Geophysical Corner February, 1999

New Life for Borehole Gravity?

The Geophysical Corner is a regular column in the EXPLORER, produced cooperatively by the AAPG Geophysical Integration and SEG Interpretation committees, and edited by M. Ray Thomasson. This month's column is titled "Borehole Gravity: An Old Technique With New Life?"

By DAVID A. CHAPIN and MARK E. ANDER

Borehole gravity is a density logging method that has been available for over 30 years – yet today it is a seldom-used technique, even though there are numerous published case studies that demonstrate its value.

By one estimate, it is thought that borehole gravity has directly or indirectly contributed to the cumulative discovery of more than one billion barrels of oil equivalent!

The physical principles behind borehole gravity logging are quite simple. By measuring minute differences in the earth's gravity field at different downhole locations, formation densities can be directly computed.

In order to do this, the borehole gravity sensor must be capable of sensitivities on the order of one part per billion. It is quite difficult to build such sensors, yet 16 borehole gravity meters have been built to these specifications since 1970.

To put this incredible sensitivity into perspective, it is equivalent to trying to weigh an entire whale in order to determine the weight of one of its whiskers!

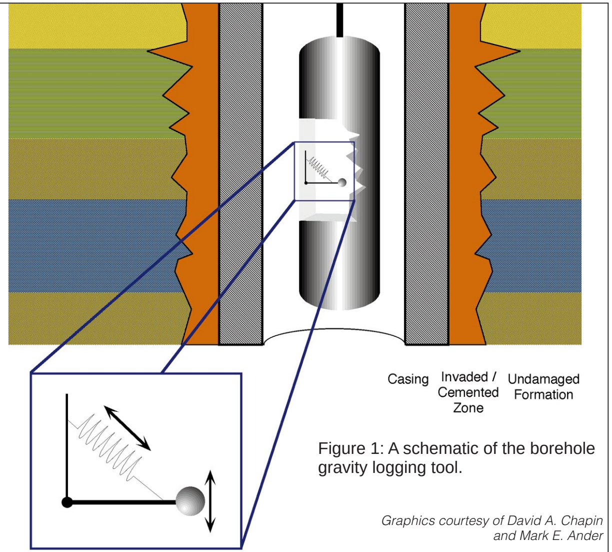

Figure 1: A schematic of the borehole gravity logging tool.

Graphics courtesy of David A. Chapin and Mark E. Ander

The physics behind this particular sensor gives it advantages over other density logging tools. For example:

❒ The computation from downhole gravity to density is direct, straightforward and does not require a lithology-dependent calibration.

❒ The entire system is passive and does not rely upon radioactive sources.

❒ And even more valuable is the depth of penetration of the sensor.

Borehole gravity can easily see beyond casing, cement, hole rugosity and near-borehole formation damage. It works just as effectively in cased holes as it does in open holes. It is a bulk density method, so when coupled with a near-borehole imaging nuclear density method such as a gamma-gamma log, the formation porosity can be computed with great accuracy.

Moreover, the pore-filling fluids can often be determined with some reliability. The best results occur with gas vs. liquid, but at higher sensitivities it may be possible to see oil-water contacts.

Figure 1 shows the gravity sensor that can detect beyond casing and cement using an inclined spring, lever arm mass. The lever arm mass pivots and stretches the spring under the influence of the local gravity field. This operates similar to a common bathroom scale.

The local gravity field measurements are directly related to nearby formation densities.

People often ask how far can the borehole gravity tool "see." This question is akin to asking how far the human eye sees. Obviously, the sensor has greater reliability at near-well distances, but if the object is large (such as a reef or salt) it may be resolved at greater distances. Typically, it can easily resolve densities within the first 50 feet of the

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well, but it is not uncommon to image features 100 to 500 feet away.

The distance resolution is a tradeoff between downhole resolution. In other words, as the object gets more distant, its signal becomes broader in wavelength. Thus, the method is tunable for more distant objects – but with the price of poorer vertical resolution.

Another question often asked is whether the direction to the object can be determined.

Unfortunately, without a multi-well logging program (akin to radio beacon triangulation), this is not currently possible. With single wells it is only possible to determine radial distance away from the borehole, but not direction.

Figure 2 shows an example of the distance resolution from borehole gravity.

In Case 1, there is no distant porous mass, therefore the near-borehole detecting gamma-gamma log and the far-detecting borehole gravity log show no difference. In Cases 2-4 the distant porous mass is increasingly moved closer to the well bore.

The wavelength of the density difference decreases as the amplitude increases. Thus the amplitude and wavelength of the density difference is diagnostic in determining the distance of the remote mass away from the borehole.

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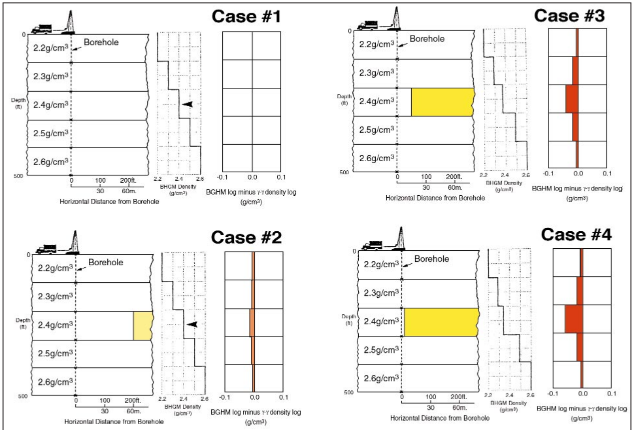

Figure 2

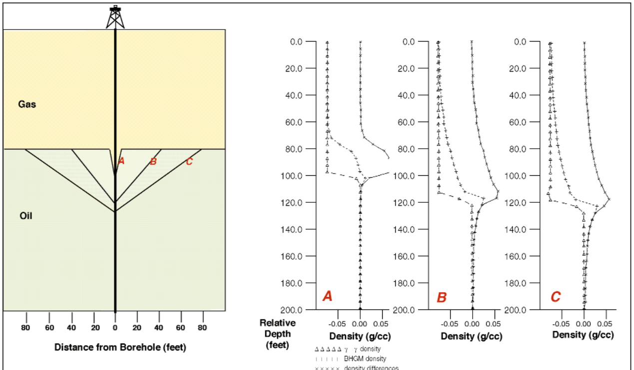

Figure 3

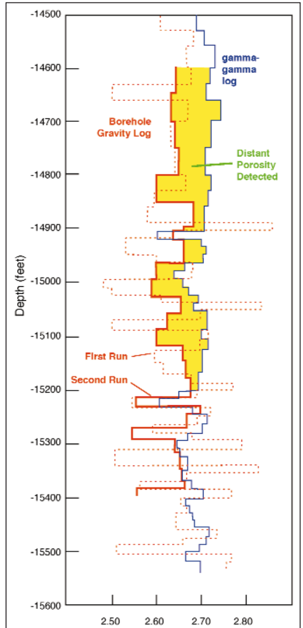

Figure 4

Figure 2: A model of the distance sensitivity of borehole gravity. (Courtesy of L.A. Beyer, adapted from A.K. Shultz)

Figure 3: Gas coning models around producing wells.

Fig. 4 - Measured borehole gravity logs from the Cannae #1 well, east Texas. (Courtesy of D.G. Ziegler and Broughton Operating Corp.)

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Notice that this model is sensitive to a distant mass as far away as 200 feet from the borehole.

Current uses of the borehole gravity method include formation evaluation, reservoir monitoring, determining behind-casing bypassed gas and exploration for distant structures.

Figure 3 shows a conceptual new use of the method for detecting the size and shape of a gas cone from a producing well.

Borehole gravity is not only capable of imaging past a gas cone to determine the true top of the gas-oil contact, but it is also capable of determining the shape of the cone, as these models show.

Figure 4 shows how borehole gravity can contribute to a gas discovery. A set of actual logs is shown, acquired in 1996.

The deviation between the near-borehole detecting gamma-gamma log and the far-imaging borehole gravity log (in yellow) helped determine that the Cannae #1 well was 300 feet away from a porous reef in the east Texas Cotton Valley trend. Based on this information, the well was sidetracked and a commercial discovery was made.

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Why hasn't borehole gravity become a more wide-spread logging method?

This is due primarily to engineering limitations of the present tool. Currently it must be used in nearly vertical, large-diameter boreholes, and takes on average about five to seven minutes to acquire a data point.

The only commercially available borehole gravity sensors are manufactured by LaCoste & Romberg of Austin, Texas. LaCoste & Romberg has begun to develop a new borehole gravity sensor that is expected to overcome the engineering limitations of the present tool using advances in digital electronics and materials science.

We predict that these advances will lead to renewed interest in the technology from oil and wireline companies. Innovative new uses, such as time lapse reservoir surveillance and gas storage monitoring, are also expected to generate new demands for the technology.

We foresee a day when borehole gravity logs will be as common as any other wireline log. While this technology is old and well-developed, it now has new life.

(Editor's note: David Chapin, formerly of Arco E&P Technology, and Mark Ander, formerly with Exploration Laboratory, both now work with LaCoste & Romberg in Austin, Texas. Chapin's e-mail address is D.Chapin@LaCosteRomberg.com, and Ander's e-mail address is mander@ix.netcom.com)