Borehole gravimetry survey in Central Luconia carbonate reservoirs

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Abstract: A borehole gravimetry log (BHGM) was taken in four wells in 1992. The gravimetry tool is a wireline logging tool that records formation density far away from the wellbore. Density differences from large structures can be detected several hundreds of feet away from the borehole compared to a conventional density log which only measures the immediate surrounding of the wellbore, in the order of one foot. The objective of running BHGM in the wells was primarily to determine lateral continuity of the porosity of the gas-bearing carbonate reservoirs.

General performance of the tool was good. An accurate BHGM density profile was obtained for each well without major operational difficulty. The BHGM density showed an overall agreement with the conventional density log indicating a good lateral continuity of the reservoirs. Small scale differences between conventional density and BHGM density can be explained by local variations in porosity. In one of the wells, the BHGM confirmed that the very low porosity of 8% observed on the conventional density log in a tight layer is a localised feature.

INTRODUCTION

Conventional wireline logging tools have a limited depth of investigation away from the wellbore. Depending on the technique considered, investigation depth is typically up to 10 feet into the formation. Conventional logs (and core data) are therefore often not a realistic representation of the reservoir which typically extends thousands of feet away from the well. A technique that is capable of measuring reservoir properties far away from the well is borehole gravimetry logging. Borehole gravimetry logs measure the earth's gravity force and respond to density variations of the formations around the borehole. The difference in gravity between two measurements in the wellbore is converted to an average density for the slab of formation between the measurements, with a depth of investigation roughly of the order of the spacing between them (Fig. 1). Thus, comparison of two measurements 100 feet apart provides an average density for the 100 feet interval, 100 to 200 feet into the formation. The vertical resolution of the gravimeter is limited by the accuracy of the measurement, to 20 feet. Since gravimetry logs provide a more representative reading of the average formation density than conventional density logs, a more accurate prediction of reservoir porosity can be obtained, which will eventually decrease risks in field development. Unfortunately, the tool is non-directional and, hence, direction of the lateral changes cannot be determined.

Objective of gravimetry logging

The Borehole Gravimeter (BHGM) was run in four wells in Central Luconia, offshore Sarawak, during the MLNG-2 Appraisal Campaign in 1992. The objective of the gravimetry logging in these wells was to determine lateral continuity of the porosity in the gas-bearing carbonate reservoirs and to study the operational performance of the tool. The log obtained may also be used as a base log for reservoir monitoring purposes such as water front movement and gas saturation quantification.

Principle of gravimetry logging

The measurement of the borehole gravimeter is based on the Law of Gravitation (Black, 1991; Anonymous, 1992). To produce a density log, the earth is modelled as a layered cake with infinite horizontal slabs (Fig. 2). The change in gravity between the top and bottom of each slab is proportional to the slab's density and thickness.

$$\rho = (4\pi G)^{-1} (\Delta g/\Delta z)$$

The borehole gravimeter is fundamentally a very sensitive spring balance in which the weight of a hinged beam with a small mass on its free end is balanced by the tension of a spring (Fig. 3). As the gravitational acceleration — and hence the weight of the mass-changes, the spring tension must be changed to hold the beam in a stationary horizontal position. The spring tension is calibrated in gravity units.

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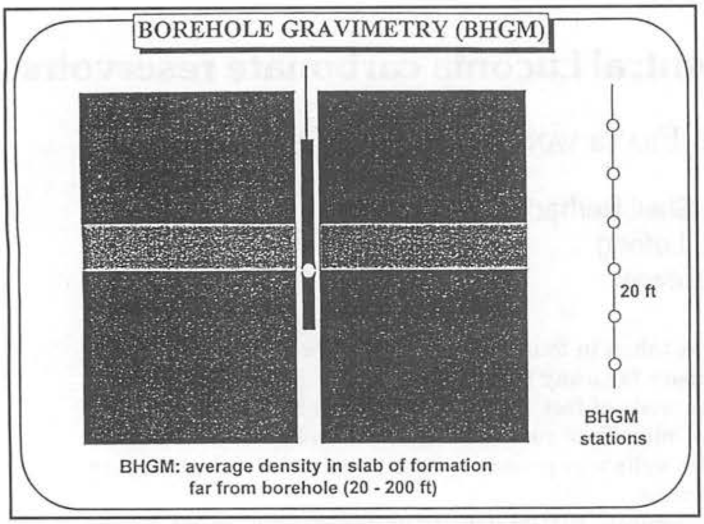

Figure 1. BHGM measurement technique.

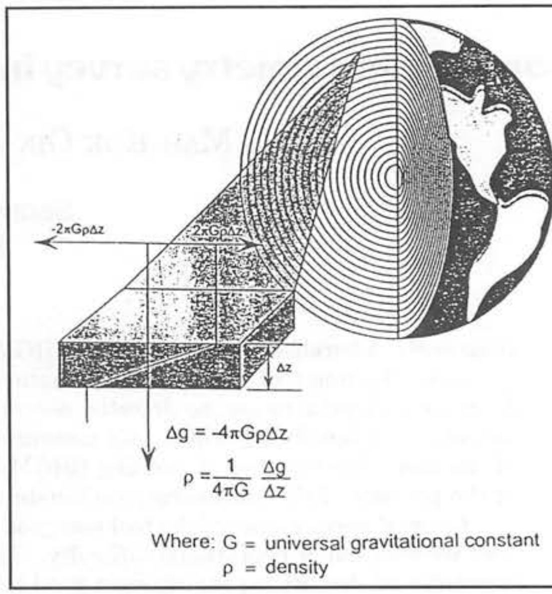

Figure 2. Horizontal slab density.

RESULTS AND DISCUSSION

The results of two wells will be discussed below as these are sufficient to cover all the observations in the four wells surveyed.

Well #1 (Fig. 4)

Gamma-ray (GRJ) of the carbonate formation is shown in Track 1. The Caliper log is presented in the Depth Track. Track 2 gives the Neutron Porosity (NPHIJ) and Bulk Density (RHOBJ). In Track 3, a comparison of environmentally corrected conventional density log (RHOBCSQ) and Borehole Gravimetry log (BHGM) is given. The density log has been averaged over the same intervals as measured by Borehole Gravity Meter. Note that the gravimetry measurement intervals were picked to fit density variations seen on the conventional density log, which enhances measurement comparison. In Track 4, the same comparison is shown, but now the conventional has been corrected for the effects of invasion of mud filtrate into the formation. The density log (RHOBFSQ) has been recomputed from known porosity and gas saturation of the formation. It is noticeable that this log has shifted to lower values after correcting for invasion effect, and that the agreement of BHGM with the log density is much better.

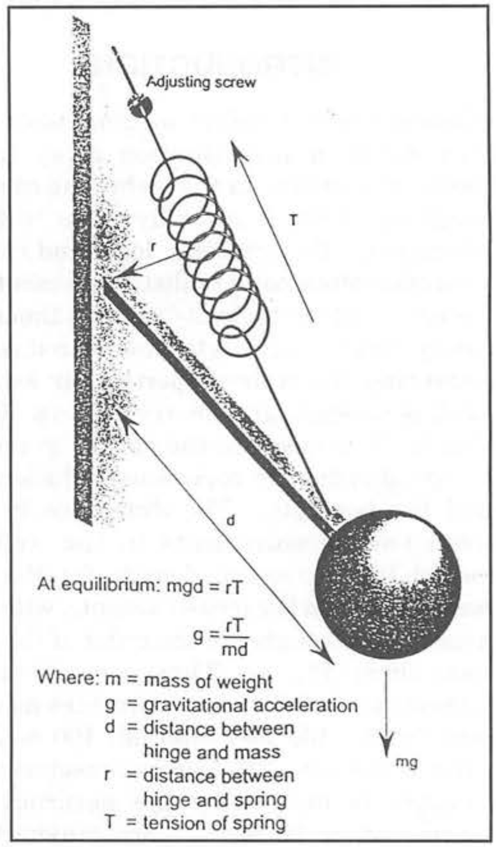

Figure 3. BHGM sensor.

Two observations can be made from the BHGM log in this example. (1) The majority of the survey intervals show very good agreement with the conventional density log, indicating reservoir porosity to be continuous to some 20 to 30 feet away from the wellbore (as given by the average survey interval). The agreement also suggests BHGM measurement is reliable. The average density of the total surveyed carbonate interval (900 feet) is also in close agreement with the average of the density log over the entire interval, which implies very little porosity variation up to some 1,000 feet away from the wellbore. (2) Higher porosity formation at depth 400 to 500 feet shows more variation while the tighter formation elsewhere generally shows less variation away from the wellbore.

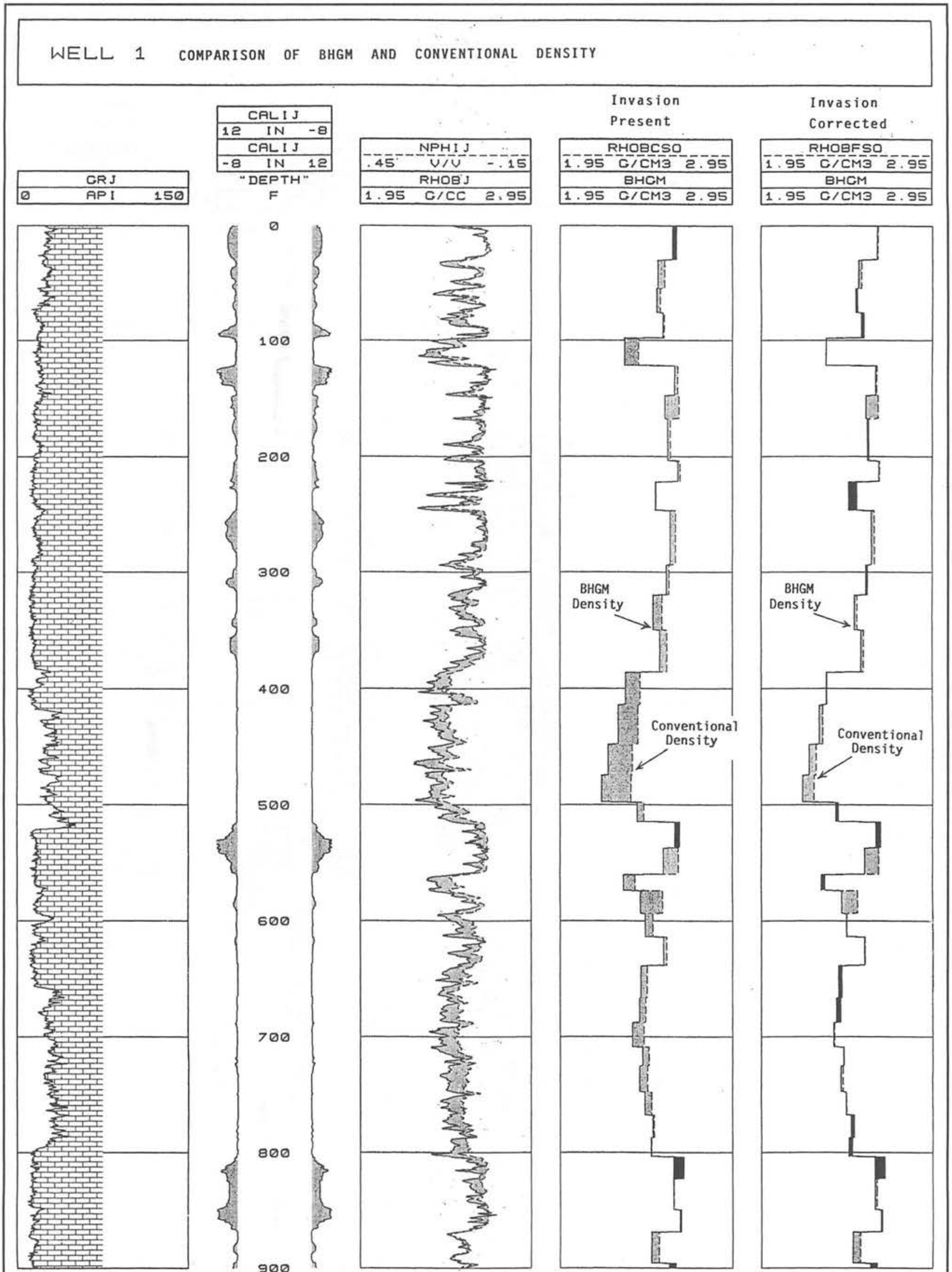

Figure 4. Comparison of BHGM and conventional density of Well 1.

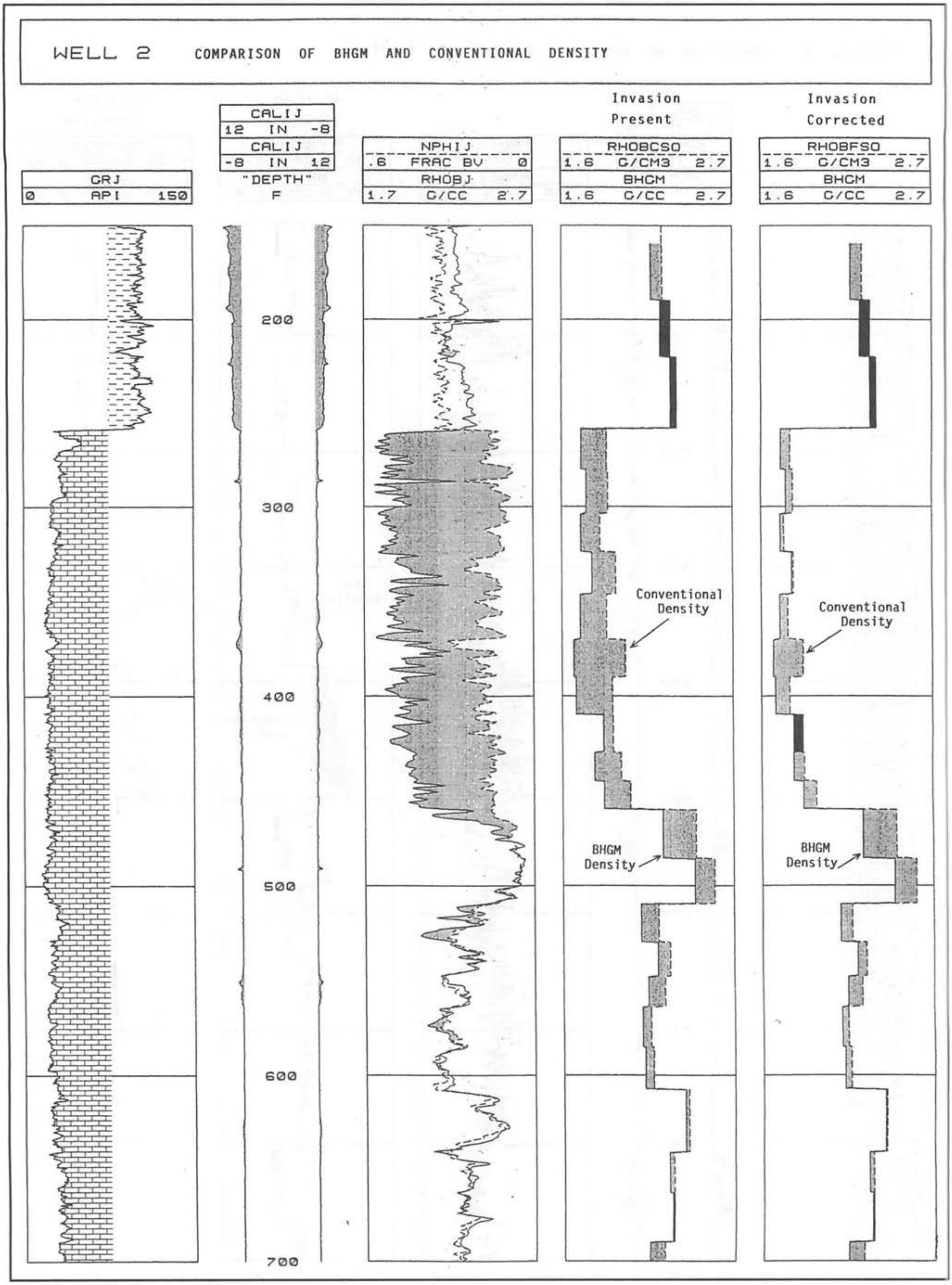

Figure 5. Comparison of BHGM and conventional density of Well 2.

Table 1. Tool specifications.

	Low Temperature Sonde	High Temperature Sonde
Maximum Temperature	110°C (230°F)	200°C (400°F)
Maximum Pressure	12,000 PSI	20,000 PSI
Outside Diameter	4.125 inches	5.25 inches
Length	96 inches	123 inches
Minimum Casing Size	5.5 inches	7 inches
Maximum	14°	14°
Tool Weight	150 lb	470 lb
Immersion Time	no limit	30 hours at 200°C

Note: The high temperature sonde may be operated at temperatures to 260°C with special preparation of the O-ring seals. The immersion time will decrease with higher well temperatures.

Well #2 (Fig. 5)

The format of presentation is similar to Well #1. Two observations can also be derived from this example. (1) In the tight layer around the depth of 500 feet, the gravimeter yields a lower average formation density than the density log. This suggests higher porosity within approximately 50 feet away from the wellbore. The exploration well 2.3 km away measures a porosity of some 20% for this tight layer compared to some 8% only in this well. The thickness of the tight layer in the exploration well is also smaller. The BHGM result therefore suggests the possibility of a large variation both in porosity and thickness of this tight layer across the reservoir. This is an important input for optimising reservoir characterisation and modelling. (2) The overall BHGM density is lower than the conventional density, suggesting higher porosity away from the wellbore. This result is in line with the observation that the exploration well has a better overall porosity development.

Limitations

Limitations of the technique should be noted while selecting objectives and planning the well for application. Well geometry limitations include hold size and deviation angle (Tool specifications are provided on Table 1). Vertical resolution is about 20 feet for sufficient accuracy of measurement. Since the technique requires sufficient density contrast, it is not suitable for time-lapse oil reservoir monitoring. The measurement is non-directional, integration with geological and seismic data is required to produce a geometrical reservoir model.

Concluding Remarks

Borehole gravimetry successfully provided a formation density measurement far away from the wellbore, the depth of investigation being equal to one to two times the measured interval under consideration.

The results obtained from the four wells have established lateral continuity of the porosity of the carbonate gas reservoirs, to an investigation depth comparable to the total carbonate interval surveyed in each well.

REFERENCES

BLACK, A., 1991. *Borehole Gravity Meter Handbook*, Edcon Inc.

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