Diagnosing the Earth

by
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"How was the Grand Canyon formed?" goes the joke. After visiting a few messy environmental job sites where "remedial actions" were taking place, I came up with an answer: "an environmental contractor was looking for an abandoned underground storage tank." A bit of an exaggeration, of course.

When I was a kid in Korea, my home town decided to punch a highway through a vast old graveyard. Descendants had to dig up their ancestors and move them to another cemetery. For years during the project, my friends and I used to walk through the pockmarked rolling hills, staring into open pits and playing on mounds of earth. Which is, by the way, not unsimilar to what I see at some environmental remediation sites. Except that those descendants knew where to dig.

Pits, trenches, dirt mounds, flattened vegetation: must we mutilate the land in order to save it? This question is related to a paradox of modern technology. In this age of moon-landings, digitally reconstructed colorful photographs of Martian surface, and satellite spy cameras that can supposedly read, at a distance of several thousand miles, the brand name of a cigarette pack, it may seem outright comical that we cannot tell where a utility pipe is without digging, how deep the ground water is without drilling, or even what is written behind this sheet of paper without flipping the page.

If we can see through a telescope a bursting galaxy billions of light years away, why is it that we cannot see an object covered by a sheet of paper, or an underground storage tank covered by a foot of dirt? The secret resides, of course, in the medium that fills the space between the viewer and the object. In a perfect vacuum, we can literally see forever, given a good pair of eyes or powerful optical equipment. This is because the electromagnetic waves, which include visual light, do not attenuate (other than geometrical spreading) in a vacuum.

When the space between the viewer and object is filled with air, images get a little hazy because the electromagnetic waves do refract, reflect, diffract, scatter, and attenuate through the air. Even so, we still can see very far or use a camera to record the images and, if necessary, computers to reconstitute and enhance them.

When the space is filled with anything else - such as soil or a sheet of paper - our visual images of the hidden object are severely blurred or simply not there. The interposed medium is opaque, and neither a high-powered astronomical telescope nor a spy satellite camera can see behind it. This opacity forces us to dig the earth and flip the page.

What do we do when faced with this maddening opacity? How do we find the fuel pipes, underground storage tanks, and burial trenches? The typical response has been to drill, dig, and cut away the opaque medium so we can have unobstructed vision.

This sounds like common sense procedure. We, environmental investigators, act like medical doctors, who open up a patient to find out what's wrong. We dig away so we can see and, we hope, solve the problem; we perform diagnostic surgery on the earth.

But let's explore this analogy further.

In modern medical science, diagnostic surgery is a last resort, not an initial inquiry. Except in extreme cases, when a patient is on the verge of death, surgery is not performed until all available diagnostic procedures have been tried. Patients undergo X-rays, CAT-scans, sonograms, EKGs, full-body imaging, etc. The point is to collect enough data so that surgery, if necessary, can be as accurate and effective as possible.

Just as medical doctors have access to remote sensing tools that enhance their performance and reduce the risk of their patients, so do environmental scientists and engineers. These are called "geophysical" tools, and those who use them and try to make sense out of the data collected by these tools are called geophysicists. These tools are imperfect, as are medical ones; the images we can construct are blurred and the data from them are often not self-explanatory. But, just like the medical tools, they are a heck of a lot better than nothing. If we ignore them, we may be guilty of environmental malpractice.

Despite their diversities, all geophysical tools are based on a few simple physical laws derived mostly from the classical physics of gravity, electricity, magnetism, and mechanics. Broadly speaking, they are grouped into two categories, active and passive sensors. Active sensors emit something and see how the hidden objects react to it. Common examples may be a flash light in the dark or traffic radar at an airport. As for geophysical tools, active methods include seismic, electromagnetic, ground-penetrating radar (GPR), and some types of electrical and radioactive surveys.

In passive methods, we attempt to sense something inherent to the object or indirectly measure some ambient field that is warped by a hidden object, as does a household infrared detector against an intruder or a chemical device that measures the ozone content in the atmosphere. As for geophysical tools, passive methods include gravity, magnetic, natural radioactivity, and some types of electrical surveys.

At the risk of being a bit technical, let me briefly explain a few basic physical principles of these methods. Seismic and GPR sensors emit short acoustic or electromagnetic pulses and measure the echoes or other responses from objects hidden in the earth. For the seismic method, the amplitude and phase of the returned signals are governed by density, Young's modulus, shear modulus, compressibility (or bulk modulus), and Poisson's ratio of the medium through which the seismic pulse travels.

Similarly, the GPR method depends on the contrast in electrical conductivity, magnetic susceptibility, and dielectric properties between the object and the host medium. In an electrical survey, we send galvanic currents into the earth through a pair of electrodes, and measure voltages through another pair of electrodes implanted into the earth over a suspected object.

The magnetic and gravity methods are passive because they measure how the existing earth's magnetic or gravity field is distorted by the presence of hidden objects. The earth's magnetic field is distorted near a ferrous (i.e., steel) object that has a higher magnetic susceptibility than its host medium. Similarly, earth gravity is distorted by an object whose density is either higher or lower than its surroundings.

I summarize in the following table the commonly used geophysical methods and their usages applicable to environmental investigations:

Geophysical Methods Applicable to Environmental Engineering

Method	Mode	Applications
Gravity	Passive	Geologic mapping, faults, cavities, fractures
Magnetic	Passive	Geologic mapping (particularly mafic rocks such as diabase dikes), USTs,
pipelines,		burial trenches, utilities
Seismic	Active	Bedrock topography, fractures, rock
hardness		
Ground-penetrating Radar	Active	Soil horizons, USTs, trenches, utilities
Electromagnetic	Active	Ground water depth, soil moisture, acid
plumes		
Electrical	Active or Passive	Ground water depth, soil moisture, fractures, acid plumes
Radioactive	Active or Passive	Geologic mapping, radioactive plumes

Most of these methods also can be used in boreholes. Commonly used geophysical well-logging methods for environmental studies include the electrical, electromagnetic, and passive radioactive (natural gamma ray) surveys.

Geophysical tools have been used for several decades, extensively and successfully, for exploring minerals, oil and gas, and other earth resources. Their applications to environmental problems, however, are still very young and case histories are, at best, spotty. Governmental research funding on environmental geophysics has been practically nil. Few universities are engaged in research or teaching on geophysical-environmental problems. To make the situation worse, few formally-trained exploration geophysicists have opted for the environmental industry to build their careers. I am, however, optimistic that the environmental industry, as it passes from adolescence to maturity, will increasingly recognize the value of geophysical surveys and that more talented geophysicists will enter into the field.

In a modern society, we spend a good portion of our GNP for "state-of-the-art" medical diagnostics. The amount we spend for environmental geophysics is an iota. Yet, performing geophysical surveys on Earth is analogous, in many ways, to performing medical diagnosis on a patient. Except that the earth doesn't talk, didn't ask for it, is much bigger, and is visible only on the surface.

X-rays and sonograms (that show a pregnant woman her fetal baby on a TV screen) are in principle the same as the seismic or GPR method. EKG or various "brain wave" measurements all use the same electrodes as we do in the electrical method to find the depth of ground water or the extent of an acidic contaminant plume. The advanced CAT-scan is a form of electromagnetic survey (better known as electromagnetic tomography).

The analogy breaks down again here because Mother Nature is too big. Where can we place the X-ray film? To shoot a UST in America, do we place an unexposed film in China? (Actually, remember the solar neutrinos to which the earth is transparent? Maybe someday.) She is too obese to put into a hole for a CAT-scan that may give cross-sectional views of her internal structure. Nevertheless, without any diagnosis of the earth, we risk performing unnecessary, or even detrimental surgery on our patient.

After all diagnostics are done, doctors use syringes, tubes, and needles to poke the patient and get blood and tissue samples. We use similar needles and tubes that we call roller bits, core drills, and hollow-stem augers to do the same to Mother Nature. Doctors use scissors, saws, and knives to open up a patient, and we use bulldozers, backhoes, and even explosives.

Some time ago, the American Medical Association told us that more than half of the surgical operations performed in this country were not necessary. Somehow, I think a similar statistics may apply to environmental drillings and remedial diggings.

Let me cite a small example: Once upon a time, a county landfill located in an eastern Triassic sedimentary basin oozed out rusty smelly liquids, particularly during hard rains, and at least one down-gradient resident reported a foul groundwater well. To find which way the pollutants were heading, the county hired a consultant who punched some eighty holes and produced a one-inch thick report of drill logs that showed essentially the same stuff: silty-clay, clayey-silt, sandy-silt, silty-sand, etc., all common to a Triassic basin. After all these drillings, the data did not point to any obvious routes for the leachate migration. A one-afternoon magnetic survey, however, found a 25-ft wide diabase dike running almost directly under the active leaching zone. The country commissioned the drilling of three more holes to confirm the dike intrusion. We all know how a diabase dike induces fractures and can act like an underground aqueduct or a gutter. The dike was the major fracture migration route in this particular landfill as far as the ground water was concerned. A small triumph of geophysics, perhaps, if only the county had tried it first.

The worst nightmare for a surgeon would be finding a surprise after he had opened up the patient. Just as medical diagnostics are used for reducing surprise, bloodshed, transfusions, and stitches, geophysical methods are used to reduce drilling, digging, and backfilling.

As no reputable doctor would open up a patient without having performed all available diagnoses, while recognizing all the imperfection of his tools and blurriness of their images, we should not open up the earth without all available geophysical data. Otherwise, it's often too messy, damaging, and costly. Nobody claims that geophysical tools are perfect, but they are the only ones available to us at this state of the art.

We should open the earth with an educated anticipation of what we may encounter. Just as a respectable medical doctor would do. Geophysical data help us to guess, or often to pinpoint, what may exist beneath the earth whom we are about to excavate. So that we know what to expect before we open her up. So that we don't dig up a whole acre to find an underground storage tank. So that we may look a little bit smarter to our client and may save a little bit of his money, which is often our tax money. So that we may keep the earth a little bit cleaner, a little bit safer, and a little bit more intact.

About the Author:

I.J. Won is currently President of Geophex, Ltd., an independent environmental and geological consulting firm based in Raleigh, North Carolina. He obtained a BS degree (1967) in mining and petroleum engineering from Seoul National University in Korea, and an MS (1971) and PhD (1973) in geophysics from Columbia University in New York. From 1976 till 1989, he was Professor of Geophysics at North Carolina State University in Raleigh. He has published over 40 research and review articles in refereed technical journals and books. He founded Geophex in 1983. He specializes in exploration geophysics for searching minerals, oil, and gas deposits, as well as recently in geophysical applications to geotechnical and environmental problems.