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12. Data Report: Long-Term Temperature Measurements in Holes 1253A and 1255A off Costa Rica, ODP Leg 205[1]

Martin Heesemann,[2] Heinrich Villinger,[2] Hans W. Jannasch,[3] Miriam Kastner,[4] and the Expedition 301T Scientists

ABSTRACT

Long-term temperature measurements using miniaturized temperature loggers (MTLs) were performed in Ocean Drilling Program Holes 1253A and 1255A across the Middle America Trench off the Nicoya Peninsula, Costa Rica. All three recovered loggers, which were retrieved fully functional, provided high-resolution temperature records. These records cover a time span of ~2 yr and were sampled at an interval of 17 min. There are a number of signals in the temperature data that are most likely caused by hydrologic events. These events are also present in the pressure data recorded by Circulation Obviation Retrofit Kit (CORK)-IIs that are installed in these boreholes. Moreover, the temperature data are important input parameters for calculating pumping rates of the OsmoSamplers, within which the MTLs were integrated. Therefore, the MTL temperature records combined with the CORK-II pressure measurements and the data from the OsmoSampler fluid samples allow the investigation of subduction zone hydrologic processes.

INTRODUCTION

During Ocean Drilling Program (ODP) Leg 205 in September and October 2002, Circulation Obviation Retrofit Kit (CORK)-II observatories were installed in Holes 1253A and 1255A across the Middle America

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[2] Universität Bremen, Department of Geoscience, Klagenfurter Strasse, 28359 Bremen, Germany. heesema@uni-bremen.de
[3] Monterey Bay Aquarium Research Institute, 7700 Sandholdt Road, Moss Landing CA 95039, USA.
[4] Scripps Institution of Oceanography, University of California, San Diego, Geoscience Research Division, 8615 Discovery Way, La Jolla CA 92093-0212, USA.

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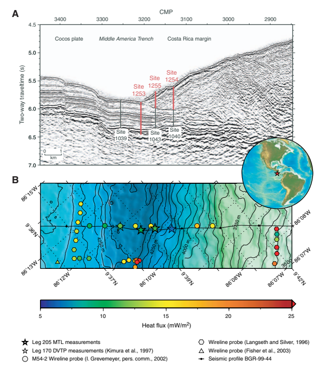
Trench off the Nicoya Peninsula, Costa Rica, in order to study fluid flow across the margin and its implication for the seismogenic zone and the subduction factory. Hole 1253A is located on the incoming plate 0.2 km seaward from the deformation front, whereas Hole 1255, which penetrates the décollement, is located 0.4 km arcward of the deformation front (Fig. **F1**) (Morris, Villinger, Klaus, et al., 2003).

F1. Borehole locations and heat flux measurements, p. 9.



The CORK-II observatories include instruments that were designed to sample fluids and measure flow rates, temperatures, and pressures. Fluid sampling is performed by OsmoSamplers that were configured to operate continuously for up to 2 yr and incorporate autonomous high-precision miniaturized temperature loggers (MTLs) (Jannasch et al., 2003).

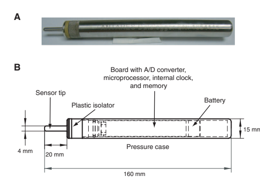
Sixteen months following the CORK-II installation, eight *Alvin* submersible dives were conducted to recover and replace the OsmoSamplers containing the MTLs. During these dives, the pressure data were successfully downloaded from the CORK heads, whereas recovering and replacing the OsmoSamplers failed. Fortunately, the *JOIDES Resolution* returned during Integrated Ocean Drilling Program (IODP) Expedition 301T in August–September 2004 and succeeded in recovering most of the OsmoSamplers and replacing them with new ones before valuable data and water samples were lost (Shipboard Scientific Party, 2004). This paper presents the complete MTL data sets and points out a number of interesting features contained in the data.

METHODS

Miniaturized Temperature Loggers

The MTLs consist of a 140 mm long × 15 mm outer diameter cylindrical data logger housing with a thin-walled tip (20 mm long with an outer diameter of 4 mm) containing the temperature sensor (Fig. **F2**). The pressure housing consists of high-strength corrosion-resistant steel and withstands pressure equivalent to 6000 m water depth. Programming the logger and downloading the data are performed using a readout unit without opening the pressure case. The readout unit contacts the MTL's tip and end cap with voltage delivered by the RS-232 interface connected to a PC-compatible computer. A high-strength plastic washer isolates the tip and main body to allow a two-point connection for data transfer.

F2. Recovered MTL and construction details, p. 10.



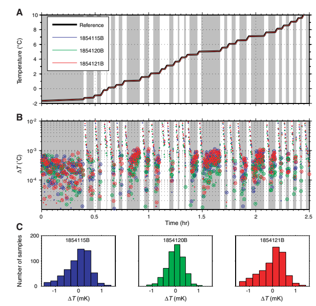
The electronics of the logger consist of a microprocessor, a 16-bit analog-to-digital converter, a real-time clock, nonvolatile memory for up to 64,800 measurements, and a standard 3-V lithium battery. Logging is automatically stopped when monitoring of an internal constant reference resistor indicates that a reduction of battery voltage causes erroneous temperature readings. Even during a total loss of voltage, the recorded data are preserved in nonvolatile memory. Sample intervals can be varied from 1 s to 255 min, and a thermistor is used as a sensing element. The sensor provides a temperature range from –5° to +60°C and a resolution of ~0.5 mK at typical deep-sea temperature of 2°C (Pfender and Villinger, 2002; Jannasch et al., 2003).

MTL Calibration

Because of the interchangeability of the thermistors, the standard absolute accuracy of the MTLs is ~0.1 mK. By means of calibration it is, however, possible to enhance the absolute accuracy to approximately

±1 mK. The loggers were calibrated by placing them into a well-stirred calibration bath along with a certified reference thermometer. While the reference temperatures and readings measured by the loggers were recorded, the bath was heated stepwise throughout the temperature range in which the loggers were to be calibrated (Fig. F3A). The thermal time constant of the reference thermometer was lower than that of the loggers. Therefore, during times of relatively high temperature changes, the reference temperatures exceeded the logger temperatures by as much as 0.01°C (Fig. F3B; white areas). Hence, only data collected during times when all loggers and the reference thermometer were in thermal equilibrium with the calibration bath could be used for a sound calibration (Fig. F3A, F3B; shaded areas).

F3. MTL calibration, p. 11.



The utilized calibration procedure involved two steps. First, logger readings were converted to thermistor resistances. This conversion, which was provided by the WinTemp software accompanying the MTLs, was based on reference measurements with a set of high-precision resistors carried out by the manufacturer, ANTARES Datensysteme GmbH. Second, measured pairs of reference temperatures T (K) and thermistor resistances R (Ω) were used to compute the calibration coefficients A_i in the equation proposed by Steinhart and Hart (1968) and Bennett (1972) as follows:

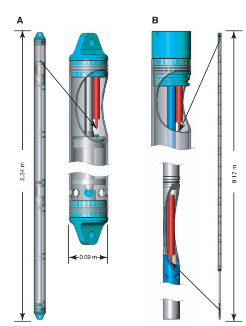
$$1/T = A_1 \times [\ln(R)]^3 + A_2 \times [\ln(R)]^2 + A_3 \times \ln(R) + A_4.$$

Even though there is no evidence of instrument drift, the long-term stability of the utilized MTL must still be confirmed by a second calibration of the loggers. Until this is carried out, an absolute temperature accuracy of ±5 mK should be used rather than the ±1 mK implied by the presented calibration (Fig. F3C). This very conservative estimate is, however, still adequate for interpretation of the recovered temperature data.

Downhole Setup

Hole 1253A is equipped with two OsmoSamplers located in the upper oceanic basement. As illustrated in Figure F4A, each OsmoSampler contains an MTL installed in the upper endcap of its housing. When the upper OsmoSampler was recovered it was discovered that it had been accidentally installed upside down so that the upper end cap became the lower endcap. Unfortunately, the Spectra line connecting the OsmoSamplers failed during the recovery operations, and the lower OsmoSampler in Hole 1253A was dropped to the seafloor. Hopefully, it will be retrieved on the next visit to the site.

F4. OsmoSampler construction sketches, p. 12.



The OsmoSampler in Hole 1255A also contains one MTL in the upper endcap, which is situated in the overthrust section of the borehole. An additional MTL is seated inside the probe that penetrates into the sealed décollement section of the borehole (Fig. F4B). For reference, a summary of the logger positions is provided in Table T1. Furthermore, Jannasch et al. (2003) give a detailed description of the OsmoSampler configuration as well as the borehole installation.

T1. MTL positions, logging times, and instrument drift, p. 20.

To obtain optimized usage of logger memory for a total logging duration of ~2 yr, the loggers were set to a sampling interval of 17 min resulting in a sampling frequency of ~85 per day, or ~0.001 Hz. The MTLs were set up to monitor the temperatures of the osmotic pumps starting with the assembly of the OsmoSamplers during Leg 205. A continuous temperature record of the osmotic pumps is important for the correct computation of osmotic pumping rates.

RESULTS

All MTLs recovered during Expedition 301T were still fully functional, and it was not necessary to change the batteries to retrieve the data. The MTLs did not show any signs of corrosion, even though the logger recovered from Hole 1253A was covered with mud and, presumably, bacteria (Fig. F5). Therefore, we anticipate that the temperature data from the lower OsmoSampler in Hole 1253A will also be available in case the OsmoSampler can be recovered on a future visit to the site.

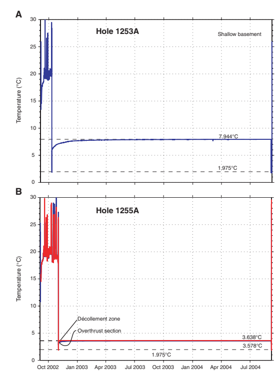
F5. Recovered MTL after 2-yr deployment, p. 13.

Complete Temperature Records

After temperature data retrieval, the internal clocks of the MTLs, which were set to Universal Time Coordinated (UTC) time before the start of logging, were compared to the actual UTC time. The observed time drifts of only a few minutes are summarized in Table T1. These offsets are small compared to the time covered by the entire data sets, so no time drift corrections were applied.

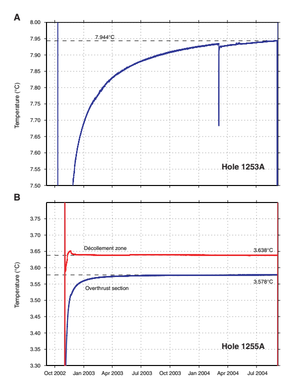
Figure F6 shows the complete temperature data sets recorded by the recovered MTLs in Holes 1253A and 1255A. At the beginning of each record there is a sudden temperature drop from room temperature to bottom water temperature. These drops occurred when the instruments were installed on 10 October 2002 in Hole 1253A and on 1 November 2002 in Hole 1255A. After installation, the measured borehole temperatures slowly approach formation temperatures until a sudden temperature drop to bottom water temperature followed by an increase to room temperature marking the recovery of the OsmoSamplers from Hole 1253A on 5 September 2004 and from Hole 1255A on 6 September 2004.

F6. Logger temperature data, p. 14.



A temperature of 7.944°C, which was reached in the shallow basement of Hole 1253A, is higher than the formation temperatures measured in Hole 1255A, which are 3.578°C in the overthrust section and 3.638°C in the décollement zone (Fig. F7). Taking into account conductive heat flux estimates, this temperature difference can be explained by the greater depth below seafloor of the OsmoSampler in Hole 1253A. Considering a seafloor temperature of 1.975° ± 0.05°C, a mean temperature gradient in the formations between the OsmoSamplers and the seafloor of ~0.012 K/m is present at both sites. Assuming average thermal conductivities of 0.85 ± 0.05 W/(m·K) for the sediments on the incoming plate and 0.95 ± 0.05 W/(m·K) for sediments in the overthrust section as measured by Kimura, Silver, Blum, et al. (1997), the average heat flux estimates at Sites 1253 and 1255 are 10 ± 0.6 and 11 ± 0.7 mW/m², respectively.

F7. Temperature equilibration comparison, p. 15.



Conductive lithospheric cooling models predict a heat flux of ~100 mW/m² for ~24-Ma oceanic crust underlying the sites (Stein and Stein, 1994). Heat flux measurements reported by Langseth and Silver (1996) and Fisher et al. (2003) show, however, that heat flux through seafloor created at the East Pacific Rise is generally suppressed by ~70% relative to estimates obtained by these models. This anomalously low heat flux is attributed to effective hydrothermal cooling of the upper oceanic crust, which is facilitated by seamounts and basaltic outcrops (Silver et al., 2000; Hutnak et al., 2004). With an average of 16.4 mW/

m² and a standard deviation of 7.4 mW/m², the heat flux in the working area, as shown in Figure F1B, is suppressed by ~85% relative to the predicted values. Moreover, the heat flux estimates derived from the borehole measurements are slightly lower than the nearby heat flux values from shallow-penetration probes used during *Meteor* cruise M54-2 (I. Grevemeyer, pers. comm., 2002). This is consistent with the observations of Ruppel and Kinoshita (2000) and is attributed to a perturbation of the thermal regime by advective flux.

The temperature equilibration in Hole 1253A took place much slower than in Hole 1255A. This is presumably due to a much higher and longer inflow of cold seawater during drilling caused by the slight subhydrostatic pressure of ~7 kPa encountered in the permeable basement in Hole 1253A. In contrast, drilling operations in Hole 1255A were much shorter and the CORK-II measured superhydrostatic pressures (Fig. F8C) in the sedimentary formation (Shipboard Scientific Party, 2004).

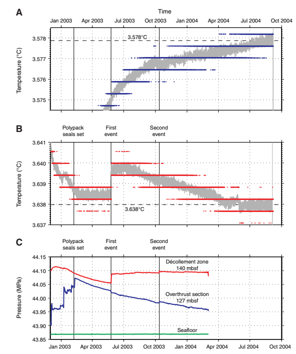
Temperature Events

Besides the long-term equilibration trends, several smaller events are documented in the temperature data. The most prominent event seen in Figure F7A is the sudden temperature drop on 4 March 2004 caused by the OsmoSampler recovery attempt during *Alvin* dive 3982. A zoom into this event, provided in Figure F9A, shows the temperature response of lifting the OsmoSamplers and thereby breaking the pressure seal at 1726 hr UTC. Also, the winch failure at 1855 hr UTC, after which the OsmoSamplers dropped back to their initial positions, is clearly seen in the temperature record. The timing of these events exactly matches the notes in the *Alvin* dive log.

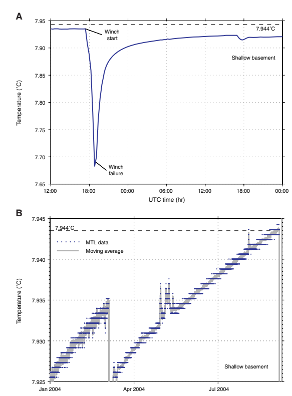
Figure F9B shows the temperature data and a moving average over 10 samples (2 hr 50 min) of small-scale temperature variations before and after the *Alvin* recovery attempt. Amplitudes of these variations after the *Alvin* dive are smaller than before the dive. This suggests that the OsmoSamplers fell back in place properly and their seal was even better than before the dive. Moreover, some strong temperature undulations well after the *Alvin* dive are present in the data. These events have to be interpreted along with the results of the fluid sample analysis and the corresponding CORK pressure data when they become available.

The first attempt to recover the Hole 1253A OsmoSamplers during IODP Expedition 301T on 5 September 2004 failed and the OsmoSamplers dropped to the seafloor ~20 m southeast of the borehole. While the OsmoSamplers remained at this location for 2 days, an exact bottom water temperature of 1.975°C at Site 1253 was measured (Fig. F10). Measurements taken during ODP Leg 205, (Morris, Villinger, Klaus, et al., 2003) estimated a similar bottom water temperature of 1.989°C with an MTL mounted on the video system while reentering Hole 1253A. Measurements also indicated that the minimum temperature in the water column is located ~1500 m above the seafloor. The minimum water temperature of 1.77°C measured during Expedition 301T recovery operation is, however, significantly lower than the minimum temperature of ~1.83°C recorded during Leg 205. This information may help to constrain extreme bottom water variations with amplitudes of 0.01°C that were observed with MTLs mounted to the CORK-heads of Holes 1253A and 1255A during November 2002–March 2004 (H. Villinger, pers. comm., 2004).

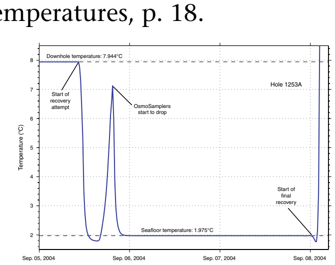
F8. Small-scale temperature variations and pressure events, p. 16.



F9. Temperature signal and variations, p. 17.



F10. Unsuccessful MTL recovery temperatures, p. 18.

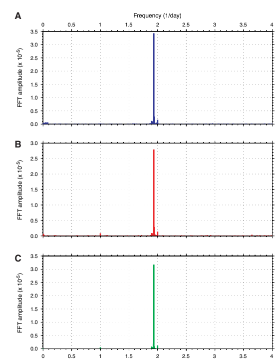


There are also some events that caused small-scale temperature variations in the data measured in Hole 1255A (Fig. F8). Most of these events can be correlated to variations that are also present in the CORK-II pressure data (Fig. F8C) These variations are (1) the setting of the polypack seals, which caused an increase of pressure in the overthrust section and a stabilization of décollement temperatures; (2) the "first event," characterized by a sudden increase of pressure as well as temperature in the décollement zone; and (3) the much smaller pressure changes of the "second event" that are hardly seen in either temperature record). At the present time, no pressure data have been downloaded from the CORK-IIs for April–July 2004 when temperatures in the décollement zone started to stabilize after an interim increase during May 2004.

Stable temperatures measured over periods of several months around April 2003 and August 2004 (Fig. F8B) demonstrate the high quality of temperature data recorded by the MTLs. No significant instrument drift can be seen, and the noise level does not exceed the loggers' resolution.

Fast Fourier Transform (FFT) amplitude spectra of the MTL temperature data and the CORK-II pressure records measured in Hole 1253A and Hole 1255A are dominated by frequencies slightly below 2 per day. These signals are most likely caused by tidal effects. As an example, Figure F11 shows the FFT amplitude spectra of MTL temperatures and CORK-II seafloor pressure data recorded during November 2003–March 2004 in Hole 1255A. This time interval was chosen because there is no interference with obvious events in any of the data. Before performing the spectral analysis, linear trends were removed from the otherwise unfiltered data. The sampling rates result in Nyquist frequencies of ~42.5 and ~72 per day for temperature and pressure data, respectively. Signals exceeding the Nyquist frequencies cannot be resolved and appear possibly in lower frequencies of the spectra due to aliasing. Problems with aliasing effects are, however, unlikely since the data measured independently at different sampling rates result in similar amplitude spectra.

F11. FFT amplitude spectra, p. 19.



CONCLUSIONS

The presented data show that the MTLs are practicable, reliable, and, at the same time, affordable instruments to measure high-resolution downhole temperatures, even over long periods of time. There are a number of signals in the temperature data that are caused by hydrologic events. These events are also present in the pressure data recorded by the CORK-IIs installed in these boreholes. Therefore, the MTL temperature records can supplement the CORK-II pressure measurements and the data gained from the OsmoSampler fluid samples in order to understand hydrologic processes of the studied subduction zone. All of the presented temperature data will be submitted to the IODP United States Implementing Organization (USIO) database. The files are in ASCII format and include calibrated temperatures as well as uncorrected UTC times.

ACKNOWLEDGMENTS

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Figure F1. Overview of borehole locations and heat flux measurements. **A.** Locations of Leg 205 sites (red) and Leg 170 sites (black) on migrated seismic profile BGR-99-44 (Morris, Villinger, Klaus, et al., 2003). CMP = common midpoint. **B.** Bathymetric map based on data compiled by Ranero and von Huene (2000) with compilation of heat flux measurements in the study area. MTL = miniaturized temperature logger, DVTP = Davis-Villinger Temperature Probe.

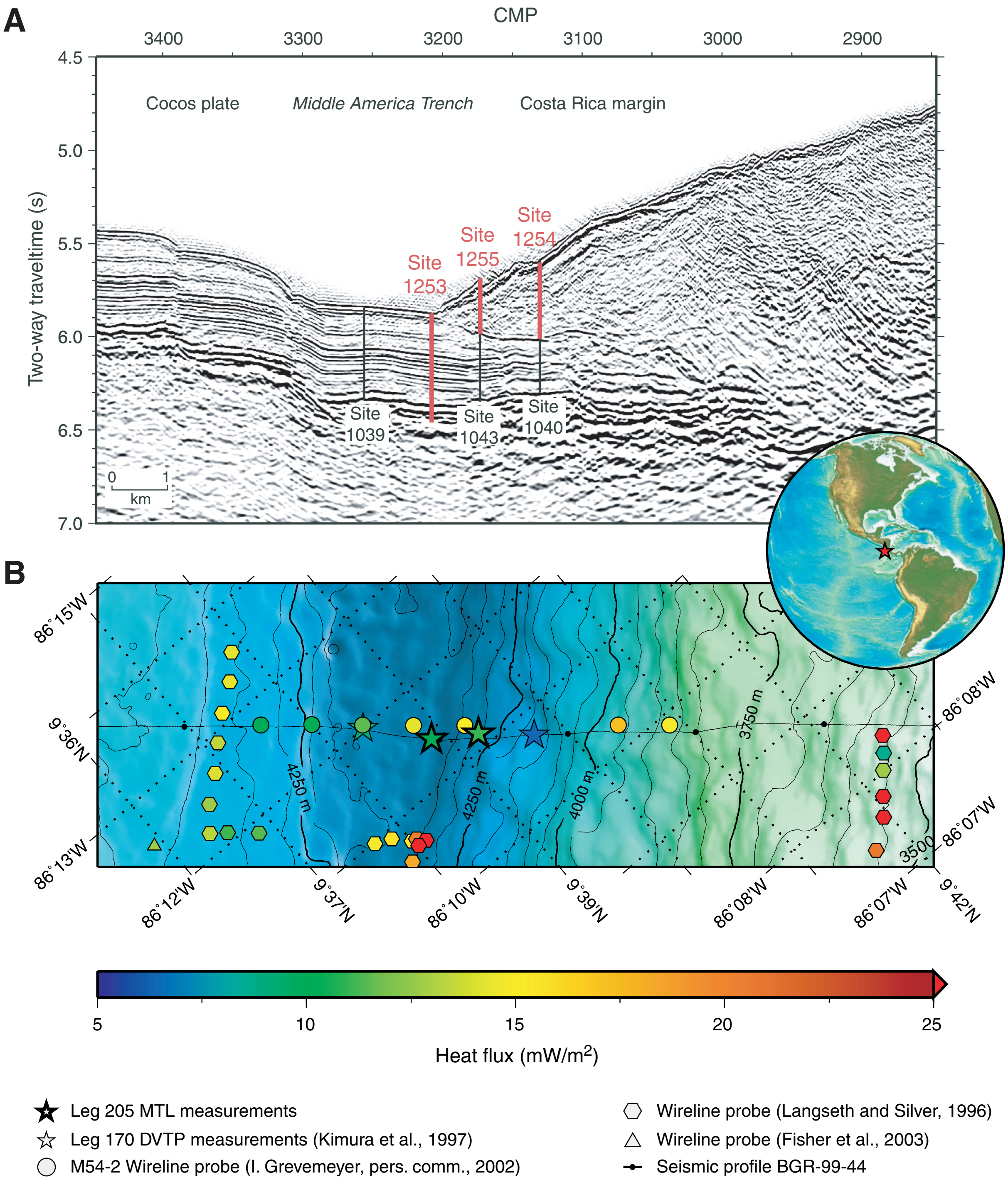

Figure F2. **A.** MTL after recovery during Expedition 301T. **B.** Construction details of an MTL (Pfender and Villinger, 2002). A/D = analog-to-digital.

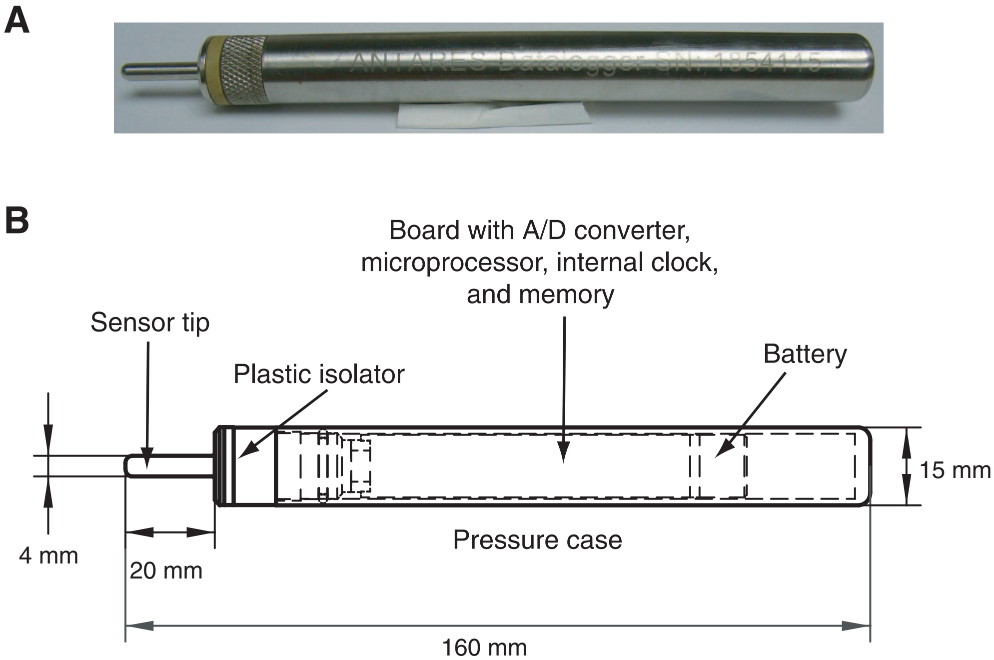

Figure F3. Calibration of MTLs with a certified reference thermometer in a well-stirred bath. **A.** Temperatures of the reference thermometer and the calibrated loggers show a stepwise increase of bath temperature. Temperatures in shaded areas are chosen for computing the calibration coefficients. **B.** Differences between the reference temperature and calibrated logger temperatures. Dots = reference temperatures that are higher than temperatures measured by the loggers, circled dots = reference temperatures slightly below the calibrated logger temperatures. **C.** Deviations of calibrated logger temperatures from reference temperatures in the shaded areas.

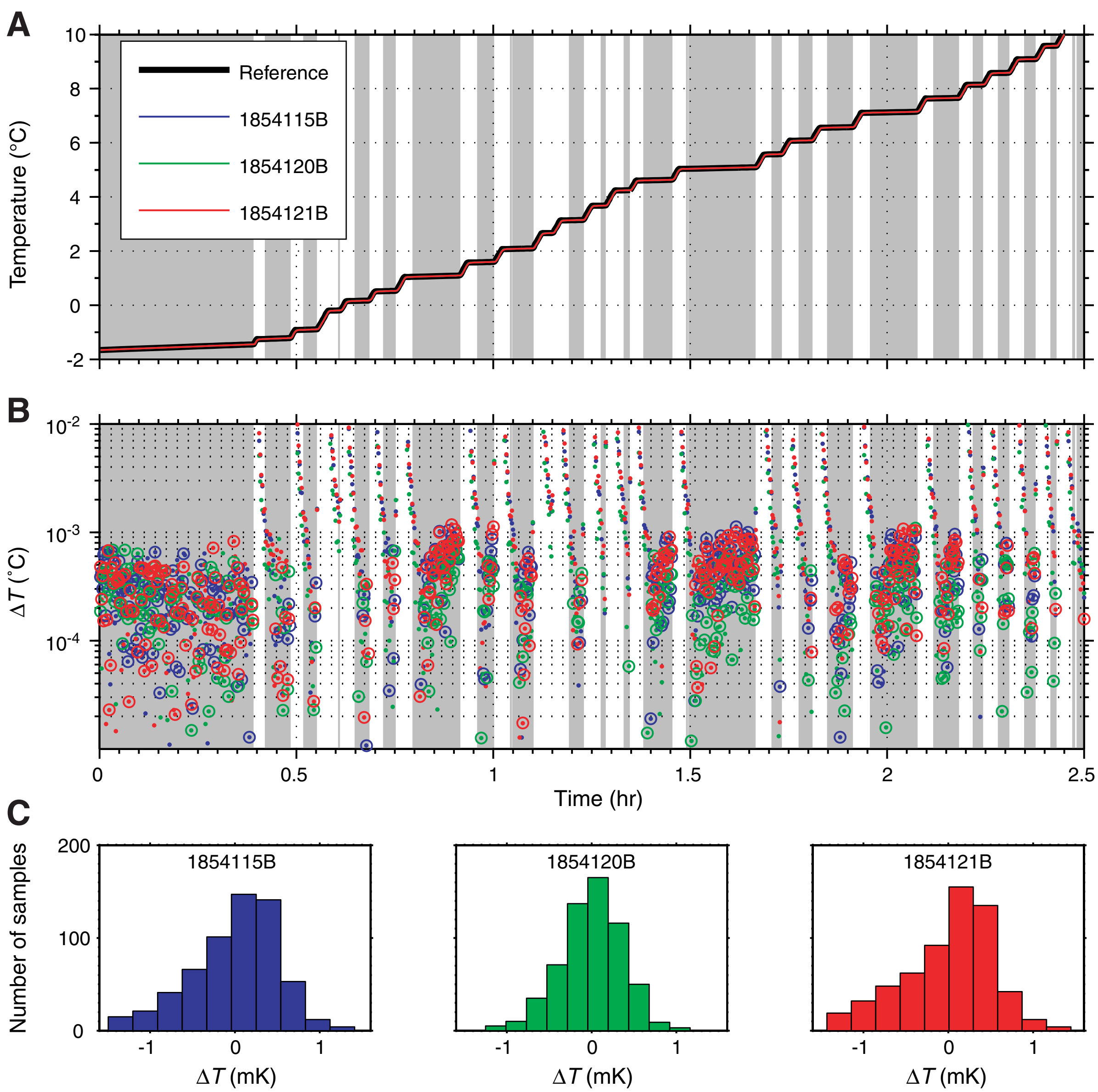

Figure F4. Construction sketches of the OsmoSamplers installed in (**A**) Hole 1253A and (**B**) Hole 1255A. Hole 1253A contains two identical OsmoSamplers with MTLs placed in the upper endcaps (cf. Fig. F5, p. 13.) The OsmoSampler installed in Hole 1255A contains an MTL in the upper endcap and in the probe that samples the décollement zone.

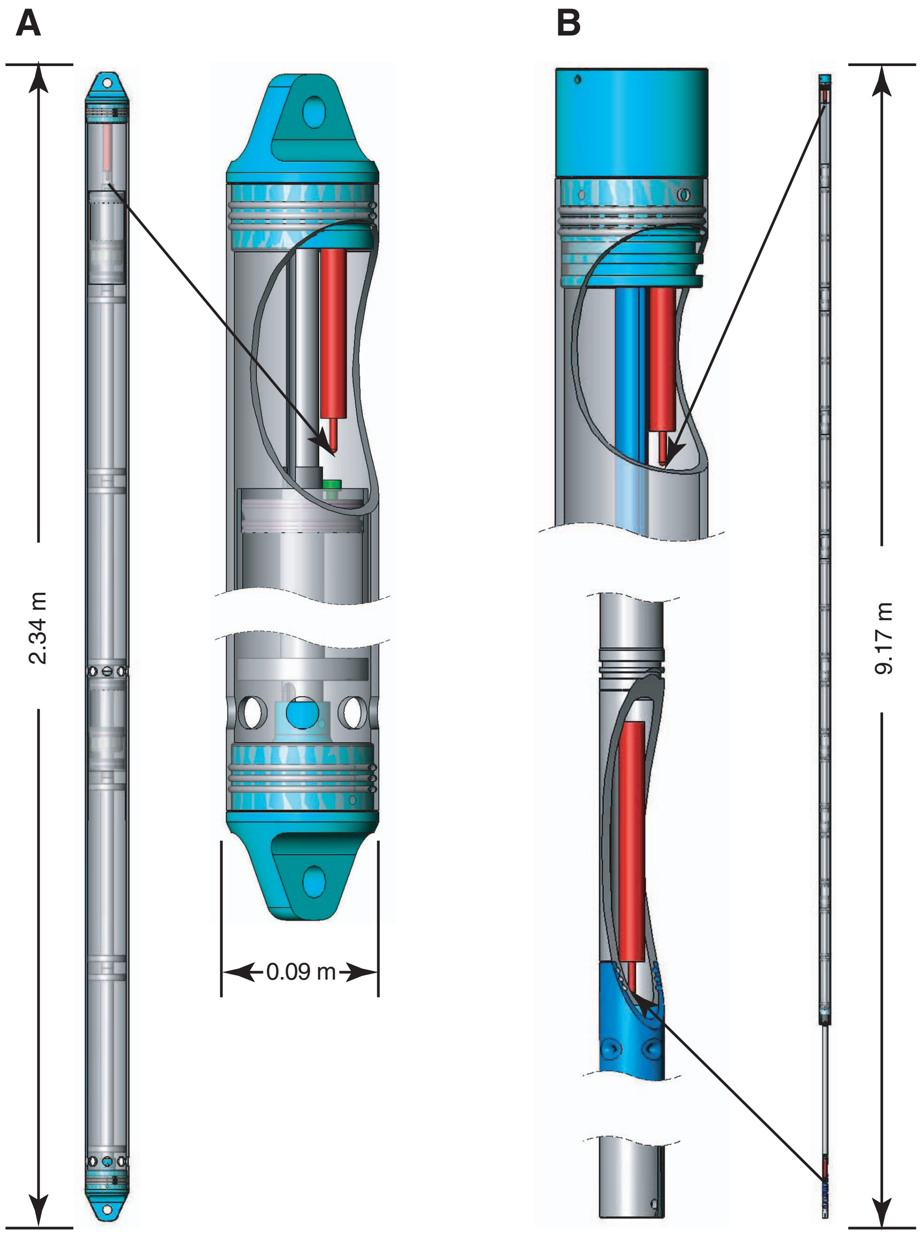

Figure F5. MTL in Hole 1253A after recovery from 2-yr deployment.

Figure F6. Complete temperature data measured by the recovered loggers. **A.** Hole 1253A. **B.** Hole 1255A.

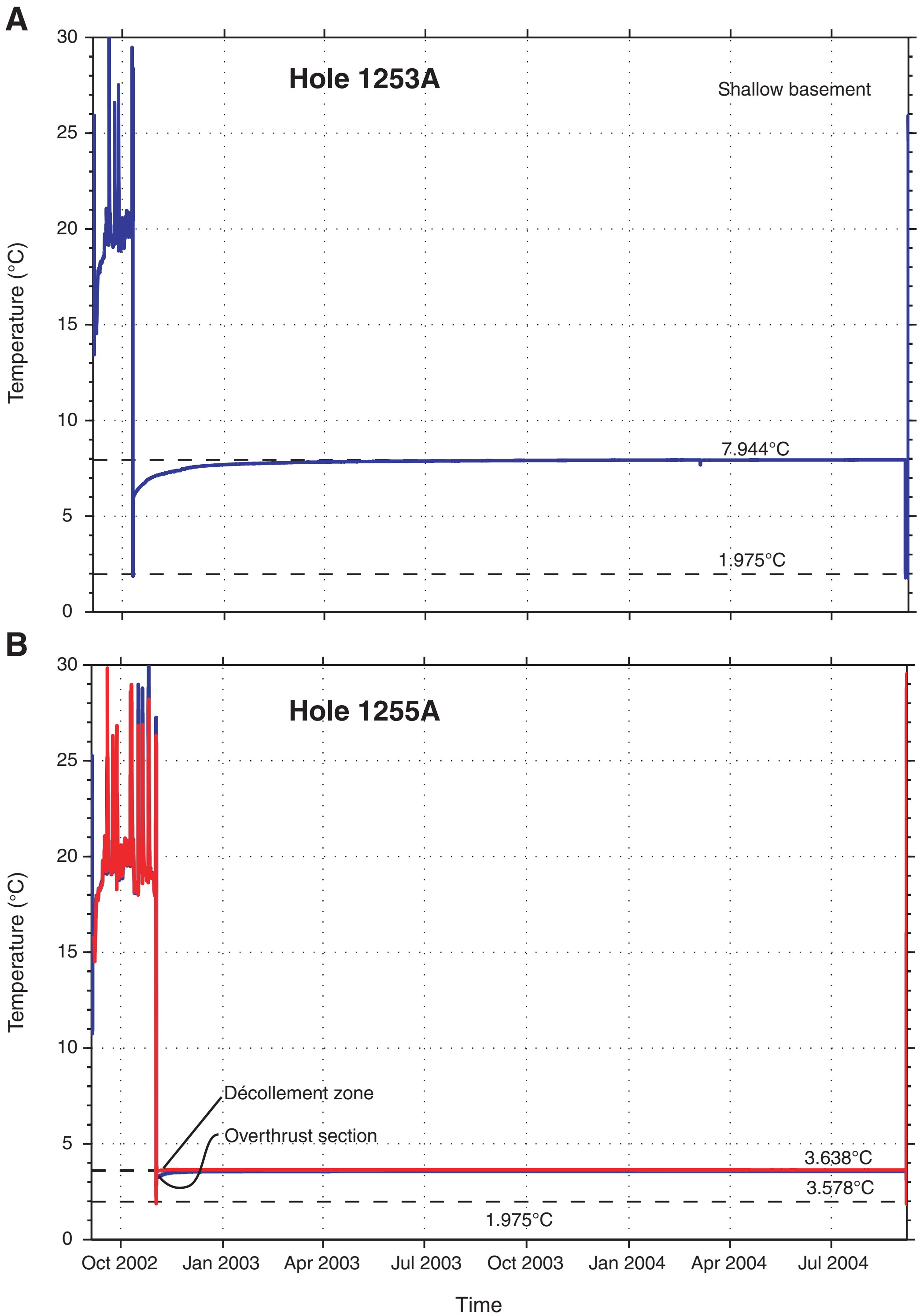

Figure F7. Comparison of the temperature equilibration following installation in (**A**) Hole 1253A and (**B**) Hole 1255A.

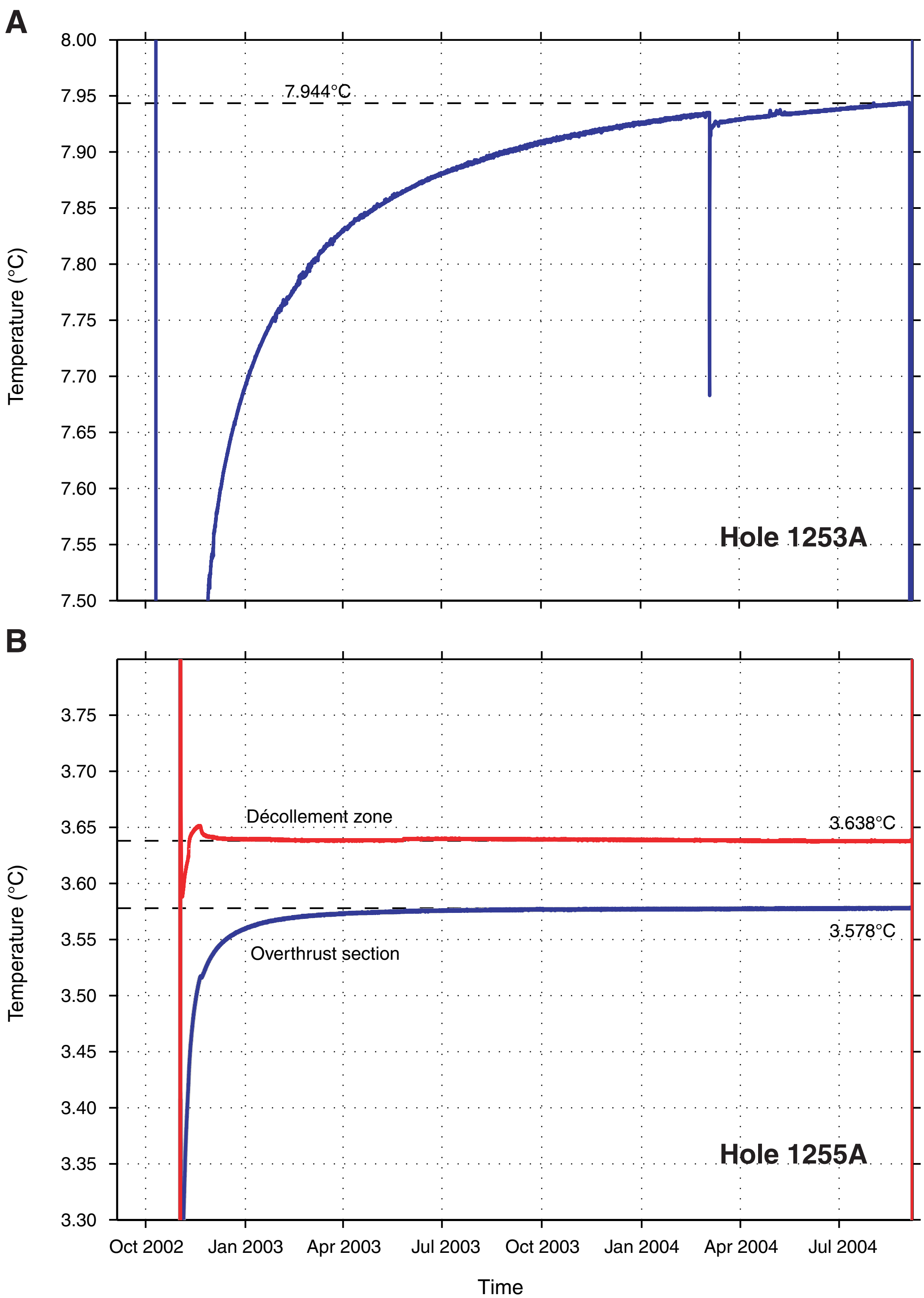

Figure F8. Small-scale temperature variations and pressure events in Hole 1255A. **A.** Overthrust section. **B.** Décollement zone. **C.** CORK-II pressure data at Site 1255.

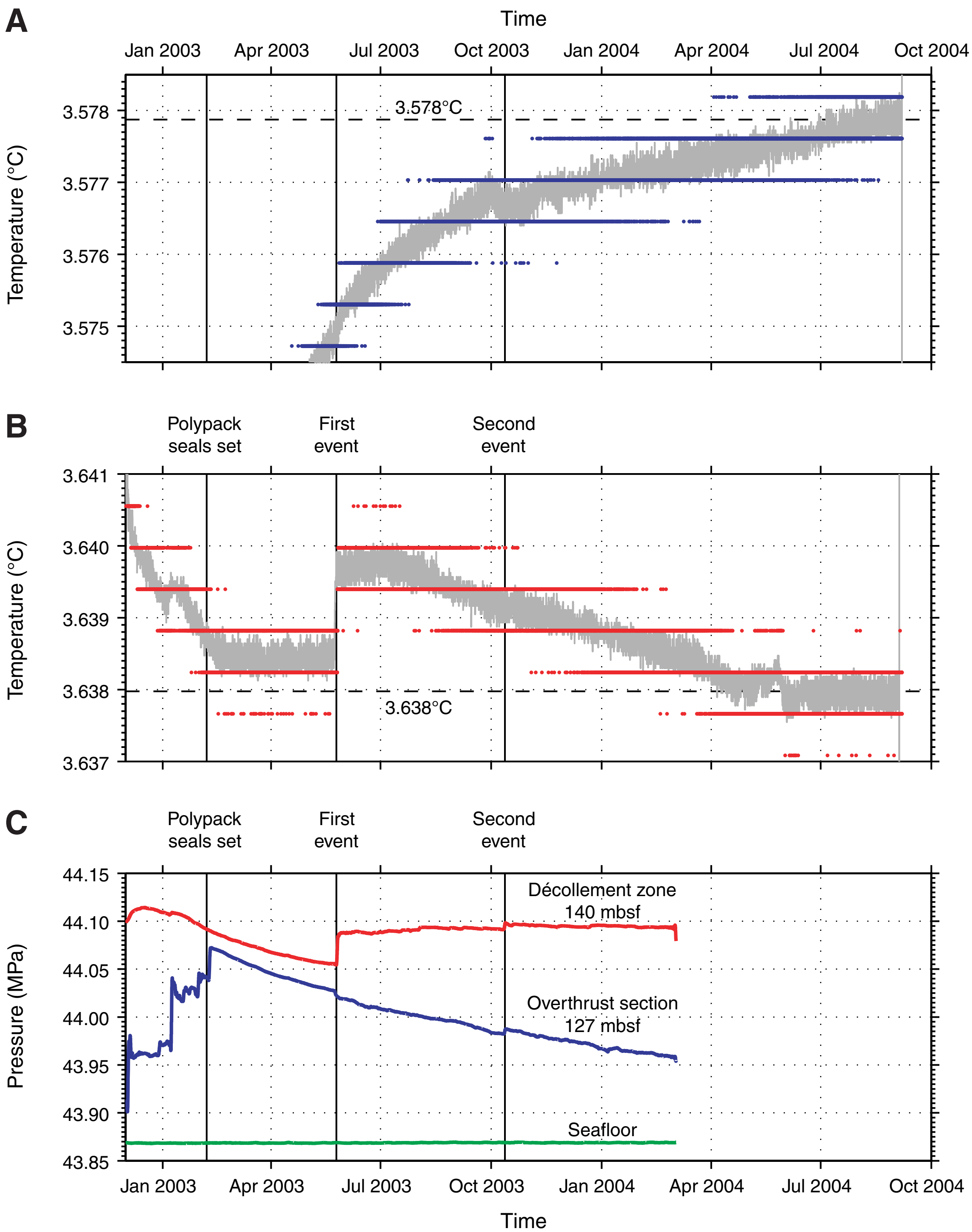

Figure F9. **A.** Temperature signal created by OsmoSampler recovery attempt during *Alvin* dive 3982 on 4 March 2004. **B.** Small-scale temperature variations in Hole 1253A. UTC = Universal Time Coordinated, MTL = miniaturized temperature logger.

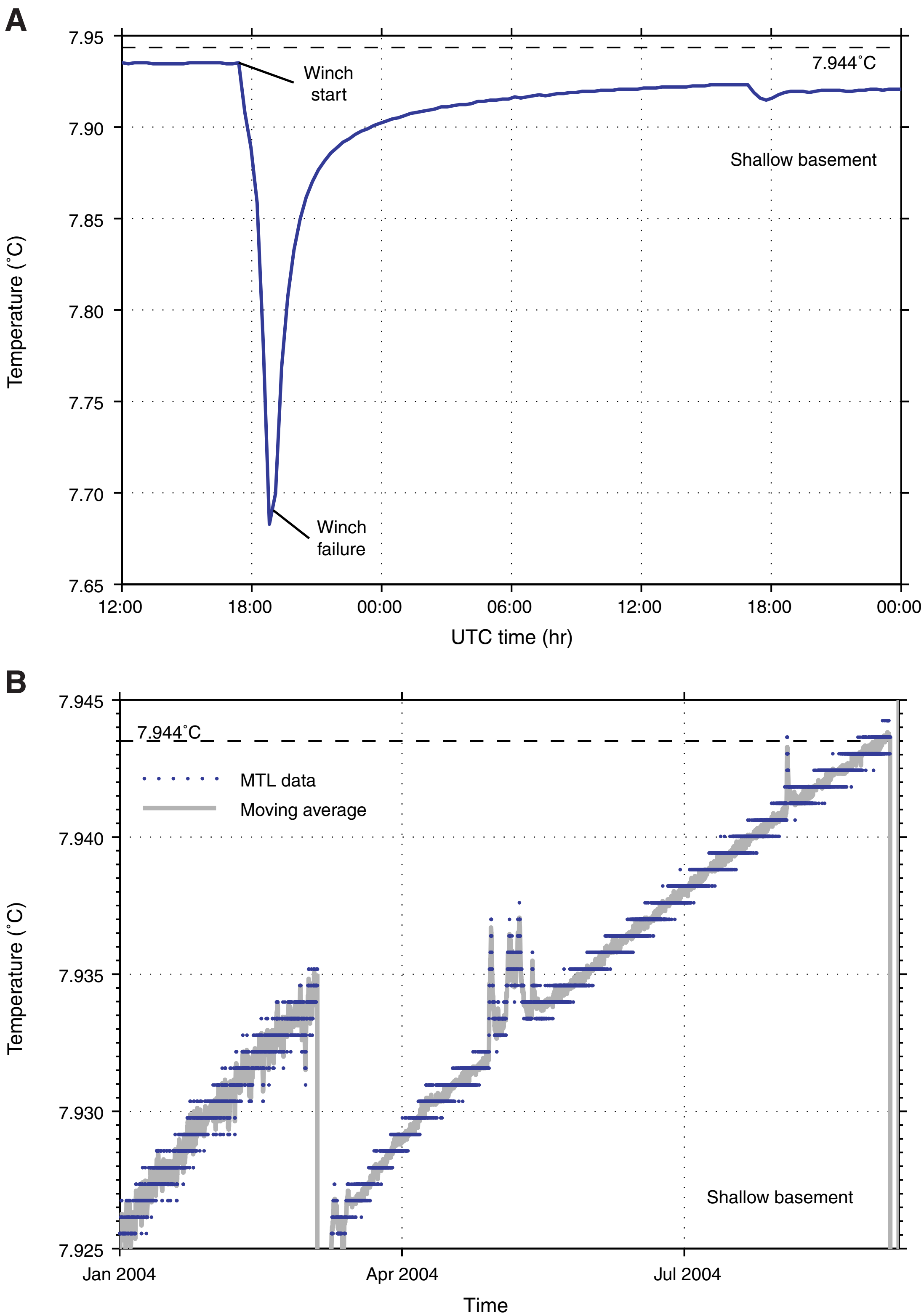

Figure F10. Temperatures measured during first unsuccessful recovery attempt during Expedition 301T when the OsmoSampler in Hole 1253A was dropped to the seafloor for ~2 days. The upper OsmoSampler with an MTL was subsequently recovered, whereas the lower OsmoSampler with an MTL could not be recovered and remains on the seafloor.

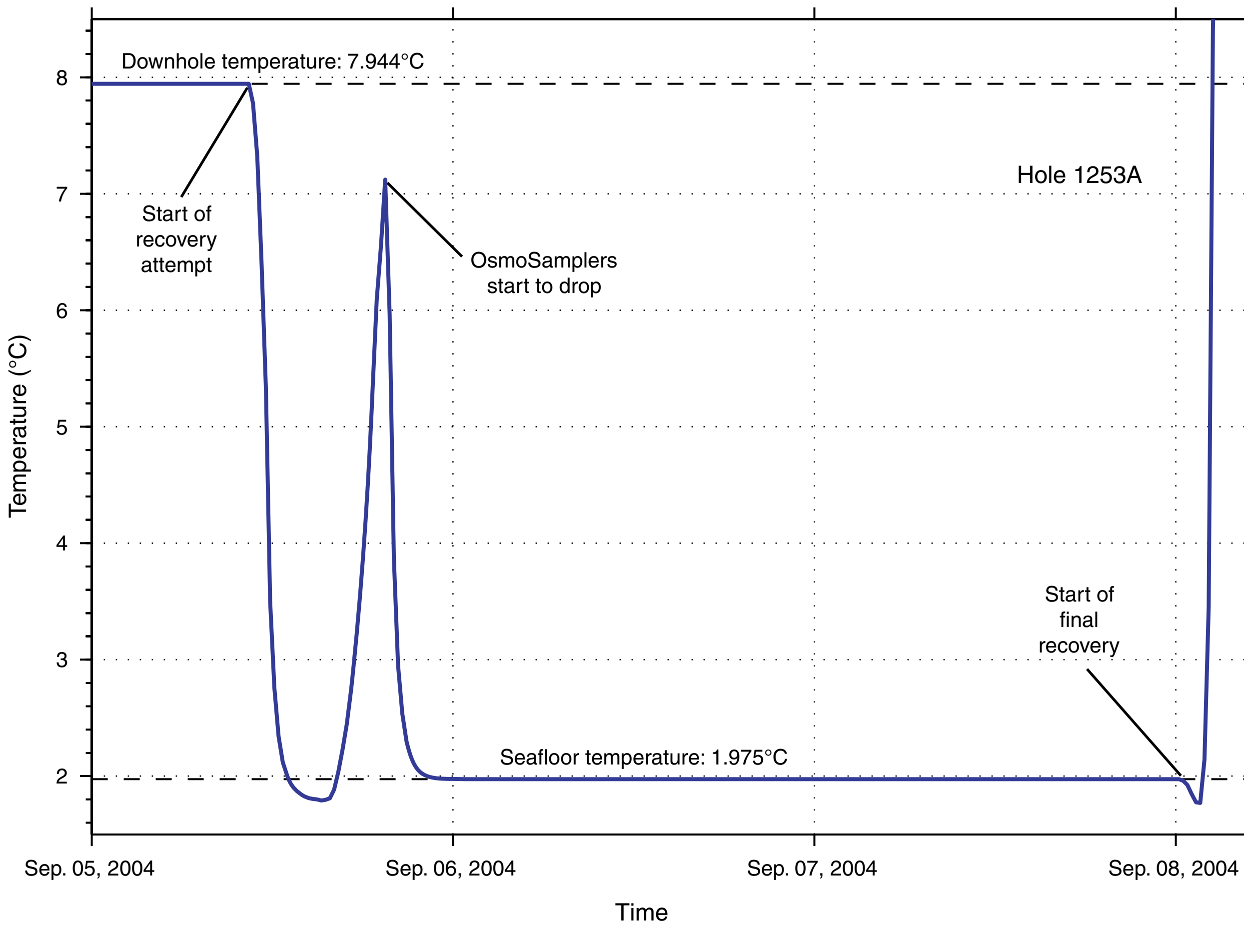

Figure F11. Fast Fourier Transform (FFT) amplitude spectra of (**A**) temperatures in the overthrust section, (**B**) temperatures in the décollement zone, and (**C**) CORK-II seafloor pressures measured during November 2003–March 2004 at Site 1255.

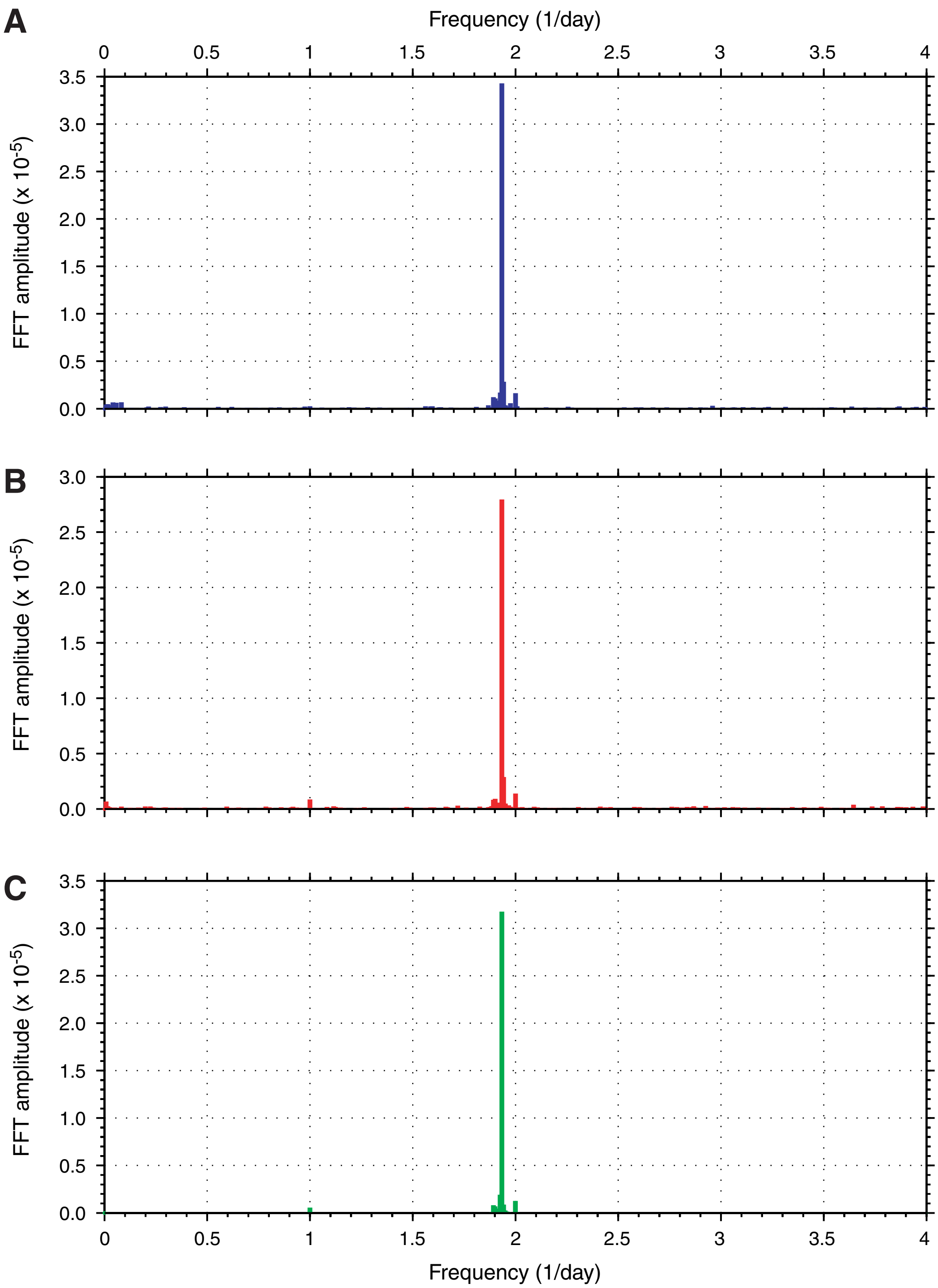

Table T1. Overview of MTL positions, logging times, and instrument drift.

MTL number	Hole	Position	Depth (mbsf)	Logging time (UTC)		Time offset (hr)
				Start	Stop	
1854115B	1255A	Overthrust section	135.1	4 Sept 2002, 1800 hr	6 Sept 2004, 1827 hr	–00:07:25
1854120B	1255A	Décollement zone	140.4	7 Sept 2002, 0000 hr	7 Sept 2004, 2132 hr	–00:06:40
1854121B	1253A	Shallow basement	501.4	4 Sept 2002, 1800 hr	8 Sept 2004, 0535 hr	00:01:52
1854131B*	1253A	Deeper basement	514.8	4 Sept 2002, 1800 hr	3 Oct 2004, 2154 hr	NA

Notes: MTL = miniaturized temperature logger, UTC = Universal Time Coordinated. * = lost on seafloor and hopefully recovered at next visit, NA = not available.