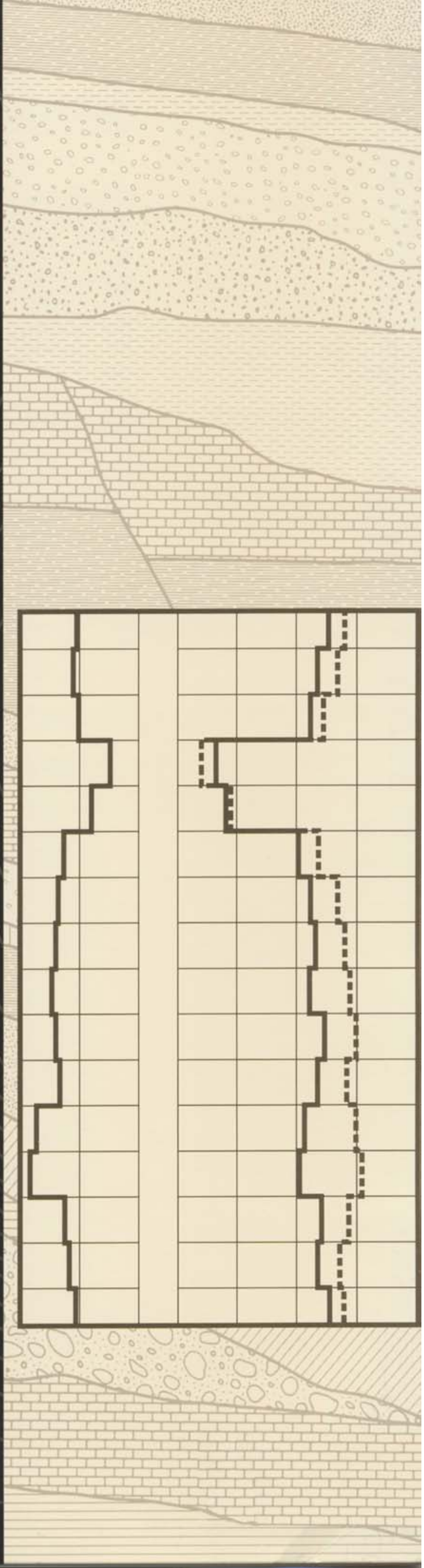
EDCON
WORLDWIDE
GRAVITY & MAGNETICS



DEEP DENSITY
BHGM

FEATURES

MEASUREMENT ACCURACY

DERIVED DENSITY MEASUREMENT

The accuracy of the Deep Density BHGM™ (Borehole Gravity Meter) measurement depends on the accuracies of the depth and gravity differentials. The combined effect of these sources of error is illustrated in figures 1 and 2. For a set gravity and depth error level, increased density accuracy is achieved by using larger depth increments. Useful density accuracy for depth increments of less than 2.5 meters requires the use of the Shuttle Sonde™. In time-lapse surveys, repeatability is confirmed by making density measurements opposite tight or water saturated zones.

GRAVITY MEASUREMENTS

An advanced electrostatic feedback positioning circuit, coupled with capacitance position sensing, controls the gravity sensor. Innovative design work has significantly reduced the electronic noise level providing improved gravity reading accuracy and survey reliability.

On surveys where the depth increment is small, gravity readings are repeated a minimum of 3 times, reducing depth and gravity uncertainties. With proper survey design and tool preparation, gravity reading standard deviations of 3 μGal (about 3 parts in10^9 of the earth's gravity field) are attainable.

DEPTH MEASUREMENT

For reservoir monitoring applications, depth increments of 2.5 meters or less may be desirable. To minimize depth errors, a Shuttle Sonde™ has been developed which enables the gravity sensor to be moved within the tool. The depth increment error is reduced to +/- 1 mm over the 2.5-meter range of the Shuttle Sonde™.

The absolute depth of the gravity sensor is provided by wireline odometer measurements. In time-lapse applications, gravity measurements must be repeated at the same absolute depth. This is achieved using high resolution Casing Collar Locator logs recorded at 1 mm sample intervals (Fig. 3).

RECORDING TIME

Gravity records are made with the tool held stationary. The time between records is from 8 to 14 minutes, depending on the distance between stations and the background noise.

COMBINATION VSP AND BHGM

Deep Density BHGM and downhole seismic surveys are a natural combination since both entail multiple stationary recordings. Two complementary data sets are acquired for the rig time cost of one. Tests conducted in Texas in 1993 show that the presence of the BHGM tool does not degrade the signal from the Schlumberger CSI tool and the seismic signal does not degrade the BHGM recording.

This approach is recommended for mapping deep salt structures.

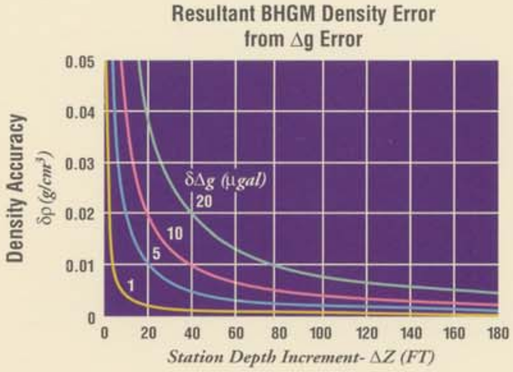


Figure 1

Density accuracy for various levels of Δg measurement uncertainty

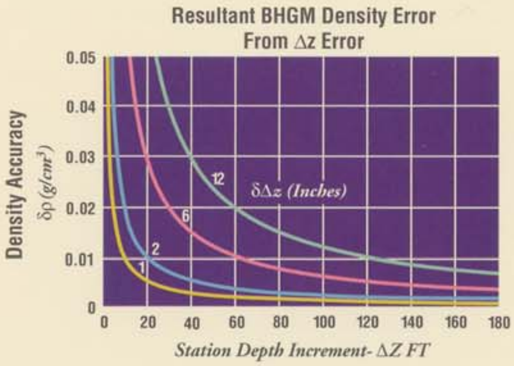


Figure 2

Density accuracy for various levels of Δz measurement uncertainty

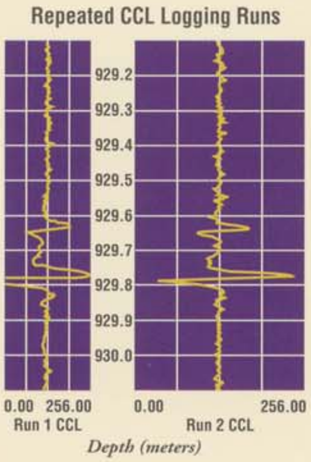


Figure 3

Absolute Depth location of gravity tool for repeat surveys

SPECIFICATIONS AND PRINCIPLES

SPECIFICATIONS

	Standard Sonde	Small Sonde	Shuttle Sonde™	Large Hi-Temp	Small Hi-Temp
Diameter	4.125"	3.875"	4.125"	5.25"	4.75"
Temp. (°C)	110	110	110	260	200
Time (hrs)	No Limit	No Limit	No Limit	30@200C	20@200C
Pressure (PSI)	12000	8000	20000	20000	15000
Deviation	14°	14°	14°	14°	14°

Downhole Tool	Weight	Length	Min. Casing
Normal Sonde	158 lb.	98"	5.5"
Small Sonde	76 lb.	89"	5.0"
Shuttle Sonde™	310 lb.	220"	5.5"
Small Hi-Temp Sonde	354 lb.	127"	6.0"
Large Hi-Temp Sonde	472 lb.	134"	7.0"
Gamma Ray	112 lb.	69"	5.0"
Hi-Res CCL	64 lb.	37"	5.0"

SHIPMENT

EDCON's BHGM sensors travel with the operator as shown in figure 5. The sensor is interchangeable among all the above sondes. The BHGM equipment is readily heliportable as shown in figure 6. Uphole equipment supplies and spare parts are shipped in carrying cases weighing up to 120 lbs. with dimensions of 28" x 24" x 18".

THE DEEP DENSITY MEASUREMENT WITH THE BHGM

The BHGM is a miniature version of the LaCoste Romberg land gravity meter. The sensor is a sensitive spring balance which measures changes in weight of a proof mass due to changes in gravity. It is precisely levelled for each recording and maintained at a constant temperature close to 126°C.

By Poisson's equation, the vertical gradient of gravity in a uniform medium is proportional to the medium's density. The BHGM density is calculated from the measured gravity gradient:

$$\rho = 3.6827 - 0.03913\ \Delta g/\Delta z$$

where ρ is in g/cc, Δz is in feet and Δg is in μGals. The constant density term compensates for the earth's normal vertical gravity gradient (the free-air gradient).

RULE OF THUMB

A useful and practical rule of thumb for Deep Density BHGM applications is that a remote body with sufficient density contrast may be detected at a distance of between one and two times the height of the body.

In most cases, before a Deep Density BHGM survey is attempted, a model should be prepared of the expected density anomalies around the borehole to evaluate their effect upon the apparent density measured by the instrument in the borehole.

Figure 6 BHGM support equipment

BENEFITS

FORMATION EVALUATION

Deep Density BHGM and Gamma-Gamma densities differ because the BHGM

- Investigates a greater volume of rock
- Sees little effect from near-well environment
- Is not related to electron density

APPLICATIONS

Deep Density BHGM provides better average density measurements

- Through casing (e.g., in old wells)
- In wash-outs, rugose or fracture zones
- Where formation is damaged (e.g., by drilling or cement)
- In invaded zones where mud filtrate density is different from original fluid density
- Where mud additives or solids may alter the apparent density near the borehole (e.g., barite mud, solids plugging)
- Where acidization products in the formation affect neutron measurements
- For accurate determination of overburden pressures for compaction studies

REMOTE SENSING

The Deep Density BHGM is influenced by structures which may be remote from the wellbore.

APPLICATIONS

- Mapping of salt flanks, flares and overhangs
- Detection of faults, especially overthrusts
- Mapping reef structures
- Evaluation of fracture systems and porosity away from well

RESERVOIR MONITORING

The Deep Density BHGM measures changes in fluid saturation

- Through casing
- Over a large volume
- Away from formation damage
- In low salinity waters

APPLICATIONS

Time-lapse monitoring of

- Gas caps
- Steam flood fronts
- Gas storage reservoirs
- Oil/water contacts in high porosities
- Hydrocarbon/water discrimination in freshwater sands

ENHANCING VSP, SURFACE GRAVITY AND SEISMIC SURVEYS

The average density profile with depth given by the Deep Density BHGM complements VSP and surface seismic and gravity information in modeling the subsurface.

APPLICATIONS

- Combination with surface seismic and gravity for model enhancement
- Investigation of the lateral extent of structural anomalies in combination with VSP (e.g., salt flares and reef boundaries)

Figure 4
BHGM sensing element
Maximum tilt and operating deviation (about 14°) is limited by gimbal travel.

Figure 5
BHGM sensor transport case
The BHGM sensor travels with the operator.

RESERVOIR MONITORING APPLICATIONS

In this Able Sand example (figs. 15-17), a baseline Deep Density BHGM log was run soon after the start of production, and a plot of Density vs. Porosity indicated that zones a, c and d were gas bearing. Subsequent production was made with increasing water-cut, and a second survey was run 11 months later. This showed substantial flushing of zones a and d, and some flushing of c. Zone b, which was shaly, remained unchanged.

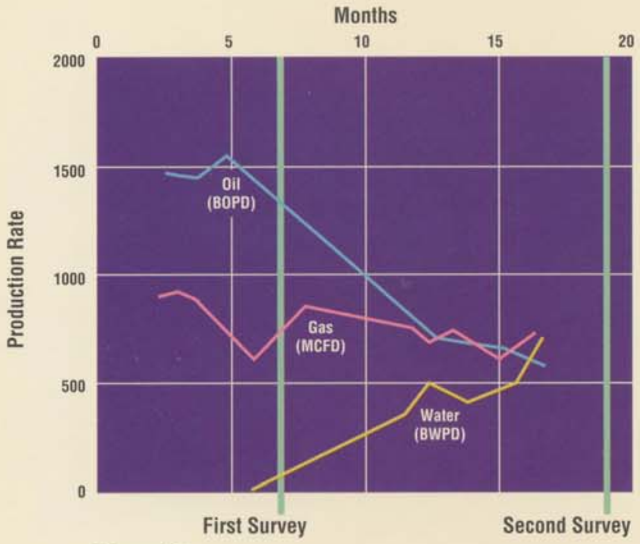


Figure 15
Production history of nearby well from interval A, Able Sand (Beginning 1/1/79)

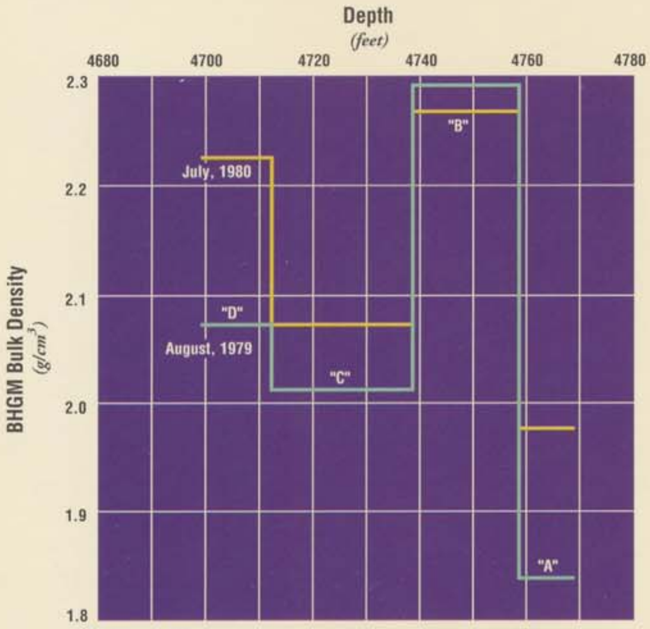


Figure 16
Reference well, Able Sand, preproduction and postproduction BHGM logs

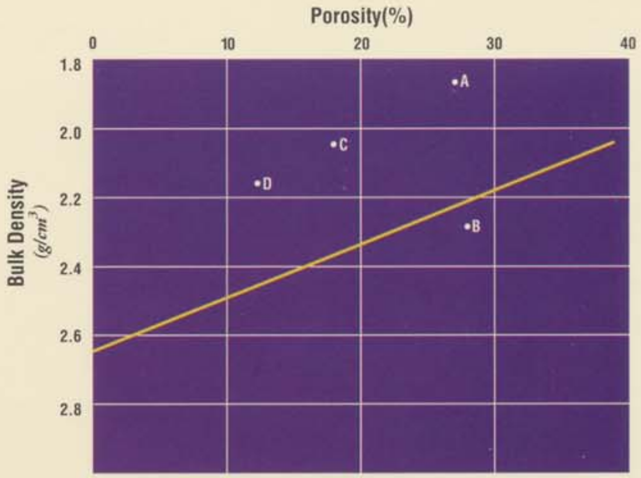


Figure 17
Crossplot of four intervals of the Able Sand, reference well (after Gournay and Maute, 1982)

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FORMATION EVALUATION APPLICATIONS

LOGGING THROUGH CASING

The Deep Density BHGM is the only means of making reliable through-casing density measurements. In old wells without density logs, zones showing high resistivity and low Neutron porosity could indicate either hydrocarbon or tight sands. The dilemma can be resolved by Deep Density BHGM, which shows low density in hydrocarbons (fig. 10) or high density in tight formation (fig. 11).

AVOIDING INVASION EFFECTS

The Deep Density BHGM at the top of this gas- and water-bearing sand (fig. 12) is lower than Gamma-Gamma density which investigates only the invaded zone. At the bottom, the Deep Density BHGM responds to the (denser) water in the virgin zone, whereas the Gamma-Gamma density is affected by the (less dense) filtrate from the oil-base drilling mud.

LOGGING IN FRACTURED ZONES, WASHED OUT BOREHOLES

The Gamma-Gamma Density/Neutron logs (fig. 13) are seriously affected by poor hole conditions in this well intersected by fractures. The Deep Density BHGM is not affected by hole conditions and generally overlays the undisturbed Density/Neutron readings to give a good average porosity.

DETECTION OF POROSITY NOT PENETRATED BY WELL

The average Deep Density BHGM reading in this fractured karstic carbonate (fig. 14) is less than that of the Gamma-Gamma Density/Neutron log, indicating that there are zones of higher porosity near the well.

The Deep Density BHGM in the Michigan reef example (fig. 8) also shows evidence of by-passed porosity in the zone between 6330 and 6370, although the Gamma-Gamma density log indicates little porosity at the wellbore.

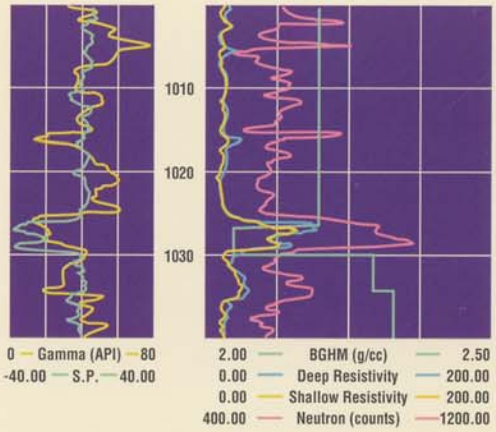


Figure 10
High resistivity
High N counts
Low density
= Gas

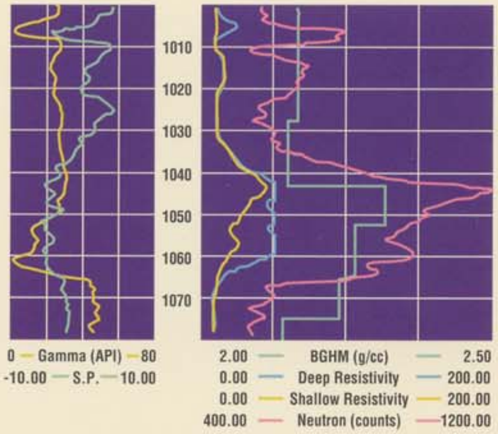


Figure 11
High resistivity
High N counts
High density =
Tight Zone

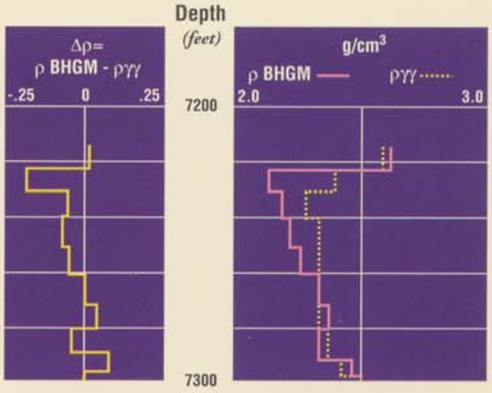


Figure 12
BHGM and γγ densities in gas sand showing invasion effects

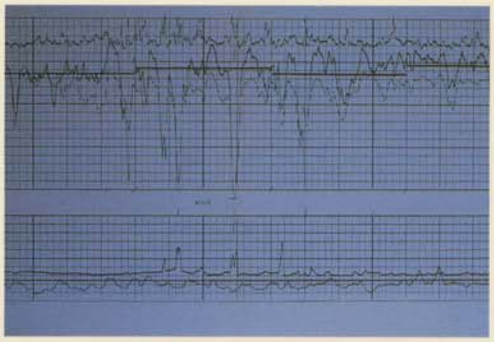


Figure 13
BHGM and γγ densities in fractured zone

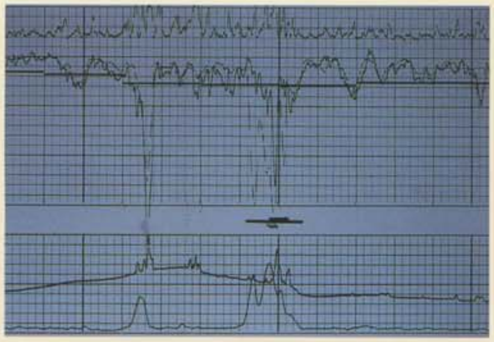


Figure 14
BHGM and γγ densities in karstic zone

REMOTE SENSING APPLICATIONS

FAULTS

In this North Sea example (fig. 7), a fault 100 ft from the well was revealed by the density differences between Deep Density BHGM and Gamma-Gamma density measurements.

REEFS

The broad departure between the Deep Density BHGM and Gamma-Gamma density logs in this Michigan reef example (fig. 8) reveals through modeling that the edge of the reef complex is within a few hundred feet of the well. The overlying low density zone near the top of the figure is salt.

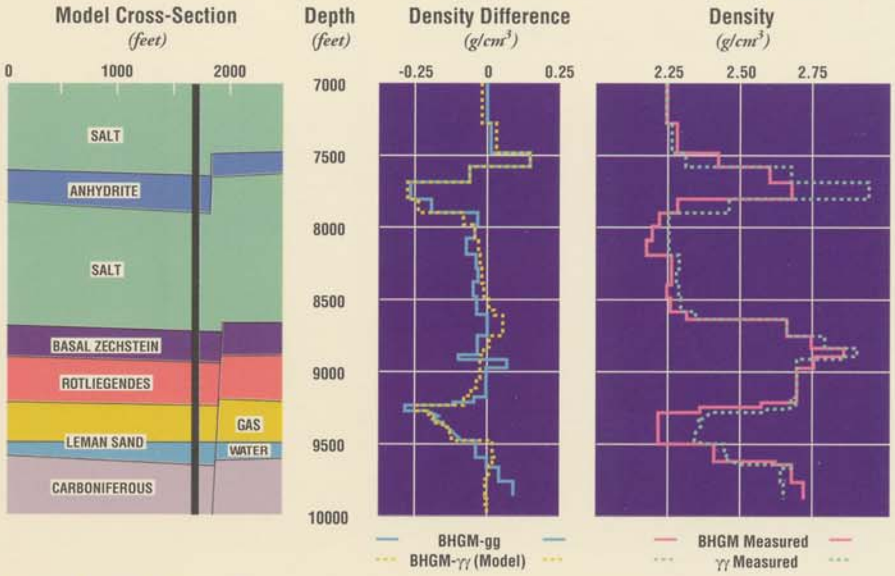


Figure 7 North Sea fault

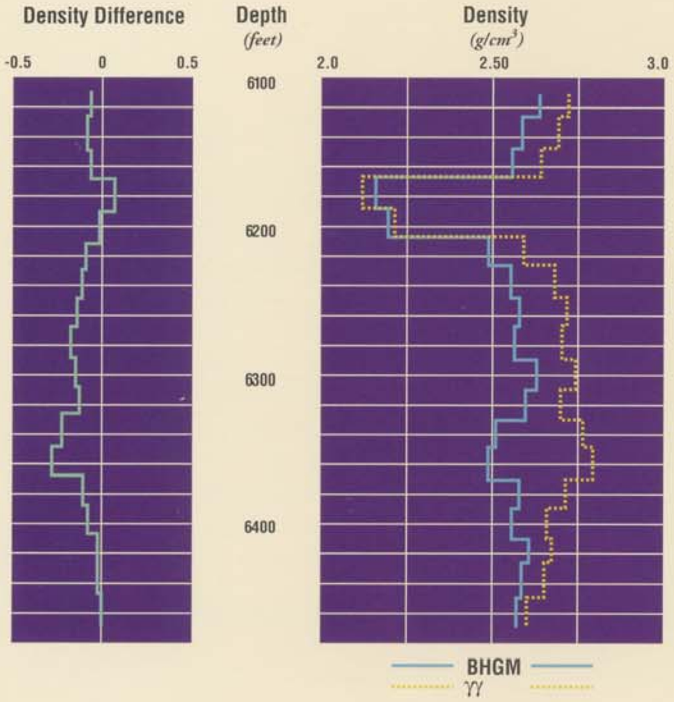


Figure 8 Michigan reef

The sharp difference in density between 6330 and 6370 is caused by a remote higher porosity zone not detected by the Gamma-Gamma density log. The broader difference anomaly observed over the length of the logged interval is explained by the structural influence of the reef complex.

SALT FLANKS

The model (fig. 9) shows the large expected differences in density between Deep Density BHGM and Gamma-Gamma measurements in the vicinity of salt flanks. Comparison of actual and model data may be used to map the salt boundaries.

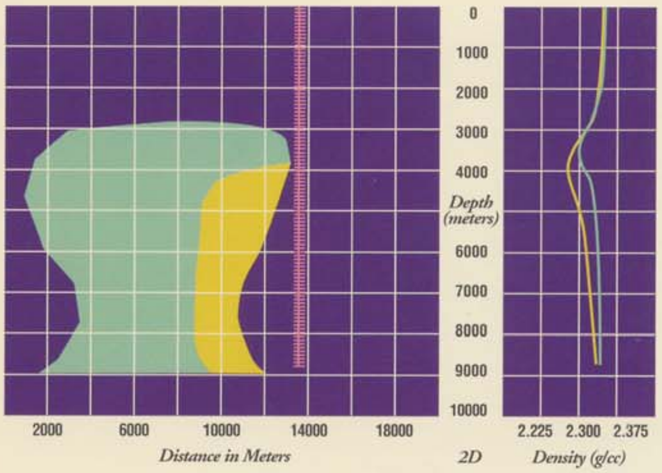
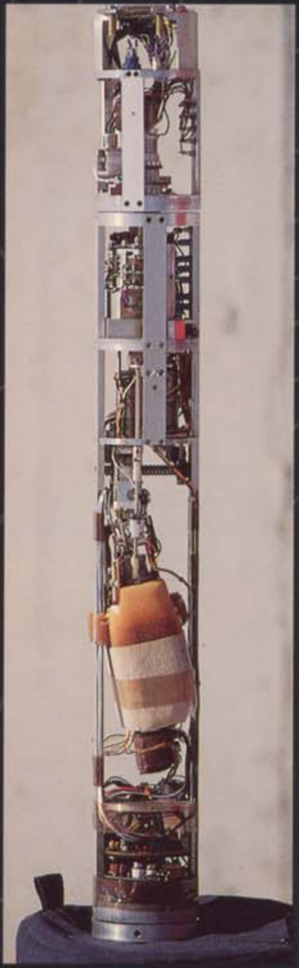


Figure 9 Structural effect of salt overhang

Resolution of seismic methods in salt environments decreases with increasing depth due to decreasing velocity contrasts and loss of high frequencies, whereas the resolution of the BHGM method increases because of increasing density contrasts between salt and surrounding formations.



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