter in several large ponds.

Subsurface reflection techniques, using either acoustics or ground penetrating radar, are routinely used to evaluate river crossings for proposed directional drilling projects or for installing piers to support pipelines. Data from these investigations provide the client with valuable information as to whether or not directional drilling is feasible, at what depth the hole should be drilled, and the maximum length that would be required for piers or piers.

Another example includes the permitting and preliminary design of a 148-mile-long, 36-inch oil pipeline in Washington state. This work involved site characterization activities along the terrestrial route, marine crossings, shore approaches, river crossings, and onshore facilities. Five major rivers and numerous smaller streams were crossed by the pipeline. Geophysicists used side-scan sonar and sub-bottom profiling geophysical techniques to measure marine currents and sample sediments. Geophysical investigations were conducted on 15 streams, and boreholes were drilled to provide additional geotechnical information.

Borehole (or downhole) geophysics are often used to supplement both terrestrial and marine investigations. Borehole geophysics provide a more specific measurement of the depth of earth material, whereas surface measurements tend to provide an average mea-

urement. Borehole geophysics is widely used in environmental, groundwater, and engineering investigations.

An example of this method involved the investigation into the potential for directional drilling for all shore approaches for the across-the-state pipeline project. Because boulders in glacial deposits were a major issue in some locations, geophysical investigations focused on defining boulder locations. Geologic mapping of beach cliffs focused on collecting sufficient information to quantitatively estimate the probability of drilling into a boulder.

Offshore, the liquefaction potential was assessed, as were the geotechnical characteristics of marine sediments using 800 track miles each of sonar, sub-bottom profiling, and marine seismic refraction data. These surveys were conducted in water depths up to 450 feet. All of the marine geophysical surveys for this project were successfully conducted over a period of two months, without any delays due to equipment malfunction.

The various terrestrial and offshore geophysics techniques mentioned in this article are applicable to any number of situations involving the need to investigate subsurface or offshore conditions. These methods provide excellent results and have proven time and time again to be a rapid and cost-effective means of obtaining information on the surface and subsurface geology.

Richard Sylvester and Robert Anderson are associates with Golder Associates. Mr. Sylvester has more than 30 years of experience in planning and conducting marine and terrestrial geophysical investigations. He has extensive experience in bathymetric and subbottom profiling, side-scan sonar, seismic reflection and refractions, electromagnetic terrain conductivity, and ground-penetrating radar. Mr. Anderson has more than 20 years of experience in the area of hydrogeology and is responsible for project management, field work, computer modeling, and reporting for hydrogeologic and geophysical investigations.