"In-Situ Sampling and Characterization of Naturally Occurring Marine Methane Hydrate Using the D/V JOIDES Resolution."

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ABSTRACT

The primary accomplishments of the JOI Cooperative Agreement with DOE/NETL in this quarter were (1) the preliminary postcruise evaluation of the tools and measurement systems that were used during ODP Leg 204 to study hydrate deposits on Hydrate Ridge, offshore Oregon from July through September 2002; and (2) the preliminary study of the hydrate-bearing core samples preserved in pressure vessels and in liquid nitrogen cryofreezers, which are now stored at the ODP Gulf Coast Repository in College Station, TX.

During ODP Leg 204, several newly modified downhole tools were deployed to better characterize the subsurface lithologies and environments hosting microbial populations and gas hydrates. A preliminary review of the use of these tools is provided herein.

The DVTP, DVTP-P, APC-methane, and APC-Temperature tools (ODP memory tools) were used extensively and successfully during ODP Leg 204 aboard the D/V JOIDES *Resolution*. These systems provided a strong operational capability for characterizing the in situ properties of methane hydrates in subsurface environments on Hydrate Ridge during ODP Leg 204. Pressure was also measured during a trial run of the Fugro piezoprobe, which operates on similar principles as the DVTP-P. The final report describing the deployments of the Fugro Piezoprobe is provided in Appendix A of this report. A preliminary analysis and comparison between the piezoprobe and DVTP-P tools is provided in Appendix B of this report.

Finally, a series of additional holes were cored at the crest of Hydrate Ridge (Site 1249) specifically geared toward the rapid recovery and preservation of hydrate samples as part of a hydrate geriatric study partially funded by the Department of Energy (DOE). In addition, the preliminary results from gamma density non-invasive imaging of the cores preserved in pressure vessels are provided in Appendix C of this report. An initial visual inspection of the samples stored in liquid nitrogen is provided in Appendix D of this report.

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INTRODUCTION

DOE/NETL funding was used by JOI/ODP to upgrade or modify many of the existing downhole tools onboard the D/V JOIDES *Resolution* so that they could be used to better characterize methane hydrates on ODP Leg 204, on Hydrate Ridge.

During ODP Leg 204, several newly modified downhole tools were deployed to better characterize the subsurface lithologies and environments hosting microbial populations and gas hydrates. Methane hydrates were sampled in cores recovered from several sites drilled during the cruise and routine use of an infrared thermal imaging system confirmed the validity of this method for locating hydrate recovered in cores from the identification of their thermal anomaly.

The ODP Pressure Core System (PCS) was deployed 39 times during ODP Leg 204 and successfully retrieved cores from a broad range of sediment depths along Hydrate Ridge. The PCS gas manifold was used in conjunction with the PCS throughout ODP Leg 204 to measure the total volume and composition of gases recovered in sediment cores, many of which contained methane hydrate. Solid pieces of gas hydrate were recovered from many discrete intervals during the leg. Infrared camera core temperature measurements as well as chemical and physical property data suggest the occurrence of gas hydrate above the GHSZ.

The HYACE/HYACINTH Fugro Pressure Corer (FPC) and HYACE Rotary Corer (HRC) were deployed 8 times and 10 times respectively on ODP Leg 204 with demonstrated success in recovering pressurized cores and logging them under pressure using a GEOTEK vertical multi-sensor core logger. Much was learned about the operation of these tools with shipboard systems on the D/V JOIDES *Resolution*.

The DVTP, DVTP-P, APC-methane, and APC-Temperature tools (ODP memory tools) were used extensively and successfully during ODP Leg 204 aboard the D/V JOIDES *Resolution*. These systems provided a strong operational capability for characterizing the in situ properties of methane hydrates in subsurface environments on Hydrate Ridge during ODP Leg 204. Pressure was also measured during a trial run of the Fugro piezoprobe, which operates on similar principles as the DVTP-P. The final report describing the deployments of the Fugro Piezoprobe is provided in Appendix A of this report. A preliminary analysis and comparison between the piezoprobe and DVTP-P tools is provided in Appendix B of this report.

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EXECUTIVE SUMMARY

The primary accomplishments of the JOI Cooperative Agreement with DOE/NETL in this quarter were (1) the preliminary postcruise evaluation of the tools and measurement systems that were used during ODP Leg 204 to study hydrate deposits on Hydrate Ridge, offshore Oregon from July through September 2002; and (2) the preliminary study of the hydrate-bearing core samples preserved in pressure vessels and in liquid nitrogen cryofreezers, which are now stored at the ODP Gulf Coast Repository in College Station, TX.

During Leg 204, a suite of downhole tools was employed to measure in situ temperature and pore pressure, to retrieve cores under pressure, and to estimate the in situ concentration of methane and other natural gases. Temperature, pressure, and gas composition and concentration are the critical factors for determining the extent of the gas hydrate stability zone (GHSZ) and whether gas hydrate can form in that zone. In addition, temperature affects rates of sediment diagenesis and microbial activity. Pore pressure is important because fluid flow occurs if the pressure gradient differs from hydrostatic, thus transporting natural gas into the hydrate stability zone, providing nutrients for microbes and modifying the temperature and pressure field.

In situ sediment thermal measurements were made during Leg 204 using the APC temperature tool (APCT) and the Davis-Villinger temperature probe (DVTP) (Davis et al., 1997). Temperatures and pressures were measured using a DVTP modified to include a pressure port and sensor (DVTP-P) that was previously used on Legs 190 and 201. Pressure was also measured during a trial run of the Fugro piezoprobe, which operates on similar principles as the DVTP-P.

ODP and FUGRO engineers deployed the modified FUGRO Piezoprobe tool for use with the ODP APC/XCB bottom hole assembly (BHA) on ODP Leg 204. This required changes to the lay out, space out, and completion of crossover subs for the piezoprobe deployment and the establishment of operational protocols for the deployment and use of this tool on Leg 204. An operations report from the shipboard FUGRO Engineer and an independent evaluation of the piezoprobe tests by researchers from the University of Pennsylvania are provided in Appendices A and B of this report.

Retrieval of cores at *in situ* pressure was a high priority during Leg 204. Natural gas in deep sediment may occur in three phases. If the concentration (molality) of gas in pore water is less than the solubility, the gas is dissolved. If the concentration of gas is greater than its solubility, gas occurs as a free phase (bubbles) below the GHSZ and is present as solid hydrate within the GHSZ. Knowledge of the gas concentration in deep sediment is critical for understanding the dynamics of hydrate formation and the effect hydrates have on the physical properties of the sediment. However, reliable data on gas concentration are difficult to obtain. Because gas solubility decreases as pressure decreases and temperature increases, cores recovered from great depth often release a large volume of gas during recovery (Wallace et al., 2000; Paull and Ussler, 2001). The only way to determine true in situ concentrations of natural gas in the subseafloor is to retrieve cores in an autoclave that maintains in situ conditions. The original ODP Pressure Corer Sampler (PCS) has proven to be an essential tool that is very effective for estimating in situ gas concentrations (Dickens et al., 1997, 2000) and was used extensively during Leg 204. However, it is less effective for studies of physical properties of hydrate-bearing sediments at in situ conditions.

The HYACINTH program, funded by the European Union, is developing the next generation of pressure corers. Two Hydrate Autoclave Coring Equipment (HYACE) coring systems were used during Leg 204. The Fugro Pressure Corer (FPC) is designed for sediments that are normally cored with the APC and XCB, and the Hyacinth Rotary Corer (HRC) is designed to drill more lithified sediments and rocks normally cored with the XCB and RCB. These pressure cores are contained in an inner plastic liner that can be transferred (under full pressure) into the GEOTEK V-MSCL (Vertical Multi Sensor Core Logger). This was used to make measurements on cores collected by the HYACE coring tools and on standard ODP cores re-pressurized to in situ pressures. By measuring P-wave velocity, attenuation and gamma density at in situ pressures and by pressure cycling we anticipated being able to distinguish between hydrate and free gas while also measuring some in situ properties that would help to constrain models of hydrate and free gas distribution.

During ODP Leg 204, a series of additional holes were cored at the crest of Hydrate Ridge (Site 1249) specifically geared toward the rapid recovery and preservation of hydrate samples as part of a hydrate geriatric study partially funded by the Department of Energy (DOE). The preliminary results from gamma density non-invasive imaging of the cores preserved in pressure vessels are provided in Appendix C of this report.

This report will present a status report of the preliminary results obtained from tool and instrument deployments on ODP Leg 204 as well as results from a preliminary examination of hydrate-bearing cores preserved as part of the hydrate geriatric study.

EXPERIMENTAL

Introduction

During Leg 204, a suite of downhole tools was employed to measure in situ temperature and pore pressure, to retrieve cores under pressure, and to estimate the in situ concentration of methane and other natural gases. Temperature, pressure, and gas composition and concentration are the critical factors for determining the extent of the gas hydrate stability zone (GHSZ) and whether gas hydrate can form in that zone. In addition, temperature affects rates of sediment diagenesis and microbial activity. Pore pressure is important because fluid flow occurs if the pressure gradient differs from hydrostatic, thus transporting natural gas into the hydrate stability zone, providing nutrients for microbes and modifying the temperature and pressure field.

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APC Temperature Tool

The APC temperature tool (APCT) fits directly into the cutting shoe on the APC and can therefore be used to measure sediment temperatures during regular piston coring. The tool consists of electronic components, including battery packs, a data logger, and a platinum resistance-temperature device calibrated over a temperature range of 0–30˚C. Descriptions of the tool and of the principles behind analysis of the data it acquires can be found in Pribnow et al. (2000) and Graber et al. (2002) and in references therein. The thermal time constant of the cutting shoe assembly into which the APC tool is inserted is ~2–3 min. The only modification to normal APC procedures required to obtain temperature measurements is to hold the corer in place for ~10 min after cutting the core. During this time, the APCT logs temperature data on a microprocessor contained within the instrument as it approaches equilibrium with the in situ temperature of the sediments. Following deployment, the data are downloaded for processing. The tool can be preprogrammed to record temperatures at a range of sampling rates. Sampling rates of 10 s were used during Leg 204. A typical APC measurement consists of a mudline temperature record lasting 10 min for the first deployment at each borehole and 2 min on subsequent runs. This is followed by a pulse of frictional heating when the piston is fired, a period of thermal decay that is monitored for 10 min, and a frictional pulse upon removal of the corer.

Davis-Villinger Temperature Probe

The temperature measurement aspects of the DVTP are described in detail by Davis et al. (1997) and summarized by Pribnow et al. (2000) and Graber et al. (2002). The probe is conical and has two thermistors; the first is located 1 cm from the tip of the probe and the other 12 cm above the tip. A third thermistor, referred to as the internal thermistor, is in the electronics package. Thermistor sensitivity is 1 mK in an operating range of –5˚ to 20˚C, and the total operating range is –5˚ to 100˚C. The thermistors were calibrated at the factory and on the laboratory bench before installation in the probe. In addition to the thermistors, the probe contains an accelerometer sensitive to 0.98 m/s^2. Both peak and mean accelerations are recorded by the data logger. The accelerometer data are used to track disturbances to the instrument package during the equilibration interval. In a DVTP deployment, mudline temperatures (within the drill pipe) are measured for 10 min during the first run within each hole and for 2 min during subsequent runs, before descent into the hole for a 10-min equilibration time series at the measurement depth in the subseafloor. The time constants for the sensors are ~1 min for the probe tip thermistor and ~2 min for the thermistor at 12 cm from the tip. Only data from the probe tip thermistor were used for estimation of in situ temperatures.

Thermal Data Reduction

Similar data reduction procedures were used for all the temperature tools. The transient thermal decay curves for sediment thermal probes are a function of the geometry of the probes and the thermal properties of the probe and sediments (Bullard, 1954; Horai and Von Herzen, 1985). Data analysis requires fitting the measurements to predicted temperature decay curves calculated based on tool geometry and the thermal properties of the sediment. Pribnow et al. (2000) discuss data analysis procedures and uncertainties. For the APCT, the software program TFIT, developed by Keir Becker and James Craig, was used. For the DVTP and DVTP-P, data were analysed using CONEFIT, developed by Davis et al. (1997). Several factors contribute to uncertainties in the *in situ* temperature estimates: (1) Because the probe does not reach thermal equilibrium during the penetration period, derived temperatures are extrapolated; (2) contrary to ideal theory, the frictional pulse upon insertion is not instantaneous; (3) temperature data are sampled at discrete intervals, so that the exact time of penetration is uncertain; and (4) the *in situ* thermal conductivity of the sediments is imperfectly known.

Mudline temperature is determined from the time the tool is held near the seafloor prior to penetration of the APC. Initial APC penetration is marked by a temperature pulse due to friction. A second pulse is observed when the tool is extracted from the sediment. The best fitting time of penetration and *in situ* temperature are calculated from data delimited by three points that are picked by the shipboard analyst. The thermal conductivity of the sediment must also be specified. Thermal conductivities measured from the core interval closest to the ACPT measurement were used. The estimated uncertainty of the derived in situ temperature for good quality measurements is 0.1 ºC (Pribnow et al., 2000), although the uncertainty may be considerably larger for poor quality measurements. Temperature gradients may be better resolved than absolute values of temperature provided the same tool is used to make all measurements at a given Site.

Davis-Villinger Temperature/Pressure Probe

Simultaneous measurement of formation temperature and pressure was achieved using a modified DVTP. The probe has a tip that incorporates both a single thermistor in an oil-filled needle and ports to allow hydraulic transmission of formation fluid pressures to a precision Paroscientific pressure gauge inside. A standard data logger was modified to accept the pressure signal instead of the second thermistor signal in the normal DVTP described above. Thermistor sensitivity of the modified tool is reduced to 0.02 K in an operating range of –5˚ to 20˚C. A typical deployment of the tool consists of lowering it by wireline to the mudline where there is a 10 minute pause to collect data. Subsequently the tool is lowered to the base of the hole and latched in at the bottom of the drill string with the end of the tool extending 1.1 m below the drill bit. The extended probe is pushed into the sediment below the bottom of the hole and pressure is recorded for ~40 minutes. If smooth pressure decay curves are recorded after penetration, then extrapolations to in situ pore pressures are possible.

Fugro-McClelland Piezoprobe

In April of 2001, a proposal was submitted to the U.S. Department of Energy to modify and implement the use of the Fugro-McClelland piezoprobe tool on the D/V JOIDES Resolution during ODP Leg 204. The piezoprobe has been tested and proven (e.g. Pelletier et al., 1999; Ostermeier et al., 2000; Ostermeier et al., 2001, Whittle et al., 2001) on numerous geotechnical cruises that measured pressure and temperature, but it had not been adapted for the ODP until now. To adapt it to the D/V *JOIDES Resolution* for testing and use with the APC/XCB bottom hole assembly required modifications prior to the Leg. The modifications were made by Fugro-McClelland and ODP and were designed to: (1) adapt the piezoprobe for a Schlumberger wireline; (2) increase landing ring size; (3) implement a stabilizer sleeve to prevent bending; (4) shorten bit to minimize risk of bending; and (5) extend pawls for the 4-cone APC bit used on the *JOIDES Resolution*.

The piezoprobe works within the borehole and measures pressure through a transducer at its tip (similar to the PUPPI; Schultheiss and McPhail, 1986). The probe is lowered through the drill pipe, measures hydrostatic pressure, and is pushed into the sediment about ~1 m beyond the base of the borehole where pressure is again measured. The resultant pressure versus time curves for multiple experiments provide in situ pressure as a function of depth. The pressure decay can be used to evaluate the permeability and coefficient of consolidation (e.g. Elsworth et al., 1997; Schnaid et al.,1998), two parameters that are necessary to describe fluid flow and deformation within the shallow subsurface. The narrow taper of the piezoprobe allows a pressure decay to be measured in low permeability sediments within hours, a time frame that is reasonable for use on the *JOIDES Resolution*. The piezoprobe also records temperature data during each measurement. Similar to the Advanced Piston Core Temperature tool (APCT) and the Davis-Villinger Temperature Probe (DVTP), the temperature decay can be used to estimate in situ temperature.

Comparison Between the Piezoprobe and the DVTP-P

The DVTP-P and the piezoprobe both provide the ability to make estimates of in situ temperature and pressure in low permeability strata at a relatively quick rate (i.e. multiple measurements per hole; dozens of measurement per cruise). The basic operational procedure for each is similar to that for the temperature tools: (1) insert probe at the base of the borehole; (2) monitor pressure disturbance from probe insertion; (3) record pressure decay and extrapolate out to infinite time for estimate of in situ pressure. The decay time is a function of the sediment permeability and the size of the initial pulse. The magnitude of the pressure pulse is a function of the taper angle and diameter of the tool (Whittle et al., 2001). The piezoprobe has a narrower diameter (6.4 mm) and smaller taper angle (<2 degrees) than the DVTP-P (a diameter of 8 mm and a taper of 2.5 degrees) and therefore produces a smaller pressure disturbance. Whittle et al. (2001) have demonstrated that it is beneficial to monitor the pressure decay long enough so that a significant proportion of the pulse has dissipated before recovery of the tool; with the piezoprobe, this takes approximately 2 hours in low permeability strata (Whittle et al., 2001), longer than is generally allowed for the DVTP-P during ODP Legs.

On Leg 204, the piezoprobe was deployed twice at Site 1244, with the second run being completely successful. For both the DVTP-P and the piezoprobe the pressure response is qualitatively similar to but slower than the thermal response. The decay time is a function of the sediment permeability and the magnitude of the initial pulse, which is a function of the taper angle and diameter of the tool (Whittle et al., 2001; Heeseman, 2002). The final report describing the deployments of the Fugro Piezoprobe is provided in Appendix A of this report. A preliminary postcruise analysis and discussion of the results obtained from the deployments of the DVTP-P and Fugro piezoprobe tools during Leg 204 is provided in Appendix B of this report.

Pressure Core Sampler

The Pressure Core Sampler (PCS) is a downhole tool designed to recover a1 m-long sediment core with a diameter of 4.32 cm at in situ pressure up to a maximum of 10,000 psi (Pettigrew, 1992; Graber et al., 2002). It consists of the inner core barrel and a detachable sample chamber. When its valves seal properly, controlled release of pressure from the PCS through a manifold permits collection of gases that would otherwise escape on the wireline trip. The PCS currently provides the only proven means to determine in situ gas abundance in deep-sea sediments where gas concentrations at depth exceed saturation at atmospheric pressure and room temperature (Dickens et al., 1997). The analysis of recorded data (e.g., time-series of pressure and the volume of released gas) may also help to determine if gas hydrate is present in the cored interval (Dickens et al., 2000a).

After retrieval, the PCS is placed into an ice bath to keep the inside temperature at ~0 ºC. A manifold is connected to the PCS to decrease pressure by releasing gas under manual control. Only a small volume of gas (~100-150 ml) should be collected during the first gas release. This is because it has been empirically determined that the first gas sample thus obtained is contaminated by air. Additional gas releases should lead to immediate pressure drops. Ideally, the pressure in the PCS should then increase with time as gas exsolves from pore water or from decomposing gas hydrate. Gas should be released when pressure does not increase significantly over a 10-15 min time interval, and the process should be repeated. Sometimes gas may be released before the pressure has built up because of operational logistics. At the end of the experiment, ice should be removed from around the PCS, and the PCS should be warmed up to release all gas remaining in the core. Splits of gases are collected into a 1 L bubbling chamber that consists of an inverted graduated cylinder placed in a plexiglass tube filled with a saturated NaCl solution. After measuring the volume of collected gas, gas aliquots are sampled from a valve at the top of the cylinder using a syringe.

Prior to Leg 204, the PCS was successfully used to study in situ gases during ODP Leg 164 on the hydrate-bearing Blake Ridge (Paull et al., 1996; Dickens et al., 1997) and during Leg 201 at sites along the gas-rich Peru margin (Dickens et al., 2002a, In: Leg 201 IR volume). One of the objectives of PCS use during Leg 201 was to test the coring capabilities in a variety of lithological conditions. Several modifications to the PCS were made prior to Leg 201 (Dickens et al., 2000b), including the addition of an optional cutting shoe for rotary coring, and the construction of a new gas manifold. The PCS was deployed 17 times on Leg 201. Dickens et al. (Leg 201 IR) concluded that: (1) the tool performed better on Leg 201 than on Leg 164; (2) the PCS can operate successfully in a variety of submarine environments; (3) cores collected at shallow sediment depth can be degassed to generate gas concentration profiles.

Two significant modifications were made between Legs 201 and 204 to better address the scientific objectives of Leg 204. First, a Methane Tool was installed inside the PCS to measure temperature, pressure, and conductivity during the PCS recovery (see next section). Second, pressure transducers that permit continuous monitoring of pressure both on the manifold and inside the PCS were installed. Pressure is recorded on a personal computer every 5 seconds, and is presented as a graph during the experiment. An ASCII file of the data is preserved at the end of the experiment. These modifications should permit better monitoring of pressure and temperature inside the PCS after the core is retrieved from the subsurface.

Methane Tools (APC-M and PCS-M)

The Methane tools, APC-M and PCS-M, continuously record the temperature, pressure and conductivity changes in the core headspace from the time the core is cut through its ascent to the rig floor. The APC-M sensors are mounted in a special piston head on the standard ODP APC piston and the data acquisition electronics are embedded within the piston. The PCS-M is a slimmed down version of the APC-M, which is mounted on the top of the PCS manifold mandrel. Both tools operate passively and require little shipboard attention. Variations in the relative amounts of gas stored in different types of sediment can be determined by establishing a family of ascent curves comprising data from successive cores. Models indicate that these data also will provide information on whether gas hydrate was present in the sediment before core retrieval. The methane tools (APC-M, PCS-M) are being developed jointly by ODP and the Monterey Bay Aquarium Research Institute (MBARI). These tools are derivatives of MBARI's Temperature-Pressure-Conductivity (TPC) tool.

Both tools are very similar in construction, the only difference being that the APC-M replaces the piston rod snubber in the APC coring system and therefore has a seal package on its exterior. The tools consist of an instrumented sensor head with the electronics and battery pack housed in a sealed case. The three sensors (temperature, pressure and conductivity) and a data port are packaged in the face of the 2-3/8" diameter sensor head. The APC-M is installed on the APC piston after removing the APC piston rod snubber and piston head body from the lower piston rod. The connection at the lower piston rod consists of a threaded connection with a transverse spring pin running through the thread relief. The spring pin prevents the connection from unscrewing due to vibration. After the spring pin is punched out, the piston rod snubber is removed and replaced with the APC-M. This swap-out operation takes less than 3-minutes. The PCS-M replaces the accumulator on the PCS and threads onto the top of the PCS manifold mandrel.

Hydrate Autoclave Coring Equipment (HYACE)

Although the PCS was successful and demonstrated the application of pressure coring on Leg 164 there were a number of aspects worthy of improvement as described by Dickens et al (2000). A proposal submitted to the European Union (EU) resulted in HYACE (Hydrate Autoclave Coring Equipment) which was a 3-year project aimed at developing new wireline pressure coring tools that would address a wide range of scientific problems. The HYACE project resulted in the development of 2 new pressure coring tools. These tools underwent only limited testing on land and at sea on ODP Legs 194 and 201 (Leg 201 was after the end of the HYACE project and at the beginning of the HYACINTH project). The current HYACINTH (deployment of HYACE tools in New Tests on Hydrates) project is a continuation of the HYACE project and is also funded by the EU. It is designed to bring these new coring tools into operational use and to develop new techniques of subsampling and analyzing cores under pressure. Leg 204 provided the opportunity for further testing and use of these new coring tools. Another important objective of Leg 204 was to test and use the core transfer mechanisms and measure physical properties of cores at in situ pressures.

The design and operation of the HYACE tools differs in two significant respects from that of the existing PCS. First, the HYACE tools penetrate the seabed using downhole driving mechanisms powered by fluid circulation rather than by top-driven rotation with the drill string. This allows the drill string to hang stationary in the hole while core is being cut, which should improve core quality and recovery. Second, the HYACE tools recover lined cores which enable them to be transferred under pressure into a family of chambers, allowing cores to be preserved and studied under pressure.

Two different tools have been developed in order to accommodate a wide range of lithologies; (1) a 'percussion' corer and (2) a 'rotary' corer. Both tools have been designed for use with the same ODP Bottom Hole Assembly (BHA) as the PCS (i.e. the APC/XCB BHA). The Fugro Pressure Corer (FPC) is designed for recovering unlithified sediment ranging from clay to sand and gravel. When used in a hydrate-bearing environment, it is considered to be most applicable where any hydrate present has not significantly cemented the sedimentary particles. The core barrel is driven into the sediment by a hammer mechanism that is driven by fluid circulation. In soft sediments the core barrel strokes out quickly, so that in these lithologies the FPC essentially behaves like a push core.

The HYACE Rotary Corer (HRC) is designed to cut a rotary core in lithified sediment and incorporates a downhole mud motor. A dry auger type of bit extending beyond the reach of the circulating seawater is used to cut the core, providing as contamination-free a core as is possible with rotary coring. It is designed primarily to recover cores in well lithified sediments and rocks that can be obtained with the XCB and RCB. The phase II PCS development proposed by Pettigrew (1992) is similar to the approach used in the HYACE Rotary Corer. However this was not pursued by ODP because of insufficient funds.

Both the FPC and the HRC use specially designed flapper valves to seal the tool's pressure chamber (autoclave), where the core is contained on recovery. This enables larger cores to be cut than with the PCS, which uses a ball valve as the sealing mechanism. The FPC cuts a 58 mm-diameter core and the HRC cuts a 50 mm-diameter core. Like the PCS, both cores are approximately one meter in length. Pressures up to 250 bar (3,625 psi) can be maintained in the present design.

After initial testing on land, the FPC and HRC underwent their first sea trials on the *JOIDES Resolution* at the start of ODP Leg 194. The FPC had limited success in recovering a core under pressure whereas the HRC encountered significant problems due to its failure to latch properly in the BHA (Rack, 2001). A core was finally cut but was not retrieved under pressure. The FPC had further trials on Leg 201 but hole conditions are thought to have been unfavorable, which prevented the recovery of a pressure core. Valuable lessons were learned during both of these engineering trials of the FPC and the HRC (Rack, 2001), and a number of significant modifications were made to the tools and to the handling procedures prior to the start of Leg 204.

Logging Cores at In Situ Pressure

The other components that make up the HYACINTH system used during Leg 204 are the transfer system, the shear mechanism, and the pressure chambers that are used to store and log the cores under pressure. The HYACE transfer mechanism is used to extract the core under pressure from either the HRC or FPC autoclave and then transfer it into a storage chamber or logging chamber. The shear mechanism (an integral part of the transfer mechanism) removes the ''technical part" of the core (piston assembly, etc.) from the core liner containing the sample prior to inserting it into the other chambers.

A specially adapted GEOTEK V-MSCL (Vertical - Multi Sensor Core Logger) was used to measure gamma density and P-wave parameters while the cores were under pressure in the HYACINTH logging chambers. It was also used to log regular APC cores that had been re-pressurized in specially designed ODP Logging Chambers (ODP-LCs). The cores were logged vertically in order to help control the process of degassing during pressure cycling and final pressure release.

As with the PCS, gases exsolved from solution or released by dissociation of gas hydrate were collected into a 1 L bubbling chamber to determine the in situ abundance of gas in the cores. An analysis of the data recorded during the degassing process should help to determine the relative amounts of free gas and gas hydrate present in the cored interval.

Pressurized core logging is unlike normal core logging with the ODP MST (Multi Sensor Track) or a standard GEOTEK MSCL in that there are two core liners to consider: a) the thin plastic core liner (the inner liner) and b) the thicker GRP (glass-reinforced plastic) pressure tube (the outer liner). To calibrate for measurements of P wave velocity (PWV) and Gamma Density (GD) similar techniques are used to those developed for the MST and MSCL, which use distilled water and aluminum as standards. In this mode of operation, the inner liner is assumed to have a constant diameter because it cannot be directly measured under pressure. The outer GRP liner was accurately calibrated to account for small variations in diameter and wall thickness along its length. The manufacturing technique necessitates that a change in the internal diameter of about 1 mm occurs along the 1.5 m length. To ensure consistency, the outer liner was always oriented to ensure that the small circumferential variations were effectively negated.

To calibrate the P wave velocity, the variations in the total P-wave travel-time along the length of the GRP tube were measured when both the inner liner and the GRP were filled with water of known velocity. All data are subsequently corrected as a function of position in the GRP tube. Changes in travel time as a function of pressure were also measured (up to 200 bar). The measured variation in P-wave velocity with pressure is close to the theoretical variation for water. We therefore conclude that the travel times in the liner material are essentially constant with changing pressure. In practice, however, P wave data for sediment cores may be harder to interpret than we thought it would be because of seismic signals that propagate around the cylindrical GRP liner.

To calibrate the Gamma Density (GD) system we used the same type of ‘standard section” as is used with the MST. During this step, graduated aluminum and water standards are placed in the GRP tube and logged at 2 mm intervals along the core. Consideration is given to the variation in GRP tube diameter by logging the complete tube filled with water and filled with air. We confirmed that are no pressure effects on the measurements by repeating the experiment at pressures up to 200 bar.

RESULTS AND DISCUSSION

Piezoprobe and DVTP-P Comparison

Fugro-McClelland Marine Geosciences Inc.'s piezoprobe, a penetration-based tool used to determine pore pressure and hydrologic properties within a borehole, was deployed for the first time in the Ocean Drilling Program (ODP) on ODP Leg 204 in July 2002. Analysis of the piezoprobe data suggests that *in situ* pore pressure is 9.5 MPa, which is approximately the hydrostatic pressure (9.53 MPa). The piezoprobe deployment and modeling of the results provides one of the first measurements of *in situ* permeability made within the borehole. From the piezoprobe dissipation data, we estimate of *in situ* permeability of approximately 1.5 $x10^{-17}$ m^2 for the hemipelagic clay. This is consistent with laboratory-measured permeability (~$1x10^{-17}$ m^2) on hemipelagic clay samples from nearby ODP Site 892. The piezoprobe results were compared to a Davis-Villinger Temperature/Pressure Probe (DVTP-P) measurement made at the same depth, and in the same lithology, but in an adjacent borehole. The DVTP- P is also a penetration-based tool, however it has a much wider probe diameter. The DVTP-P generated a higher peak pressure that did not dissipate as much as the piezoprobe pressure, which resulted in a DVTP-P estimate of *in situ* pressure that nearly equals the overburden stress.

The results, which are provided in Appendices A and B of this report, suggest that a narrow diameter probe like the piezoprobe can be used to rapidly determine *in situ* pressure and hydrologic properties in sites investigated by the Ocean Drilling Program. The results also show that the DVTP-P, which can be deployed on a wireline rather than on the (Schlumberger) conductor cable, allows for greatly reduced operations time with similar results. These tools will continue to be developed and tested.

Postcruise Gamma Density Logging of Pressurized Hydrate Cores

Cores recovered at the end of ODP Leg 204 from the summit of Hydrate ridge (Site 1249) were rapidly stored to preserve the methane hydrate for further analysis. It is inevitable that some dissociation of hydrate will have occurred during the coring process as a result of a decrease in pressure and the increase in temperature during the core retrieval process. However, we knew from previous coring during the Leg that massive hydrate still existed in cores from Site 1249 when examined on the catwalk. For the cores that were preserved under pressure, significant efforts were made to ensure that the time between coring at the seabed and cutting the core into sections was minimized. In this way the minimum amount of dissociation will have occurred and the maximum amount of hydrate will be preserved. Some of the core sections were then rapidly frozen and stored in liquid nitrogen while others were rapidly repressurized in steel storage chambers (to about 500-600 psi) under methane gas and stored at around 4-5 ^{o} C. At these pressures and temperatures methane hydrates are stable and hence can be stored without any further dissociation occurring. All the samples were stored carefully under these conditions and shipped to ODP at College Station, Texas.

As a ‘quick look’ to determine the nature of the samples stored under pressure in the steel pressure vessels, the pressure vessels were subjected to gamma logging to determine the density structure. Logging took place at ODP using the GEOTEK vertical logging system during the period 7th to 14th October 2002. This was about 6 weeks after the samples had originally been recovered.

The cores were logged in the main core store at around 4-5 ^{o} C. A standard calibration section was run using aluminum and distilled water in a standard ODP liner placed inside one of the empty steel pressure vessels. This produced the calibration equation used to calculate density from the raw data:

$$D = -2.5066 * Ln(CPS) + 23.81$$

Where: D = density (g/cc) and CPS = gamma Counts Per Second

Each core section was logged from the top down at 0.5cm intervals. Count times were longer than normally used on ODP cores because of the steel pressure cylinder used (OD approx 90 mm, wall thickness approx. 7.5 mm) Typical count rates in sediments were 7000 cps; therefore, a minimum total count time of 25 s was used. These count times produced total counts in excess of 150,000 counts, resulting in gamma density values that will have a precision of about 1-2%.

The data are plotted as density profiles. The bottom of the pressure vessel was used as a section depth reference; the last data point before the steel end cap was assigned a depth of 150 cm. Short core sections will appear to start at 80-90 cm.

Three different gamma density zones are identified:

1) greater than 1.4 g/cc – mainly sediment

2) 0.95 g/cc to 1.4 g/cc – sediment plus gas, may include some hydrate

3) less than 0.95 g/cc – contains some gas

It should be remembered that the gamma density values represent the average density of a 5 mm diameter horizontal cylinder through the center of the core. Any values lower than 0.95 definitely contain some gas. Many (or possibly most) of the abundant low-density zones (0.95 to 1.4 g/cc) are sediment with sub-horizontal gas cracks. Densities above 1.4 g/cc are mainly sediment. There is no definitive method of ascertaining the existence of methane hydrate at any location in each core. However, the general nature of the density profiles in each core may act as a good guide to the occurrence of hydrates, especially as more information is gathered. For example, X-ray CT scanning may be able to determine more accurately the nature of the gas cracking, and hence allow an accurate assessment of the amounts of hydrate remaining in the core.

Additional data and visual plots of the logging results and initial interpretations are provided in Appendix C of this report.

Examination of Hydrate-Bearing Cores in Liquid Nitrogen

In addition to the hydrate-bearing cores that are preserved using methane gas in steel pressure vessels, there are approximately 35 meters of hydrate-bearing cores that are preserved in liquid nitrogen cryofreezers. Following their return to the ODP Gulf Coast Repository, these cores were examined to confirm the inventory of samples that was assembled during Leg 204 and to remove extraneous pieces of plastic core liner that were stored with the samples when they were originally inserted into the cryofreezers. This process took approximately 5 days to complete.

During the process of archiving the samples stored in liquid nitrogen an annotated table of samples was produced. This table, which is provided in Appendix D of this report, describes any prominent features of each sample, as well as identifies visible hydrate in each sample at breaks in the core, or at either end of each sample.

CONCLUSION

The primary accomplishments of the JOI Cooperative Agreement with DOE/NETL in this quarter were (1) the preliminary postcruise evaluation of the tools and measurement systems that were used during ODP Leg 204 to study hydrate deposits on Hydrate Ridge, offshore Oregon from July through September 2002; and (2) the preliminary study of the hydrate-bearing core samples preserved in pressure vessels and in liquid nitrogen cryofreezers, which are now stored at the ODP Gulf Coast Repository in College Station, TX.

Fugro-McClelland Marine Geosciences Inc.'s piezoprobe, a penetration-based tool used to determine pore pressure and hydrologic properties within a borehole, was deployed for the first time in the Ocean Drilling Program (ODP) on ODP Leg 204 in July 2002. Analysis of the piezoprobe data suggests that *in situ* pore pressure is 9.5 MPa, which is approximately the hydrostatic pressure (9.53 MPa). The piezoprobe deployment and modeling of the results provides one of the first measurements of *in situ* permeability made within the borehole.

The results, which are provided in Appendices A and B of this report, suggest that a narrow diameter probe like the piezoprobe can be used to rapidly determine *in situ* pressure and hydrologic properties in sites investigated by the Ocean Drilling Program. The results also show that the DVTP-P, which can be deployed on a wireline rather than on the (Schlumberger) conductor cable, allows for greatly reduced operations time with similar results. These tools will continue to be developed and tested.

Cores recovered at the end of ODP Leg 204 from the summit of Hydrate ridge (Site 1249) were rapidly stored to preserve the methane hydrate for further analysis. As a 'quick look' to determine the nature of the samples stored under pressure in the steel pressure vessels, the pressure vessels were subjected to gamma logging to determine the density structure.

Logging took place at ODP using the GEOTEK vertical logging system during the period 7th to 14th October 2002. This was about 6 weeks after the samples had originally been recovered. The data from these logs are plotted as gamma density profiles in Appendix C of this report together with an initial interpretation of the results.

In addition to the hydrate-bearing cores preserved in steel pressure vessels, there are approximately 35 meters of hydrate-bearing cores preserved in liquid nitrogen cryofreezers. These cores were examined and an annotated table was produced. This table is provided in Appendix D of this report.

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LIST OF ACRONYMS AND ABBREVIATIONS

APC	Advanced Piston Corer
APC-M	Advanced Piston Corer-methane tool
APC-T	Advanced Piston Corer-temperature tool
BHA	Bottom Hole Assembly
BSR	Bottom Simulating Reflector
DOE	Department of Energy
DVTP	Davis Villinger Temperature Probe
DVTP-P	Davis Villinger Temperature Probe with Pressure
FMMG	Fugro-McCleland Marine Geosciences
FPC	Fugro Pressure Corer
GHSZ	Gas Hydrate Stability Zone
HR	Hydrate Ridge
HRC	HYACE Rotary Corer
HYACE	Hydrate Autoclave Coring Equipment
HYACINTH	Deployment of HYACE tools In New Tests on Hydrates
IR-TIS	Infrared Thermal Imaging System
JOI	Joint Oceanographic Institutions
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
LDEO	Lamont Doherty Earth Observatory (Columbia University)
L/L	Liters per Liter
LTC	Laboratory Transfer Chamber
LWD	Logging While Drilling
MBRF	Meters Below Rig Floor
MBSF	Meters Below Sea Floor
MH	Methane Hydrate
MPa	Mega-Pascals
MSCL-V	Multi-Sensor Core Logger - Vertical
NETL	National Energy Technology Laboratory
NSF	National Science Foundation
ODP	Ocean Drilling Program
ODP-LC	Ocean Drilling Program – Logging Chamber
PCS	Pressure Core Sampler
PSI	Pounds per Square Inch
RAB	Resistivity at the Bit
RAB-c	Resistivity at the Bit with Coring
RCB	Rotary Core Barrel
R/V	Research Vessel
TAMU	Texas A&M University
XCB	Extended Core Barrel

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APPENDIX A

PIEZOPROBE DISSIPATION TESTING FOR SITE 1244

ODP LEG 204, OFFSHORE OREGON

Ko Min Tjok

Jean M.E. Audibert

Fugro-McClelland Marine Geosciences, Inc.

Report No. 0201-4655

(5 pg. Report, plus 5 Plates)

Report No. 0201-4655
August 28, 2002

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Attention: Mr. Frank R. Rack, Ph.D.

Ocean Drilling Program (ODP)
Piezoprobe Dissipation Testing for Site 1244
ODP Leg 204, Offshore Oregon

This report presents the results of our piezoprobe dissipation test conducted at the above location. This study was authorized by your Purchase Order No. J020045, dated March 7, 2002.

1. Introduction

During ODP Leg 204, Fugro-McCleland Marine Geosciences (FMMG) Inc. was contracted by Joint Ocean Institutions (JOI) to perform piezoprobe testing from the R/V *Joides Resolution* at ODP Site 1244, Offshore Oregon.

The objectives of this study were: (a) to adapt (modify) FMMG's piezoprobe tool for use with the ODP's Bottom Hole Assembly (BHA), and (b) to deploy and perform piezoprobe testing on ODP Leg 204. To accomplish these objectives, the following tasks were performed:

(1) Modifications to Fugro's piezoprobe tool included design and fabrication of a protective sleeve, weight collars, hang off unions, connector, adaptors, lifting heads and communication module upgrade;

(2) The piezoprobe tool was assembled and tested with the ODP's BHA at College Station, Texas; and

(3) One piezoprobe test was successfully performed at Site 1244 (HR1A Location) to measure the in situ temperature and in situ pore water pressure and dissipation characteristics in the soil formation.

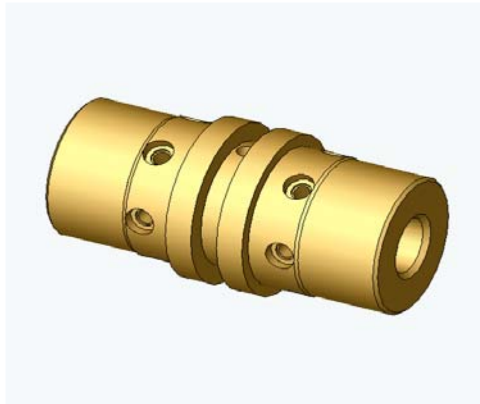
2. Modifications to Piezoprobe for ODP Leg 204

The following modification were made to Fugro's piezoprobe:

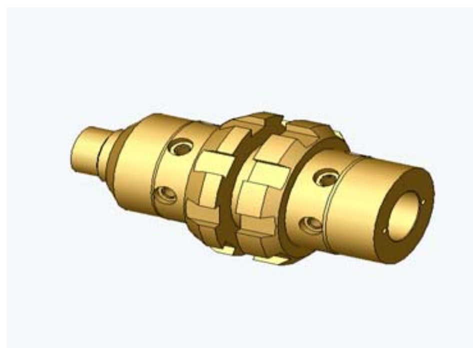
(1) Designed and fabricated a new shaft for the piezoprobe tool, with a protective sleeve to protect the piezoprobe tip as it is passed through the ODP BHA float valve.

(2) Designed and fabricated two (2) sets of four (4) weight collars (10 feet long). The weight collars served to accommodate the long distance between the reaction point in the ODP BHA, and added weight required to lower the tool through the long drill string.

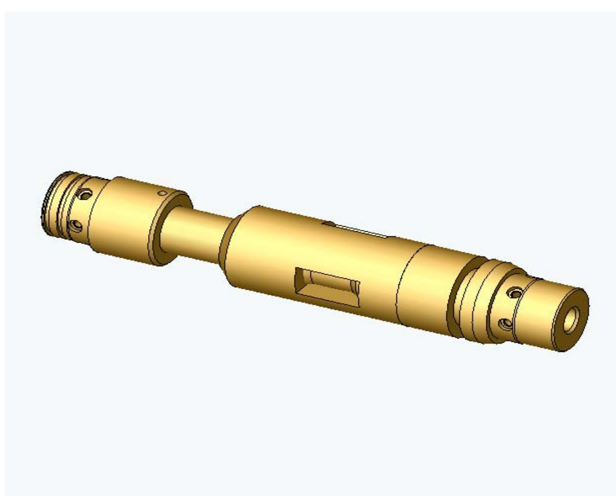
(3) Designed and fabricated hang off unions. The hang off unions enabled the long tool to be assembled in the drill string



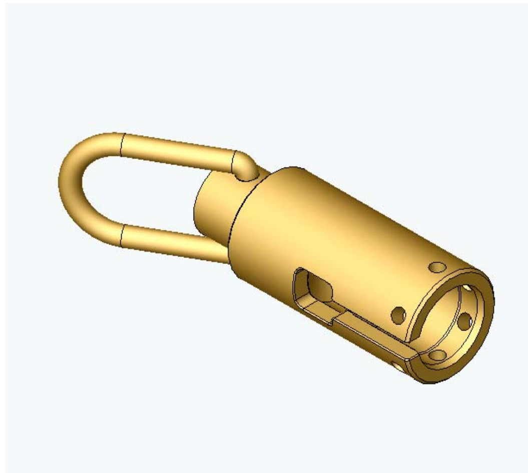
(4) Designed and fabricated the interface connector between the connection on the end of the logging cable on the R/V Joides Resolution and Fugro's piezoprobe.



(5) Designed and fabricated adaptors to connect the mechanical pawls to thick wall tube.



(6) Designed and fabricated lifting heads with bail to accommodate longer and heavier system.



(7) Upgraded communication module to accommodate long logging cable on R/V *Joides Resolution.*

(8) Tested assembled system at College Station, Texas.

3. Piezoprobe Testing

Piezoprobe testing was performed using FMMG's wireline-operated, small-diameter tapered piezoprobe device to measure excess pore water pressure and dissipation characteristics and in situ temperature in the soil formation. The piezoprobe testing was conducted during ODP Leg 204 from July 9, 2002 to July 19, 2002, from the R/V *Joides Resolution.* The field activities are summarized chronologically in the Summary of Field Operations presented on Plate 1.

During ODP Leg 204, three piezoprobe tests were planned for the original testing program. The first attempt to deploy the piezoprobe tool at about 54m below seafloor in Hole 1244B was unsuccessful, because the connection between the end of the pig tail cable and the piezoprobe tool was disconnected downhole. The second attempt to repeat the piezoprobe test at about 53.5m below seafloor was successfully performed in Hole 1244C. The second piezoprobe test was cancelled due to the tight schedule of the ODP drilling program. The last test schedule to be deployed at the termination depth of the borehole (about 380m BML) was also cancelled due to squeezing of the hole formation and the borehole had to be abandoned at about 330m BML.

Prior to the deployment of the tool, the piezoprobe tool was pre-assembled on deck in three sections of approximately 20 feet long each. This was done to make it easier to handle the tool. The top section was made up of a top knob, a sinker bar, a pawl assembly and one thick wall extension complete with signal cable. The middle section consisted of two thick-walled extensions with signal cable. The bottom section consisted of one thick-walled extension, stinger rod, shroud assembly, Spartek gauge, needle tip probe assembly, and a curly cord signal cable.

After the borehole was drilled to the desired test depth, the top, middle and bottom sections of the piezoprobe tool were assembled together as they entered the drill pipe. The entire tool assembly was lowered on wireline through the drill pipe to the bottom of the borehole. While lowering the piezoprobe tool down the pipe the mud pump was pumping at a slow rate to maintain circulation in the hole. When the tool was about 30-40 meters from the bottom of the hole, the wireline winch lowering the piezoprobe tool was stopped and the drill bit was raised about 7meters above the bottom of the borehole. At this time the mud pump was turned off. The piezoprobe tool was then lowered until the top knob rested on the landing ring in the BHA. The piezoprobe was allowed to sit for about thirty seconds to measure the hydrostatic pressure. The wireline winch operator was then instructed to pick up the slack by applying tension to the wireline until it supported the weight of the piezoprobe tool. The drill string was then lowered until the bit was about 3.5 meters from the bottom of the borehole. The heave compensation system was then activated.

To insert the piezoprobe tip into the virgin soil below the bottom of the borehole, the piezoprobe tool was lowered until the weight of the tool was supported by the soil. At this stage, with the tool resting on the bottom, the mechanical pawls were fully extended and located just below the landing ring. Subsequently the drill string was lowered to engage the pawls. The piezoprobe tip was then pushed with the drill string into the soil. The length of the push was about 0.6 to 1.0m beyond the bottom of the borehole, depending on the stiffness of the soils. After the tool was pushed, the drill string was raised about 1.5m to prevent contact with the pawls and the landing ring while the piezoprobe acquired data. The pressure transducer transmitted electronic signals through an armored cable to a computer on deck, where the data were continuously displayed in real time and stored digitally. The pore pressures were sampled at a rate of one reading per second during the test. When sufficient data had been obtained, the tool was retrieved. A schematic drawing showing the small diameter piezoprobe device is presented on Plate 2. A pore pressure transducer was used to measure the pore pressures in the soil formation, which was in contact with the sediment through a porous stone. Silicon oil was used as the pressure transducing fluid. A temperature transducer was also incorporated in the tool and the data were used to correct the measured pressures.

The absolute pressures recorded after measuring hydrostatic pressure are presented as plots of pore pressure versus elapsed time in Plates 3 and 4. The plots show peak pressure after insertion followed by pore pressure dissipation stabilizing at ambient condition. The excess pore-water pressure in the soil formation is the difference between the equilibrium piezometric pressure (ambient pressure) and the calculated hydrostatic pressure at the test depth. Calculated hydrostatic pressures are annotated on the plots. The temperature data recorded during the test and normalized excess pore-water pressure dissipation curve are presented in Plate 5.

We appreciate the opportunity to be of service to you on this project. Please call us if you have any questions or when we can be of further assistance.

Sincerely,

FUGRO-McCLELLAND
Marine Geosciences, Inc.

Ko Min Tjok
Senior Project Supervisor

Jean M. E. Audibert, Ph.D., P.E.
Engineering Department Manager

(KMT\JMEA\4655lrpt.doc)
Copies Submitted: (1)

Date	Time From	Time To	Description of Activities
July 9, 2002	0900	1900	FMMG Engineer and EM technician travel from Houston to Ogden Point Dock, Victoria, BC, Canada and board R/V *Joides Resolution*.
	1900	2400	Standby onboard R/V *Joides Resolution*.
July 10, 2002	0000	0900	Standby onboard R/V *Joides Resolution*.
	0900	1100	Safety meeting.
	1100	1300	Standby onboard R/V *Joides Resolution* .
	1300	1400	Scientist meeting.
	1400	2400	Standby onboard R/V *Joides Resolution*.
July 11, 2002	0000	0830	Standby onboard R/V *Joides Resolution.*
	0830	0930	Pre-sail meeting.
	****	0930	R/V *Joides Resolution* departs Ogden Point Dock.
	0930	2400	Travel to Site 1244, Offshore Oregon.
July 12, 2002	0000	1030	Standby onboard R/V *Joides Resolution*.
	1030	1530	Pre-assemble the piezoprobe tool in three sections. Arrive on location and start rigging up BHA at about 1200 hrs.
	1530	1700	Perform trial run of the entire piezoprobe assembly with the BHA.
	1700	2400	Commence running drill pipe.
July 13, 2002	0000	0600	Standby onboard R/V *Joides Resolution*.
	0600	0800	Assembled the piezoprobe as they entered drill pipe.
	0800	0850	Rig up wireline.
	0850	1015	Lowering the piezoprobe to bottom of borehole.
	1015	1100	Attempt to set the tool downhole (loss communication with the tool).
	****	1100	Loss the tool downhole, because the connection between the end of the pig tail cable and the piezoprobe tool was disconnected downhole.
	1100	1200	Recover wireline and pig tail cable on deck.
	1200	1600	Pull pipe to recover piezoprobe tool.
	1600	1935	Trip pipe downhole.

SUMMARY OF FIELD OPERATIONS

Ocean Drilling Program (ODP)
Site 1244 (HR1A), Offshore Oregon

Date	Time From	To	Description of Activities
July 13, 2002	1935	2400	Continue drilling and obtained APC cores.
July 14, 2002	0000	0030	Assembled the piezoprobe tool.
	0030	0230	Deploy and perform piezoprobe dissipation test at 53.5m below mudline (BML).
	0230	0315	Recover piezoprobe tool on deck.
	0315	2400	Standby for piezoprobe testing.
July 15, 2002	0000	2400	Standby for piezoprobe testing.
July 16, 2002	0000	0015	Advise by ODP that the schedule piezoprobe test at the termination of the borehole is cancelled due to squeezing of the hole formation and instructed to rig down the piezoprobe tool.
	0015	1000	Standby.
	1000	1700	Continue to rig down the piezoprobe equipment and prepare the piezoprobe equipment to be ship onshore.
	1700	2400	Standby onboard R/V *Joides Resolution*.
July 17, 2002	0000	2400	Standby onboard R/V *Joides Resolution*.
July 18, 2002	0000	2400	Standby onboard R/V *Joides Resolution*.
July 19, 2002	0000	1200	Standby for Helicopter.
	****	1200	FMMG personal depart R/V *Joides Resolution* by Helicopter.

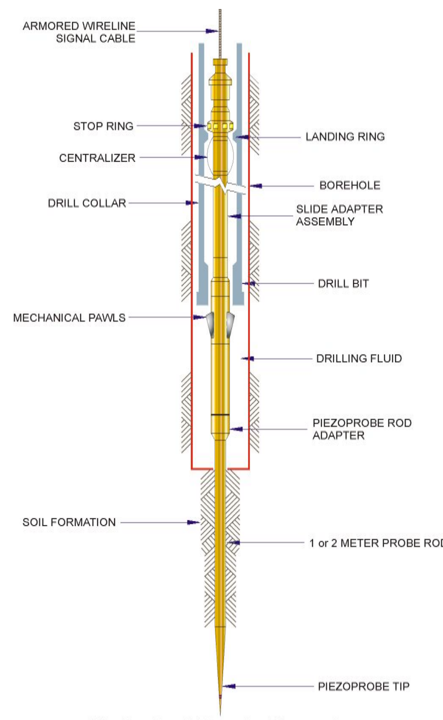
SUMMARY OF FIELD OPERATIONS

Ocean Drilling Program (ODP)
Site 1244 (HR1A), Offshore Oregon

Small Diameter Piezoprobe

During testing, the pressure transducer transmits signals through the armored cable to a computer on deck of the vessel, where the data are continuously displayed in real time on the computer screen. Data are collected every second over the first hour and then once every 5 to 10 seconds. The frequency of reading accommodates the 90 to 95 percent dissipation in the first few hours of testing.

The data from the tests are synthesized to determine the excess pore pressure and the rate of pore pressure dissipation. Additionally, the data can be used to estimate the permeability and consolidation characteristics. The data has been utilized to better calculate the pile-soil set-up phenomenon for driven piles.

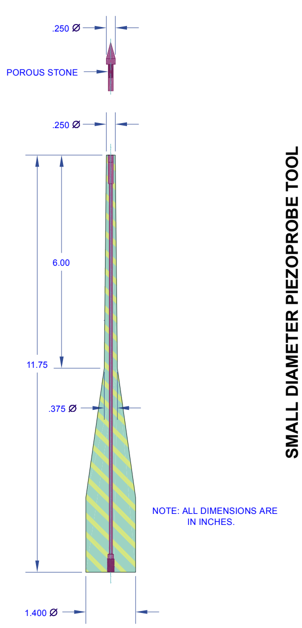


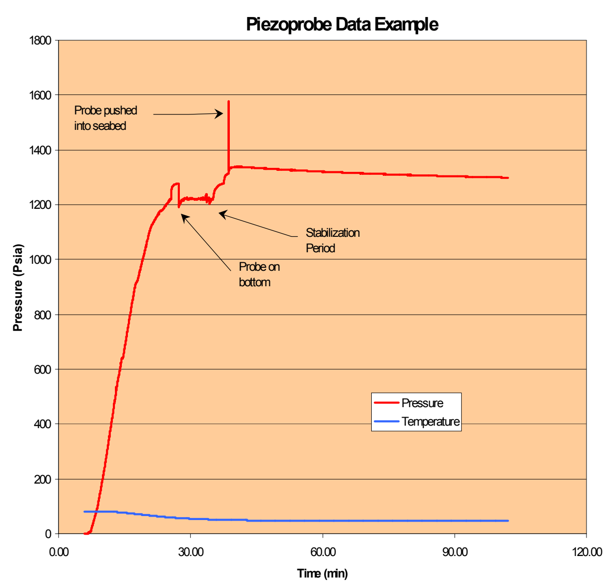
Wireline Small-Diameter Piezoprobe

General Tool Specifications

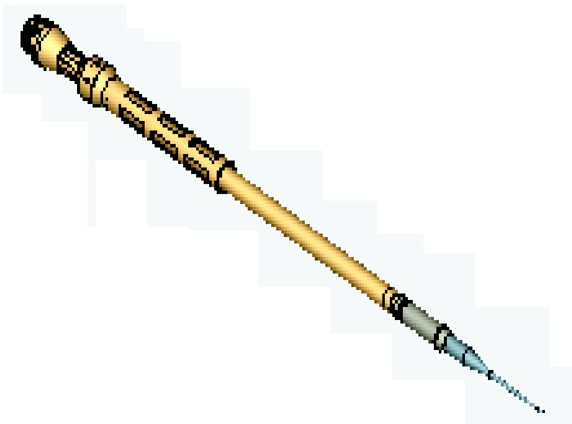
<u>SPARTEK SS2700 Sapphire Pressure/Temperature</u>

Temperature range:	150	°C (Max)
Pressure range:	5000	psia
Pressure resolution:	0.0004%	FS
Total system accuracy:	+/-0.022%	FS
Min. Sample rate:	1	HZ





Small Diameter Piezoprobe



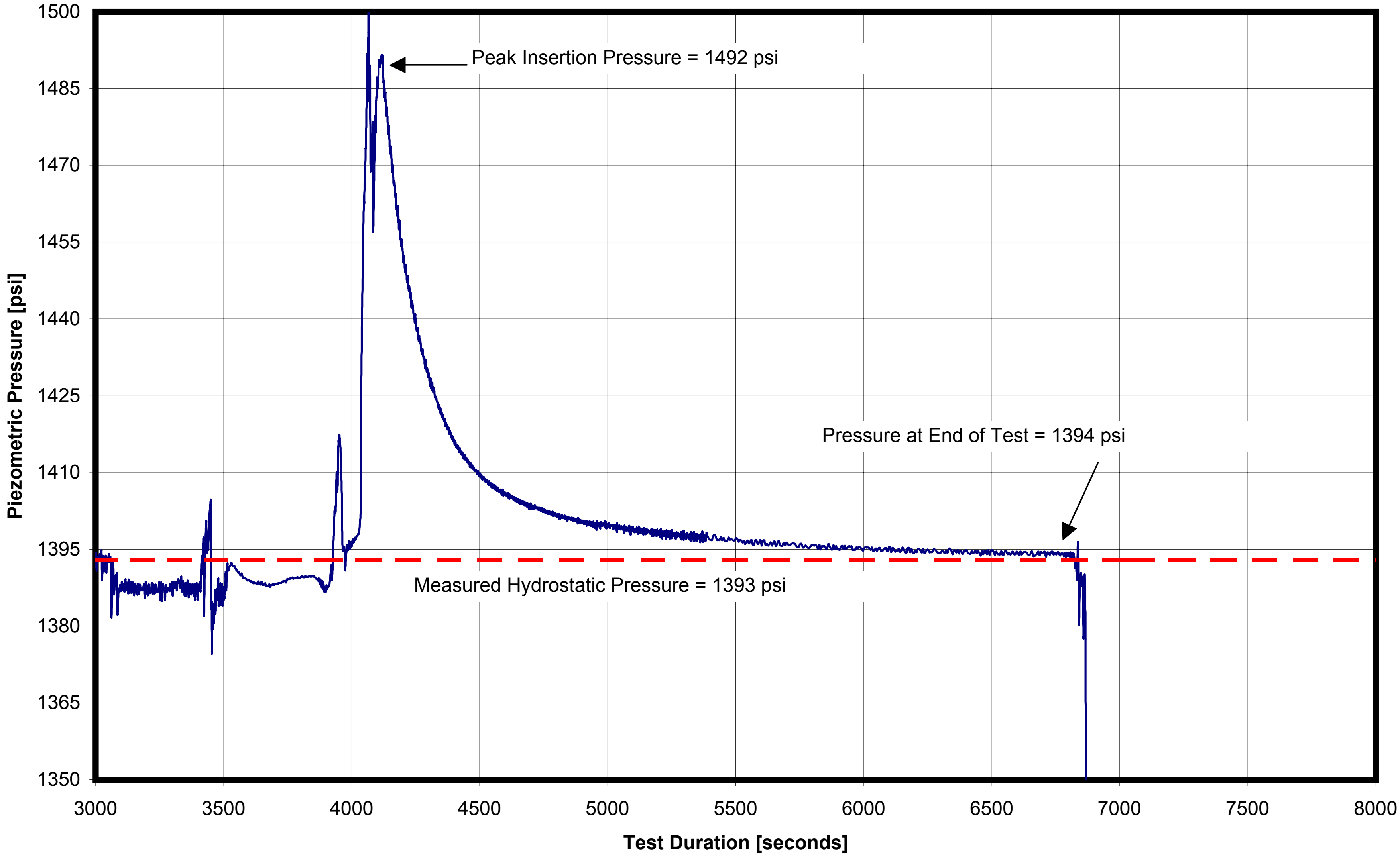
The small diameter Piezoprobe was designed to measure excess pore pressure and determine the dissipation characteristics of the sub-soils. In addition, results from the tests could be used to estimate the insitu permeability and consolidation characteristics of the soil, as well as provide insight into pile-soil set-up. The tool was made compatible with the Dolphin suite of in-situ tools to facilitate deployment.

The probe has a sleeve diameter of 1.4-inches reduced down to 1/4-inch at the tip of the tool. The pore pressure-measuring device is located at the tip of the tool. The pressure at the porous stone is measured using a Panex pressure transducer. The tool is capable of recording the pressure and temperature data on a remote memory unit attached to the tool, as well as in "real time" via a small umbilical to the vessels deck.

The tool is deployed using wireline techniques to enable testing to be performed at any designed depth. Once the test depth is achieved, the probe is lowered through the annulus of the drill string using an armored wireline signal cable and constant tension winch. The tool latches into the drillstring and is pushed into the soil using the weight of the drill pipe. The tool is typically pushed from 2 to 3 feet into the soil in front of the drill bit. After the tool is pushed into the virgin soil, the drillstring is raised to prevent contact with the drill pipe during data acquisition.

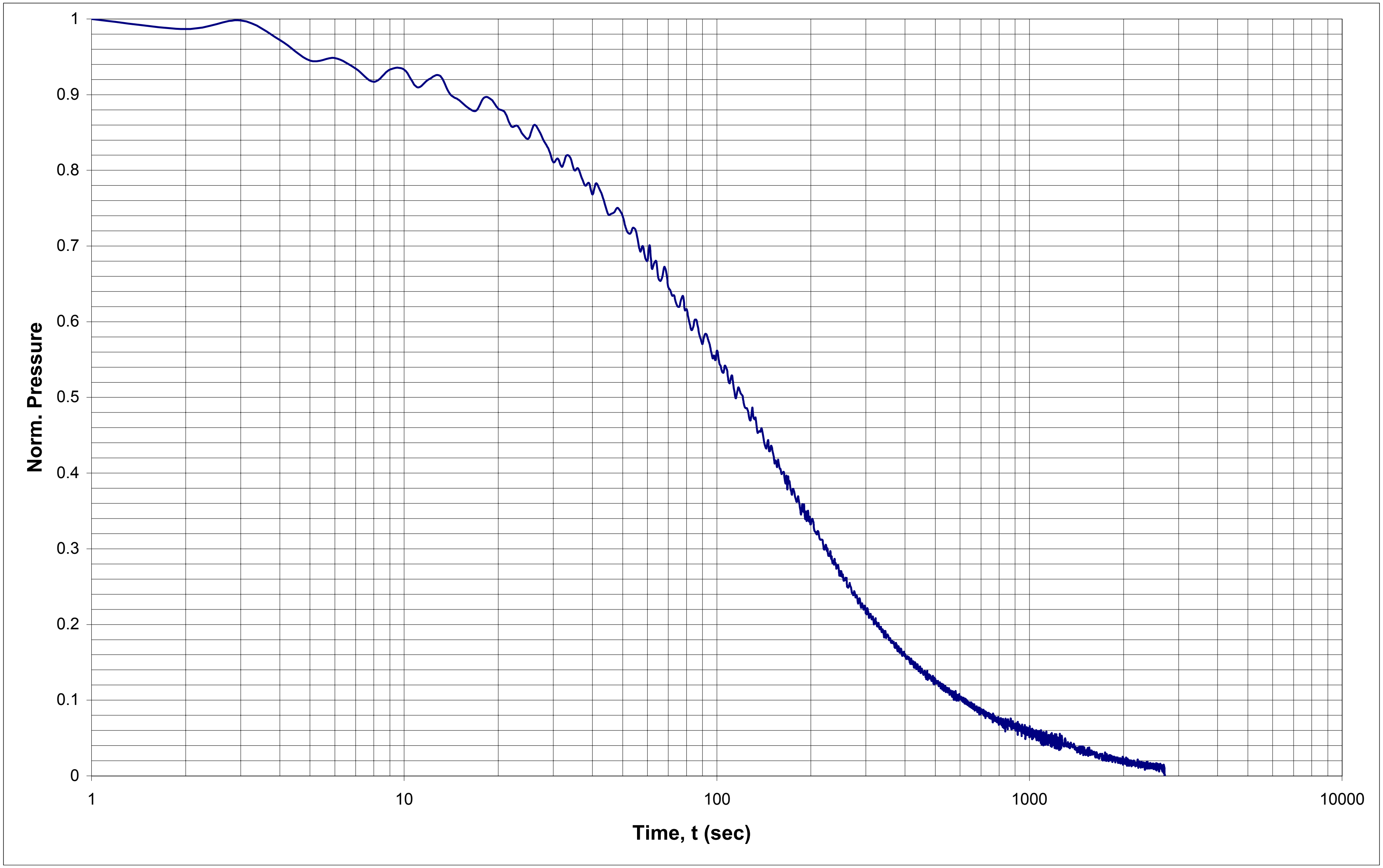
Applications

- Measure excess pore pressure
- Measure pore pressure dissipation
- Estimate insitu permeability
- Estimate consolidation characteristics
- Estimate pile set-up characteristics

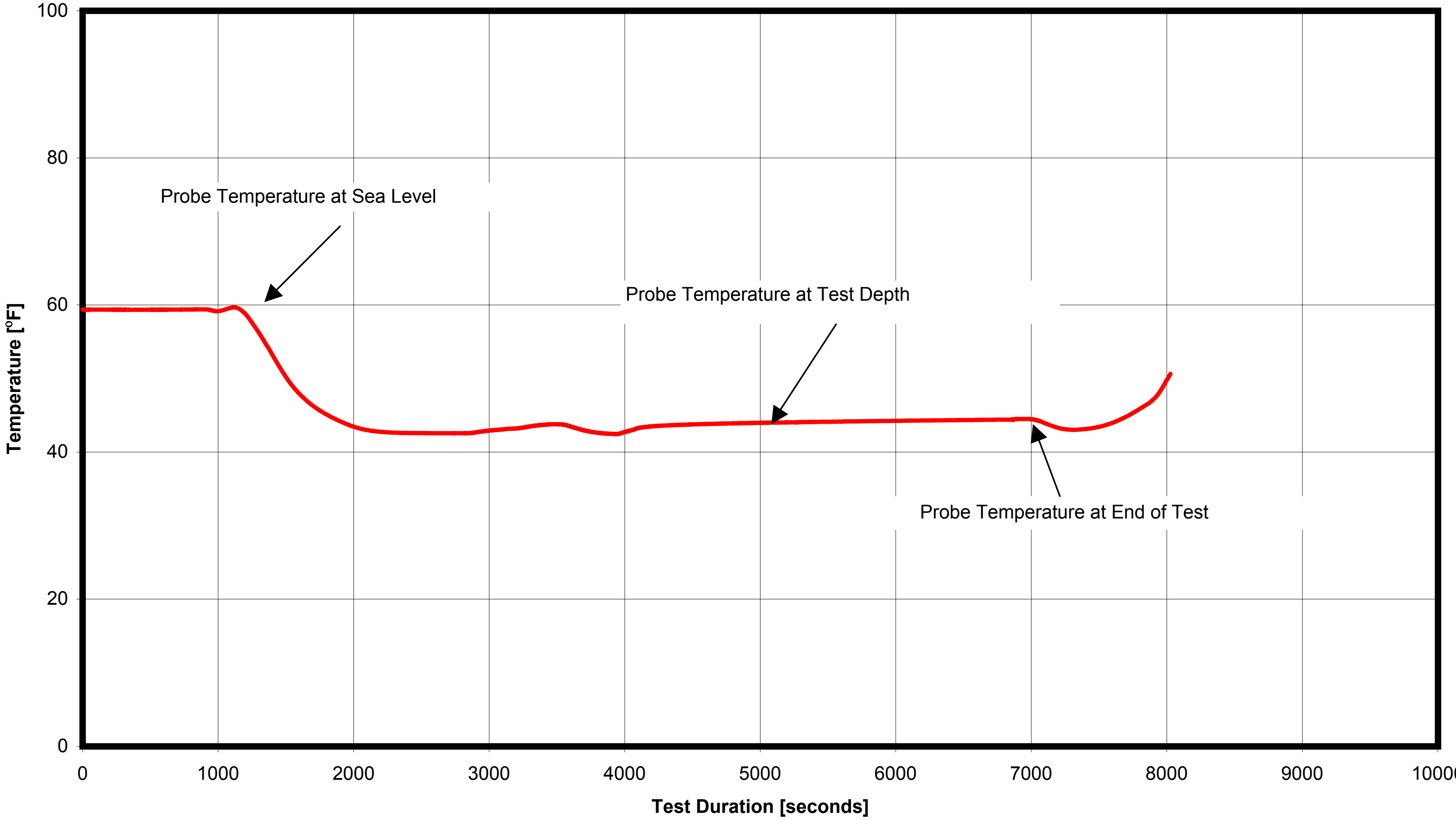


Pore Pressure Dissipation versus Time

Piezoprobe Test at 53.5m BML
Site 1244 (Location HR1A)



Normalized Pore Pressure versus Log Time Curve
Piezoprobe Test Depth: 53.5m (176-ft)
Site 1244 (Location HR1A)



Piezoprobe Temperature versus Time

Piezoprobe Test at 53.5m BML

Site 1244 (Location HR1A)

APPENDIX B

MEASURING PORE PRESSURE IN MARINE SEDIMENTS WITH PENETROMETERS: COMPARISON OF THE PIEZOPROBE AND DVTP-P TOOLS IN ODP LEG 204.

Brandon Dugan
Pennsylvania State University

(19 pg. Report, plus 8 Figures)

Measuring Pore Pressure in Marine Sediments with Penetrometers: Comparison of the Piezoprobe and DVTP-P Tools in ODP Leg 204

Brandon Dugan

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Penn State University, University Park PA 16801

Research Advisor: Peter B. Flemings

Report Authors: Brandon Dugan, Peter B. Flemings (Penn State University), Frank R. Rack (Joint Oceanographic Institutions, Inc.), Gerhard Bohrmann (GEOMAR), Anne M. Trehu (Oregon State University), Derryl Schroeder (Ocean Drilling Program), and the Shipboard Scientists of ODP Leg 204

ABSTRACT

Fugro-McClelland Marine Geosciences Inc.'s piezoprobe, a penetration-based tool used to determine pore pressure and hydrologic properties within a borehole, was deployed for the first time in the Ocean Drilling Program (ODP) on ODP Leg 204 in July 2002. Analysis of the piezoprobe data suggests that *in situ* pore pressure is 9.5 MPa, which is approximately the hydrostatic pressure (9.53 MPa). The piezoprobe deployment and modeling of the results provides one of the first measurements of *in situ* permeability made within the borehole. From the piezoprobe dissipation data, we estimate of *in situ* permeability of approximately 1.5 $x10^{-17}$ m^2 for the hemipelagic clay. This is consistent with laboratory-measured permeability (~$1x10^{-17}$ m^2) on hemipelagic clay samples from nearby ODP Site 892. The piezoprobe results were compared to a Davis-Villinger Temperature/Pressure Probe (DVTP-P) measurement made at the same depth, and in the same lithology, but in an adjacent borehole. The DVTP- P is also a penetration-based tool, however it has a much wider probe diameter. The DVTP-P generated a higher peak pressure that did not dissipate as much as the piezoprobe pressure, which resulted in a DVTP-P estimate of *in situ* pressure that nearly equals the overburden stress. The results suggest that a narrow diameter probe like the piezoprobe can be used to rapidly determine *in situ* pressure and hydrologic properties in sites investigated by the Ocean Drilling Program.

INTRODUCTION

Rock deformation, sediment strength, and regional fluid fluxes are directly related to pore pressure and hydrologic properties of the sub-seafloor sediments. Three geologic systems that can be more completely defined through direct measurements of pressure are (1) fluid flow and stability of continental margins, (2) fault activation, decollement location and propagation, and geometry in accretionary prisms, and (3) free gas and water migration, hydrate formation, and rock strength in gas hydrate provinces.

The role that pore fluids have in sculpting continental slope geomorphology has intrigued scientists since the diverse structure of slopes was identified [1, 2] (Figure 1A). Excess fluid pressure has been attributed to landslides and failures on low angle slopes that would not fail without excess pressure [3, 4]. More recently focused fluid migration along permeable layers has been invoked as a major contributor to the timing and distribution of sediment deformation and failure [5, 6, 7, 8]. Models predict the magnitude of pressure required to generate slope instability and provide insights into the origins of the required excess pressure. Relatively few direct measurements exist to test the models, so the models are typically compared to pressure estimates from proxy data such as porosity [9] or seismic velocity [10].

Fluid migration within accretionary complexes has been described for its importance to heat and chemical transport [11] (Figure 1B). Fluids have also been cited as a driving force in the geometry and structure of accretionary complexes [12, 13, 14]. Porosity and seismic data have been used with models to estimate pressure, flow paths, and fluid fluxes [15, 16, 17]. These models also constrain the contribution of fluids to deformation, chemical transport, and heat flow. Validation of these models and their interpretations has not been extensive because of the lack of direct pressure measurements. The Ocean Drilling Program (ODP) has started to collect direct measurements of pressure, temperature, and pore fluid chemistry with long-term observatories (CORKs, ACORKs) [18, 19, 20].

The pressure and stress in gas hydrate provinces is not well defined, is lacking robust multiphase models, and has very few direct observations. These pressures and stresses, however, are critical to the dynamics of this multiphase system. Fluid pressure impacts the solubility of gas in water, governs the stability of gas hydrate [21, 22], defines the permeability of the system, and pressure gradients dictate the flow field (Figure 1C). A detailed analysis of the complex hydrate system is required: (1) to define the volume of gas stored as hydrate and as free gas beneath hydrate [21]; (2) to understand the mechanics by which gas migrates and is released [23, 24, 25]; (3) to characterize the role of hydrate dissociation in slope failure [26, 27]; and (4) to estimate the potential role of catastrophic methane release on climate [28].

In this report, we describe the results of the Fugro-McClelland Marine Geosciences Inc.'s piezoprobe and the Davis-Villinger Temperature/Pressure Probe (DVTP-P) pressure measurements made on ODP Leg 204 at ODP Site 1244, Hydrate Ridge, offshore Oregon, USA. The tools are designed to make rapid measurements of pressure and hydrologic properties in low permeability sediments. We analyze the results from both tools, compare their results, and comment on the *in situ* conditions by analyzing the data that most accurately represent the natural system.

PRESSURE MEASUREMENT

Direct pressure measurements are rare and expensive, but are required to advance research of submarine hydrodynamic systems. The ODP has historically relied on CORKs and ACORKs to monitor pressure, temperature, and fluid chemistry over many years. This characterizes the *in situ* conditions but the time and cost of acquiring data make the studies unrealistic for making robust and routine measurements beneath the seafloor.

An alternative approach to measuring *in situ* pressure is to use a penetration device. These measurements only take hours. Penetration devices that have been deployed in deep marine settings include free-fall penetration devices that sample pressure within a few meters of the seafloor. These include the Puppi [29, 30] and an early probe by Davis *et al.* [31]. A second class of instruments has been developed for use in boreholes. Two examples of these include the DVTP-P tool deployed on ODP Leg 190 [32] and the piezoprobe device [33, 34, 35].

The DVTP-P tool and the piezoprobe are similar devices. The tools have certain operational differences, with the key difference being the geometry of the tools (Figure 2). The tools induce a pressure pulse as they are inserted into sediments. The initial pressure response and its decay are defined by the insertion rate of the probe, the modulus of the sediment, and the bulk permeability of the sediment. The tool geometry coupled with the penetration rate dictate the spatial distribution of induced pressure; for a similar insertion rate, these tools produce different excess pore pressure distributions because of their different geometries. The pressure dissipation is used to infer *in situ* pressure and rock properties [34, 35].

The piezoprobe has a narrow probe that is 170 mm long including the short, tapered tip. The probe has diameter of 6.4 mm. A larger diameter shoulder assembly connects the probe to the drillstring [34] (Figure 2). At the tip of the probe, a porous element allows communication of pore fluid with the pressure transducer.

The DVTP-P has a different geometry and thus a different pressure response. The DVTP-P has a longer and wider taper than the piezoprobe (Figure 2); its length is over twice that of the piezoprobe and the maximum diameter is almost twice that of the shoulder of the piezoprobe [36]. The pressure transducer is located farther from the probe tip than it is on the piezoprobe (Figure 2); this impacts the time required to interpret the *in situ* pressure and rock properties.

The tools have been designed to allow estimation of pressure and rock properties from the pressure data. The initial excess pressure during steady penetration can be related to the peak excess pressure and used to estimate the shear modulus of the sediments if conditions are undrained [37] or local permeability if partial drainage occurs [38]. After the tool insertion has ceased, the pressure dissipation allows estimation of the coefficient of consolidation [37, 39, 40], which can be used to infer permeability.

Penetration devices and long term monitoring stations will provide a full suite of pressure and rock property data beneath the seafloor that will increase our understanding of the sub-seafloor hydrologic system. The cooperative use of the devices will provide real-time and human-time scale data sets for understanding the dynamics of complex hydrodynamic systems. The data will also provide tests and calibrations of laboratory techniques used to interpret pressure, stress, and deformation. Many approaches have been used in the laboratory to estimate basin-scale pressures and rock properties from core samples [16, 41, 42, 43].

TEST SITE

ODP Site 1244 is located on Hydrate Ridge in 895.43 m of water (Figure 3). The presence of gas hydrate and free gas are interpreted based on a prominent bottom simulating reflector in seismic data [44]. One piezoprobe measurement was made at 53.66 meters below seafloor (mbsf) in Hole 1244C. This measurement was made in an interval of hemipelagic clay. A DVTP-P measurement was made in Hole 1244E at 52.6 mbsf in hemipelagic clay. Holes 1244C and E are located approximately 40 m apart. Site 1244 was dominated by hemipelagic clay with some turbiditic interlayers of silt and sand that find upward; the turbidite layers were most common and thickest between 69 and 245 mbsf. Below 245 mbsf, the lithology changes to indurated and fractured claystone with glauconite rich silt and sand interbeds.

At the depth of the piezoprobe and DVTP-P measurements, *in situ* porosity is between 61 and 64% (void ratio between 1.56 and 1.78), based on shipboard measurements of porosity from samples collected near the tool deployments (Figure 4). Porosity decreases downhole from 70% at the seafloor to just below 50% at 160 mbsf. The piezoprobe and DVTP-P deployments coincide to a depth where an increase in porosity is present (Figure 4).

Shipboard bulk density measurements were integrated to calculated the vertical hydrostatic effective stress (σ_{vh}') at Site 1244 (Figure 4); σ_{vh}' is the total overburden stress less hydrostatic fluid pressure ($\sigma_{vh}' = \sigma_v - u_h$). The vertical hydrostatic stress at the piezoprobe deployment depth is 0.331 MPa. At the DVTP-P deployment depth, σ_{vh}' is 0.327 MPa. Measurements on samples from ODP Site 892 (located near Site 1244 in Figure 3) establish the permeability for the hemipelagic clay to be ~1×10^{-17} m^2 (range = 3.4×10^{-17} - 8.5×10^{-18} m^2) at *in situ* stress [16].

PIEZOPROBE AND DVTP-P DEPLOYMENT

The piezoprobe was deployed on ODP Leg 204, Site 1244, Hole C on 14 July 2002. The deployment events for the test are described in Table 1 and the pressure history recorded by the piezoprobe is shown in Figure 5. We calculated the hydrostatic pressure (u_h) by assuming a fluid density of 1.024g/cm^3 (Table 2). We calculated the overburden stress (σ_v) by integrating core porosity and density measurements (Figure 4; Table 2). Thirty minutes into the deployment (#2, Figure 5A) the tool reached the seafloor. Thereafter it was lowered 53 meters to the bottom of the borehole (#4, Figures 5A, 5B). The tool pressure when the probe is at or near the base of the hole is slightly greater than the estimated hydrostatic stress (Figure 5B). This could be due to poor tool calibration, a borehole fluid density greater than 1.024 g/cm^3 (due to sediment in the borehole or greater salinity), or additional borehole pressure resulting from pumping. The piezoprobe test lasted 45 minutes (Table 1, Figure 5A). An initial peak pressure of 10.29 MPa declined ultimately to 9.615 MPa (Table 3). This final pressure is 0.08 MPa greater than u_h (Figure 6).

The DVTP-P test lasted 33.5 minutes with a peak pressure of 10.55 MPa and a final pressure of 9.79 MPa (Table 3; Figure 6). Abrupt jumps in the pressure data approximately five minutes after insertion may have resulted from tension on the probe. The DVTP-P measurement was made in Hole 1244E, approximately 40 m from the piezoprobe test at Hole 1244C. It is reasonable to assume that these probes are sampling approximately the same material. Differences between the two measurements are: (1) the initial penetration pressure of the DVTP-P is significantly greater than the piezoprobe, (2) the DVTP-P pressure does not decline to as low a pressure as the piezoprobe pressure does, and (3) the DVTP-P pressure is dropping more rapidly than the piezoprobe pressure at the end of the test (Figure 6).

The excess pore pressure ratio (Figure 7A) is the pore pressure (u) normalized by the peak pore pressure (u_i) (Table 3). It is a useful way to measure the relative dissipation that has occurred. In this case, we have normalized the pressure relative to the hydrostatic pressure (u_h). From this plot is clear that the piezoprobe has dissipated significantly more relative to its peak pressure than the DVTP-P has dissipated. The normalized excess pore pressure (Figure 7B) is a measure of the magnitude of the pore pressure (u) relative to the hydrostatic effective stress (σ_{vh}'). The DVTP-P generates pore pressure three times greater than σ_{vh}', while the piezoprobe generates pressure only two times σ_{vh}' (Figure 7B).

PIEZOPROBE AND DVTP-P INTERPRETATION

We desire to interpret both the *in situ* pressure and hydraulic properties (e.g. permeability) from the piezoprobe test. Whittle *et al*. [34] propose that there is a characteristic dissipation curve associated with the piezoprobe and that given a soil model, permeability can be derived based on the following equation for normally consolidated clays,

$$T = \frac{s' kt}{g_w R_2^{\,2}} \quad . \tag{1}$$

T is the time factor and s' is the mean effective stress. We have assumed $s' = 0.67 s_{vh}'$. g_w is the unit weight of water, k is the hydraulic conductivity, t is time, and R_2 is the radius of the piezoprobe at the shaft (35.6 mm). T_{50} is the time factor at 50% dissipation, while t_{50} is the absolute time at 50% dissipation. Whittle *et al*. [34] model T_{50} to be 1.72×10^{-3} for Boston Blue Clay with an overconsolidation ratio of 1.2.

To determine permeability we substitute T_{50} and t_{50} into Equation 1. However, to determine t_{50}, we must determine the final pressure, u^*. We assumed two values for u^*: 9.5 and 9.6 MPa. With these assumptions, two pore pressure ratio curves generated and t_{50} is determined to be 120 and 165 seconds (gray and black solid curves, Figures 8A, 8B). The two u^* values yield hydraulic conductivities of 1.9×10^{-8} cm/sec and 1.4×10^{-8} cm/sec. These hydraulic conductivities equate to permeabilities of 1.96×10^{-17} m^2 and 1.43×10^{-17} m^2. The small variation in permeability suggests that the permeability is not very sensitive to the estimate of *in situ* pressure. These values are in the same range as those measured by [16].

To determine which of the proposed u^* values is appropriate, the curves are fitted to Whittle's normalized dissipation curve for Boston Blue Clay (dotted and dashed lines, Figures 8A, 8B) [34]. In linear time (Figure 8A) and log time (Figure 8B), it is clear that with $u^* = 9.5$ MPa there is a much better fit of the modeled curve than with $u^* = 9.6$ MPa. $u^* = 9.5$ MPa is very close to the hydrostatic pressure ($u_h = 9.53$ MPa).

This prediction is compared to an inverse time extrapolation (Figure 8C). In this approach, measured pressures are plotted as a function of inverse time and the y-intercept is an estimate of the *in situ* pressure (u_{lt}) [31, 33, 34]. We find u_{lt} is 9.71 MPa for the DVTP-P and 9.59 MPa for the piezoprobe (Figure 8C). u_{lt} is an overestimate of the *in situ* pressure [45] and thus the u^* of 9.5 MPa derived from the piezoprobe is a reasonable estimate.

In summary, analysis of the piezoprobe data suggests that *in situ* pore pressure (9.5 MPa) is nearly hydrostatic (9.53 MPa) and *in situ* permeability is approximately 1.5×10^{-17} m^2. Over the time span of the piezoprobe test (45 minutes), 90% of the penetration-induced pore pressure was dissipated. It is important to recognize that the prediction of u^*, the *in situ* pressure, relies heavily on the model-based normalized pressure dissipation curve derived specifically for the piezoprobe geometry and specific soil parameters. Whittle *et al*. [34] describe in detail the fact that because of the geometry of the piezoprobe where a large diameter shaft overlies a narrow diameter probe, there is a shelf in the pressure data (Figure 8B, between 100 and 1000 min). The pressure induced by the large diameter shaft that reaches the pressure transducer causes this shelf.

A second primary result is that the DVTP-P pressures have not dissipated as much as the piezoprobe pressures either relative to their peak pressures (Figure 7) or in absolute pressure (Figure 6). This is not surprising because the radius of the DVTP-P is three times that of the piezoprobe at the pressure port and the DVTP-P continues to widen above the pressure port (Figure 2). The dissipation time is proportional to the square of the radius (Equation 1). Thus, based on a cylindrical probe geometry, t_{50} for the DVTP-P should be nine times that of the piezoprobe, but experimentally it is only five times as great (Figure 8B).

CONCLUSIONS

Deployment of the piezoprobe and the DVTP-P at Site 1244 of ODP Leg 1244 provided tests of both tools and estimates of *in situ* fluid pressures and rock properties. The piezoprobe data provide an estimate of *in situ* pressure equal to 9.5 MPa, which is nearly equal to the hydrostatic pressure at the depth of the experiment. The piezoprobe deployment and modeling of the results provides one of the first measurements of *in situ* permeability within the borehole. The dissipation data from the piezoprobe yield a permeability estimate of 1.5 $\times 10^{-17}$ m^2 for the hemipelagic clay; this is consistent with laboratory measurements (~1×10^{-17} m^2) on hemipelagic clay samples from nearby Site 892. The piezoprobe experiment only took approximately two hours from initial deployment until the tool was returned to the deck of the ship; 45 minutes of this time was the piezoprobe dissipation. The DVTP-P tool experiment, conducted in similar sediments, produced a significantly different pressure estimate. With 33 minutes of pressure dissipation, the DVTP-P pressure had dissipated to approximately the overburden stress and yields a pressure estimate of 9.71 MPa. Comparison of the DVTP-P and piezoprobe results suggest that a narrow diameter probe like the piezoprobe can be used to quickly and accurately determine *in situ* pressure and hydrologic properties of marine sediments.

The tests conducted on ODP Leg 204 are promising and suggest that future studies in marine geoscience and engineering can be strengthened with piezoprobe pressure and permeability observations. Continued use of the piezoprobe in sub-seafloor studies will expand research in a variety of geologic settings and will also provide real-time data that can be used to efficiently isolate regions of interest during emplacement of long term monitoring observatories.

ACKNOWLEDGEMENTS

This work could not have been accomplished without the extraordinary efforts of the participants of ODP Leg 204. Assistance by J. Germaine (MIT) and A. Whittle (MIT) is deeply appreciated. Deployment of the piezoprobe was supported by the Ocean Drilling Program and the Department of Energy. This research used samples and/or data provided by the Ocean Drilling Program (ODP). ODP is sponsored by the US National Science Foundation and participating countries under management of Joint Oceanographic Institutions (JOI), Inc.

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TABLES

Table 1: Piezoprobe Deployment Log

Event #	Time GMT	Time (minutes since deployment)	Event Description
1	7:32:34	0.565	Sitting in pipe--tip in water
2	8:09:22	37.365	Setting bit 7 meters from bottom
3	8:16:27	44.449	Lowering
4	8:22:11	50.182	Taking hydrostatic pressure
5	8:26:23	54.365	Pulled up 1.3 meters off of landing ring, now ~8 feet off bottom
6	8:27:13	55.215	Lowering bit down to 3.5 meters off bottom
7	8:36:35	64.582	Stopped pumping
8	8:38:22	66.365	Tagging bottom
9	8:39:31	67.515	Pushing
10	9:26:30	114.498	End of test - pulling
11	9:28:20	116.332	Coming to surface
12	9:45:42	133.699	At top of pipe

Table 2: Site Parameters

	Site, hole	mbsf (meters)	Depth Below Sea Level (meters)	Overburden Stress, σ_v (MPa)	Hydrostatic Pressure, u_h (MPa)	Hydrostatic Effective Stress, σ_{vh}' (MPa)
Seafloor	1244C	0.0	895.43	8.995	8.995	0.0
Piezoprobe (7/14/02)	1244C	53.66	949.09	9.867	9.534	0.331
Seafloor	1244E	0	893.3	8.974	8.974	0
DVTP-P#2, Run 19 (8/19/02)	1244E	52.6	945.9	9.829	9.502	0.327

* calculations assume seawater density of 1.024 g/cm^3

Table 3: Key Pressure Readings and Calculations

Test	Duration of Dissipation (min)	Peak Pressure, u_i (MPa)	Pressure at End of Test (MPa)	Hydrostatic Pressure, u_h (MPa)	Inverse Time Prediction, u_{It} (MPA)	Final Pressure, $u*$ (MPa)
Piezoprobe	45	10.29	9.614	9.53	9.59	9.5
DVTP-P	33.5	10.55	9.79	9.598	9.71	-

Table 4: Nomenclature

Symbol	Definition	Dimensions
k	hydraulic conductivity	L/T
R_2	radius at transducer	L
T	time factor	dimensionless
T_{50}	time factor at 50% dissipation	dimensionless
t	Time	T
t_{50}	time at 50% dissipation	T
u	pore pressure	M/LT^2
u_h	hydrostatic pressure	M/LT^2
u_i	peak pressure	M/LT^2
u_{It}	inverse time pressure estimate	M/LT^2
$u*$	final pressure	M/LT^2
g_w	unit weight of water	M/L^2T^2
s'	mean effective stress	M/LT^2
s_v	overburden stress	M/LT^2
s_{vh}'	vertical hydrostatic effective stress	M/LT^2

FIGURE CAPTIONS

Figure 1. Direct pressure observations are necessary to describe a variety of sub-seafloor processes and seafloor geomorphology. Arrows illustrate flow paths that have been postulated for the systems, but require direct measurements to verify. (A) Continental slopes are environments where slope failure and seeps are common. High fluid pressures are often attributed to failure along low angle slopes but few direct measurements of *in situ* pressure have been collected to test the models. (B) Pore fluid pressure affects the flow of fluids along the decollement and within faults in accretionary complexes. Pressures also control the geometry of the accretionary complex, e.g. the angle between the decollement and seafloor is small when excess pressures are high and is large when pressures are hydrostatic. The transition from the proto-decollement (minimal to no deformation) to the decollement (failure and faulting) is believed to be a function of flow and fluid pressure. (C) Gas hydrate provinces are dynamic hydrologic systems where gas and water pressures affect the formation and dissociation of gas hydrate. Permeability and gas storage are interpreted to be self-controlling based on the pressure state. The release of hydrates and gas is important for its role in global climate and for its contribution to seafloor geomorphology. GHZ = gas hydrate zone. FGZ = free gas zone.

Figure 2. Geometry of the DVTP-P and the piezoprobe. Both tools have pressure transducers near their tip, but the tools have different geometries. The DVTP-P has a long, tapered cone that extends beyond the drillbit. DVTP-P geometry modified from [36]. The piezoprobe has a short, wide shoulder that is attached to a narrow lance where the pressure transducer is located. Geometry of piezoprobe based on [34]. The geometry of the probe and location of the pressure transducer affects the time required to accurately estimate *in situ* conditions.

Figure 3. Hydrate Ridge is located offshore Oregon, USA (inset map). Bathymetry contour interval is 100 m. Site 1244 is located near the southern crest of Hydrate Ridge. Core samples from Site 892 on the northern crest of Hydrate Ridge were used to estimate *in situ* stress and pressures [16]. DVTP-P and piezoprobe measurements at Site 1244 will help to test these inferences based on consolidation behavior of the sediments from Site 892. Consolidation experi-

ments from Site 1244 will also be completed to estimate pressure and stress for comparison to piezoprobe and DVTP-P measurements.

Figure 4. Summary of ODP Site 1244. PP = piezoprobe. Lithology is based on shipboard observations. Hydrostatic effective stress (σ_{vh}') is determined from density measured in Hole 1244C. Porosity from Hole 1244C is based on shipboard measurements and plotted on a linear scale; minimum and maximum void ratio are identified for reference.

Figure 5. Pressure versus time for the piezoprobe deployment to 53.66 mbsf in Site 1244C on 14 July 2002. (A) Long term pressure record during the time the piezoprobe was near the seafloor. Hydrostatic pressure (u_h) and overburden stress (s_v) for the depth of the piezoprobe penetration are shown. The piezoprobe deployment events are identified by number and are explained in Table 1. (B) Expanded view of the pressure prior to penetration. These data are generally used to estimate hydrostatic pressure. (C) Expanded view of the end of the dissipation profile. Piezoprobe pressure equilibrates to approximately the hydrostatic pressure.

Figure 6. Comparison of piezoprobe pressure dissipation and DVTP-P pressure dissipation. The DVTP-P has a higher pressure than the piezoprobe during and after insertion; maximum pressure is 10.55 MPa for the DVTP-P versus 10.29 MPa for the piezoprobe. Hydrostatic pressure (u_h) and overburden stress (s_v) at the piezoprobe deployment depth are shown for reference.

Figure 7. (A) Excess pore pressure ratio. Assuming that the *in situ* pressure is hydrostatic (u_h), the piezoprobe has dissipated 90% of its induced pressure while the DVTP-P has dissipated approximately 80% of its induced pressure. (B) Normalized pore pressure for the piezoprobe and DVTP-P. The piezoprobe has an initial pressure that is approximately two times the inferred *in situ* effective stress (σ_{vh}'). The DVTP-P pressure has a higher insertion pressure that only declines to approximately the *in situ* hydrostatic effective stress (normalized pressure = 1).

Figure 8. (A) Pore pressure ratio dissipation plots in linear time for the piezoprobe data assuming u^* equals 9.5 MPa (solid grey line) or 9.6 MPa (solid black line). Modeled pore pressure ratio

dissipation plots in linear time are also shown assuming hydraulic conductivity is 1.4×10^{-8} cm/sec (dotted line) or 1.9×10^{-8} cm/sec (dashed line). Model results with either hydraulic conductivity are most similar to piezoprobe data assuming u^* equals 9.5 MPa (B) Pore pressure ratio dissipation plots in log time for the piezoprobe data assuming u^* equals 9.5 MPa (solid grey line) or 9.6 MPa (solid black line). Modeled pore pressure ratio dissipation plots in log time are also shown assuming hydraulic conductivity is 1.4×10^{-8} cm/sec (dotted line) or 1.9×10^{-8} cm/sec (dashed line). An *in situ* pressure of 9.5 MPa is consistent with model results. (C) Inverse time-pressure extrapolation to estimate *in situ* pore pressure for piezoprobe and DVTP-P data. DVTP-P data yield an estimate of 9.71 MPa whereas the piezoprobe data yield an estimate of 9.59 MPa. u^* values of 9.5 and 9.6 MPa used in (8A) and (8B) are shown for reference. u_h is also shown for reference.

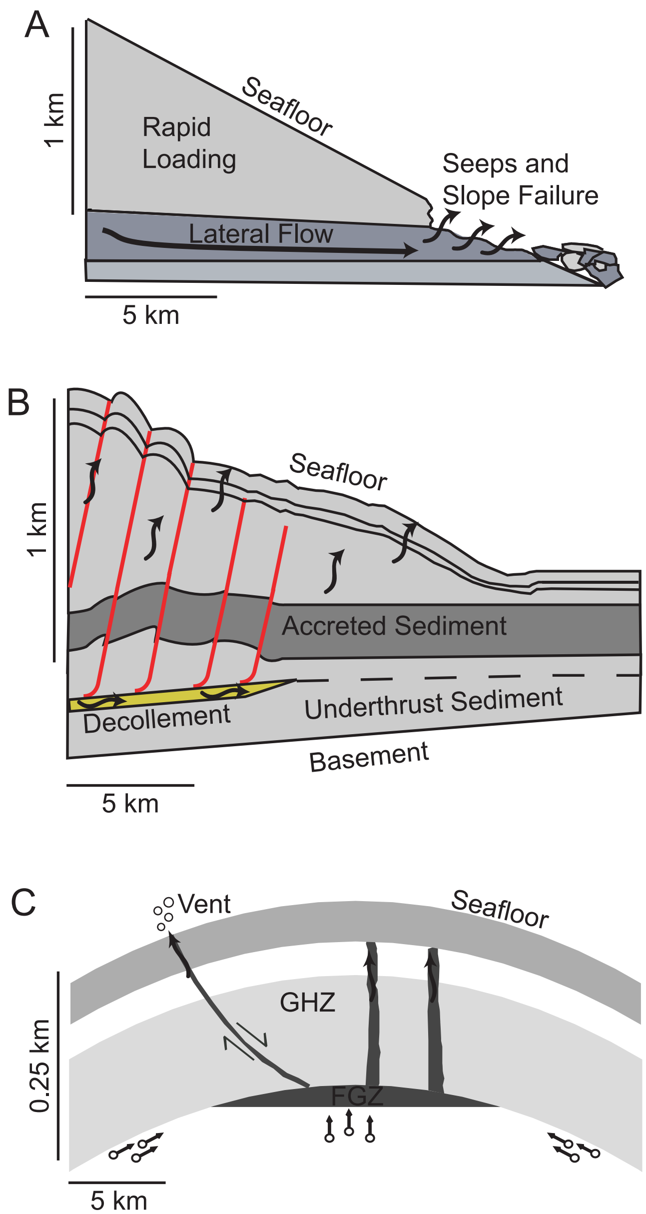

Figure 1
Dugan

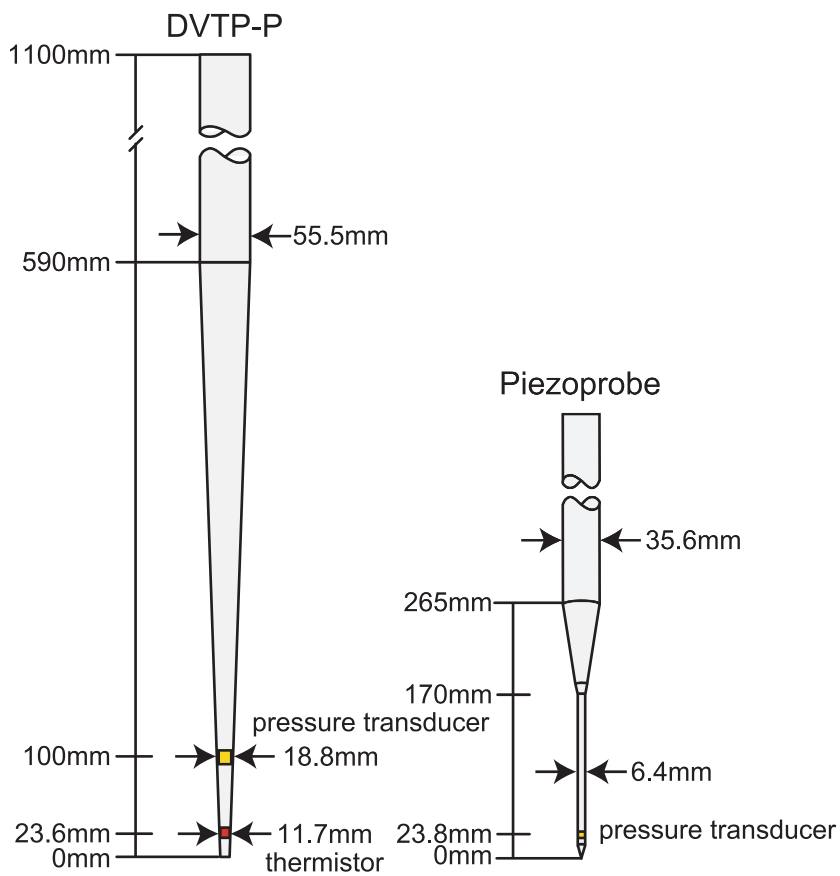

Figure 2
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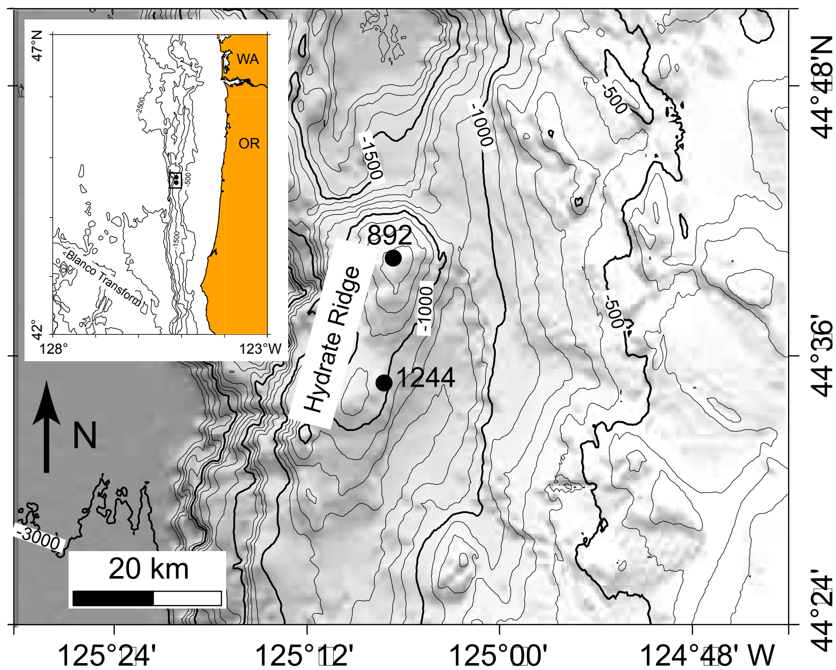
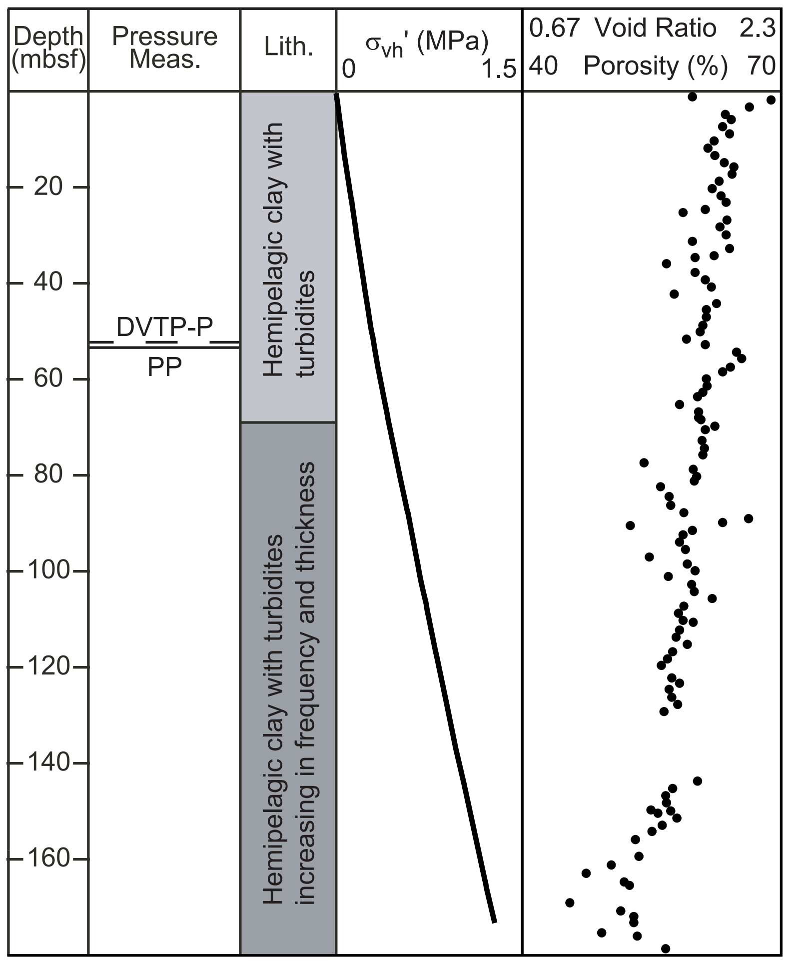


Figure 3
Dugan

Site 1244



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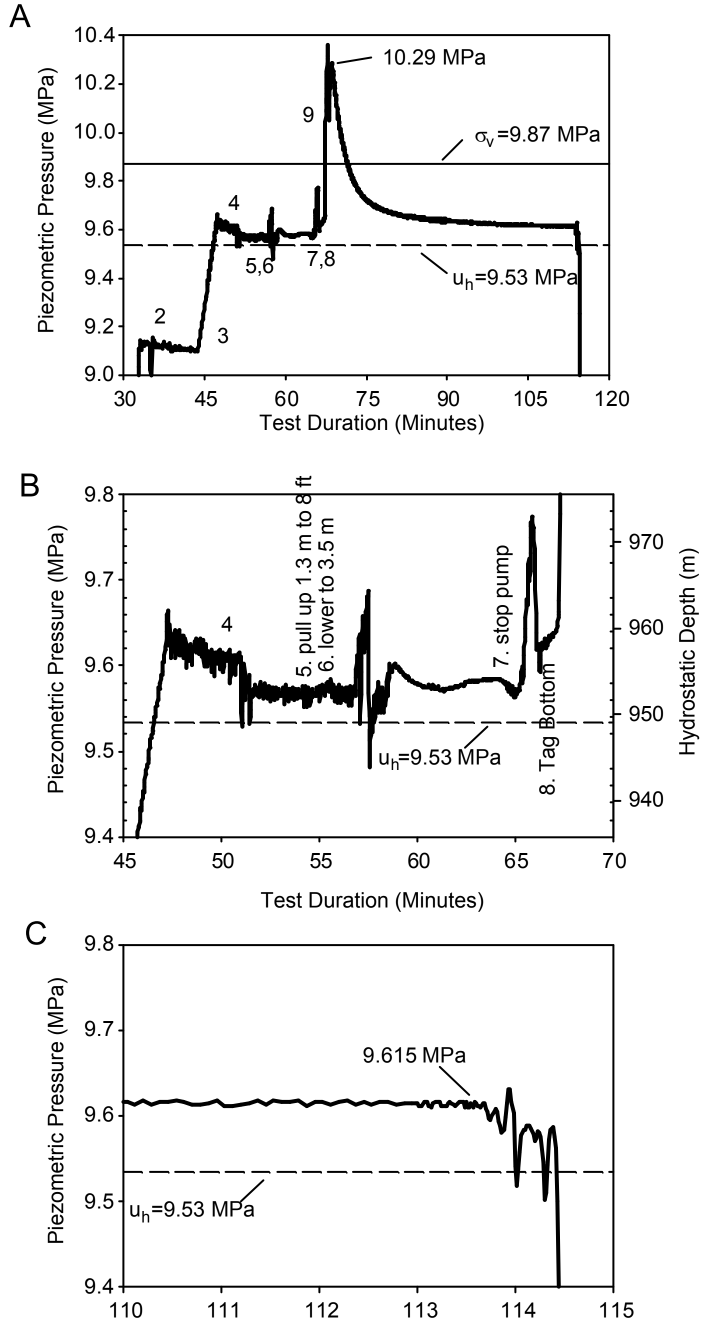

Figure 5
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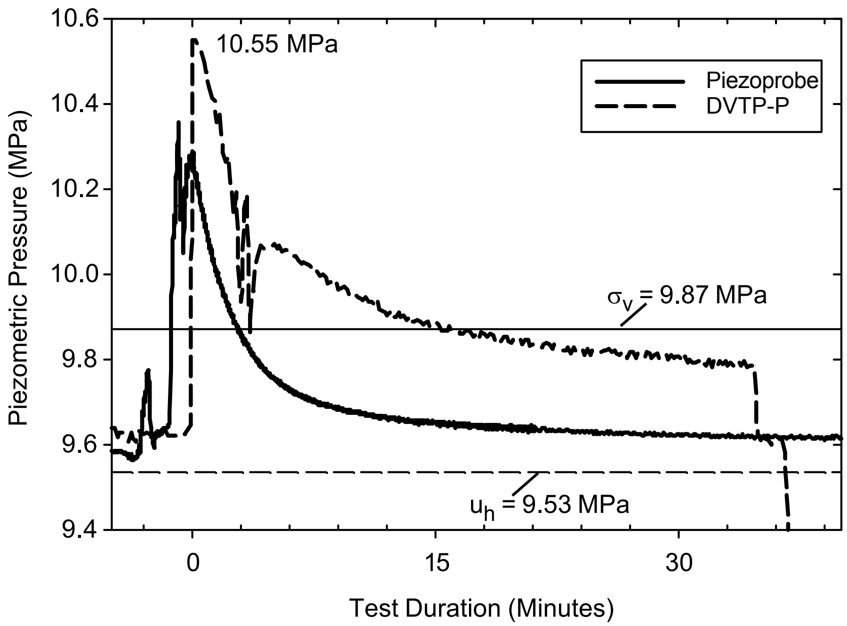

Figure 6
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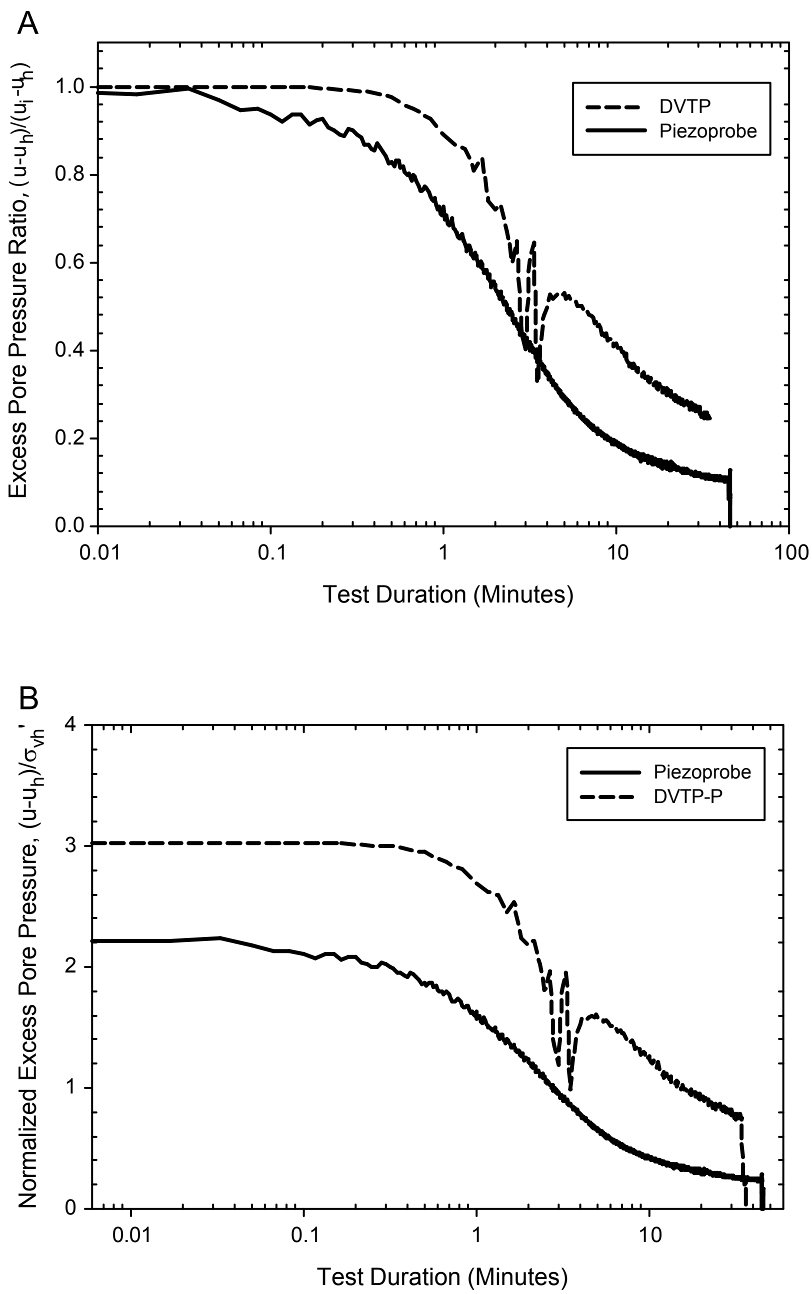

Figure 7
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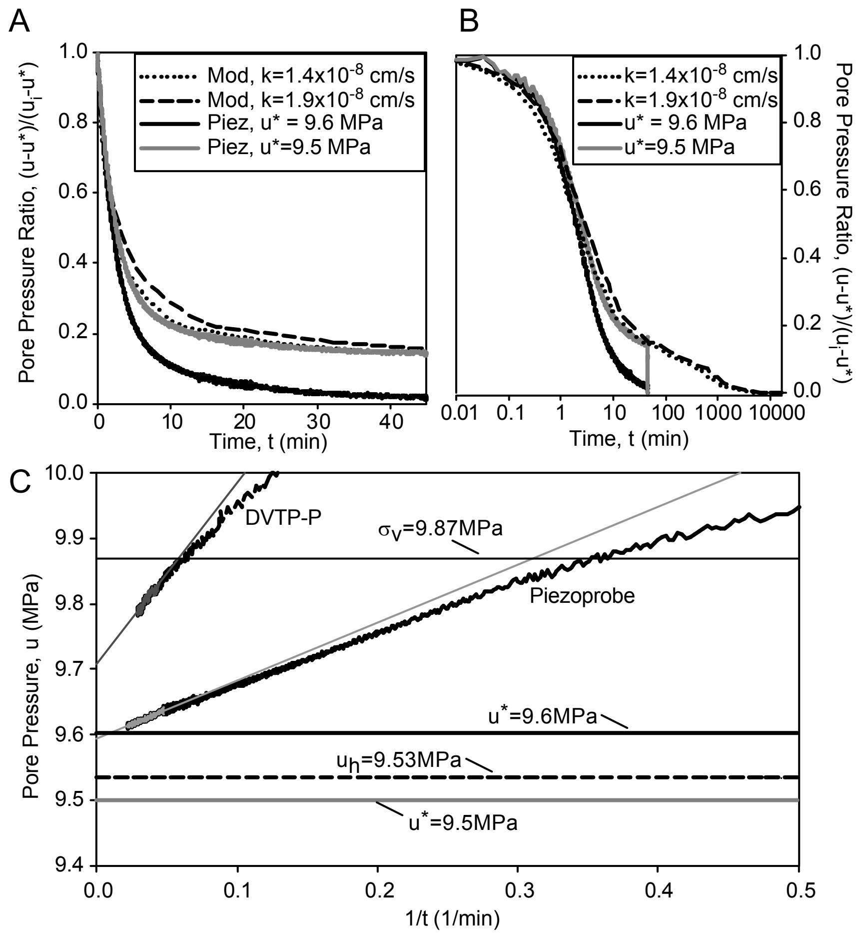

Figure 8
Dugan

APPENDIX C

GAMMA DENSITY LOGGING OF COLD, PRESSURIZED HYDRATE CORES FROM ODP LEG 204.

Peter Schultheiss
Geotek Ltd., U.K.

(4 page Report, plus 35 Figures)

Gamma Density Logging
of Cold, Pressurized Hydrate Cores
from
ODP Leg 204

October 2002

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Gamma Density Logging of Cold, Pressurized Hydrate Cores from ODP Leg 204

Cores recovered at the end of ODP Leg 204 from the summit of Hydrate ridge (Site 1249) were rapidly stored to preserve the methane hydrate for further analysis. It is inevitable that some dissociation of hydrate will have occurred during the coring process as a result of a decrease in pressure and the increase in temperature during the core retrieval process. However, we knew from previous coring during the Leg that massive hydrate still existed in cores from Site 1249 when examined on the catwalk. For the cores that were preserved under pressure, significant efforts were made to ensure that the time between coring at the seabed and cutting the core into sections was minimized. In this way the minimum amount of dissociation will have occurred and the maximum amount of hydrate will be preserved. Some of the core sections were then rapidly frozen and stored in liquid nitrogen while others were rapidly repressurized in steel storage chambers (to about 500-600 psi) under methane gas and stored at around 4-5 ^{o}C. At these pressures and temperatures methane hydrates are stable and hence can be stored without any further dissociation occurring. All the samples were stored carefully under these conditions and shipped to ODP at College Station, Texas.

As a ‘quick look’ to determine the nature of the samples stored under pressure in the steel pressure vessels, the pressure vessels were subjected to gamma logging to determine the density structure. Logging took place at ODP using the GEOTEK vertical logging system during the period 7^{th} to 14^{th} October 2002. This was about 6 weeks after the samples had originally been recovered.

The cores were logged in the main core store at around 4-5 ^{o}C. A standard calibration section was run using aluminum and distilled water in a standard ODP liner placed inside one of the empty steel pressure vessels. This produced the calibration equation used to calculate density from the raw data:

$$D = -2.5066 * \mathrm{Ln}(CPS) + 23.81$$

Where: D = density (g/cc) and CPS = gamma Counts Per Second

Each core section was logged from the top down at 0.5cm intervals. Count times were longer than normally used on ODP cores because of the steel pressure cylinder used (OD approx 90 mm, wall thickness approx. 7.5 mm.) Typical count rates in sediments were 7000 cps; therefore, a minimum total count time of 25 s was used. These count times produced total counts in excess of 150,000 counts, resulting in gamma density values that will have a precision of about 1-2%.

The data are plotted as density profiles. The bottom of the pressure vessel was used as a section depth reference; the last data point before the steel end cap was assigned a depth of 150 cm. Short core sections will appear to start at 80-90 cm.

Three different gamma density zones are identified:

1) greater than 1.4 g/cc – mainly sediment
2) 0.95 g/cc to 1.4 g/cc – sediment plus gas, may include some hydrate
3) less than 0.95 g/cc – contains some gas

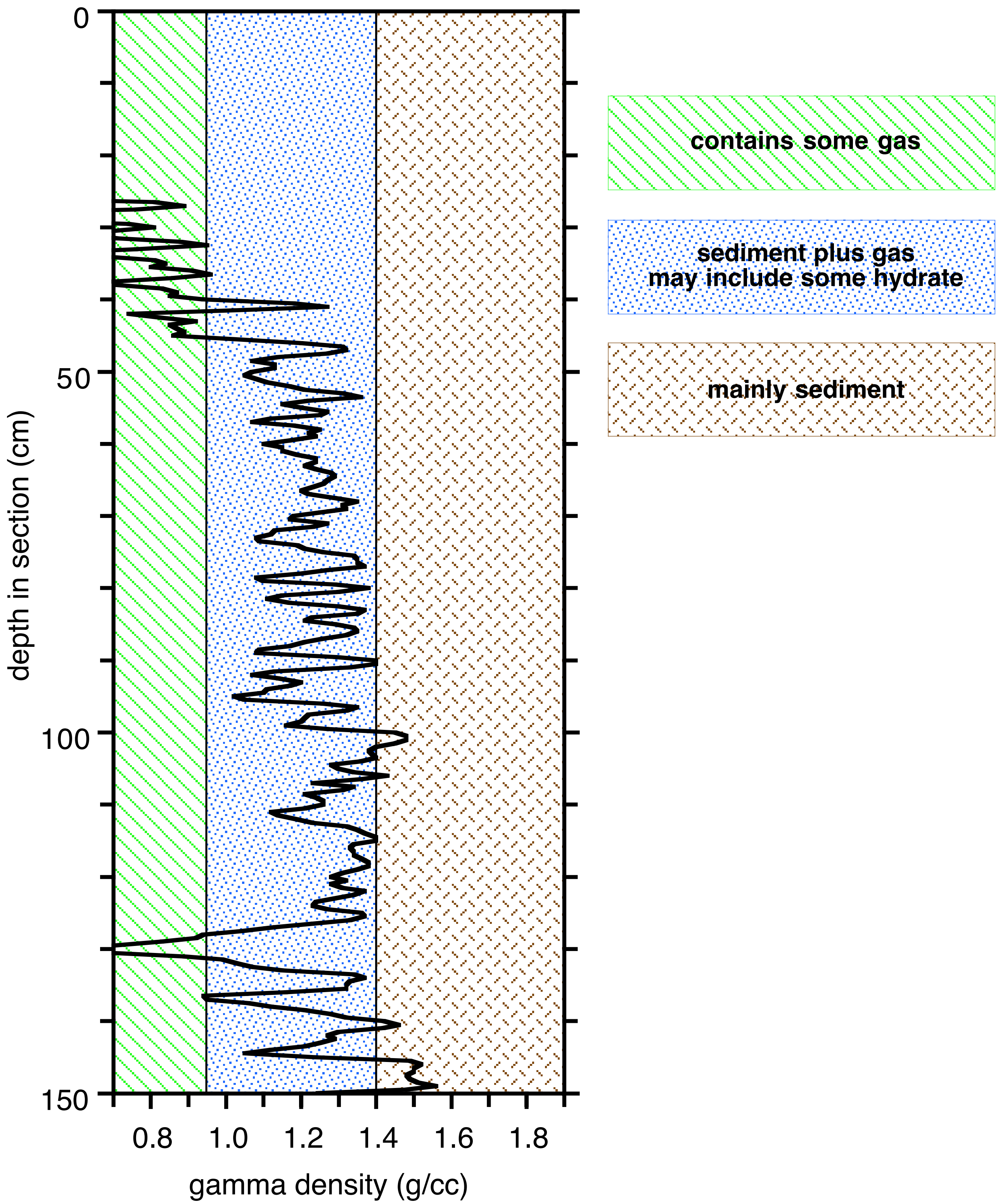
It should be remembered that the gamma density values represent the average density of a 5 mm diameter horizontal cylinder through the center of the core. Any values lower than 0.95 definitely contain some gas. Many (or possibly most) of the abundant low-density zones (0.95 to 1.4 g/cc) are sediment with sub-horizontal gas cracks. Densities above 1.4 g/cc are mainly sediment. There is no definitive method of ascertaining the existence of methane hydrate at any location in each core. However, the general nature of the density profiles in each core may act as a good guide to the occurrence of hydrates, especially as more information is gathered. For example, X-ray CT scanning may be able to determine more accurately the nature of the gas cracking, and hence allow an accurate assessment of the amounts of hydrate remaining in the core.

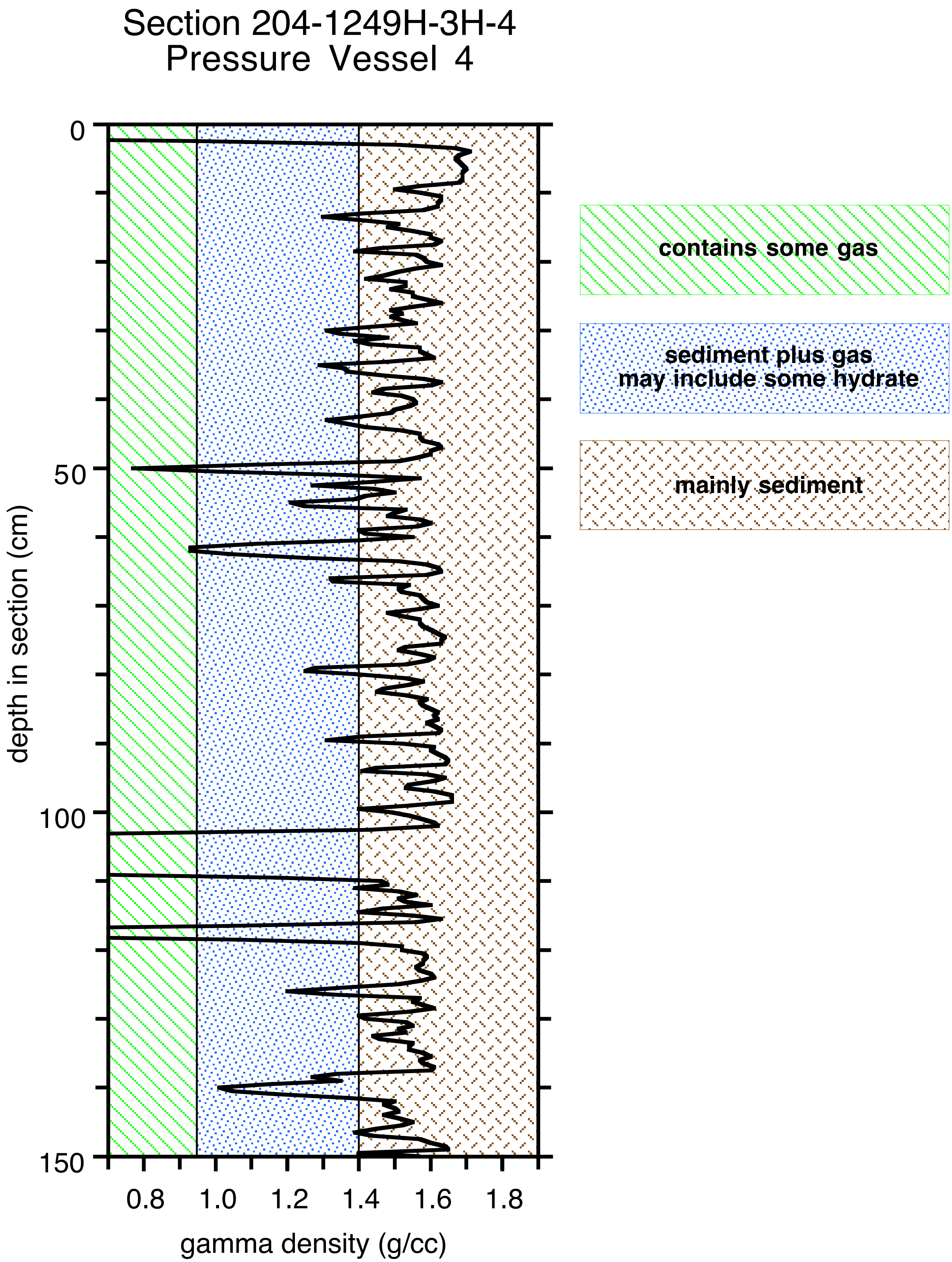
A summary table of the pressure vessels and cores is shown below. The pressures were recorded on 13^{th} October 2002.

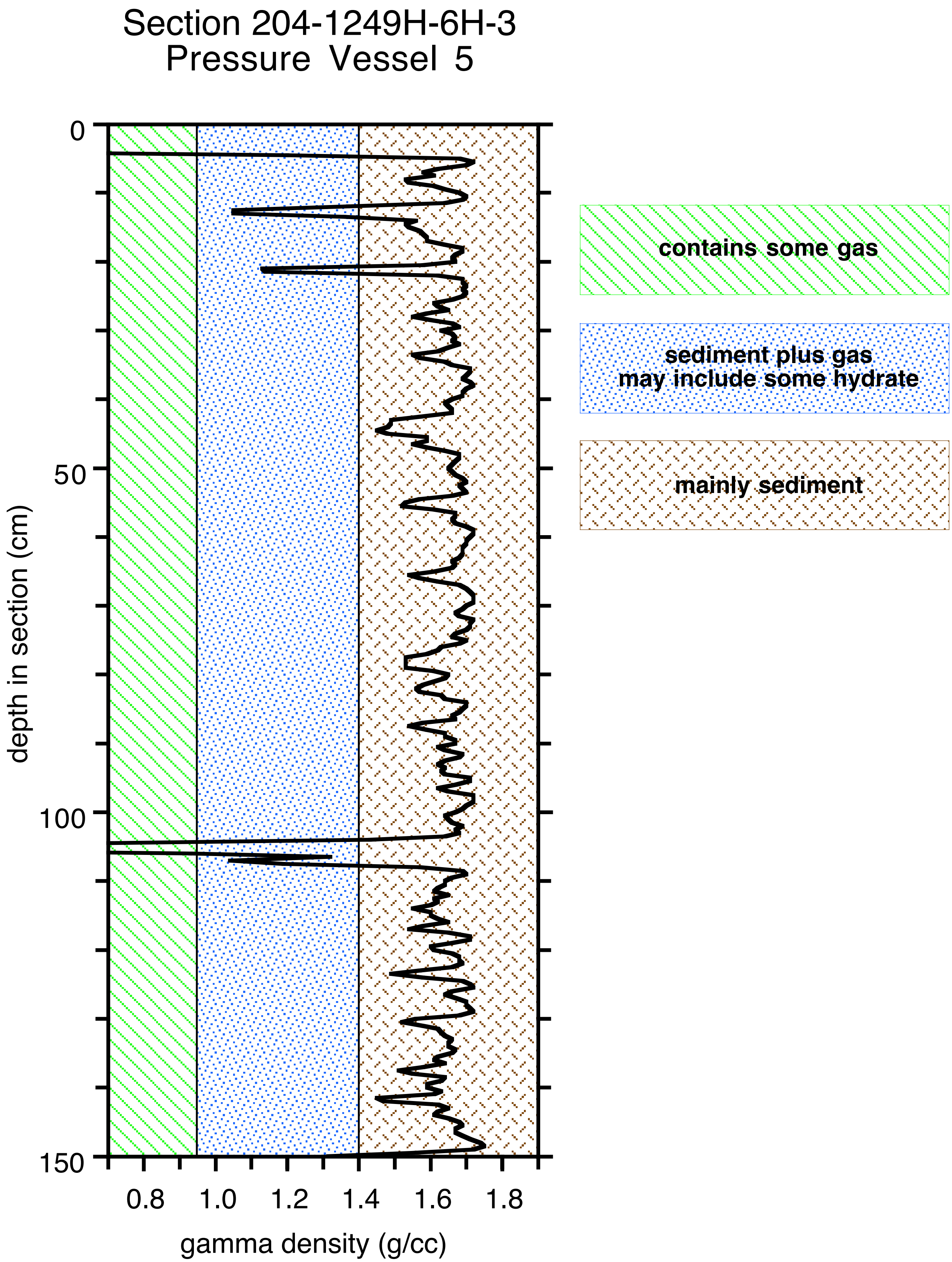
PV No	Core 204-1249-	Gamma Count Time s	Pressure psi		PV No	Core 204-1249-	Gamma Count Time s	Pressure psi
01	Empty	-	0		21	Empty	-	0
02	Empty	-	0		22	K-3H-2	25	540
03	G-3H-1	25	560		23	K-3H-1	30	540
04	H-3H-4	60	630		24	K-3H-5	30	560
05	H-6H-3	60	510		25	K-4H-1	60	550
06	H-3H-1	25	590		26	K-5H-4	25	530
07	H-5H-3	25	570		27	K-4H-2	25	650
08	H-6H-6	25	600		28	K-5H-1	25	500
09	H-4H-3	25	550		29	I-4H-6	25	700
10	H-4H-4	25	610		30	I-4H-2	25	570
11	H-6H-1	25	600		31	K-5H-2	30	490
12	H-5H-1	25	570		32	L-2H-2	25	600
13	H-5H-2	25	590		33	L-2H-3	60	590
14	H-6H-4	60	500		34	L-2H-1	25	520
15	H-6H-2	25	0		35	Empty	-	0
16	H-6H-5	25	560		36	L-4H-1	25	560
17	J-2H-1	25	650		37	L-4H-2	25	570
18	J-3H-4	25	660		38	L-3H-1	40	500
19	J-3H-1	30	640		39	Empty	-	0
20	I-4H-3	120	640		40	L-3H-3	40	540

Table 1. Pressure vessel (PV) numbers, core section identification, total gamma count time at each interval and the pressure reading for each vessel.

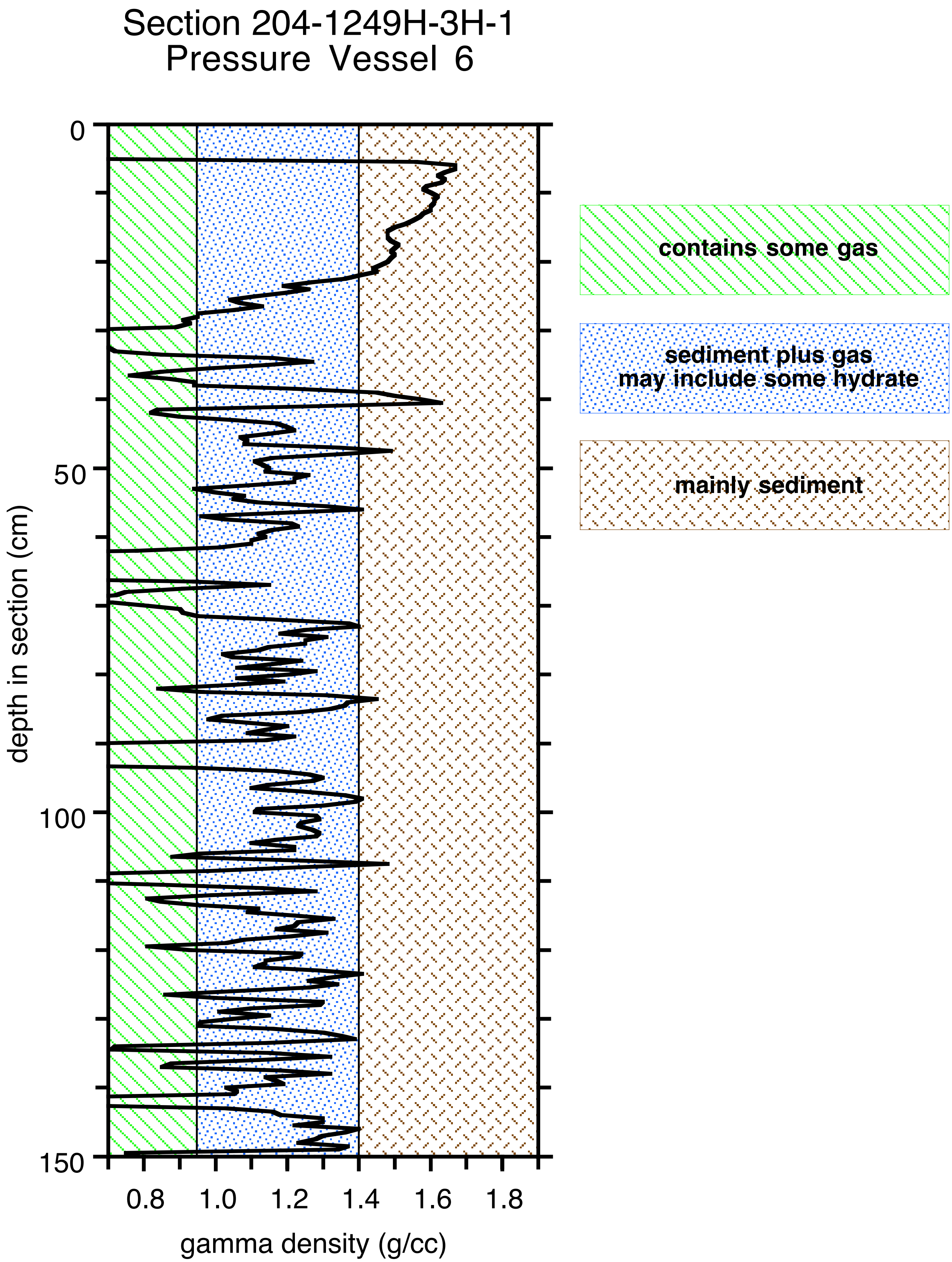
Section 204-1249G-3H-1
Pressure Vessel 3




Section 204-1249H-3H-4
Pressure Vessel 4
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

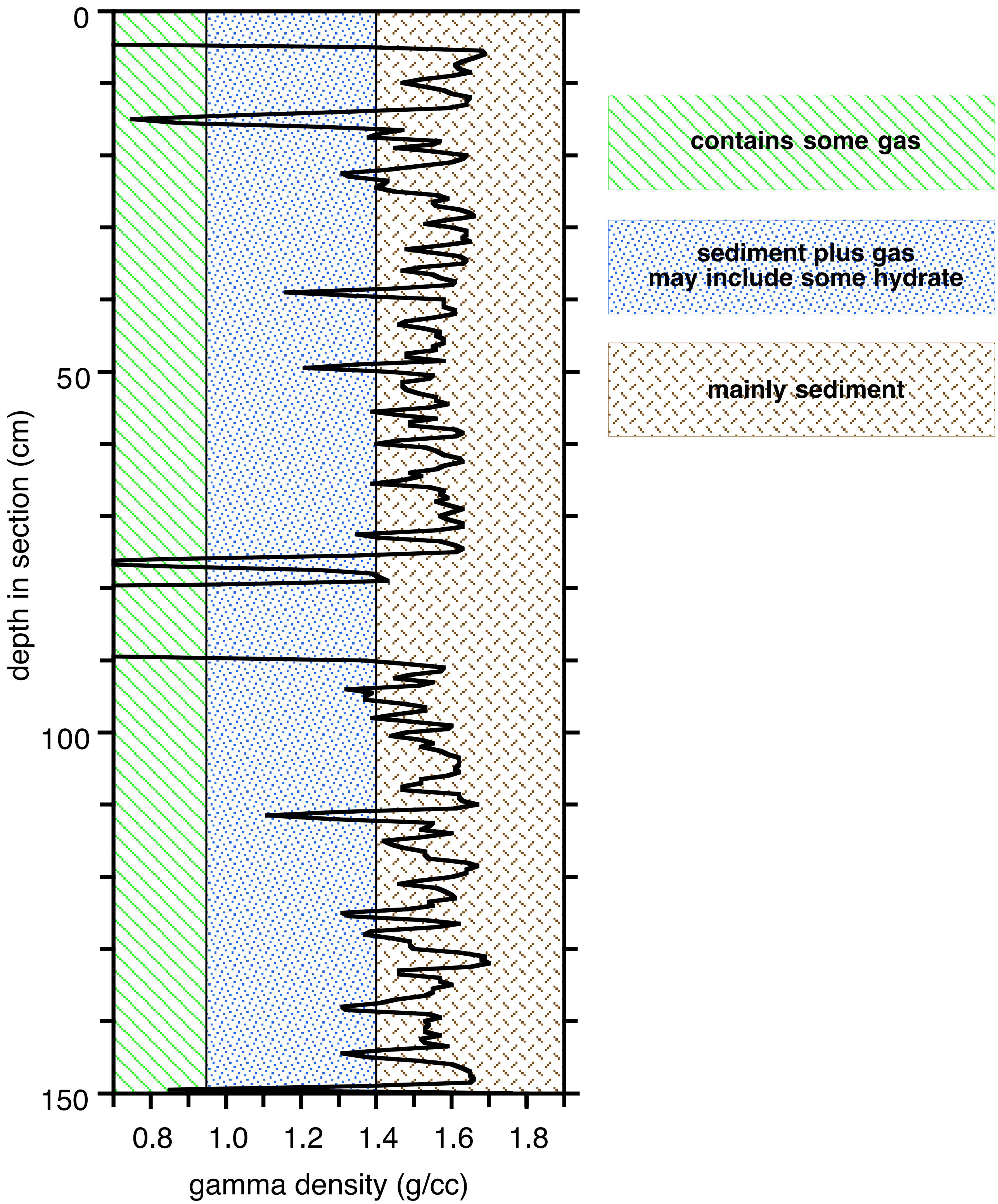


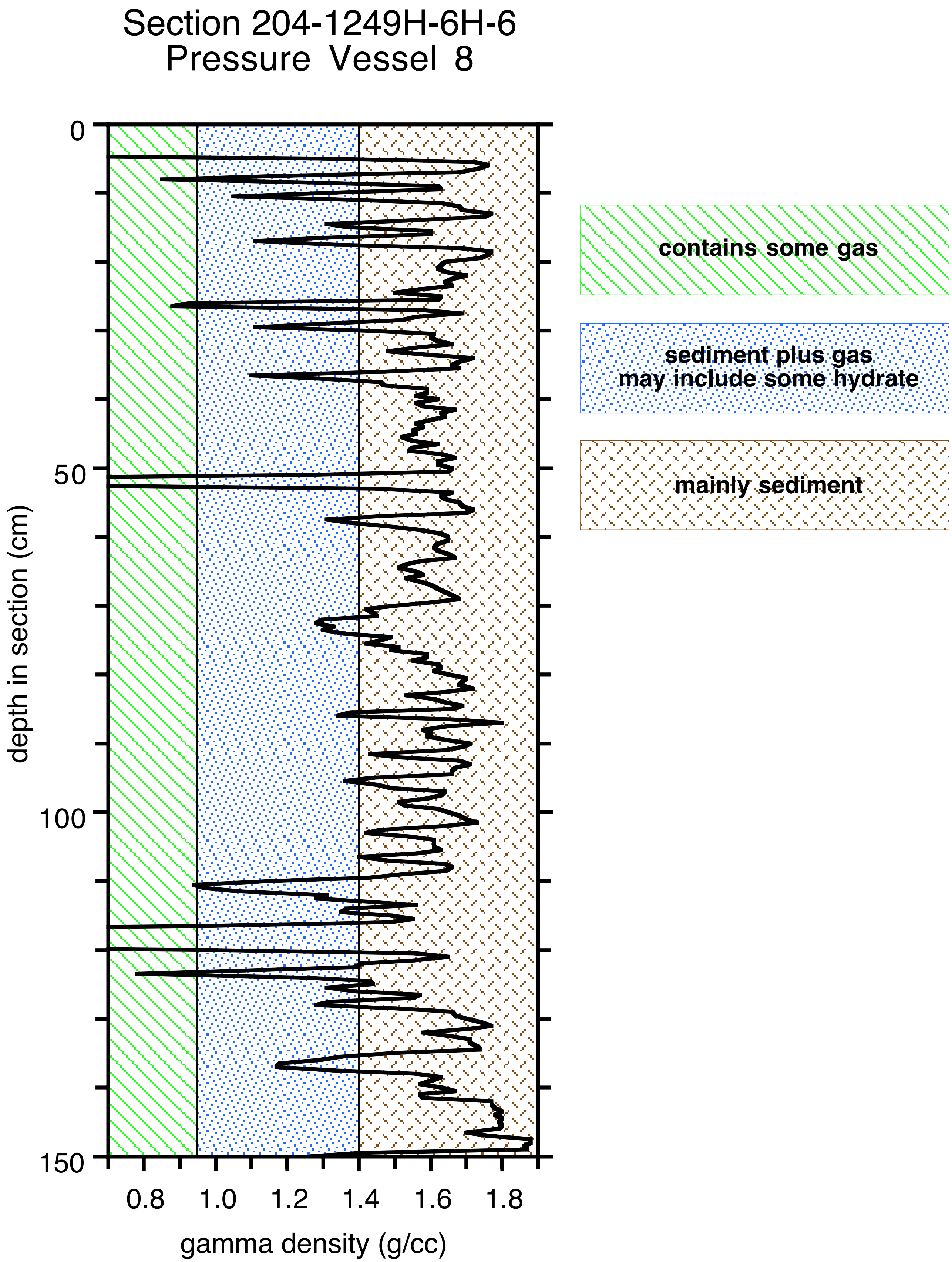
Section 204-1249H-6H-3
Pressure Vessel 5
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

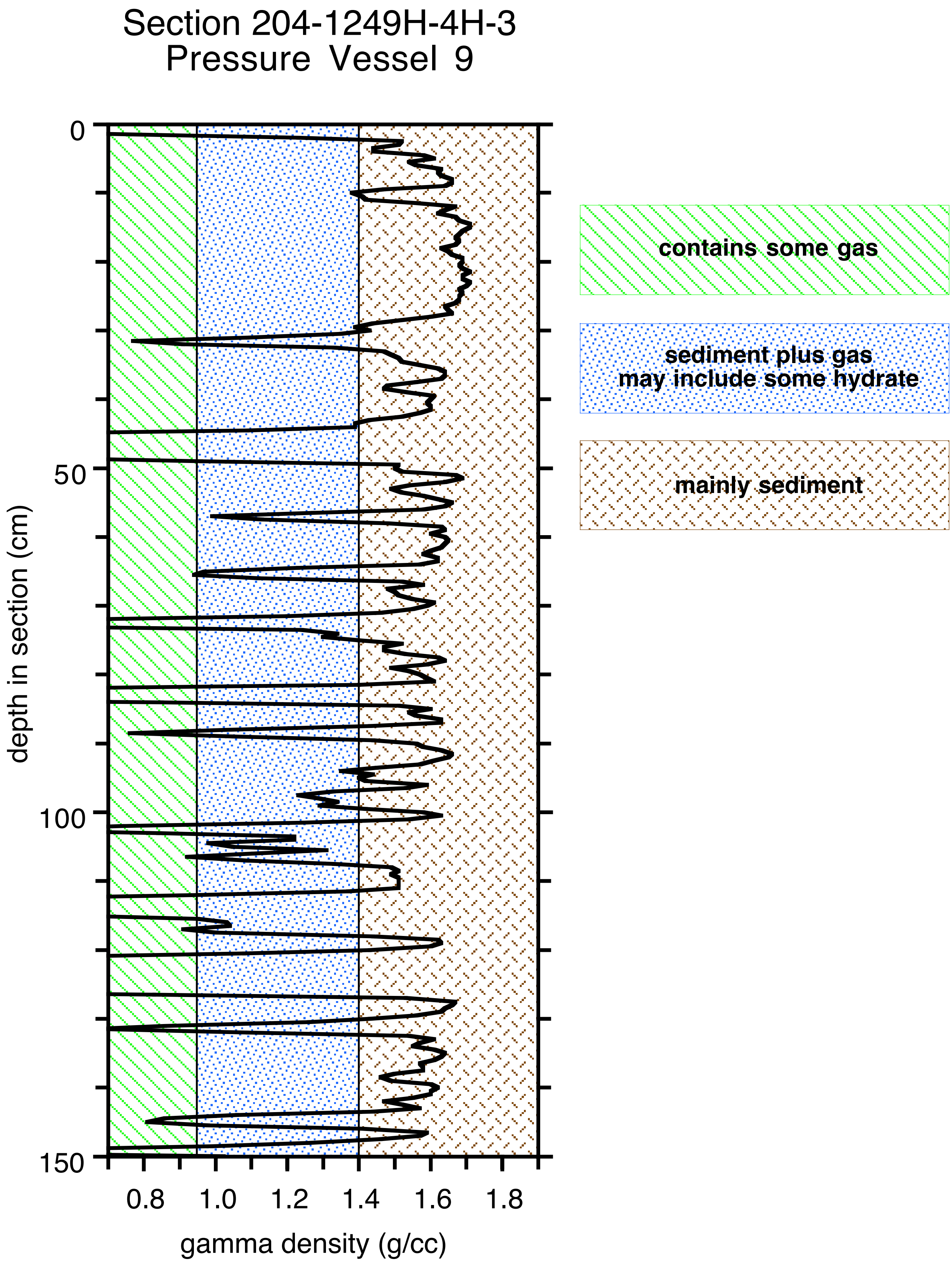


Section 204-1249H-3H-1
Pressure Vessel 6
depth in section (cm)
0
50
100
150
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

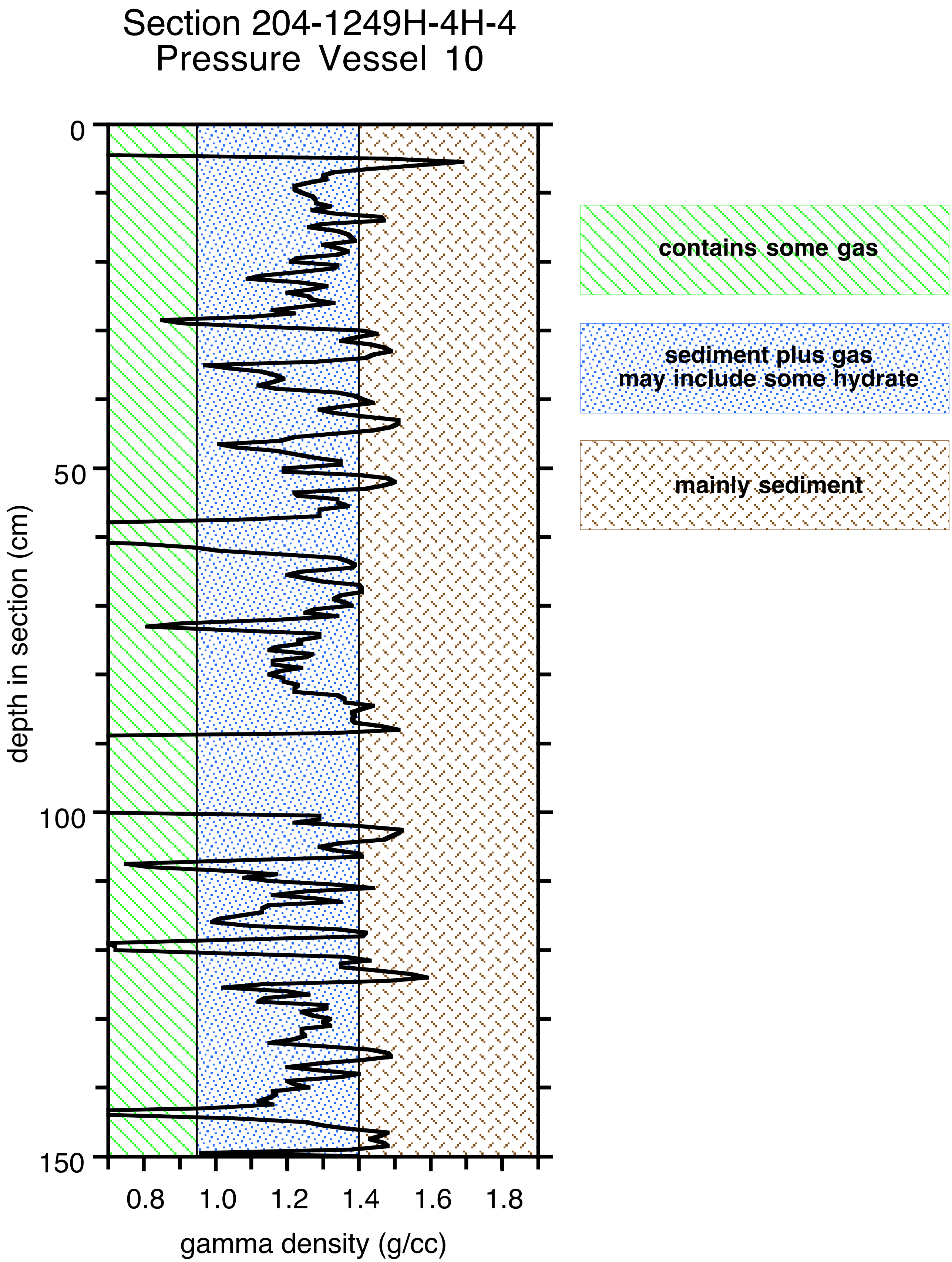
Section 204-1249H-5H-3
Pressure Vessel 7




Section 204-1249H-6H-6
Pressure Vessel 8
depth in section (cm)
0
50
100
150
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

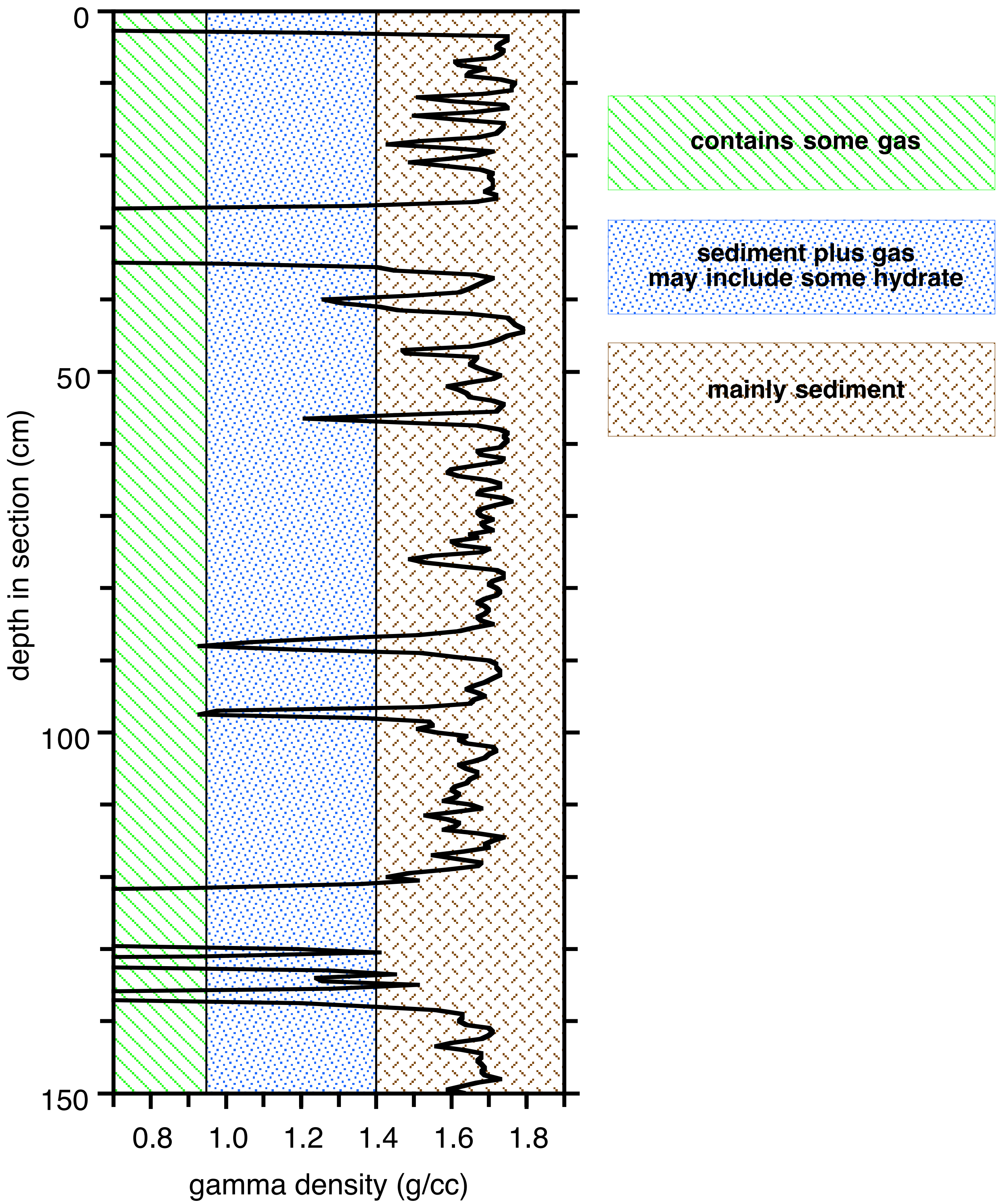


Section 204-1249H-4H-3
Pressure Vessel 9
depth in section (cm)
0
50
100
150
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

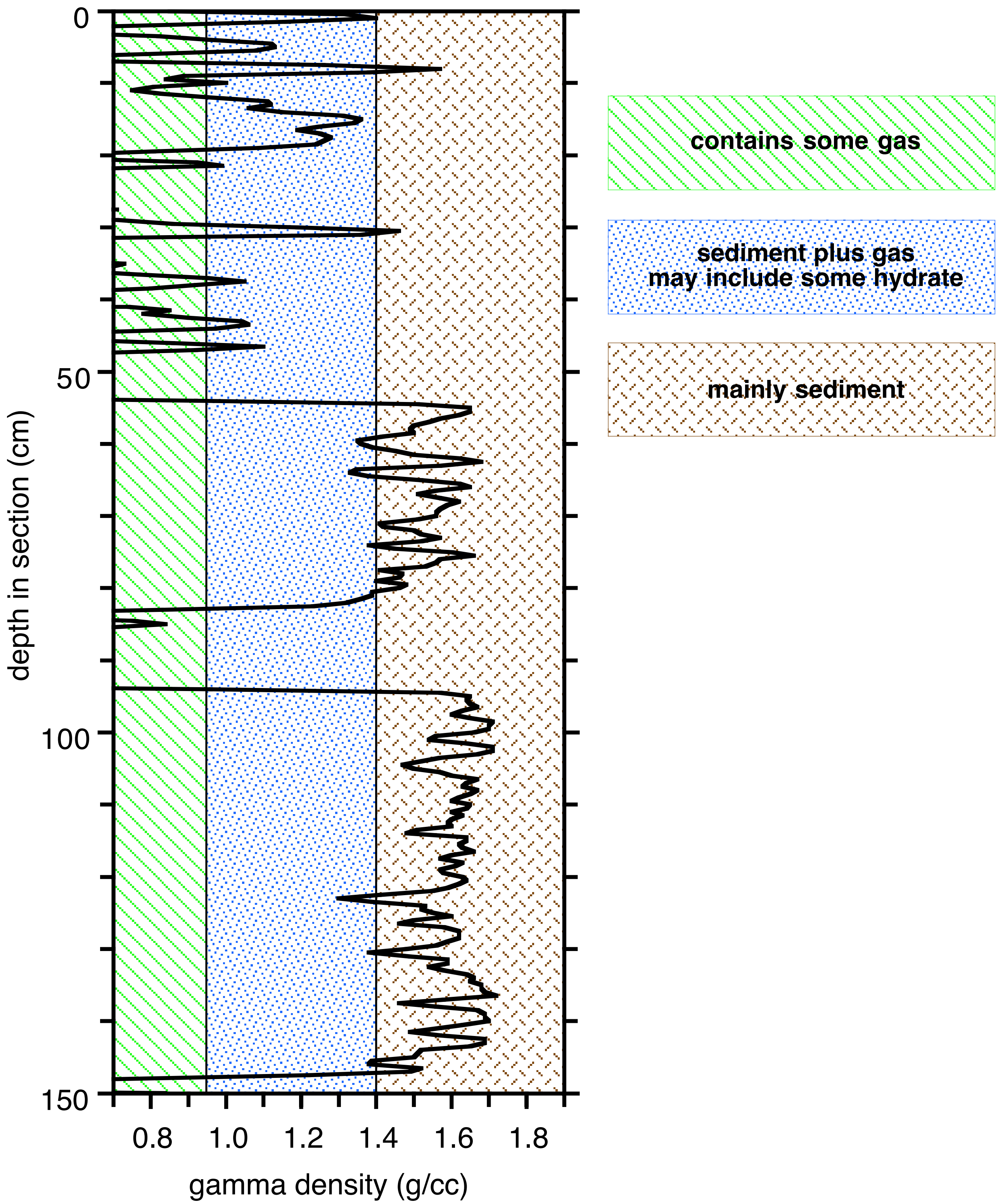


Section 204-1249H-4H-4
Pressure Vessel 10
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

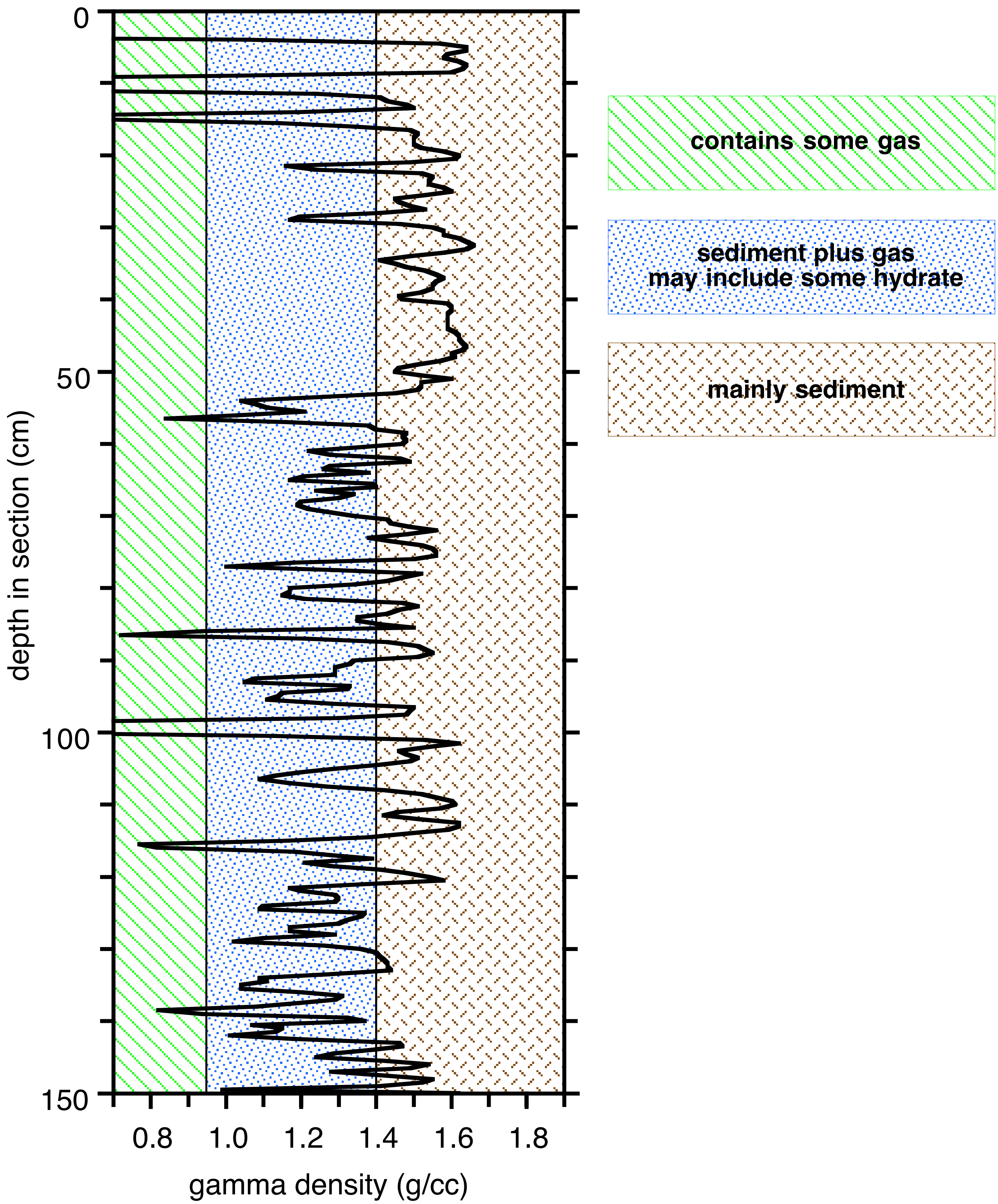
Section 204-1249H-6H-1
Pressure Vessel 11

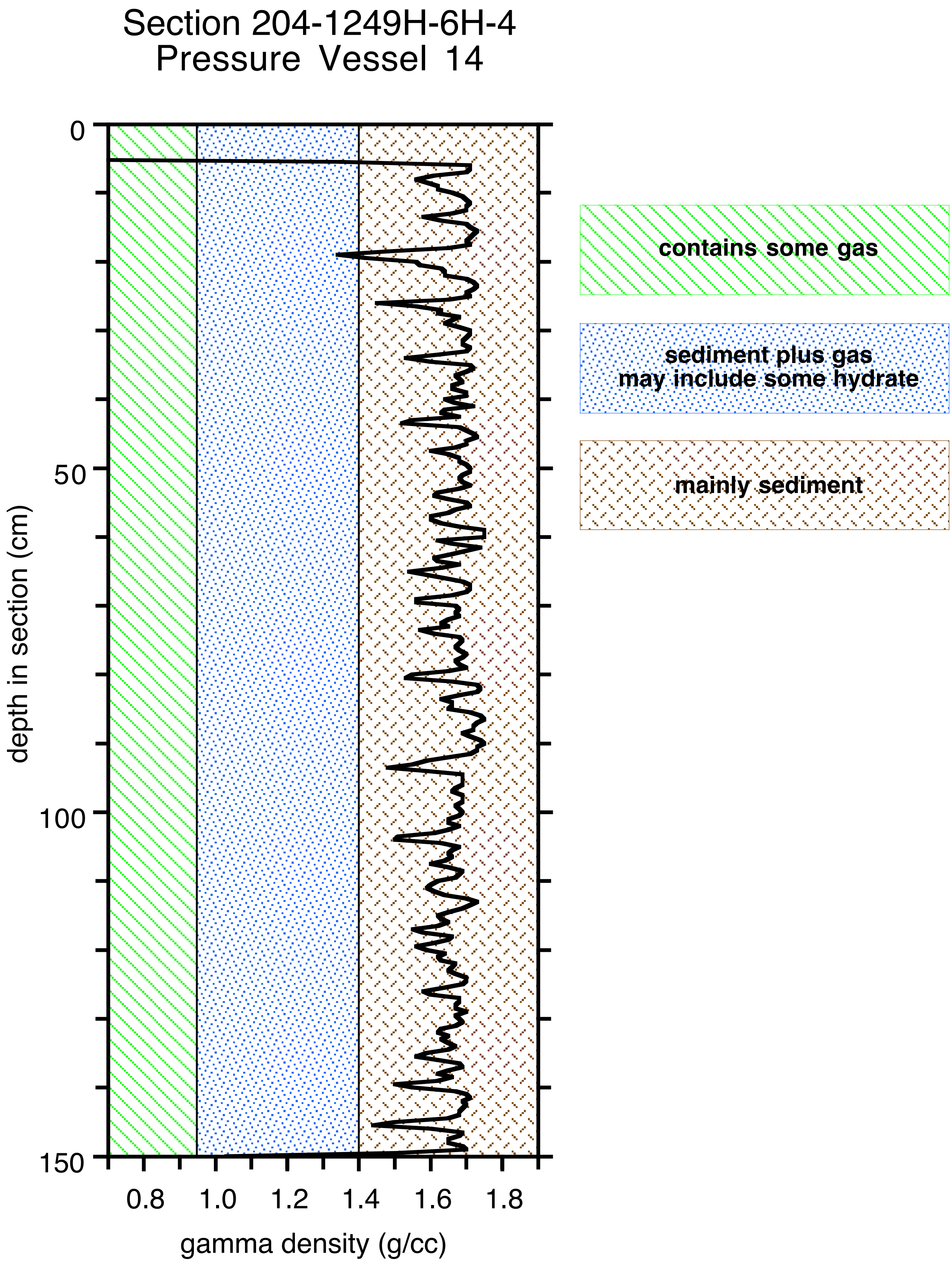


Section 204-1249H-5H-1
Pressure Vessel 12

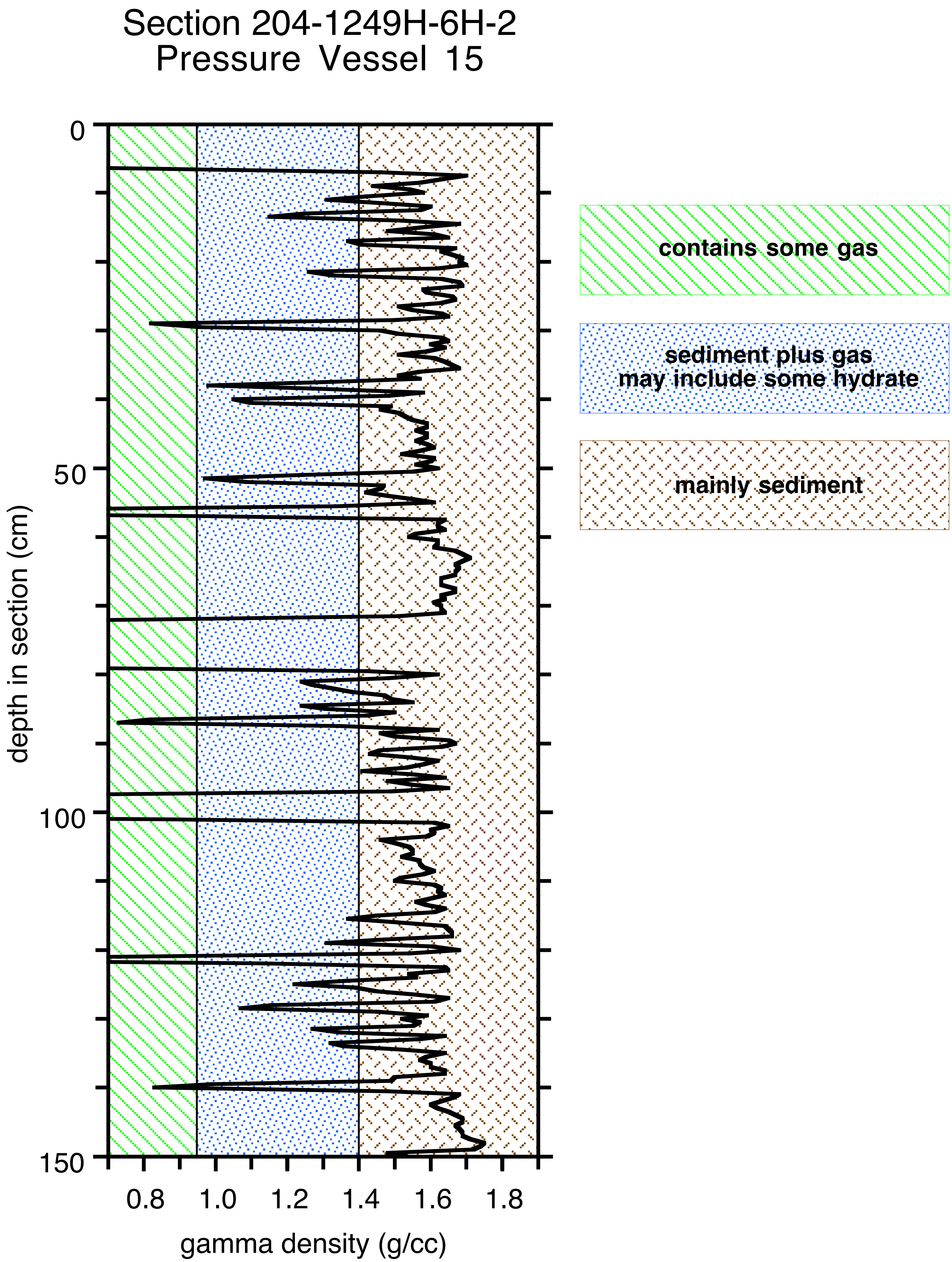


Section 204-1249H-5H-2
Pressure Vessel 13

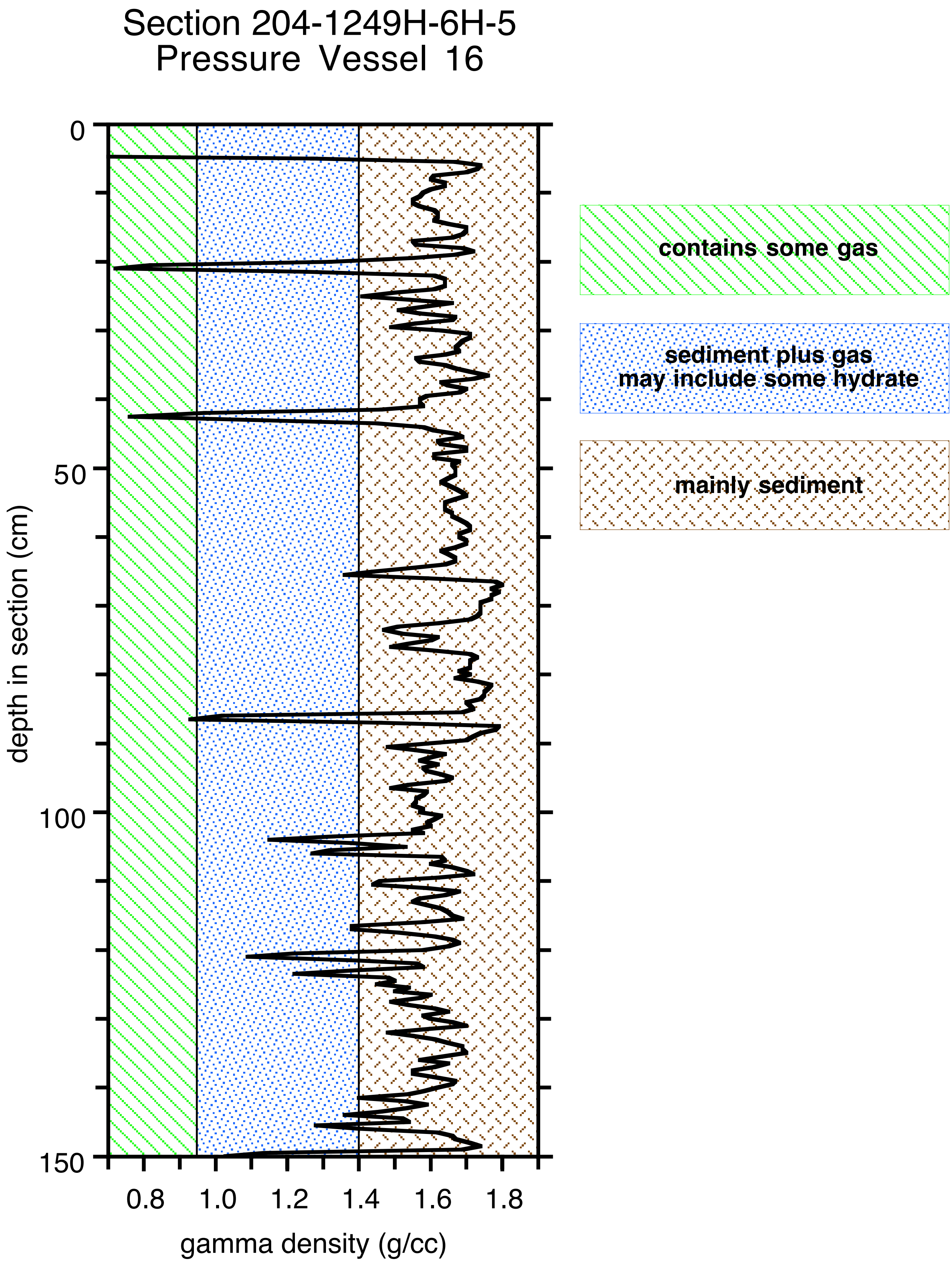




Section 204-1249H-6H-4
Pressure Vessel 14
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

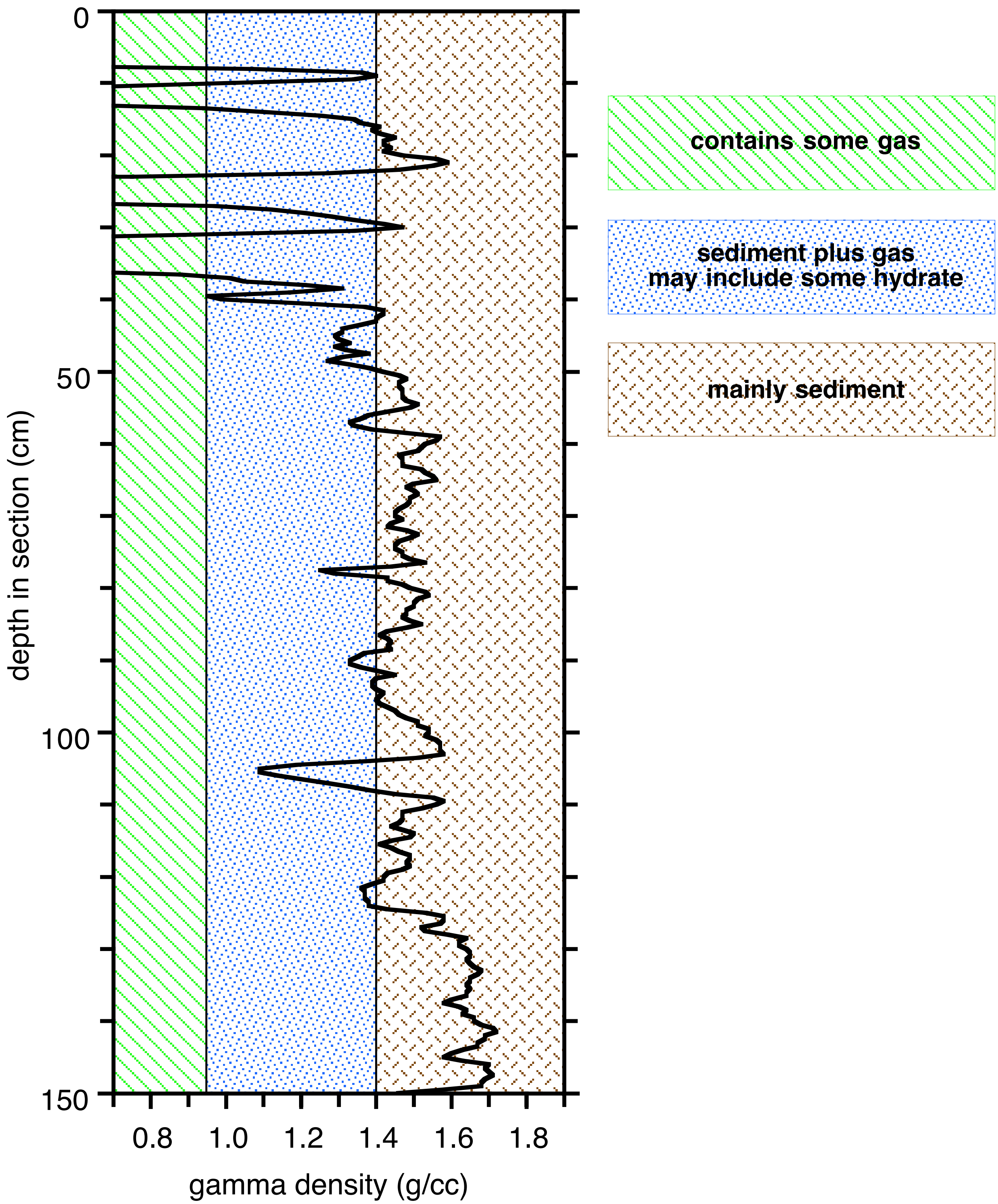


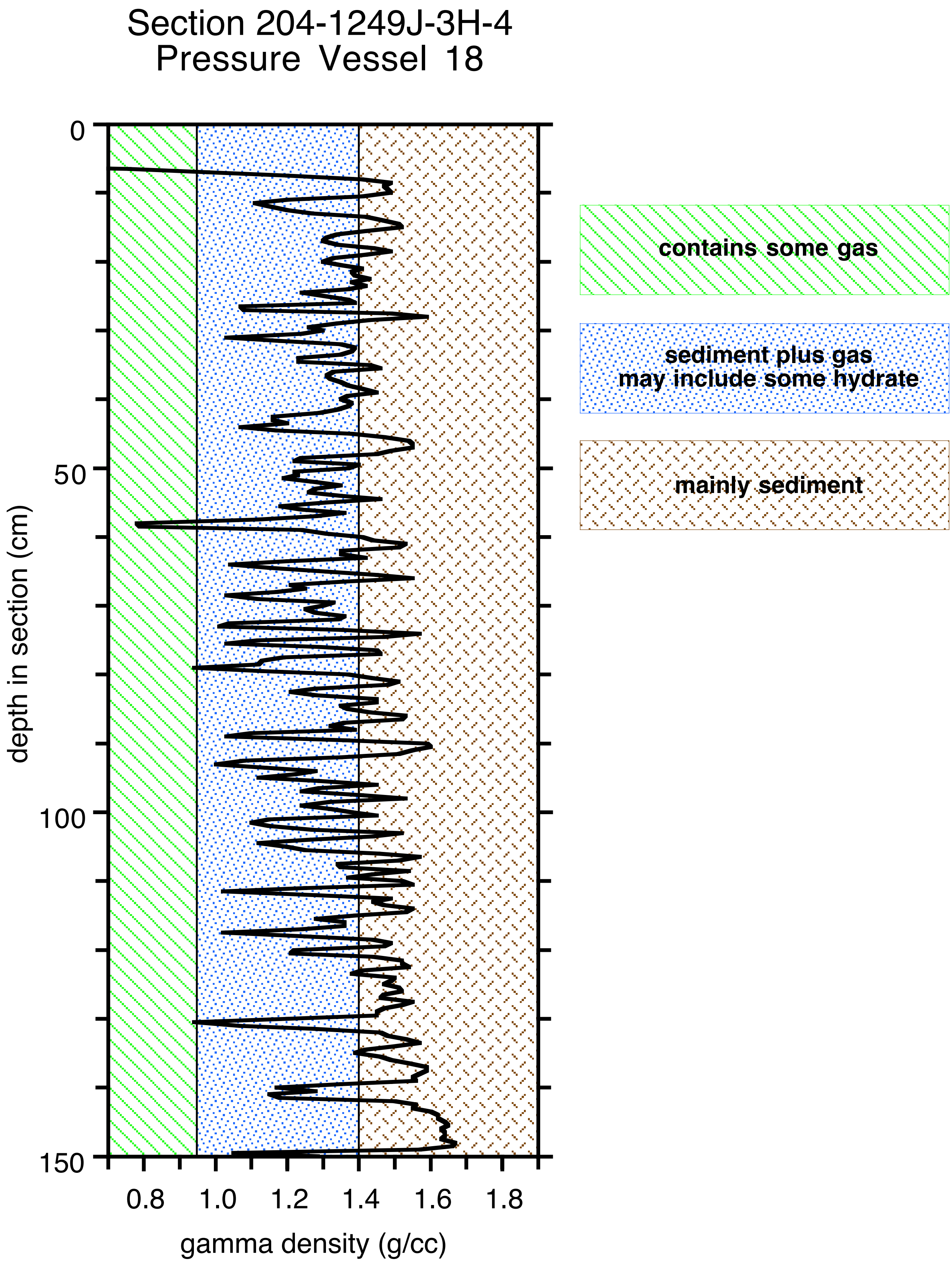
Section 204-1249H-6H-2
Pressure Vessel 15
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment



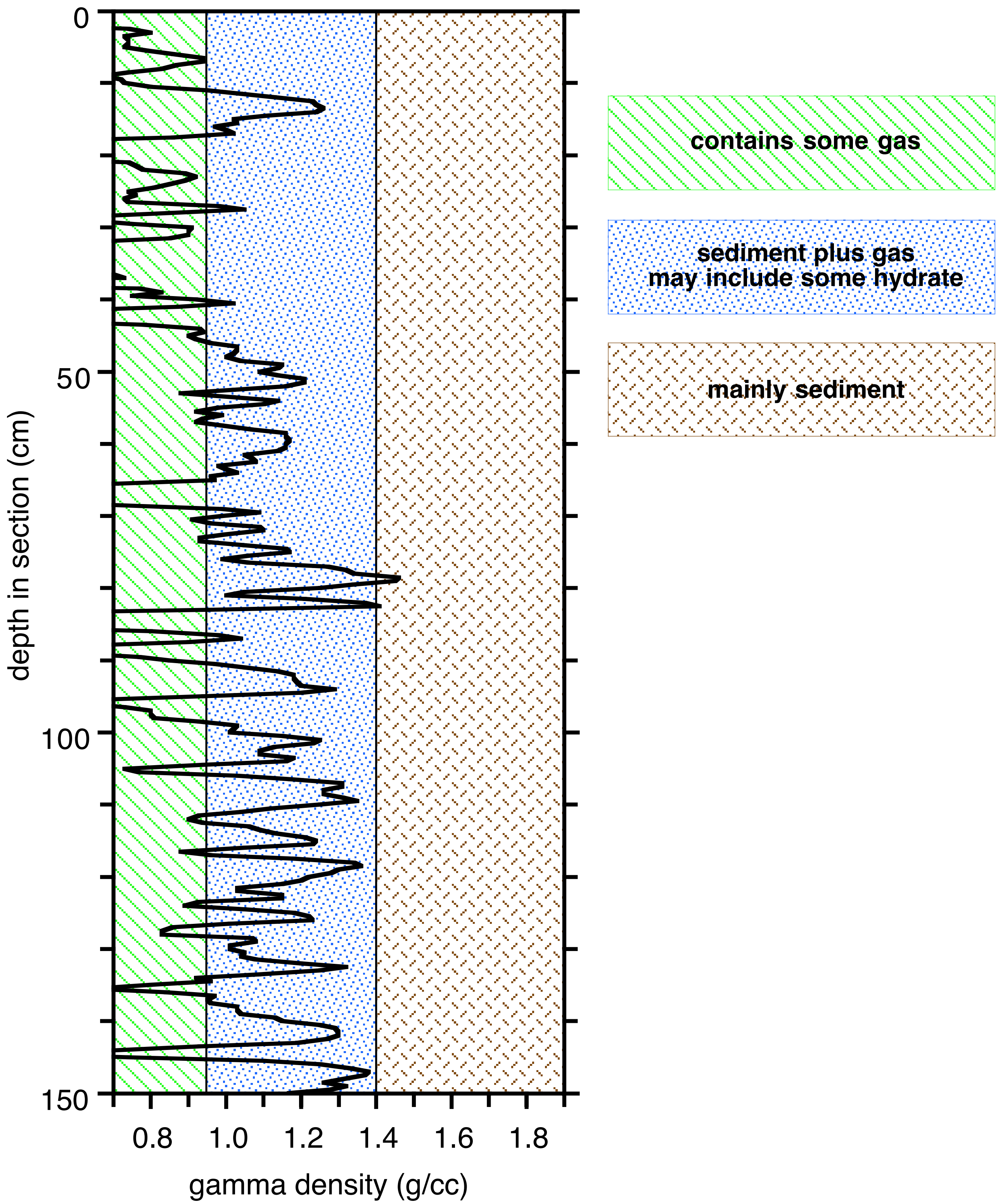
Section 204-1249H-6H-5
Pressure Vessel 16
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

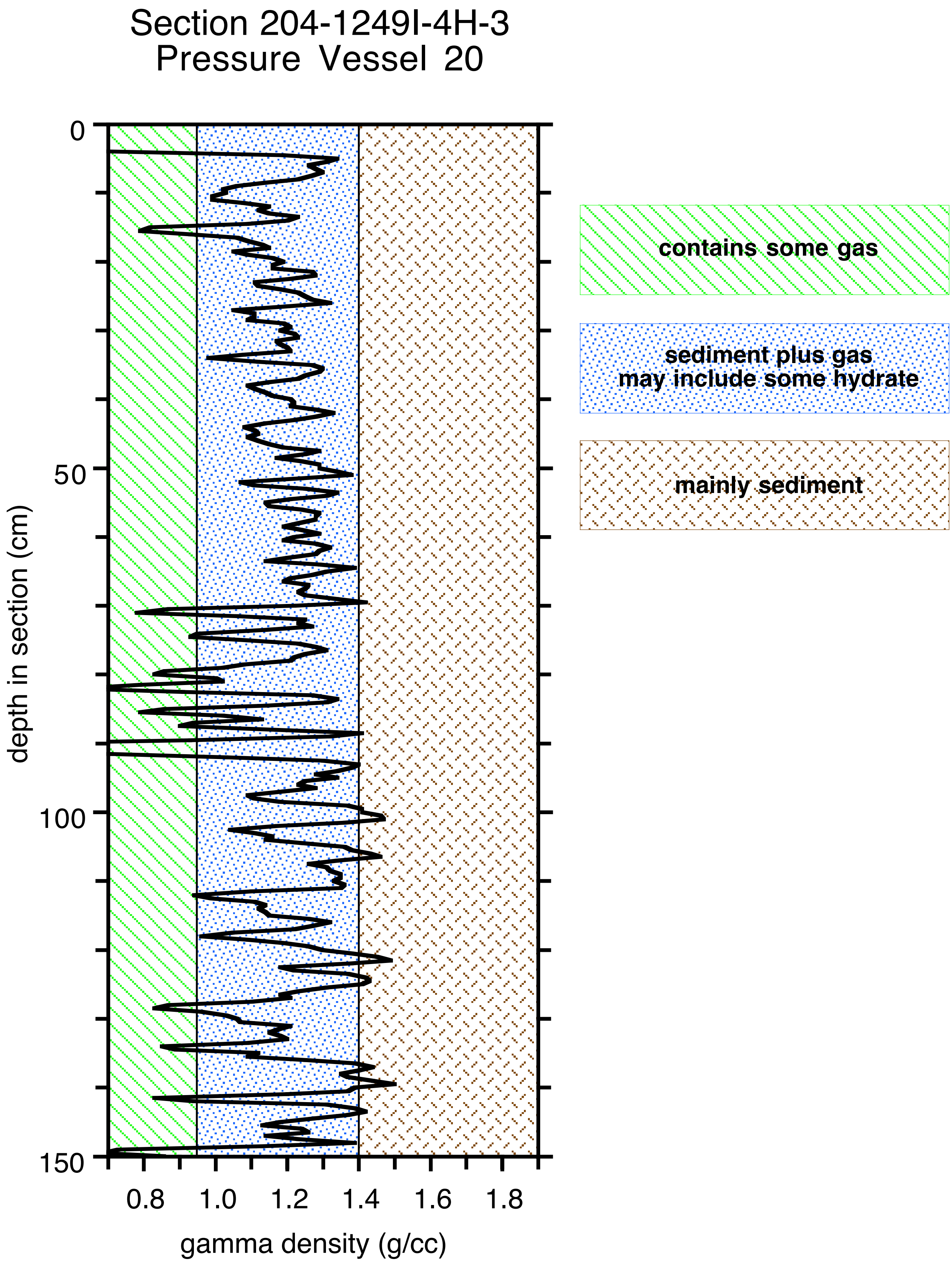
Section 204-1249J-2H-1
Pressure Vessel 17



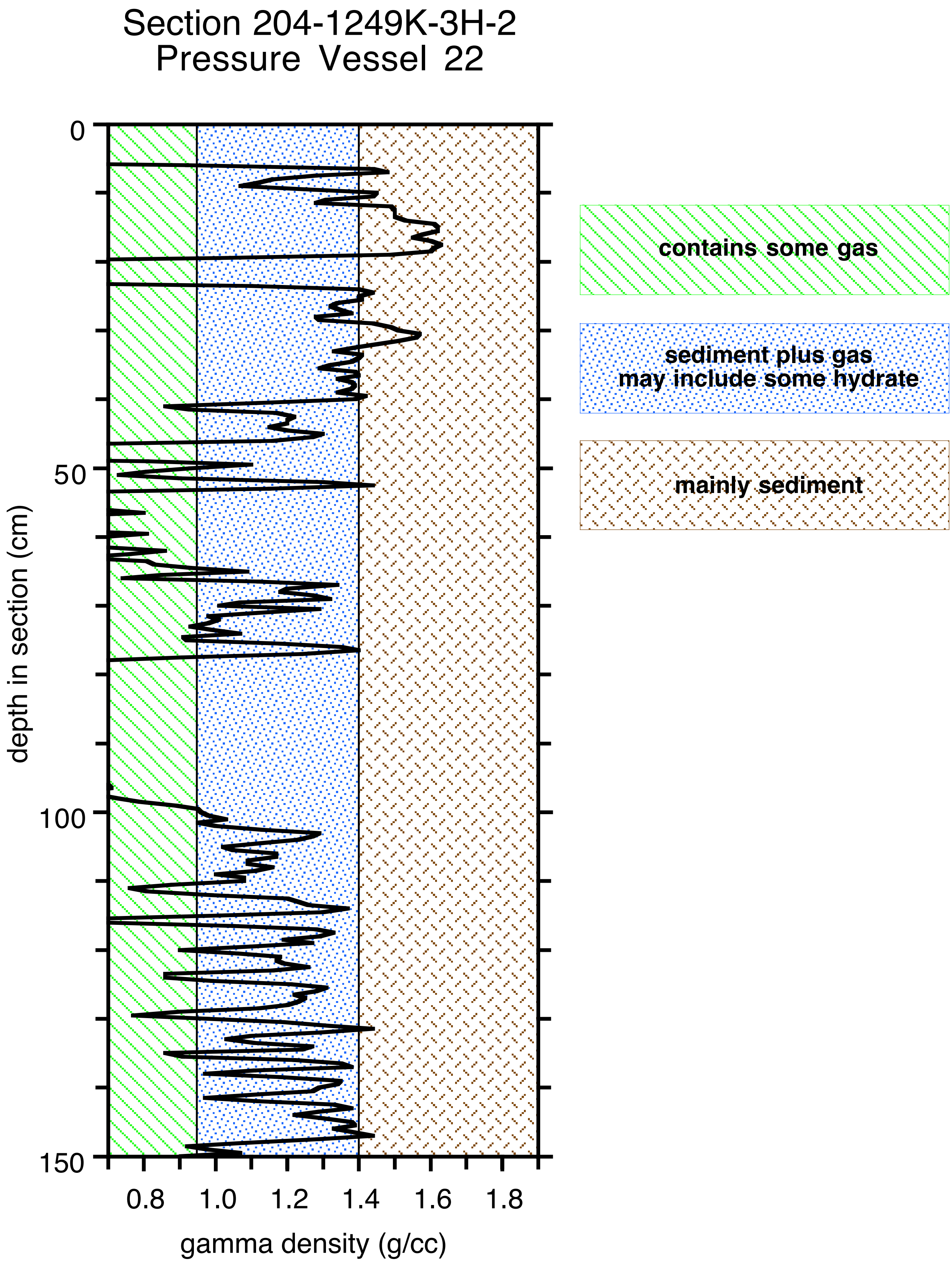

Section 204-1249J-3H-4
Pressure Vessel 18
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

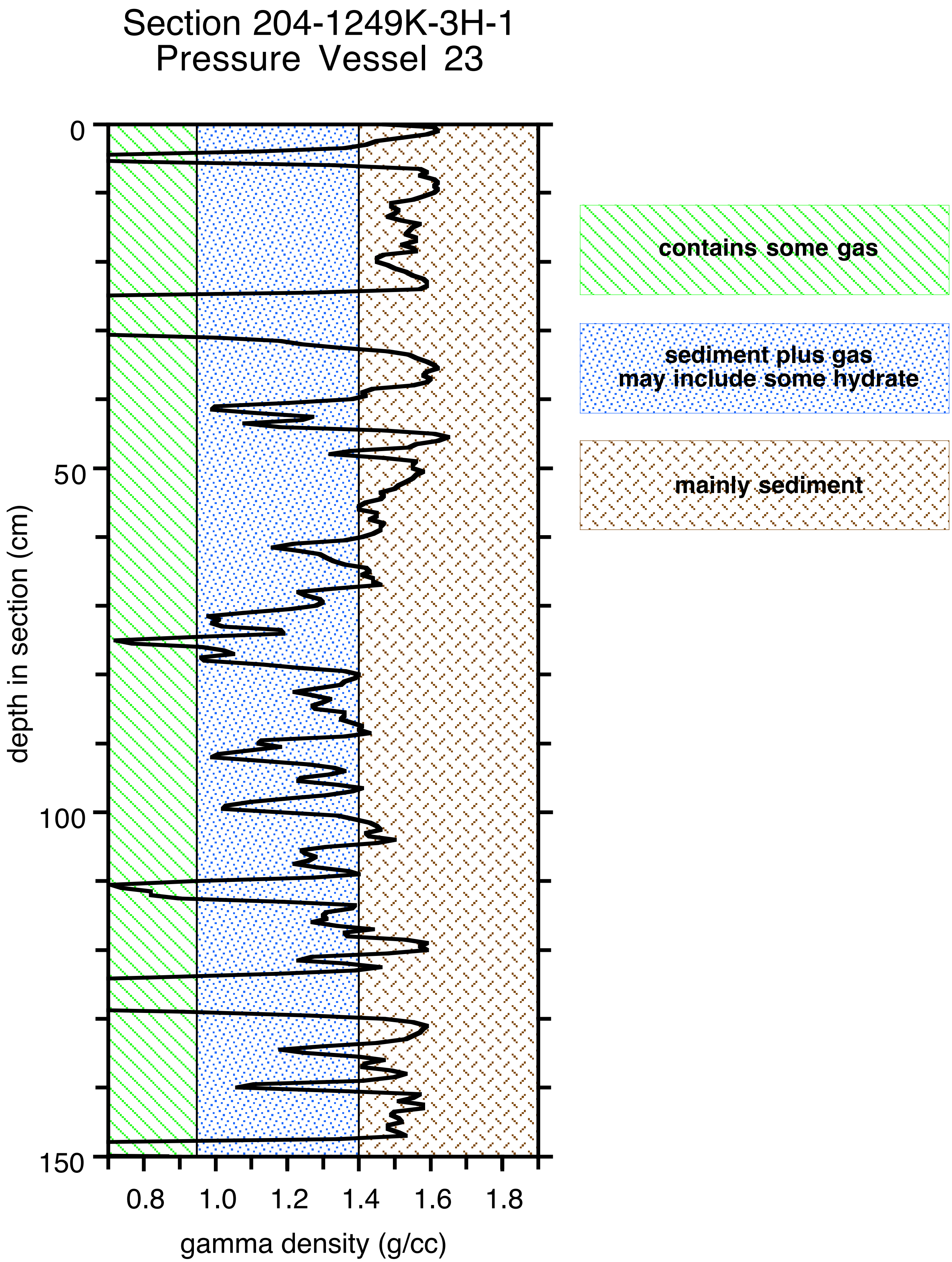
Section 204-1249J-3H-1
Pressure Vessel 19

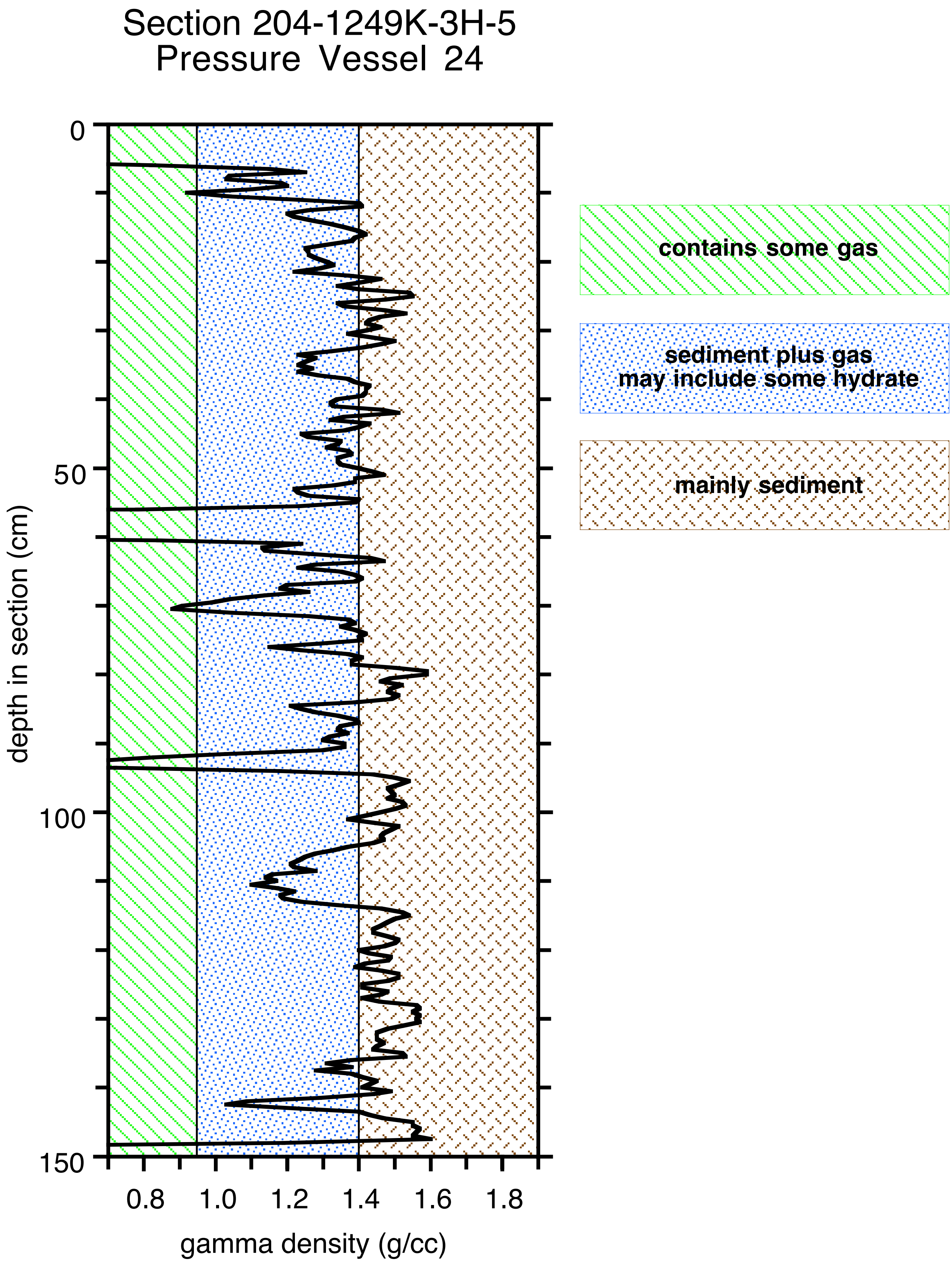


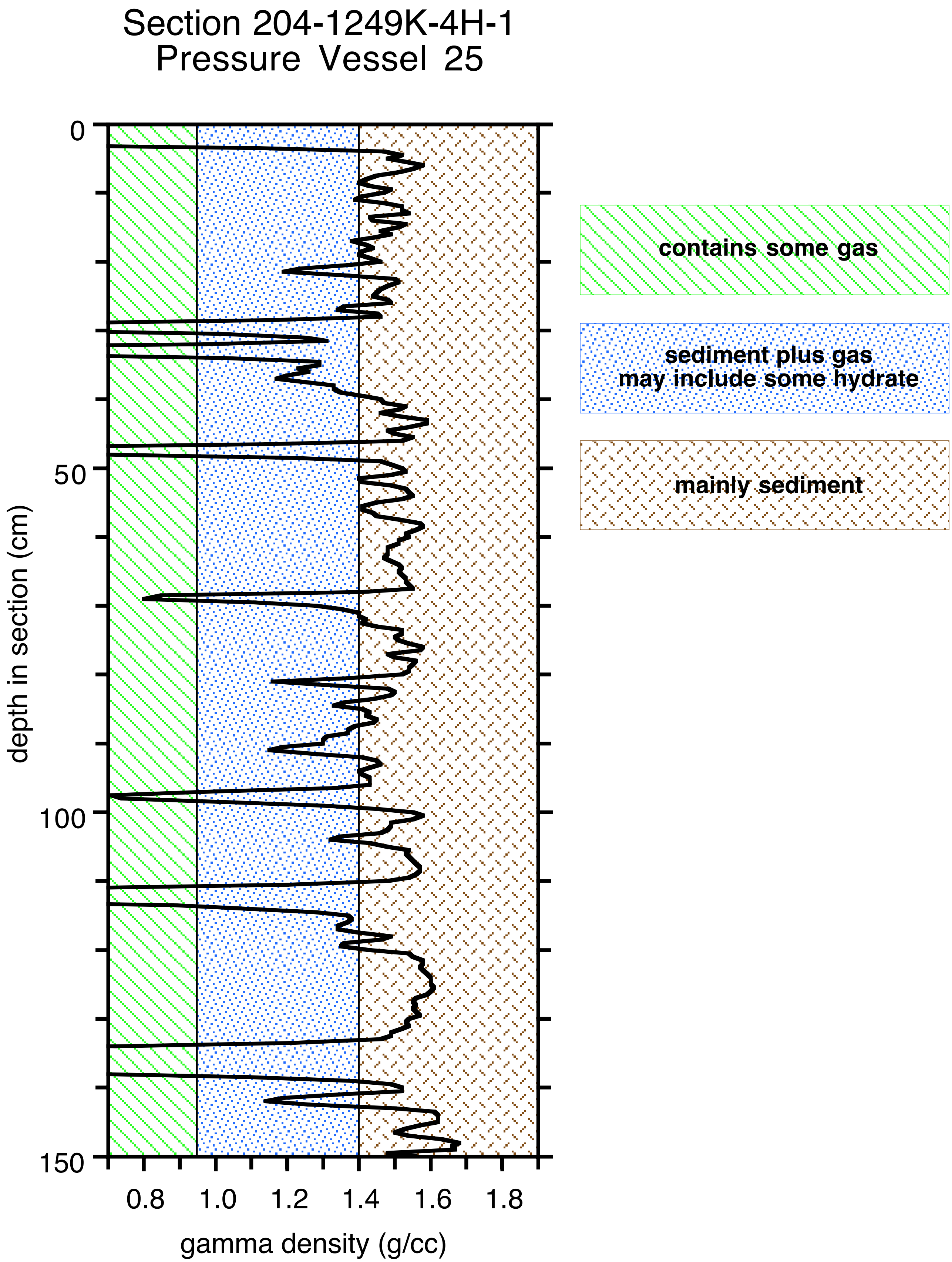


Section 204-1249I-4H-3
Pressure Vessel 20
depth in section (cm)
0
50
100
150
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

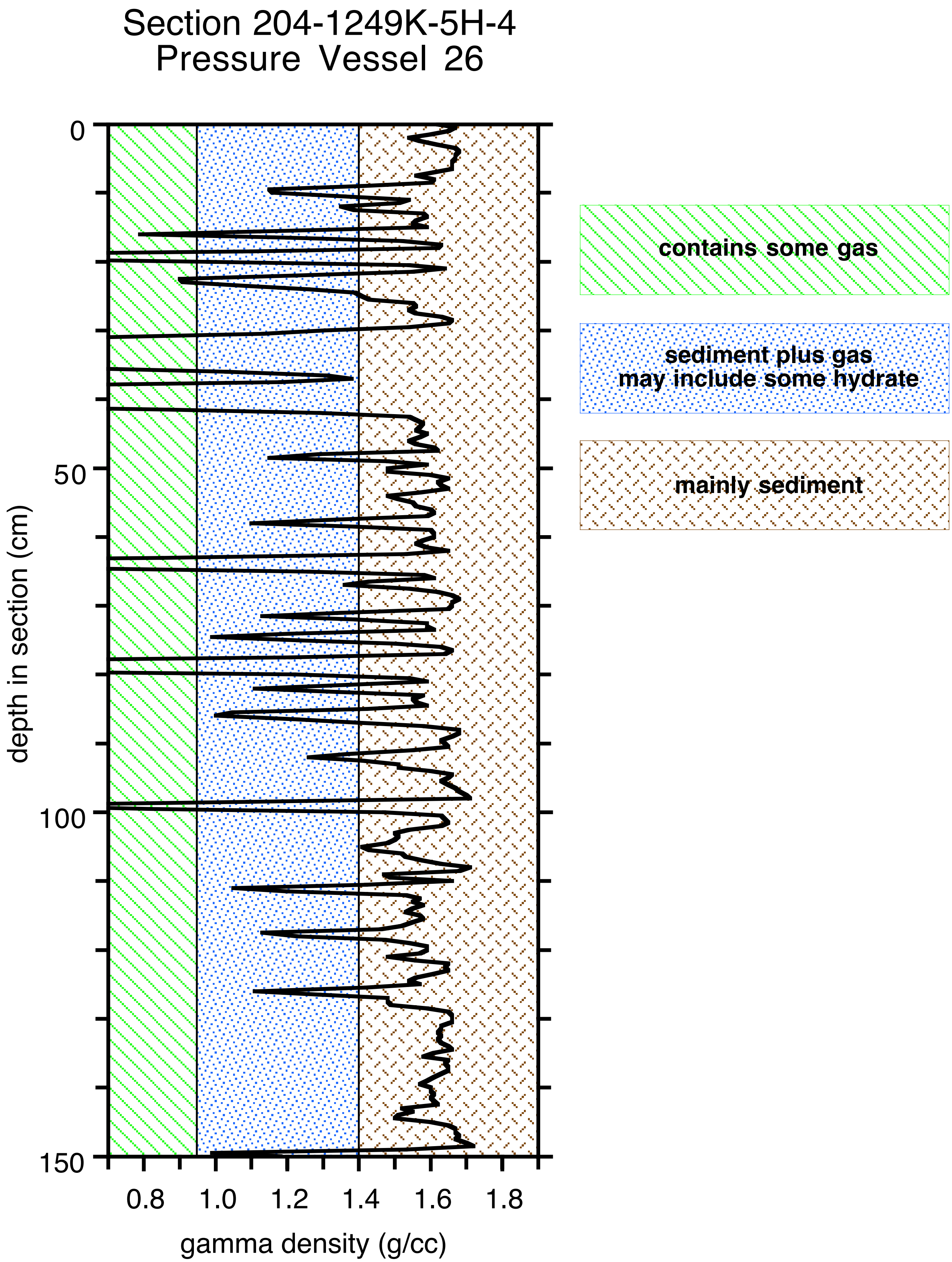

Section 204-1249K-3H-2
Pressure Vessel 22
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

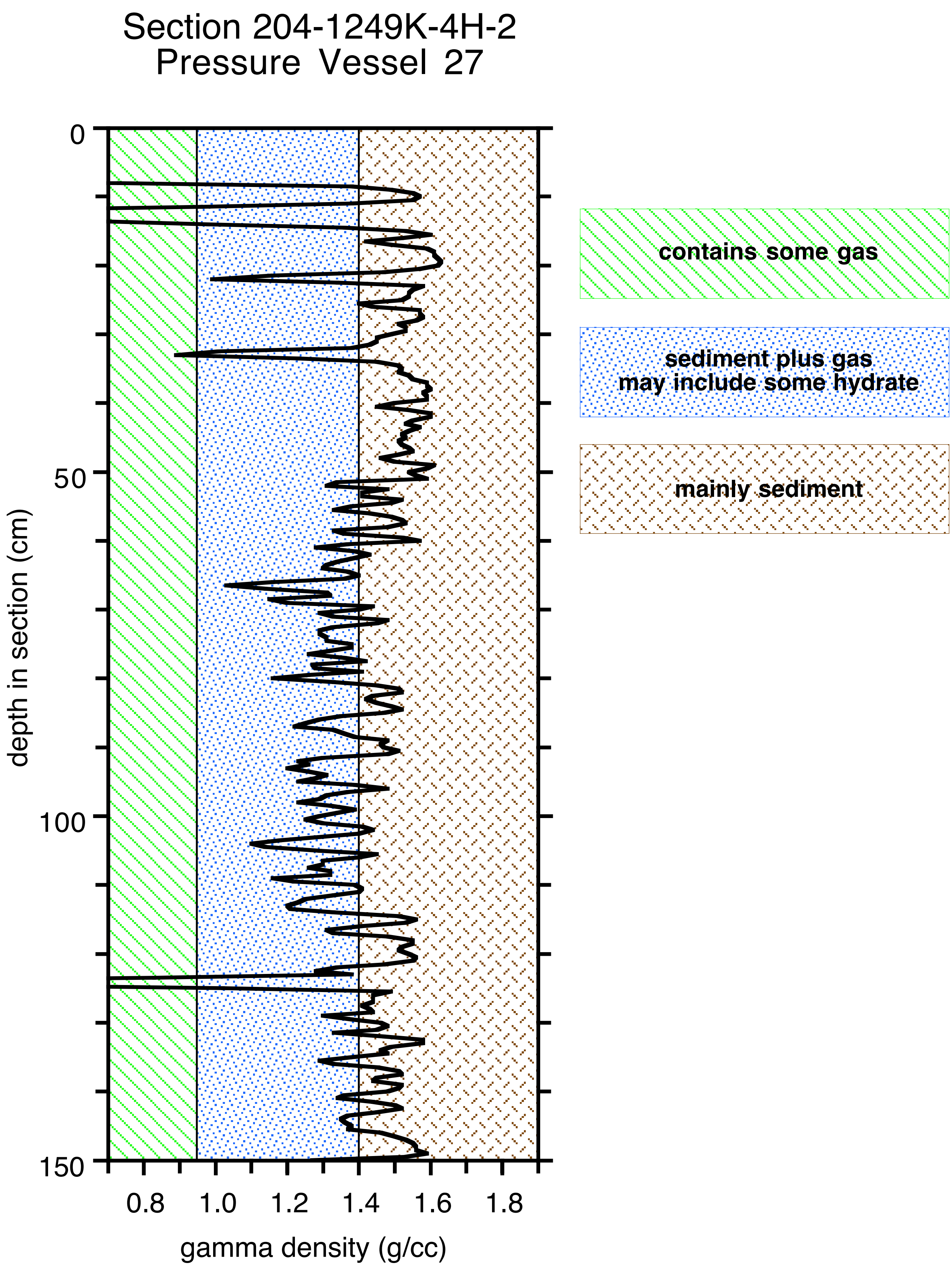

Section 204-1249K-3H-1
Pressure Vessel 23
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

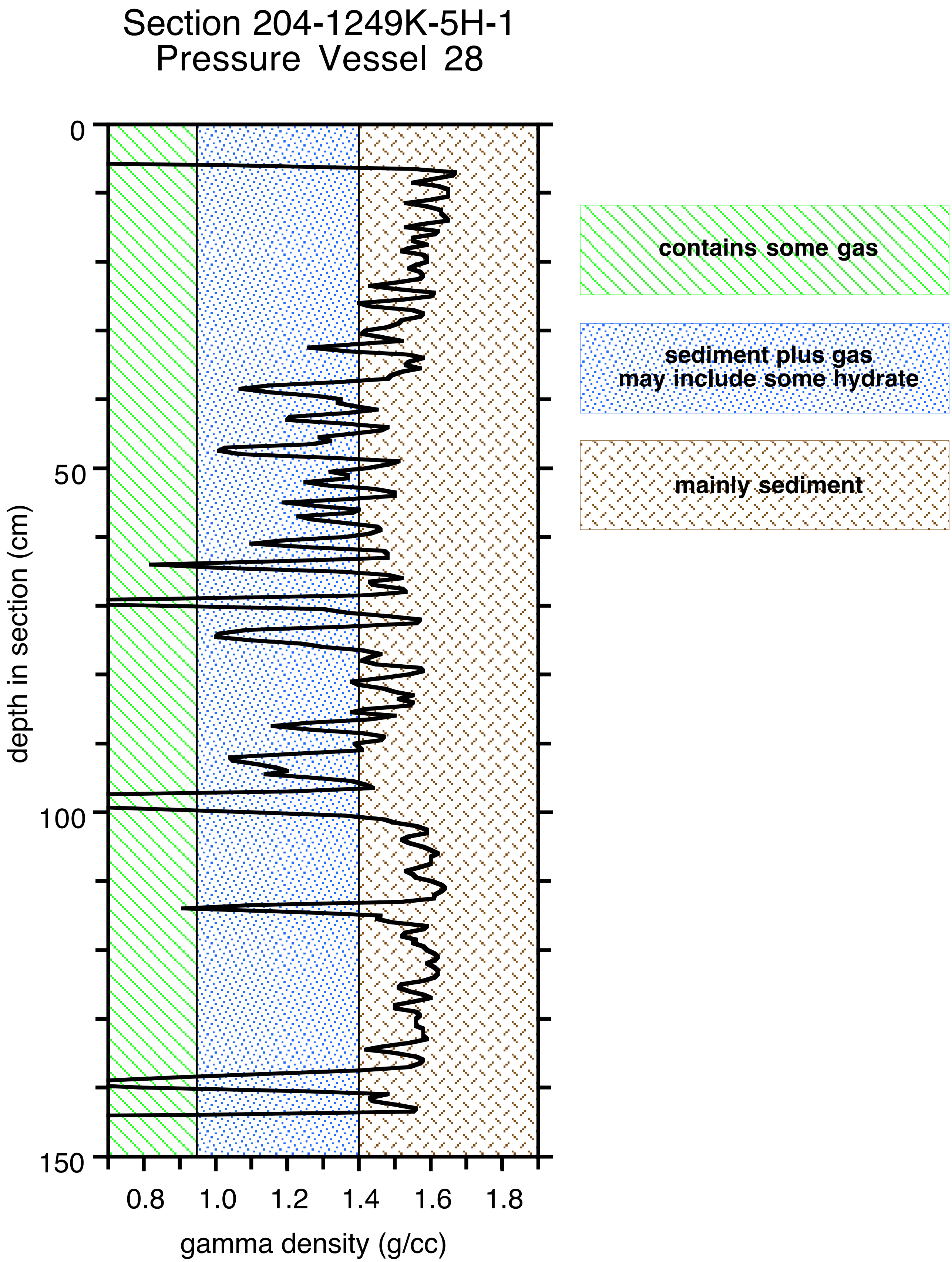

Section 204-1249K-3H-5
Pressure Vessel 24
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

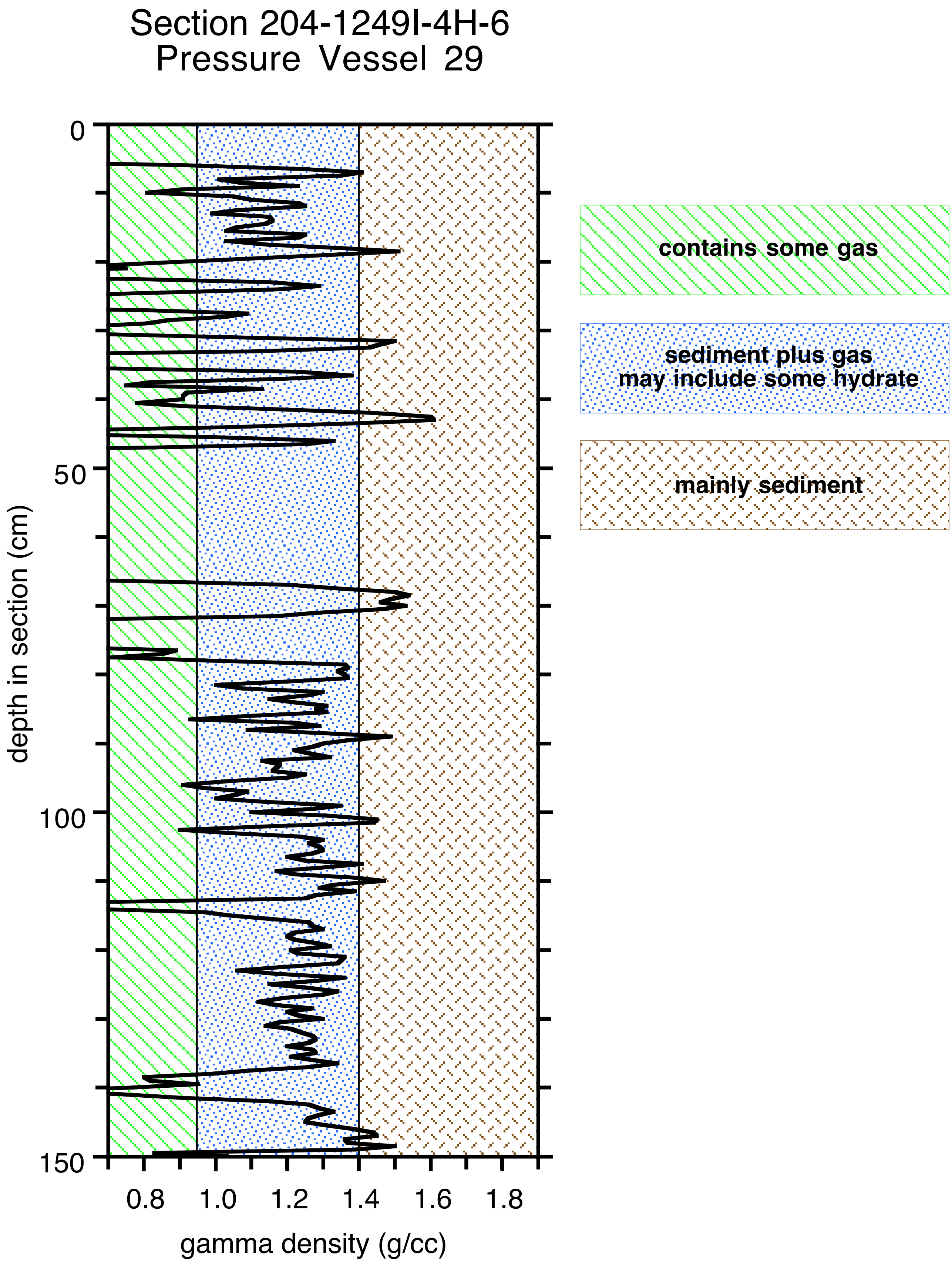


Section 204-1249K-4H-1
Pressure Vessel 25
depth in section (cm)
0
50
100
150
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment


Section 204-1249K-5H-4
Pressure Vessel 26
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

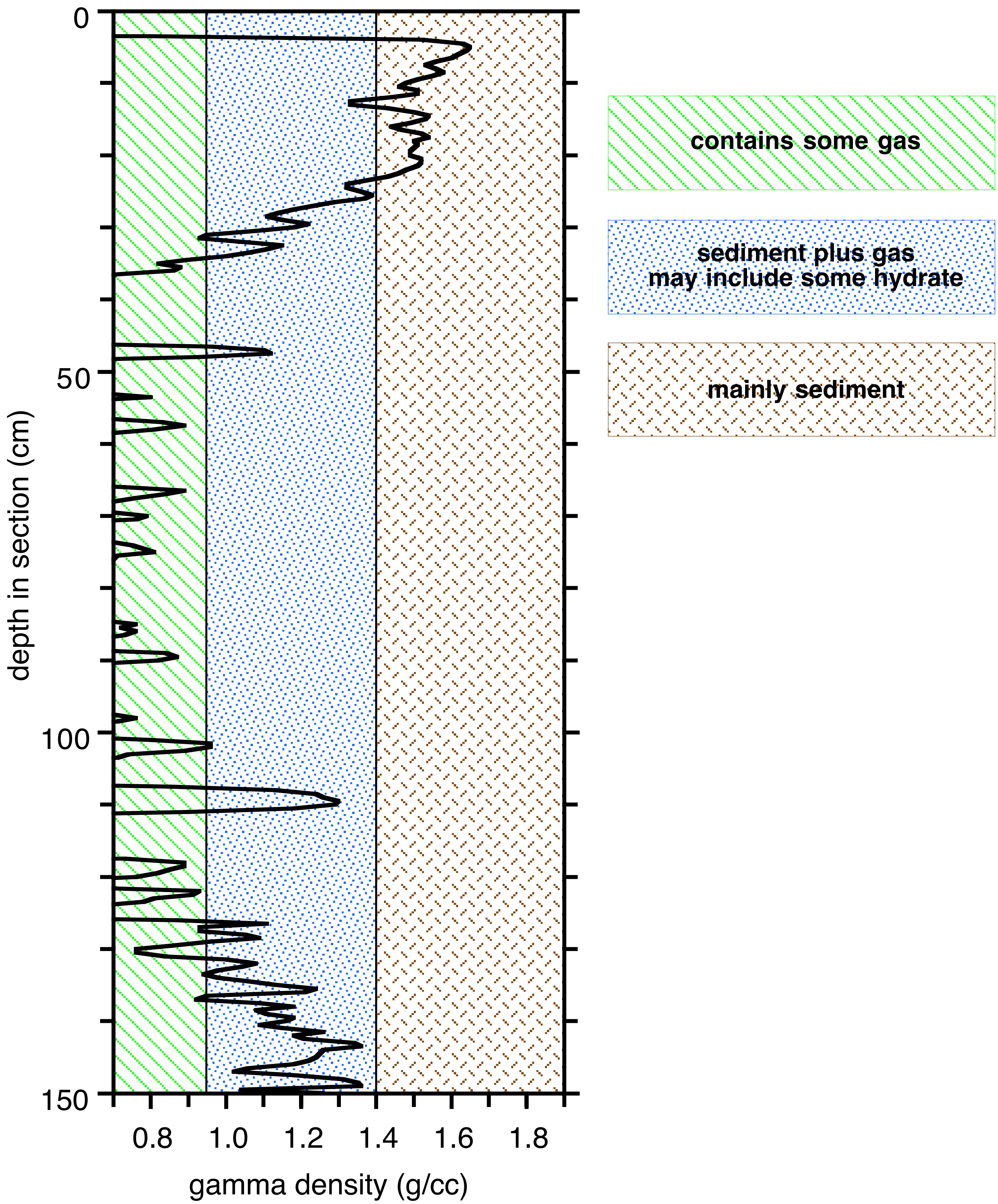

Section 204-1249K-4H-2
Pressure Vessel 27
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

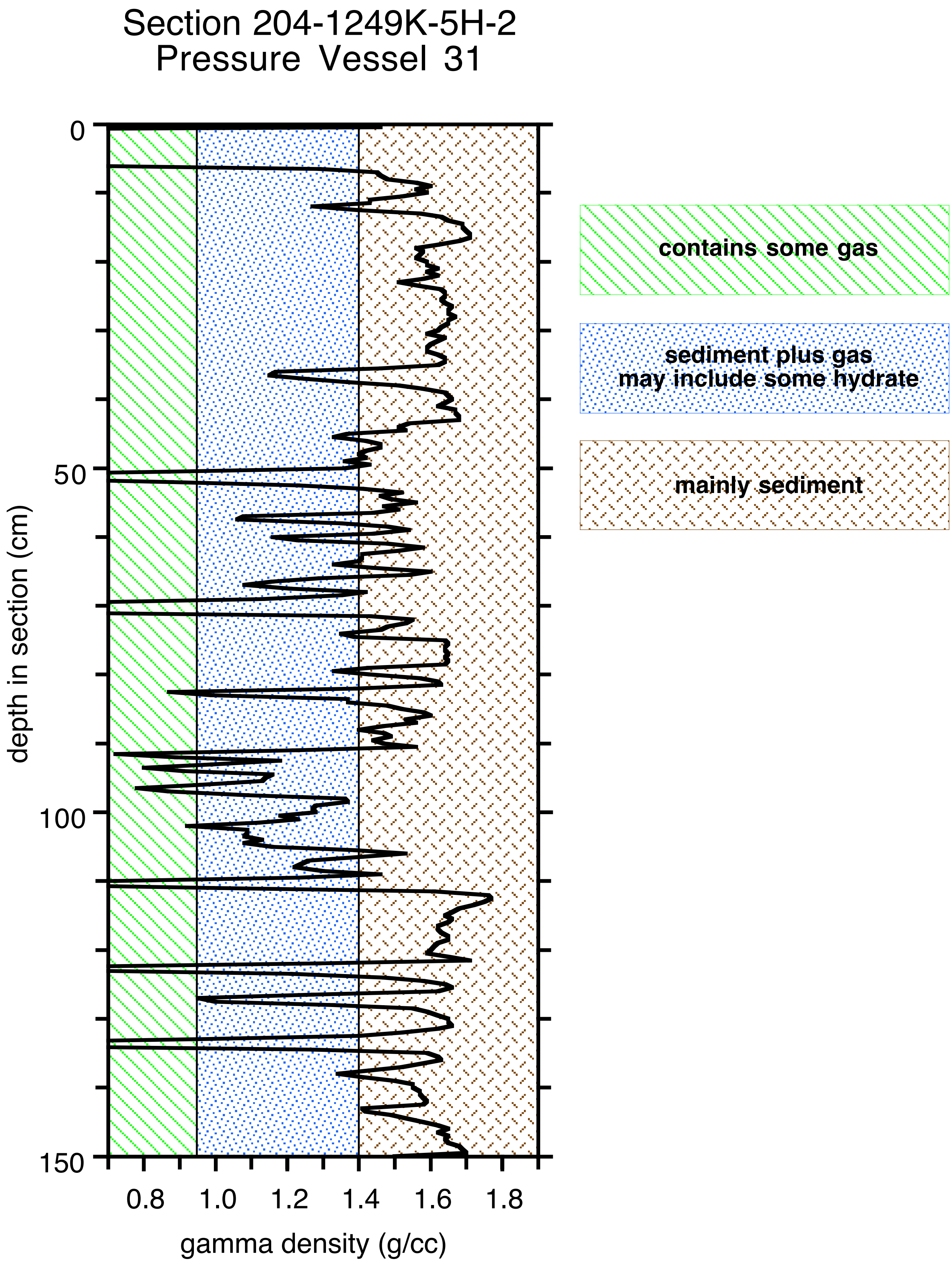

Section 204-1249K-5H-1
Pressure Vessel 28
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment



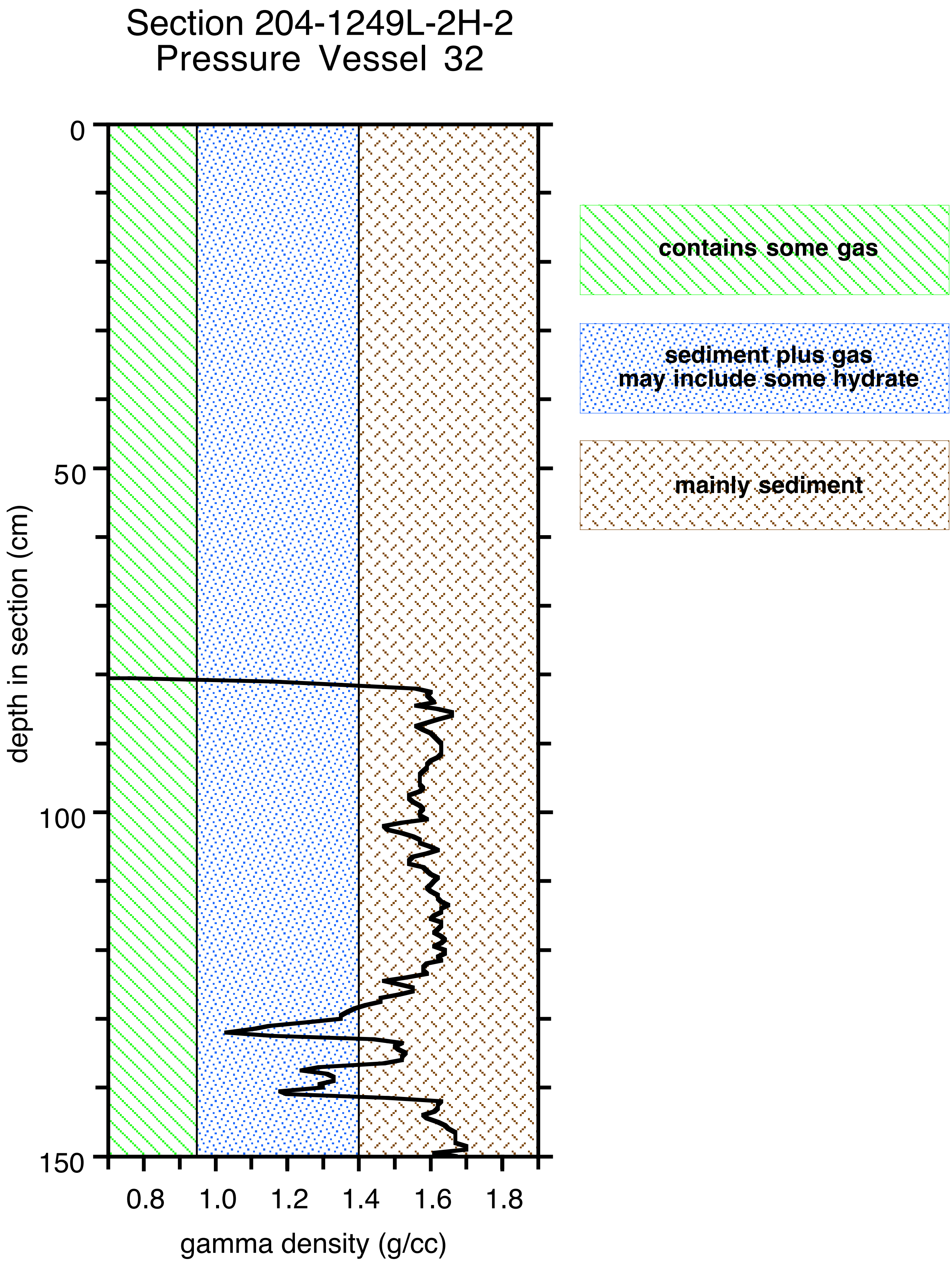
Section 204-1249I-4H-6
Pressure Vessel 29
depth in section (cm)
0
50
100
150
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

Section 204-1249I-4H-2
Pressure Vessel 30



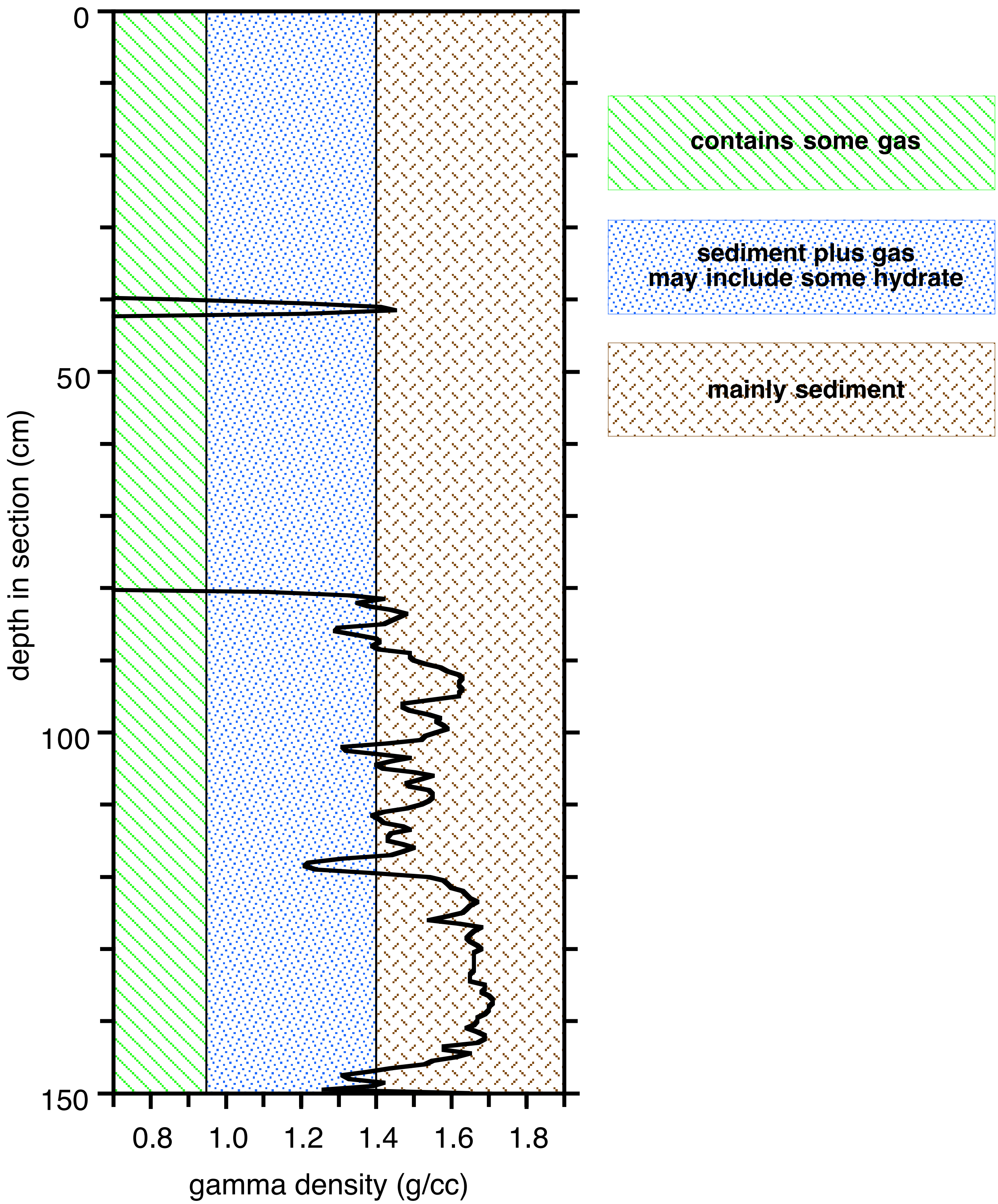


Section 204-1249K-5H-2
Pressure Vessel 31
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

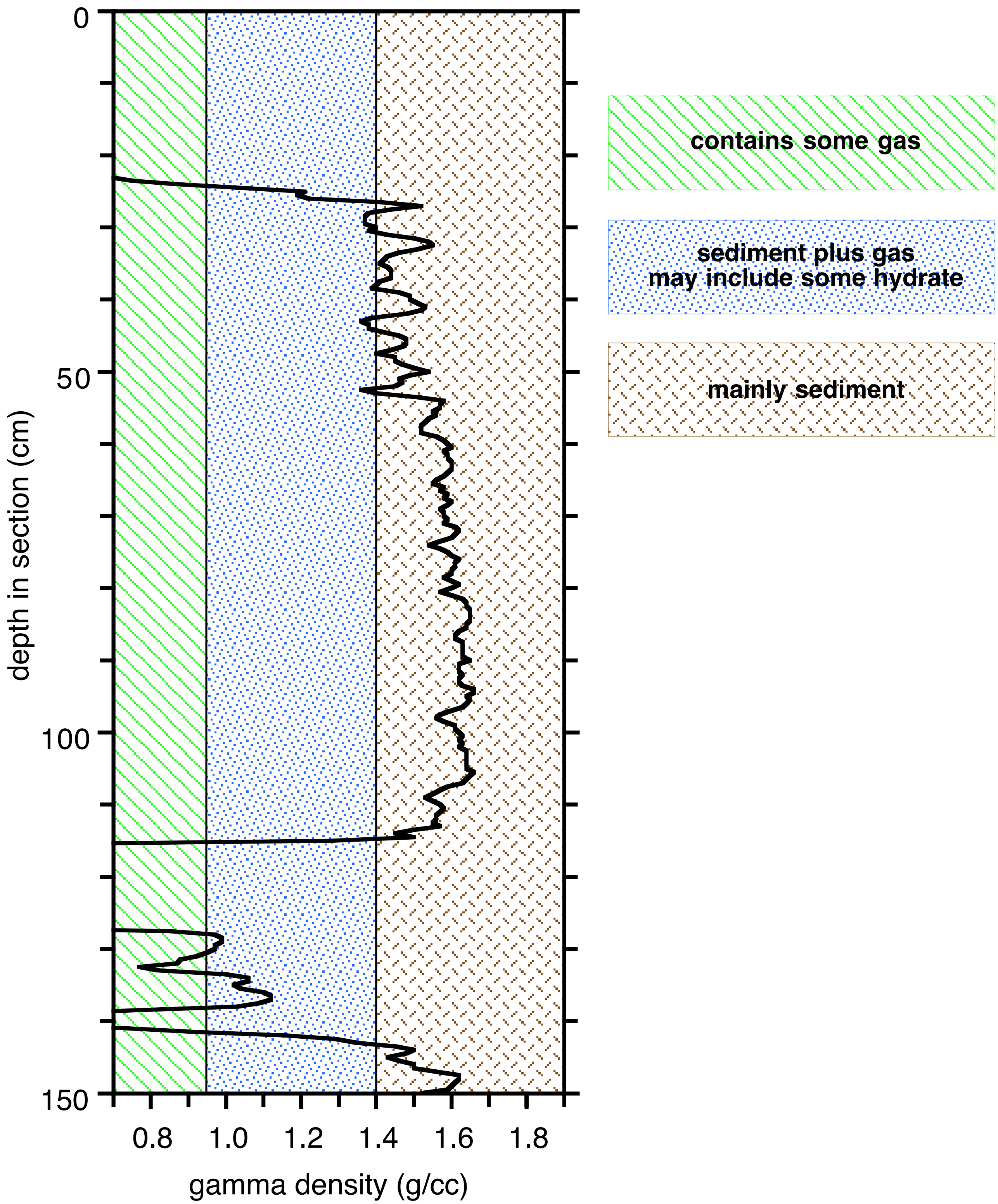


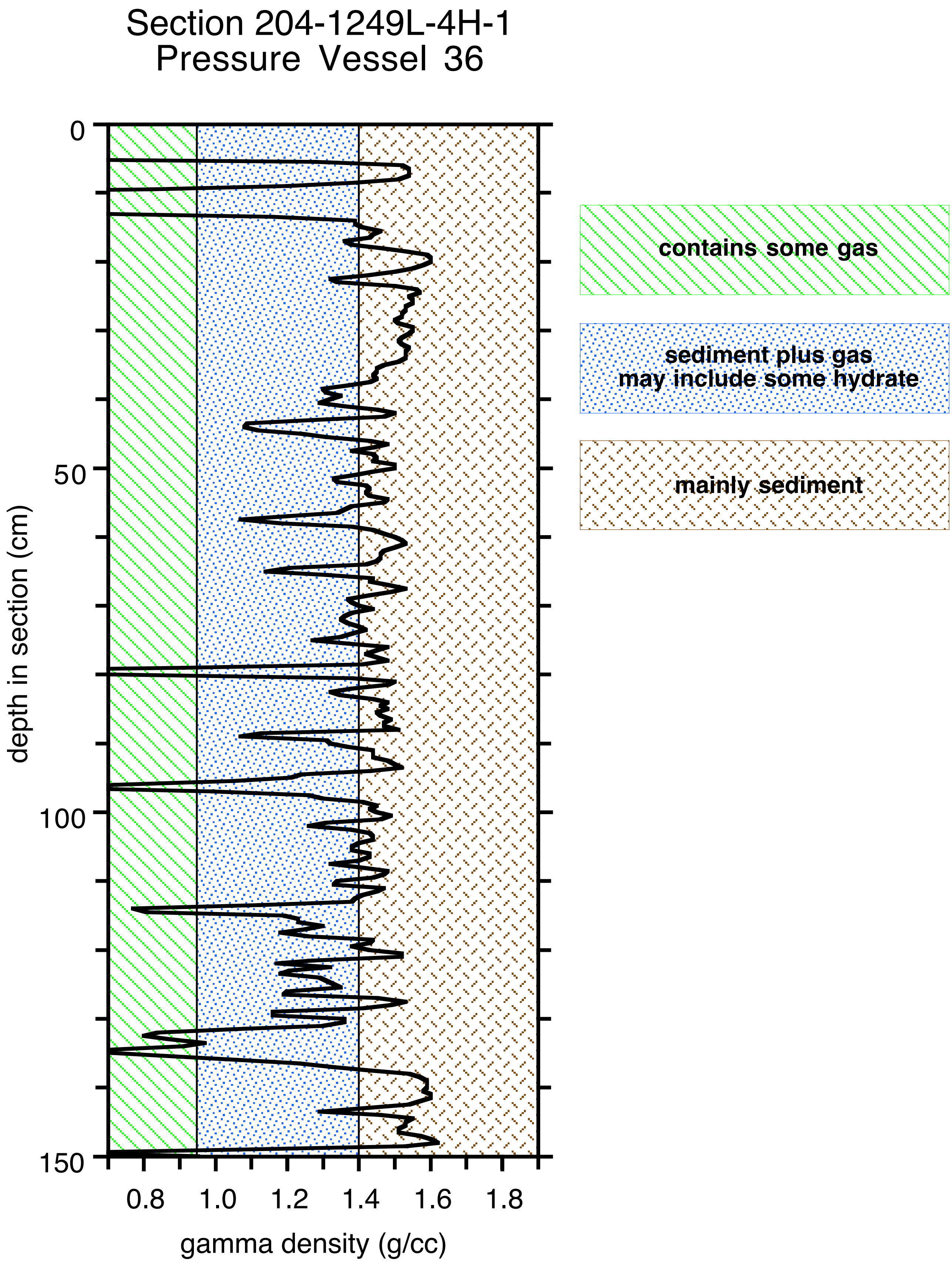
Section 204-1249L-2H-2
Pressure Vessel 32
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

Section 204-1249L-2H-3
Pressure Vessel 33



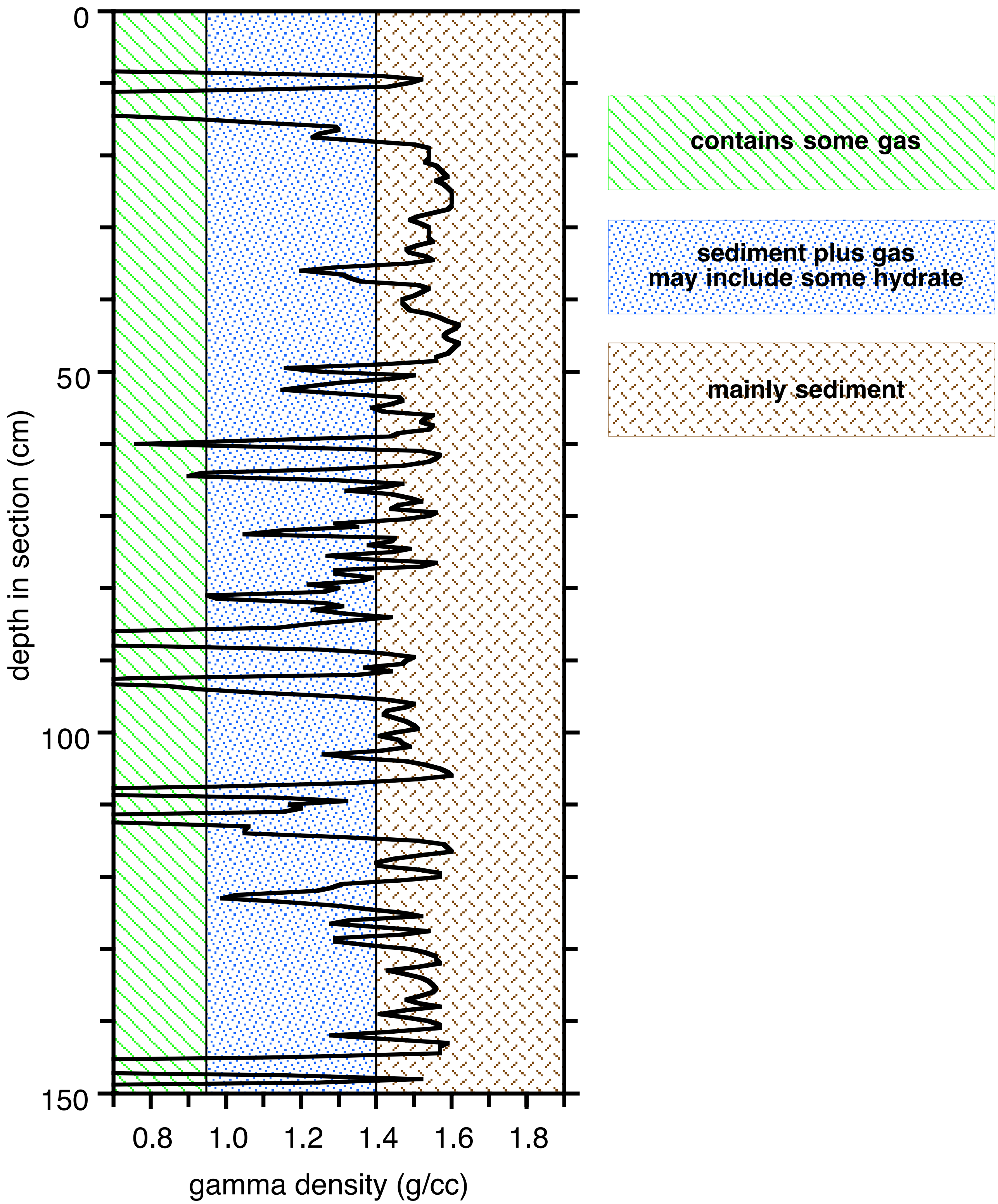
Section 204-1249L-2H-1
Pressure Vessel 34

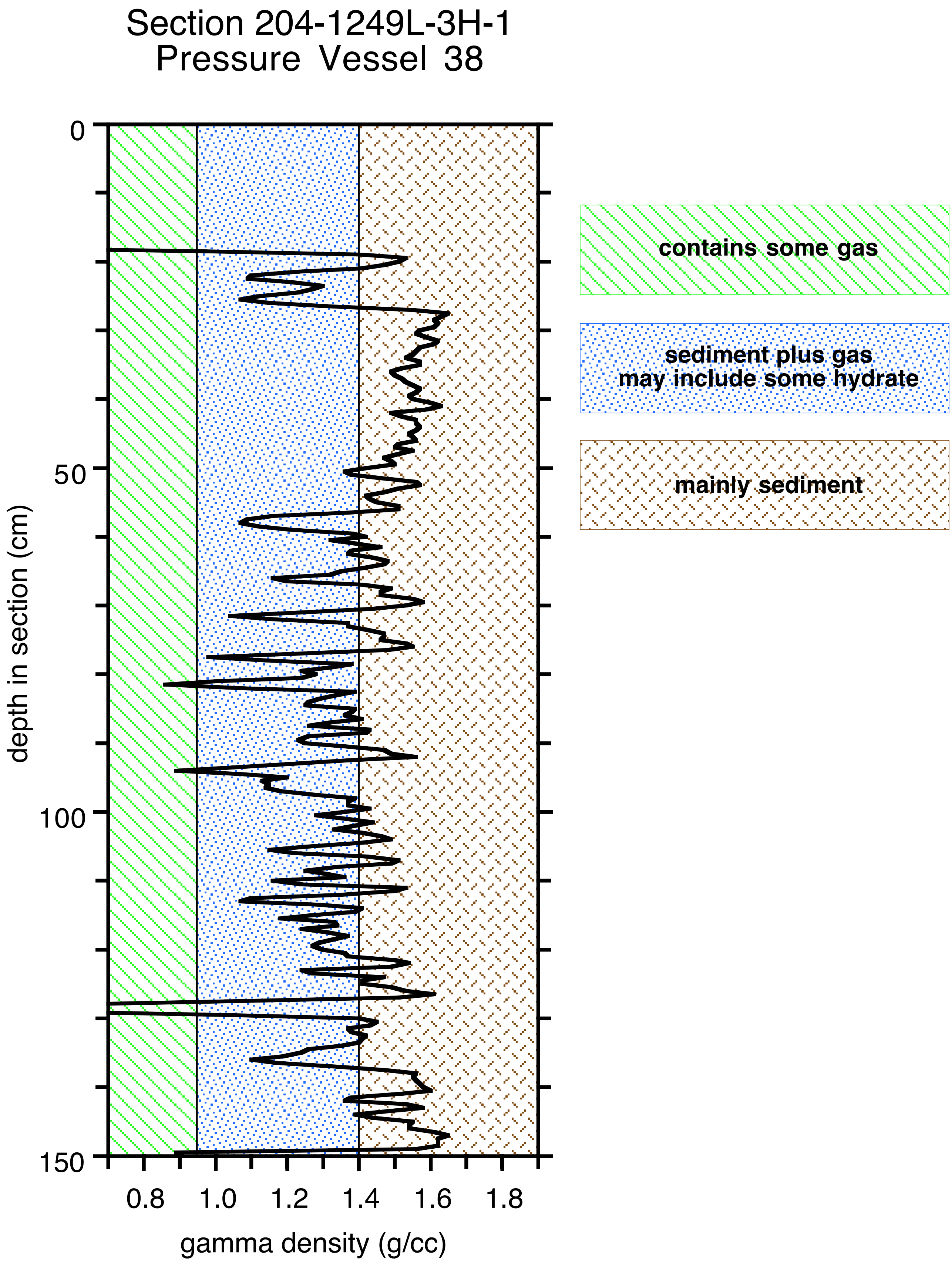




Section 204-1249L-4H-1
Pressure Vessel 36
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

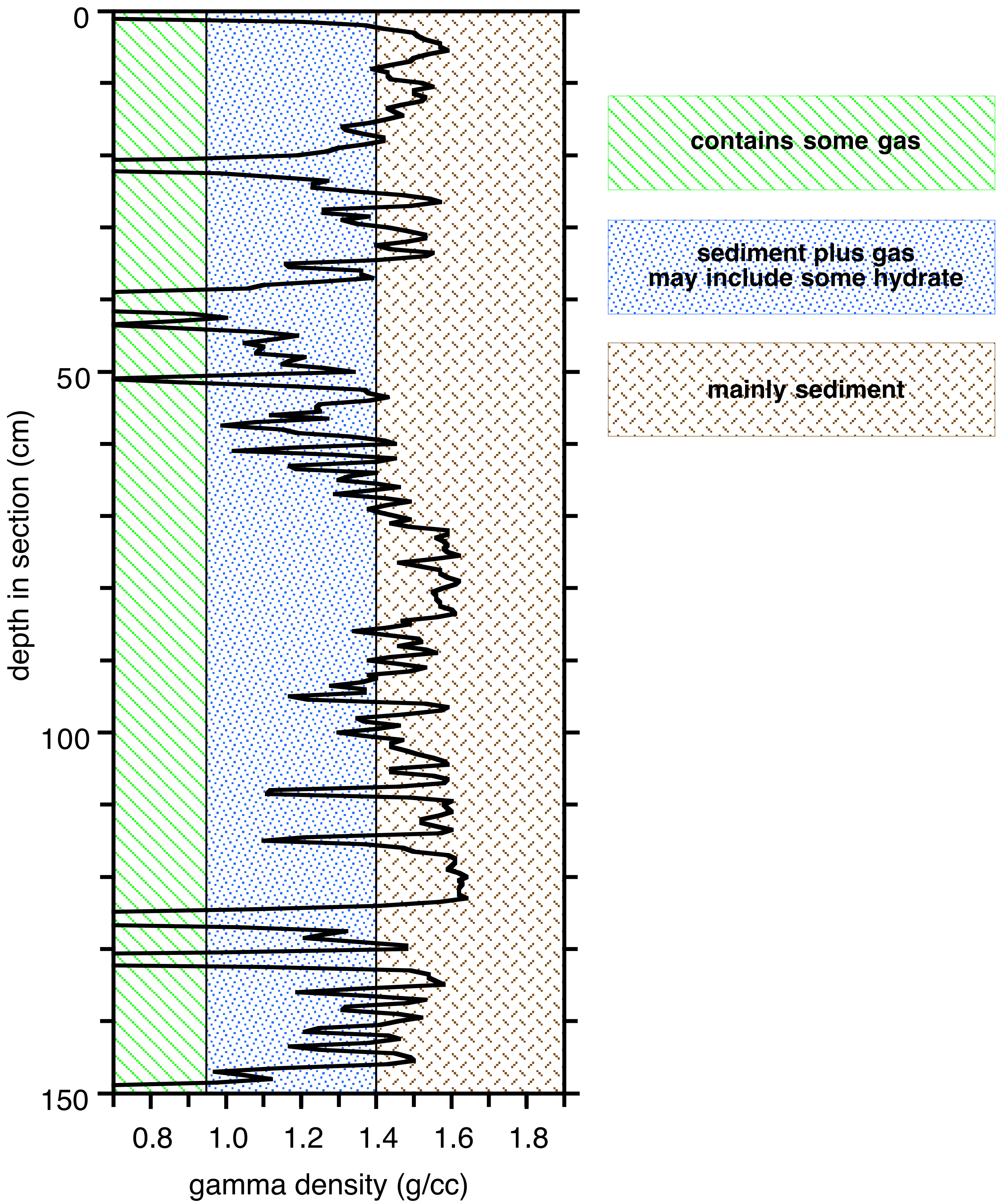
Section 204-1249L-4H-2
Pressure Vessel 37





Section 204-1249L-3H-1
Pressure Vessel 38
0
50
100
150
depth in section (cm)
0.8
1.0
1.2
1.4
1.6
1.8
gamma density (g/cc)
contains some gas
sediment plus gas
may include some hydrate
mainly sediment

Section 204-1249L-3H-3
Pressure Vessel 40



APPENDIX D

STATUS OF ODP LEG 204 GERIATRIC STUDY SAMPLES STORED IN LIQUID NITROGEN CRYOFREEZERS IN THE ODP GULF COAST REPOSITORY.

Frank R. Rack
Joint Oceanographic Institutions

(2 pg. Table)

Table 1.
Status of ODP Leg 204 Geriatric Study Samples Stored in Liquid Nitrogen Cryofreezers in the ODP Gulf Coast Repository.

Cryofreezer	Hole	Core/Type/Section	Length (cm)	Comments
08	1249G	4H-3	43 cm-long	several pieces
08	1249K	4H-4	44 cm-long	solid piece, visible hydrate at end of section
08	1249I	4H-1	16-19 cm-long	tapered from 16 to 19 cm at lower end
08	1249L	1X-4	38 cm-long	slight taper at upper end, knob at lower end
08	1249J	2H-4	47 cm-long	2 main pieces, upper one longer than lower one
08	1249L	1X-1	48 cm-long	one solid piece
08	1249J	3H-5	45 cm-long	2 pieces; break at 10-11 cm
08	1249L	1X-3	33 cm-long	vuggy at upper end; squared off at lower end

Cryofreezer	Hole	Core/Type/Section	Length (cm)	Comments
04	1249I	4H-Rig Floor	large bag	sediment collected from rig floor after blow-off
04	1249I	1X-CC	18 cm-long	small bag
04	1249J	3H-CC	unknown	string on small bag broke; fell to bottom of cryofreezer
04	1249J	3H-2	48.5 cm-long	2 pieces; break at 18 cm; visible massive hydrate at break
04	1249J	3H-3	45 cm-long	2 pieces; break at 21 cm
04	1249J	2H-2	32 cm-long	2-3 main pieces; break at 17-18 cm; hydrate nodules/lenses
04	1249G	3H-2B	large bag	sediment collected from rig floor after blow-off
04	1249J	2H-3	31.5 cm-long	2 pieces; angular break at 16-18 cm; massive hydrate at break
04	1249K	3H-3	53 cm-long	3 pieces; breaks at 13-15 cm and 30-32 cm; visible hydrate

Cryofreezer	Hole	Core/Type/Section	Length (cm)	Comments
06	1249L	3H-2	28 cm-long	visible hydrate
06	1249L	3H-4	47 cm-long	
06	1249L	3H-CC	~17 cm-long	small bag

Cryofreezer	Hole	Core/Type/Section	Length (cm)	Comments
05	1249L	1X-2	45.5 cm-long	1 piece; vuggy at top
05	1249K	3H-CC and 3H-Rig Floor	large bag	sediment collected from rig floor after blow-off and CC sample
05	1249K	3H-4	50 cm-long	2 long pieces with visible disseminated hydrate at break
05	1249K	5H-3	45 cm long	5 pieces; visible hydrate in piece #3
05	1249K	5H-CC	unknown	string on small bag broke; fell to bottom of cryofreezer
05	1249K	1X-1	47 cm-long	
05	1249K	5H-Rig Floor	small bag	
05	1249K	4H-CC	small bag	
05	1249K	2H-CC	small bag	
05	1249L	1X-CC	small bag	
05	1249K	2H-1	46 cm-long	2 pieces; break at 10-12 cm
05	1249K	2H-2	50 cm-long	3 pieces; massive hydrate visible at break
05	1249K	4H-3	50 cm-long	2 pieces; no visible hydrate
05	1249K	1X-2	~30 cm-long	

Cryofreezer	Hole	Core/Type/Section	Length (cm)	Comments
07	1249I	2H-3	50 cm-long	2 pieces; break at 24-25 cm; visible hydrate at break
07	1249I	2H-2	12-14.5 cm-long	tapered end to 14.5 cm-long; no visible hydrate
07	1249I	2H-1	49-50 cm-long	angular break at 19-21 cm; lg. Volid/vug at 25-30 cm; visible massive hydrate at break
07	1249I	4H-5	49-51 cm-long	breaks at 40 cm and 44-46 cm; visible nodular and massive hydrate
07	1249I	3H-3	24 cm-long	break at 3-4 cm; distinctive vugs and voids at lower end
07	1249I	4H-4	50 cm-long	breaks at 23 cm, 27 cm, and 31 cm; angular break at 38-41 cm; no visible hydrate

Cryofreezer	Hole	Core/Type/Section	Length (cm)	Comments
01	1249G	4H-3A	38 cm-long	2 pieces; break at 10-11 cm; no visible hydrate
01	1249G	3H-3	47.5 cm-long	3 pieces; visible massive hydrate at break
01	1249G	3H-4A	50 cm-long	no visible hydrate
01	1249G	3H-2B	43 cm-long	2 pieces; break at 33 cm; visible hydrate
01	1249G	3H-4C	34 cm-long	
01	1249G	3H-CC	small bag	
01	1249G	4H-CC	small bag	
01	1249G	3H-4B	51 cm-long	2 pieces; break at 11-12 cm; visible massive hydrate
01	1249G	4H-2	41 cm-long	visible massive hydrate
01	1249G	3H-2A	39.5 cm-long	no visible hydrate
01	1249G	1X-3	10-12 cm-long	
01	1249G	4H-4A	46 cm-long	visible hydrate lens at 8-10 cm; break at 34 cm (fractured section)
01	1249G	1X-CC	small bag	
01	1249G	4H-4B	32 cm-long	2 pieces; break at 13-14 cm; no visible hydrate
01	1249G	4H-1	38.5 cm-long	cloth-like textured interval near top; break at 26 cm; no visible hydrate

Cryofreezer	Hole	Core/Type/Section	Length (cm)	Comments
03	1249H	4H-6	31.5 cm-long	3 pieces; no visible hydrate
03	1249I	3H-1	48.5 cm-long	3 pieces; several lenses of hydrate in piece #2
03	1249I	1X-1	~19 cm-long	tapered upper end with possible hydrate visible, mud nodules
03	1249H	5H-Rig Floor	small bag	string broke; sample in bottom of cryofreezer
03	1249I	3H-2	28 cm-long	2 pieces; break at 19-20 cm; visible hydrate at break
03	1249I	1X-CC	small bag	samples consolidated in single larger bag
03	1249I	2H-CC	small bag	samples consolidated in single larger bag
03	1249I	3H-CC	small bag	samples consolidated in single larger bag
03	1249I	3H-Rig Floor	small bag	samples consolidated in single larger bag
03	1249I	4H-CC	small bag	samples consolidated in single larger bag
03	1249H	5H-CC	small bag	samples consolidated in single larger bag
03	1249H	6H-CC	larger bag	
03	1249H	5H-4	51 cm-long	3 pieces; breaks at 14-15 cm and 40-41 cm; visible hydrate at top
03	1249H	6H-7	42 cm-long	3 pieces; breaks at 31 cm and 36 cm; no visible hydrate
03	1249H	5H-6	~65 cm-long	3 pieces; breaks at 9-10 cm and 25 cm; wrapped as 2 pieces (#1 = ~24 cm-long, #2 = ~41 cm-long)

Cryofreezer	Hole	Core/Type/Section	Length (cm)	Comments
02	1249H	1H-1	49 cm-long	3 pieces; maybe some hydrate visible; H2S smell
02	1249H	4H-2	40 cm-long	2 pieces; break at 23-24 cm; very vuggy; no visible hydrate
02	1249H	1H-3	44 cm-long	2 piceces; angular break at 26-28 cm; very vuggy with visible hydrate; H2S smell
02	1249H	1H(X?)-CC	small bag	
02	1249H	1H-2	53 cm-long	2 pieces; break at 17-19 cm; massive hydrate visible throughout upper piece (both ends) and continuing into lower piece
02	1249H	4H-CC	small bag	
02	1249H	3H-CC (A) and 3H-Rig Floor	2 small bags	each sample is about 10 cm-long; consolidated in larger bag
02	1249H	3H-CC (B)	small bag	sample is about 10 cm-long
02	1249H	4H-5	33-34 cm-long	2 main pieces with 3-4 broken pieces in between; maybe some disseminated hydrate
02	1249H	4H-1	26-28 cm-long	vuggy at lower end
02	1249H	3H-3	55 cm-long	solid piece; perhaps some hydrate visible at lower end
02	1249H	4H-Rig Floor	large bag	sediment collected from rig floor after blow-off
02	1249H	3H-4 (3H-2?)	49 cm-long	2 pieces; break at 30-32 cm; maybe hydrate veins at lower end