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23. DATA REPORT: A TEST OF THE TEMPERATURE, PRESSURE, AND CONDUCTIVITY TOOL PROTOTYPE AT HYDRATE RIDGE[1]

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ABSTRACT

A prototype tool to continuously monitor temperature, pressure, and conductivity (TPC) changes during Ocean Drilling Program (ODP) coring was used successfully 107 times at Hydrate Ridge during Leg 204.

TPC sensors are located on the face of the standard ODP advanced piston corer piston, and the data logging electronics and batteries are embedded within the piston. This tool operates autonomously and requires little shipboard attention. The objective is to measure the temperature and pressure changes that occur in gas-rich and gas hydrate–bearing cores during collection and ascent to the surface and to use these data to learn about the processes that occur inside a core during recovery. Gas exsolution and expansion during core recovery alter both the temperature and pressure conditions within the core barrel, and the amount of gas in the core affects where these changes occur. The core collection process dramatically affects pressure inside the core barrel, which reduces core temperature and changes gas saturation conditions. Families of temperature-time curves generated from TPC data show distinct cooling anomalies associated with core pullout and with movement of the core through the shallow water column and on the deck of the drillship.

Here the performance of the TPC tool and the response of the tool at sites with significant quantities of sediment gas and gas hydrate near the seafloor are described.

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[1] Ussler, W., III, Paull, C.K., McGill, P., Schroeder, D., and Ferrell, D., 2006. A test of the temperature, pressure, and conductivity tool prototype at Hydrate Ridge. *In* Tréhu, A.M., Bohrmann, G., Torres, M.E., and Colwell, F.S. (Eds.), *Proc. ODP, Sci. Results,* 204: College Station TX (Ocean Drilling Program), 1–41. doi:10.2973/odp.proc.sr.204.112.2006

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INTRODUCTION

In this paper we describe the design and discuss tests conducted during Ocean Drilling Program (ODP) Leg 204 of the temperature, pressure, conductivity (TPC) downhole tool that has been developed to measure the effects of expanding gas within the ODP advanced piston corer (APC) assembly during core recovery and that may be used extensively during the Integrated Ocean Drilling Program.

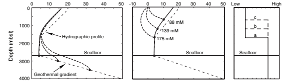
Catwalk Core Temperatures

During more than a quarter-century of Deep Sea Drilling Project (DSDP) and ODP drilling, vigorous gas expansion and anomalously cold temperatures in cores from continental margins have been commonly observed. Compositional data clearly indicate that the expanding gas is usually dominated by methane; however, very little is known about how much methane was actually in these sediments before recovery (e.g., Paull and Ussler, 2001). Thermal observations have included cores feeling cold (e.g., Leg 146 Site 889 [Westbrook, Carson, Musgrave, et al., 1994]) and the occurrence of frozen pore waters along the interior wall of the core liner (e.g., Leg 164 [Paull, Matsumoto, Wallace, et al., 1996]). A few investigations have quantified these observed thermal anomalies by inserting thermistors into the core after it has been removed from the core barrel and delivered to the catwalk (Leg 164 Site 994 [Paull, Matsumoto, Wallace, et al., 1996]) or to the core laboratory immediately after core splitting (temperatures as low as –2°C have been recorded; e.g., Leg 66 Site 490 [Watkins, Moore, et al., 1982] and Leg 146 Site 889 [Westbrook, Carson, Musgrave, et al., 1994]) and by scanning core liner on the catwalk with infrared (IR) imaging cameras (e.g., Leg 201 [D'Hondt, Jørgensen, Miller, et al., 2003] and Leg 204 [Tréhu, Bohrmann, Rack, Torres, et al., 2003]). These "catwalk core temperature" measurements show that some core sections arrived on deck at distinctly lower temperatures (5°–10°C cooler) than other cores recovered from the same drill site. Moreover, when in the core recovery process these cooler temperatures are generated is largely unknown.

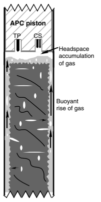
Three processes can cause a temperature decrease in sediment cores during their ascent to the sea surface: (1) gas expansion, (2) gas exsolution, and (3) gas hydrate decomposition. Predictions about the temperature changes that will occur in gassy sediments (with or without gas hydrates) during core recovery based on simple thermodynamic calculations (Ussler et al., 2002) indicate that these changes are of the right order of magnitude and direction.

Thermal modeling has shown that cores which exsolve gas during their ascent to the surface have distinct ascent temperature profiles (Fig. F1) (Ussler et al., 2002). Ascent temperature profiles track profiles for gas-free cores until gas saturation occurs and exsolution commences. Free gas coming out of solution along the length of the core buoyantly rises within the core barrel (Fig. F2). As soon as free gas is trapped at the top of the core barrel, temperatures should drop as a result of gas exsolution and gas expansion (Fig. F1B). Most of the gas exsolution and expansion, and thus the largest temperature changes occur in the upper water column. In situ gas concentration can be calculated using the pressure and temperature of the inflection in ascent temperature profiles and the methane gas solubility model of Duan et al. (1992), assuming that no gas was introduced during the coring process.

F1. Radial heat transfer models, p. 15.



F2. APC core barrel, p. 16.



Previous TPC Tool Deployments

The TPC tool was used previously during Leg 201 at Site 1226 (Ussler et al., 2006). Because no observations of core degassing or anomalously low core temperatures were made at this site, the cores contain sulfate throughout, and the measured methane gas concentrations were low, the in situ gas concentrations at this site are believed to be considerably less than those needed to achieve gas saturation of the pore water during core recovery (D'Hondt, Jørgensen, Miller, et al., 2003). Thus, no gas exsolution from the sediments should have occurred during core ascent to the surface at Site 1226. Measurements at Site 1226 were expected to provide background data suitable for determining the response of the TPC tool in gas-poor sediments without the additional complexity of thermal and pressure effects associated with the presence of gas. Surprisingly, some ascent curves showed thermal phenomena that would have been anticipated for gas-bearing cores. Understanding the source of this gas is critical for interpreting TPC data. A geological source for the observed gas has been excluded because sediment gas data for Site 1226 show no indication of significant quantities of methane gas in these sediments (D'Hondt, Jørgensen, Miller, et al., 2003).

Conductivity measurements at Site 1226 (Ussler et al., 2006) indicate that in every case gas was trapped in headspace at the face of the TPC tool during the *initial* deployment of the tool downhole. In many cases, the conductivity sensor indicated that this gas headspace disappeared during descent and reappeared during ascent, albeit at a slightly shallower depth. This suggests that gas completely dissolved during the long descent to the seafloor (~3350 meters below sea level) and then exsolved during ascent. There are no cases where the initial headspace does not return during ascent, whereas in some cases the gas headspace never completed disappeared. Thus, the size of the initial trapped gas headspace was quite variable, but it was always present during the APC coring runs at Site 1226.

Trapping a gas headspace at the face of the TPC tool when the tool is first deployed is probably an inevitable consequence of the coring procedure (Ussler et al., 2006). When the top of the drill string is opened for insertion of the APC corer, the level of seawater in the pipe drains down from the rig floor to sea level, a distance of ~11.2 m. When the drill pipe is reassembled and connected to the mud pumps, as much as ~100 L of atmospheric gas could become trapped within the drill pipe. This trapped gas is circulated down the hole by the mud pumps and eventually should exit at the seafloor. However, the conductivity data suggest that sufficient amounts of gas remain trapped and/or dissolved in the seawater adjacent to the TPC tool to affect the conductivity sensor. This gas may also have contributed to the thermal signal measured by the TPC thermistor. Entrainment of atmospheric gases into the coring system is also a likely explanation for some runs of the pressure core sampler (PCS) during Leg 201 coming up with pressurized air (J. Dickens, pers. comm., 2003).

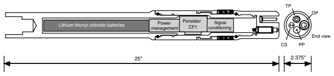
In the Leg 201 *Initial Reports* volume (D'Hondt, Jørgensen, Miller, et al., 2003) the TPC tool was renamed the APC-Methane (APC-M) tool, and this naming was also used in the Leg 204 *Initial Reports* volume (Tréhu, Bohrmann, Rack, Torres, et al., 2003). Although this fits better with the naming convention used by ODP, this is an unfortunate misnomer because the tool does not detect methane or measure its concentration. Because the original National Science Foundation proposal and previous publications (Ussler et al., 2000, 2001, 2002, 2003) described the tool as the TPC, we will continue using this name because of its more accurate description of what is measured.

METHODS

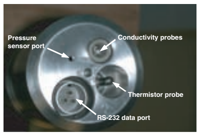
Temperature, Pressure, and Conductivity Tool

The TPC tool is designed to continuously record temperature, pressure, and conductivity at the face of a modified ODP APC piston assembly (Figs. F2, F3, F4) during deployment, core collection, and recovery. The APC piston was modified to contain the TPC tool components (Fig. F3). The tool has a maximum design pressure of 10,000 psi, which corresponds to ~6.9 km total hydrostatic depth.

F3. APC piston and TPC tool, p. 17.



F4. APC piston, p. 18.



Making measurements at the piston face allows for standardization of the effects of cooling during core ascent. This location was chosen for practical reasons: (1) the APC piston could be easily modified to incorporate TPC sensors; (2) the data logging electronics and battery could be housed in the existing piston corer subassembly, making this an autonomous downhole tool; (3) no special downhole tool runs would be necessary to collect TPC data, causing little disruption to the tempo of coring operations; and (4) gas can collect in a recess on the piston face, making electrical conductivity measurements possible.

The conductivity sensor is designed to detect the formation of gas headspace by taking advantage of the large contrast in electrical properties between a gas phase and wet sediment (Fig. F2). This information aids in analyzing the temperature and internal pressure data obtained during core ascent by providing an independent confirmation of headspace formation.

Sensors

The temperature and conductivity sensors are recessed in shallow wells on the piston face for mechanical protection and for the accumulation of headspace gas (Figs. F2, F3, F4). The pressure port opens directly onto the face of the APC piston. The sensors are threaded into the sensor head for ease of replacement.

Temperature is measured using a YSI 55036 thermistor encapsulated within a thin-walled stainless steel probe (3/16 in diameter × 1/4 in long) with a pressure rating of 10,000 psi (Logan Enterprises, West Liberty, Ohio). The time constant for this thermistor probe is 1.5 s, and the accuracy is ±0.05°C. Pressure is measured using a transducer designed for use in corrosive downhole environments and for temperature stability (model 211-37-520; Paine Corporation, Seattle, Washington). Measurement error is ±0.15% of the full-scale reading of 10,000 psi. The conductivity probe is a miniature bulkhead connector with an inconel body and three gold-plated 0.040-in diameter Kovar pins (PMS-series; Kemlon Products and Development, Pearland, Texas). Pin spacing is 3.2 mm.

Electronics

Design objectives for the electronics included minimal power consumption, low component count, 12-bit or better analog to digital (A/D) resolution, low long-term sensor drift, vibration tolerance, large amounts of onboard nonvolatile data storage, and ease of programming and component replacement. Three elements comprise the electronics package: (1) the sensor conditioning electronics, (2) an off-the-shelf microprocessor unit, and (3) the batteries. Low-power 3.3-V CMOS semiconductor components were selected to minimize current drain. The discrete components are surface-mounted on a narrow multilayer printed circuit board that supports the detachable microprocessor unit. To prevent polarization of the conductivity electrodes, the conductivity sensor is excited using an alternating-current signal generated by a simple oscillator circuit. After signal conditioning, the analog signals from the sensors are fed into either a Maxim MAX147 12-bit A/D converter (thermistor and conductivity) or a Cirrus CS5509 16-bit A/D converter (pressure). These A/D converters are connected to a Persistor CF1 microprocessor unit via the queued serial peripheral interface implemented by the onboard Motorola 68338 central processing unit. Data are stored in an onboard 48-MB CompactFlash card hardwired to the CF1 microprocessor unit. Communications with the CF1 occur on the deck of the ship through an RS-232 interface. The CF1 is programmed in C language, using the Metrowerks CodeWarrior programming environment. Temperature, pressure, and conductivity data were collected at 1-s intervals throughout tool deployment.

Power is supplied by two double-C lithium thionyl chloride batteries within a 1 in diameter × 9 in long battery pack that provides 7.3 V, with a 100-mA rating. The electronics/battery assembly was designed for no less than 100 hr of continuous operation.

Data transfer can be accomplished on deck while the TPC tool is installed in the APC drill string through an RS-232 communications port on the face of the piston. This data port is a three-pin keyed bulkhead connector (PMJ-series; Kemlon Products and Development, Pearland, Texas). During coring operations this port is O-ring sealed with a faceplate that is easily removed for access (Fig. F4).

Data Reduction

Temperature

Raw TPC temperature data were converted to thermistor resistance (*R*, ohms) using either fifth- or sixth-order polynomial equations fit with empirically derived calibration coefficients, which are summarized in Table T1. Temperature in K was calculated from these thermistor resistance values using the Steinhart and Hart relationship (Anonymous, 1980):

T1. Polynomial coefficients, p. 31.

$$1/T = A + [B \times (\ln R)] + [C \times (\ln R)^3] \qquad (1)$$

The manufacturer-supplied Steinhart-Hart coefficients for the thermistors used during Leg 204 are summarized in Table T2.

T2. Steinhart-Hart equation coefficients, p. 32.

Pressure

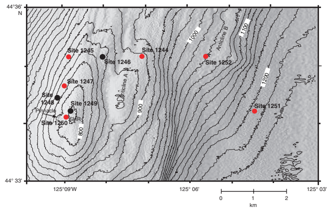
One of two pressure transducers was used for each particular site. Both transducers had nearly identical electrical response; thus, the same empirically derived constant of 0.1812 psi/bit was used to convert raw bit count data to pressure (psig). During some tool runs an offset from zero was obtained, which was subtracted during data analysis. Spurious pressure data were rare, but obvious single-point anomalies and noise that occurred when the tool was on the deck of the ship were eliminated from the data sets analyzed.

Because local hydrographic profiles were not obtained during Leg 204, an average seawater density (1031 kg/m³) appropriate for the latitude and water depth of Leg 204 drilling was computed from an estimate of seafloor pressure computed using a MATLAB m-file (see the "Appendix," p. 14) based on the UNESCO 1980 equation of state for seawater (Saunders, 1981). Pressure measurements from the TPC tool (in psig) were converted to depth using this value of average seawater density.

Conductivity

Because the conductivity circuit was designed to avoid polarization and electrode corrosion in seawater, measured values oscillate rapidly between two extreme values. A change in the difference between the minimum and maximum values indicates a change in the conductivity of the medium contacting the electrodes. Conductivity data for each sensor were normalized by subtracting the mean value from each data point and then taking the absolute value. Visual calibration of the conductivity signal was accomplished during Monterey Bay Aquarium Research Institute (MBARI) remotely operated vehicle (ROV) dive T-2075 in October 2001, using an actual TPC tool assembly. Large values of normalized conductivity correspond to gas headspace, and small values correspond with the presence of seawater at the sensor electrodes.

F5. Leg 204 location map, p. 19.



Coreline Measurements

At four of the six coring sites where the TPC tool was used, measurements of the length of wireline deployed as a function of time, referred to as coreline (Cline) data by the drilling engineers on the *JOIDES Resolution*, were obtained from the drill rig instrumentation system. These independent measurements of wireline length proved invaluable during analysis of TPC pressure data because in contrast with the TPC deployment during Leg 201 (Ussler et al., 2006), large pressure excursions occurred during APC core insertion and removal, making pressure an unsuitable proxy for depth during these time periods.

T3. Drilling data, Hole 1244E, p. 33.

T4. Drilling data, Hole 1245C, p. 35.

T5. Drilling data, Hole 1247B, p. 37.

T6. Drilling data, Hole 1250D, p. 38.

T7. Drilling data, Hole 1251D, p. 39.

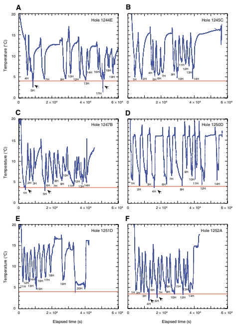
T8. Drilling data, Hole 1252A, p. 41.

RESULTS

The TPC tool was deployed in six holes during Leg 204 (Fig. F5) (Holes 1244E, 1245C, 1247B, 1250D, 1251D, and 1252A). Summaries of drilling data for each hole in which the TPC was deployed are listed in Tables T3, T4, T5, T6, T7, and T8. APC cores that have TPC data are highlighted in yellow in these tables. In four holes (Holes 1244E, 1245C, 1247B, and 1250D) TPC tool deployment was interleaved with other tool runs (e.g., the PCS and Fugro pressure corer), whereas deployments in Holes 1251D and 1252A were continuous. Raw and derived temperature, pressure, and conductivity data and Cline measurements are compiled in data sets (see "Supplementary Material").

Temperature Time Series

F6. Temperature-time data, p. 20.



Temperature data for each hole are plotted vs. time in Figure F6A–F6F. Comparison with mudline temperatures obtained from APC temperature (APCT) and Davis-Villinger Temperature-Pressure Probe (DVTPP) tool measurements (Tréhu, Bohrmann, Rack, Torres, et al.,

2003) show that in seven runs temperatures inside the APC core barrel at the face of the TPC piston are significantly cooler (up to 2.6°C lower). These cooler temperatures (e.g., Cores 204-1244E-5H and 17H, 204-1247B-1H and 5H, 204-1250D-4H, and 204-1252A-4H and 6H) cannot be explained by thermal equilibration with the coldest bottom water in each respective hole (3.5°–4.0°C), indicating the possibility that this cooling is a consequence of gas expansion within the APC core.

Temperature-Depth History

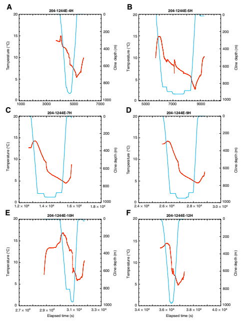
Figures **F7**, **F8**, **F9**, and **F10** illustrate the temperature-depth history for cores from sites where Cline data provide an independent measure of depth (Holes 1244E, 1245C, 1250D, and 1251D). Huge pressure anomalies (up to ~90 bar) in some cores (e.g., Core 204-1247B-14H) (Fig. **F11**) make the use of pressure measured within the APC core by the TPC as a proxy for depth unsuitable (Holes 1247B and 1252A). The same range of temperature (20°C) and elapsed time (6000 s) is used for all the core plots in Figures **F7**, **F8**, **F9**, and **F10**, except where noted. This permits direct visual comparison of cooling rates and magnitude of temperature anomalies between cores.

Examination of individual temperature-depth plots (Figs. **F7**, **F8**, **F9**, **F10**) shows that there are two types of cold temperature anomalies: (1) a sharply-defined cooling (ΔT up to ~4°C) that closely follows pullout of the core from the sediment ("pullout" anomaly) and (2) a broadly defined cooling anomaly (ΔT up to ~2°C) that typically occurs in the shallow water column (<100 m) or on the deck of the ship (SWC/D anomaly). A pullout anomaly is considered real if two or more data points define the peak of the anomaly; single data-point anomalies attributed to sensor noise were disregarded. The pullout anomaly generally lasts from 2 to ~10 s, whereas the SWC/D anomaly lasts anywhere from 10 to 180 s. The initiation of a SWC/D anomaly is defined by a change in the slope of the temperature-time curve toward cooler temperatures. Typically, SWC/D anomalies show the coldest temperatures obtained during the entire temperature history of the core. They occur near the sea surface and not when the core is passing through the coldest part of the water column. As indicated in Figure **F6**, some of these anomalies are cooler than the coldest part of the water column.

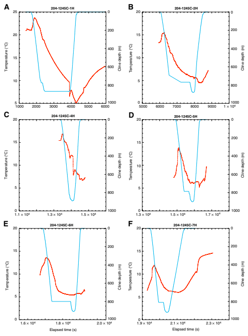
Rates of Core Descent and Ascent

For most of the descent and ascent profiles, rates of wireline movement as shown by plots of Cline depth vs. time, are steady (Figs. **F7**, **F8**, **F9**, **F10**) and similar between successive cores. The generally steady rates of wireline movement indicate that the thermal signals measured during core descent and ascent are the result of the temperature structure of the ocean and thermal changes in the headspace inside the APC and not the consequence of erratic core movement through the water column. This relatively smooth wireline movement simplifies the interpretation of temperature and pressure anomalies measured inside the core barrel by the TPC tool. However, a large source of temperature variation between successive cores results from how long the APC coring tool is kept near the bottom.

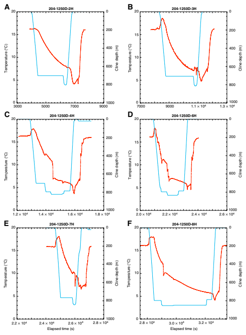
F7. Temperature- and Cline-time profiles, Hole 1244E, p. 21.



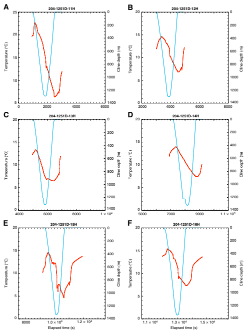
F8. Temperature- and Cline-time profiles, Hole 1245C, p. 23.



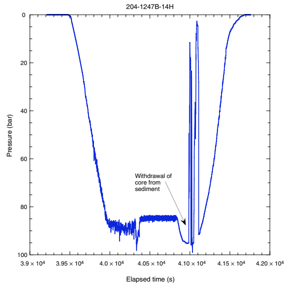
F9. Temperature- and Cline-time profiles, Hole 1250D, p. 25.



F10. Temperature- and Cline-time profiles, Hole 1251D, p. 27.



F11. Pressure vs. time data, p. 29.



Conductivity Measurements

Results from Leg 201 (Ussler et al., 2006) show that normalized conductivity values indicate the presence of gas headspace in many tool runs. These data suggest that atmospheric gas was entrained into the coring string during APC core exchange on deck and was initially carried down into the borehole with the tool. In some cases this headspace gas disappeared near the seafloor and then reappeared during ascent, and in many cases the tool never lost this gas headspace during the entire run.

In contrast with Leg 201, the conductivity data from Leg 204 do not provide easily interpretable results. Leg 204 normalized conductivity measurements show a variety of patterns. Data from many runs suggest that a high-conductivity medium persisted between the electrodes at the face of the APC piston during descent and ascent of the APC core (referred to as "wet"). These data are consistent with the continuous presence of water or another conductive medium (e.g., sediment) at the headspace during the entire coring process. Conductivity measurements indicating continuous presence of a low-conductivity medium (e.g., gas) in the headspace occurred in a few cores (previous referred to as "dry") (Ussler et al., 2006). The conductivity in the headspace of the remaining cores fluctuated between what can be inferred to be wet and dry conditions in no systematic or predictable manner. Because the TPC conductivity data collected during Leg 204 were dominated by artifacts that appear to be associated with clogging of the sensor path with mud, they are not be presented here.

DISCUSSION

Headspace temperature and pressure curves obtained using the TPC tool during Leg 204 are the first systematic attempt to record the temperature and pressure inside a coring system during recovery of gas-rich and gas hydrate–bearing sediment. Some core ascent curves show that distinct temperature and pressure anomalies occur during both pullout and retrieval of an APC core through the water column.

Cold Temperature Anomalies during Core Ascent

Two types of cold temperature anomalies were identified in the TPC data: (1) a broad cooling anomaly in the shallow water column and on deck (SWC/D) and (2) a sharply defined cooling anomaly associated with core pullout. The SWC/D anomalies are influenced by thermal lag associated with equilibration of the coring string with cold bottom water temperatures. However, there are seven clear examples where these SWC/D temperature anomalies are significantly colder than any water temperature along the ascent path (Fig. F6). These colder temperature anomalies occur as or soon after the core passes through the warmest part of the water column or during exposure on deck (air temperatures ≥ 12°C). In addition, these temperature anomalies are associated with an increase in the rate of cooling (a change in slope of the temperature-time curve toward cooler temperature in the shallow water column or on deck; e.g., Core 204-1244E-4H) (Fig. F7A). Although some of the cooling may be attributed to thermal lag, another source of cooling, such as gas expansion, must contribute in a significant way to the overall thermal signature.

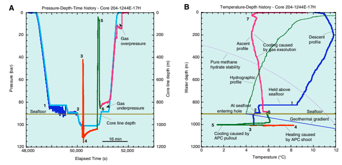
Temperature spikes associated with pullout of the APC from sediment show a trend toward cooler temperatures, and the magnitude of these anomalies also often increases in successive runs (i.e., with increasing depth below the seafloor) at the same site. In cores taken near the seafloor, minimum temperatures for these pullout anomalies are typically higher than minimum temperatures associated with the SWC/D anomalies (e.g., Fig. F8C, Core 204-1245C-4H). However, as core depth increases, there are cores where the pullout temperature anomalies become progressively cooler than the SWC/D anomaly temperatures (e.g., Fig. F8H, Core 204-1245C-10H, and F8L, Core 204-1245C-14H). This may reflect depth-related changes in sediment physical properties. The decrease in pullout temperature with increasing depth occurs despite the warming associated with the geothermal gradient (~53°–60°C/km) (Tréhu, Bohrmann, Rack, Torres, et al., 2003).

Sediment gas data from PCS measurements for all the sites where the TPC was deployed indicate that pore water methane gas concentrations are substantially elevated and often close to in situ saturation concentrations, with either a free-methane gas phase or with methane gas hydrates (e.g., Tréhu, Bohrmann, Rack, Torres, et al., 2003). Massive gas hydrate was found in some portions of the sedimentary column sampled by APC/TPC coring. Although the TPC measurements are believed to be influenced by escaping gas, the strength of the thermal anomaly is overpowered by the length of time the APC corer is kept in the hole and near the seafloor. In addition, no systematic variations in the area under the temperature-time curves for the pullout and SWC/D anomalies were observed that could be readily used to quantitatively estimate gas amounts.

Pressure and Temperature Variations during Core Pullout and Recovery

An example of the pressure and temperature variations that occur inside an APC core during collection is illustrated in Figure F12. Sharp negative pressure anomalies (Fig. F12A, 3 and 5) and a positive pressure anomaly (Fig. F12A, 4) show that internal conditions in the APC core barrel change dramatically over a few seconds when core insertion and pullout occurs. Rapid increases and decreases in temperature are associated with these pressure anomalies (Fig. F12B, 4 and 5). Cooling spike 5 is a sharply defined anomaly associated with core pullout, and the cooling trend in the upper water column (7) corresponds to a SWC/D temperature anomaly. The pullout temperature (1.4°C) for this core is the lowest recorded by the TPC during Leg 204. This core was collected just above the seismic depth for the bottom-simulating reflector (127 mbsf) (fig. F11 in Shipboard Scientific Party, 2003).

F12. Pressure and temperature changes, p. 30.



Implications of Pressure and Temperature Variations

Pressure anomalies formed during core pullout may provide insight into APC core expansion. Excess core recovery (>100% length; e.g., Leg 204 [Tréhu, Bohrmann, Rack, Torres, et al., 2003]) by APC cores is common and may be the result of the negative pressure anomalies generated during core pullout that irreversibly expand the length of the core.

Pressure changes of the magnitude seen in Figure F12A (ΔP = approximately –100 bar) and rapid temperature changes over a range of ~7°C (Fig. F12B) will change the phase relationships and saturation states for gas hydrate and dissolved gases (e.g., CH_4, CO_2, and H_2S) inside the core barrel. The severity of these pressure and temperature fluctuations may move gas hydrates contained in the sediment into and out of stability, transporting gas initially dissolved in sediment pore water as a gas phase to other parts of the core and/or core barrel. In addition, if gases rapidly come out of solution they may not redissolve before core recovery.

The large pressure reductions during core pullout and recovery that cause pore water degassing and gas redistribution within the core barrel contribute to the historically low values measured for pore water methane concentrations in cores obtained during DSDP and ODP drilling (Paull and Ussler, 2001). PCS data have shown clearly that large discrepancies in methane concentrations exist in gas-rich cores (e.g., Leg 164 [Dickens et al., 1997]; Leg 204 [Tréhu, Bohrmann, Rack, Torres, et al., 2003]), and TPC data suggest that large negative pressure anomalies may initiate core degassing.

The large temperature changes that occur during core pullout and ascent to the surface affect interpretation of IR-camera image data (e.g., Tréhu, Bohrmann, Rack, Torres, et al., 2003). When these temperature changes occur, why they occur when they do, and what they represent are not easily resolved with the type of temperature data that have been collected. The redistribution of gas from its precoring position following large pressure anomalies confounds interpretation of IR thermal images. Whether this is a subtle or large effect is largely unknown.

CONCLUSIONS

TPC data collected during Leg 204 demonstrate how the tool performs at gas-rich and gas hydrate–bearing sites in a relatively shallow water setting. Profound changes in pressure and temperature occur within the core barrel during core pullout and recovery. Temperature-time curves document thermal changes consistent with the occurrence of gas at the face of the TPC tool. The occurrence of a cooling anomaly late in the core retrieval process indicates that thermal changes within the sediment are still ongoing while the core is on the deck of the drillship.

The TPC tool has recorded thermal signatures of gas expansion that have occurred during core pullout and movement of the core through the shallow water column. These thermal anomalies are consistent with models of what gas evolution would look like in gas-rich sediment cores. Although much has been learned about gas dynamics using the TPC tool, inconsistencies in coring operations and inherent artifacts (large pressure and temperature anomalies) of the coring process make it difficult to quantify the amount of gas that is present. In the future, it would be beneficial to have a series of TPC tool runs in gas-rich sediments in greater water depths than at Hydrate Ridge. In addition, a routine method to clean the conductivity sensor after every APC/TPC core run will be necessary to obtain reliable conductivity measurements.

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APPENDIX

MATLAB m-file for Computing Seafloor Pressure at a Specified Latitude and Water Depth

```
function P80=pressure(DPTH,XLAT);
% PRESSURE Computes pressure given the depth at some latitude
% P=PRESSURE(D,LAT) gives the pressure P (dbars) at a depth D (m)
% at some latitude LAT (degrees).
%
% Ref: Saunders, "Practical Conversion of Pressure to Depth,"
% Journal of Physical Oceanography, April 1981.
%
% CHECK VALUE: P80=7500.004 DBARS;FOR LAT=30 DEG., DEPTH=7321.45 % % METERS

   PLAT=abs(XLAT*pi/180.);
   D=sin(PLAT);
   C1=5.92E-3+(D.*D)*5.25E-3;
   P80=((1-C1)-sqrt(((1-C1).^2)-(8.84E-6*DPTH)))/4.42E-6;
```

Figure F1. Results of radial heat transfer models of ascent temperature paths that would be followed during core recovery. The most important control on heat transfer is the plastic core liner, which has very low relative thermal conductivity (11.3 J/min·m·°C). Broadly spaced dashed line = combined hydrographic geothermal temperature profile. **A.** Three profiles from nongassy cores that differ by their initial temperatures. Solid line = mudline core (2700 mbsl), dotted lines = 3000 and 3500 mbsl cores. Thus, all gas-free cores from a drill site should have the same thermal overprinting and their recovery temperatures indistinguishable. **B.** Thermal signatures generated by cores with varying amounts of initial interstitial methane gas concentrations. These curves converge with and follow the mudline core temperature path (solid line) until gas bubbles are generated. When gas bubbles form, the temperature profiles show distinct cooling. **C.** Corresponding records of conductivity predicted for the thermal paths indicated in B. a = 175 mM, b = 139 mM, c = 88 mM. Low conductivity indicates the presence of gas headspace; high conductivity indicates the conductivity electrodes are bathed in seawater or mud. A sudden offset in conductivity is expected to occur as soon as a headspace gas volume has been generated.

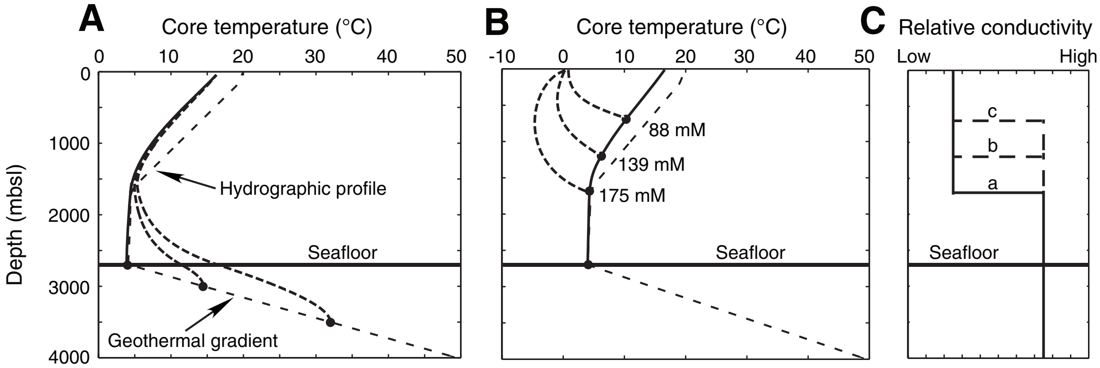

Figure F2. Schematic cross section of the upper portion of an advanced piston corer (APC) core barrel filled with a sediment core illustrates how gas bubbles migrate out of the sediment and move upward along the side of the core liner to accumulate at the top of the core barrel under the face of the APC piston. TP = thermistor probe, CS = conductivity sensor.

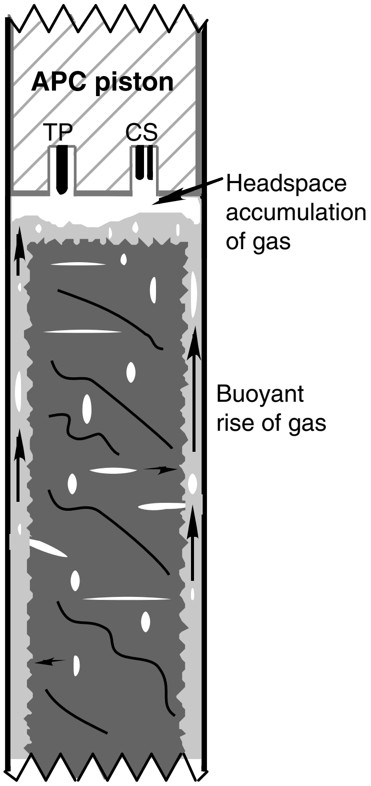

Figure F3. Schematic cross section and end view of the APC piston containing the TPC tool. The end view of the APC piston face shows the arrangement of the TPC sensors. TP = thermistor probe, CS = conductivity sensor, PP = pressure port, DP = data dump port, which is sealed during deployment but available for data downloads on the drillship catwalk.

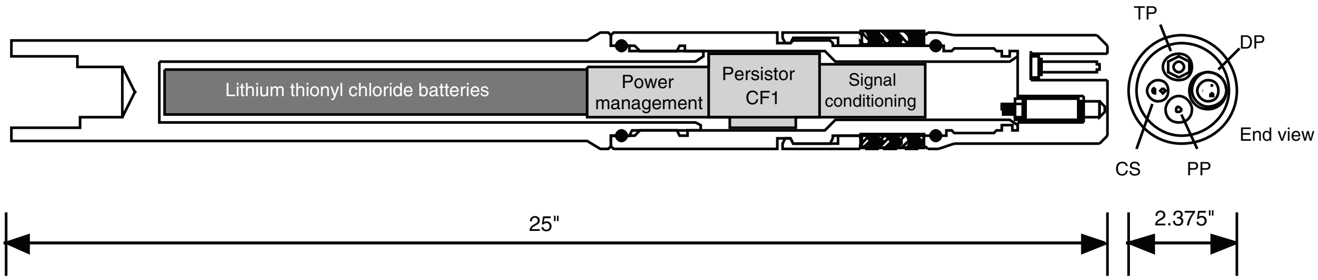

Figure F4. End view of the APC piston (Fig. F3, p. 17) shows placement of sensors and ports.

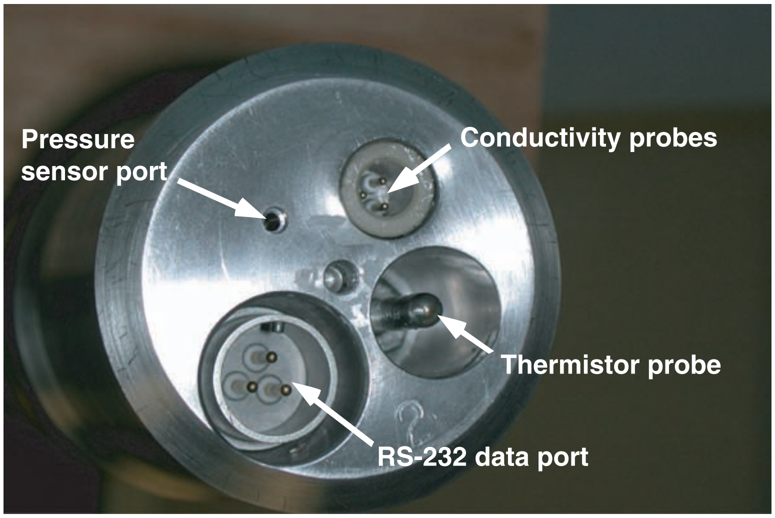

Figure F5. Location map for sites cored during Leg 204. Solid red circles = sites where the TPC tool was deployed. Detailed bathymetric map is from Clague et al. (2001); water depth is in meters. SHR = southern Hydrate Ridge. Modified from Tréhu, Bohrmann, Rack, Torres, et al. (2003).

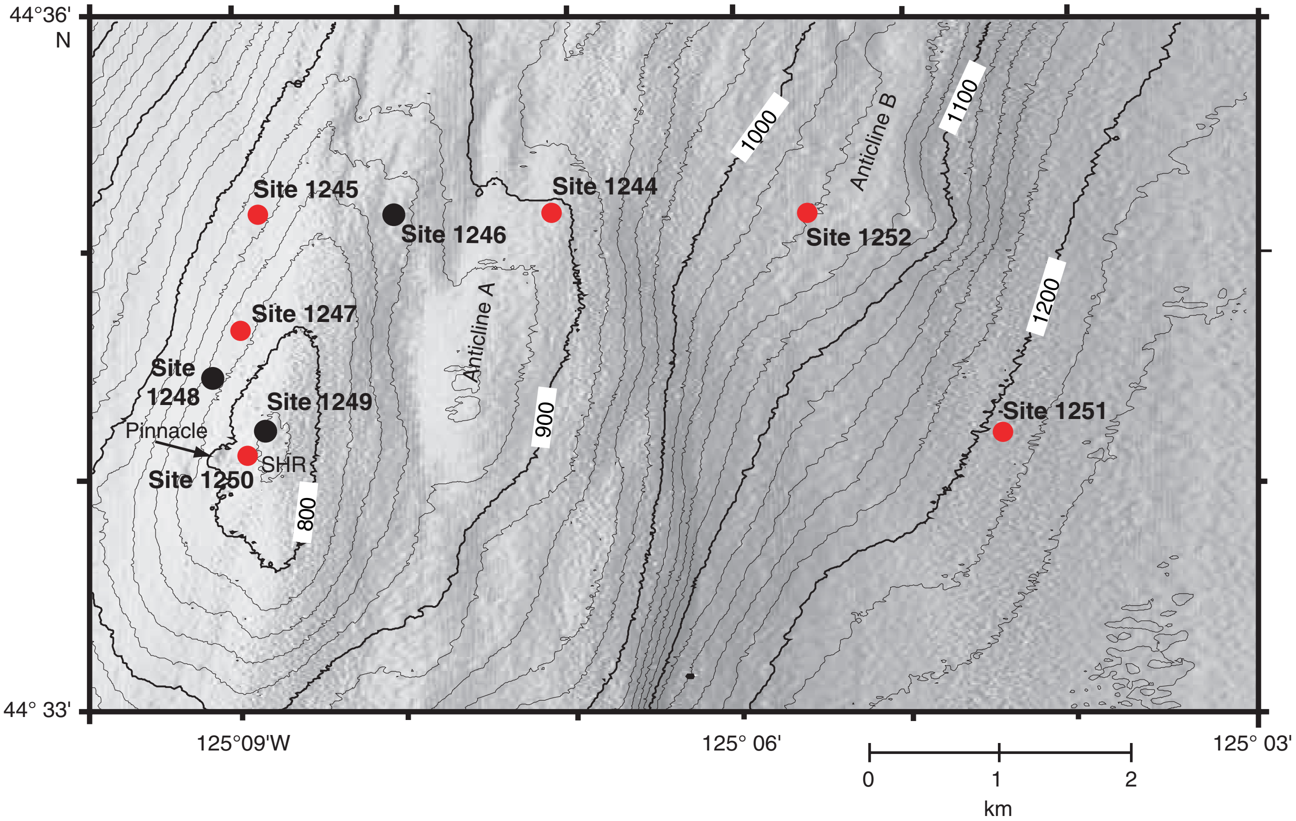

Figure F6. Plots of temperature-time data collected by the TPC tool in Holes (**A**) 1244E, (**B**) 1245C, (**C**) 1247B, (**D**) 1250D, (**E**) 1251D, and (**F**) 1252C. Each core is identified at its temperature minimum. Red lines = mudline temperatures obtained from APCT and DVTPP tool runs. Arrows = significant temperature anomalies cooler than measured mudline temperatures. All figures are plotted with the same temperature and time scales.

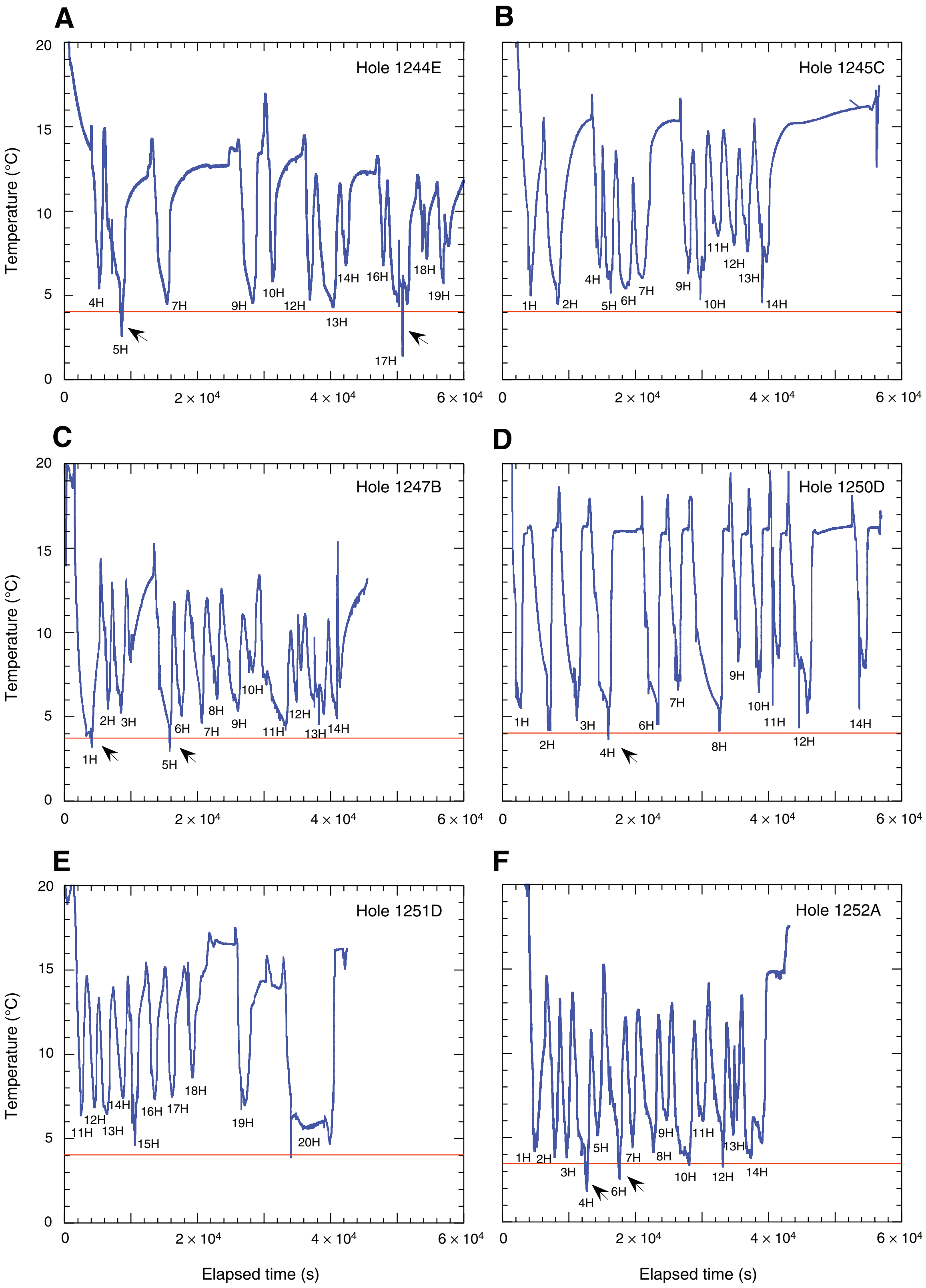

Figure F7. A–F. Temperature-time (red) and Cline-time (blue) profiles for successive APC cores collected in Hole 1244E. (Continued on next page.)

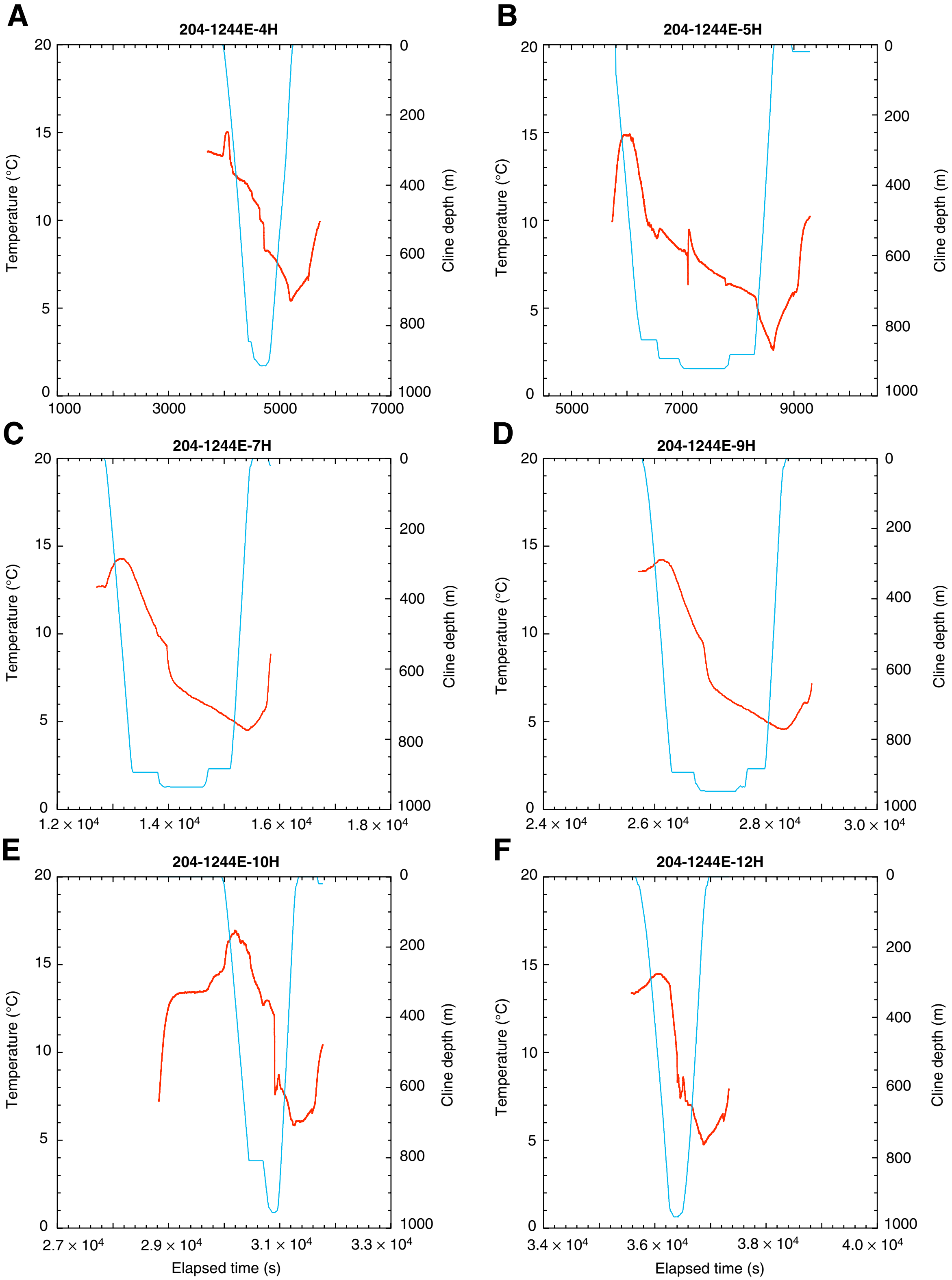

Figure F7 (continued). G–L. Temperature- and Cline-time profiles, Hole 1244E.

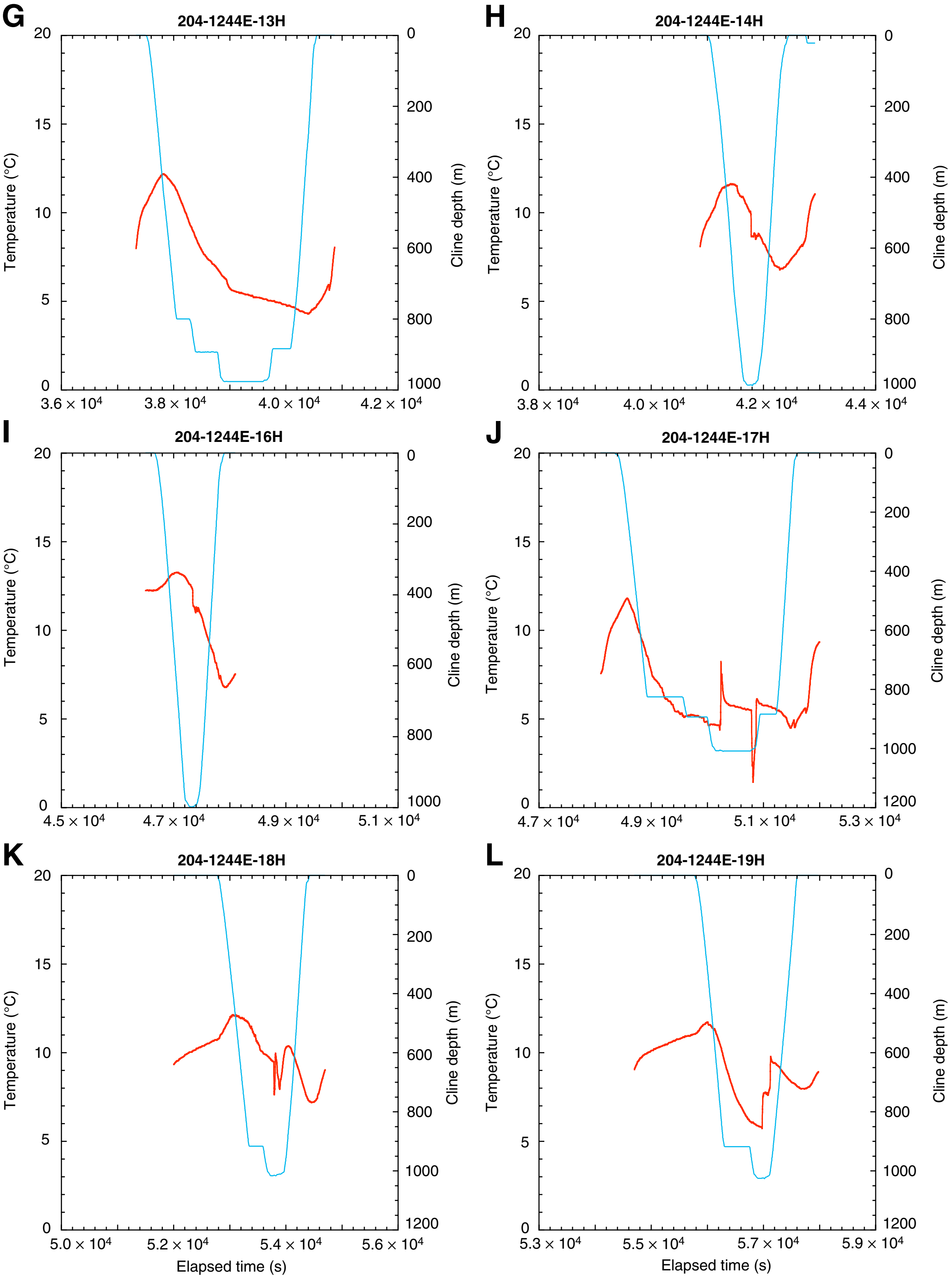

Figure F8. A–F. Temperature-time (red) and Cline-time (blue) profiles for successive APC cores collected in Hole 1245C. (Continued on next page.)

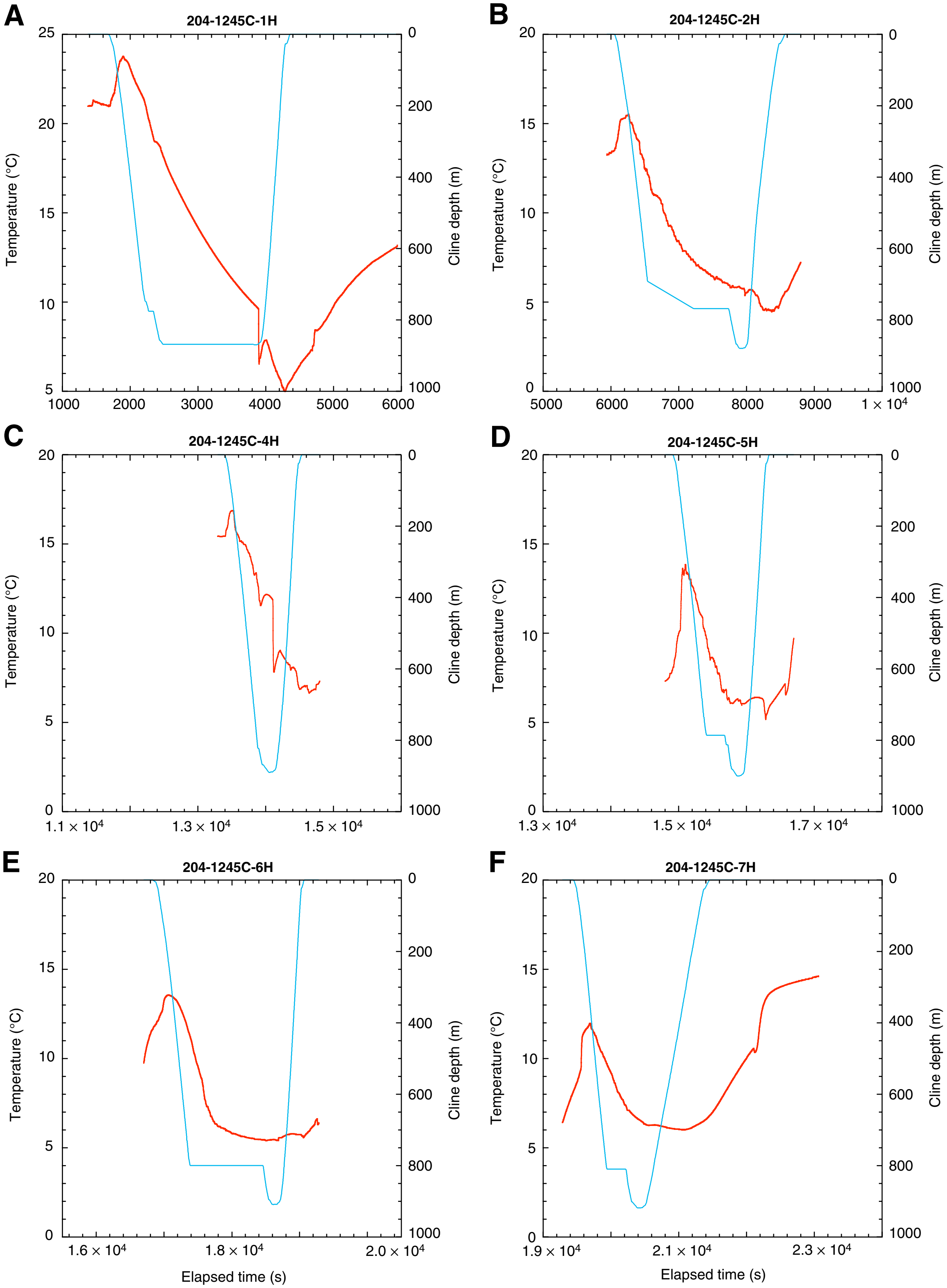

Figure F8 (continued). G–L. Temperature- and Cline-time profiles, Hole 1245C.

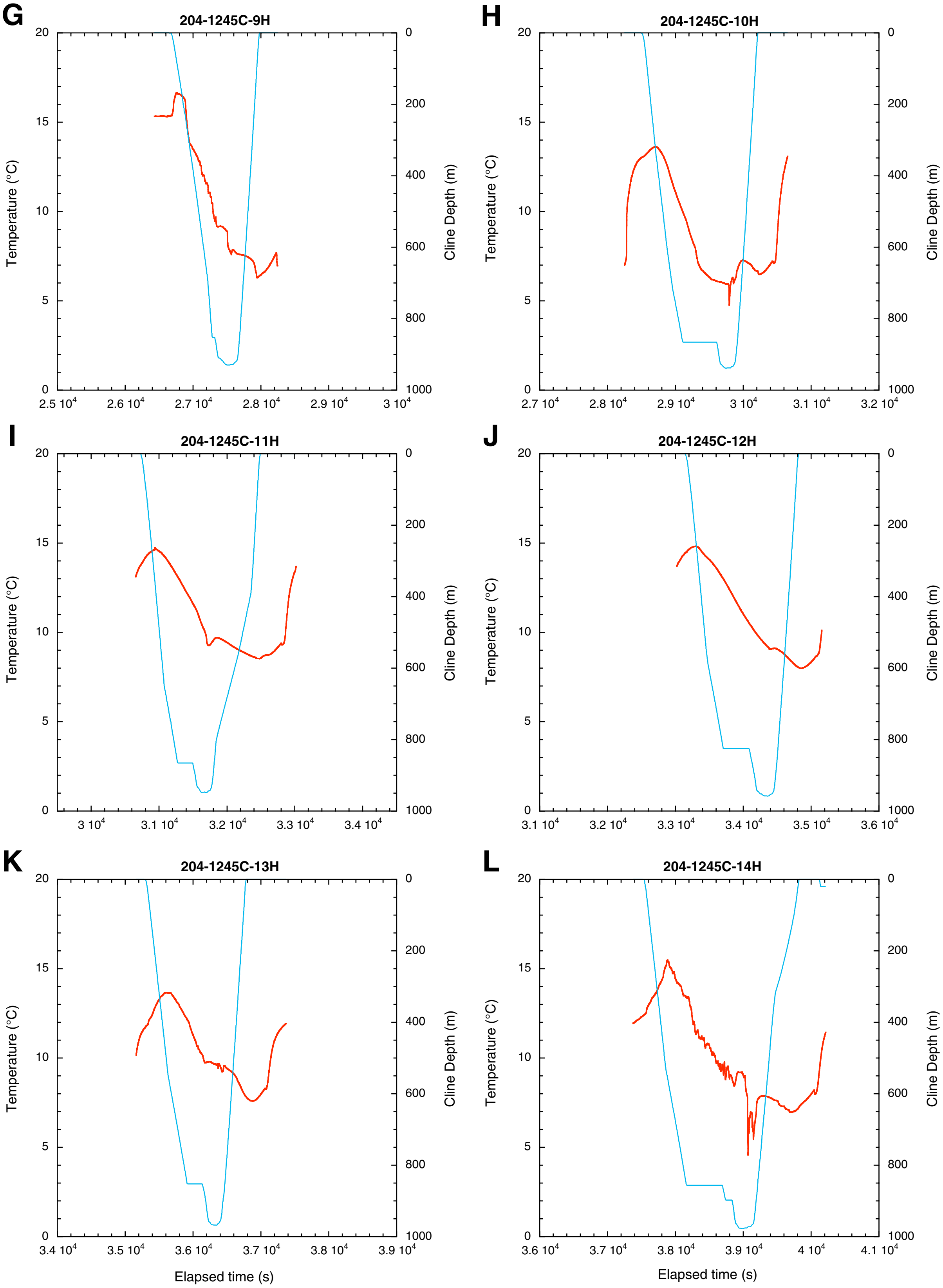

Figure F9. A–F. Temperature-time (red) and Cline-time (blue) profiles for successive APC cores collected in Hole 1250D. (Continued on next page.)

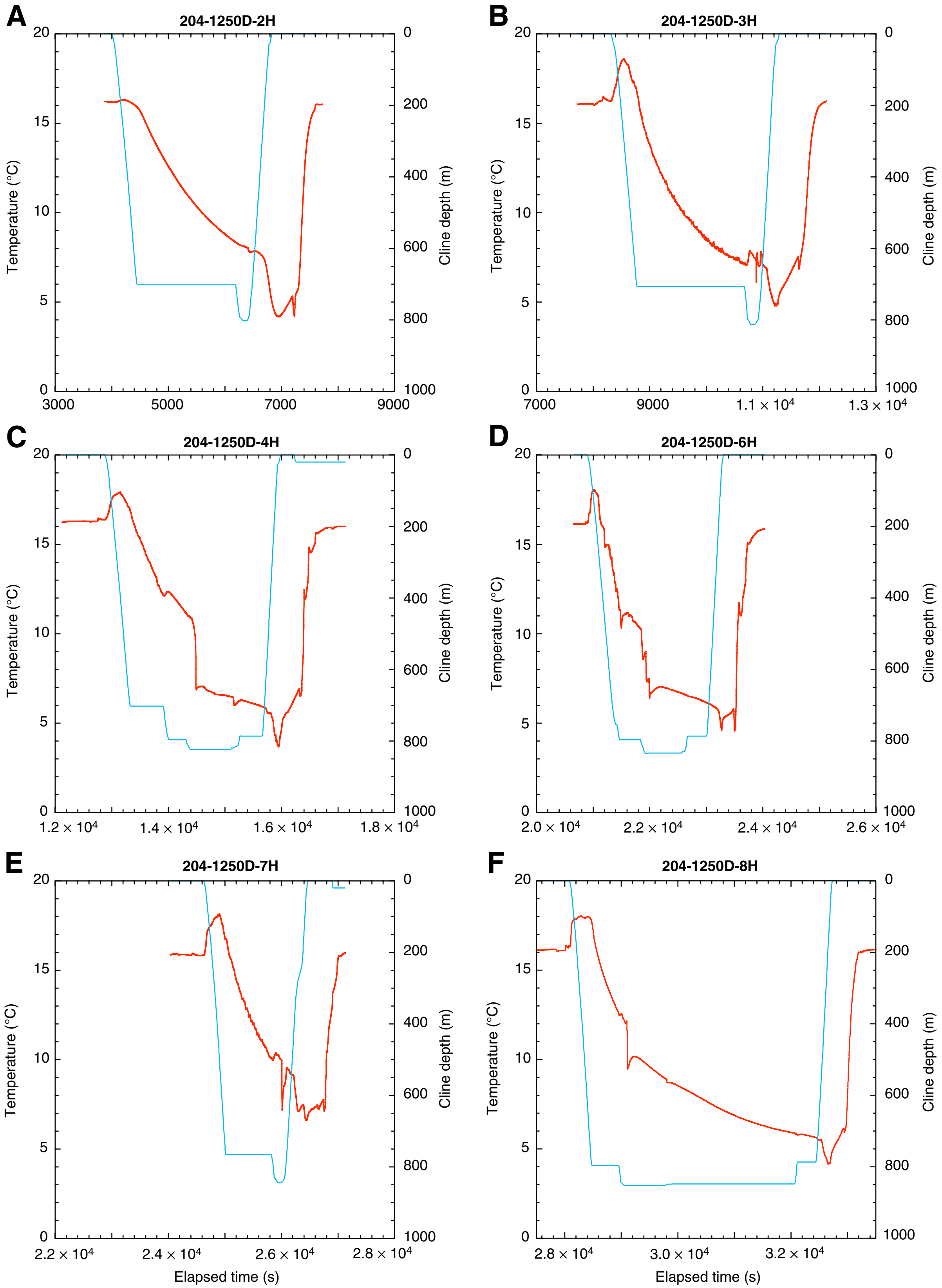

Figure F9 (continued). G–K. Temperature- and Cline-time profiles, Hole 1250D.

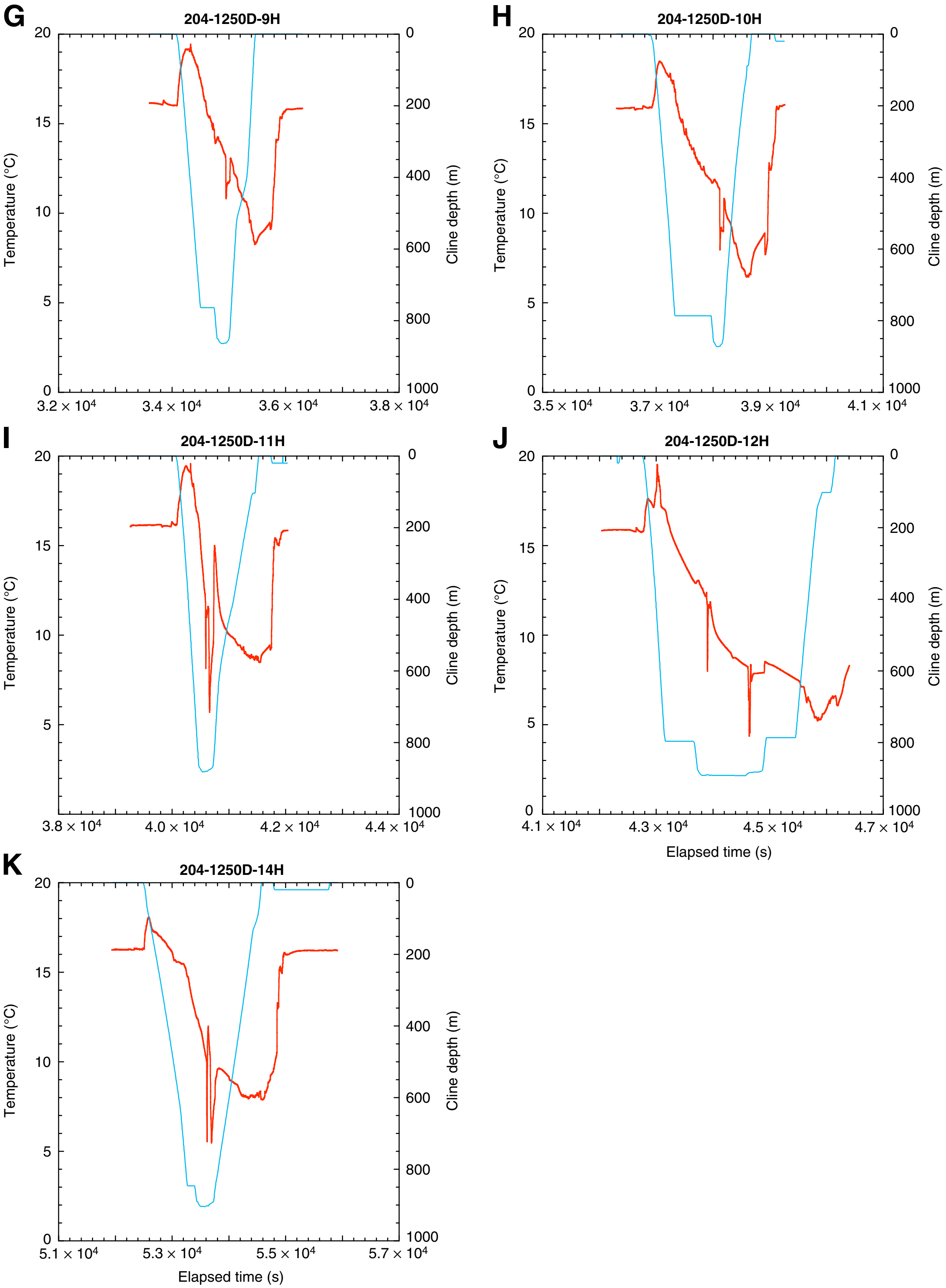

Figure F10. A–F. Temperature-time (red) and Cline-time (blue) profiles for successive APC cores collected in Hole 1251D. Note the x-axis in J has a range of 10,000 rather than 6,000 s. (Continued on next page.)

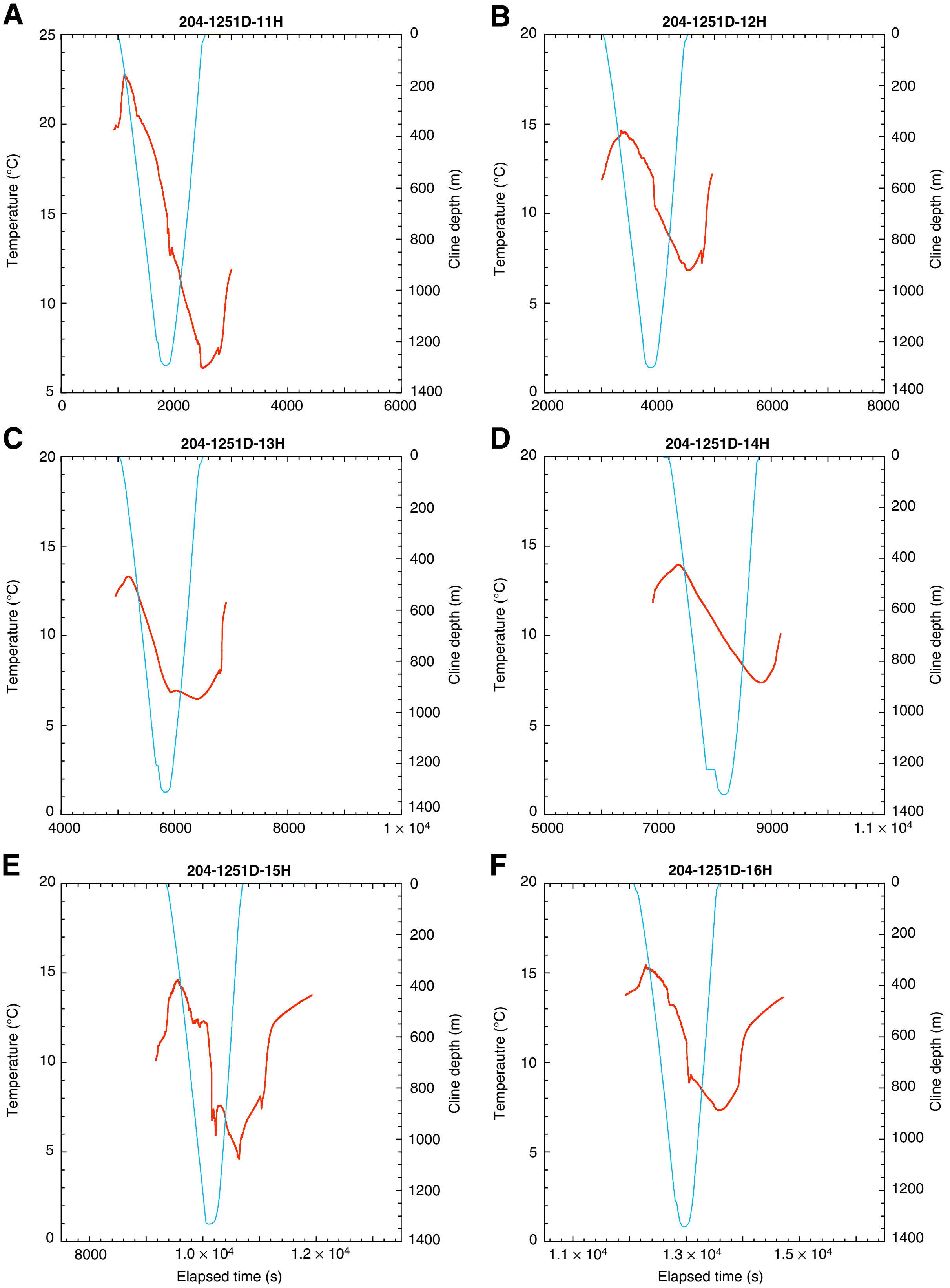

Figure F10 (continued). G–J. Temperature- and Cline-time profiles, Hole 1251D.

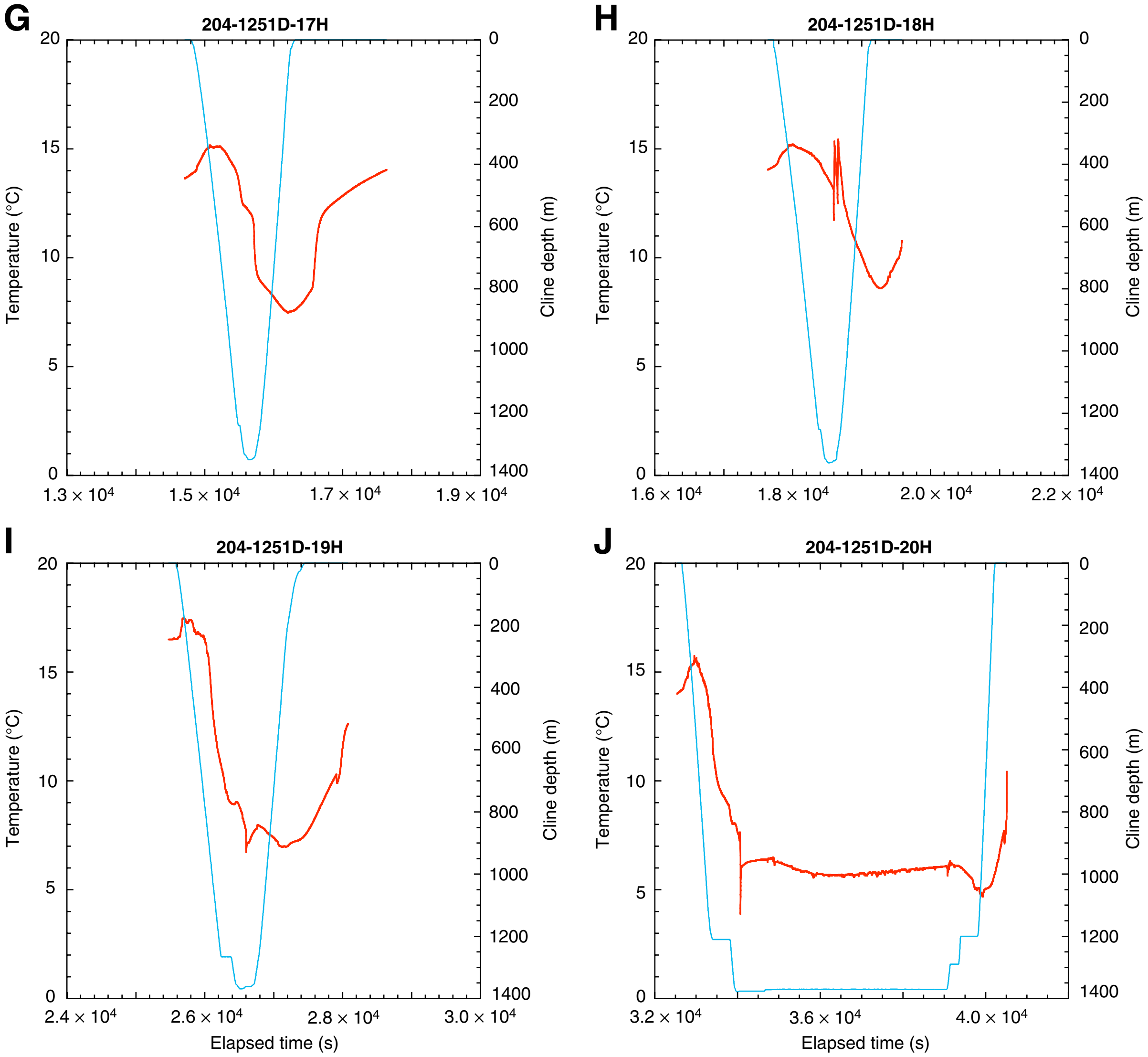

Figure F11. TPC-collected pressure vs. time data from Core 204-1247B-14H are an example of the large pressure anomalies that occur during APC core pullout. Pressure measured within the APC is not a good proxy for core depth; thus, wireline distance data are essential for interpretation of TPC data.

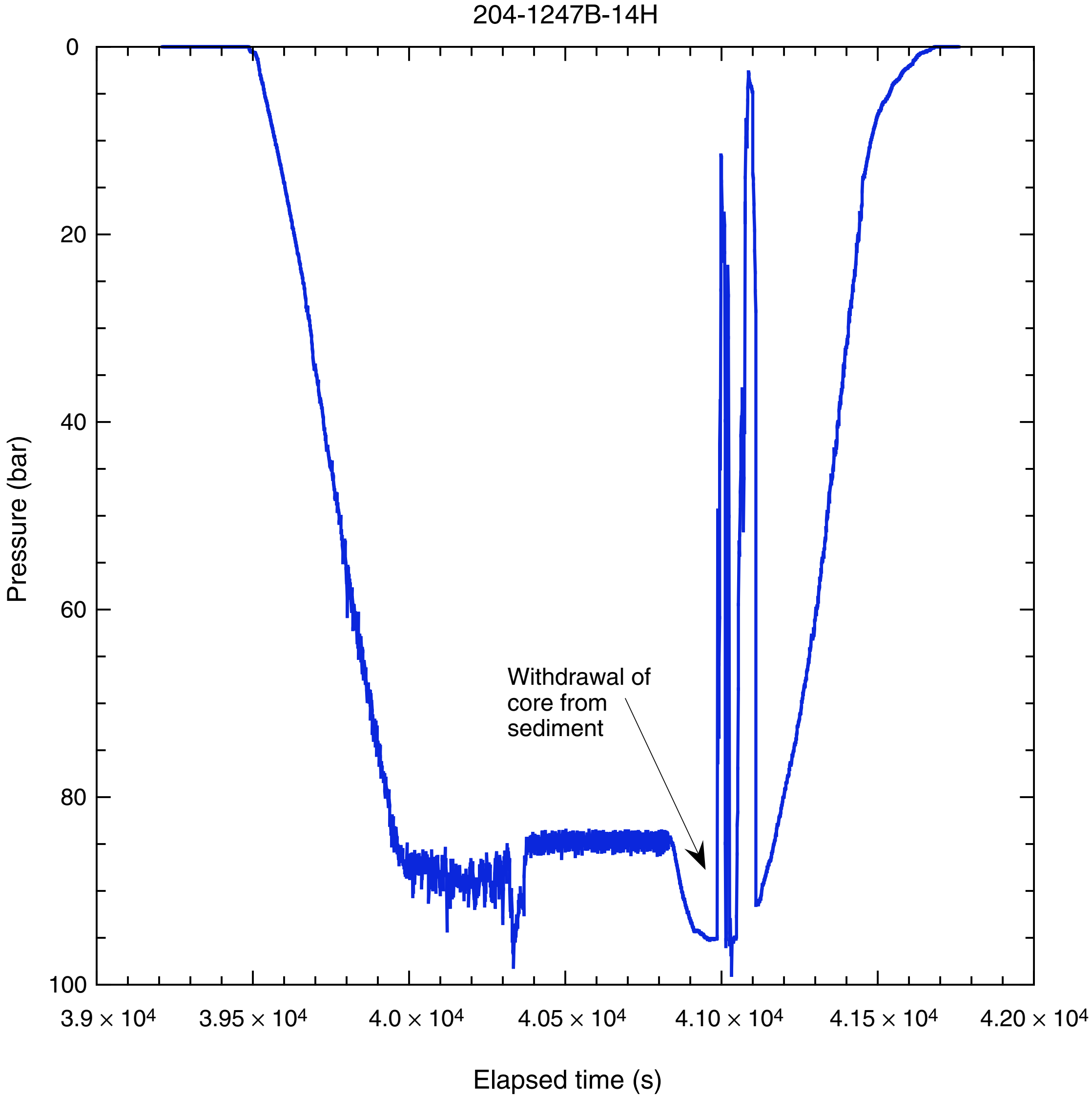

Figure F12. Examples of the (**A**) pressure and (**B**) temperature changes that occur during core collection illustrated using Core 204-1244E-17H data. Line colors distinguish parts of the coring operation into temperature-pressure-time space and help correlate phenomena shown in parts A and B. Coreline data = light blue line in A. Events during coring: 1 = corer is held above seafloor to allow wireline to stabilize; 2 = corer is held at seafloor for stabilization before entry into the hole; 3 = APC core is fired by breaking a shear pin, causing pressure oscillations above and below in situ pressure; 4 = 4°C temperature increase caused by insertion heating, pressure increases above in situ conditions; 5 = ~4°C cooling occurs during core pullout, pressure nearly reaches sea-surface pressure; 6 = core cools slightly upon reaching the mudline, pressure has not returned to in situ pressure, gas is underpressured inside APC core barrel until ~100 m above the seafloor during ascent; 7 = shallow water column temperature anomaly (SWC/D). Overpressure conditions occur near the surface, ~150 m water depth. Hydrographic profile is from MBARI ROV *Tiburon* dive T195 conducted over southern Hydrate Ridge on 13 July 2000. Note in panel B that core temperatures continue to fall after crossover with the hydrographic temperature profile and the pure methane hydrate stability curve. This may be due to lag in the thermal response of the core/TPC tool assembly to bottom water temperatures and to cooling caused by gas expansion inside the core barrel. Pure methane hydrate curve is computed using equation 7 in Peltzer and Brewer (2000). Bottom water temperature was ~4°C; geothermal gradient was 60°C/km (Tréhu, Bohrmann, Rack, Torres, et al., 2003).

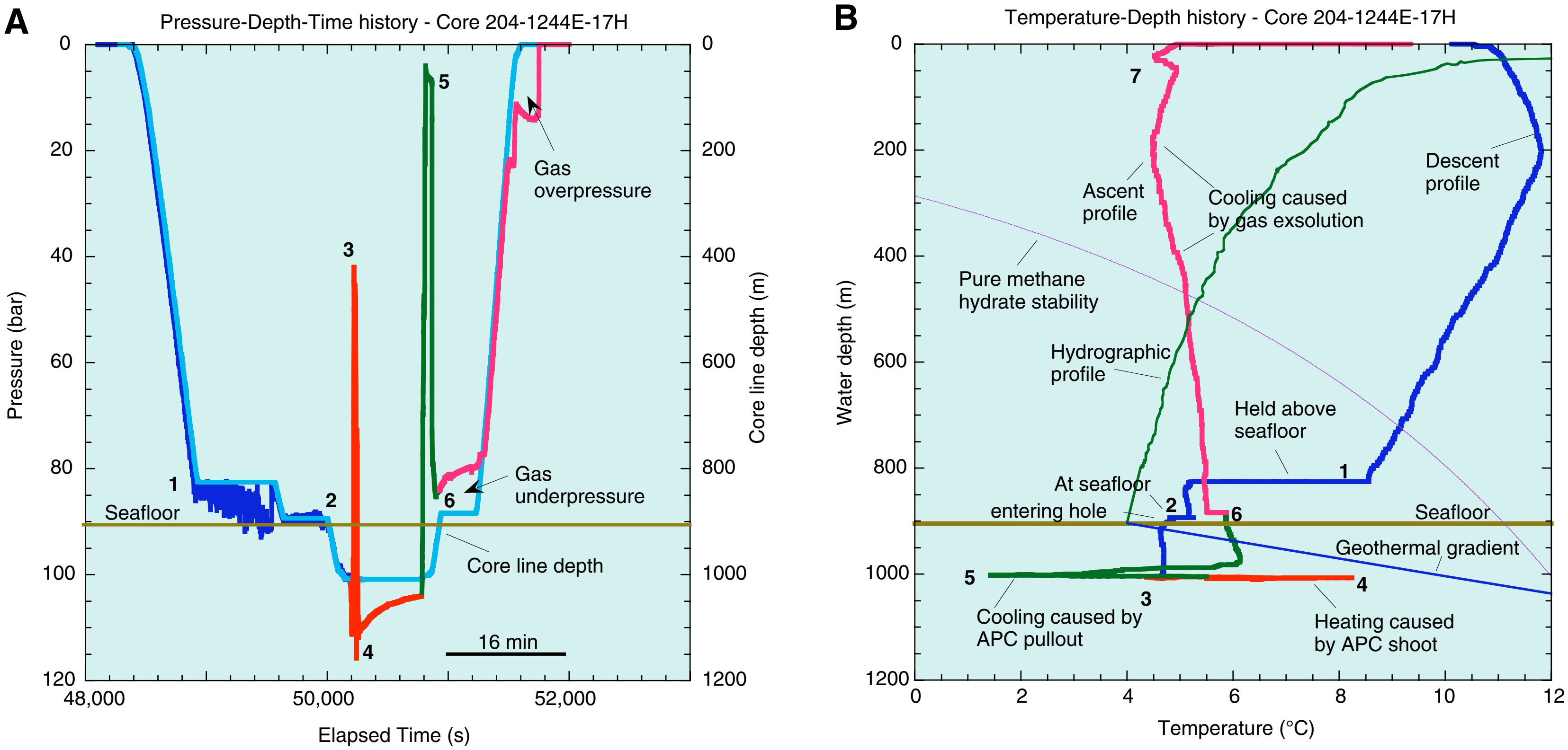

Table T1. Polynomial coefficients for conversion of raw temperature data to resistance.

Order of polynomial coefficient	Holes 1244E, 1247B, and 1252A	Holes 1245C, 1250D, and 1251D
6	+3.3808E–16	
5	–5.7748E–12	–3.1384E–12
4	+4.1015E–08	+3.5348E–08
3	–1.5676E–04	–1.5919E–04
2	+3.4774E–01	+3.6475E–01
1	–4.4716E+02	–4.4556E+02
0	+2.9834E+05	+2.6349E+05

Table T2. Steinhart-Hart equation coefficients from the manufacturer's thermistor calibration for conversion of resistance to temperature.

Steinhart-Hart coefficient	Holes 1244E, 1247B, and 1252A	Holes 1245C, 1250D, and 1251D
A	1.134754819E–03	1.13442892E–03
B	2.333425717E–04	2.33373683E–04
C	9.032046858E–08	8.99784317E–08

Table T3. Drilling data, Hole 1244E. (See table notes. Continued on next page.)

Core	Time on deck	Depth (m) Top	Bottom	Below seafloor	Advanced (m)	Length (m) Cored	Recovered	Recovery (%)	Shear pins	Shear pressure (psi)	Speed holes	Pull (kips)	Stroke	Core catcher used (rpm)	Wireline (F/A)	Runs
204-1244E-																
1H	0640	904.8	913.5	8.7	8.7	8.7	8.76	101	2H	2700	0	0	Y	FP	F	1
2H	0745	913.5	923.0	18.2	9.5	9.5	9.94	105	2H	2700	0	0	Y	FP	F	1
3P	0840	923.0	924.0	19.2	1.0	1.0	0.00	0	0 SPM	0	—	—	4 K	45	F	1
DI	0845	924.0	925.0	20.2	1.0	—	—	—	50 SPM	125	—	—	4 K	45	—	—
4H	0910	925.0	934.5	29.7	9.5	9.5	10.24	108	2H	2700	0	0	Y	FP	F	1
5H	1000	934.5	944.0	39.2	9.5	9.5	10.11	106	2H	2700	0	30	Y	FP	F	1
6P	1105	944.0	945.0	40.2	1.0	1.0	1.00	100	20 SPM	125	—	—	4 K	60	F	1
DI	1110	945.0	946.0	41.2	1.0	—	—	—	50 SPM	125	—	—	4 K	60	—	—
7H	1155	946.0	955.5	50.7	9.5	9.5	10.59	111	2H	2700	0	30	Y	FP	F	1
8Y	1310	955.5	956.5	51.7	1.0	1.0	0.92	92	40 SPM	700	—	—	12 K	0	F	1
DI	1315	956.5	957.4	52.6	0.9	—	—	—	50 SPM	150	—	—	6 K	50	F	1
9H	1530	957.4	966.9	62.1	9.5	9.5	9.91	104	2H	2700	2	40	Y	FP	F	1
10H	1625	966.9	976.4	71.6	9.5	9.5	9.78	103	2H	2700	4	40	Y	FP	F	1
11P	1725	976.4	977.4	72.6	1.0	1.0	1.00	100	20 SPM	200	—	—	5 K	50	F	1
DI	1730	977.4	978.4	73.6	1.0	—	—	—	60 SPM	150	—	—	6 K	60	—	—
12H	1750	978.4	987.9	83.1	9.5	9.5	10.11	106	2H	2700	4	40	Y	FP	F	1
13H	1855	987.9	997.4	92.6	9.5	9.5	8.69	91	2H	2700	4	60	Y	FP	F	1
14H	1925	997.4	1006.9	102.1	9.5	9.5	9.40	99	2H	2700	4	45	Y	FP	F	1
15P	2040	1006.9	1007.9	103.1	1.0	1.0	1.00	100	20 SPM	125	—	—	5 K	100	F	1
DI	2045	1007.9	1008.9	104.1	1.0	—	—	—	60 SPM	150	—	—	6 K	60	—	—
16H	2100	1008.9	1018.4	113.6	9.5	9.5	8.94	94	2H	2700	4	45	Y	FP	F	1
17H	2200	1018.4	1027.9	123.1	9.5	9.5	9.66	102	2H	2700	4	60	N	FP	F	1
18H	2300	1027.9	1037.0	132.2	9.1	9.1	9.09	100	2H	2700	4	60	N	FP	F	1
19H	2340	1037.0	1045.5	140.7	8.5	8.5	8.59	101	2H	2700	4	60	N	FP	F	2
DI	0945	1045.5	1154.8	250.0	109.3	—	—	—	70 SPM	1000	—	—	14 K	70	F	1

Core	Time on deck	Depth (m) Top	Bottom	Below seafloor	Shoe (type)	Orientation (type)	Min	AHC	Drill over	Remarks
204-1244E-										
1H	0640	904.8	913.5	8.7	APCT	None	0	N	N	Bottom water sampler/Fluorescent microspheres and tracers
2H	0745	913.5	923.0	18.2	Standard	None	5	N	N	Fluorescent microspheres and tracers
3P	0840	923.0	924.0	19.2			10	Y	N	PCS with Methane Tool with RBI PDC
DI	0845	924.0	925.0	20.2			5	Y	N	
4H	0910	925.0	934.5	29.7	Standard	None	5	Y	N	APCM in/Fluorescent microspheres and tracers
5H	1000	934.5	944.0	39.2	APCT	None	5	Y	N	Fluorescent microspheres and tracers
6P	1105	944.0	945.0	40.2			5	Y	N	PCS with Methane Tool with RBI PDC
DI	1110	945.0	946.0	41.2			3	Y	N	
7H	1155	946.0	955.5	50.7	APCT	None	5	Y	N	Fluorescent microspheres and tracers
8Y	1310	955.5	956.5	51.7			10	Y	N	Fugro Pressure Corer/DSA
DI	1315	956.5	957.4	52.6			5	Y	N	DVTPP at 957.4 m (52.6 mbsf)
9H	1530	957.4	966.9	62.1	APCT	None	5	N	N	Fluorescent microspheres and tracers
10H	1625	966.9	976.4	71.6	Standard	None	5	Y	N	Fluorescent microspheres and tracers
11P	1725	976.4	977.4	72.6			7	Y	N	PCS with Methane Tool with RBI PDC
DI	1730	977.4	978.4	73.6			5	N	N	
12H	1750	978.4	987.9	83.1	Standard	None	5	N	N	Fluorescent microspheres and tracers
13H	1855	987.9	997.4	92.6	APCT	None	5	N	N	Fluorescent microspheres and tracers
14H	1925	997.4	1006.9	102.1	Standard	None	5	N	N	Fluorescent microspheres and tracers
15P	2040	1006.9	1007.9	103.1			12	Y	N	PCS with Methane Tool with RBI PDC
DI	2045	1007.9	1008.9	104.1			3	Y	N	
16H	2100	1008.9	1018.4	113.6	Standard	None	5	N	N	Fluorescent microspheres and tracers
17H	2200	1018.4	1027.9	123.1	APCT	None	13	N	N	Fluorescent microspheres and tracers
18H	2300	1027.9	1037.0	132.2	Standard	None	10	N	N	Fluorescent microspheres and tracers
19H	2340	1037.0	1045.5	140.7	Standard	None	10	N	N	Fluorescent microspheres and tracers DVTPP
DI	0945	1045.5	1154.8	250.0	Center bit		338	Y	N	Drill with XCB center bit

Table T3 (continued).

Measurement	FPC	PCS	APC	Hole 1244E
Number of cores	1	4	14	19
Total drilled (m)	0.9	4.0	109.3	114.2
Total cored (m)	1.0	4.0	130.8	135.8
Total recovered (m)	0.92	3.00	133.81	137.73
Recovery (%)	92.0	75.0	102.3	101.4
Total wireline runs	1	4	17	22
Total bit F/hole (hr)	0.25	0.83	7.02	8.10
Total F/bit CD980 (hr)				126.00
Total active heave (hr)	0.25	0.75	7.63	8.63
Total penetration (m)				250

Notes: Spud date = 20 August 2002, rig time = 0614, GMT = rig time + 7 hr. Bottom-hole assembly length = 126.85 m. Seafloor = 904.8 mbsl, precision depth recorder = 913.4 mbsl. An 11-7/16-inch RBI C-3 bit with 4 jets was used (serial number CD980). All measurements are from pump 1. Rerun hours on used bit = 117.90. Stroke: Y = core barrel had full stroke, N = core barrel did not have full stroke. F = fore core liner winch was used, A = aft core liner winch was used. Min = minutes required to advance bit. AHC: Y = active heave compensator (AHC) on and operating, N = AHC off and not operating. Drill over: Y = drill over used to recover core barrel, N = drill over not required to recover core barrel. APCT = advanced piston corer temperature tool, PCS = pressure core sampler, RBI = Rock Bit International auger bit (**www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm**), PDC = RBI polycrystalline diamond compact drill bit (**www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm**), APCM = advanced piston corer methane tool (same as TPC tool), DSA = drill string accelerator tool, DVTPP = Davis-Villinger Temperature-Pressure Probe, XCB = extended core barrel, FPC = Fugro pressure corer, APC = advanced piston corer. APC cores with TPC data are highlighted in yellow.

Table T4. Drilling data, Hole 1245C. (See table notes. Continued on next page.)

	Time on deck		Depth (m)				Length (m)								
Core	Time	Date (Aug 2002)	Top	Bottom	Below seafloor	Advanced (m)	Cored	Recovered	Recovery (%)	Shear pins	Shear pressure (psi)	Speed holes	Pull (kips)	Stroke	Core catcher used (rpm)
204-1245C-															
1H	1740	10	880.0	887.5	7.5	7.5	7.5	7.84	105	2H	2700	0	0	Y	FP
2H	1850	10	887.5	897.0	17.0	9.5	9.5	9.78	103	2H	2700	0	0	Y	FP
3P	2005	10	897.0	898.0	18.0	1.0	1.0	1.00	100	0 SPM	0	—	—	3 K	45 RPM
DI	2010	10	898.0	899.0	19.0	1.0	—	—	—	30 SPM	75	—	—	3 K	45 RPM
4H	2030	10	899.0	908.5	28.5	9.5	9.5	9.74	103	2H	2700	0	10	Y	FP
5H	2100	10	908.5	918.0	38.0	9.5	9.5	10.12	107	2H	2700	0	10	Y	FP
6H	2145	10	918.0	927.5	47.5	9.5	9.5	6.23	66	2H	2700	2	25	Y	FP-10F
7H	2230	10	927.5	937.0	57.0	9.5	9.5	9.27	98	2H	2700	2	25	Y	FP
8P	2350	10	937.0	938.0	58.0	1.0	1.0	1.00	100	20 SPM	75	—	—	4 K	65 RPM
DI	2355	10	938.0	939.0	59.0	1.0	—	—	—	20 SPM	75	—	—	4 K	65 RPM
9H	0020	11	939.0	948.5	68.5	9.5	9.5	9.47	100	2H	2700	2	25	Y	FP-10F
10H	0055	11	948.5	958.0	78.0	9.5	9.5	9.40	99	2H	2700	2	25	Y	FP
11H	0130	11	958.0	967.5	87.5	9.5	9.5	8.92	94	2H	2700	4	40	Y	FP-10F
12H	0210	11	967.5	977.0	97.0	9.5	9.5	5.04	53	2H	2700	4	40	Y	FP
13H	0250	11	977.0	986.5	106.5	9.5	9.5	9.75	103	2H	2700	4	40	Y	FP-10F
14H	0410	11	986.5	996.0	116.0	9.5	9.5	10.09	106	2H	2700	4	50	Y	FP-10F
24H	1450	11	1057.1	1066.6	186.6	9.5	9.5	8.70	92	2H	2700	4	60	N	FP
25H	1640	11	1066.6	1071.1	191.1	4.5	4.5	4.56	101	2H	2700	4	60	N	FP
26H	1750	11	1071.1	1075.9	195.9	4.8	4.8	4.83	101	2H	2700	4	60	N	FP
28H	2030	11	1076.9	1080.7	200.7	3.8	3.8	3.80	100	2H	2700	4	60	N	FP

	Time on deck		Depth (m)			Wireline							
Core	Time	Date (Aug 2002)	Top	Bottom	Below seafloor	(F/A)	Runs	Shoe (type)	Orientation (type)	Min	AHC	Drill over	Remarks
204-1245C-													
1H	1740	10	880.0	887.5	7.5	F	1	APCT	None	0	N	N	APC Methane Tool In, BWS, Fluorescent microspheres and tracer
2H	1850	10	887.5	897.0	17.0	F	1	Standard	None	15	N	N	Fluorescent microspheres and tracer
3P	2005	10	897.0	898.0	18.0	F	1	—	—	0	Y	N	PCS with RBI PDC Bit
DI	2010	10	898.0	899.0	19.0	—	—	—	—	5	N	N	
4H	2030	10	899.0	908.5	28.5	F	1	Standard	None	5	N	N	Fluorescent microspheres and tracer
5H	2100	10	908.5	918.0	38.0	F	1	Standard	None	5	N	N	Fluorescent microspheres and tracer
6H	2145	10	918.0	927.5	47.5	F	1	Standard	None	20	N	N	Liner exploded
7H	2230	10	927.5	937.0	57.0	F	1	Standard	None	5	N	N	Fluorescent microspheres and tracer
8P	2350	10	937.0	938.0	58.0	F	1	—	—	16	Y	N	PCS with RBI PDC Bit
DI	2355	10	938.0	939.0	59.0	—	—	—	—	2	N	N	
9H	0020	11	939.0	948.5	68.5	F	1	Standard	None	5	N	N	
10H	0055	11	948.5	958.0	78.0	F	1	Standard	None	5	N	N	Fluorescent microspheres and tracer
11H	0130	11	958.0	967.5	87.5	F	1	Standard	None	5	Y	N	
12H	0210	11	967.5	977.0	97.0	F	1	Standard	None	10	Y	N	Fluorescent microspheres and tracer
13H	0250	11	977.0	986.5	106.5	F	1	Standard	None	10	Y	N	
14H	0410	11	986.5	996.0	116.0	F	1	Standard	None	20	Y	N	APC Methane Tool out
24H	1450	11	1057.1	1066.6	186.6	F	1	APCT	None	5	N	N	Fluorescent microspheres and tracer
25H	1640	11	1066.6	1071.1	191.1	F	1	APCT	None	45	N	N	Fluorescent microspheres and tracer
26H	1750	11	1071.1	1075.9	195.9	F	1	APCT	None	20	N	N	Fluorescent microspheres and tracer
28H	2030	11	1076.9	1080.7	200.7	F	1	APCT	None	5	N	N	Fluorescent microspheres and tracer

Table T4 (continued).

Measurement	PCS	APC
Number of cores	3	16
Total drilled (m)	3782.0	
Total cored (m)	337.0	134.6
Total recovered (m)	337.00	127.54
Recovery (%)	100	94.8
Total wireline runs	2	16
Total bit F/hole (hr)	0.38	3.00
Total active heave (hr)	0.3	0.8

Notes: Spud date = 10 August 2002, rig time = 1730, GMT = rig time + 7 hr. Bottom-hole assembly length = 136.14 m. Seafloor = 880.0 mbsl, precision depth recorder = 886.4 mbsl. An 11-7/16-inch RBI C-3 bit with 4 jets was used (serial number CD980). All measurements are from pump 1. Rerun hours on used bit = 107.23. Stroke: Y = core barrel had full stroke, N = core barrel did not have full stroke. F = fore core liner winch was used, A = aft core liner winch was used. Min = minutes required to advance bit. AHC: Y = active heave compensator (AHC) on and operating, N = AHC off and not operating. Drill over: Y = drill over used to recover core barrel, N = drill over not required to recover core barrel. APCT = advanced piston corer temperature tool, PCS = pressure core sampler, RBI = Rock Bit International auger bit (**www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm**), PDC = RBI polycrystalline diamond compact drill bit (**www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm**), APCM = advanced piston corer methane tool (same as TPC tool), DSA = drill string accelerator tool, DVTPP = Davis-Villinger Temperature-Pressure Probe, XCB = extended core barrel, FPC = Fugro pressure corer, APC = advanced piston corer. APC cores with TPC data are highlighted in yellow.

Table T5. Drilling data, Hole 1247B.

Core	Time on deck	Depth (m) Top	Depth (m) Bottom	Depth (m) Below seafloor	Advanced (m)	Length (m) Cored	Length (m) Recovered	Recovery (%)	Shear pins	Shear pressure (psi)	Speed holes	Pull (kips)	Stroke	Core catcher used (rpm)	Wireline (F/A)	Wireline Runs
204-1247B-																
1H	1035	845.9	849.5	3.6	3.6	3.6	3.60	100	2H	2700	0	0	Y	FP-10F	F	1
2H	1115	849.5	859.0	13.1	9.5	9.5	10.16	107	2H	2700	0	0	Y	FP-10F	F	1
3H	1150	859.0	868.5	22.6	9.5	9.5	9.88	104	2H	2700	0	0	Y	FP-10F	F	1
4P	1305	868.5	869.5	23.6	1.0	1.0	1.00	100	0 SPM	0	—	—	5 K	50	F	1
DI	1310	869.5	870.5	24.6	1.0	—	—	—	40 SPM	125	—	—	5 K	40	—	—
5H	1350	870.5	880.0	34.1	9.5	9.5	10.47	110	2H	2700	0	30	Y	FP-10F	F	1
6H	1420	880.0	889.5	43.6	9.5	9.5	10.32	109	2H	2700	0	15	Y	FP-10F	F	1
7H	1505	889.5	899.0	53.1	9.5	9.5	9.53	100	2H	2700	0	40	Y	FP-10F	F	1
8H	1550	899.0	908.5	62.6	9.5	9.5	10.03	106	2H	2700	0	35	N	FP-10F	F	1
9H	1645	908.5	918.0	72.1	9.5	9.5	9.71	102	2H	2700	0	45	N	FP-10F	F	1
10H	1715	918.0	927.5	81.6	9.5	9.5	9.85	104	2H	2700	4	45	N	FP-10F	F	1
11H	1845	927.5	937.0	91.1	9.5	9.5	8.94	94	2H	2700	4	60	N	FP-10F	F	1
12H	1915	937.0	946.5	100.6	9.5	9.5	9.40	99	2H	2700	4	50	N	FP-10F	F	1
13H	2015	946.5	952.6	106.7	6.1	6.1	6.17	101	2H	2700	4	60	N	FP-10F	F	1
14H	2055	952.6	959.5	113.6	6.9	6.9	6.93	100	2H	2700	4	60	N	FP-10F	F	1

Core	Time on deck	Depth (m) Top	Depth (m) Bottom	Depth (m) Below seafloor	Shoe (type)	Orientation (type)	Min	AHC	Drill over	Remarks
204-1247B-										
1H	1035	845.9	849.5	3.6	APCT	None	0	N	N	BWS, APC Methane Tool in
2H	1115	849.5	859.0	13.1	Standard	None	5	N	N	
3H	1150	859.0	868.5	22.6	Standard	None	5	Y	N	
4P	1305	868.5	869.5	23.6	—	—	15	Y	N	PCS with Methane Tool with RBI PDC Bit
DI	1310	869.5	870.5	24.6	—	—	10	N	N	
5H	1350	870.5	880.0	34.1	APCT	None	5	N	N	
6H	1420	880.0	889.5	43.6	Standard	None	5	N	N	
7H	1505	889.5	899.0	53.1	APCT	None	5	N	N	
8H	1550	899.0	908.5	62.6	Standard	None	15	N	N	
9H	1645	908.5	918.0	72.1	APCT	None	10	N	N	
10H	1715	918.0	927.5	81.6	Standard	None	10	N	N	
11H	1845	927.5	937.0	91.1	APCT	None	10	N	Y	
12H	1915	937.0	946.5	100.6	Standard	None	30	N	N	
13H	2015	946.5	952.6	106.7	APCT	None	15	N	N	
14H	2055	952.6	959.5	113.6	Standard	None	10	N	N	

Measurement	PCS	APC
Number of cores	1	13
Total drilled (m)	1.0	
Total cored (m)	1.0	111.6
Total recovered (m)	1.00	114.99
Recovery (%)	100	103
Total wireline runs	1	13
Total bit F/hole (hr)	0.42	2.08
Total active heave (hr)	0.25	0.08

Notes: Spud date: 23 August 2002, rig time = 1016, GMT = rig time + 7 hr. Bottom-hole assemble length = 126.85 m. Seafloor = 845.9 mbsl, precision depth recorder = 844.4 mbsl. An 11-7/16-inch RBI C-3 bit with 4 jets was used (serial number CD980). All measurements are from pump 1. Rerun hours on used bit = 126.25. Stroke: Y = core barrel had full stroke, N = core barrel did not have full stroke. F = fore core liner winch was used, A = aft core liner winch was used. Min = minutes required to advance bit. AHC: Y = active heave compensator (AHC) on and operating, N = AHC off and not operating. Drill over: Y = drill over used to recover core barrel, N = drill over not required to recover core barrel. APCT = advanced piston corer temperature tool, PCS = pressure core sampler, RBI = Rock Bit International auger bit (**www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm**), PDC = RBI polycrystalline diamond compact drill bit (**www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm**), APCM = advanced piston corer methane tool (same as TPC tool), DSA = drill string accelerator tool, DVTPP = Davis-Villinger Temperature-Pressure Probe, XCB = extended core barrel, FPC = Fugro pressure corer, APC = advanced piston corer. APC cores with TPC data are highlighted in yellow.

Table T6. Drilling data, Hole 1250D.

	Time on deck		Depth (m)				Length (m)								
Core	Rig	GMT	Top	Bottom	Below seafloor	Advanced (m)	Cored	Recovered	Recovery (%)	Shear pins	Shear pressure (psi)	Speed holes	Pull (kips)	Stroke	Core catcher used (rpm)
204-1250D-															
1H	1755	0055	807.0	813.5	6.5	6.5	6.5	2.76	42	2H	2700	0	0	Y	FP-10F
2H	1910	0210	813.5	823.0	16.0	9.5	9.5	7.57	80	2H	2700	0	0	Y	FP-10F
3H	2020	0320	823.0	832.5	25.5	9.5	9.5	10.15	107	2H	2700	0	20	Y	FP
4H	2140	0440	832.5	842.0	35.0	9.5	9.5	9.89	104	2H	2700	0	40	Y	FP
5P	2255	0555	842.0	843.0	36.0	1.0	1.0	1.00	100	20 SPM	75	—	—	5 K	80
DI	2300	0600	843.0	844.0	37.0	1.0	—	—	—	40 SPM	125	—	—	5 K	80
6H	2345	0645	844.0	853.5	46.5	9.5	9.5	10.01	105	2H	2700	0	45	Y	FP
7H	0045	0745	853.5	863.0	56.0	9.5	9.5	9.92	104	2H	2700	0	45	Y	FP-10F
8H	0220	0920	863.0	872.5	65.5	9.5	9.5	9.80	103	2H	2700	0	45	Y	FP
9H	0310	1010	872.5	882.0	75.0	9.5	9.5	10.17	107	2H	2700	2	40	Y	FP-10F
10H	0400	1100	882.0	891.5	84.5	9.5	9.5	9.55	101	2H	2700	2	40	Y	FP
11H	0450	1150	891.5	901.0	94.0	9.5	9.5	9.85	104	2H	2700	2	40	Y	FP-10F
12H	0610	1310	901.0	910.5	103.5	9.5	9.5	7.82	82	2H	2700	2	50	Y	FP
13P	0745	1445	910.5	911.5	104.5	1.0	1.0	1.00	100	20 SPM	125	—	—	5 K	80
DI	0748	1448	911.5	912.5	105.5	1.0	—	—	—	20 SPM	125	—	—	5 K	80
14H	0825	1525	912.5	922.0	115.0	9.5	9.5	6.21	65	2H	2700	4	40	Y	FP

	Time on deck		Depth (m)			Wireline				
Core	Rig	GMT	Top	Bottom	Below seafloor	(F/A)	Runs	Shoe (type)	Orientation (type)	Remarks
204-1250D-										
1H	1755	0055	807.0	813.5	6.5	F	1	Standard	None	APC Corer Methane Tool in
2H	1910	0210	813.5	823.0	16.0	F	1	Standard	None	
3H	2020	0320	823.0	832.5	25.5	F	1	Standard	None	Fluorescent microspheres and tracers
4H	2140	0440	832.5	842.0	35.0	F	1	APCT	None	Fluorescent microspheres and tracers
5P	2255	0555	842.0	843.0	36.0	F	1	—	—	PCS with Methane Tool and RBI PDC Bit
DI	2300	0600	843.0	844.0	37.0	—	—	—	—	
6H	2345	0645	844.0	853.5	46.5	F	1	APCT	None	Fluorescent microspheres and tracers
7H	0045	0745	853.5	863.0	56.0	F	1	Standard	None	
8H	0220	0920	863.0	872.5	65.5	F	1	APCT	None	Fluorescent microspheres and tracers, drillover
9H	0310	1010	872.5	882.0	75.0	F	1	Standard	None	
10H	0400	1100	882.0	891.5	84.5	F	1	Standard	None	Fluorescent microspheres and tracers
11H	0450	1150	891.5	901.0	94.0	F	1	Standard	None	
12H	0610	1310	901.0	910.5	103.5	F	1	APCT	None	Fluorescent microspheres and tracers
13P	0745	1445	910.5	911.5	104.5	F	1	—	—	PCS with Methane Tool and RBI PDC Bit
DI	0748	1448	911.5	912.5	105.5	—	—	—	—	
14H	0825	1525	912.5	922.0	115.0	F	2	Standard	None	WP and tracers/ DVTPP at 922.0 m APC Methane Tool out

Measurement	PCS	APC
Number of cores	2	12
Total drilled (m)	2.0	
Total cored (m)	2.0	111.0
Total recovered (m)	2.00	103.70
Recovery (%)	100	93.4
Total wireline runs	2	13
Total bit F/hole (hr)	0.65	2.95
Total active heave (hr)	0.65	2.03

Notes: Spud date = 3 August 2002, rig time = 1745, GMT = rig time + 7 hr. Bottom-hole assembly length = 136.14 m. Seafloor = 807.0 mbsl, precision depth recorder = 809.4 mbsl. An 11-7/16-inch RBI C-3 bit with 4 jets was used (serial number CD980). All measurements are from pump 1. Rerun hours on used bit = 62.80. Stroke: Y = core barrel had full stroke, N = core barrel did not have full stroke. F = fore core liner winch was used, A = aft core liner winch was used. Min = minutes required to advance bit. AHC: Y = active heave compensator (AHC) on and operating, N = AHC off and not operating. Drill over: Y = drill over used to recover core barrel, N = drill over not required to recover core barrel. APCT = advanced piston corer temperature tool, PCS = pressure core sampler, RBI = Rock Bit International auger bit (**www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm**), PDC = RBI polycrystalline diamond compact drill bit (**www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm**), APCM = advanced piston corer methane tool (same as TPC tool), DSA = drill string accelerator tool, DVTPP = Davis-Villinger Temperature-Pressure Probe, XCB = extended core barrel, FPC = Fugro pressure corer, APC = advanced piston corer. APC cores with TPC data are highlighted in yellow.

Table T7. Drilling data, Hole 1251D. (See table notes. Continued on next page.)

Core	Time on deck		Depth (m)			Advanced (m)	Length (m)		Recovery (%)	Shear pins	Speed pressure (psi)	Speed holes	Pulls (kips)	Stroke	Core catcher used (rpm)
	Rig	GMT	Top	Bottom	Below seafloor		Cored	Recovered							
204-1251D-															
4H	0905	1605	1248.3	1257.8	36.4	9.5	9.5	7.77	82	2H	1500	0	0	Y	FP
5H	0945	1645	1257.8	1267.3	45.9	9.5	9.5	9.67	102	2H	2700	0	0	Y	FP
6P	1055	1755	1267.3	1268.3	46.9	1.0	1.0	1.00	100	20 SPM	115			5 K	50
DI	1100	1800	1268.3	1269.3	47.9	1.0				20 SPM	115			5 K	50
7H	1135	1835	1269.3	1278.8	57.4	9.5	9.5	8.27	87	2H	2700	0	0	Y	FP-10F
8H	1205	1905	1278.8	1288.3	66.9	9.5	9.5	8.90	94	2H	2700	0	10	Y	FP
9H	1240	1940	1288.3	1297.8	76.4	9.5	9.5	8.86	93	2H	2700	2	10	Y	FP-10F
10P	1405	2105	1297.8	1298.8	77.4	1.0	1.0	1.00	100	20 SPM	115			5 K	80
DI	1410	2110	1298.8	1299.8	78.4	1.0				40 SPM	125			5 K	40
11H	1450	2150	1299.8	1309.3	87.9	9.5	9.5	9.18	97	2H	2700	2	15	Y	FP
12H	1520	2220	1309.3	1318.8	97.4	9.5	9.5	9.13	96	2H	2700	2	15	Y	FP-10F
13H	1555	2255	1318.8	1328.3	106.9	9.5	9.5	9.36	99	2H	2700	4	15	Y	FP
14H	1640	2340	1328.3	1337.8	116.4	9.5	9.5	9.68	102	2H	2700	4	35	Y	FP-10F
15H	1705	0005	1337.8	1347.3	125.9	9.5	9.5	9.21	97	2H	2700	4	35	Y	FP
16H	1800	0100	1347.3	1356.8	135.4	9.5	9.5	10.04	106	2H	2700	4	35	Y	FP-10F
17H	1840	0140	1356.8	1366.3	144.9	9.5	9.5	9.90	104	2H	2700	4	40	Y	FP
18H	1925	0225	1366.3	1375.8	154.4	9.5	9.5	3.26	34	2H	2700	4	45	Y	FP-10F
19H	2145	0445	1375.8	1385.3	163.9	9.5	9.5	9.59	101	2H	2700	4	45	Y	FP-10F
20H	0125	0825	1385.3	1394.8	173.4	9.5	9.5	9.67	102	2H	2700	4	45	Y	FP
21P	0335	1035	1394.8	1395.8	174.4	1.0	1.0	1.00	100	26 SPM	100			5 K	70
DI	0340	1040	1395.8	1396.8	175.4	1.0				55 SPM	125			5 K	60

Core	Time on deck		Depth (m)			Wireline		Shoe (type)	Orientation (type)	Remarks
	Rig	GMT	Top	Bottom	Below seafloor	(F/A)	Runs			
204-1251D-										
4H	0905	1605	1248.3	1257.8	36.4	F	1	Standard	None	Fluorescent microspheres and PFT tracers, mechanical shear
5H	0945	1645	1257.8	1267.3	45.9	F	1	Standard	None	Fluorescent microspheres and PFT tracers
6P	1055	1755	1267.3	1268.3	46.9	F	1	Standard	None	PCS with Methane Tool-RBI2 Pdc Bit
DI	1100	1800	1268.3	1269.3	47.9					
7H	1135	1835	1269.3	1278.8	57.4	F	1	Standard	None	
8H	1205	1905	1278.8	1288.3	66.9	F	1	Standard	None	Fluorescent microspheres and PFT tracers
9H	1240	1940	1288.3	1297.8	76.4	F	1	Standard	None	
10P	1405	2105	1297.8	1298.8	77.4	F	1			PCS with Methane Tool-RBI2 Pdc Bit
DI	1410	2110	1298.8	1299.8	78.4					
11H	1450	2150	1299.8	1309.3	87.9	F	1	Standard	None	APC Methane in/with Fluorescent microspheres and PFT tracers
12H	1520	2220	1309.3	1318.8	97.4	F	1	Standard	None	
13H	1555	2255	1318.8	1328.3	106.9	F	1	Standard	None	Fluorescent microspheres and tracers
14H	1640	2340	1328.3	1337.8	116.4	F	1	Standard	None	
15H	1705	0005	1337.8	1347.3	125.9	F	1	Standard	None	Fluorescent microspheres and tracers
16H	1800	0100	1347.3	1356.8	135.4	F	1	Standard	None	
17H	1840	0140	1356.8	1366.3	144.9	F	1	Standard	None	Fluorescent microspheres and tracers
18H	1925	0225	1366.3	1375.8	154.4	F	1	Standard	None	
19H	2145	0445	1375.8	1385.3	163.9	F	1	Standard	None	
20H	0125	0825	1385.3	1394.8	173.4	F	1	APCT	None	Fluorescent microspheres and tracers/Drillover
21P	0335	1035	1394.8	1395.8	174.4	F	2	Sheared overshot		PCS with Methane Tool-RBI2 Pdc Bit
DI	0340	1040	1395.8	1396.8	175.4	F	1		0	DVTPP at 1396.8 m (175.4 mbsf)

Table T7 (continued).

Measurement	PCS	APC
Number of cores	3	15
Total cored (m)	3.0	142.5
Total recovered (m)	3.00	132.49
Recovery (%)	100	93
Total wireline runs	4	16
Total bit F/hole (hr)	0.52	2.42
Total active heave (hr)	0.52	1.58

Notes: Spud date = 31 July 2002, rig time = 0710, GMT = rig time + 7 hr. Bottom-hole assembly length = 136.14 m. Seafloor = 1221.4 mbsl, precision depth recorder = 1222.4 mbsl. An 11-7/16-inch RBI C-3 bit with 4 jets was used (serial number CD980). All measurements are from pump 1. Rerun hours on used bit = 43.92. Stroke: Y = core barrel had full stroke, N = core barrel did not have full stroke. F = fore core liner winch was used, A = aft core liner winch was used. Min = minutes required to advance bit. AHC: Y = active heave compensator (AHC) on and operating, N = AHC off and not operating. Drill over: Y = drill over used to recover core barrel, N = drill over not required to recover core barrel. APCT = advanced piston corer temperature tool, PCS = pressure core sampler, RBI = Rock Bit International auger bit (**www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm**), PDC = RBI polycrystalline diamond compact drill bit (**www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm**), APCM = advanced piston corer methane tool (same as TPC tool), DSA = drill string accelerator tool, DVTPP = Davis-Villinger Temperature-Pressure Probe, XCB = extended core barrel, FPC = Fugro pressure corer, APC = advanced piston corer. APC cores with TPC data are highlighted in yellow.

Table T8. Drilling data, Hole 1252A.

Core	Time on deck	Depth (m)			Advanced (m)	Length (m)		Recovery (%)	Shear pins	Shear pressure (psi)	Speed holes	Pull (kips)	Stroke	Core catcher used (rpm)	Wireline	
		Top	Bottom	Below seafloor		Cored	Recovered								(F/A)	Runs
204-1252A-																
1H	0340	1051.0	1055.9	4.9	4.9	4.9	4.94	101	2H	2700	0	0	Y	FP-10F	F	1
2H	0420	1055.9	1065.4	14.4	9.5	9.5	10.03	106	2H	2700	0	0	Y	FP-10F	F	1
3H	0455	1065.4	1074.9	23.9	9.5	9.5	9.50	100	2H	2700	0	0	Y	FP-10F	F	1
4H	0545	1074.9	1084.4	33.4	9.5	9.5	9.92	104	2H	2700	0	20	Y	FP-10F	F	1
5H	0610	1084.4	1093.9	42.9	9.5	9.5	10.10	106	2H	2700	0	0	Y	FP-10F	F	1
6H	0710	1093.9	1103.4	52.4	9.5	9.5	10.15	107	2H	2700	2	30	Y	FP-10F	F	1
7H	0745	1103.4	1112.9	61.9	9.5	9.5	9.38	99	2H	2700	2	30	Y	FP-10F	F	1
8H	0835	1112.9	1122.4	71.4	9.5	9.5	9.57	101	2H	2700	2	40	Y	FP-10F	F	1
9H	0905	1122.4	1131.9	80.9	9.5	9.5	9.93	105	2H	2700	2	20	Y	FP-10F	F	1
10H	1000	1131.9	1141.4	90.4	9.5	9.5	9.95	105	2H	2700	4	45	Y	FP-10F	F	1
11H	1035	1141.4	1150.9	99.9	9.5	9.5	10.24	108	2H	2700	4	30	Y	FP-10F	F	1
12H	1125	1150.9	1160.4	109.4	9.5	9.5	10.31	109	2H	2700	4	45	Y	FP-10F	F	1
13H	1200	1160.4	1169.9	118.9	9.5	9.5	10.21	107	2H	2700	4	45	N	FP-10F	F	1
14H	1300	1169.9	1176.0	125.0	6.1	6.1	9.87	162	2H	2700	4	50	N	FP-10F	F	1

Core	Time on deck	Depth (m)			Shoe (type)	Orientation (type)	MIN	AHC	Drill over	Remarks
		Top	Bottom	Below seafloor						
204-1252A-										
1H	0340	1051.0	1055.9	4.9	Standard	None	0	N	N	APC Methane Tool on
2H	0420	1055.9	1065.4	14.4	Standard	None	5	N	N	
3H	0455	1065.4	1074.9	23.9	Standard	None	5	N	N	
4H	0545	1074.9	1084.4	33.4	APCT	None	5	N	N	
5H	0610	1084.4	1093.9	42.9	Standard	None	5	N	N	
6H	0710	1093.9	1103.4	52.4	APCT	None	5	N	N	
7H	0745	1103.4	1112.9	61.9	Standard	None	5	N	N	
8H	0835	1112.9	1122.4	71.4	APCT	None	5	N	N	
9H	0905	1122.4	1131.9	80.9	Standard	None	5	Y	N	
10H	1000	1131.9	1141.4	90.4	APCT	None	5	Y	N	
11H	1035	1141.4	1150.9	99.9	Standard	None	5	Y	N	
12H	1125	1150.9	1160.4	109.4	APCT	None	5	Y	N	
13H	1200	1160.4	1169.9	118.9	Standard	None	10	Y	N	
14H	1300	1169.9	1176.0	125.0	APCT	None	5	Y	N	APC Methane Tool off

Measurement	APC
Number of cores	14
Total cored (m)	125.0
Total recovered (m)	134.10
Recovery (%)	107.3
Total wireline runs	14
Total bit F/hole (hr)	1.17
Total active heave (hr)	0.6

Notes: Spud date = 31 August 2002, rig time = 0325, GMT = rig time + 7 hr. Bottom-hole assembly length = 126.85 m. Seafloor = 1051 mbsl, precision depth recorder = 1051.4 mbsl. An 11-7/16-inch RBI C-3 bit with 4 jets was used (serial number CD980). All measurements are from pump 1. Rerun hours on used bit = 152.19. Stroke: Y = core barrel had full stroke, N = core barrel did not have full stroke. F = fore core liner winch was used, A = aft core liner winch was used. Min = minutes required to advance bit. AHC: Y = active heave compensator (AHC) on and operating, N = AHC off and not operating. Drill over: Y = drill over used to recover core barrel, N = drill over not required to recover core barrel. APCT = advanced piston corer temperature tool, PCS = pressure core sampler, RBI = Rock Bit International auger bit (www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm), PDC = RBI polycrystalline diamond compact drill bit (www-odp.tamu.edu/publications/tnotes/tn31/pcs/fig_02.htm), APCM = advanced piston corer methane tool (same as TPC tool), DSA = drill string accelerator tool, DVTPP = Davis-Villinger Temperature-Pressure Probe, XCB = extended core barrel, FPC = Fugro pressure corer, APC = advanced piston corer. APC cores with TPC data are highlighted in yellow.