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Marine Induced Polarization Used for 3D Mapping Of Subseafloor Minerals and 4D Oil-in-Seawater Characterization

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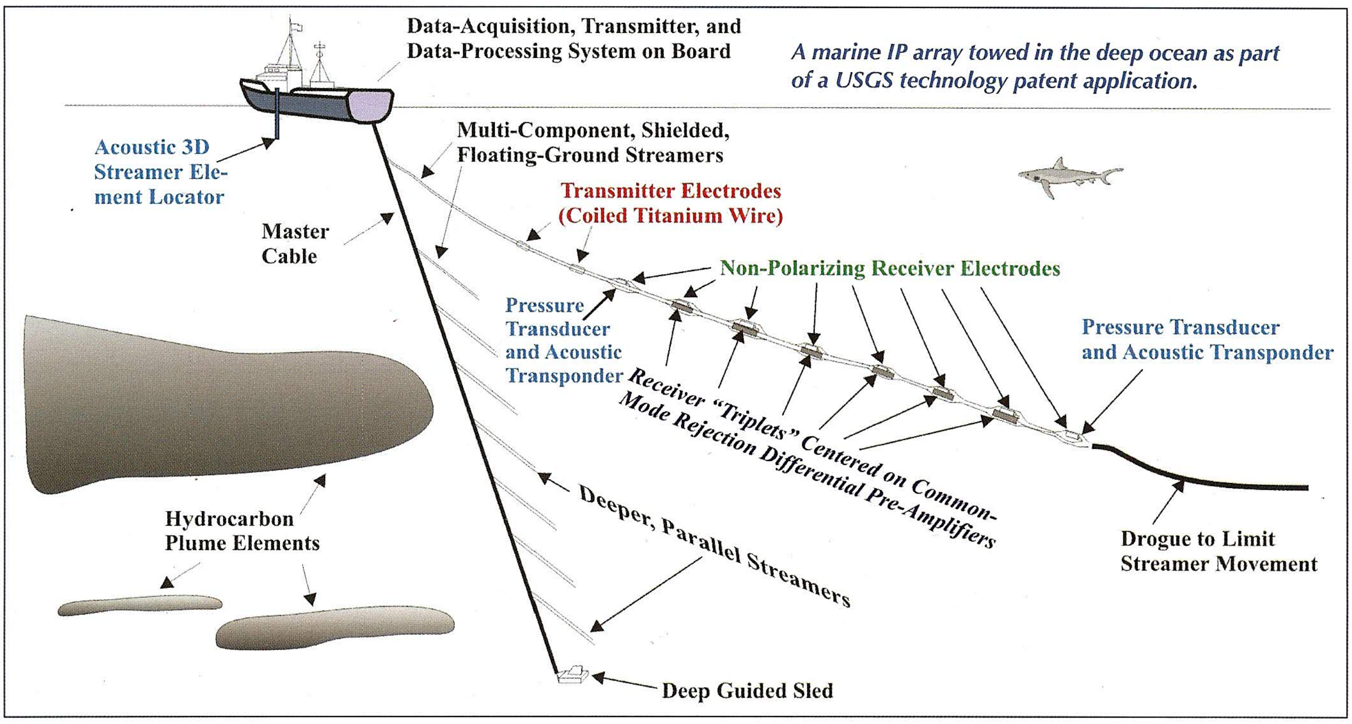
The U.S. Geological Survey (USGS) has developed and patented an electrical geophysical technology called marine induced polarization (IP) to map placer heavy minerals on and below the seafloor. A large-scale survey using marine IP, conducted with industry partners off the coast of southeastern Africa, successfully identified a large offshore placer titanium (ilmenite, or FeTiO3) resource beneath the modern seafloor. In other areas of the world, these "black sand" deposits are associated with zircon and precious heavy metals, including gold, platinum and heavy rare earth elements.

Recent laboratory experiments suggest that oil dispersed in the deep ocean contributes a large capacitance to seawater, which has been measured in the laboratory with the same marine IP technology. Hydrocarbons in seawater can theoretically be detected down to a concentration below 0.1 percent, and the technique can track hydrocarbon plumes and monitor their degradation through time and space.

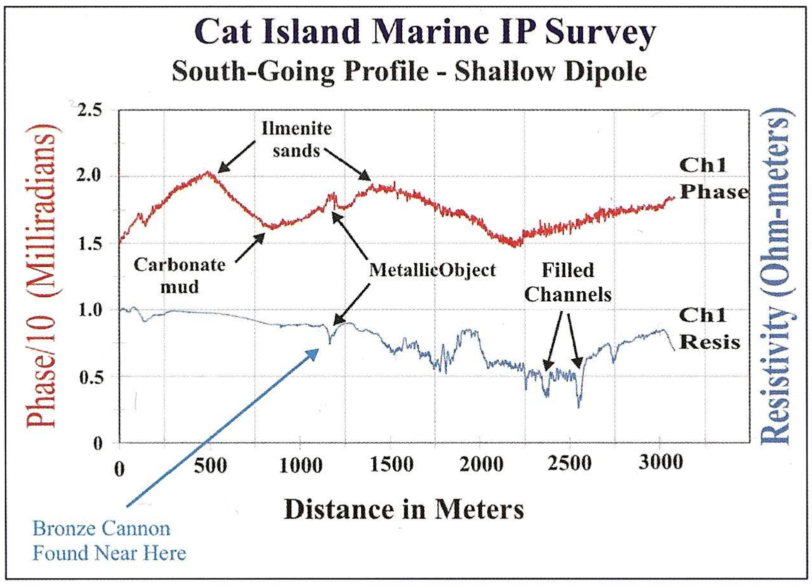
A cooperative research and development agreement with several private companies has been set up to exploit this placer-mineral and hydrocarbon-mapping technology, which can be useful for mapping wrecks and is promising for rapidly mapping buried unexploded ordnance.

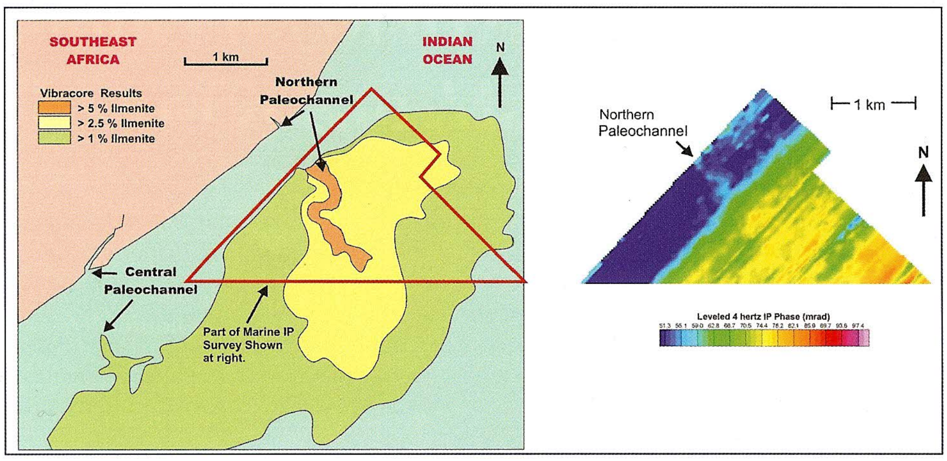
Induced Polarization

IP is a subtle surface-effect, electrophysical phenomenon that was first observed by Conrad Schlumberger in 1912.



A marine IP array towed in the deep ocean as part of a USGS technology patent application.





(Top) An example of a seafloor marine IP profile acquired in the Gulf of Mexico, with several different features identified. The baseline system IP response is about 13 to 14 milliradians. Typical seawater has a resistivity of about 0.3 ohm-meters.

(Bottom) Part of a five-week-long marine IP survey conducted off the coast of southeast Africa.

Under an induced voltage, charge adsorbs onto certain mineral grains. When the induced voltage is removed, a time-delayed charge release can be measured. In modern IP systems, this reaction is measured as a phase shift between transmitted and received signals. The frequency at which the maximum phase shift occurs has been shown in other studies to be diagnostic of the specific minerals being polarized. For instance, the pyrite response peaks below 0.1 hertz, while ilmenite peaks around 4 hertz. Both these minerals are particularly strong responders to IP.

Subseafloor Mineral Surveys Using IP

For a subseafloor minerals application, the USGS uses a single streamer with a single current transmitter dipole, followed by multiple receiver dipoles at increasing distances. This allows mapping of IP-reactive minerals at different depths using various receiver channels.

Southeast Africa Survey. In a two-month survey carried out off the coast of southeast Africa in 2007, paleochannels known to have transported ilmenite from land during a previous low-seawater stand can be seen in bathymetry and also in coarser results from gridded vibracoring carried out earlier. The IP anomaly coincides closely with the bathymetric signature of the northern paleochannel, seen approximately in contoured ilmenite assays. A much larger IP anomaly lies south and east of this paleochannel, where one would expect the Agulhas Current along with longshore currents to have dispersed the ilmenite over time. A large debris field from a wreck was also observed with resistivity and IP data during this survey, in an area well-known for shipwrecks caused by rogue waves.

Gulf of Mexico Survey. A subseafloor survey was carried out in the Gulf of Mexico in which broad IP anomalies correlated with ilmenite-bearing black sands east of Cat Island, south of Gulfport, Mississippi. This site was chosen because it is a known locus of heavy placers draining the entire Mississippi Basin.

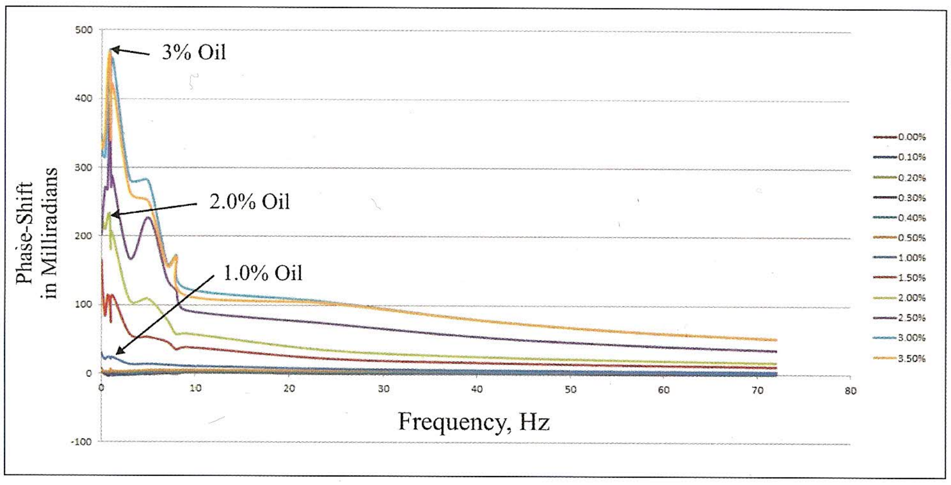
A narrow IP increase, coincident with a small drop in resistivity, was observed in the profile near where a bronze cannon was earlier dredged. This area is shoal rich, with a number of known wrecks dating back to the 17th century, and more metallic debris remains below the seafloor.

The USGS has also observed this kind of anomaly in the Atlantic, near the entrance to Murrell's Inlet, South Carolina. Additionally, IP anomalies are routinely observed on land over pipelines. These observations led to the belief that unexploded ordnance buried beneath younger sediments would be a logical target for marine IP. Two resistivity lows in the Cat Island profile, without coincident IP anomalies, lie over dredged channels leading to the east side of the island. These channels have been refilled by storm surges with less-consolidated sediments, which are expected to have higher seawater content and thus give the lower resistivity anomalies observed.

Characterizing Oil in Seawater

The IP principle has been used for decades to search for disseminated sulfide deposits (so-called "porphyry copper" ore bodies). The ocean analog appears to work in a similar fashion, with the peak frequency correlating inversely with oil in the case of droplet size.

Normally, a square wave voltage signal is transmitted into the seawater. A fast Fourier transform of transmit and receive signals, deconvolved against each other, allows characterization of the evolving oil-droplet size distribution. IP measurements on land require the manual emplacement of transmitter and receiver electrodes (a labor- and time-intensive project), but these measurements can be conducted in the sea as fast as an active streamer can be towed through the water or along the seafloor, as seawater provides an immediate electrical connection to the substrate.



Laboratory IP results for a range of oil-in-saltwater mixture.

If multiple cables are used, then towing the array in lawnmower fashion will map the dispersed hydrocarbons in 3D, or 4D with repeat surveys. As the peak polarization response frequency to oil droplets increases over time, it should thus be possible to monitor ongoing oil biodegradation.

Existing methods used to monitor hydrocarbon plumes include Rosette sampling and use of an AUV-deployed membrane inlet mass spectrometer.

However, these are not as efficient as IP because the former requires hours of an immobilized ship to acquire data and captures only a few discrete vertical points, resulting in data that do not account for a plume's movement, and the latter gives only a one-dimensional profile of something that is inherently 3D and in motion.

USGS conducted laboratory measurements from August to September 2011 for different percentages of multiviscosity oil that was titrated and then stirred into seawater. The different peaks apparently correlate with different oil-droplet size populations in the mix.

The results showed very strong IP phase shifts, nearly 500 milliradians for 3 percent oil in seawater. To put this in perspective, an economic porphyry copper deposit on land may give an IP anomaly up to 20 milliradians in field surveys and laboratory core measurements.

The experimental surveys in the Gulf of Mexico suggest that it is possible to maintain a noise envelope as low as approximately 1 milliradian, which suggests a detection threshold for oil below 0.1 percent in seawater.

Marine IP Potential

IP is a surface-sensitive physical property, which means it is ideal for mapping very low concentrations of finely disseminated metallic-luster sulfide minerals (with the notable exception of sphalerite), but IP also responds to ilmenite, oil in seawater and metallic debris. It has been reported that IP responds to magnetite but not to hematite.

Placer heavy minerals such as gold, zircon, rare earth elements and platinum tend to accumulate in the same places as ilmenite, and ilmenite can be detected at concentrations as low as 0.01 percent. If ilmenite can thus be tracked with a streamer and if vibracoring shows that it is associated with gold (e.g., in coastal Alaska and South Africa), platinum (e.g., in Sierra Leone) or rare earth elements (e.g., in the Atlantic Continental Shelf), then marine IP can be an effective precious-metal prospecting tool for the subseafloor. Experiments are tentatively scheduled for June to August 2013 offshore Nome, Alaska, to determine if marine IP responds directly to gold.

The marine IP approach also works for ferrous and nonferrous metallic debris, such as shipwrecks and unexploded ordnance, in dispersed concentrations on and beneath the seafloor.

Conclusions

Laboratory and sea trials suggest that IP is a powerful tool for mapping the subseafloor for placer minerals, buried wrecks, metallic debris and unexploded ordnance. IP responds to sulfide minerals, titanium-bearing placer sands and metallic debris even when covered by younger inert sediments.

Perhaps more significant, in light of a number of recent environmental disasters, is that the technology could also be used to detect and map dispersed oil in seawater down to very low concentrations. The apparent frequency dependence of the IP response to oil-droplet size suggests that it is possible to monitor the biodegradation of dispersed oil.

Acknowledgments

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References

For a list of references, contact Jeff Wynn at jwynn@usgs.gov. ■

Jeff Wynn is a research geophysicist and science manager with the U.S. Geological Survey. He has earned patents for the USGS on the marine technologies discussed in this article and published more than 200 papers in geology, geophysics, volcanology, mineral resources and hypervelocity-impact physics. He is also a jujitsu sensei.

Mike Williamson is a geologist in Washington State with a 40-year interest in mining, developed as a teenager working in a coal mine. Subsequent education and U.S. Navy experience led him to the marine environment, but he still likes to dig holes and develops remote-sensing methodologies to find missing ships.

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