

The Meaning of Anomaly

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It began by accident, when I casually asked a class of fourth-year geophysics students to define the term *anomaly*. The disconcerting, blank silence that ensued was repeated by many subsequent senior classes in the following years, and at various schools.

Meanwhile, a client wanted to know about EM anomalies on his mineral property, another asked if anomalies in a derivative magnetic map were real or processing artifacts, an oilman wondered if gravity anomalies might help to delineate a frontier basin, somebody else was giving a talk about separating intrasedimentary from intrabasement magnetic anomalies, a software vendor offered anomaly enhancement, and a voice on the phone enthused that seeing good anomalies in one 3-D seismic survey surely made up for finding none in the more expensive other.

Some things seem so blindingly self-evident that no one bothers to examine them. The sun rises in the east and sets in the west. The Earth is round not flat (we say today), or flat not round (we said a few centuries ago). Oil and mineral deposits are found in the rock mass, and we use geophysics to locate them. And a geophysical anomaly is... what exactly? We say "anomaly" all the time. What could be more obvious?

In an appalling, guilty, dreadful chill of sudden horror at my own dismal ignorance, I got busy looking it up. But because everyone is assumed to know, it seemed, many geophysics texts and reference books don't even bother to offer a definition. Our exploration bible, the SEG dictionary (Sheriff, 1991), spake thus.

anomaly. 1. A deviation from uniformity in physical properties; a perturbation from a normal, uniform, or predictable field. 2. Observed minus theoretical value. 3. A portion of a geophysical survey, such as magnetic or gravitational, which is different in appearance from the survey in general. 4. A gravity measurement which differs from the value predicted by some model, for example, a Bouguer or free-air anomaly (q.v.). 5. In seismic usage, generally synonymous with structure. Occasionally used for unexplained seismic events. 6. Especially, a deviation which is of exploration interest; a feature which may be associated with petroleum accumulation or mineral deposit. 7. An induced-polarization anomaly is usually positive and greater than background (or the **normal effect**) to be economically interesting. In the frequency domain an anomalous region has a resistivity which decreases with frequency. An interesting resistivity anomaly is generally smaller than background.

Well, fine. These specific points are useful, as far as they go. But what do they add up to? Item 2 only seems to mathematize item 4, but 4 is unaccountably restricted only

to gravity surveys. And is an anomaly source generally a structure (item 5)? Is a geophysical anomaly the same as the geologic feature which is its source (items 1 and 5), or are these phenomena of different categories? Are only those anomalies deemed of exploration interest worthy of the title (item 6)? Why different anomaly definitions for different survey types? Some of these items seem to record colloquialisms (5), others are descriptive not definitional (7). When all is said and done, what is an anomaly?

To be most useful, an ideal definition would (a) be general to all exploration geophysics regardless of survey type and target, and (b) provide an interpretive link between an anomaly and its rock-made source. Without claiming the final word, allow me humbly to offer the following (cf. Lyatsky and Pana, 2003). *A geophysical anomaly is the difference between the observed (measured) geophysical-field or -survey value and the value that would be observed at the same location if the earth were more uniform than it is.*

This definition incorporates Sheriff's (1991) items 2 and 4, but is broad enough to be relevant for many geophysical fields. It hints at interpretational utility, linking anomalies to detectable non-uniformities in the earth.

But what is the survey value that would be measured "if the earth were more uniform than it is"? And how much more uniform? Exploration geophysics commonly aims to find local rock-property variations. The International Geomagnetic Reference Field is a conventional global uniform-earth magnetic model, so we can reasonably pretend the anomalies left after the IGRF data reduction are attributable to local (map-scale) rock-magnetization changes. Free-air, Bouguer and isostatic reductions offer idealized uniform-earth models for gravity data, accounting imperfectly but progressively well for the earth's overall character and leaving post-reduction anomalies more purely related to map-scale rock-density variations. In seismic data, a perfectly uniform earth lacking reflectors, refractors or diffractors would bounce back no signal at all: no wiggles in the trace, no colors to indicate amplitude.

Can an anomaly be related directly to a particular type of geologic feature? Without previously known geological constraints, no. The first reason is the non-uniqueness that arises from physics: an infinite number of different source geometries can produce exactly the same anomaly. The second reason lies in the phrase *rock-property variation*. An anomaly-causing change in the rocks' physical properties may or may not be related to any significant change in lithology, and vice versa.

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A geophysical anomaly is detected when a survey encounters some geometric perturbation in the distribution of a particular physical property in the rocks. Not just any perturbation, of course, and not with any geometry. Whereas reflection seismic data generally reveal horizontal or low-angle discontinuities, gravity and magnetic data help with high-angle ones. Gravity anomalies arise due to lateral perturbations in rock density, magnetic ones are caused by lateral changes in rock magnetization, and seismic anomalies indicate variations in acoustic impedance. Intraformational variations in the rocks' magnetite content, even without changes in bulk lithology, may cause big magnetic anomalies but nothing much in gravity maps or seismic sections. Perfectly flat-lying strata would produce vivid railroad-track seismic reflections, but a featureless gravity map. And so on.

A crucial intermediate logical step must thus be taken when linking geophysical anomalies to geology. We can't simply go from lithology to anomaly or from anomaly to lithology. First, we must consider what perturbations in the physical properties of rocks (velocity, density, magnetization, electrical resistivity, etc.) a particular geometry of lithology changes would be accompanied by, and then design a geophysical survey to delineate the anomalies these rock-property perturbations are expected to cause. The same consideration applies when interpreting anomalies in terms of their geologic sources. Geophysical anomalies indicate rock-property variations, not simply lithology changes.

And the moral of the story? Things are both less and more complicated than they seem, but our logic must always be crystal clear. And perhaps it sometimes pays to look into the seemingly obvious. Therein may hide the most subversive pitfall of them all: something fundamental we don't quite grasp, which gives us a false sense of security by masquerading as reassuring trivia. *R*

References

- Lyatsky, H.V. and Pana, D.I., 2003. *Catalogue of Selected Regional Gravity and Magnetic Maps of Northern Alberta*; EUB/Alberta Geological Survey, Special Publication 56, 40 p.
- Sheriff, R.E., 1991. *Encyclopedic Dictionary of Exploration Geophysics (third edition)*; Society of Exploration Geophysicists, 384 p.