Appendix E. Cruise Logging Report

ChevronTexaco GOM Gas Hydrate JIP Drilling Program
Downhole Logging Program

-CRUISE REPORT-

Prepared by
Timothy S. Collett
U.S. Geological Survey

Table of Contents

May 21, 2005

ChevronTexaco GOM Gas Hydrate JIP Drilling Program
Downhole Logging Program

-EXPLANATORY NOTES-

Prepared by Timothy S. Collett, U.S. Geological Survey

May 21, 2005

Introduction

The downhole logging while drilling (LWD) and conventional wireline (CWL) logging operations in the Gulf of Mexico Gas Hydrate JIP Drilling Program (GOM-JIP) was designed in part to obtain data needed to assess the occurrence and concentration of gas hydrates in several key sites within the Gulf of Mexico. LWD and CWL operations were conducted in two different offshore lease areas, Atwater Valley 13/14 and Keathley Canyon 151, in water depths ranging from 1280 to 1330 m. Proposed drilling and logging depths range from 307 to 553 m beneath the sea floor. Not all tool strings were run in each hole; refer to individual site chapters for details of tool strings deployed at each site.

Logging While Drilling (LWD/MWD) Operations

During the GOM-JIP program, five Anadrill LWD and measurement-while-drilling (MWD) tools were deployed at three deep drill sites in the Atwater Valley 13/14 and Keathley Canyon 151. These tools were provided by Schlumberger-Anadrill services.

LWD and MWD tools measure different parameters. LWD tools measure *in-situ* formation properties with instruments that are located in the drill collars immediately above the drill bit. MWD tools are also located in the drill collars and measure downhole drilling parameters (e.g., weight on bit, torque, etc.). The difference between LWD and MWD tools is that LWD data are recorded into downhole computer memory and retrieved when the tools reach the surface, whereas MWD data are transmitted through the drilling fluid within the drill pipe by means of a modulated pressure wave, or “mud pulsing”, and monitored in real time. However, MWD tools enable both LWD and MWD data to be transmitted uphole when the tools are used in conjunction. The term LWD is often used more generically to cover both LWD and MWD type measurements.

The LWD and MWD tools (on 6-3/4 inch collars) used during the GOM-JIP drilling program included the resistivity-at-the-bit GeoVision tool (GVR6), the EcoScope tool (DVD with APWD), the TeleScope MWD tool (TeleScope), a magnetic resonance while drilling tool (MWD-ProVision), and the azimuthal density neutron (VDN) tool. Figure-1 shows the configuration of the LWD/MWD bottom hole assembly (BHA). The BHA was changed for the Keathley Canyon 151-2 well, in which the TeleScope was replaced with the MWD Power Pulse tool and the DVD was replaced with the Array Resistivity Compensated tool (ARC).

LWD measurements are made shortly after the hole is drilled and before the adverse effects of continued drilling or coring operations. Fluid invasion into the borehole wall is also reduced relative to wireline logging because of the shorter elapsed time between drilling and taking measurements.

The LWD equipment is partially battery powered and uses erasable/programmable read-only memory chips to store logging data until they are downloaded. The LWD tools take measurements at evenly spaced time intervals and are synchronized with a system on the rig that monitors time and drilling depth. After drilling, the LWD tools are retrieved and the data downloaded from each tool through an RS232 serial link to a laptop computer. Synchronization of the uphole and downhole clocks allows merging of the time-depth data (from the surface system) and the downhole time-measurement data (from the tools) into depth-measurement data files. The resulting depth-measurement data were transferred to the processing systems in the Schlumberger-Anadrill logging unit onboard the Uncle John for reduction and interpretation.

To provide the highest quality LWD data, the target instantaneous ROP of the drill string was 30 m/hr, with a pump rate of 300 GPM, and a bit rotation target between 80-100 RPM. To improve the quality of the near surface data within the upper 25-35 mbsf at spud in, we tried to advanced the near surface portion of each hole very slowly, with pump rates at about 50-100 GPM (building to 300 GPM from 25 to 35 mbsf) and a bit rotation target of about 50 RPM.

GeoVision Tool

GeoVision tool (RAB or GVR6) provides resistivity measurements of the formation and electrical images of the borehole wall, similar to the Formation MicroScanner but with complete coverage of the borehole walls and lower vertical and horizontal resolution. In addition, the RAB tool contains a scintillation counter that provides a total gamma ray measurement.

The GVR6 is connected directly above the drill bit and it uses the lower portion of the tool and the bit as a measuring electrode. This allows the tool to provide a bit resistivity measurement with a vertical resolution just a few inches longer than the length of the bit. A 1-in (4 cm) electrode is located 3 ft (91 cm) from the bottom of the tool and provides a focused lateral resistivity measurement (*R*RING) with a vertical resolution of 2 in (5 cm). The characteristics of *R*RING are independent of where the RAB tool is placed in the BHA and its depth of investigation is ~7 in (18 cm). In addition, button electrodes provide shallow-, medium-, and deep-focused resistivity measurements as well as azimuthally oriented images. These images can then reveal information about formation structure and lithologic contacts. The button electrodes are ~1 in (2.5 cm) in diameter and reside on a clamp-on sleeve. The buttons are longitudinally spaced along the RAB tool to render staggered depths of investigation of ~1, 3, and 5 in (2.5, 7.6, and 12.7 cm). The tool's orientation system uses the Earth's magnetic field as a reference to determine the tool position with respect to the borehole as the drill string rotates, thus allowing both azimuthal resistivity and gamma ray measurements. Furthermore, these measurements are acquired with an ~6° resolution as the RAB tool rotates.

RAB Programming

For quality control reasons, the minimum data density is one sample per 6-in (15.2 cm) interval; hence, a balance must be determined between the rate of penetration (ROP) and the sampling rate. This relationship depends on the recording rate, the number of data channels to record, and the memory capacity (46 MB) of the LWD tool. During the GOM-JIP drilling program, we used a data acquisition sampling rate of 5 seconds for high-resolution GVR6 images. The maximum ROP allowed to produce one sample per 6-in interval is given by the equation: ROP(m/hr) = 548/sample rate. This relationship gives 110m/hr maximum ROP for the GVR6. For the GOM-JIP the, the target ROP is 30 m/hr, roughly 30% of the maximum allowable for the GVR6 tool. These reduced rates improve the vertical resolution of the resistivity images to 5-10 cm per rotation. Under this configuration the GVR6 tool has enough memory to record up to six days of data. This is sufficient, under normal operating conditions, to complete the scheduled LWD operations at Atwater and Keathley Canyon.

Bit Resistivity Measurements

For the bit resistivity measurements, a lower transmitter (T2) produces a current and a monitoring electrode (M0) located directly below the ring electrode measures the current returning to the collar. When connected directly to the bit, the GVR6 tool uses the lower few inches of the tool as well as the bit as a measurement electrode. The resultant resistivity measurement is termed *R*BIT and its depth of investigation is ~12 in (30.48 cm).

Ring Resistivity Measurements

The upper and lower transmitters (T1 and T2) produce currents in the collar that meet at the ring electrode. The sum of these currents is then focused radially into the formation. These current patterns can become distorted depending on the strength of the fields produced by the transmitters and the formation around the collar. Therefore, the GVR6 tool uses a cylindrical focusing technique that takes measurements in the central (M0) and lower (M2) monitor coils to reduce distortion and create an improved ring response. The ring electrode is held at the same potential as the collar to prevent interference with the current pattern. The current required for maintaining the ring at the required potential is then measured and related to the resistivity of the formation. Because the ring electrode is narrow (~4 cm), the result is a measurement (*R*RING) with 5-cm vertical resolution.

Button Resistivity Measurements

The button electrodes function the same way as the ring electrode. Each button is electrically isolated from the body of the collar but is maintained at the same potential to avoid interference with the current field. The amount of current required to maintain the button at the same potential is related to the resistivity of the mud and formation. The buttons are 4 cm in diameter and the measurements (*R*BUTTON) can be acquired azimuthally as the tool rotates within 56 sectors to produce a borehole image.

Interpreting RAB Images

Structural data were determined from GeoVision or RAB images using Schlumberger's GeoFrame software. GeoFrame presents RAB data as a planar, "unwrapped" 360° resistivity image of the borehole with depth. The image orientation is referenced to north, which is measured by the magnetometers inside the tool, and the hole is assumed to be vertical. Horizontal features appear horizontal on the images, whereas planar, dipping features are sinusoidal in aspect. Sinusoids are interactively fitted to beds and fractures to determine their dip and azimuth, and the data are exported from GeoFrame for further analysis.

Methods of interpreting structure and bedding differ considerably between core analysis and wireline Formation MicroScanner (FMS) images and RAB image analysis. Resolution is considerably lower for RAB image interpretation (5-10 cm at best, compared with millimeters within cores and 0.5 cm for FMS images), and therefore identified features are likely to be different in scale. For example, microfaults ("small faults," <1 mm width) and shear bands (1-2 mm, up to 1 cm width) can only be identified in FMS data. This should be considered when directly comparing FMS and RAB images. RAB provides 360° coverage at a lower resolution, FMS provides higher resolution data but coverage is restricted to only ~35% of the borehole wall. Fractures were identified within RAB images by their anomalous resistivity or conductivity and from contrasting dip relative to surrounding bedding trends. Differentiating between fractures and bedding planes can be problematic, particularly if both are steeply dipping and with similar orientations.

EcoScope Tool

The EcoScope service integrates a full suite of formation evaluation, well placement, and drilling optimization measurements in a single collar to increase operational efficiency, reduce risk, and increase confidence in data interpretation and calculations of production and reserves. This tool is designed around a pulsed neutron generator (PNG). In addition to the suite of resistivity, thermal neutron porosity, and azimuthal gamma ray and density measurements, it provides the first commercial LWD measurements of elemental capture spectroscopy, neutron gamma density, photoelectric factor, and sigma. The dual-frequency propagation resistivity array makes 10 phase and 10 attenuation measurements at several depths of investigation, providing invasion profiling and formation resistivity. Drilling optimization measurements include Annular Pressure While Drilling (APWD), caliper, and shock detection. The PNG used in the EcoScope allows generation of neutrons without a chemical source. The EcoScope service integrates multiple LWD sensors in a single collar. This compact design reduces the amount of rathole that must be drilled to provide comprehensive evaluation measurements.

Array Resistivity Compensated Tool

Because of equipment failure, the TeleScope MWD tool in the KC 151-2 well was swapped for the Power Pulse MWD tool; which also required the EcoScope to be swapped out for the Array Resistivity Compensated Tool (ARC). The ARC tool provides resistivity measurements for logging while drilling holes. The tool is battery powered and can be operated in memory mode. For real-time applications, the ARC tool can be combined with Power Pulse MWD tool for realtime data transmission capabilities. Multiple depth resistivity measurements are achieved with high frequency electromagnetic propagation. Three transmitters are placed above the receiver pair and two transmitters are placed below the receivers for a total of five transmitter/ receiver spacings. Each transmitter sequentially broadcasts a 2-MHz electromagnetic wave into the formation. The phase shift and attenuation difference is measured between the receiver pair. The result is five depths of investigation of borehole compensated resistivities. Borehole compensation is important because it significantly reduces the effects of borehole rugosity and precisely cancels measurement errors caused by differences in each receiver's electronics that change with temperature. Multiple depths of investigation are useful to differentiate between borehole effects, invasion, shoulder beds and anisotropy. Resistivity inversion processing is available to correct for shoulder bed and invasion effects to resolve true formation resistivity (*Rt*), flushed zone resistivity (*Rxo*) and diameter of invasion (*di*). Inversion processing may also resolve horizontal resistivity (*Rh*) and vertical resistivity (*Rv*) in anisotropic formations. The ARC tool also carries the standard APWD tool.

Measurement-while-Drilling (MWD) Tool

During the GOM-JIP project, two different MWD tools were deployed: the TeleScope (in the AT 13-1 and AT 14-1 wells) and Power Pulse (in the KC 151-2 well) measurement tools. The MWD data are transmitted by means of a pressure wave (mud pulsing) through the fluid within the drill pipe. Both of the MWD tools operate by generating a continuous mud-wave transmission within the drilling fluid and by changing the phase of this signal (frequency modulation) to convert relevant bit words representing information from various sensors. Two pressure sensors were attached to the standpipe (one near the top and the second near the bottom) on the rig floor and was used to measure the pressure wave acting on the drilling fluid when information is transmitted up the drill pipe by the MWD tool (Table 1). With the MWD mud pulsing systems, pulse rates range from 1 to 6 bits/s, depending primarily on water depth and mud density. In contrast to the real-time data, the downhole memory in the LWD tools records data at a minimum rate of one sample per 15 cm.

LWD/MWD indications of gas

As discussed above, the LWD/MWD tools deployed on the GOM-JIP project allowed for the communication of real-time data to the surface to monitor both drilling performance and physical properties of the sediments penetrated by the drill bit. The data sent (pulsed) to the surface (Table 1), include formation resistivity, natural gamma ray, density-neutron-NMR porosity, APWD measured borehole pressures, and other drilling performance information. One of the primary goals of the LWD/MWD monitoring program during drilling will be to predict and detect the presence of sedimentary sections in the borehole that have the potential to release or flow gas into the borehole. Results of previous gas hydrate drilling programs, such as ODP Legs 146, 164, and 204, have shown that gas-hydrate-bearing sections do not represent a significant threat to drilling operations and that as long as the hole is advanced at relatively normal drilling rates with mud temperatures near that of the deeper water column we do not see significant gas flows from gas-hydrate-bearing formations. However, the real concern of the LWD/MWD monitoring program will be the recognition of free-gas intervals below the base of the gas hydrate stability zone (i.e., BSR) with the potential to flow. With the pulsed LWD/MWD data, it is possible to identify a set of downhole measurements to detect the occurrence of free-gas-bearing sedimentary sections below the base of the gas hydrate stability zone. The LWD/MWD responses considered in this well monitoring program are listed below:

(1) One of the most important criteria for identifying a potential free gas zone in a borehole with LWD/MWD data is the recognition of porous sand units that could host enough gas to actually

enter the borehole. One of the best first indicators of "reservoir" quality sands would be the response of the natural gamma ray log on the GVR6 (resistivity-at-bit) LWD tool. The expected gamma ray response to a sand section, relative to a shale-base-line, will vary from one area to another; but a relative gamma ray increase over base-line of about 50 API units would be indicative of a possible "reservoir" quality sand section.

(2) Beyond the identification of potential "reservoir" quality sand sections it is also possible to use the pulsed LWD/MWD data to directly detect the presence of gas in the penetrated section. Within this project, MMS and the project partners have defined a set of LWD/MWD measurements indicative of gas-bearing sediments. A log identified sedimentary section more then 5-m-thick with resistivities more than five times over background has been defined as a gas-bearing sedimentary section with the potential to flow.

(3) In standard downhole log analysis, neutron-density porosity log data is often used to indicate the presence of gas-bearing zones. Neutron porosity logs image gas-bearing sediments by apparent reductions in measured porosities. A relative shift in recorded neutron porosities of about 10%, generally indicate the presence of a gas-bearing zone with the potential to flow.

(4) But it needs to be highlighted that the first most important indicator of fluid flow into the formation would likely be detected as a borehole pressure change recorded by the APWD tool.

During the GOM-JIP project, the above described downhole measured criteria were monitored to identify potential gas-bearing zones that may represent drilling hazards. No "significant" gas-bearing zones were encountered in this project. However, we did experience shallow water flows with limited gas in both the KC 151-2 and 151-3 wells. MMS required that if a free gas zone or shallow flow was encountered, the well will be filled with 12.0 ppg mud, drilling will be ceased for this particular well and an abandonment procedure will be initiated. In the case of the KC 151-3 well a cement plug was set near the surface.

Nuclear Magnetic Resonance While-Drilling (ProVision) Tool

The basic technology behind the ProVision nuclear magnetic resonance tool is similar to modern wireline nuclear magnetic resonance technology, based on measurement of the relaxation time of the magnetically induced precession of polarized protons. A combination of bar magnets and directional antennas are used to focus a pulsed, polarizing field into the formation. The ProVision tool measures the relaxation time of polarized molecules in the formation, which is suited to provide information related to the formation porosity. By exploiting the nature of the chemical bonds within pore-fluids, for hydrogen in particular, the ProVision tool can provide estimates of the total porosity and bound fluid volume, and thus be useful to determine whether water, gas, or gas hydrates are present in the formation.

During the GOM-JIP project, the ProVision tool acquired formation and engineering information in memory and transmitted some data to the surface via MWD. The relaxation time spectra was recorded downhole and total porosity estimates were be transmitted to the surface in real time. These spectra were stacked in post-processing to improve the measurement precision. The signal investigates a 15-cm cylindrical volume of the borehole, and for a 8-1/2" bit size, the depth of investigation of the measurement is ~5 cm into the formation. Lateral tool motion may reduce ProVision data quality in some circumstances. Therefore, accelerometers and magnetometers contained in the downhole tool are used to evaluate data quality and determine the maximum relaxation times that can be resolved.

Vision Density Neutron (VDN) Tool

The VDN tool is similar in principle to the Azimuthal density neutron (ADN) tool. The density section of the tool uses a 1.7-Ci 137Cs gamma ray source in conjunction with two gain-stabilized scintillation detectors to provide a borehole-compensated density measurement. The detectors are located 5 and 12 in (12.7 and 30.48 cm) below the source. The number of Compton scattering collisions (change in gamma ray energy by interaction with the formation electrons) is related to the formation density. Returns of low energy gamma rays are converted to a photoelectric effect value, measured in barns per electron. The photoelectric effect value depends on electron density and hence responds to bulk density and lithology. It is particularly sensitive to low-density, high-porosity zones.

The density source and detectors are positioned behind holes in the fin of a full gauge clamp-on stabilizer. This geometry forces the sensors against the borehole wall, thereby reducing the effects of borehole irregularities and drilling. The vertical resolution of the density and photoelectric effect measurements is about 15 and 5 cm, respectively. For measurement of tool standoff and estimated borehole size, a 670-kHz ultrasonic caliper is available on the VDN tool. The ultrasonic sensor is aligned with and located just below the density detectors. In this position the sensor can also be used as a quality control for the density measurements. Neutron porosity measurements are obtained using fast neutrons emitted from a 10-Ci americium oxide-beryllium (AmBe) source. Hydrogen quantities in the formation largely control the rate at which the neutrons slow down to epithermal and thermal energies. The energy of the detected neutrons has an epithermal component because much of the incoming thermal neutron flux is absorbed as it passes through the 1-in drill collar. Neutrons are detected in near- and far-spacing detector banks, located 12 and 24 in (30.48 and 60.96 cm), respectively, above the source. The vertical resolution of the tool under optimum conditions is ~34 cm. The neutron logs are affected to some extent by the lithology of the matrix rock because the neutron porosity unit is calibrated for a 100% limestone environment. Neutron logs are processed to eliminate the effects of borehole diameter, tool size, temperature, drilling mud hydrogen index (dependent on mud weight, pressure, and temperature), mud and formation salinities, lithology, and other environmental factors.

In near-vertical drill holes, the VDN tool does not collect quadrant azimuthal data. Data output from the VDN tool includes apparent neutron porosity (i.e., the tool does not distinguish between pore water and lattice-bound water), formation bulk density, and photoelectric effect. In addition, the VDN tool outputs a differential caliper record based on the standard deviation of density measurements made at high sampling rates around the circumference of the borehole. The measured standard deviation is compared with that of an in gauge borehole, and the difference is converted to the amount of borehole enlargement. A standoff of <1 inch between the tool and the borehole wall indicates good borehole conditions, for which the density log values are considered to be accurate to ±0.015 g/cm^3.

Conventional Wireline Logging Operations

Conventional wireline (CWL) logging operations in the Gulf of Mexico Gas Hydrate JIP Drilling Program (GOM-JIP) was scheduled to include the deployment of a signal logging string (Figure 2) and a vertical seismic profiling (VSP) tool (Figure 3) in several of the Atwater Valley and Keathley Canyon drill sites. The only wireline logging tool deployed was the FMS-sonic tool string, which consisted of the Formation MicroScanner (FMS), a general purpose inclinometer tool (GPIT), and the dipole shear sonic imager tool (DSI). The FMS-sonic tool also included a natural gamma ray tool to provide a reference log to correlate depths between different log runs. The vertical seismic imager tool (VSI) was also deployed during the GOM-JIP drilling program. Neither the FMS-sonic tool string nor the VSI tool were run in each hole; refer to individual site chapters for details of which holes were logged. The wireline logging tools were provided by Schlumberger Technology Corporation.

Early in the planning phase for the GOM-JIP drilling project, considerable effort was made to assess the use of existing LWD acoustic logging technology for logging near-surface, relatively acoustically "slow", formations. It was decided that emerging quadrapole acoustic LWD logging technology may theoretically yield both compressional- and shear-wave data form these slow formations, it could not be conclusively proven that we would acquire the needed acoustic data. Thus, it was decided to move ahead with plans for a conventional wireline logging program with the DSI, which has been used in the past to obtain both compressional- and shear-wave acoustic log data in very slow formations during ODP and IODP operations.

Dipole Shear Sonic Imager Tool

The DSI tool employs a combination of monopole and dipole transducers to make accurate measurements of sonic wave propagation in a wide variety of formations. In addition to a robust and high-quality measurement of compressional wave velocity, the DSI excites a flexural mode in the borehole that can be used to estimate shear-wave velocity even in highly unconsolidated formations. When the formation shear velocity is less than the borehole fluid velocity, particularly in un-consolidated sediments, the flexural wave travels at the shear-wave velocity and is the most reliable way to estimate a shear velocity log. Meanwhile, the omni-directional source generates compressional, shear, and Stoneley waves into hard formations. The configuration of the DSI also allows recording of both in-line and cross-line dipole waveforms. In many cases the dipole sources can yield estimates of shear wave velocity in hard rocks better than or equivalent to the monopole source. These combined modes can be used to estimate shear-wave splitting caused by preferred mineral and/or structural orientation in consolidated formations. A low-frequency (80 Hz) source enables Stoneley waveforms to be acquired as well.

DSI measures the transit times between sonic transmitters and an array of eight receiver groups with 15-cm spacing, each consisting of four orthogonal elements that are aligned with the dipole transmitters. During acquisition, the output from these 32 individual elements are differenced or summed appropriately to produce in-line and cross-line dipole signals or monopole-equivalent (compressional and Stoneley) waveforms, depending on the operation modes. In the GOM-JIP drilling program we followed standard GOM practices and the DSI logs were recorded for Stoneley, monopole compressional- and shear-waves, and both crossed receivers (BCR) modes; with the main pass ran at "low" frequency and a second pass conducted at "standard" frequency.

Formation MicroScanner Tool

The FMS produces high-resolution images of borehole wall micro-resistivity that can be used for detailed sedimentologic or structural interpretation. This tool has four orthogonally oriented pads, each with 16 button electrodes that are pressed against the borehole walls. Good contact with the borehole wall is necessary for acquiring good-quality data. Approximately 30% of a borehole with a diameter of 25 cm is imaged during a single pass. The vertical resolution of FMS images is ~5 mm, allowing features such as burrows, thin beds, fractures, veins, and vesicles to be imaged. The resistivity measurements are converted to color or grayscale images for display. FMS images are oriented to magnetic north using the GPIT (General Purpose Inclinometer Tool). This allows the dip and strike of geological features intersecting the hole to be measured from processed FMS images. FMS images can be used to visually compare logs with the core to ascertain the orientations of bedding, fracture patterns, and sedimentary structures and to identify stacking patterns, and in some cases to identify gas-hydrate-bearing sedimentary sections.

Because of problems experienced trying to log out of the drill pipe in AT 13-2, the FMS was removed for the only other CWL run in KC 151-3.

General Purpose Inclinometer Tool

The GPIT is included in the FMS-sonic tool string to calculate tool acceleration and orientation during logging. The GPIT contains a triple-axis accelerometer and a triple-axis magnetometer. The GPIT records the orientation of the FMS images and allows more precise determination of log depths than can be determined from cable length, which may experience stretching and/or be affected by ship heave.

Vertical Seismic Imager (VSI)

The Vertical Seismic Imager (VSI-4) is a borehole seismic wireline tool optimized for obtaining vertical and walkaway seismic profiles (VSP; W-VSP) in both cased hole and open hole, vertical, and deviated wells. The VSI consists of multiple three-axis geophones in series separated by "hard wired", acoustically-isolating spacers. A schematic illustration of the tool is given in Figure 3. The tool diameter is 3 3/8 inches, with temperature and pressure ratings to 175 °C and 20,000 psi, respectively.

During the GOM-JIP drilling program, the VSI was configured using four geophone shuttles (approximately 7 ft (2.06 m) spacing with rigid interconnections) and combined with a natural gamma ray tool. Only one vertical incident or zero-offset VSP experiment was conducted during the GOM-JIP drilling program; in the KC 151-3 well. During the vertical incidence VSP operations in the KC 151-33 well, the shuttles were mechanically clamped against the borehole wall and the source (1520 cubic inch guns in a Dual Itaga Air Gun Array) on the *Uncle John* was fired between 6 and 10 times by control hardware in the Schlumberger logging unit. The VSI tool was then unclamped and pulled 28 ft (8.5 m) uphole, maintaining a 7 ft (2.06 m) receiver station depth spacing throughout the hole. The VSI records the full seismic waveform for each firing. These waveform data are stacked by the Schlumberger recording software and output in both LDF (internal Schlumberger format) and SEG-Y formats.

Logging Data Flow and Processing

Data for each LWD and CWL logging run were recorded and stored digitally and monitored in real time as the data was acquired. After logging was completed, the data were transferred first to Schlumberger Anadrill and wireline services for compilation and data quality check. The Provision NMR data was processed by Anadrill and returned to the ship during the cruise. The final and complete field data sets were than transferred to the LDEO-BRG for processing. Data processing at LDEO-BRG consists of (1) depth-shifting all logs relative to a common datum (i.e., mbsf), (2) corrections specific to individual tools, and (3) quality control and rejection of unrealistic or spurious values. Once processed at LDEO-BRG, log data will be made available to the JIP members and project scientist through either the JIP website or direct transfers via DVDs.

Logging data quality may be seriously degraded by changes in the hole diameter and in sections where the borehole diameter greatly decreases or is washed out. Deep-investigation measurements such as resistivity and sonic velocity are least sensitive to borehole conditions. Nuclear measurements (density and neutron porosity) are more sensitive because of their shallower depth of investigation and the effect of drilling fluid volume on neutron and gamma ray attenuation. Corrections can be applied to the original data in order to reduce these effects. The effects of very large washouts, however, cannot be corrected. Logs from the LWD and CWL tool strings will have minor depth mismatches caused by that fact that the data was obtained in two different holes at each site surveyed. A gamma ray log has been included in each tool run to correlate the log data between each at hole within a drill site. Because of technical difficulties, the CWL surveys were conducted without heave compensation. In the case of the Atwater Valley LWD holes, the drill-string heave compensator was not used during LWD operations.

Gas Hydrate Detection and Evaluation

With growing interest in natural gas hydrate, it is becoming increasingly important to be able to identify the occurrence of *in-situ* gas hydrate and accurately assess the volume of gas hydrate and included free gas within gas-hydrate accumulations. Numerous publications (Mathews, 1986; Collett, 1993, 1998a, 1998b, 2001; Goldberg, 1997; Guerin et al., 1999; Goldberg et al., 2000; Helgerud et al., 2000) have shown that downhole geophysical logs can yield information about the occurrence of gas hydrate.

Since gas hydrates are characterized by unique chemical compositions and distinct electrical resistivities, physical and acoustic properties, it is possible to obtain gas-hydrate saturation (percent of pore space occupied by gas hydrate) and sediment porosity data by characterizing the electrical resistivity, acoustic properties, and chemical composition of the pore-filling constituents within gas-hydrate-bearing reservoirs. Two of the most difficult reservoir parameters to determine are porosity and the degree of gas-hydrate saturation. Downhole logs often serve as a source of porosity and hydrocarbon saturation data. Most of the existing gas hydrate log evaluation techniques are qualitative in nature and have been developed by the extrapolation of untested petroleum industry log evaluation procedures. To adequately test the utility of standard petroleum log evaluation techniques in gas-hydrate-bearing reservoirs would require numerous laboratory and field measurements. However, only a limited number of gas hydrate occurrences have been sampled and surveyed with open-hole logging devices.

Reviewed below are downhole log measurements that yield useful gas hydrate reservoir information. The downhole measurements considered include gamma-gamma density, neutron porosity, electrical resistivity, acoustic transit-time, and nuclear magnetic resonance.

Gamma-Gamma Density Logs

Density logs are primarily used to assess sediment porosities. The theoretical bulk-density of a Structure-I methane hydrate is about 0.9 g/cm^3 (Sloan, 1998). Gas hydrate can cause a small but measurable effect on density-derived porosities. At relatively high porosity (>40%) and high gas-hydrate saturation (>50%), the density-log-derived porosities need to be corrected for the presence of gas hydrate (Collett, 1998b).

Neutron Porosity Logs

Neutron logs are also used to determine sediment porosities. Since Structure-I methane hydrate and pure water have similar hydrogen concentrations it can be generally assumed that neutron porosity logs, which are calibrated to pure water, are not significantly affected by the presence of gas hydrates. At high reservoir porosities, however, the neutron porosity log could overestimate porosities (Collett, 1998b).

Electrical Resistivity

Water content and pore-water salinity are the most significant factors controlling the electrical resistivity of a formation. Other factors influencing resistivity of a formation include the concentration of hydrous and metallic minerals, volume of hydrocarbons including gas hydrates, and pore structure geometry. Gas-hydrate-bearing sediments exhibit relatively high electrical-resistivities in comparison to water-saturated units, which suggests that a downhole resistivity log can be used to identify and assess the concentration of gas hydrates in a sedimentary section. The relation between rock and pore-fluid resistivity has been studied in numerous laboratory and field experiments. From these studies, relations among porosity, pore-fluid resistivity, and rock resistivity have been found. Among these findings is the empirical relation established by Archie

(Archie, 1942), which is used to estimate water saturations in gas-oil-water-matrix systems. Research has shown that the Archie relation also appears to yield useful gas-hydrate saturation data (reviewed by Collett, 2001).

Acoustic transit-time

The velocity of compressional and shear acoustic waves in a solid medium, such as gas-hydrate-bearing sediment, is usually several times greater than the velocity of compressional and shear acoustic waves in water or gas-bearing sediments. Studies of downhole acoustic log data from both marine and permafrost associated has hydrate accumulations have shown that the volume of gas hydrate in sediment can also be estimated by measuring interval velocities (Guerin et al., 1999; Helgerud et al., 2000; Collett, 2001; Guerin and Goldberg, 2002).

Nuclear Magnetic Resonance Logs

Nuclear magnetic resonance (NMR) logs use the electromagnetic properties of hydrogen molecules to analyze the nature of the chemical bonds within pore-fluids. Relative to other pore-filling constituents, gas hydrates exhibit unique chemical structures and hydrogen concentrations. In theory, therefore, it should be possible to develop NMR well-log evaluation techniques that would yield accurate reservoir porosities and water saturations in gas-hydrate-bearing sediments. Because of tool design limitations, gas hydrates cannot be directly detected with today's downhole NMR technology; however, they can be useful to yield very accurate gas-hydrate saturation estimates. Due to the short transverse magnetization relaxation times (*T2*) of the water molecules in the clathrate, gas hydrates are not "seen" by the NMR tool and may be assumed to be part of the solid matrix. Thus, the NMR-calculated total porosity in a gas-hydrate-bearing sediment should be lower than the actual porosity. With an independent source of accurate total porosity, such as density- or neutron-porosity-log measurements, it should be possible to accurately estimate gas-hydrate saturations by comparing the apparent NMR-derived porosity to the total density-derived porosity.

References

Archie, G.E., The electrical resistivity log as an aid in determining some reservoir characteristics. Journal of Petroleum Technology, v. 5, p. 1-8, 1942.

Collett, T.S., Natural gas hydrates of the Prudhoe Bay and Kuparuk River area, North Slope, Alaska: American Association of Petroleum Geologists Bulletin, v. 77, no. 5, p. 793-812, 1993.

Collett, T.S., Well log evaluation of gas hydrate saturations. Transactions of the Society of Professional Well Log Analysts, Thirty-Ninth Annual Logging Symposium, May 26-29, 1998, Keystone, Colorado, USA, Paper MM, 1998a.

Collett, T.S., Well log characterization of sediment porosities in gas-hydrate-bearing reservoirs. Proceedings of the 1998 Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, September 27-30, 1998, New Orleans, Louisiana, USA, 12 p. (CD-ROM), 1998b.

Collett, T.S., A review of well-log analysis techniques used to assess gas-hydrate-bearing reservoirs: In Natural Gas Hydrates: Occurrence, Distribution, and Detection, American Geophysical Union, Geophysical Monograph 124, p. 189-210, 2001.

Goldberg, D., The role of downhole measurements in marine geology and geophysics. Review of Geophysics, v. 35, no. 3, p. 315-342, 1997.

Goldberg, D., Collett. T.S., and Hyndman, R.D., Ground truth: in-situ properties of hydrate. *in* Max, M.D., ed., Natural Gas Hydrate in Oceanic and Permafrost Environments, Kluwer Academic Publishers, The Netherlands, p. 295-310, 2000.

Guerin, G., Goldberg, D., and Melster, A., Characterization of in situ elastic properties of gas hydrate-bearing sediments on the Blake Ridge. Journal of Geophysical Research, v. 104, 17,781-17,795, 1999.

Guerin, G., and D. Goldberg, Sonic attenuation measurements in the Mallik 2L-38 gas hydrates research well, MacKenzie Delta, NWT Canada, Journal of Geophysical Research, v. 107, 2002.

Helgerud, M.B., Dvorkin, J., and Nur, A., Rock physics characterization for gas hydrate reservoirs, elastic properties. In Holder, G.D., and Bishnoi, P.R., eds., Gas Hydrates, Challenges for the Future, Annals of the New York Academy of Sciences, v. 912, p. 116-125, 2000.

Mathews, M., Logging characteristics of methane hydrate. The Log Analyst, v. 27, no. 3, p. 26-63, 1986.

Sloan, E.D., 1998. Clathrate hydrates of natural gases. Marcel Dekker Inc. Pub., New York, pp. 641.

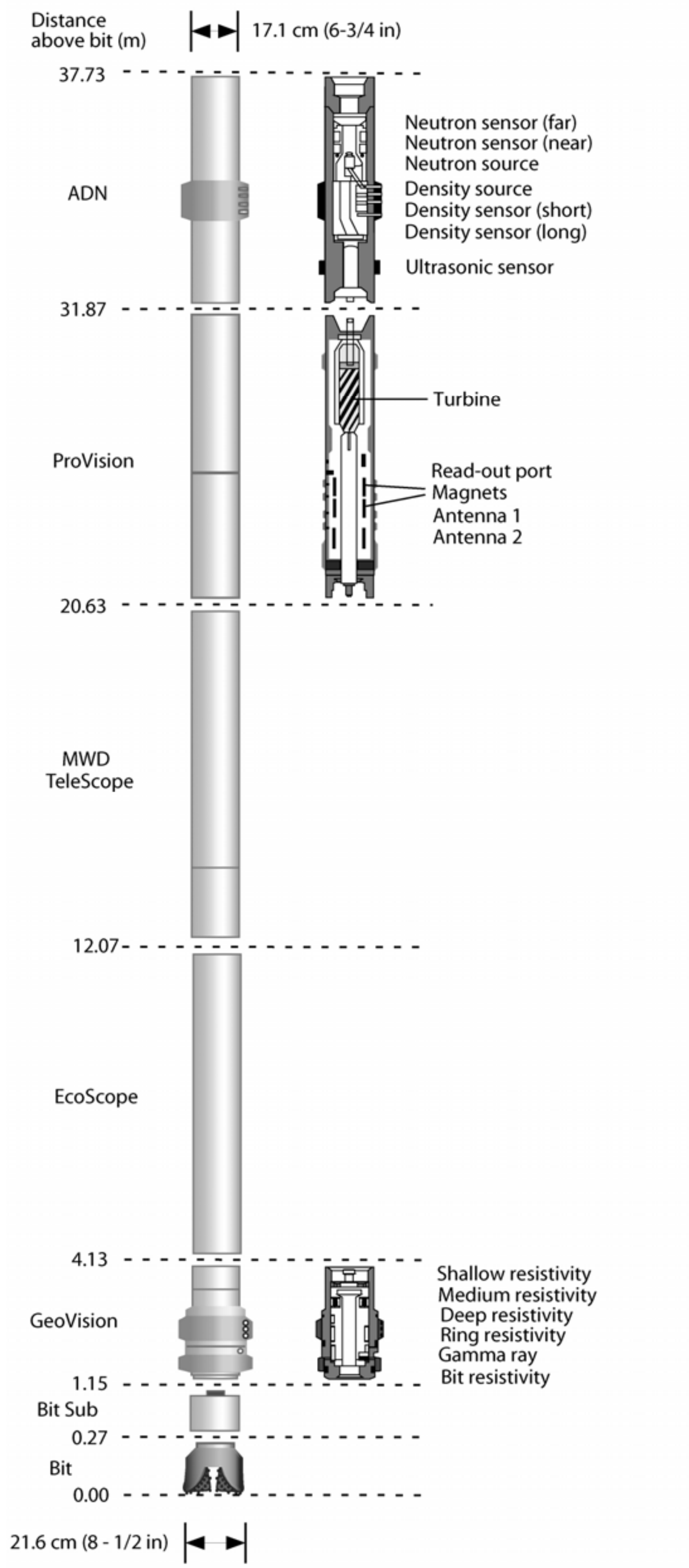

Figure 1. Configuration of the drill string used for LWD-MWD operations

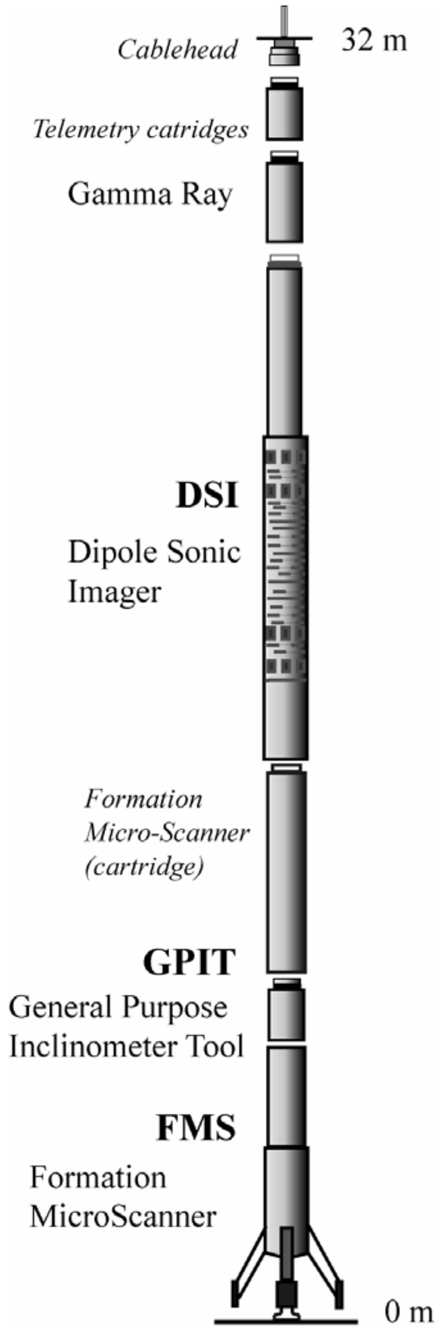

Figure 2. Configuration of the FMS-sonic CWL tool string

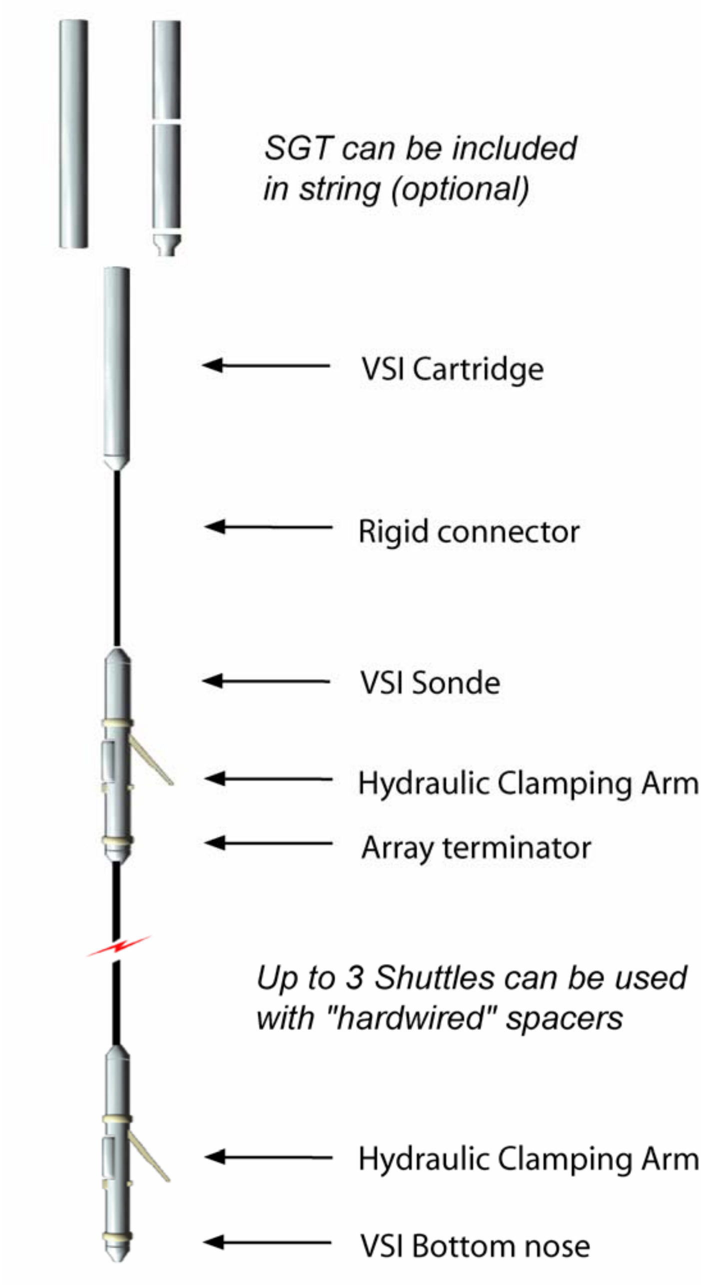

Figure 3. Configuration of the VSI wireline tool string

Table 1. Frame Builder Power Frame listing of Data-Points (Dpoint) for pulsed real time data for both Atwater Valley LWD/MWD holes drilled during the GOM-JIP gas hydrate research drilling and coring leg (ROP 100 ft/hr; Bit rate 12.00 bps).

Mtfs	ATMP_v
GRRA_r	GRRA_r
APRS_v	IDPE_a
RBIT_r	RBIT_r
RING_r	RING_r
RDBA_r	RDBA_r
MON_v	Shock_i
IDRO_a	IDRO_a
IDDR_a	IDDR_a
TNRA_a	TNRA_a
C_SPEC_v	SRFA_v
RA40B_v	DCAV_a
DCAV_a	Shkrsk
Tur_rpm	DCAV_v
BFV1C_m	IDRO_v
MRP1C_m	Itbrt
MRTCRPM_m8	A_jam

ChevronTexaco GOM Gas Hydrate JIP Drilling Program

Atwater Valley 13-1

OCS-G-24203

-LOGGING WHILE DRILLING-

Prepared by Timothy S. Collett, U.S. Geological Survey

May 21, 2005

Operations

LWD operations (Table 1) began at the Atwater Valley 13-1 (AT 13-1) drill site on April 19, 2005 at 00:28 CT with initial BHA make-up, tool initialization, and calibration. The LWD tools (6-3/4" collars) included the resistivity-at-the-bit GeoVision tool (GVR6) with a 8-1/8" button sleeve, the EcoScope tool (DVD with APWD), a MWD tool (Telescope), a magnetic resonance while drilling tool (MWD-ProVision), and the azimuthal density neutron (VDN) tool. Figure-1 in the *Explanatory Notes* shows the configuration of the LWD/MWD bottom hole assembly (BHA). Memory and battery life allowed for at least six days of continuous drilling. Atwater Valley 13-1 was spudded at 23:00 CT (April 19, 2005) at a drillers water depth of 1,303.7 mbrf to the northwest of the seismic inferred surface Mound F in Atwater Valley Block 14. The ROV from the *Uncle John* was used to position the BHA and monitor the drilling operations at the sea floor throughout the drilling of the AT 13-1 well. The drill-string heave compensator was not used during LWD operations at AT 13-1. For the most part the AT 13-1 well was drilled with only sea water as the drilling fluid, but as the hole was advanced periodic sweeps of Attapulgite based drilling mud was used to sweep and stabilize the hole.

In an attempt to acquire high quality resistivity-at-bit log and image data within the near-surface sedimentary section, we implemented a controlled spud in drilling protocol which consisted of drilling at a low mud flow rate of about 100 gpm (33 strokes per minute), a limited penetration rate of less than 30 m/hr (which was actually maintained at about 35 m/hr), and a spud in bit rotation rate of 50 RPM. It is important to note that the turbine powered tools on the BHA, including the DVD, MWD, ProVision, and the VDN do not operate at a flow rate of less than about 230 gallons per minute. At a depth about 25 mbsf the mud pump rates were increased to 240 GPM to turn-on the turbine powered tools in the BHA. However, in this case a flow rate of 300 GPM was required to activate the turbine powered tools, based on assumed pump efficiency of three gallons per pump stroke; which could not verified.

Below 25 mbsf, the hole was advanced at an instantaneous rate of approximately 20-30 m/hr to a TD at 246.3 mbsf without significant difficulty and real-time data were transmitted to the surface throughout the drilling of the well. The AT 13-1 well was TD early because of hole clearing problems and because all of our science objectives were achieved. Some extraneous pump noise affected the data transmission, but caused minimal real-time data loss. The BHA was pulled back to sea floor while running a sweep of heavy drilling mud. The tools were pulled out of the hole at 08:30 CT on April 21, 2005 and the recorded LWD data were retrieved at the rig floor at 14:30 CT on April 24, 2005 after drilling the AT 14-1 well.

Log Quality

After the completion of LWD operations in the AT 13-1 well, a highly reduced version of the “primary” set of downhole recorded well log data was transferred to the onboard science party for initial analysis. For this report, we have loaded this primary data set into Microsoft Excel and generated a series of well log displays; which has been included with this report (Figures 1-13).

The target rate-of-penetration (ROP) of 30 m/hr (± 5 m/hr) in the interval from the seafloor to total depth (TD) was generally achieved (Figure 1). Using slow drilling rates enhanced the quality of the NMR porosity data and RAB images. The quality of RAB images is quite high and no significant resolution loss is observed with variation in ROP in the AT 13-1 well.

The caliper log (DCAV), which provides a measurement of the diameter of the borehole as recorded by the VDN density tool is the best indicator of borehole conditions (Figure 4). The calculated differential caliper values (assuming a bit size of 8-1/2 inches) are <1 inch over 78% of the total section in AT 13-1. With the uppermost 25 mbsf of the hole showing the most sever washouts. The bulk density correction (IDDR), calculated from the difference between the short- and long-spaced density measurements, varies from -0.04 to +0.02 g/cm^3, which shows the high quality of the density measurements (Figure 6). The interval below 158 mbsf shows minor washouts due to borehole breakouts, with caliper measurements up to 13 inches. Reducing BIT and RING electrical resistivity values below 217 mbsf also indicate that the borehole is enlarged (Figures 10 and 11); which was due to a borehole cleaning problem and an increase in mud pump rates to 380 GPM.

The depths, relative to seafloor, for all of the LWD logs were fixed by using the *Uncle John* ROV to identify the actual BHA bit contact with the sea floor and shifting the log data to the appropriate depth as determined by the drillers' pipe tallies. For AT 13-1 it was determined that the seafloor was at a depth of 1303.7 mbrf. The rig floor logging datum was located 13.2 m above sea level for this hole.

Interpretation of LWD Logs

LWD logs along with core analyses reveals that both AT 13-1 and AT 13-2 penetrated mostly a fine-grained clay dominated sedimentary section with no apparent suitable sand reservoir sections. The higher electrical resistivities within the upper 40 m of the well are in part a product of bad borehole conditions, as is the section below 217 mbsf. The high resistivities within the interval 110-140 mbsf appears to be associated with increased formation densities and reductions in core derived pore-water salinities.

On ODP Leg 204, RAB images were proven to be a very useful tool with which to evaluate the occurrence of borehole breakouts, which are the product of differential horizontal stress acting on the borehole; similar breakout features were identified in the RAB image log from the AT 13-1 well.

Log Porosities

Sediment porosities can be determined from analyses of recovered cores and from numerous borehole measurements. Data from the LWD density, neutron, and nuclear magnetic resonance logs have been used to calculate sediment porosities in the AT 13-1 well. The VDN log-derived measurements of bulk-density (Figure 7) in AT 13-1 for the most part ranges from about 1.6 g/cm^3 to 1.8 g/cm^3, with values less than about 1.4 g/cm^3 near the seafloor. The density log measurements are degraded in the upper 25 mbsf, as discussed earlier in this report. The LWD log-derived bulk density measurements from AT 13-1 were used to calculate sediment porosities (∅) using the standard density-porosity relation: $\varnothing=(\rho m-\rho b)/(\rho m-\rho w)$. Water densities ($\rho w$) were assumed to be constant and equal to 1.05 g/cm^3; while the grain/matrix densities (ρm) were assumed to be 2.65 g/cm^3 for each log density porosity calculation. The density-log derived porosities range from about 50 to 70 percent (Figure 8). However, the density log porosities near the top of the hole (above 35 mbsf), ranging from 60 to near 95 percent, is in part controlled by degraded borehole conditions. The LWD neutron porosity log (Figure 9) yielded sediment porosities ranging from an average value at the top of the logged section of about 65% to near 50% at the bottom of the hole. NMR data were transmitted to shore for processing to estimate bound fluid volume and total free fluid porosity and for comparison with neutron, density, and core porosity estimates. The sediment porosities derived by the LWD NMR tool are very similar to the both the density and neutron log derived porosities.

Gas Hydrate

The presence of gas hydrates was not verified at the Atwater Valley 13 drill site by either sampling in the 13-2 well or in the LWD well log data from the 13-1 well. The LWD

GVR6 resistivity tool, however, reveals several thin high-resistivity zones with depth in the 13-1 well, suggesting the possible occurrence of gas hydrate.

Resistivity log data have been used to quantify the amount of gas hydrate at AT 13-1. For the purpose of this discussion, it is assumed that any high resistivities measured in the 13-1 well are due to the presence of gas hydrate. The Archie relation ($S_w=(aR_w/\varnothing^m R_t)^{1/n}$) was used with resistivity data (R_t) from the LWD RAB tool and porosity data ($\varnothing$) from the VDN density tool to calculate water saturations. It should be noted that gas hydrate saturation (S_h) is the measurement of the percentage of pore space in a sediment occupied by gas hydrate, which is the mathematical complement of Archie derived water saturations (S_w), with S_h=1-S_w. For the Archie relation, the formation water resistivity (R_w) was calculated from recovered core water samples and assumed to range from 30 to 38 ppt. Because of the wide range of reported core derived pore water salinities from AT 13-2, a constant pore water salinity of 34.5 ppt (sea water salinity) was assumed to represent the in-situ R_w conditions. The Archie a and m variables were calculated using a cross plot technique (a= 0.44, m= 3.4), which compares the downhole log derived resistivities and density porosities (Figure 12). The APCT temperature data obtained from the AT 13-2 well revealed an equilibrium seabed temperature of 4.37°C and a geothermal gradient of 3.2°C/100m.

The Archie relation for the most part yielded water saturations near 100%, values less than 100% within the near-surface section (above 35 mbsf) are a product of degraded density porosity measurements. The plot of the Archie water saturations also reveal several thin stratigraphic sections with apparent reduced water saturations, which are likely do to the presence of gas hydrate. The most prominent of these zones is at a depth of about 125-128 mbsf. This interval was shown to contain pore-waters with relatively low salinities (near 30 ppt) in the cores from the AT 13-2 well, which could be a product of gas hydrate dissociation pore-water freshening in the recovered cores

A review of the well log data from AT 13-1 shows little evidence of any significant gas hydrate occurrences, other than several thin, possibly stratigraphically controlled, gas-hydrate-bearing intervals. The LWD logs from this site further suggests the presence of a complex pore water fluid regime, with variable well log inferred pore water salinities.

Borehole Temperature and Pressure Data

The APWD measured borehole pressures (DHAP) generally indicate a uniform pressure gradient with depth (Figure 3), with some pressure deviations associated with running heavy mud sweeps near the end of pipe connections. The DHAT temperature log indicates that the circulating fluids were cooled in their descent in the drill pipe to a relatively uniform temperature in the range of 3-7 degrees Celsius (Figure 2).

Table 1. Atwater 13-1 LWD/MWD Logging Program

Water depth: 1303.7m RKB

Drillers TD: 1550.0m RKB

RKB above sea level: 13.2m

Date	Time (CT)	Depth of drill bit (mbrf)*	Event
18-Apr-05	20:30	0.0	Move LWD/MWD tools to pipe rack
	22:20	0.0	Pre-spud and safety meeting
	22:30	0.0	Power check tools
19-Apr-05	0:28	0.0	Begin to pickup LWD/MWD tools
	4:45	0.0	Finish assembling the LWD/MWD BHA
	5:00	0.0	Run tools string to 120 mbrf
	9:00	120.0	Pump test LWD/MWD tool string and run to sea floor
	20:50	1303.7	LWD/MWD reached sea floor
	23:00	1303.7	Spud well, controlled drill 100 GPM, 35 m/hr ROP, 50 RPM
	23:50	1328.0	Bring pump rate up to 240 GPM, than to 300 GPM, MWD tool powered up
20-Apr-05	14:30	1456.0	Bring pump rate up to 380 GPM, for hole clearing
21-Apr-05	6:30	1550.0	Well reaches TD at 246.3 mbsf
	6:35	1550.0	Begin trip of BHA to sea floor, running heavy mud sweep
	8:30	1303.7	BHA clears sea floor

*1m = 3.28084ft

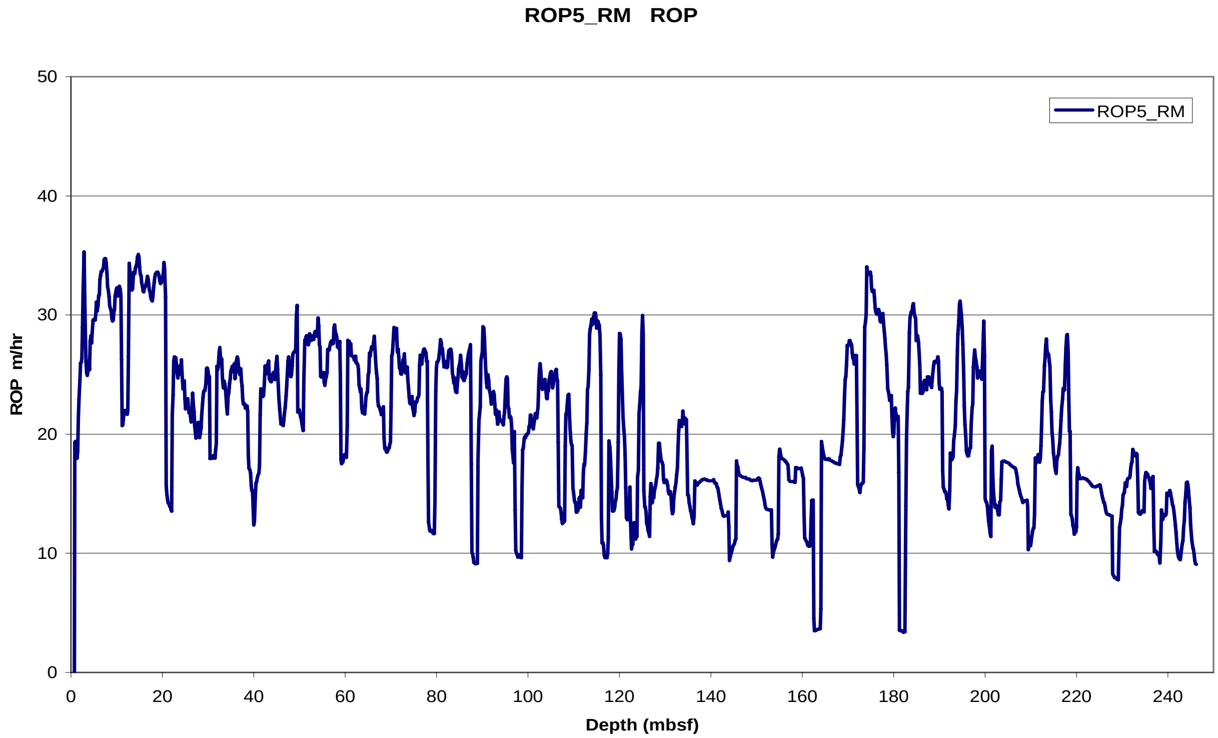

Figure 1. Rate of penetration (ROP) while drilling the AT 13-1 well (recorded data)

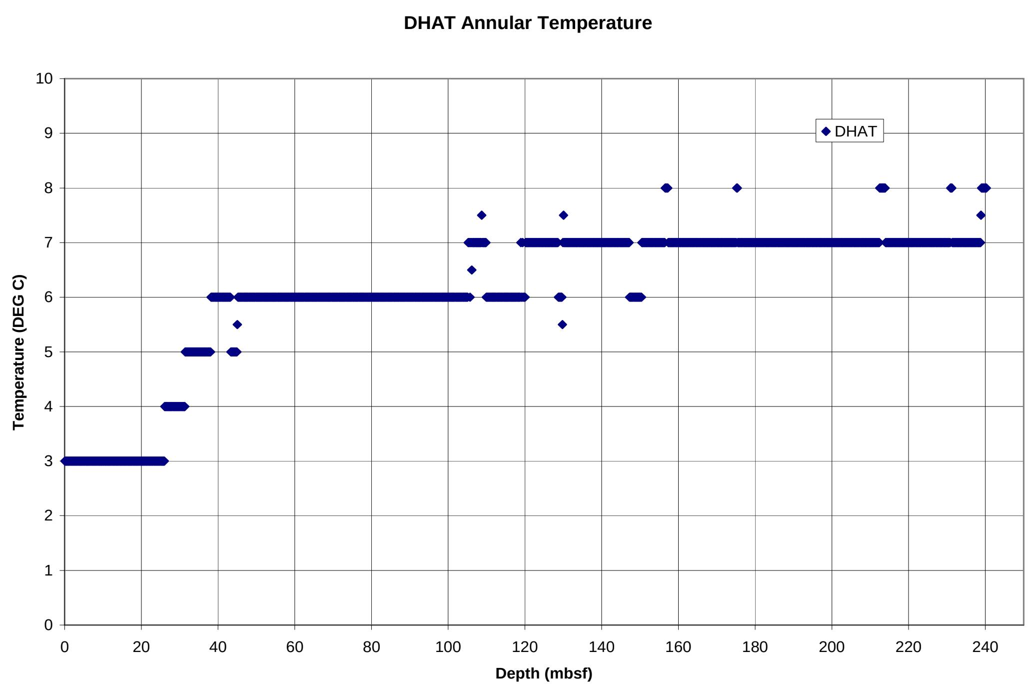

Figure 2. Annular temperature for AT 13-1 from the APWD tool (recorded data)

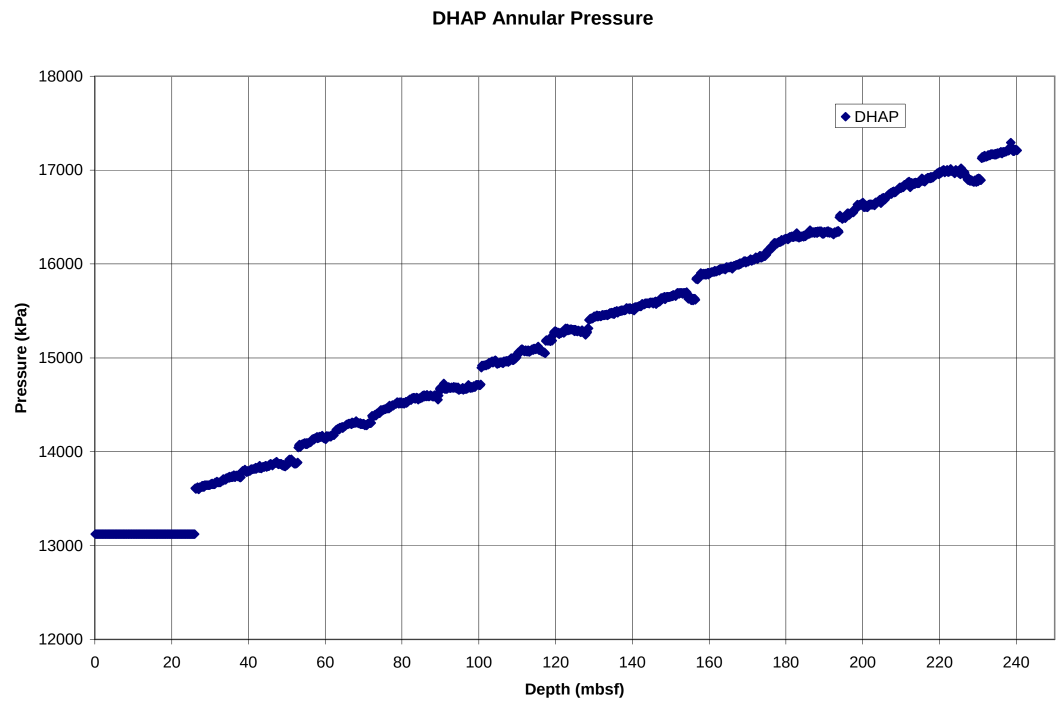

Figure 3. Annular pressure as recorded by the APWD tool in the AT 13-1 well (recorded data)

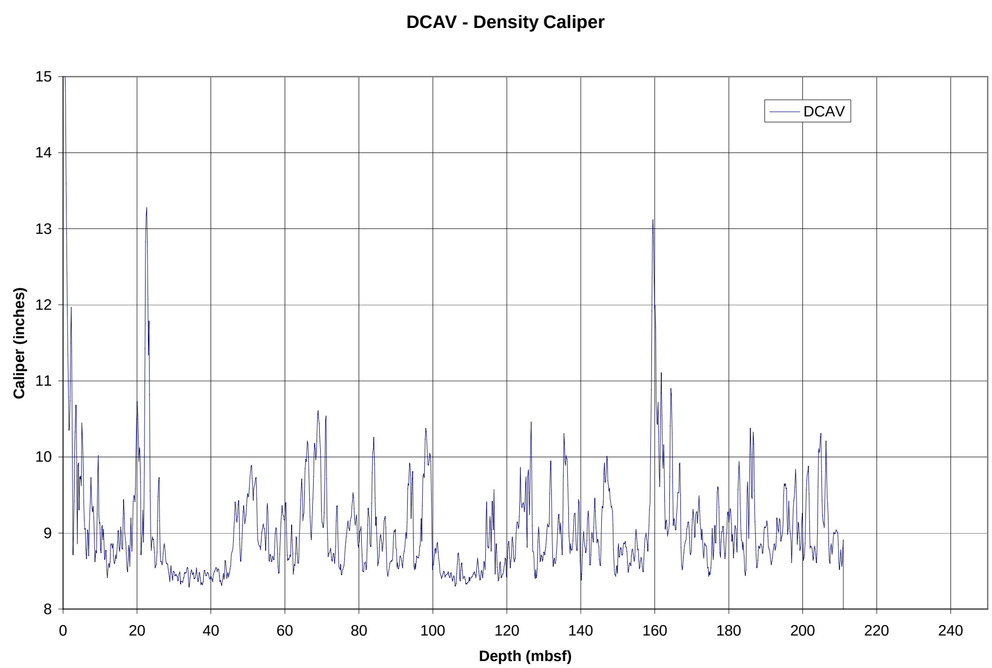

Figure 4. Borehole density caliper as measured by the VDN tool in the AT 13-1 well (recorded data)

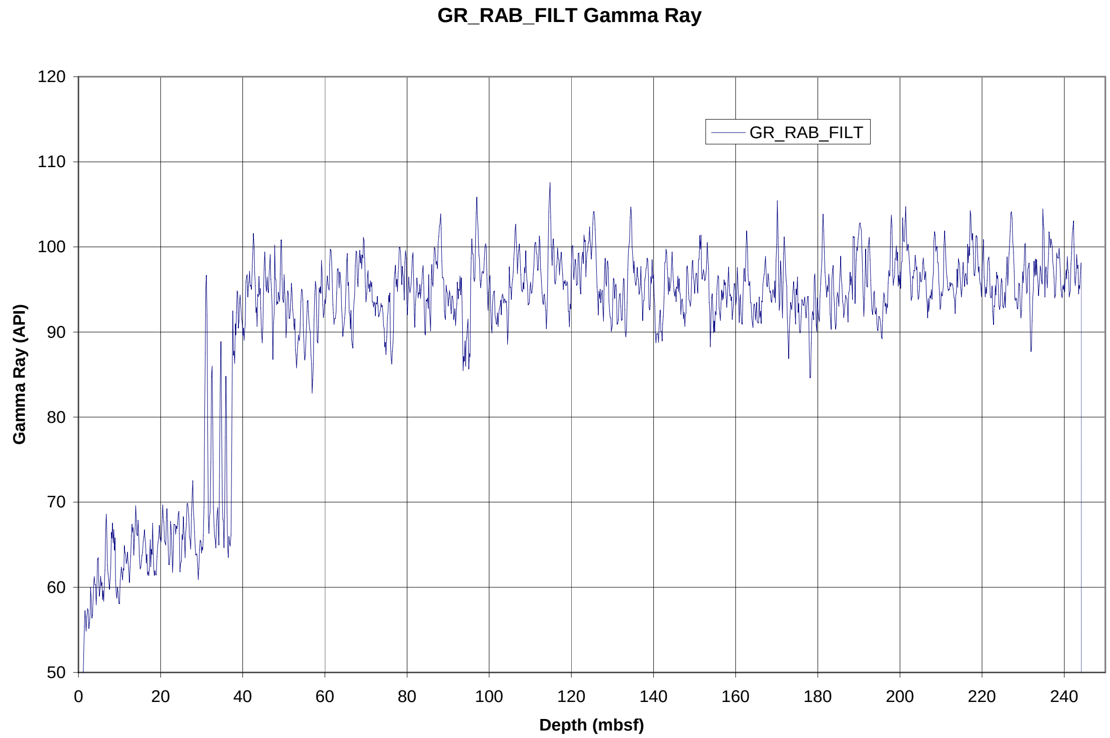

Figure 5. Gamma ray log as measured by GVR6 tool in the AT 13-1 well (recorded data)

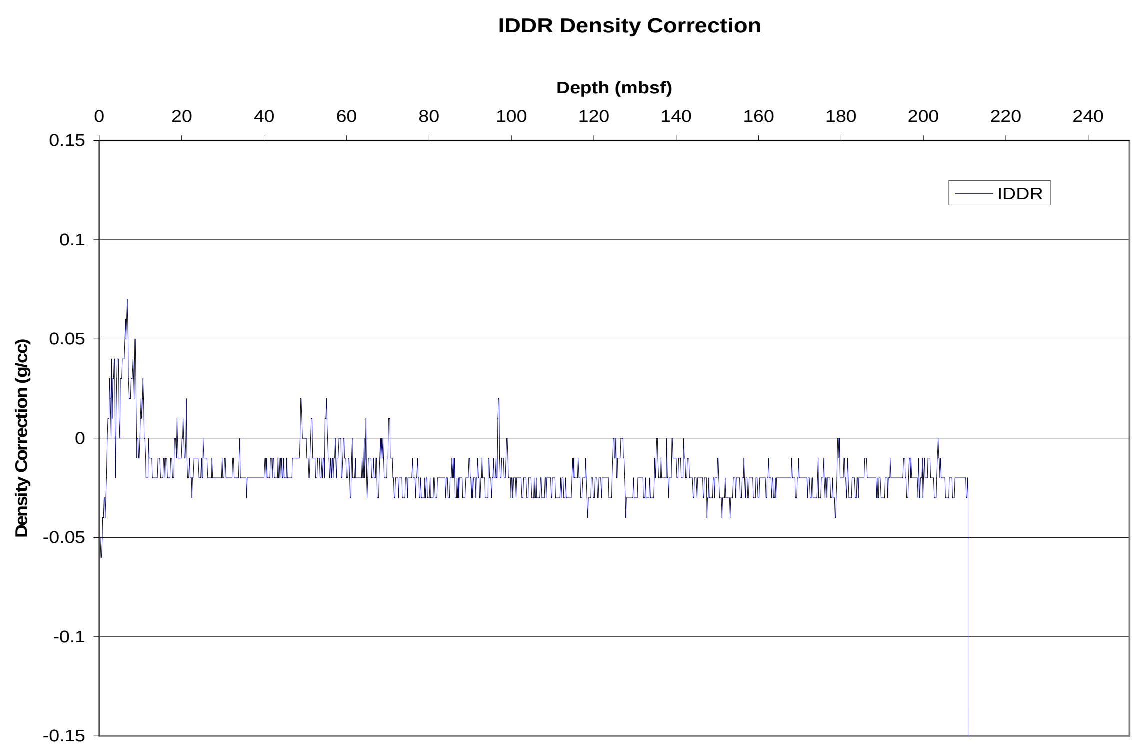

Figure 6. Density log correction for the density log as measured by the VDN tool in the AT 13-1 well (recorded data)

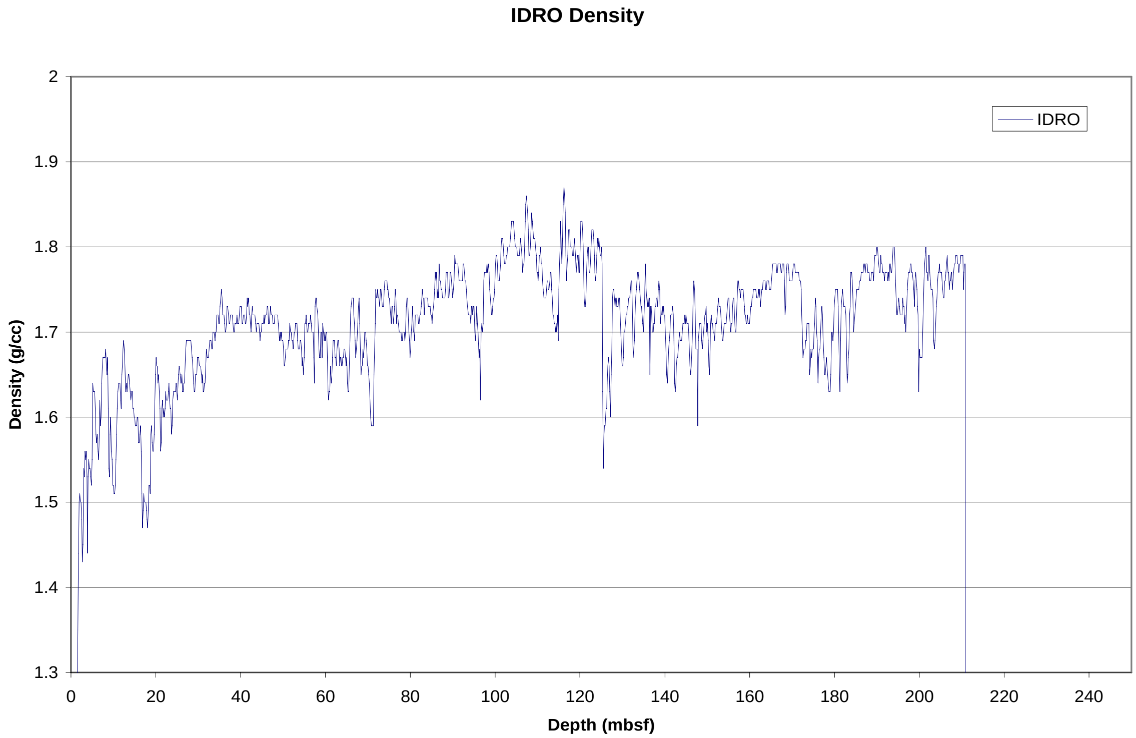

Figure 7. Density log as measured by the VDN tool in the AT 13-1 well (recorded data)

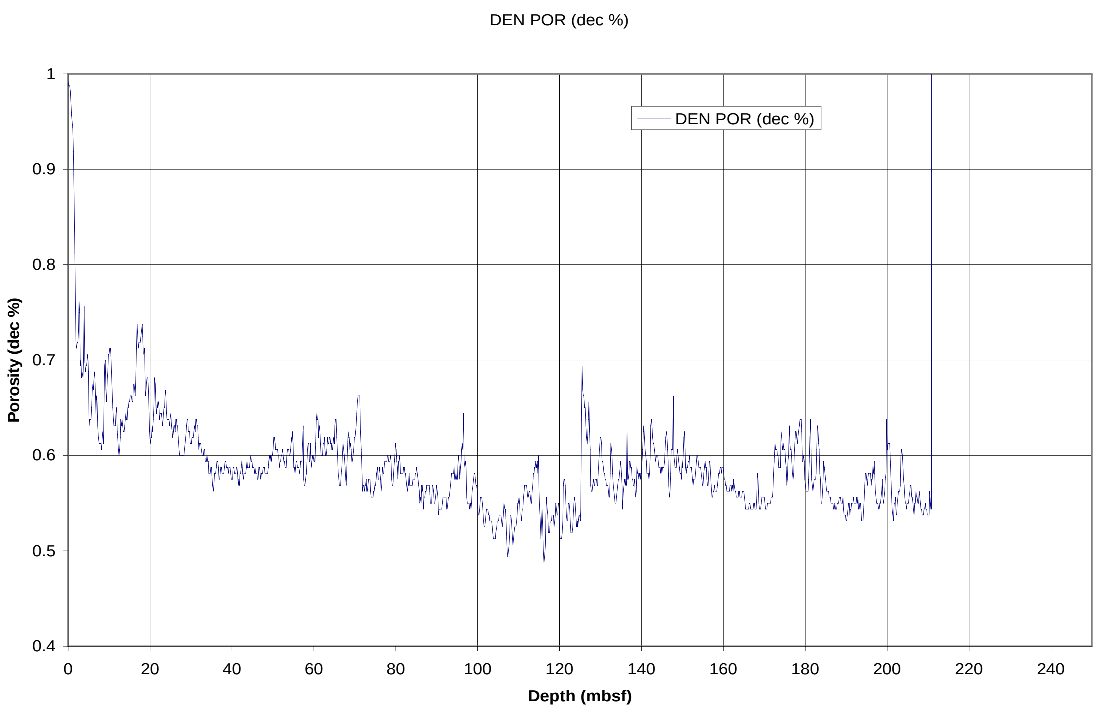

Figure 8. Density log derived porosities in the AT 13-1 well (recorded data)

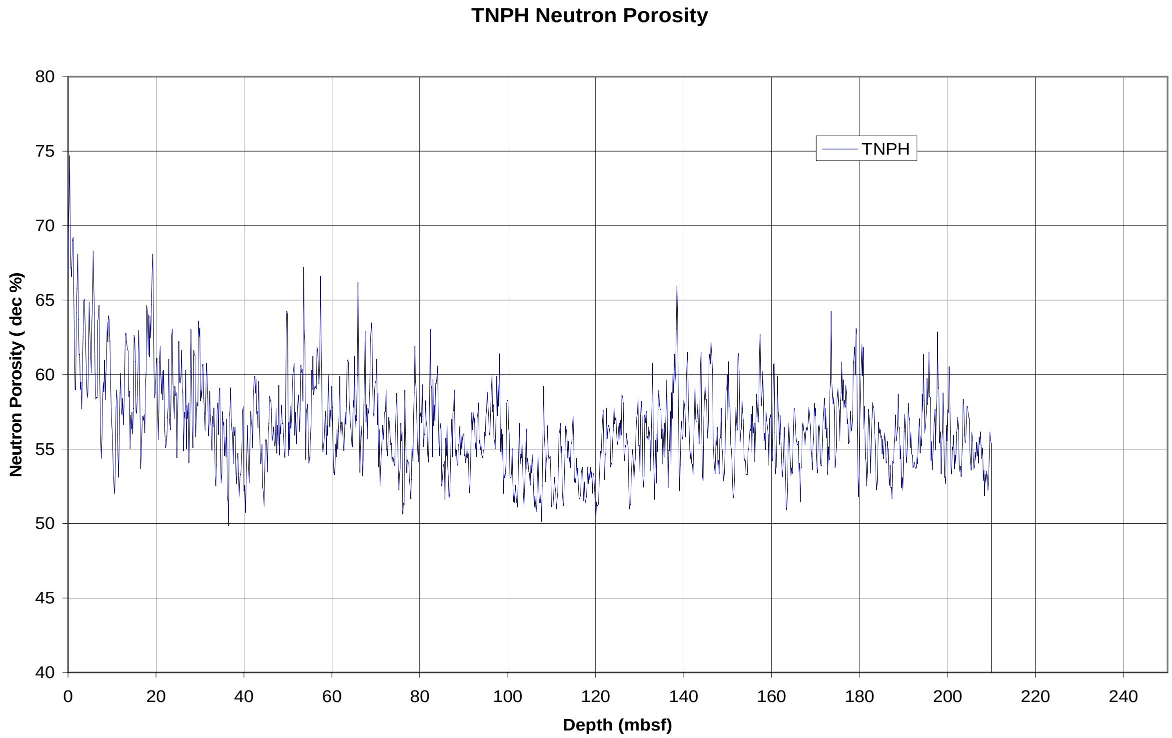

Figure 9. Neutron porosity log as measured by the VDN tool in the AT 13-1 well (recorded data)

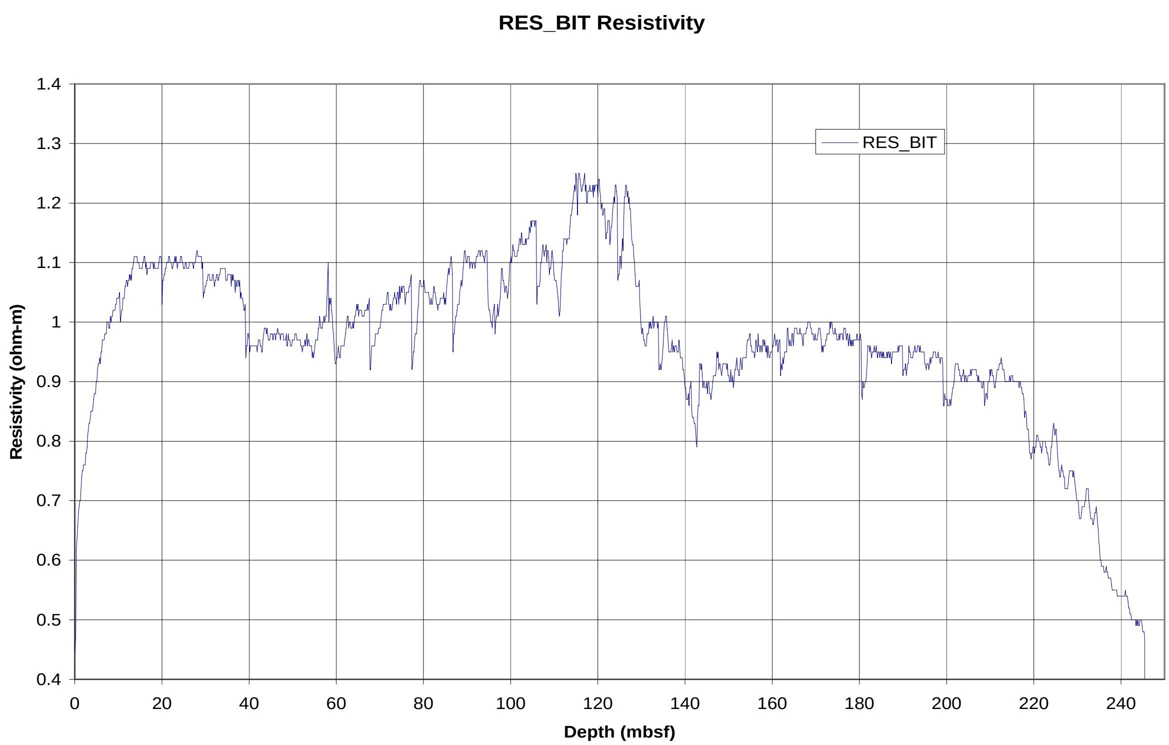

Figure 10. Bit resistivity log as measured by the GVR6 tool in the AT 13-1 well (recorded data)

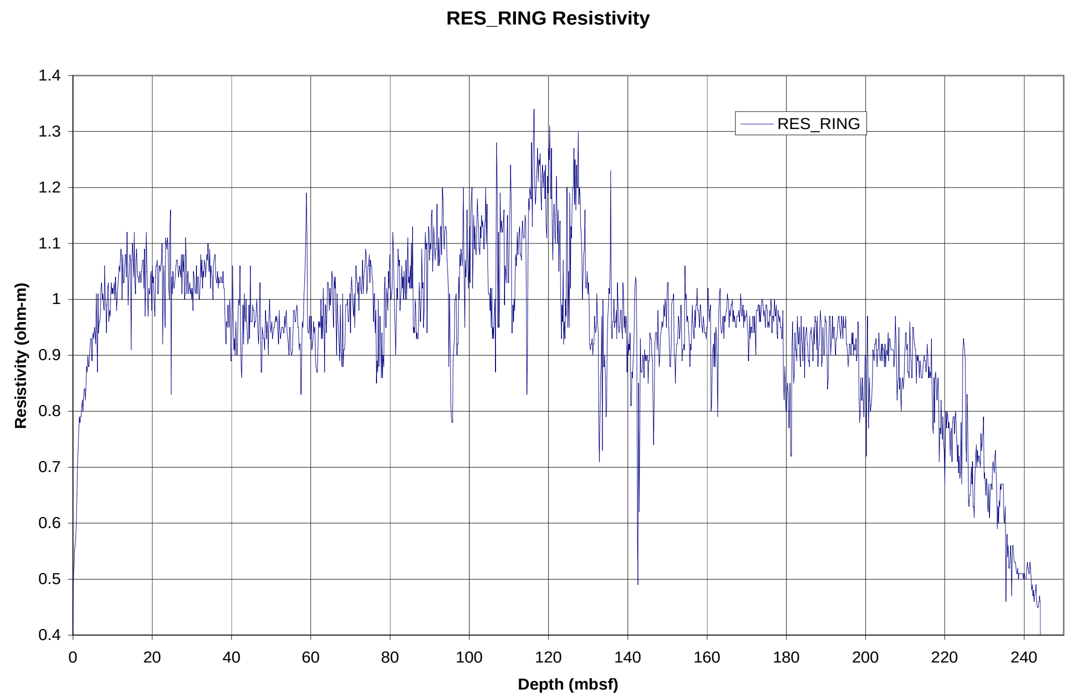

Figure 11. Ring resistivity log as measured by the GVR6 tool in the AT 13-1 well (recorded data)

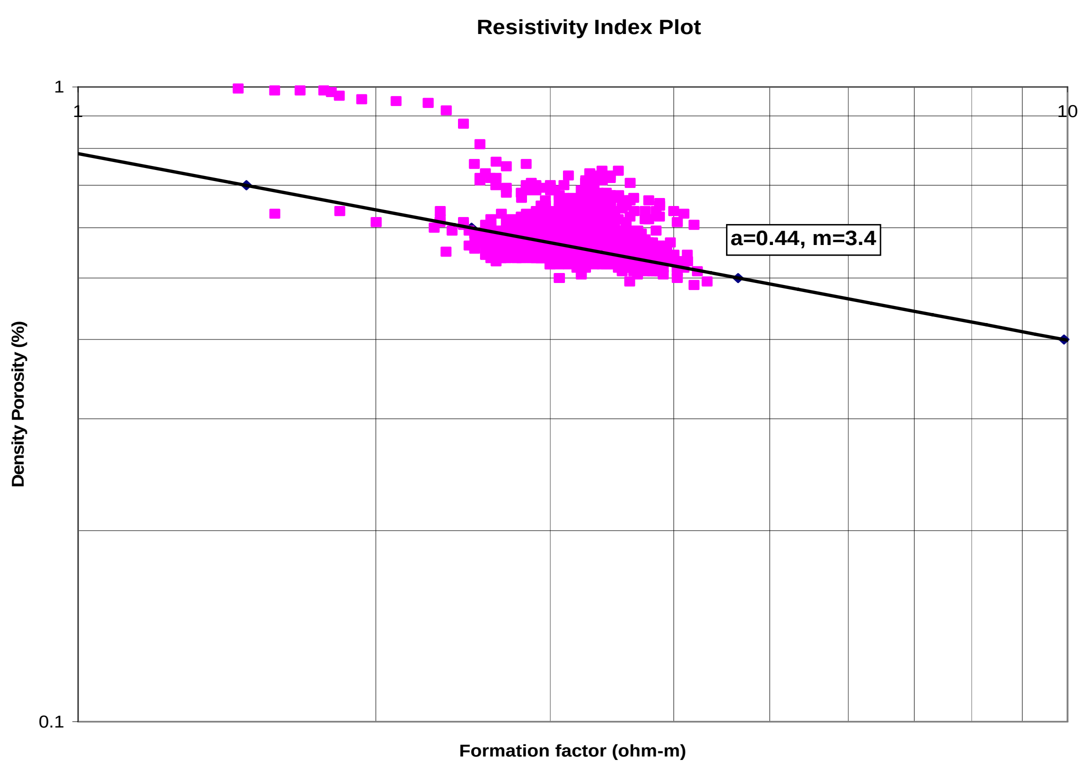

Figure 12. Resistivity index plot (formation factor vs. porosity) for the AT 13-1 well (recorded data)

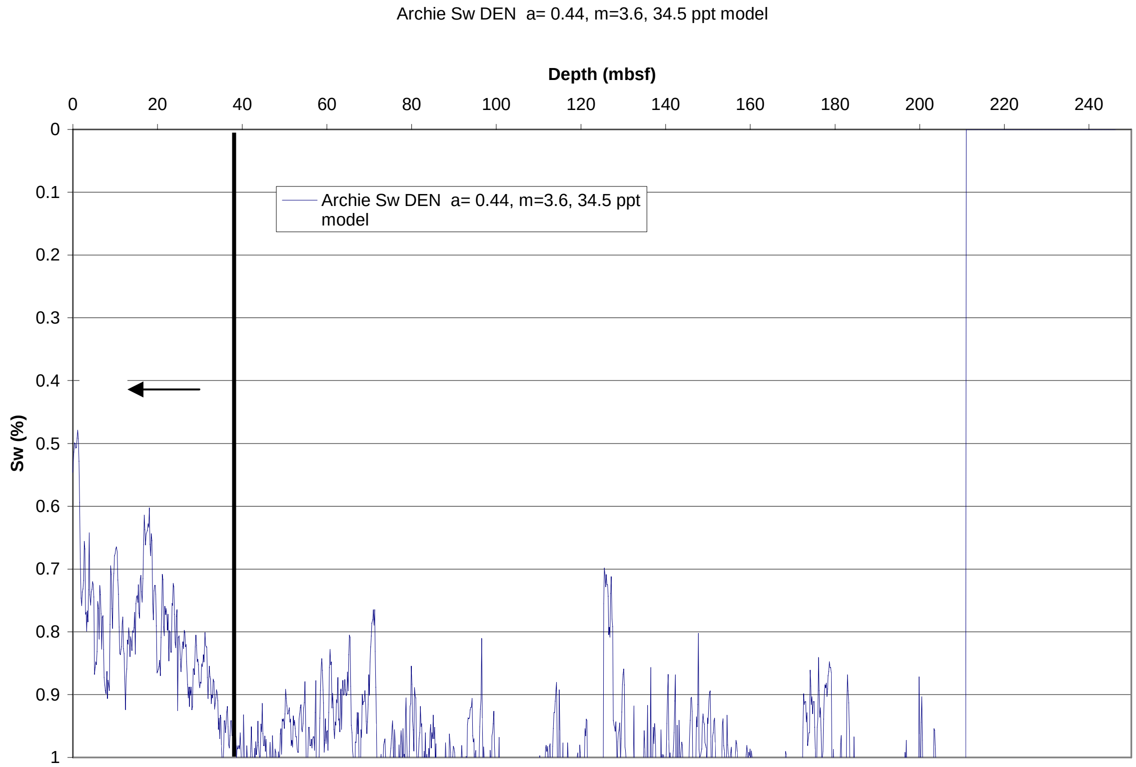

Figure 13. Archie derived water saturations for the AT 13-1 well (recorded data)

ChevronTexaco GOM Gas Hydrate JIP Drilling Program

Atwater Valley 13-2

OCS-G-24203

-WIRELINE LOGGING-

Prepared by Timothy S. Collett, U.S. Geological Survey

May 21, 2005

Operations

Atwater Valley 13-2 (AT 13-2) was cored (FHPC, FC, HRC, FPC) and drilled to a total depth of 200.0 mbsf (drillers depth). Conventional wireline logging (CWL) operations began at 19:40 CT on April 30, 2005 with the makeup of the FMS-sonic tool string. See Table 1 for detailed information on the AT 13-2 CWL program. Figure 2 in the *Explanatory Notes* shows the configuration of the FMS-sonic tool string. For the most part the AT 13-2 well was drilled with only sea water as the drilling fluid, but as the hole was advanced periodic sweeps of Attapulgite based drilling mud was used to sweep and stabilize the hole. Because of concerns associated with severe weather conditions, it was decided to pull the drill string back to only 13.2 mbsf.

After the makeup of the FMS-sonic tool string, it was run into the hole at 1830 m/hr. Upon encountering the drill bit at 13.2 mbsf (1317.4 mbrf), the FMS-sonic could not exit the drill pipe. It appears that we had swabbed drilling cuttings into the pipe and packed off the bit. We tried to wash the pipe clean by pumping on the drill string; however, we were still unable to exit the drill pipe. A drill pipe drift test at the surface later determined that the closed arms of the FMS caliper were a very tight fit through the bit used on the AT 13-2 well (with a drill bit ID of 3.78 inches and a maximum FMS tool OD of 3.66 inches), which likely contributed to the problems we experienced trying to get out of the pipe. After working for more than an hour to get out of the drill pipe, it was decided to abandon this logging attempt and move a ahead with a proposal to attempt an open water logging run.

At 0:20 CT on May 1, 2005 the FMS-sonic tool was deployed through one of the rigs mouse holes into the open ocean. The *Uncle John* ROV was used to monitor the decent of the FMS-sonic tool to the seafloor. While attempting to enter the hole, the logging cable became tangled around the drill string that had been pulled form the hole to about 10 m above the seafloor. After over two hours of labor, the ROV was able to remove the logging cable from the drill string. We were than able to spud the FMS-sonic tool into the open hole, but we encountered a bridge at only 26.8 mbsf. The FMS-sonic tool string was pulled from the hole and tripped back to the surface reaching the rig floor at 7:12 CT on May 1, 2005; without recording any data.

Table 1. Atwater 13-2 Wireline Logging Program

Water depth: 1304.2m RKB

Drillers TD: 1504.2 m RKB

RKB above sea level: 13.2 m

Date	Time (CT)	Depth of logging string (mbrf)	Event
30-Apr-05	9:00	0.0	Drilled well to total depth (200.0 mbsf)
	9:35	0.0	Begin wiper trip to 110 mbsf, return to bottom of hole
	12:20	0.0	Begin mud displacement run to 13.2 mbsf
	16:00	0.0	Weather hold and seafloor frame "repair"
	19:40	0.0	Begin picking up logging tools
	20:15	0.0	Running into hole at 1830 m/hr
	20:45	1317.4	Could not run out of pipe - pumped pipe (13.2 mbsf)
	22:20	0.0	Pulled logging tools to the derrick floor
	23:20	0.0	Rig up for open water logging run
1-May-05	0:20	0.0	Running in through open ocean at 1830 m/hr
	1:05	1304.2	Attempted open ocean entry, tangle cable
	3:30	1331.0	Spudded tool, bridge at 26.8 mbsf (2000 lb over pull)
	6:00	1304.2	Begin pulling logging tools from sea floor at 1200 m/hr
	7:12	0.0	Pulled tools to the derrick floor and laid down tools

*1m = 3.28084ft

ChevronTexaco GOM Gas Hydrate JIP Drilling Program

Atwater Valley 14-1

OCS-G-25212

-LOGGING WHILE DRILLING-

Prepared by Timothy S. Collett, U.S. Geological Survey

May 18, 2005

Operations

Drilling at Atwater Valley 14 site was designed to penetrate the side of a seismic inferred intrusive feature that is capped by an amplitude anomaly believed to represent free gas. LWD operations (Table 1) began at the Atwater Valley 14-1 (AT 14-1) drill site on April 22, 2005 at 01:17 CT with the spudding of the well, following a short DP move from AT 13-1. The BHA was not tripped to the surface after completing AT 13-1. The LWD tools (6-3/4" collars) included the resistivity-at-the-bit GeoVision tool (GVR6) with a 8-1/8" button sleeve, the EcoScope tool (DVD with APWD), a MWD tool (Telescope), a magnetic resonance while drilling tool (MWD-ProVision), and the azimuthal density neutron (VDN) tool. Figure-1 in the *Explanatory Notes* shows the configuration of the LWD/MWD bottom hole assembly (BHA). Memory and battery life allowed for at least six days of continuous drilling. The initial BHA make-up and tool initialization started at 00:28 CT on April 19, 2005 before drilling AT 13-1. AT 14-1 was spudded at a drillers water depth of 1,313.4 mbrf near the crest of the seismic inferred surface Mound F in Atwater Valley Block 14. The ROV from the *Uncle John* was used to position the BHA and monitor the drilling operations at the sea floor throughout the drilling of the AT 14-1 well. The drill-string heave compensator was not used during LWD operations at AT 14-1. For the most part the AT 14-1 well was drilled with only sea water as the drilling fluid, but as the hole was advanced periodic sweeps of Attapulgite based drilling mud was used to sweep and stabilize the hole.

In an attempt to acquire high quality resistivity-at-bit log and image data within the near-surface sedimentary section, we implemented a controlled spud in drilling protocol which consisted of drilling at a low mud flow rate of about 90 GPM (30 strokes per minute), a limited penetration rate of less than 30 m/hr (which was actually maintained at about 28 m/hr), and a spud in bit rotation rate of 50 RPM. It is important to note that the turbine powered tools on the BHA, including the DVD, MWD, ProVision, and the VDN do not operate at a flow rate of less than about 230 gallons per minute. At a depth about 30 mbsf the mud pump rates were increased to 300 GPM to turn-on the turbine powered tools in the BHA. A flow rate of 300 GPM was required to activate the turbine powered tools, based on assumed pump efficiency of three gallons per pump stroke; which could not verified.

Below 30 mbsf, the hole was advanced at an instantaneous rate of approximately 20-28 m/hr to a TD at 286.6 mbsf without difficulty and real-time data were transmitted to the surface throughout the drilling of the well. Some extraneous pump noise affected the data transmission, but caused minimal real-time data loss. After completion, the BHA was pulled back to sea floor while running a sweep of heavy drilling mud. The tools were pulled out of the hole at 20:38 CT on April 23, 2005, the drill bit cleared the rig floor at 12:00 CT on April 24, 2005, and the recorded LWD data from AT 13-1 and AT 14-1 were retrieved at the rig floor at 14:30 CT on April 24, 2005.

Log Quality

After the completion of LWD operations in the AT 14-1 well, a highly reduced version of the “primary” set of downhole recorded well log data was transferred to the onboard science party for initial analysis. For this report, we have loaded this primary data set into Microsoft Excel and generated a series of well log displays; which has been included with this report (Figures 1-13).

The target rate-of-penetration (ROP) of 30 m/hr (± 5 m/hr) in the interval from the seafloor to total depth (TD) was generally approved upon with instantaneous ROPs ranging from about 20 m/hr to about 25 m/hr (Figure 1). Using slow drilling rates enhanced the quality of the NMR porosity data and RAB images. The quality of RAB images is quite high and no significant resolution loss is observed with variation in ROP in the AT 14-1 well.

The caliper log (DCAV), which provides a measurement of the diameter of the borehole as recorded by the VDN density tool is the best indicator of borehole conditions (Figure 4). The calculated differential caliper values (assuming a bit size of 8-1/2 inches) are <1 inch over 80% of the total section in AT 14-1. With the uppermost 25 mbsf of the hole characterized by significant washouts, as is the section from about 160 mbsf to near the bottom of the hole (286.6 mbsf). The bulk density correction (IDDR), calculated from the difference between the short- and long-spaced density measurements, varies from -0.03 to +0.02 g/cm^3, which shows the high quality of the density measurements (Figure 6).

The depths, relative to seafloor, for all of the LWD logs were fixed by using the *Uncle John* ROV to identify the actual BHA bit contact with the sea floor and shifting the log data to the appropriate depth as determined by the drillers' pipe tallies. For AT 14-1 it was determined that the seafloor was at a depth of 1313.4 mbrf. The rig floor logging datum was located 13.2 m above sea level for this hole.

Interpretation of LWD Logs

LWD gamma ray measurements suggests that the AT 14-1 penetrated mostly a fine-grained clay dominated sedimentary section with no apparent suitable sand reservoir units. The low gamma ray values and slightly elevated density porosity values within the upper 30 m of the well are in part a product of bad borehole conditions. A notable characteristic of the AT 14-1 site is the apparent uniform reduction in formation resistivity in comparison to the AT 13-1 well, which probably indicates an increase in the pore water salinity concentrations. The most significant well log response is the step wise shift with depth to lower formation densities and resistivities at a depth of about 180 mbsf, which probably corresponds to the depth of the BSR or "intrusion" like feature on the seismic surveys at this site.

Log Porosities

Sediment porosities can be determined from analyses of recovered cores and from numerous borehole measurements. Data from the LWD density, neutron, and nuclear magnetic resonance logs have been used to calculate sediment porosities in the AT 14-1 well. The VDN log-derived measurements of bulk-density (Figure 7) in AT 14-1 for the most part ranges from about 1.6 g/cm^3 to 1.8 g/cm^3, with values less than about 1.6 g/cm^3 near the seafloor. The density log measurements are degraded in the upper 25 mbsf, as discussed earlier in this report. The LWD log-derived bulk density measurements from AT 14-1 were used to calculate sediment porosities (∅) using the standard density-porosity relation: $\varnothing=(\rho m-\rho b)/(\rho m-\rho w)$. Water densities ($\rho w$) were assumed to be constant and equal to 1.05 g/cm^3; while the grain/matrix densities (ρm) were assumed to be 2.65 g/cm^3 for each log density porosity calculation. The density-log derived porosities range from about 55 to 70 percent (Figure 8), with the most notable high porosity zone in the interval from 180 mbsf to 220 mbsf. However, the density log porosities near the top of the hole (above 10 mbsf), ranging from 60 to near 70 percent, are in part controlled by degraded borehole conditions. The LWD neutron porosity log (Figure 9) yielded sediment porosities ranging from an average value at the top of the logged section of about 58% to near 55% at the bottom of the hole. NMR data were transmitted to shore for processing to estimate bound fluid volume and total free fluid porosity and for comparison with neutron, density, and core porosity estimates. The sediment porosities derived by the LWD NMR tool are very similar to the both the density and neutron log derived porosities.

Gas Hydrate

The presence of gas hydrates was not verified at any of the Atwater Valley drill sites by either sampling in the AT 13-2 well or in the LWD well log data from the AT 13-1 or AT 14-1 wells. The LWD GVR6 resistivity tool, however, reveals several thin high-resistivity zones within the depth interval 18-78 mbsf in the AT 14-1 well, suggesting the possible occurrence of gas hydrate.

Resistivity log data have been used to quantify the amount of gas hydrate at AT 14-1. For the purpose of this discussion, it is assumed that any high resistivities measured in the AT 14-1 well are due to the presence of gas hydrate or possibly free-gas. The Archie relation ($S_w=(aR_w/\varnothing^m R_t)^{1/n}$) was used with resistivity data (R_t) from the LWD RAB tool and porosity data ($\varnothing$) from the VDN density tool to calculate water saturations. It should be noted that gas hydrate saturation (S_h) is the measurement of the percentage of pore space in a sediment occupied by gas hydrate, which is the mathematical complement of Archie derived water saturations (S_w), with S_h=1-S_w.

For the Archie relation, the formation water resistivity (R_w) was calculated from recovered core water samples in AT 13-2 and assumed to range from 30 to 38 ppt. However, both resistivity log data from AT 14-1 and the Mound cores obtained from the top of Mound F suggests that the porewater salinities in the AT 14-1 may be higher than those in AT 13-1. Because of the lack of any deep core data from the AT 14 site, a constant pore water salinity of 34.5 ppt (sea water salinity) was assumed to represent the in-situ R_w conditions. The Archie a and m variables were calculated using a cross plot technique (a= 0.40, m= 3.0), which compares the downhole log derived resistivities and density porosities (Figure 12). The APCT temperature data obtained from the AT 13-2 well revealed an equilibrium seabed temperature of 4.37°C and a geothermal gradient of 3.2°C/100m.

The Archie relation generally yielded water saturations near 100% for most the well. There is some indication of low gas hydrate saturations (percent of pore space occupied by gas hydrate) of less than 10-20% in the upper 0-65 mbsf of the AT 14-1 well. There is also some indication of low gas hydrate or free-gas saturations (i.e., reduced Archie derived water saturations), ranging from 10-20 %, within the depth interval between 180-

220 mbsf. But this section is closely associated with the apparent changes in formation resistivities and inferred pore water salinities at 180 mbsf, the affect of which needs to be further investigated.

It is possible that the BSR or “intrusion” like feature at 180 mbsf marks a fluid boundary between upwelling higher salinity brines in the seep feature and lower more normal salinities in the surrounding section. As noted above, the slight drop in the recorded BIT and RING resistivities within the interval 180-220 mbsf appears to be associated with low density values and elevated neutron porosities. However, lower formation densities are not compatible with the occurrence of a more dense brine intrusion. But the apparent drop in the Archie derived water saturations within the interval from 180 mbsf to 220 mbsf, which suggest the presence of free gas below the BSR like feature is compatible with an apparent reduction in log measured formation densities. Without acoustic log data, however, we cannot conclusively prove the occurrence of free gas within this feature.

The review of the well log data from AT 14-1 shows relatively little evidence for any significant gas hydrates at this site. The LWD logs from this site further suggests the presence of a complex pore water fluid regime, with variable well log inferred pore water salinities. It is important to highlight, however, that the well log and seismically inferred fluid salinity and possible free-gas feature associated with the Atwater 14-1 site is limited in spatial size and likely exhibits only local influence on gas hydrate stability conditions.

Borehole Temperature and Pressure Data

The APWD measured borehole pressures (DHAP) generally indicate a uniform pressure gradient with depth (Figure 3), with some pressure deviations associated with running heavy mud sweeps near the end of pipe connections. The DHAT temperature log indicates that the circulating fluids were cooled in their descent in the drill pipe to a relatively uniform temperature in the range of 4-8 degrees Celsius (Figure 2).

Table 1. Atwater 14-1 LWD/MWD Logging Program

Water depth: 1313.4 m RKB

Drillers TD: 1600.0 m RKB

RKB above sea level: 13.2 m

Date	Time (CT)	Depth of drill bit (mbrf)*	Event
22-Apr-05	1:17	1313.4	Spud well, controlled drill 90 GPM, 28 m/hr ROP, 50 RPM
	2:01	1343.0	Pump rate up to 300 GPM, 27 m/hr ROP, 90 RPM; MWD tool powered up
23-Apr-05	9:41	1600.0	Well reaches TD at 286.6 mbsf
	10:21	1600.0	Begin trip of BHA to sea floor, running heavy mud sweep
	13:35	1352.0	Hold at 38.6 mbsf for mud pump repairs
	18:30	1352.0	Pump-out logging as BHA pulled to sea floor, 300 GPM, 25 m/hr ROP
	20:38	1313.4	BHA clears sea floor
24-Apr-05	2:00	1313.4	Begin trip of BHA to the rig floor
	12:00	0.0	BHA clears rig floor and laid down tools
	14:30	0.0	LWD/MWD log data transfer completed

*1m = 3.28084ft

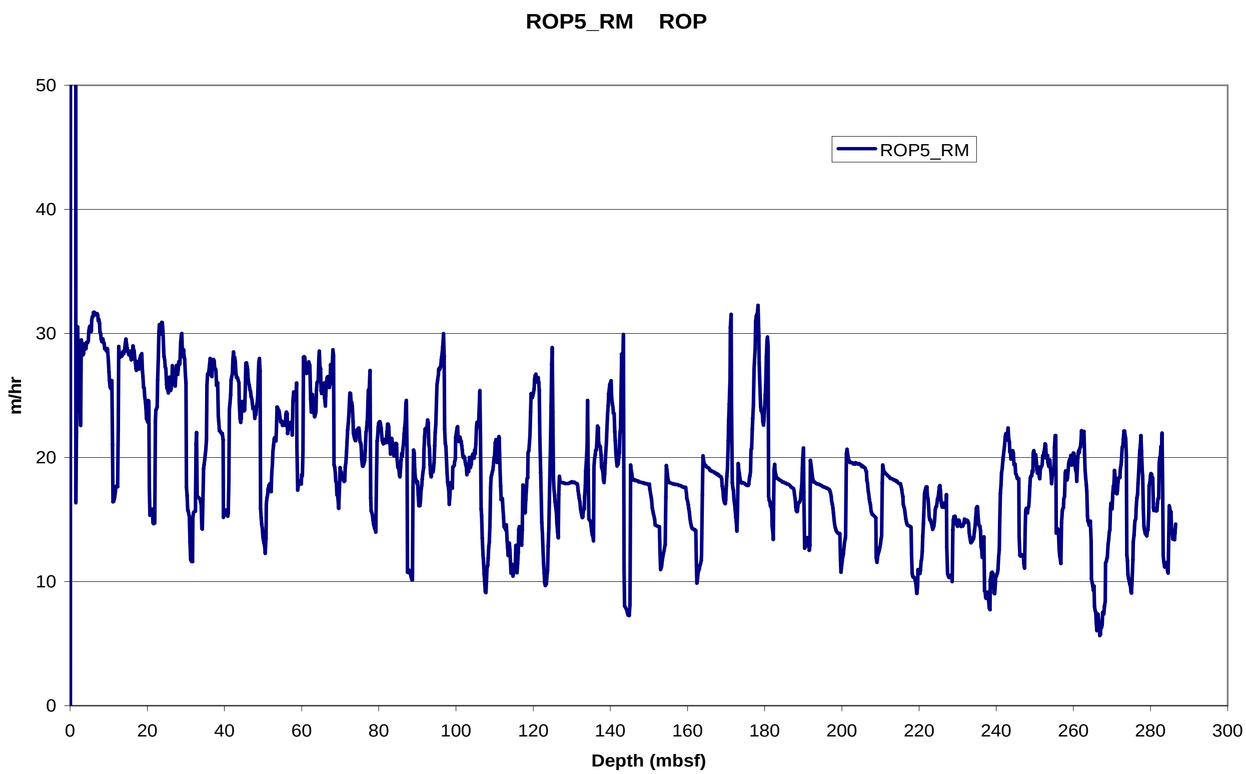

Figure 1. Rate of penetration (ROP) while drilling the AT 14-1 well (recorded data)

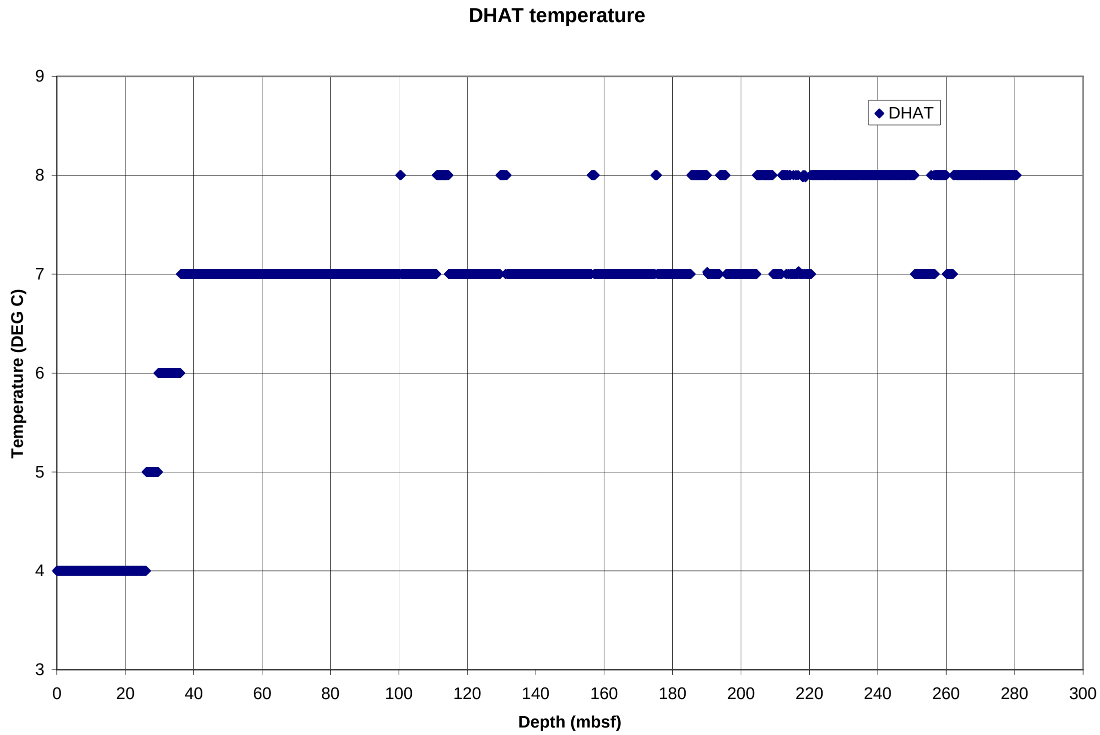

Figure 2. Annular temperature for AT 14-1 from the APWD tool (recorded data)

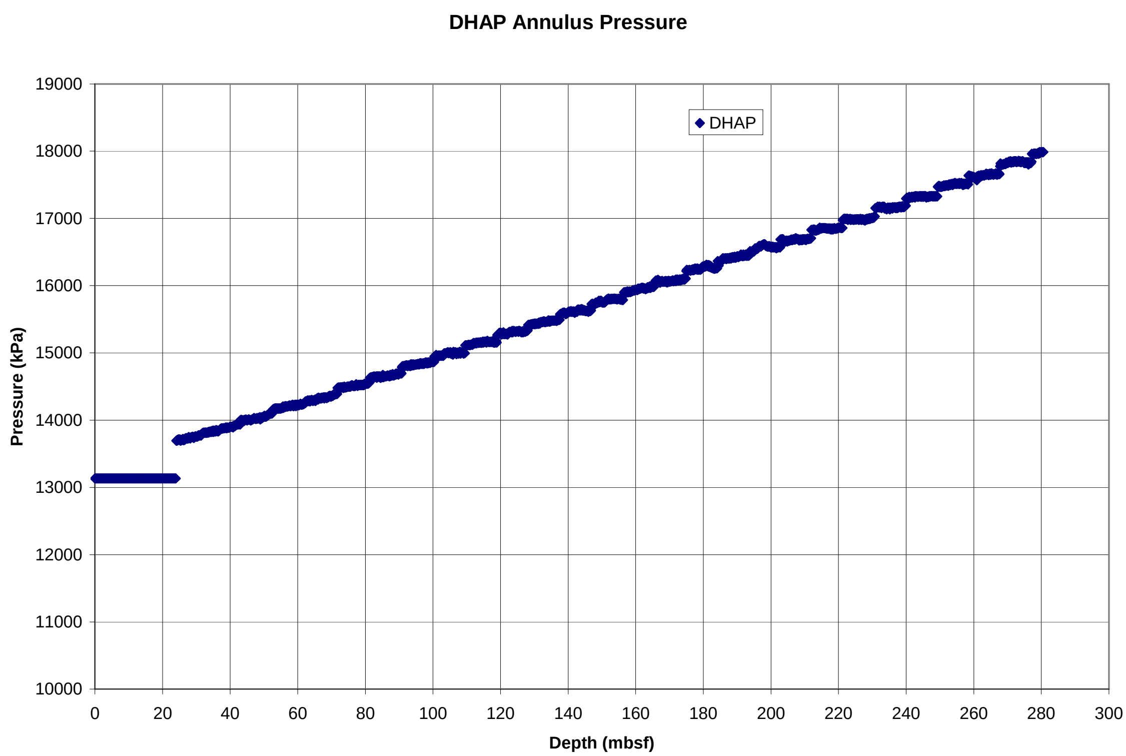

Figure 3. Annular pressure as recorded by the APWD tool in the AT 14-1 well (recorded data)

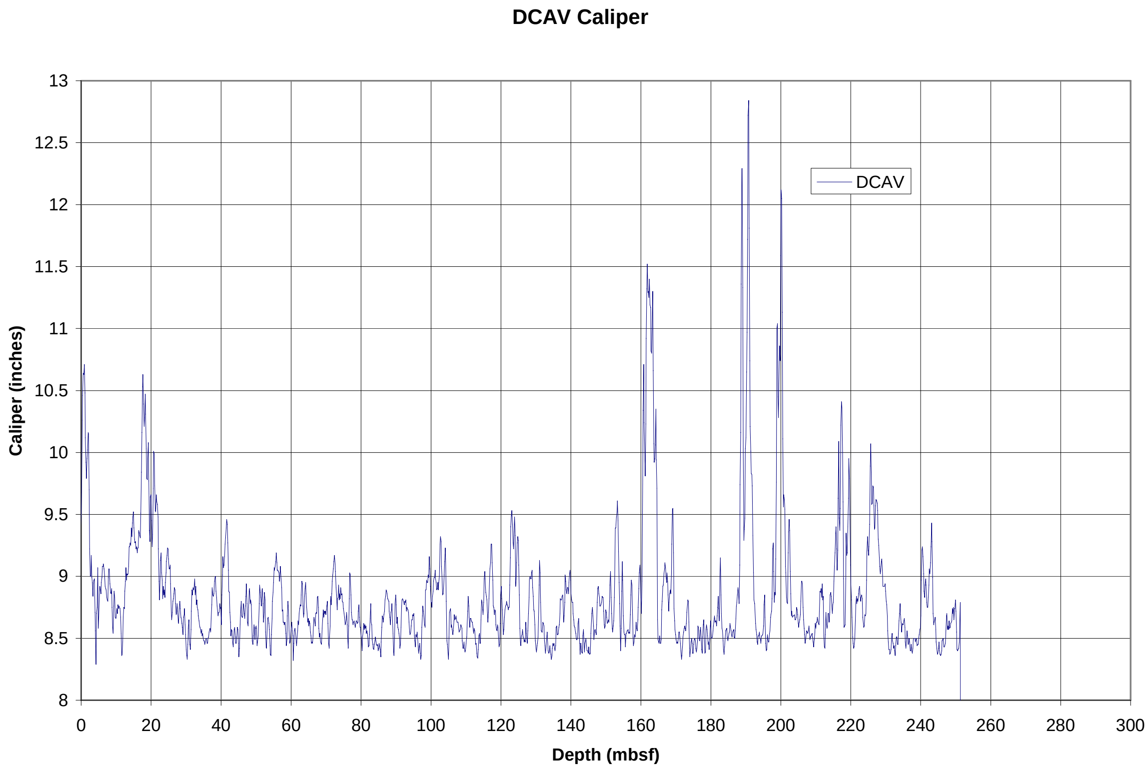

Figure 4. Borehole density caliper as measured by the VDN tool in the AT 14-1 well (recorded data)

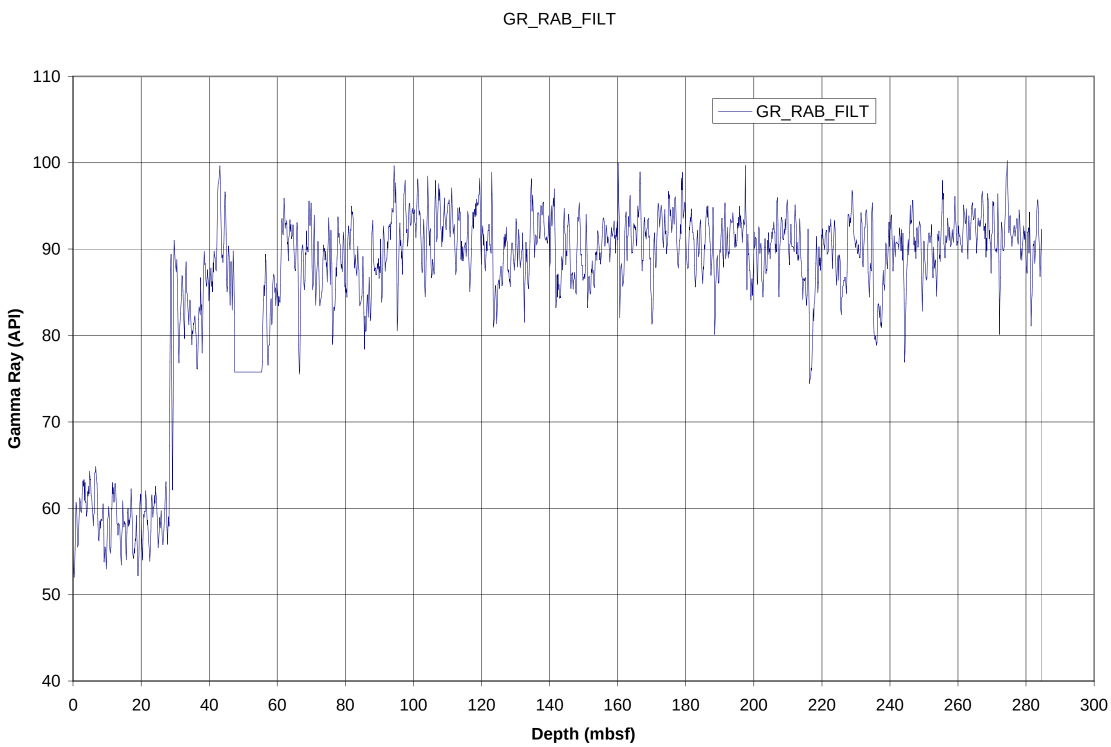

Figure 5. Gamma ray log as measured by GVR6 tool in the AT 14-1 well (recorded data)

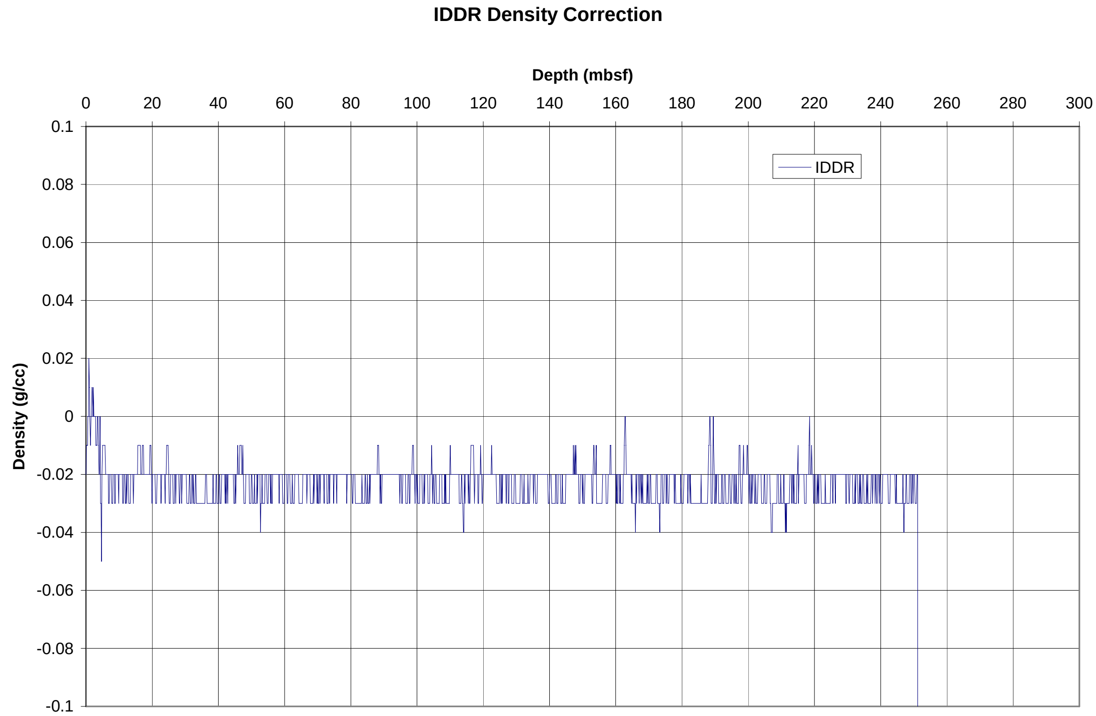

Figure 6. Density log correction for the density log as measured by the VDN tool in the AT 14-1 well (recorded data)

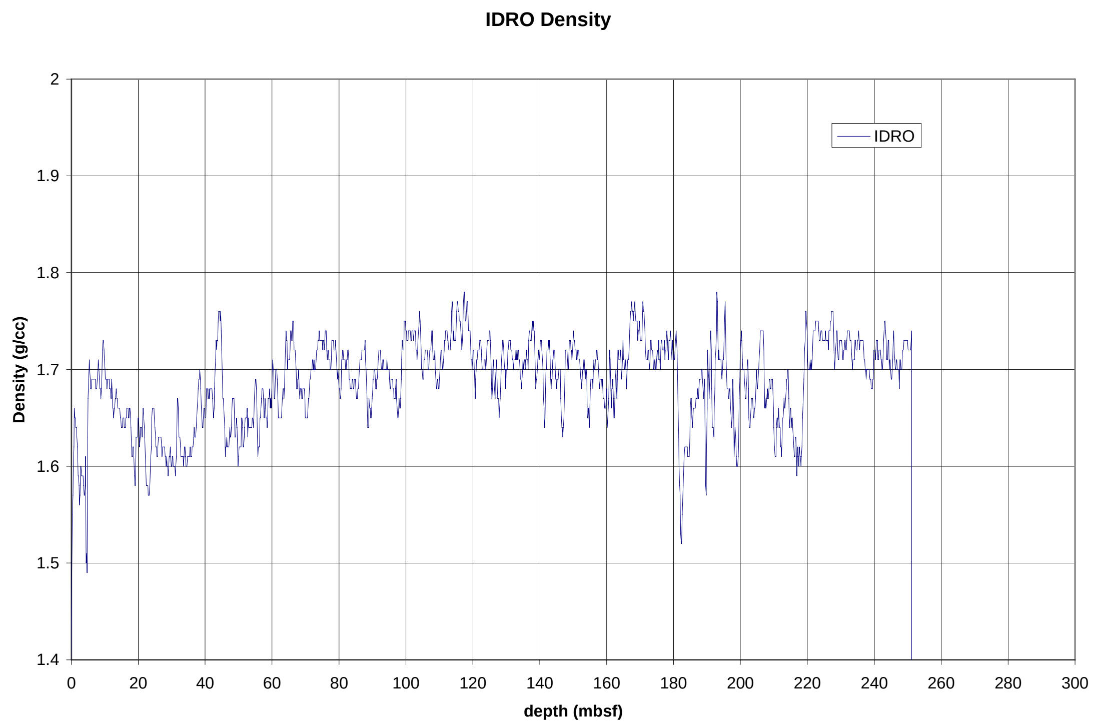

Figure 7. Density log as measured by the VDN tool in the AT 14-1 well (recorded data)

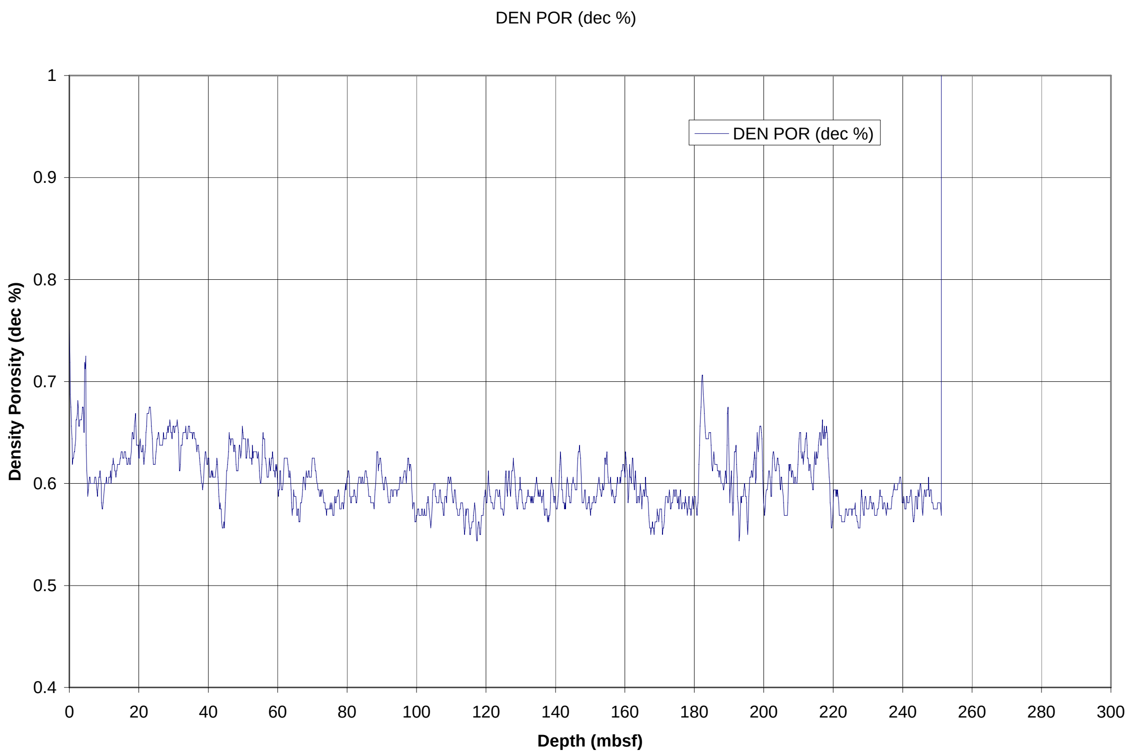

Figure 8. Density log derived porosities in the AT 14-1 well (recorded data)

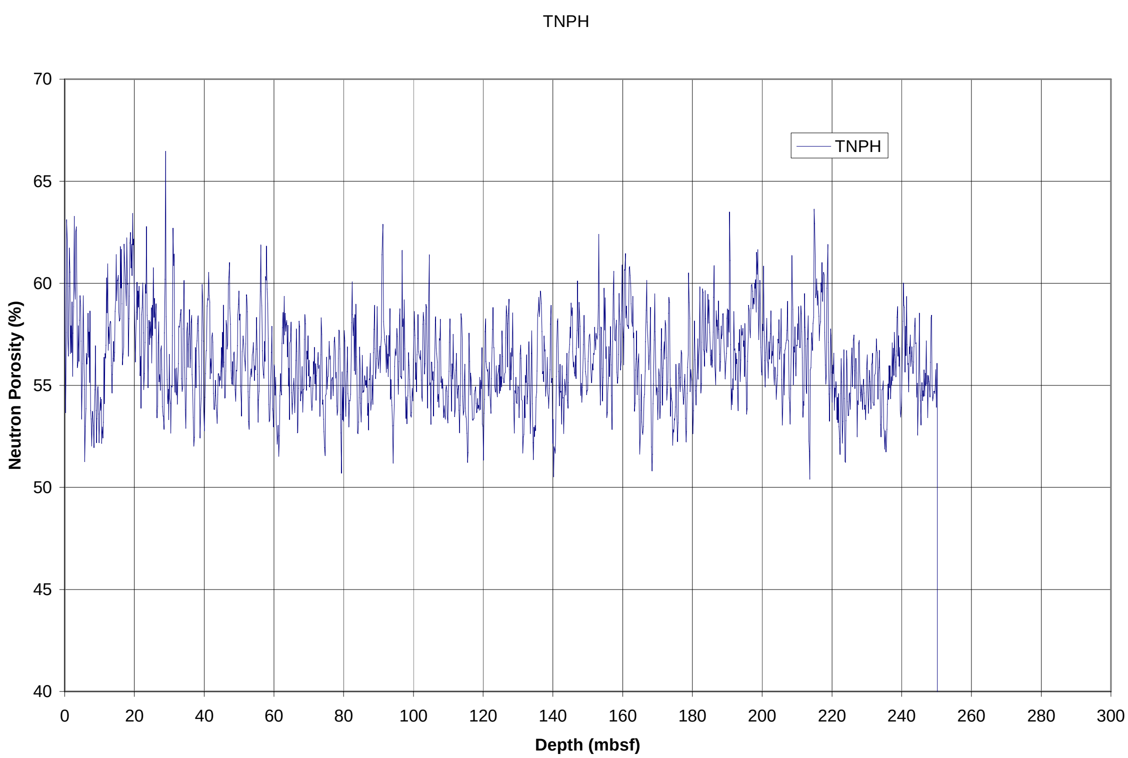

Figure 9. Neutron porosity log as measured by the VDN tool in the AT 14-1 well (recorded data)

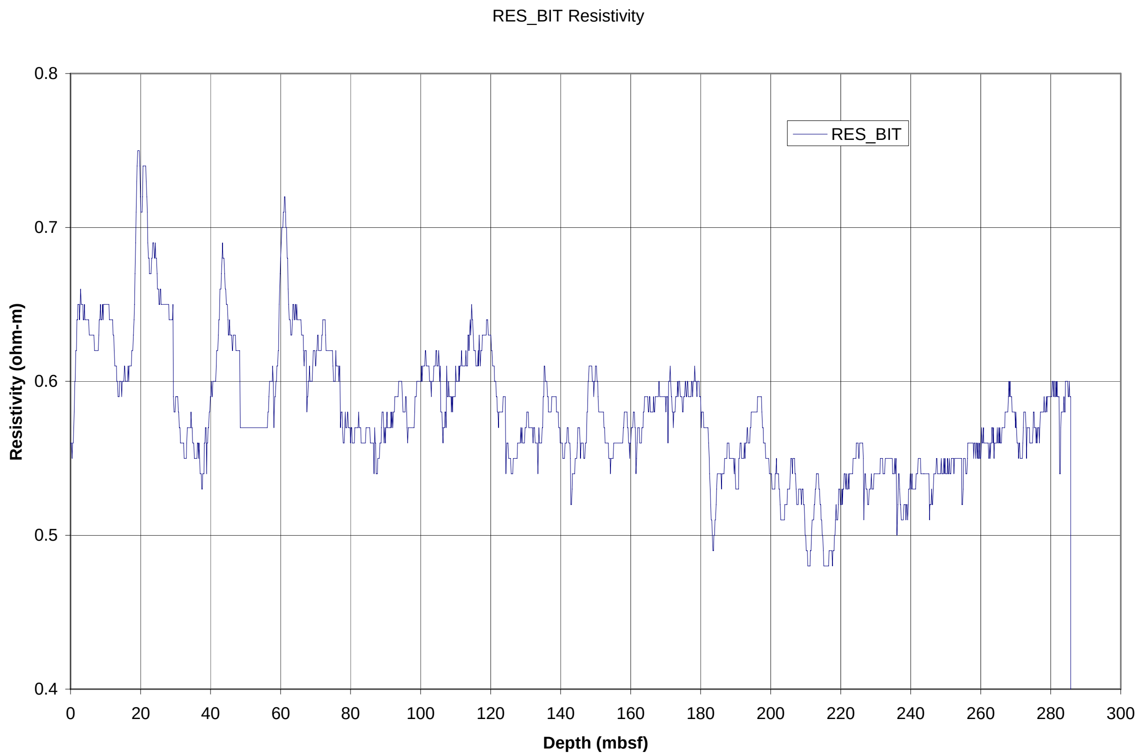

Figure 10. Bit resistivity log as measured by the GVR6 tool in the AT 14-1 well (recorded data)

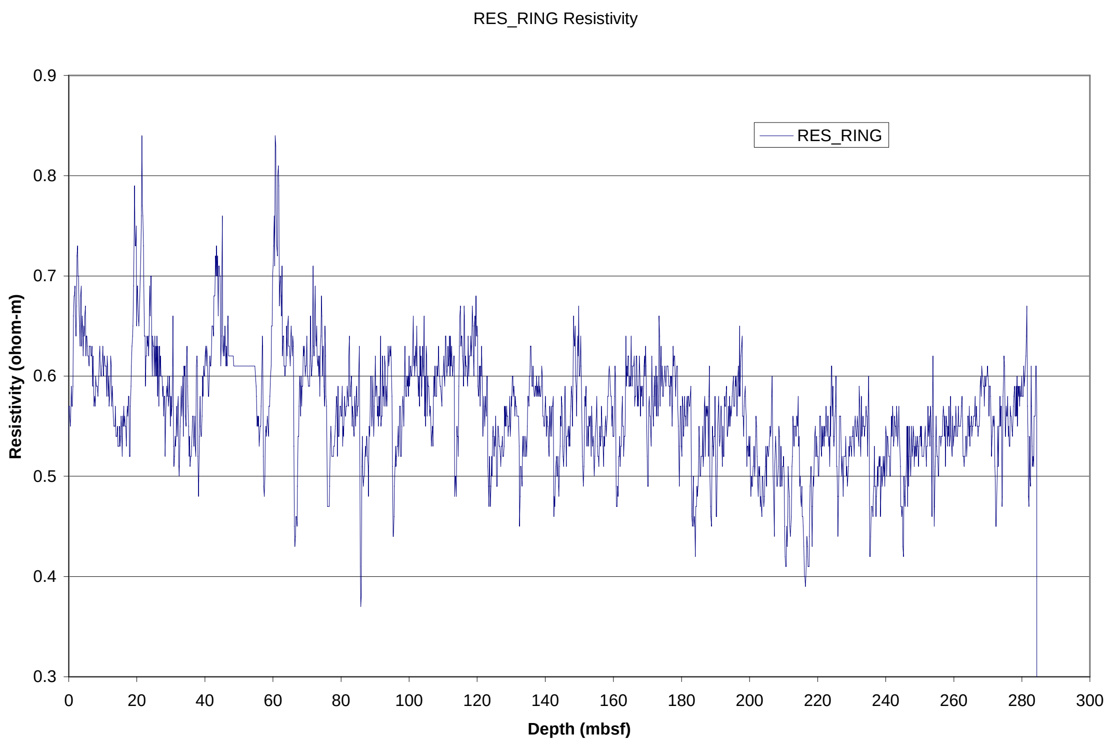

Figure 11. Ring resistivity log as measured by the GVR6 tool in the AT 14-1 well (recorded data)

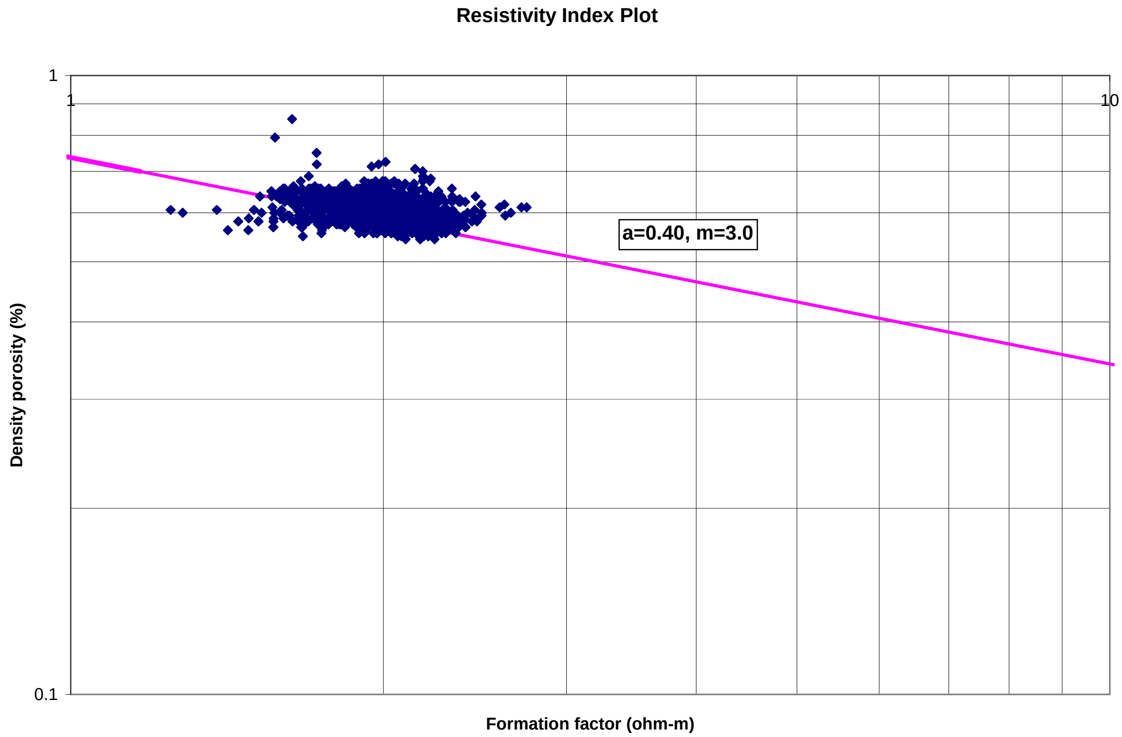

Figure 12. Resistivity index plot (formation factor vs. porosity) for the AT 14-1 well (recorded data)

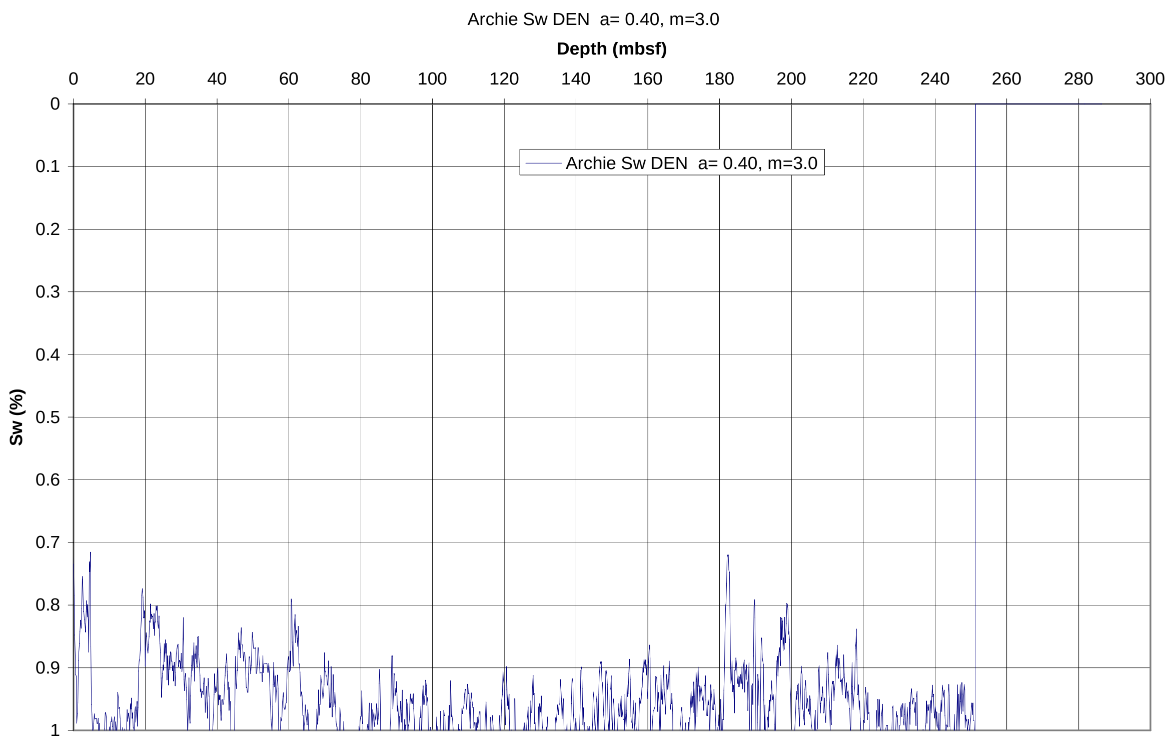

Figure 13. Archie derived water saturations for the AT 14-1 well (recorded data)

ChevronTexaco GOM Gas Hydrate JIP Drilling Program

Keathley Canyon 151-2

-LOGGING WHILE DRILLING-

Prepared by Timothy S. Collett, U.S. Geological Survey

May 21, 2005

Operations

The drilling objectives at the Keathley Canyon 151 site was to characterize the possible occurrence of a gas hydrate related bottom simulating reflector (or BSR). Seismic lines from both high resolution research seismic surveys and from regional 3D surveys through the Keathley Canyon 151 proposed drill site reveal the presence of a BSR at a depth of about 385 mbsf. Thus, the Keathley Canyon 151 block contains one of the rare instances of a BSR in the Gulf of Mexico, and may indicate the occurrence of gas hydrates at depth.

LWD operations (Table 1) began at the Keathley Canyon 151-2 (KC 151-2) drill site on May 7, 2005 at 01:31 CT with initial BHA make-up, tool initialization, and calibration. The LWD tools (6-3/4" collars) included the resistivity-at-the-bit GeoVision tool (GVR6) with a 8-1/8" button sleeve, the EcoScope tool (DVD with APWD), a MWD tool (Telescope), a magnetic resonance while drilling tool (MWD-ProVision), and the azimuthal density neutron (VDN) tool. Figure-1 in the *Explanatory Notes* shows the configuration of the LWD/MWD bottom hole assembly (BHA). Memory and battery life allowed for at least six days of continuous drilling.

A pump test of the BHA (at a subsea depth of about 128.0 mbrf), indicated a power failure in the ProVision and GVR6 tools, which was linked to a possible problem in the Telescope MWD tool. The BHA was pulled back to the surface, and the backup ProVision and GVR6 tools were inserted into the BHA. Because of concerns associated with minor communication/power problems observed during the drilling of the AT 13-1 and AT 14-1 wells (mostly noticed in the ProVision tool) it was decided to also swap out the TeleScope MWD tool for the more conventional Power Pulse MWD tool; which also required the EcoScope to be swapped out for the Array Resistivity Compensated Tool (ARC). The new BHA was initialized, ran to the sea floor, and the KC 151-2 well was spudded at 06:35 CT on May 8, 2005 at a drillers water depth of 1,335.0 mbrf along the western flank of a subtle ridge feature in Keathley Canyon 151. The ROV from the *Uncle John* was used to monitor the drilling operations at the sea floor throughout the drilling of the KC 151-2 well. The active drill-string heave compensator on the *Uncle John* was used during LWD operations at KC 151-2. For the most part the KC 151-2 well was drilled with only sea water as the drilling fluid, but as the hole was advanced periodic sweeps of Attapulgite based drilling mud was used to sweep and stabilize the hole. A barite kill mud was also used to control a water/gas flow problem that developed after the well was drilled, thus the logs should not be affected by any of the normal barite mud affects.

In an attempt to acquire high quality resistivity-at-bit log and image data within the near-surface sedimentary section, we implemented a controlled spud in drilling protocol which consisted of drilling at a low mud flow rate of about 100 GPM (33 strokes per minute), a limited penetration rate of less than 25 m/hr, and a spud in bit rotation rate of 50 RPM. It is important to note that the turbine powered tools on the BHA, including the DVD (ARC), MWD, ProVision, and the VDN do not operate at a flow rate of less than about 230 gallons per minute. At a depth about 25 mbsf the mud pump rates were increased to 360 GPM to turn-on the turbine powered tools in the BHA. It was decided that a flow rate of 360 GPM was required to adequately clear the hole of drill cuttings, which did contribute to some borehole erosion problems.

Below 30 mbsf, the hole was advanced at an instantaneous rate (Figure 1) of approximately 15 to about 35 m/hr (with most of the well drilled at rates below 25 m/hr) to a TD at 459.8 mbsf without difficulty. The ROP in the KC 151-2 well was much more variable than what we experienced in either of the Atwater Valley wells, which was attributed to the more complex geologic conditions encountered at the Keathley Canyon site. Real-time data were transmitted to the surface throughout the drilling of the KC 151-2 well. Some extraneous pump noise affected the data transmission, but caused minimal real-time data loss. In comparison to the Atwater Valley wells, the quality of the pulsed ProVision data was vastly improved in the KC 151-2 well.

After completion, the BHA was pulled back to sea floor while running a sweep of heavy drilling mud. The tools were pulled out of the hole at 08:30 CT on May 9, 2005, the drill bit cleared the rig floor at 09:45 CT on May 9, 2005, and the recorded LWD data were retrieved at the rig floor at 11:45 CT on May 9, 2005. It was later determined that the ARC tool failed to record any data into the tool memory because of a software problem. Thus, we have only MWD pulsed (real time) data from ARC and APWD tools; which was limited to the ARC “blended” resistivity measurement (Figure 11) and the APWD temperature and pressure measurements (Figures 2 and 3).

It is also important to note that the KC 151-2 well began to flow water (probably a high salinity brine) and a small amount of gas while tripping the LWD BHA out of the hole. A barite kill mud was pumped through the LWD BHA to control the well. It was speculated that the source of the water flow was from a deep horizon near the TD of the hole. But a thick sand section at a depth of 100 mbsf, later determined to contain high salinity pore waters (also characterized by very low electrical resistivities), could have been the source of this shallow water flow. The shallow sand at 100 mbsf also exhibited a slight APWD measured annular pressure response of about a 300 kPa increase when originally drilled (Figure 3).

Log Quality

After the completion of LWD operations in the KC 151-2 well, a highly reduced version of the “primary” set of downhole recorded well log data was transferred to the onboard science party for initial analysis. For this report, we have loaded this primary data set into Microsoft Excel and generated a series of well log displays; which has been included with this report (Figures 1-13).

As noted earlier in this report, the target rate-of-penetration (ROP) of 30 m/hr (± 5 m/hr) in the interval from the seafloor to the total depth (TD) of the well was generally achieved, with instantaneous ROPs ranging from about 15 m/hr to about 35 m/hr (Figure 1). The quality of RAB images is quite high; however it appears that the RAB image in the first 10 m of the hole may have been degraded by low ROPs.

The caliper log (DCAV), which provides a measurement of the diameter of the borehole as recorded by the VDN density tool is the best indicator of borehole conditions (Figure 4). The calculated differential caliper values (assuming a bit size of 8-1/2 inches) are <1 inch over 75% of the total section in KC 151-2. With the uppermost 20 mbsf of the hole characterized by significant washouts, as is the section from about 25 mbsf to about 110 mbsf. This lower interval is dominated by a series of thin sand units and one thick sand section at 95-110 mbsf. The bulk density correction (IDDR), calculated from the difference between the short- and long-spaced density measurements, varies from 0 to as high as +0.1 g/cm^3, which shows some deterioration in the quality of the density measurements (Figure 6).

The depths, relative to seafloor, for all of the LWD logs were fixed by using the *Uncle John* ROV to identify the actual BHA bit contact with the sea floor and shifting the log data to the appropriate depth as determined by the drillers' pipe tallies. For KC 151-2 it was determined that the seafloor was at a depth of 1335.0 mbrf. The rig floor logging datum was located 13.2 m above sea level for this hole.

Interpretation of LWD Logs

LWD gamma ray measurements suggests that the KC 151-2 well penetrated mostly a fine-grained clay dominated sedimentary section, except for one thick sand section at 95-110 mbsf. There are also several notable sand rich sections deeper in the well near 140 and 150 mbsf. The low gamma ray values and slightly elevated density porosity values within the upper 35 m of the well are in part a product of bad borehole conditions. The most notable characteristic of the KC 151-2 well is a high resistivity interval (measured by both the GVR6 and the ARC tools) within the section from about 220 mbsf to 300 mbsf, which probably indicates the occurrence of gas hydrates (Figures 10 and 11). RAB images from this high resistivity interval, also reveals the presence of numerous steeply dipping (82 plus degrees) fractures throughout this section.

The other most significant well log response is the relatively subtle resistivity response within the interval 371-392 mbsf associated with the expected depth of the BSR (seismic inferred at 385mbsf). The comparison of the ARC measured resistivity data (blended resistivity) with that RING resistivities recorded by the GVR6 reveal that within the "high resistivity interval" from 220 mbsf to 300 mbsf, the ARC measured resistivities were significantly higher than those measured by the GVR6. The reason for this discrepancy is unclear at this time, but it may be related to the way these two tools function.

Log Porosities

Sediment porosities can be determined from analyses of recovered cores and from numerous borehole measurements. Data from the LWD density, neutron, and nuclear magnetic resonance logs have been used to calculate sediment porosities in the KC 151-2 well. The VDN log-derived measurements of bulk-density (Figure 7) in KC 151-2 for the most part ranges from about 1.7 g/cm^3 to 2.05 g/cm^3, with values less than about 1.5 g/cm^3 near the seafloor. The density log measurements are degraded in the upper 25 mbsf, as discussed earlier in this report. The LWD log-derived bulk density measurements from KC 151-2 were used to calculate sediment porosities (∅) using the standard density-porosity relation: $\varnothing=(\rho m-\rho b)/(\rho m-\rho w)$. Water densities ($\rho w$) were assumed to be constant and equal to 1.05 g/cm^3; while the grain/matrix densities (ρm) were assumed to be 2.65 g/cm^3 for each log density porosity calculation. The density-log derived porosities for the most part range from about 37 to 60 percent (Figure 8), with the most notable high porosity zone in the interval from 88 mbsf to 107 mbsf. However, the density log porosities near the top of the hole (above 45 mbsf), ranging from 50 to near

80 percent, is in part controlled by degraded borehole conditions. The LWD neutron porosity log (Figure 9) yielded sediment porosities ranging from an average value at the top of the logged section of about 62% to near 50% at the bottom of the hole. NMR data were transmitted to shore for processing to estimate bound fluid volume and total free fluid porosity and for comparison with neutron, density, and core porosity estimates. The sediment porosities derived by the LWD NMR tool are very similar to the both the density and neutron log derived porosities.

Gas Hydrate

The presence of gas hydrates was not fully verified by coring in the KC 151-3 well. In several instances IR identified cold spots in cores, mousey sediment textures in the recovered cores, and anomalous low pore water salinity values inferred the presence of gas hydrate. Several, of the recovered pressure cores also indicated gas concentrations exceeding normal solubility, but no gas hydrate was physically observed. However, the conspicuous LWD measured high resistivity zone in the KC 151-2 well from 220 mbsf to 300 mbsf is indicative of a gas hydrate or free gas bearing sediments. It is also possible that very low pore water salinities could yield the high resistivity values observed in this anomalous section. Subsequent analysis of pore waters from cores in this interval, however, revealed elevated pore water salinities with values exceeding 50 ppt. Also since this anomalous section is well above the base of the BSR inferred gas hydrate stability field, it is unlikely that this interval contains free gas. It is also important to note that a portion of this interval from about 220 mbsf to 258 mbsf (plus other sections) are characterized by relatively low acoustic transit-times (high acoustic velocities) as recorded by the DSI wireline tool in the KC 151-3 well, which is also indicative of gas-hydrate-bearing sediment.

Both the GVR6 (Figure 10) and the ARC (Figure 11) resistivity logs also reveal a zone of elevated resistivities around depth of the expected BSR, between 371 mbsf and 392 mbsf. In this case we cannot easily differentiate between the occurrence gas hydrate or free gas; and since we failed to log this interval with the wireline DSI tool in the AT 151-3 well we are unable to conclusively identify the actual contact between gas hydrate and free gas section (i.e., the BSR) at this site.

Resistivity log data have been used to quantify the amount of gas hydrate at KC 151-2. For the purpose of this discussion, it is assumed that any high resistivities measured in the KC 151-2 well are due to the presence of gas hydrate or possibly free-gas at the depth of the BSR. The Archie relation ($S_w=(aR_w/\varnothing^m R_t)^{1/n}$) was used with resistivity data (R_t) from the LWD RAB tool and porosity data ($\varnothing$) from the VDN density tool to calculate water saturations. It should be noted that gas hydrate saturation (S_h) is the measurement of the percentage of pore space in a sediment occupied by gas hydrate, which is the mathematical complement of Archie derived water saturations (S_w), with S_h=1-S_w.

For the Archie relation, the formation water resistivity (R_w) were calculated assuming a constant pore water salinity of 34.4 ppt (sea water salinity). However, pore water salinities calculated from recovered core water samples in KC 151-3 were often very high, exceeding 50 ppt. It was decided for now, to take a conservative approach and assume a sea water salinity, which would yield generally higher water saturations (or lower gas hydrate saturations). The Archie *a* and *m* variables were calculated using a cross plot technique (*a*=0.62, *m*=2.15), which compares the downhole log derived resistivities and density porosities (Figure 12). The APCT temperature data obtained from the KC 151-3 well revealed an equilibrium seabed temperature of 4.79°C and a geothermal gradient of about 3.0°C/100m.

The Archie relation generally yielded water saturations from 100% to as low as 60%. The low water saturations in the upper 110 mbsf of the well is likely in error and is a product of density log data that has been degraded by enlarged borehole conditions. In Figure 13, the previously identified high resistivity interval from 220 mbsf to 300 mbsf is characterized by relatively low water saturations or high gas hydrate saturations, with inferred peak gas hydrate saturations averaging about 30%. The BSR feature however is marked by only a very small reduction in water saturations at a depth of 388 mbsf.

The review of the well log data from KC 151-2 does suggests the presence of significant gas hydrate occurrences. As previously noted above, the RAB images in the high resistivity interval from 220 mbsf to 300 mbsf, reveals the presence of numerous steeply dipping fractures throughout this section. It is likely that the RAB imaged fractures are the “reservoir” or void space in which the deep reading resistivity inferred gas hydrates occur in the KC 151-2 well.

Borehole Temperature and Pressure Data

The APWD measured borehole pressures (DHAP) generally indicate a uniform pressure gradient with depth (Figure 3), with some pressure deviations associated with running heavy mud sweeps near the end of pipe connections. The anomalous APWD pressure response near 100 mbsf needs to be further examined. The DHAT temperature log indicates that the circulating fluids were cooled in their descent in the drill pipe to a relatively uniform temperature in the range of 6-9 degrees Celsius (Figure 2).

Table 1. Keathley Canyon 151-2 LWD/MWD Logging Program

Water depth: 1335.0 m RKB

Drillers TD: 1794.8 m RKB

RKB above sea level: 13.2 m

Date	Time (CT)	Depth of drill bit (mbrf)*	Event
7-May-05	1:31	0.0	Move LWD/MWD tools to pipe rack and initialize tools
	10:22	0.0	Begin to pickup LWD/MWD tools and run into hole
	12:00	128.0	Pump test LWD/MWD tool string, test fails, pull BHA to surface
	13:23	0.0	Swap in Power Pulse and ARC, re-initialize tools and RIH
	15:30	65.0	Pump test LWD/MWD tool string, past test
8-May-05	6:35	1335.0	Spud well, controlled drill 100 GPM, 25 m/hr ROP, 50 RPM
	8:10	1358.6	Bring pump rate up to 360 GPM, MWD powered up, problem with GVR6
9-May-05	20:40	1794.8	Well reached TD at 459.8 mbsf
	22:06	1794.8	Start trip of BHA to sea floor, running heavy mud sweep
	8:30	1335.0	BHA clears sea floor
	13:00	1335.0	Begin trip of BHA to the rig floor
	9:45	0.0	BHA clears rig floor and laid down tools
	11:45	0.0	LWD/MWD log data transfer completed

*1m = 3.28084ft

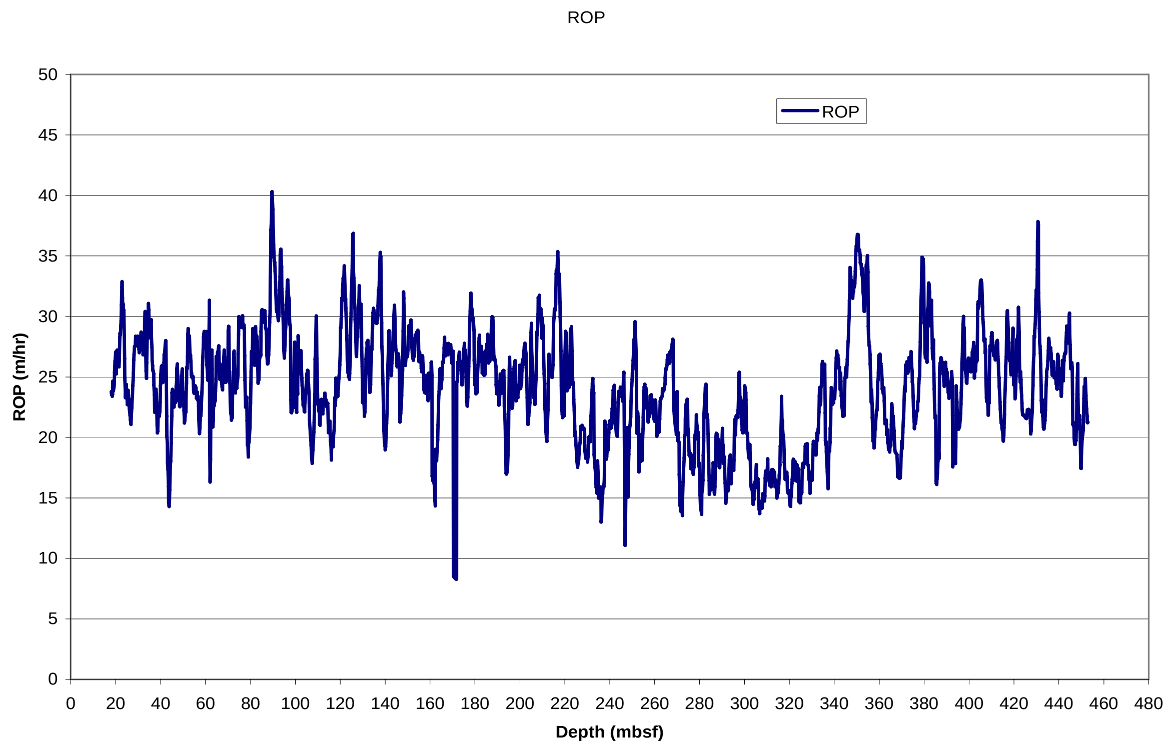

Figure 1. Rate of penetration (ROP) while drilling the KC 151-2 well (real time data)

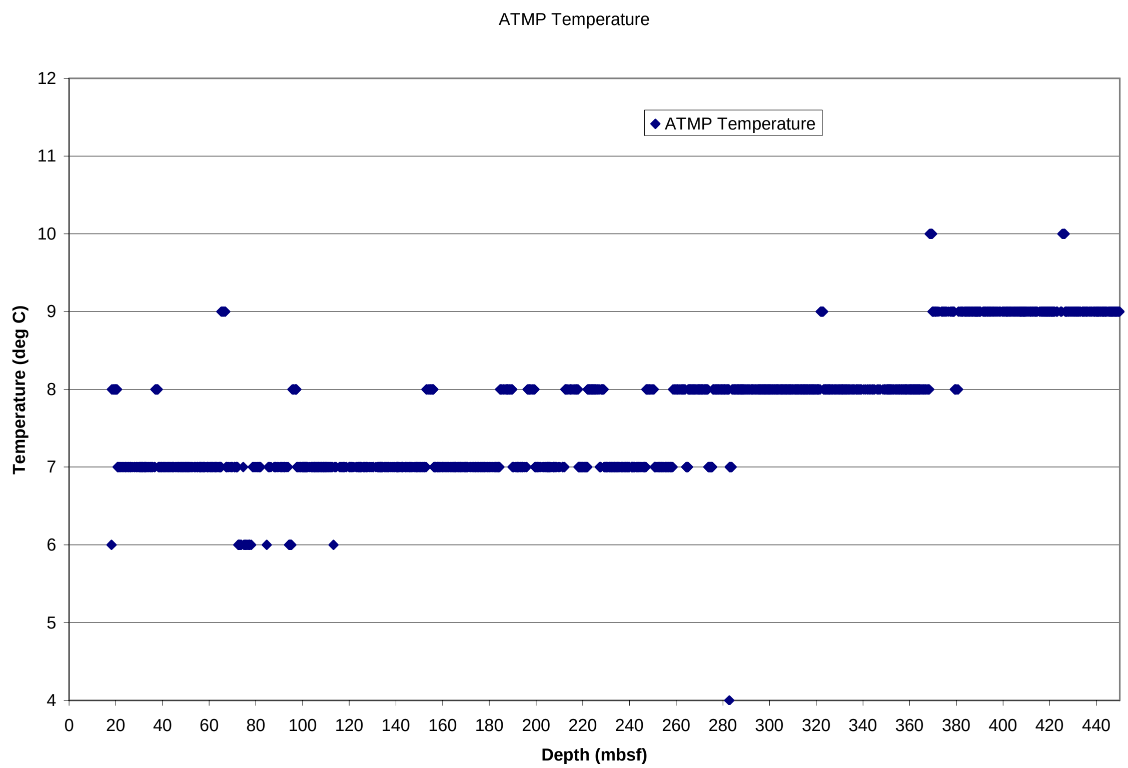

Figure 2. Annular temperature for KC 151-2 from the APWD tool (real time data)

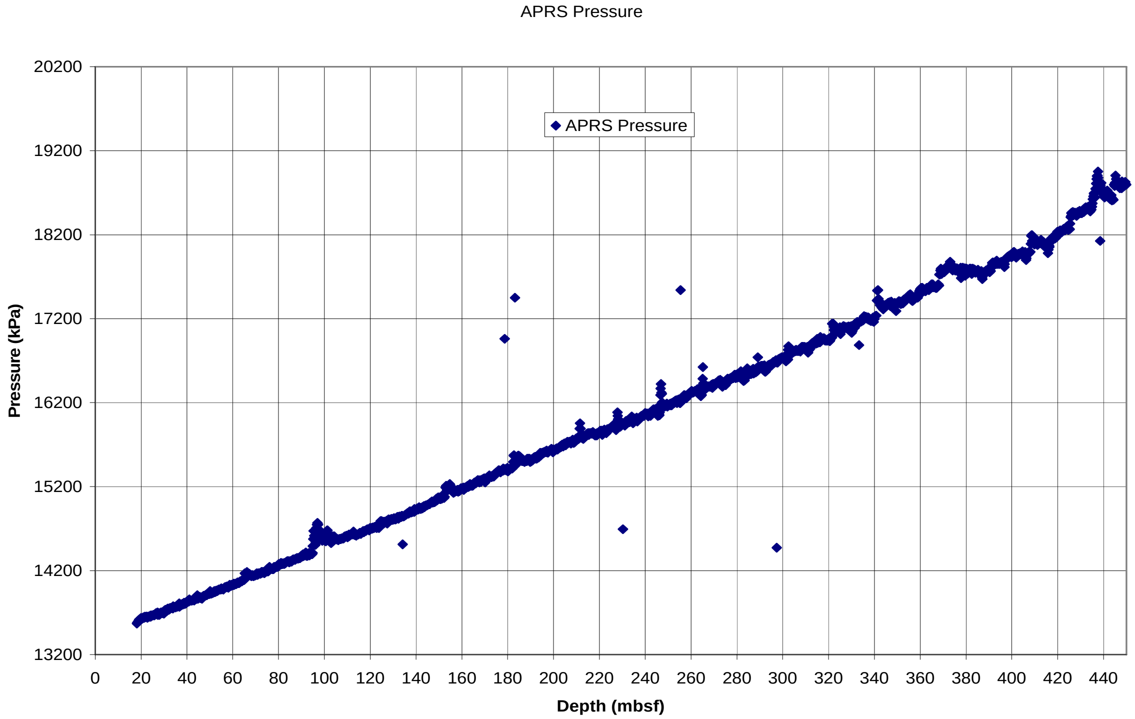

Figure 3. Annular pressures recorded (APWD tool) in the KC 151-2 well (real time data)

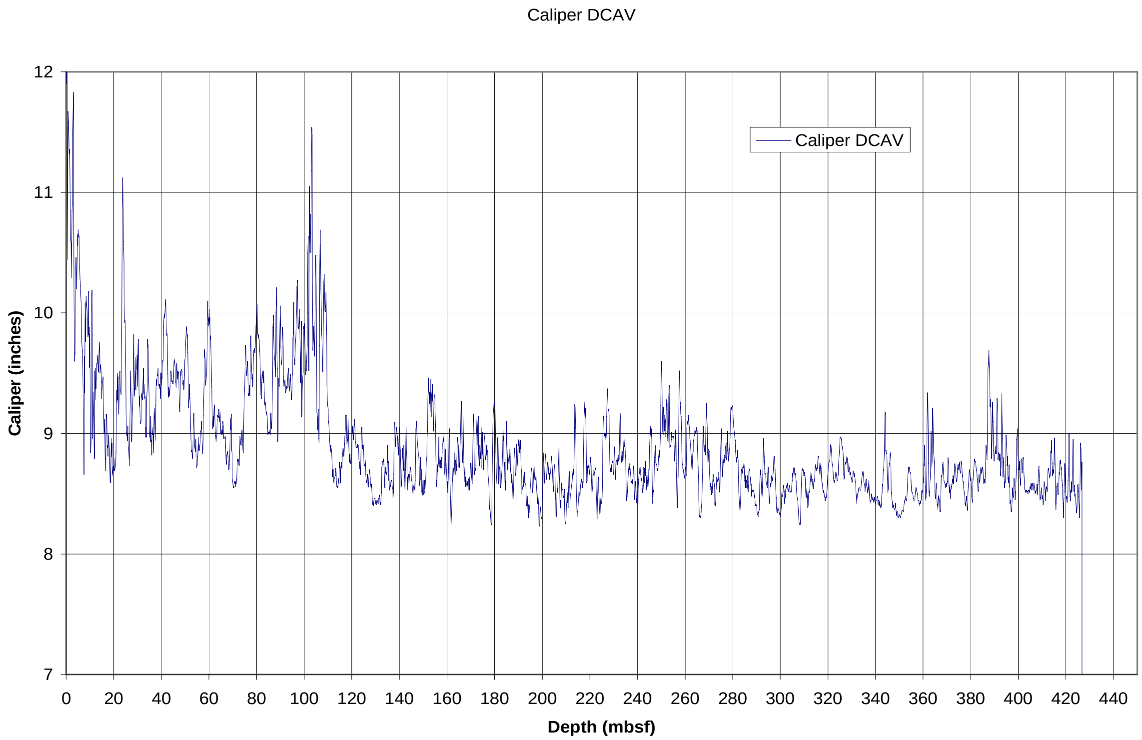

Figure 4. Borehole density caliper as measured by the VDN tool in the KC 151-2 well (recorded data)

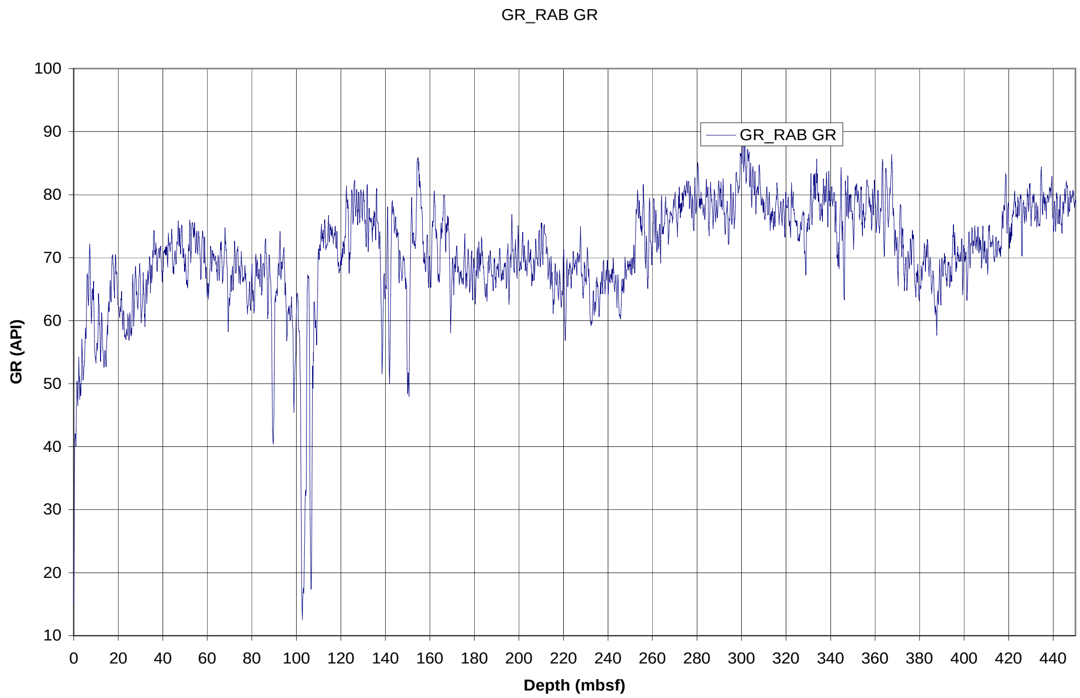

Figure 5. Gamma ray log as measured by the GVR6 tool in the KC 151-2 well (recorded data)

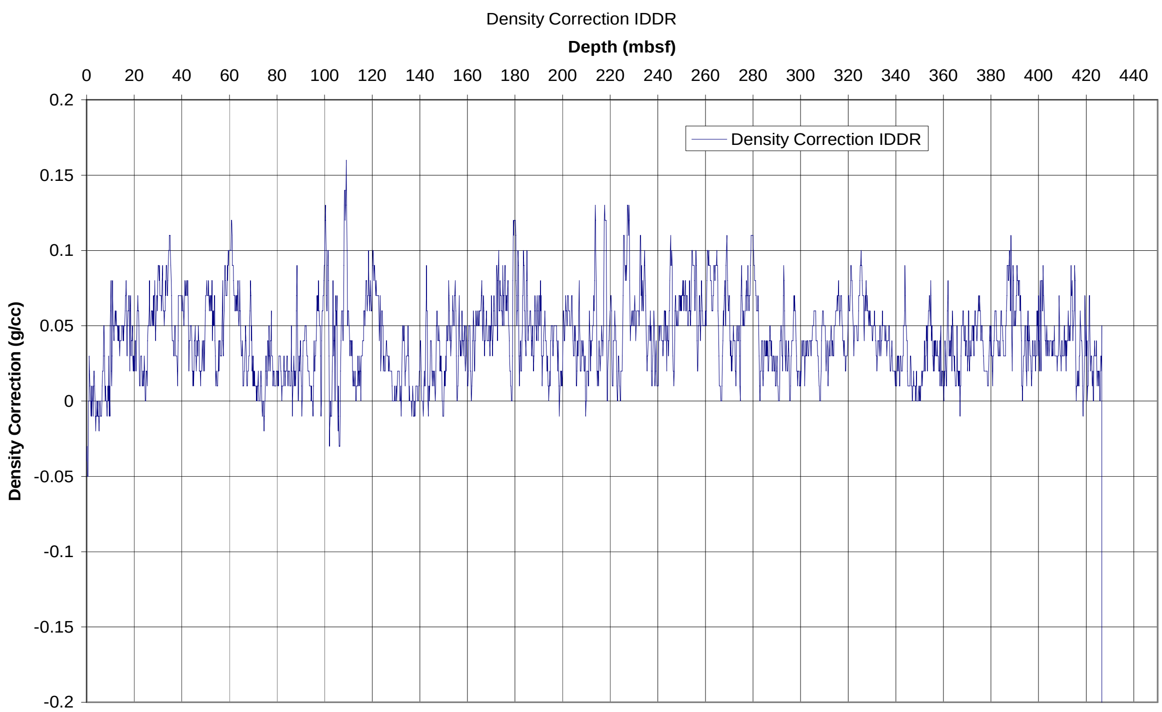

Figure 6. Density log correction for the density log as measured by the VDN tool in the KC 151-2 well (recorded data)

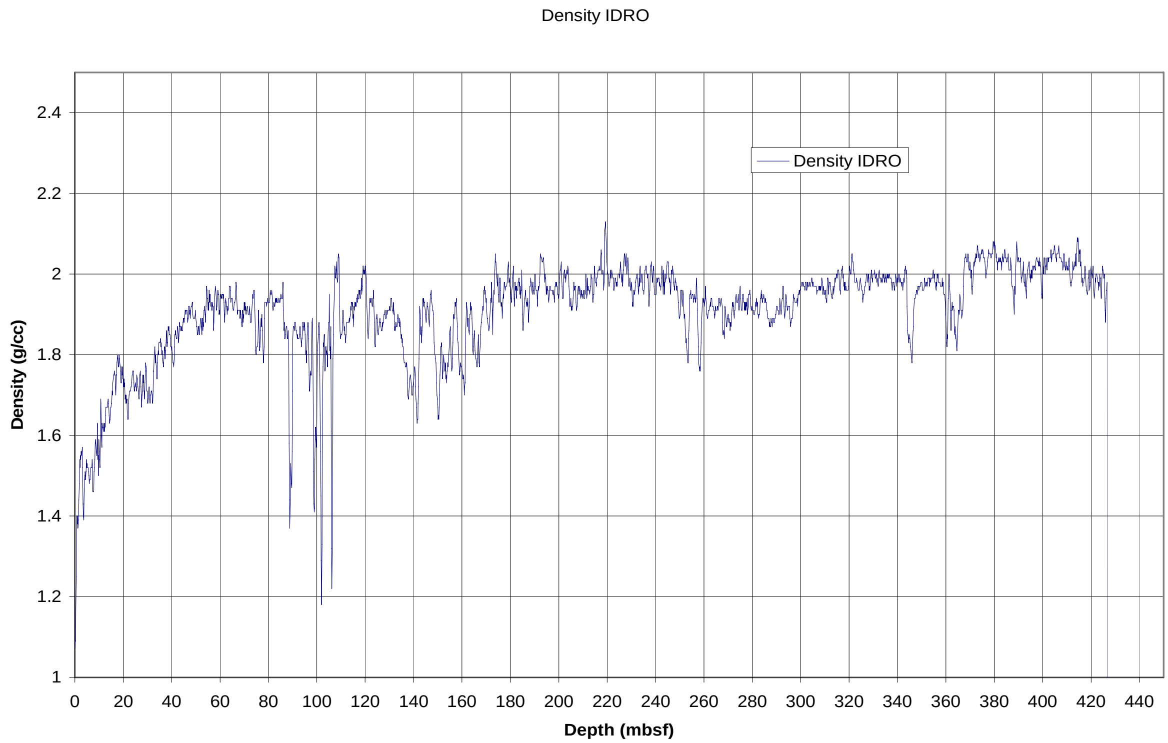

Figure 7. Density log as measured by the VDN tool in the KC 151-2 well (recorded data)

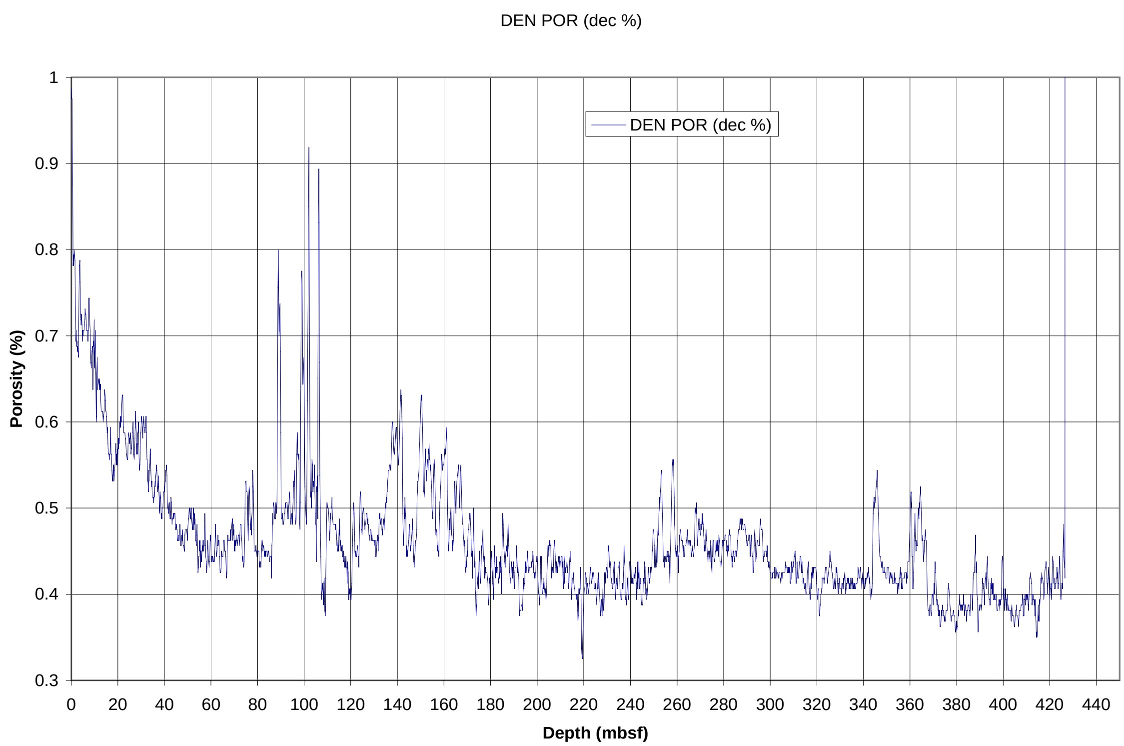

Figure 8. Density log derived porosities in the KC 151-2 well (recorded data)

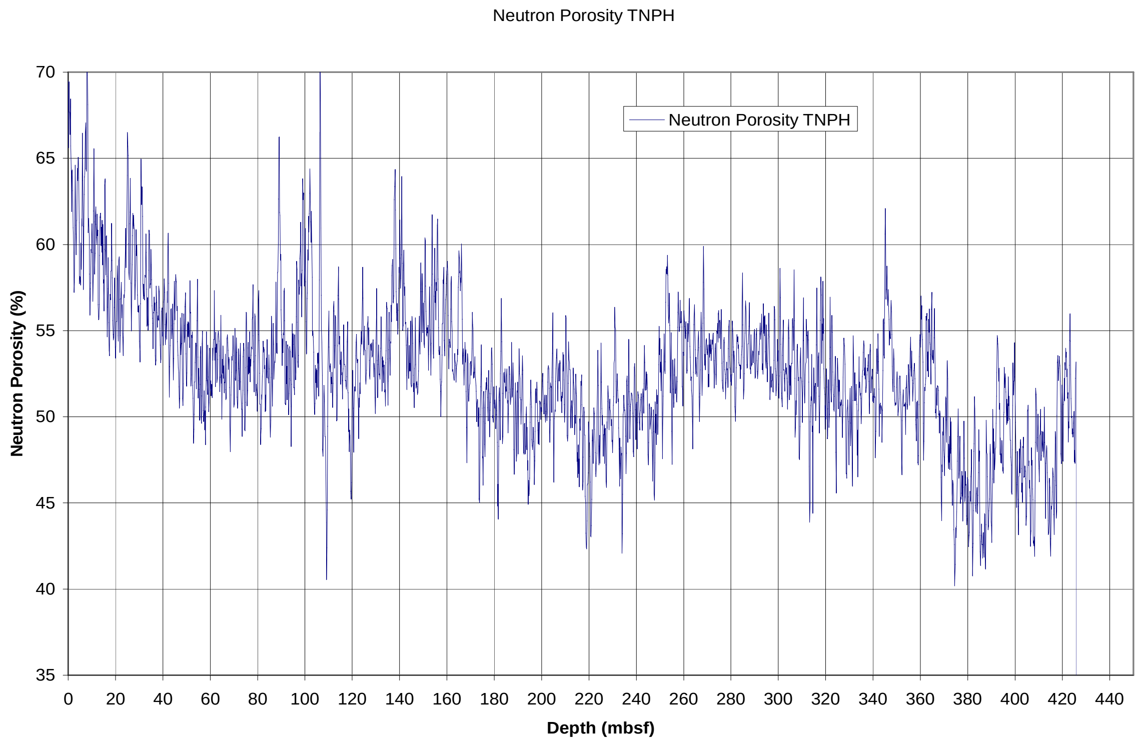

Figure 9. Neutron porosity log as measured by the VDN tool in the KC 151-2 well (recorded data)

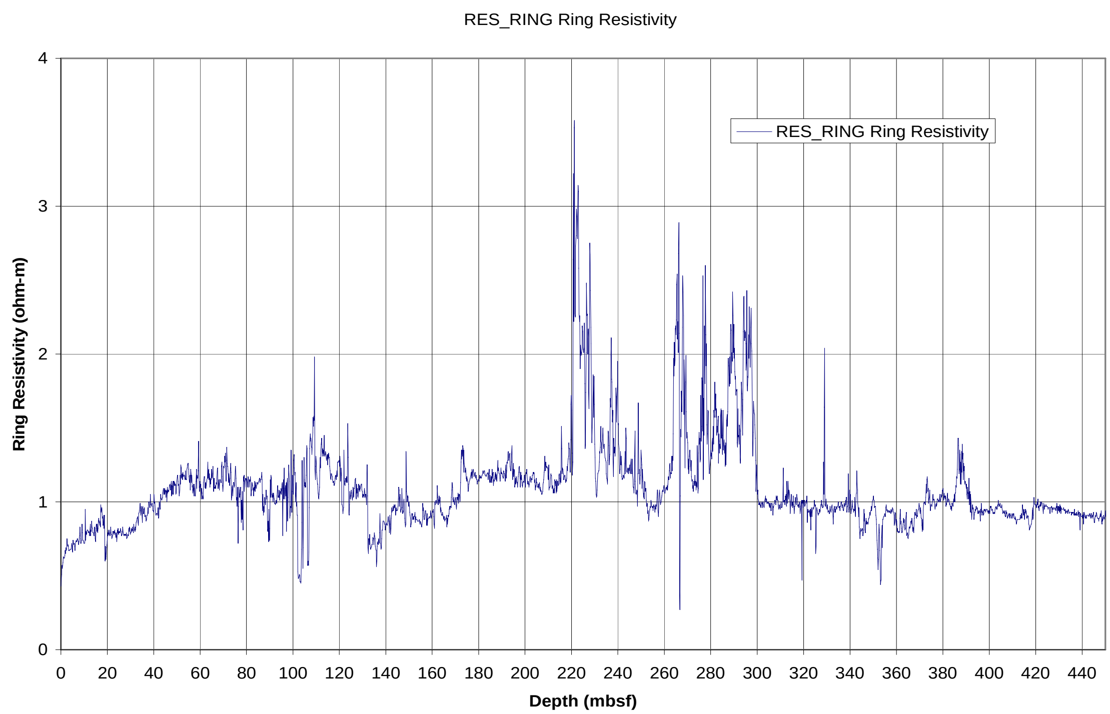

Figure 10. Ring resistivity log as measured by the GVR6 tool in the KC 151-2 well (recorded data)

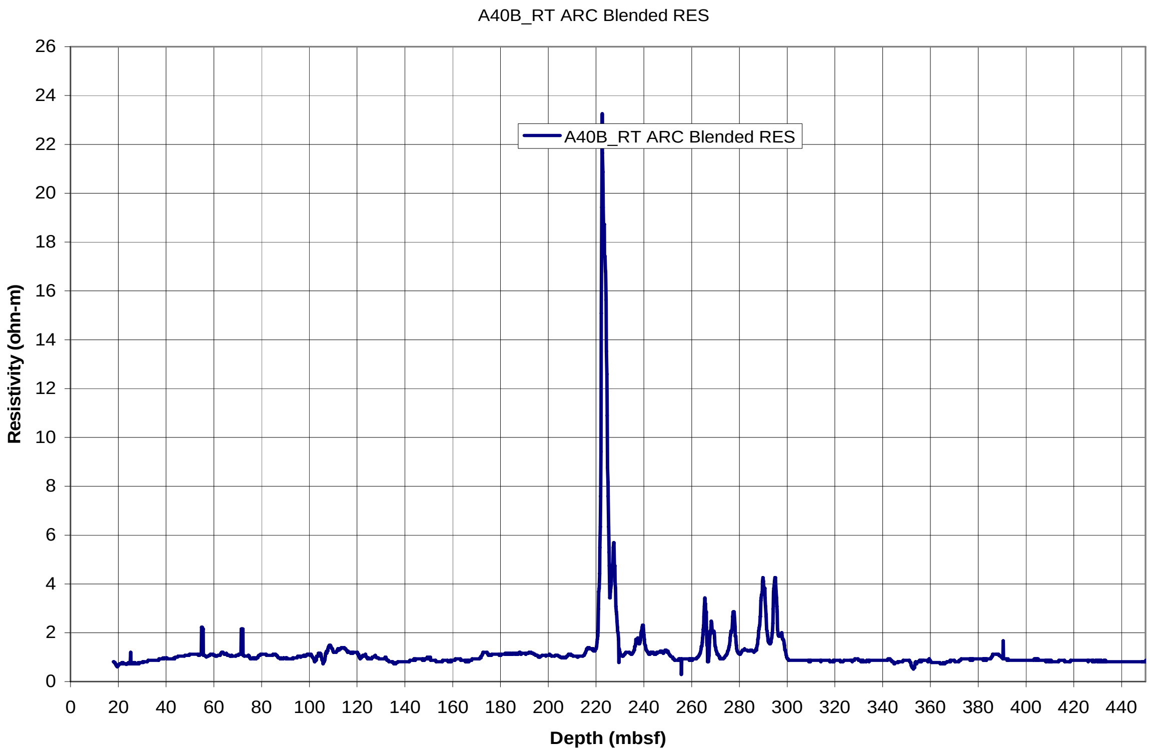

Figure 11. Deep blended resistivity log as measured by the ARC tool in the KC 151-2 well (recorded data)

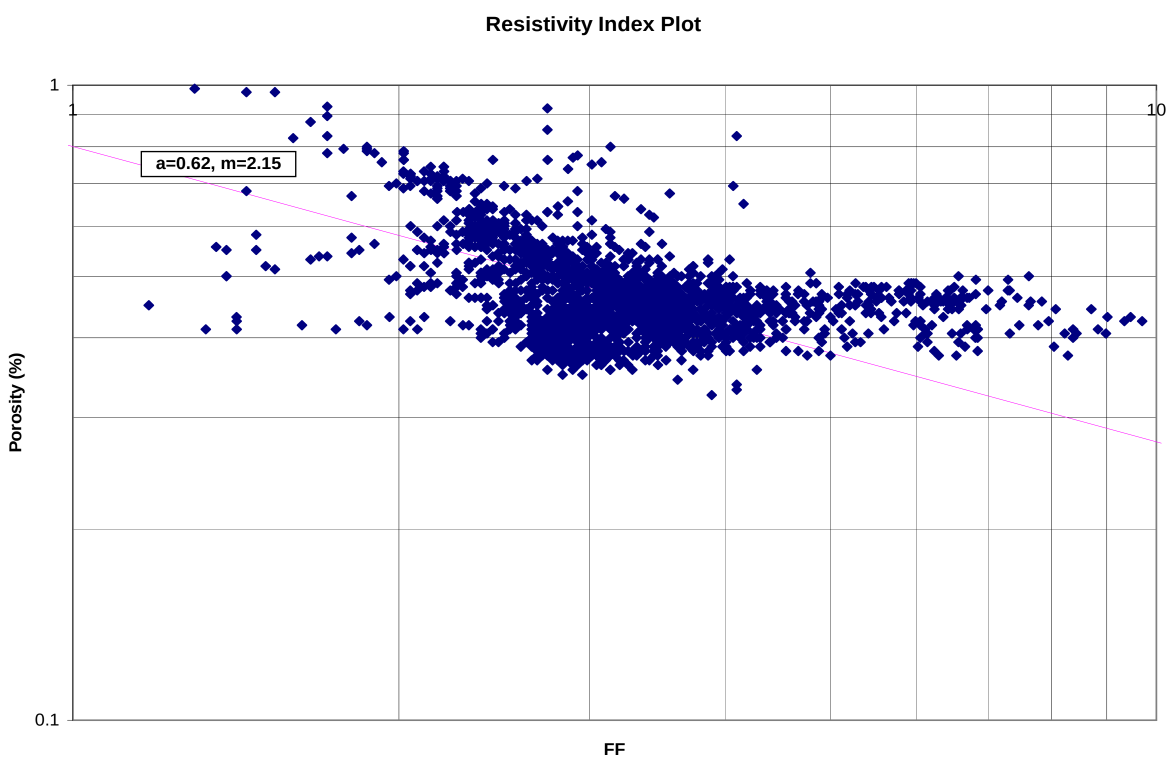

Figure 12. Resistivity index plot (formation factor vs. porosity) for the KC 151-2 well (recorded data)

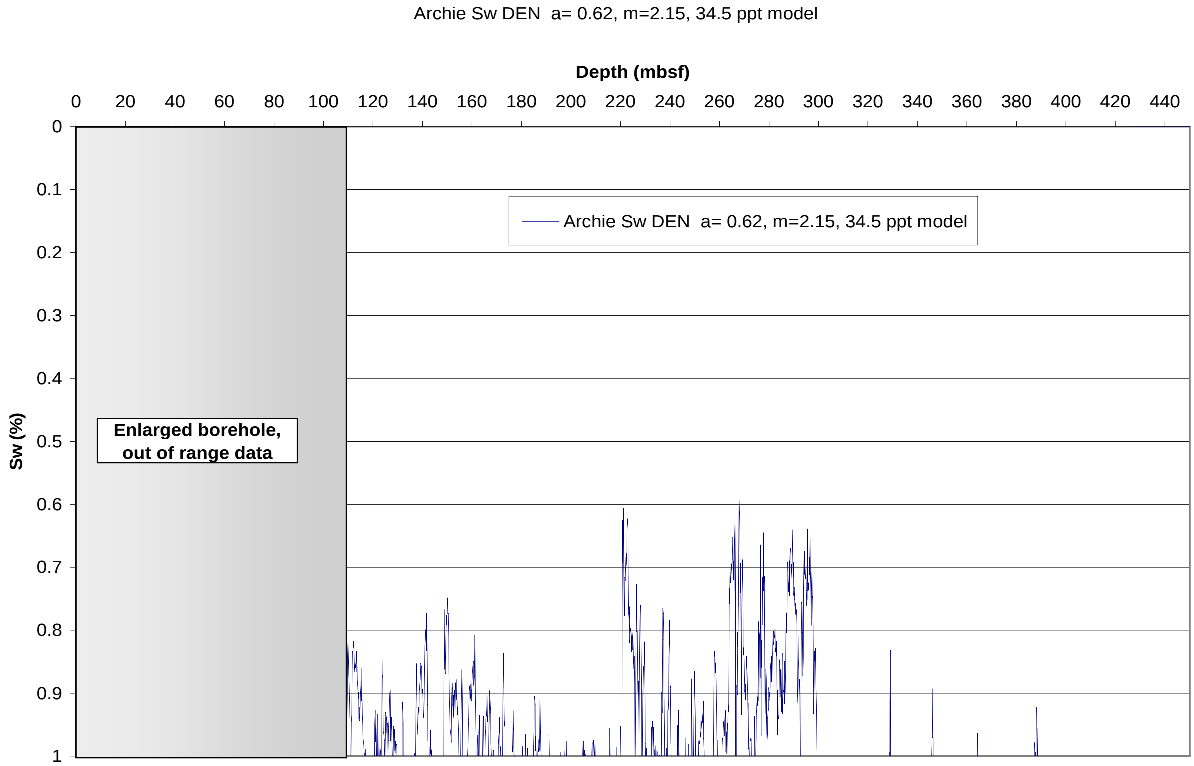

Figure 13. Archie derived water saturations for the KC 151-2 well (recorded data)

ChevronTexaco GOM Gas Hydrate JIP Drilling Program

Keathley Canyon 151-3

-WIRELINE AND VSP LOGGING-

Prepared by Timothy S. Collett, U.S. Geological Survey

May 21, 2005

Operations

The drilling objectives at the Keathley Canyon 151 site were to further characterize the possible occurrence of gas hydrate related bottom simulating reflector (or BSR). Seismic lines from both high resolution research seismic surveys and from regional 3D surveys through the Keathley Canyon 151 proposed drill site reveal the presence of a BSR at a depth of about 380 mbsf. Thus, the Keathley Canyon 151 block contains one of the rare instances of a BSR in the Gulf of Mexico, and may indicate the occurrence of gas hydrates at depth.

Keathley Canyon 151-3 (KC 151-3) was cored (FHPC, FC, HRC, FPC) and drilled to a total depth of 444.1 mbsf (drillers depth). Conventional wireline logging (CWL) operations began at 03:00 CT on May 19, 2005 with makeup of the DSI-GR-GPIT tool string and ended with the final rig-down for the VSI tool at 15:15 CT on May 19, 2005. See Table 1 for detailed information on the KC 151-2 CWL program. Figures 2 and 3 in the *Explanatory Notes* show the configuration of the FMS-sonic tool and the VSI tool. For the most part the KC 151-3 well was drilled with only sea water as the drilling fluid, but as the hole was advanced periodic sweeps of Attapulgite based drilling mud was used to sweep and stabilize the hole. Additional sweeps of a polymer based mud was used to clear the KC 151-3 well. A barite kill mud was also used to control a water flow problem that developed after the well was drilled and before the deployment of the CWL tools.

CWL operations in KC 151-3, began with the deployment of the FMS-sonic tool (GR-DSI-GPIT) without the FMS tool. After the drill pipe exiting problems experienced in the AT 13-2 well, it was decided remove the FMS tool from the CWL tool string deployed in the KC 151-3 well. In the KC 151-3 well, the GR-DSI-GPIT tool string exited the drill pipe without any problems; however, we did require several attempts to re-enter the drillpipe after the uphole main pass of the tool string.

The GR-DSI-GPIT tool string reached a depth of only 341 mbsf, some 103.1 m above the drillers TD of 444.1 mbsf and 44 m above the depth of the expected BSR (385 mbsf). Because of concerns associated with borehole stability problems, a down going log was collected while tripping in at 245 m/hr. Also the drillpipe was set at a relatively deep depth of 123 mbsf, to avoid expected borehole stability problems in the overlying section. The down going DSI survey was acquired in BCR mode, with the monopole source ran at a “standard central frequency” of 12.5 kHz. Excellent quality data were acquired during the main up hole pass, at a wireline speed of 245m/hr. During the uphole main pass the DSI survey was acquired in BCR mode, with the monopole source set at a lower frequency of 6 kHz. Without the FMS tool, we were unable to mechanically centralize the DSI tool. Also we had no caliper measurements to evaluate the hole conditions. The shuttle clamps from the VSI tool (acquired during the VSP survey), however, showed only a slightly enlarged borehole with the hole diameter seldom exceeding 11 inches (bit size was 8.75 inches). The sonic waveforms recorded from the two DSI log runs (downhole and uphole passes) suggests that we acquired generally high quality compressional wave acoustic data, but the shear wave coherence plot revealed only a faint shear-wave coherence. The very low velocity of the formation made it difficult for the automatic slowness/time coherence (STC) picking program to select accurate compressional- or shear-wave velocities. Some adjustment of the STC parameters allowed for improved compressional- and shear-wave picking, but still further reprocessing will be required.

After completing the GR-DSI-GPIT log run, the VSI tool (VSP logging tool) was assembled and lowered to a depth of 337.3 mbsf (Tables 1 and 2). The VSI was configured using four geophone shuttles (approximately 2.06 m spacing with rigid interconnections) and combined with a natural gamma ray tool. One uphole vertical incident or zero-offset VSP experiment was conducted in the KC 151-3 well. During the vertical incidence VSP operations in the KC 151-3 well, the shuttles were mechanically clamped against the borehole wall and the source (1520 cubic inch guns in a Dual Itaga Air Gun Array) on the *Uncle John* was fired between 6 and 10 times by control hardware in the Schlumberger logging unit. The VSI tool was then unclamped and pulled 8.5 m uphole, maintaining a 2.06 m receiver station depth spacing throughout the hole. The VSI recorded the full seismic waveform for each firing. These waveform data were stacked by the Schlumberger recording software and output in both LDF (internal Schlumberger format) and SEG-Y formats. The VSP survey in the KC 151-3 well was conducted in the interval from 334 mbsf to 124 mbsf, with 26 open hole stations and 104 individual shuttle clampings.

The depths, relative to seafloor, for the GR-DSI-GPIT log runs and the VSP survey were fixed by using the *Uncle John* ROV to identify the actual BHA bit contact with the sea floor and shifting the log data to the appropriate depth as determined by the drillers' pipe tallies. For KC 151-3 it was determined that the seafloor was at a depth of 1335.0 mbrf. The rig floor logging datum was located 13.1 m above sea level for this hole. The absolute logger's depth, relative to seafloor, will be further analyzed post cruise by identifying the gamma ray signal associated with the seafloor and depth shifting the log data appropriately.

Interpretation of Wireline Logs

After the completion of CWL operations in the KC 151-3 well, a highly reduced version of the "primary" set of the GR-DSI-GPIT well log data was transferred to the onboard science party for initial analysis. For this report, we have loaded this primary data set into Microsoft Excel and generated two well log displays (Figures 1 and 2). The well log data plots of compressional- and shear-wave transit times for KC 151-3 show relatively high quality CWL logs.

Gamma ray measurements from the GR-DSI-GPIT tool string also indicates that the KC 151-3 well penetrated mostly a fine-grained clay dominated sedimentary section, except for one thick sand section at 95-110 mbsf. There are also several notable sand rich sections deeper in the well near 139-143 mbsf and 150-165 mbsf (similar to those observed in the LWD gamma ray data from the KC 151-2 well).

As discussed in the LWD logging report for KC 151-2, the presence of gas hydrates was not fully verified by coring in the KC 151-3 well. In several instances cold spots, mousey sediment textures in the recovered cores, and anomalous low pore water salinity values inferred the presence of gas hydrate. Several, of the recovered pressure cores also indicated gas concentrations exceeding normal solubility, but no gas hydrate was physically observed. However, the conspicuous LWD measured high resistivity zone in the KC 151-2 well from 220 mbsf to 300 mbsf is indicative of a gas hydrate bearing sediment. It is also important to note that a portion of this interval from about 220 mbsf to 258 mbsf (plus other sections) are characterized by relatively low acoustic transit-times (high acoustic velocities) as recorded by the DSI wireline tool in the KC 151-3 well, which is also indicative of gas-hydrate-bearing sediment.

It is important to highlight, that portions of the CWL and LWD logged sections in both of the Keathley Canyon wells are characterized by zones of distinct high resistivities and high acoustic velocities (low acoustic travel-times), with the resistivity in one relatively thin zone exceeding 22.0 ohm-m and compressional-wave transit-times as low as 155 msec/ft. As previously discussed in the Explanatory Notes, gas hydrate occurrences are generally characterized by increases in log measured electrical resistivities and acoustic velocities.

Table 1. Keathley Canyon 151-3 Wireline Logging Program

Water depth: 1335.0 m RKB
Drillers TD: 1776.1 m RKB
RKB above sea level: 13.1 m

Date	Time (CT)	Depth of logging string (mbrf)	Event
18-May-05	14:30	0.0	Drilled well to total depth (441.1 mbsf)
	16:25	0.0	Begin wiper trip to 306.1 mbsf, return to bottom of hole
	17:15	0.0	Well flowed during wiper trip, killed with 12lb/g mud
	20:45	0.0	Begin mud displacement run to 123.0 mbsf
19-May-05	3:00	0.0	Begin picking up logging tools
	3:35	0.0	Running into hole at 1200 m/hr
	4:40	1458.0	DSI tool exits drillpipe, 123.0 mbsf
	4:40	1458.0	Logging down at 245 m/hr, DSI medium frequency
	5:32	1676.0	Reached loggers TD at 341 mbsf
	5:32	1676.0	Logging up at 245 m/hr, DSI low frequency
	6:14	1458.0	DSI tool entered drillpipe
	8:10	0.0	Pulled logging tools to the derrick floor, 1200 m/hr
	8:15	0.0	Rig up for VSP survey and RIH at 1200 m/hr
	9:45	1421.8	Conduct air gun and tool check
	9:58	1458.0	VSP tool exits pipe, RIH at 245 m/hr
	10:35	1672.3	Reach loggers new TD at 337.3 mbsf
	10:40	1669.0	Begin up logging at 8.4m stations w/ 4 shuttles
	13:28	1459.0	Complete up log VSP, 26 stations w/ 4 shuttles
	13:30	1458.0	VSP tool entered drillpipe, POH 1200 m/hr
	15:15	0.0	Pulled tools to the derrick floor and laid down tools

*1m = 3.28084ft

Table 2. Keathley Canyon 151-3 VSP stations and shots, four shuttle VSI tool at 2.06 m spacing.

Water depth: 1335.0 m RKB
Drillers TD: 1776.1 m RKB
RKB above sea level: 13.1 m

Station Number	Depth of deepest shuttle (mbrf)	Shot numbers
1 (pipe)	1429.1	xx
2	1669.0	28-31
3	1660.9	32-35
4	1652.7	36-40
5	1644.5	41-48
6	1636.3	49-53
7	1628.0	54-58
8	1619.7	59-63
9	1611.4	64-69
10	1603.2	70-76
11	1595.0	77-82
12	1586.6	83-91
13	1578.4	92-97
14	1570.2	98-103
15	1562.0	104-110
16	1553.6	111-116
17	1545.4	117-123
18	1537.1	124-129
19	1528.9	130-136
20	1520.7	137-143
21	1512.5	144-150
22	1504.1	151-161
23	1495.8	162-172
24	1487.6	173-179
25	1479.3	180-186
26	1471.2	187-193
27	1462.8	194-201
28 (pipe)	1429.1	202-208

*1m = 3.28084ft

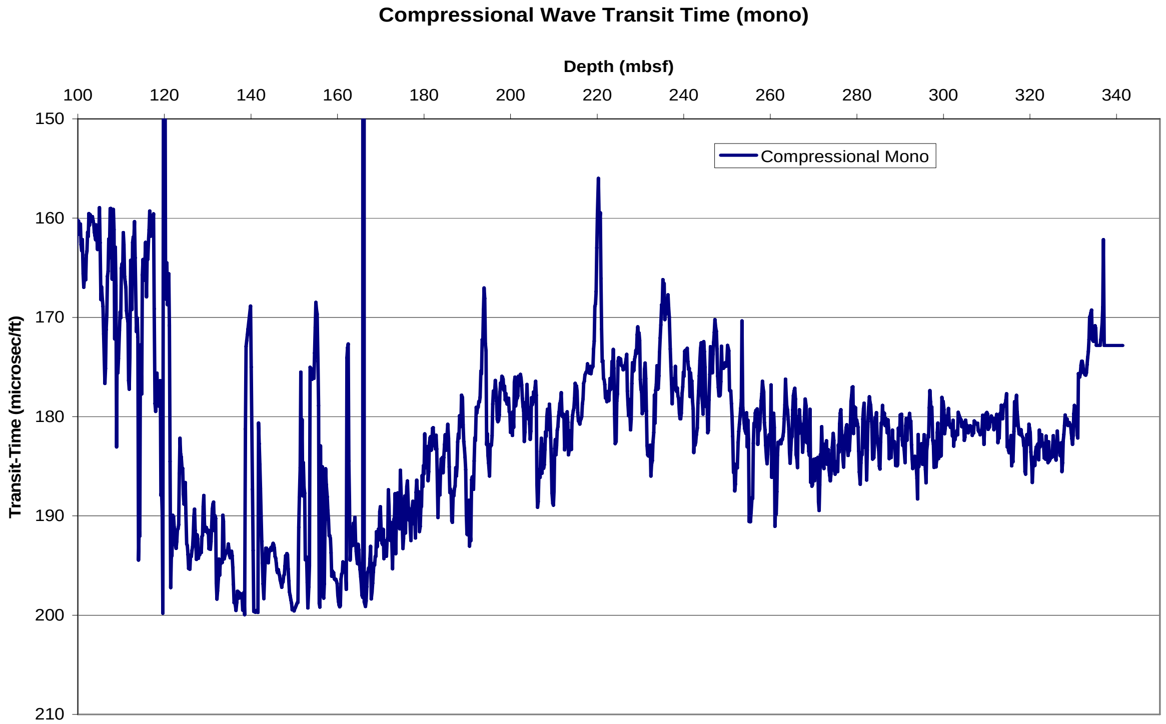

Figure 1. Compressional-wave acoustic transit-time log data from the DSI tool run in the KC 151-3 well

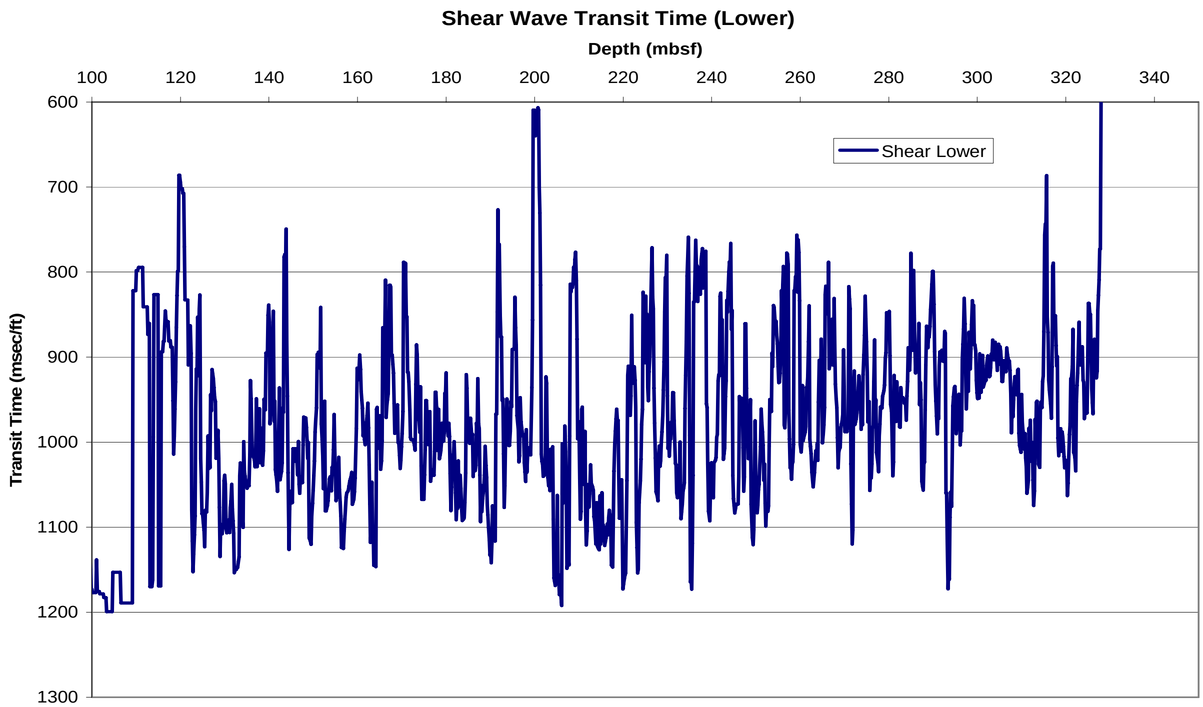

Figure 2. Shear-wave acoustic transit-time log data from the DSI tool run in the KC 151-3 well