Core-Tube Data Logger

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ABSTRACT

Three types of core-tube data loggers (CTDL) have been built and tested to date by Sandia National Laboratories. They are: 1) temperature-only logger, 2) temperature/inclinometer logger and 3) heat-shielded temperature/inclinometer logger. All were tested during core drilling operations using standard wireline diamond core drilling equipment. While these tools are designed for core-tube deployment, the tool lends itself to be adapted to other drilling modes and equipment.

Topics covered in this paper include: 1) description on how the CTDLs are implemented, 2) the components of the system, 3) the type of data one can expect from this type of tool, 4) lessons learned, 5) comparison to its counterpart and 6) future work.

INTRODUCTION

Wireline core drilling, increasingly used for geothermal exploration, employs a core-tube to capture a rock core sample during drilling. The core-tube free falls through the drilling mud where it self latches behind the drill bit. As the drill bit penetrates rock, the core-tube fills. The driller retrieves the core-tube via a wireline fitted with a mechanism to mate with the core-tube.

The repetitive process of core sampling gave birth to an idea. What if a memory based electronic sensory package were mounted in the core-tube? Such a package has been developed at Sandia. It is referred to as a Core-Tube Data Logger (CTDL). The CTDL is a memory tool that rides inside the core-tube, measuring and storing data. The CTDL requires little, if any, additional rig time to use, resulting in essentially "free" information. Downloading data at the surface can be done very quickly, and the CTDL can be returned downhole with the core-tube. In hot wells the tool will need time to equilibrate with ambient conditions, but alternating between two tools would eliminate lost time.

Communications between Sandia and Tonto Drilling led to the idea and development of the core-tube data logger. Using previously developed hardware and software from Sandia's high-temperature instrumentation program made implementation straight forward. It uses the same basic technology that is present in the Pressure/Temperature Precision Memory Tool. It is not designed to be as precise due to the requirements of this tool. The CTDL can perform basic functions such as temperature measurement and more based on the need/requirements of a particular drilling operation. The CTDLs are fabricated to be rugged (no special handling is required) and easy to operate (using a standard laptop computer).

Tonto Drilling supplied the initial mating parts to connect the CTDL to the interior of the core-tube for the first series of tests in Elko, NV. Boart Longyear supplied the mating parts for the second series of tests at Fort Bliss. A Dewared CTDL containing two inclinometers is shown in Figure 1.

DISCLAIMER

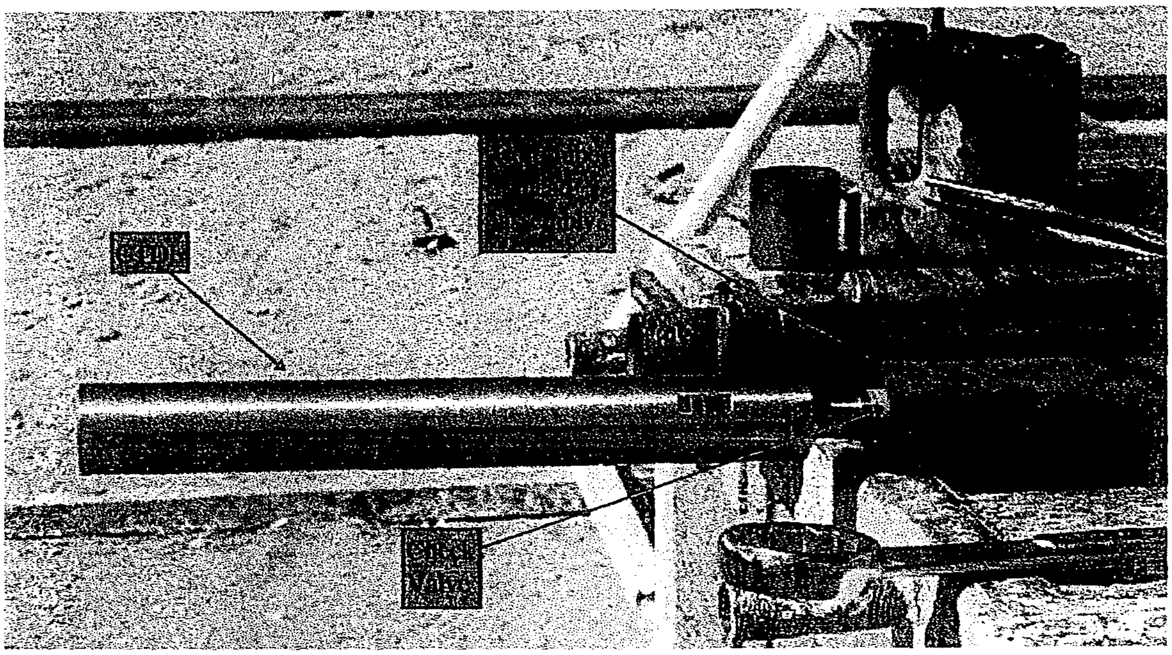

Figure 1. Pictured is the Dewared temperature/inclinometer CTDL prior to deployment.

THE SYSTEM

The CTDL takes up room inside the core-tube, resulting in a short run; but only about 18 inches out of a 10 or 20 foot barrel is occupied by the CTDL. Periodic short runs are often part of the normal drilling process. In some formations, the driller can predict when a short run will be encountered. By coordinating with the driller, these short runs can be utilized as CTDL runs.

To deploy the CTDL, a check valve nut located in the lower end of the core-tube head assembly is required to be modified. This valve prevents drilling mud from being pumped into the core-tube area during drilling, allows well-bore fluid to pass through the check valve while the core-tube assembly is dropped into place, and provides a path for the drilling fluid to exit as core enters the tube. The modification consists of threading the inside bore of the check valve nut that is used to secure the inner workings of the check valve. Once the modified nut is in place, the CTDL can be securely held in position and is properly aligned with respect to the drill string. This nut can be easily removed from the core-tube head assembly and does not disrupt the drilling operation. The CTDL assembly includes an adapter that is threaded onto this check valve nut and is ported to allow normal operation of the valve. The CTDL is threaded onto this adapter.

The length of the tool varies, depending on the type of sensors desired. The tools fabricated thus far are approximately 10 inches in length for the CTDL that measures temperature only, and approximately 18 inches in length for the CTDL that contains the temperature probe and inclinometers. The Dewared CTDL is also 18 inches in length. This length will have to be increased for temperature requirements above 400° F to allow room for additional heat sinks. This would increase the time the CTDL can remain in the well. Heat sinks are normally large metal masses of stainless steel or brass. Eutectic material can be used in conjunction with, or instead of, the stainless steel or brass heat sink. By increasing the length of the CTDL to approximately 50 inches (to allow room for additional heat sinks), the CTDL could be deployed in wells with temperatures exceeding 700°F.

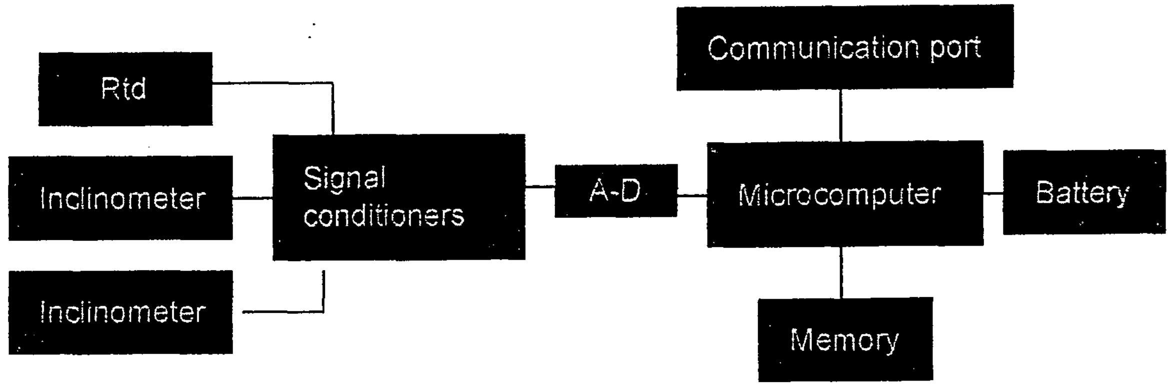

Figure 2. Block diagram of the electronics for the temperature/inclinometer CTDL

THE ELECTRONICS

The electronics consist of: 1) sensors to make the required measurements; 2) signal conditioners; 3) analog-to-digital converter; 4) microcomputer; 5) memory;, and 6) battery. A block diagram of the electronic section of the temperature/inclinometer CTDL is pictured in Figure 2.

By deploying a complete logging system, a variety of sensors can be utilized in future applications. Measurements such as pressure, temperature, and inclination are easily implemented. To date, temperature and inclination measurements have been incorporated. Depending on the expected well-bore temperature, a resistance temperature detector (RTD) or a thermistor is implemented in the CTDL. Inclinometers are one-axis accelerometers calibrated to provide a linear voltage output based on tilt in its sensitive axis. Inclination measurement requires two inclinometers mounted 90 degrees with respect to each other and with respect to the drill bit's longitudinal axis. This allows the CTDL to resolve inclination regardless of the orientation of the CTDL.

The microcomputer utilized in the three tools tested is manufactured by Onset Computing Company (North Falmouth, MA). They make a line of computers that have seen use in remote-sensing applications.

The temperature-only CTDL was the first built and tested. It uses a one-channel 8-bit analog-to-digital converter and can store 1800 data points. The data interval is software-configurable between 1 second and 288 minutes. It utilizes a Windows-driven software package that has built-in plotting functions. The data can be exported for use in spreadsheets such as Excel. The logger has nonvolatile (EEPROM) memory enabling the data to be retained without batteries. The logger uses a watch-size battery that lasts for approximately one month. The physical size is ≈ .75 inches by 1.75 inches, making it ideal for space-restrictive designs. The temperature resolution for this device is approximately ± 4° F. The tool communicates through an RS232 communication port on a laptop PC to establish runtime conditions and to offload its data.

The next CTDL built and tested uses an 8-channel 12-bit analog-to-digital converter, 1 frequency measurement port, and 14 general purpose I/O lines that can be used for various control functions. It has 0.5 Mbytes of memory that can store 10,000 or more data points, depending on the number of channels in use. This CTDL's parameters are programmed using BASIC. The software enables the CTDL to make decisions based on time and/or sensor information. The current program asks the user pertinent questions to set parameters, such as Time of Day and sample interval desired.

External temperature, internal temperature, inclination, and battery voltage are currently monitored. An on-board Light Emitting Diode (L.E.D.) illuminates when the tool is storing data. This insures the operator the CTDL is functioning properly prior to deployment. The microcomputer in this CTDL uses static RAM memory. This type of memory is volatile and requires the battery to remain connected for memory retention.

This CTDL is presently deployed using a DOS based program, but a Windows version is imminent. As with the CTDL above, it communicates through an RS232 port on a laptop PC. This CTDL can resolve approximately 0.2°F and 0.3 degree for a tilt measurement. The basic electronic section is 1.2 inches by 6 inches. Its length is increased based on the number and type of attached sensors. The CTDL with an RTD and two inclinometers has an electronic section that is 12 inches in length. Batteries for this tool consist of a standard 9-volt alkaline battery for low-temperature wells where the internal tool temperatures remain below 160°F. For higher-temperature wells, batteries that are rated to 300°F are available from Battery Engineering Incorporated (Hyde Park, MA).

The final CTDL built and tested contains the same instrument package as the second. This CTDL has an enhanced operating temperature range by virtue of its heat shielding.

FIELDING

The CTDLs have been tested in the laboratory and in the field at depths of up to 4,000 feet. The temperature-only CTDL and the temperature/inclinometer CTDL (unshielded) have been involved in two field activities. The temperature-only CTDL has seen approximately 15 deployments. The temperature/inclinometer CTDL has seen approximately 40 deployments. To date, the Dewared CTDL has been involved in one field activity and approximately 6 deployments. All CTDLs performed well with no loss of data.

Examples of the type of data generated by these loggers are pictured in Figures 3 and 4. The data contains interesting characteristics. It is worth noting that inclinometers are vibration-sensitive devices. As such, the tilt readings will fluctuate when they are subjected to vibration.

The inclinometer data in Figure 4 can be explained as follows. The large readings at time 0 to 500 seconds indicate the CTDL is being handled. At approximately 500 seconds the tilt reading drops, indicating the tool is just about to be inserted into the well. The tilt readings are low with some fluctuation as the tool is traveling down the well. The tilt readings with no fluctuation from approximately 1,000 to 1,200 seconds indicate the core-tube is in place. At approximately 1,200 seconds the fluctuations vary between 0 and 25 degrees. This is an indication drilling has started.

Drilling continued until 4,000 seconds. At that time, the tilt readings did not fluctuate. This is an indication that drilling has stopped and the overshot is being lowered. This is a good time to determine the inclination of the well. In this case it was 2.5 degrees. At 4,300 seconds, the overshot has latched onto the core-tube and it is on its way to the surface. The 50 degree tilt reading between 4,500 and 4,900 indicate the core-tube is out of the well and has been placed on the deck waiting to be disassembled.

The temperature plot in Figure 3 can be interpreted using the inclinometer data in Figure 4 as an indicator of drilling activities.

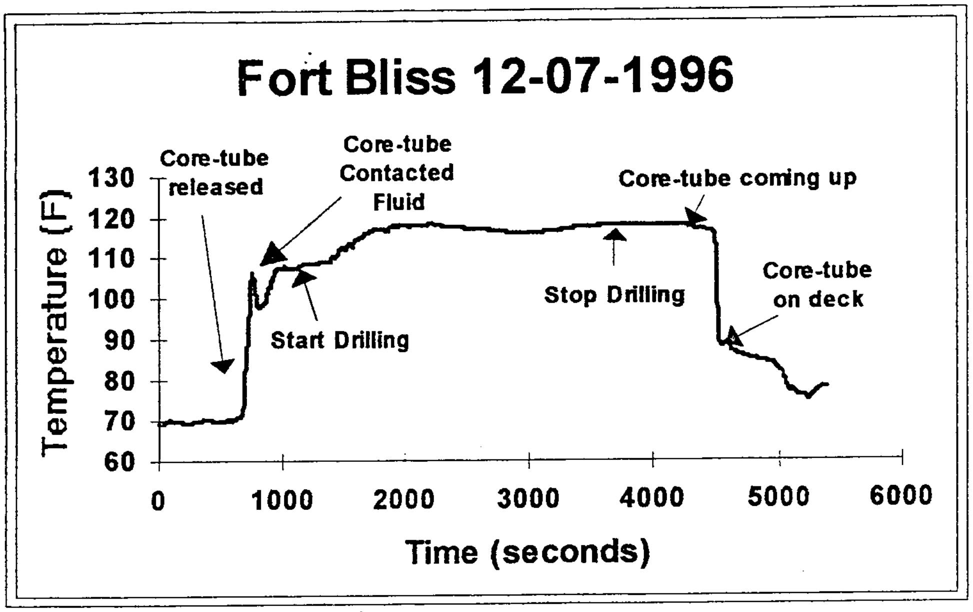

Figure 3. Typical temperature plot.

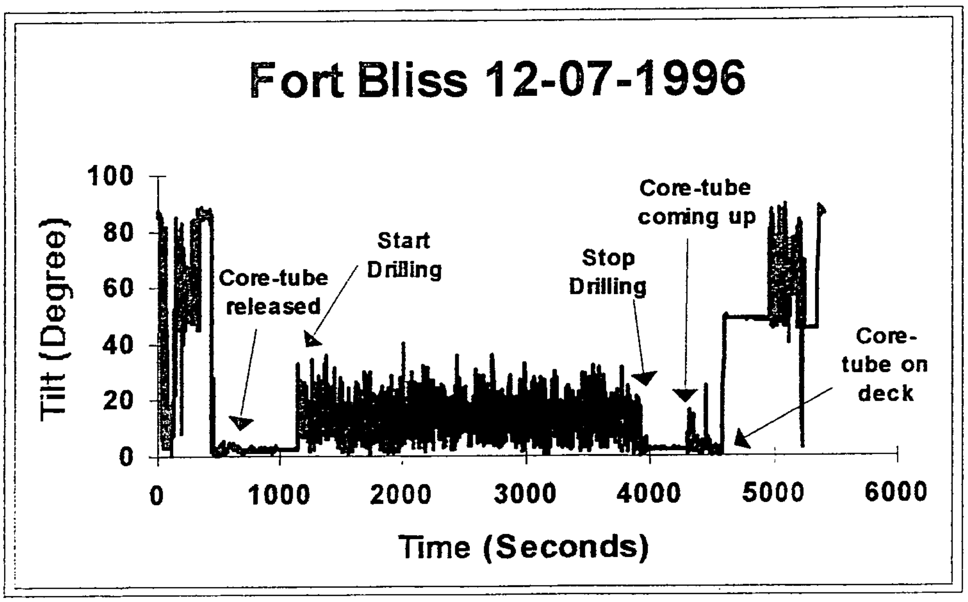

Figure 4. Typical inclinometer plot

When drilling has stopped and the overshot is being lowered, the drilling fluid has some time to equalize with the formation. This is the time to determine the bottom-hole-temperature. In this case it was 117.7°F.

At Fort Bliss, a "pseudo log" capability for the core-tube logger was demonstrated. An ideal time to have the core-tube logger in place is during a bit change. Removing/installing drill rod to change bits allows for the CTDL to slowly log the entire well. At Fort Bliss, Sandia has a computerized data acquisition system that records the drilling parameters including depth. By synchronizing both computer clocks, the two files can be merged after the CTDL is retrieved to provide a temperature data vs. depth plot. An example of such a log is pictured in Figure 5.

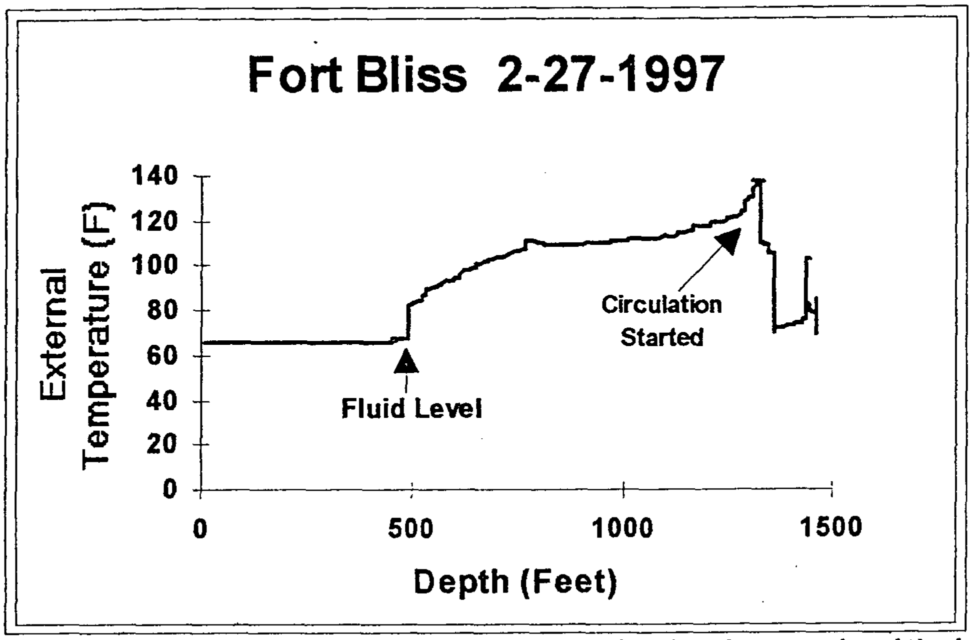

Figure 5. Results of a Pseudo log. The CTDL was placed in the core-tube while the drill string was lowered into the well.

LESSONS LEARNED

Temperature measurement is a function of a number of drilling conditions. When analyzing temperature data, care must be exercised to account for these conditions. For example, if the mud pump is circulating downhole, temperature will be affected. The more that is known about the drilling conditions during the log, the easier the log will be to interpret.

Understanding the inclinometer data also required being aware of drilling activities. By writing down the sequence of events after the core-tube was dropped, a correlation between the events and sensors' output was observed. The signatures in the data seemed to correlate to the following events: 1) tool going in and coming out of the well; 2) dead time between the core-tube landing and the start of drilling; 3) drilling; 4) drilling stopped; 5) overshot going in; and 6) core-tube at the surface. After observing the data of several runs, the history of the core run could be recognized. Also, the ideal time to obtain the inclinometer and the bottom-hole-temperature readings became apparent. This time is when the overshot is being lowered to pick up the core-tube. The inclinometer data not only provides an inclination measurement, it provides a record of the core run. This record helps interpret the temperature data by providing a means of determining when drilling has stopped and the overshot is being deployed. At this point in the process, there is no fluid circulation. Thus, the well is allowed to equilibrate with its surroundings. The bottom-hole temperature measurement will be optimized during this period.

COMPARISON OF THE CTDL AND CONVENTIONAL DRILLING AIDS

Maximum reading thermometers have been used successfully in the drilling industry for many years. The information provided to the driller is limited and the maximum temperature location in the well is not guaranteed, but a general idea of the bottom-hole-temperature is learned.

The present configuration of the temperature/inclinometer tool is comparable to a Drift Indicator Tool. This type of tool is used to track bore-hole drift. It utilizes some form of a centralizer to insure the tool is in alignment with the drill string. This simple, mechanical tool punches a hole in a paper disk to record the well-bore's inclination from vertical. To ensure accuracy, the tool provides a redundant measurement 90 degrees from the first. The tool is deployed between drilling runs and is triggered to take the measurements based on time, motion or the presence of monel. Both of these tools are deployed using the rig's wireline.

The CTDL developed at Sandia will provide the same basic information as the tools above and a wealth of additional information. The temperature-only CTDL provides a means of obtaining a temperature profile of the well and the apparent drop time of the tool (based on when the tool contacted the wellbore fluid). The temperature profiles change based on well-bore conditions. A record of the profiles provides the driller additional information on the characteristics of the well. The temperature/inclinometer CTDL provides the above information and a history of the core run based on both the temperature and the inclination data along with the inclinometer measurement.

Cost is a topic worth noting. The cost for a CTDL is higher than a maximum reading thermometer, but is comparable to a Drift Indicator Tool. When one adds the benefits of obtaining information not achievable with the other two tools, the CTDL is a worthwhile investment. The estimated cost breakdown for the Dewared temperature/inclination CTDL is listed in Table 1. These costs reflect the component parts, and they do not take into account engineering overhead, and any profit that a service company would require if it is to undertake support of the tool.

Table 1

Sensors	**$ 550**
Electronics	**600**
Hardware	**1500**
Totals	**$2650**

FUTURE WORK

A strain-gauge type pressure transducer would be a valuable addition to the CTDL. It would provide insight on the fluid level in the well. By observing the pressure decay during the "quiet" time (when the overshot is going down to retrieve the core-tube), an indication of the wellbore's permeability would be ascertained. Knowing the fluid level of the wellbore fluid would also be helpful in interpreting the temperature data. Implementation of a pressure transducer in the current Dewared CTDL would not be difficult. It would add approximately $600 to the cost of the CTDL.

This basic concept can also be carried over to other types of drilling. For example, a tool could easily be modified to work in conjunction with a single shot or multi-shot camera used in mud rotary drilling.

It also could be utilized to determine wellbore temperature prior to placing a cement plug. The cement is mixed with a retardant and this ratio is wellbore temperature dependent. Too much retardant will result in long curing times while not enough may lead to premature curing. Knowing the temperature would optimize the curing time thus reducing wasted rig time.

While the core-tube tools take up valuable interior space inside the core-tube, this loss of room has not been an issue thus far. Heat shielding capable of protecting the electronics from temperatures of up to 750°F would require the length to be increased to approximately 50 inches. This may be acceptable for logs performed daily. Another approach would be to install the logger outside the core-tube. A location between the wireline connection and the core-tube assembly is plausible. This approach may be necessary for NQ coring where the inside diameter of the core-tube may not be large enough for a Dewared CTDL.

Sandia is currently working on a high-temperature electronics project utilizing high-temperature components as they become available. These components will be capable of withstanding temperatures of 570°F without heat shielding. A temperature logger containing high-temperature components would therefore not require a Dewared vessel or heat sinks. Batteries are a problem also being addressed by Sandia. The Battery Development Department at Sandia is working on a battery capable of bridging the gap between commercially available 390° F high-temperature batteries and 570° F electronics. It is conceivable that a high-temperature temperature logger could be fabricated within the next two years.

Three additional concepts are being considered for core-tube logging. In one, an inertial navigation system could be packaged into a tool that would travel downhole with the wireline that is used to retrieve the core-tube, thus storing and retrieving directional data with each trip of the wireline. In the second concept, a two-axis inclinometer would be packaged in the core-tube logger and would measure and store data that could be used to orient the rock core to determine its *in situ* direction. The core entering the core-tube would be scribed to enable the core to be aligned. A continuous directional survey of the well would be performed after drilling to obtain azimuth and inclination data. By coupling the survey information with the inclination data taken with each core run, the orientation of the core would be determined.

In the third, the CTDL would be utilized as a memory logging tool. This would be accomplished by outfitting the rig's wireline with an encoder to enable the wireline's depth to be recorded. A data logger at the surface would store this information. The CTDL would be lowered into the well at a constant speed. After the log, the two data files would be merged to obtain a data vs. depth profile of the well.

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