AGGREGATES MANAGER
PULL-OUT GUIDE
by Therese Dunphy, Editor-in-Chief

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Getting Better Geologic Intelligence

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Fill in the Blanks Through Geophysics

Aggregate operators who want to learn more about mineral reserves — either as part of the exploration process or during mine planning — should understand the opportunities offered through the use of geophysics.

"Geophysics is really a valuable tool box," says Bill Langer, a geologist with the U.S. Geological Survey's (USGS) Mineral Resources Team. "There are a lot of things that aggregate operators, particularly sand and gravel producers, can use."

In 2007, Langer and two other USGS team members, Jeffrey Lucius and Karl Ellefsen, wrote USGS *Circular 1310*, "An Introduction to Using Surface Geophysics to Characterize Sand and Gravel Deposits." The report provides an overview of five established geophysical methods including seismic refraction and reflection; electrical resistivity; ground penetrating radar; time-domain electromagnetism; and frequency-domain magnetism. The circular is available online at *http://pubs.usgs.gov/circ/2007/1310/*.

Langer describes the various methods as tools because each method is suitable for specific applications, based on geologic conditions, financial constraints, and access to the deposit. In some circumstances, more than a single geophysical method may be used to characterize the mineral deposit. Depending on the method, information can be generated regarding the areal extent and thickness of the deposit, the thickness of the overburden, the depth to the water table, geological contacts, and geologic features.

Geophysical methods also may be combined with more traditional borehole sampling to determine the deposit's characteristics. "One of the most important things about mining geophysics is that it is not a replacement for, but rather a supplement to, direct exploration," says Konrad Crist, PG, senior geophysicist with Enola, Pa.-based Dawood Engineering, Inc. "Direct exploration provides hands-on, real subsurface data, but for a very small amount of area and volume, especially given the size of mining properties. Geophysics is an indirect measure of the subsurface and is, therefore, an estimate, but often a very close estimate, of the measured parameter, such as rock depth or overburden thickness."

The advantage of geophysics, he says, is that a tremendous amount of subsurface data at high densities — both vertically and horizontally — can be collected relative to the cost of a direct exploration program. Geophysics also can detect even subtle changes in the subsurface that a much more widely spaced direct exploration program may miss or mischaracterize.

Geophysical methods can yield cost savings in a variety of forms. For example, an operator using these techniques will have a higher degree of confidence in the value of a greenfield site prior to purchasing it. The operator also will be able to calculate overburden removal costs and be able to drill fewer boreholes.

"We frequently use the geophysics to direct where to most profitably place the borings," Crist notes. "By combining both direct and geophysical exploration, the mining operator or manager can get far better subsurface information."

1 Seismic investigation

Seismic investigations require a fair amount of preparation, but provide detailed information about a deposit. These studies depend on the transmission of strained energy, called either an elastic wave or a seismic wave. Highly sensitive microphones, called geophones, are laid out across the study area and electrical signals are converted into digital values. While this method has traditionally been used to characterize deposits down to the water table, new technology allows seismic evaluation to see under a water table, greatly expanding its potential use with sand and gravel deposits.

4 Electromagnetic options

Two methods of geophysics employ electromagnetics. Time-domain electromagnetic uses sound to determine resistivity at various depths below the measurement device. Used for mineral exploration and mapping, it is similar to electrical resistivity. Frequency-domain electromagnetics (pictured above) is often used for the exploration stage. Working much like a metal detector, the instrument calculates conductivity of the ground.

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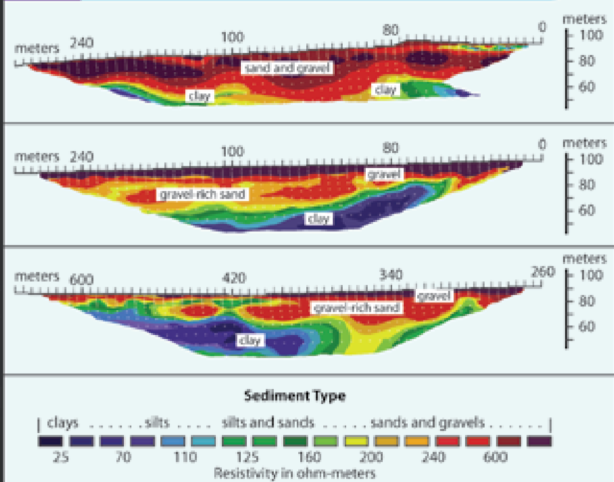
2 Electrical resistivity



Developed in the early 1900s, electrical resistivity site preparation is similar to the seismic method, in terms of positioning monitors around the site. In the case of electrical resistivity, metal-stake electrodes are driven into the ground. An electrical current is sent using a portion of the electrodes and the electric potential is measured between the remaining electrodes. Through computer modeling, a representation of the deposit is created. In sand and gravel deposits, it can be used to detect differing layers of sand coarseness.

3 Ground penetrating radar

Ground penetrating radar (GPR) depends on the production of high-frequency electromagnetic energy in the ground. An antenna transmits an electromagnetic wave into the ground. When that wave hits a change in electromagnetic properties — most often water content — a portion of it bounces back to the receiving antenna where the amplitude of the electric field and arrival time are detected. Water is often indicative of sedimentary structure, lithology, and density. Clay and metallic materials also cause changes in electromagnetic properties.

5 Understand properties of geologic material

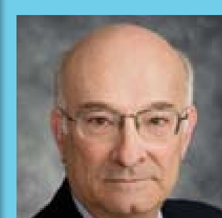
Material	Conductivity (millisiemens per hour)	Resistivity (ohm per meter)	Relative dielectric permittivity [1]	P-wave velocity (meter per second)
Soil	< 10 to > 50	< 20 to > 100	Low to high	100 to 500
Dry sand and gravel	< 5	> 200	Low	450 to 950
Saturated sand and gravel	> 20	< 50	Medium	1,200 to 1,850
Clay	10 to 200	5 to 100	Medium to high	900 to 2,700
Sandstone	1 to 20	50 to 1,000	Low	1,800 to 4,000
Shale	20 to 200	5 to 50	Low	2,500 to 4,300
Limestone, dolomite	< 1	> 1,000	Low	2,100 to 6,100
Igneous rock	< 1	> 1,000	Low	4,500 to 6,000
Metamorphic rock	< 1	> 1,000	Low	3,000 to 7,000

[1] For RDP, low is generally less than 10, medium is 10 to 36, and high is greater than 36.

This table, originally published in USGS *Circular 1310*, "An Introduction to Using Surface Geophysics to Characterize Sand and Gravel Deposits," lists the typical limits and ranges of selected properties of some common geologic material. The most appropriate geophysical method depends on how much information is needed, as well as the characteristics of the deposit itself.

OUR EXPERTS

Bill Langer is a research geologist with the Mineral Resources Team of the U.S. Geological Survey. He has 38 years of experience in geologic mapping and applied research of sand, gravel, and crushed stone. Langer has degrees in geology from Alfred University (bachelor's degree) and from Boston University (master's degree). A frequent industry speaker and author, Langer writes the award-winning *Carved in Stone* column for *Aggregates Manager.*



Konrad Crist, PG, is a senior geophysicist with Enola, Pa.-based Dawood Engineering, Inc. He has a master's degree in geology from Rensselaer Polytechnic Institute, as well as a master's degree in earth science from Virginia Polytechnic Institute. Crist is also a registered professional geologist in the state of Pennsylvania and has more than 30 years of experience conducting groundwater, environmental, engineering, mining, and mineral investigations. He can be contacted via telephone at 717-732-8576 or via e-mail at kcrist@dawood.cc.

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Bill Langer

There are numerous good reasons why operators should consider the use of geophysics, says Bill Langer, a geologist with the U.S. Geological Survey (USGS). A primary driver is the ability to provide detailed information about mineral reserves, which is especially important for publicly traded companies that must comply with U.S. Security and Exchange Commission rules, he says. "Even if you're not publicly traded but you want to keep your drilling costs down, you can use the same techniques," Langer says.

"To be sure that you're picking up all the hidden underground changes in the bedrock topography that the gravel is sitting on, you would have to have a really tight pattern of drill holes," he adds. "The geophysics does a really nice job because you'll have the few drill holes you need to give you the 'ground truth' and once you have it, you can fill in nicely with geophysics. It's a great way to improve your knowledge of what's going on without just saturating the site with drill holes."

According to Langer, an operator should select geophysics based on the site's geology and accessibility, as well as the amount of detailed information required. Some methods work better than others based on those criteria. For example, seismic refraction involves laying out highly sensitive microphones across the area. Using a simple device, such as a sledgehammer, vibrations are sent out across the ground. Those vibrations behave differently among the different layers in the ground, and that influences the amount of time it takes for the vibrations to be reflected back. Electrical resistivity works in a very similar manner, except instead of measuring vibrations, electrical current is transmitted, and its travel time to an array of receivers is measured. Both methods require the ability to access and prepare the site.

"It's up to the person who is applying the technique as to what they want to find out," Langer explains. "It may be that somebody knows they have a great gravel deposit, but they're prohibited from mining under the water table. The thing that's really important to them is the depth to the water table, so they'll use a technique that stops at the water table."

In some circumstances, more than one geophysical method is needed to address an operator's information needs. For example, Langer says that USGS performed a pilot study at an Indiana quarry with very thick glacial gravels. The operator there needed to know not only how deep the gravel went, but also where the significant layers of clay were located. "We picked a variety of techniques," Langer says. "In this case, some of the electric ones did great at seeing the clay, and the seismic ones did great at seeing the bottom of the gravel and the top of the bedrock."

Konrad Crist, PG

Use of geophysics is increasingly common among aggregate operators, says Konrad Crist, PG, senior geophysicist with Dawood Engineering, Inc., based in Enola, Pa. "Our ability to get better quality data is increasing," he says. "With the improvements in software processing, we can derive higher quality information from, sometimes, the same data."

Despite tough business conditions, aggregate companies continue to be proactive in planning and are using geophysics to assess the viability of future sites. "We tend to get greenfield surveys where they're trying to assess an undeveloped property," Crist notes. "Frequently, greenfield projects revolve around a more cursory survey using, for example, electromagnetics. When you want to get an idea of the site's variability, without a lot of in-depth detail, it covers the site in a rapid manner."

Crist says he also employs geophysics to troubleshoot problems in existing mines. "One of the most common problems is dealing with water," he says. For example, if a producer has water coming into the quarry floor, its subsurface water flow and its path can be identified. The producer can then develop a grouting program to reduce the water flow into the quarry.

"One of the most interesting new techniques we have used is to combine borehole resistivity with surface resistivity," Crist says. By installing electrodes, not only across the surface of the parcel, but also into the boreholes, much more detailed information can be obtained. "One of the key things with geophysics from the surface is that the resolution decreases with depth," he explains. "By putting electrodes down the boreholes, we greatly increase the resolution of the deeper features between the boreholes, and between the boreholes and the surface."

Although downhole geophysical techniques are less commonly used than other options, Crist says that he has had interesting applications using optical and acoustic televiewers. "By using a televiewer probe down the borehole, we can actually map the rock, including the fractures, the joints, and the lithology, in place at incredibly high detail. It's a virtual borehole, but in some cases, I think, better."

In another application, an operator called Crist into his limestone quarry to address deposit issues between boreholes. Two boreholes had been drilled a few hundred feet apart and indicated reasonable levels of overburden between them. After running resistivity testing, Crist found that more than 120 feet of overburden topped the deposit in the location between the two boreholes. "It resulted in a complete reorientation of future mining activities for the quarry," he says. "The geophysics provided them with a much more detailed view of what was happening and saved them a lot of money in the future."