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3. The Pressure Core Sampler (PCS) on ODP Leg 201: General Operations and Gas Release[1]

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ABSTRACT

During Leg 201, the Pressure Core Sampler (PCS) was deployed 17 times (1) to evaluate the operational range of the tool in different lithologies and water depths and (2) to determine gas volumes at multiple depths at Site 1230 in the Peru Trench. Of these runs, 11 were entirely successful, collecting between 0.50 and 1.00 m of sediment core at >75% of hydrostatic pressure, and 4 were partly successful, collecting either between 0.50 and 1.00 m of sediment core or retrieving the tool at >75% of hydrostatic pressure. The successfully retrieved cores came from a broad spectrum of lithologies between 22 and 378 meters below seafloor (mbsf), although generally from deeper water depths. Cores retrieved from Site 1230 released between 200 and 6100 mL of gas, mostly CH_4, and can be used to construct a gas concentration profile from the seafloor to nearly 280 mbsf. Operations during Leg 201 suggest that the tool can be deployed for scientific pursuits in a variety of settings.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 201 was devoted to understanding the range and nature of microbial activity below the seafloor. Of importance to this objective, as well as to the goals of future legs (e.g., Leg 204), are the amounts and distributions of gas, specifically CH_4, in marine sediment sequences. Traditionally, gas concentrations are deter-

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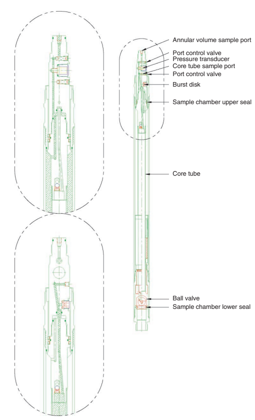
mined using a headspace technique where a plug of sediment is taken from a core retrieved at depth, placed into a closed container on the ship, and degassed. Although this approach may work for cores with low in situ gas concentrations (e.g., Fossing et al., 2000; Hoehler et al., 2000), it clearly fails where targeted sediment sequences contain abundant gas (Dickens et al., 1997; Paull et al., 2000). In these cases, significant amounts of gas can escape from cores during recovery when the drop in pressure or increase in temperature lowers CH_4 saturation (Dickens et al., 2000a).

The Pressure Core Sampler (PCS) is a downhole tool designed to recover a cylindrical sediment core—including gas and interstitial water—at in situ pressure (Pettigrew, 1992). When properly sealed at depth, controlled release of pressure from the PCS through a manifold (below) should permit collection of gases that would otherwise escape on the wireline trip. In late 1995, after several early attempts at coring under pressure (e.g., Kvenvolden et al., 1983), the PCS was used successfully to capture and analyze gases for their composition and volume during Leg 164 (Paull, Matsumoto, Wallace, et al., 1996; Dickens et al., 1997, 2000a, 2000b). Consequently, there was community interest in deploying the PCS during Leg 201 (1) to ensure that the tool was fully operational for future legs targeting gas-rich sediments, especially Leg 204 off the Oregon margin, and (2) to quantify gas abundance along the Peru margin, where gas concentrations at depth exceed solubility at shipboard pressures and temperatures. This paper describes basic PCS operations during Leg 201 and resultant gas yields from recovered cores. Advanced interpretations of these experiments will be presented elsewhere.

F1. Schematic of the PCS, p. 11.



BACKGROUND OF THE PRESSURE CORE SAMPLER

Basic Tool and Manifold Descriptions

The PCS (Fig. F1) is a tool designed to retrieve a 1.00-m-long sediment core from depth under pressure (Pettigrew, 1992). The basic principles of a PCS run are as follows. A cutting shoe (Fig. F2) is connected to the bottom of the tool. The tool is deployed, free falling within the drill string to reach the bottom of the hole, where it mounts the bottom-hole assembly. The drill string is turned to cut a core. When the wireline is pulled, a ball drops within the PCS to redirect internal fluid circulation and stroke the core through a lower ball valve that seals the core at pressure. The tool is then retrieved to the rig floor like other cores, such as those from the advanced hydraulic piston corer (APC) or extended core barrel (XCB). The PCS is separated from the drill string and brought to a shipboard laboratory for experiments. Much more expansive descriptions of mechanical and wireline operations of the PCS are presented elsewhere (Pettigrew, 1992).

F2. New cutting shoes, p. 12.

Once in a laboratory, the adopted protocol for releasing gas from the PCS is as follows (Dickens et al., 2000b). The tool is placed in a mounting sleeve and surrounded with ice to maintain the core at a constant temperature, where gas hydrate will not dissociate at high pressure (Dickens et al., 2000a). A gas manifold system and bubbling chamber (Fig. F3) are attached to a port on the PCS. Incremental volumes of gas are then released through the port and manifold to the bubbling cham-

F3. Degassing the PCS, p. 13.

ber over time until the inside of the PCS is at atmospheric pressure. The PCS is removed from the ice bath and warmed to at least 15°C. Additional incremental volumes of gas are collected. Aliquots of gas for various analyses (e.g., hydrocarbon composition by gas chromatography) are taken from individual gas volume increments by releasing gas from the bubbling chamber into a syringe. The PCS is disassembled and the sediment core is extruded. The core is then examined for length and overall condition and is sampled for physical properties, especially porosity.

Previous PCS Operations (Leg 164)

A long and mostly unsuccessful history of pressure coring operations marks scientific deep-sea drilling prior to Leg 164 and drilling operations in 1995 (Pettigrew, 1992; Paull, Matsumoto, Wallace, et al., 1996). Two main problems particularly plagued early operations: (1) tools did not retrieve lengthy cores at pressure, and (2) available manifolds could not easily measure gas volumes. Both problems were mostly overcome during Leg 164 on the Blake Ridge off the southeast margin of the United States. At Sites 995 and 997 during this cruise, 17 cores of between 3 and 100 cm length were recovered by the PCS at pressures between 750 and 4800 psi and were successfully degassed through a manifold to quantify gas volume (Dickens et al., 2000a, 2000b).

Although successful PCS operations during Leg 164 led to long-desired gas concentration profiles across a bottom-simulating reflector (Dickens et al., 1997), they immediately raised several issues relevant to future use in scientific drilling operations. In particular:

1. Sediment on the Blake Ridge consists of very fine grained and fairly homogenous "nannofossil-bearing clay." Can the PCS be used to collect cores at high pressure on other margins or in other lithologies?
2. Only one PCS deployment retrieved a full 1.00-m sediment core, and most deployments recovered cores <50 cm long. Can the PCS be modified to collect longer cores?
3. Many of the cores were unconsolidated after removal from the tool. Can cores be extruded from the tool so they retain their dimensions?
4. Only cores taken below 150 meters below seafloor (mbsf) were successfully degassed at Sites 995 and 997 because unlithified sediment at shallow depth clogged the manifold. Can the manifold and PCS be reconfigured to collect gas at shallow sediment depth?

New Modifications

Three modifications were made to the PCS prior to Leg 201 in an attempt to improve the length and quality of cores. First, three new cutting shoes for rotary coring were developed (Fig. F2). These shoes are (1) the Christensen auger shoe with carbide cutters, (2) a Rock Bit International (RBI) tapered auger with polycrystalline diamond compact (PDC) cutters, and (3) an RBI standard PDC cutting shoe. Second, to minimize washing of sediment during coring, the cutting shoe was placed ~50 cm ahead of the XCB bit. Third, the 4.32-cm-diameter core barrel was lengthened to 1.00 m to give an effective volume of 1465 cm^3 (instead of 1385 cm^3 during Leg 164).

Following designs constructed late during Leg 164, a new free-standing, lightweight manifold was constructed for Leg 201 (Fig. F3). However, the basic components and operational principles are the same (see "PCS-M4;" Paull, Matsumoto, Wallace, et al., 1996, p. 25). Several short lengths of high-pressure pipe are connected so that (1) air can be displaced through one valve, (2) gas can enter at high pressure from the PCS through a second valve, (3) pressure can be measured by a gauge or transducer, and (4) gas can be released into a bubbling chamber through a third valve. The bubbling chamber, which consisted of an inverted 1-L graduated cylinder in a plexiglass tube filled with a saturated NaCl solution, was the same as used during Leg 164 (Paull, Matsumoto, Wallace, et al., 1996, p. 25).

LEG 201 PCS OPERATIONS

Site Locations

The PCS was deployed at six of the locations drilled during Leg 201: Sites 1225 and 1226 at 3771 and 3308 mbsf, respectively, in the eastern equatorial Pacific; Sites 1227, 1228, and 1229 at 439, 274, and 151 mbsf, respectively, along the Peruvian shelf; and Site 1230 at 5086 mbsf on the lower slope of the Peru Trench. All six of these locations had been drilled previously during ODP Legs 112 or 138 (Suess, von Huene, et al., 1988; Mayer, Pisias, Janecek, et al., 1991).

Sediments at the six locations vary considerably (Suess, von Huene, et al., 1988; Mayer, Pisias, Janecek, et al., 1991; also see "Lithology" sections in the site chapters). The sequences at Sites 1225 and 1226 consist mostly of stiff, fine-grained nannofossil ooze. By contrast, the sediment records at Sites 1227, 1228, and 1229 are composed of alternating diatomaceous and siliciclastic packages with occasional hardgrounds and coarse-grained units. The sequence at Site 1230 consists mostly of clay and diatom ooze.

Observations made from conventional cores during Leg 201 and the previous legs suggest that significant gas loss on the wireline trip undoubtedly occurs at one site and possibly at two additional sites. Visible gas escape structures appeared in cores below 30 mbsf at Site 685/1230. Structures potentially representing gas release also were documented between 58 and 62 mbsf at Site 681/1229. High headspace methane concentrations (>1000 µL/L), which may signify gas concentrations approaching or exceeding saturation at depth, were present at these two sites as well as at ODP Site 684/1227. Gas hydrate also exists in sediment at Site 685/1230 (Kvenvolden and Kastner, 1990; also see "Gas Hydrate," p. 35, in the "Site 1230" chapter).

Post-Retrieval Processing

The PCS cores were degassed in the rock polishing room at the top of the laboratory stack (Fig. F3). Other than the precruise cutting shoe modifications, the most significant change between Leg 164 and Leg 201 PCS operations was the location of gas venting. The PCS has connected inner and outer chambers with a sampling port to each (Fig. F1). The inner chamber contains the sediment core (and excess borehole water in the case of a short core) of ~1465 mL, whereas the outer chamber contains ~ 2700 mL of borehole water. For many of the PCS cores on Leg 164, gas was released from the port to the inner chamber. With this configuration, however, unconsolidated sediment often extruded into the port and manifold at high pressure, clogging the system and preventing gas release. To rectify this problem, gas was released through the port of the outer chamber on PCS cores retrieved toward the end of Leg 164 (Dickens et al., 2000b). This configuration was used for all PCS cores during Leg 201.

Measurements of PCS data were kept simple during Leg 201. Time was recorded to the nearest half minute with a clock. Discrete gauge pressures were obtained in pounds per square inch gauge pressure (psig) using a pressure transducer inside of the PCS. When possible, these pressures were then corrected to account for the expected 15-psi reading at atmospheric pressure. Incremental gas volumes were recorded to the nearest 5 mL. The length of the sediment core was determined to the nearest 1 cm. Unlike during Leg 164, most of the extruded cores were in sufficiently good condition to accurately measure length. A thermometer showed that temperature inside the laboratory stayed at 21° ± 2°C.

Data Presentation

The **"Appendix,"** p. 10, presents shipboard data collected during the PCS gas release experiments in a set of nine columns: Shipboard Local Time, Elapsed Run Time, Gauge Pressure, Corrected Pressure, PCS Opening Number, Gas Release Volume, Gas Sample Number, Gas Split Volume, and Cumulative Gas Volume. These columns follow those used and discussed in previous PCS data reporting (Dickens et al., 2000b). For several reasons, not all PCS cores recovered at pressure have values in all nine columns. In particular, problems with the pressure transducer prevented collection of pressure measurements for some cores.

RESULTS AND DISCUSSION

Overall Summary

During Leg 201, the PCS was deployed 17 times, a total surpassed previously only by operations during Leg 164. The first seven runs, at Sites 1225 to 1229, were primarily undertaken to test whether the modified tool and cutting shoes would operate in rotary mode across a range of lithologies. The 10 runs at Site 1230 were specifically targeted to construct an "in situ" gas concentration profile from shallow depths near the seafloor to deeper depths below intervals with gas hydrate. Table **T1** summarizes the pertinent information for all these cores.

T1. PCS operations, p. 21.

Trial Runs

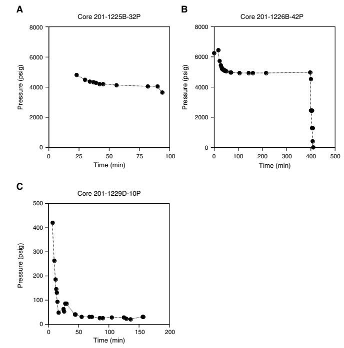
Sites 1225 and 1226 (Eastern Equatorial Pacific)

Two runs of the PCS were made at Site 1225. Core 201-1225A-29P recovered 1.00 m of sediment under pressure using the Christensen auger shoe and an additional 0.41 m of sediment in the extended shoe. However, the recovery pressure was not determined because the port for the internal pressure transducer leaked. After ~30 min and possible release of some internal pressure, a gauge inserted into a side port indicated ~1200 psig. Approximately 70 mL of gas escaped through the manifold when the PCS was opened to atmospheric pressure. Core 201-1225C-32P recovered 1.00 m of sediment using the RBI auger shoe, although the pivot pins on the ball valve broke. A pressure gauge inserted ~30 min after recovery and several minutes after placement on ice showed 4800 psig. Over the following hour, the pressure of this core dropped to 4010 psig (Fig. **F4A**). No gas volume was determined when the PCS was opened to atmospheric pressure.

The PCS was also deployed twice at Site 1226, although targeted intervals were significantly deeper and harder than at Site 1225. Using the Christensen auger shoe, Core 201-1226B-42P reached the rig floor at 6208 psig with 1.00 m of sediment inside the tool and an additional 0.66 m of sediment in the extended shoe. After placing this core on ice, the pressure decreased in a logarithmic manner to 4907 psi within 150 min (Fig. **F4B**). Approximately 60 mL of gas was released upon opening the tool to atmospheric pressure. Using the RBI auger shoe, Core 201-1226E-21P recovered 1.00 m of sediment, but at atmospheric pressure. A post-mortem autopsy revealed that a chert layer was present at the level of the ball valve and prevented the tool from sealing at depth. There was no damage to the cutting shoe or tool.

Numerous gas release experiments during Leg 164 demonstrated that all PCS cores retrieved at high pressure (1) decreased in pressure in a logarithmic manner to a new elevated pressure over ~150 min after placement on ice and (2) released 60 to 120 mL of air upon first opening the tool (Paull, Matsumoto, Wallace, et al., 1996; Dickens et al., 2000a). Experiments at Sites 1225 and 1226, which contain very little CH_4 according to conventional headspace analyses (see "Biogeochemistry" sections in the site chapters), confirm these findings. Presumably, air becomes trapped inside the tool as headspace during deployment. Despite the lack of hydrocarbon gas, the trial PCS runs at Sites 1225 and 1226 clearly show that the tool can collect full 1.00-m cores at pressure in sediment other than the fine-grained clay of the Blake Ridge.

F4. Time-pressure plots for trial runs, p. 14.



Sites 1227, 1228, and 1229 (Peru Shelf)

One run of the PCS was made at Site 1227 with the RBI auger shoe. However, the tool never closed at depth and Core 201-1227A-15P failed to recover a sediment core and return to the ship at pressure.

A single PCS run was also made at Site 1228 with the RBI auger shoe, although this cutting shoe was lost in the hole after snapping off. Core 201-1228A-23P recovered 0.07 m of sediment. However, pressure could not be determined on the rig floor because water again leaked into the port with the pressure transducer. A pressure gauge inserted into the side port of the PCS immediately before placing the tool on ice gave a reading of 35 psig. Approximately 60 mL of gas was released the core when it was opened to atmospheric pressure. This gas was air.

The PCS was deployed once at Site 1229 in an interval near where gas escape structures were described during Leg 112 (Suess, von Huene, et al., 1988). Core 201-1229A-10P recovered 0.86 m of sediment at 78 mbsf using the Christensen auger shoe. However, the release of gas from this core was not straightforward. First, the pressure transducer apparently failed again, so a pressure gauge was inserted into the side port. This gauge read 420 psi before placing the tool on ice, a pressure higher than the 338 psig expected, assuming hydrostatic loading. An alternate digital pressure recorder was then connected to the tool, but pressures oscillated between 19 and 100 psig over time, even when the tool was closed on ice (Fig. **F4C**). After about an hour, the tool was opened and 2880 mL of gas was incrementally released though the manifold. Essentially all of this "gas" was composed of air. We assume the air was introduced during drilling; however, we do not understand where and how such a large amount of air entered the tool or whether it relates to the anomalous pressure readings.

PCS Deployments at Site 1230 (Peru Trench)

Basic Measurements

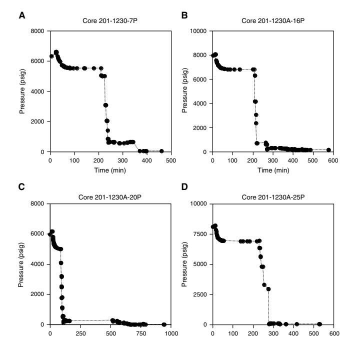
The PCS was deployed 10 times at Site 1230 using the Christensen auger or RBI PDC cutting shoes (Table T1). Pressures measured on the rig floor for these deployments ranged from 254 to 8044 psi, or from 4% to 105% of hydrostatic pressure (Table T1). The range in observed pressures, including values higher than hydrostatic, is similar to that obtained at sites on the Blake Ridge (Paull, Matsumoto, Wallace, et al., 1996). However, these PCS pressures should not be used to accurately assess downcore variations in pressure. All PCS deployments trap a small volume of headspace air, as noted previously. Consequently, pressures inside the PCS change as this headspace volume warms and cools between the subsurface and the first measurement on the rig floor (Dickens et al., 2000b).

The length of core recovered by the PCS at Site 1230 varied from 0.18 to 1.00 m (Table T1), with six of the deployments retrieving the maximum length. This overall core recovery is much better than that at Sites 994, 995, and 997, where many PCS runs retrieved cores of <0.50 m (Paull, Matsumoto, Wallace, et al., 1996). Core 201-1230A-25P was extruded as a series of incoherent sediment masses that totaled 0.18 m, a length that probably represents a maximum. All sediment cores recovered by the PCS are lithologically similar to surrounding cores recovered by APC or XCB at adjacent depths.

T2. Composition of gas released from the PCS, p. 22.

Total gas volumes released from the PCS ranged from 200 to 6330 mL (Table T1). These volumes are primarily mixtures of helium, air (nitrogen and oxygen), methane, and carbon dioxide (Table T2), although not all incremental volumes were analyzed (see "Appendix," p. 10). In general, helium and air dominate the first 150 mL of gas because helium was used to purge the small manifold volume (~30 mL) prior to gas release, and a small volume of air is trapped in the tool during deployment. Methane comprises most of the remaining gas after release of air, although carbon dioxide and sometimes air increasingly constitute minor components at low pressure. These results are the same as those found during Leg 164.

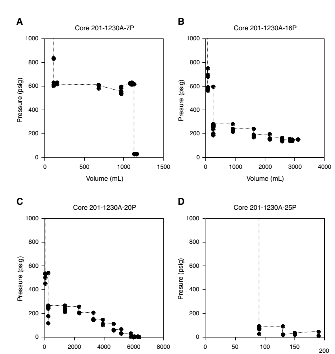
F5. Time-pressure plots, Site 1230, p. 15.



Detailed Gas Release Experiments

Using information in the "Appendix," p. 10, we have constructed time-pressure (Fig. F5) and volume-pressure (Fig. F6) plots for each of the 10 PCS cores at Site 1230. In constructing these plots, pressures have not been corrected for gauge offset and volumes include all gas released at all temperatures from 0° to 21°C. Pressure axes on the volume-pressure plots are linear and range from 0 to 1000 psig to emphasize gas release at low pressure (Dickens et al., 2000a).

F6. Volume-pressure plots, Site 1230, p. 18.



Gas escapes the PCS in a predictable manner, as observed by common features of the time-pressure and volume-pressure plots (Figs. F5, F6). After recording an initial pressure on the rig floor (generally >6000 psig at Site 1230), the pressure rises until the core is surrounded with ice and cooled. Pressure then decreases almost exponentially to reach a baseline value in ~100 min. Upon first opening the PCS to the manifold, a small volume of gas (air) escapes and pressure plummets to <500 psig. With each successive opening of the PCS, an incremental loss of gas (mostly methane) and drop in pressure occurs. The change in volume and pressure during these openings decrease with time until warmed to ambient laboratory conditions, when an additional volume of gas exits the tool. These time-pressure-volume relationships are entirely consistent with gas release experiments at Sites 995 and 997 on the Blake Ridge (Paull, Matsumoto, Wallace, et al., 1996; Dickens et al., 2000).

Gas Profile

In situ methane concentrations can be calculated from gas volumes, core volumes, and porosities after correction for air contamination (Dickens et al., 1997; 2000). Preliminary estimates suggest that in situ methane concentrations at Site 1230 range from 13 mM (Core 201-1230B-4P) to 400 mM (Core 201-1230A-20P). The latter value greatly exceeds methane solubility with respect to the dissolved CH_4–CH_4 hydrate partial saturation curve (Handa, 1990); it is consistent with the presence of several percent gas hydrate in pore space around 150 mbsf.

SUMMARY

With several modifications since Leg 164, the PCS was deployed 17 times during Leg 201 for two primary purposes: (1) to test the capabilities of the tool across a range of lithologies and depths and (2) to collect a series of cores from the seafloor to several hundred meters depth at a site where abundant evidence indicates extreme loss of gas on the wireline trip. Both objectives were accomplished fairly successfully. Eleven cores of >50 cm length were retrieved at >75% hydrostatic pressure. Another two PCS deployments collected cores <50 cm length but at >75% hydrostatic pressure, and another two PCS deployments came to the ship with cores >50 cm length but at <20% hydrostatic pressure. Only two PCS deployments, both taken on the Peru shelf, failed to recover a significant sediment core or core barrel at pressure. Of the sediment cores collected, all could be extruded as coherent masses except Core 201-1230A-25P. The tool definitely performed better during Leg 201 than during Leg 164. In summary, evidence from Leg 201 suggests that the PCS can operate successfully in a variety of deepwater settings. Moreover, cores collected at shallow sediment depth can be degassed, enabling the generation of gas concentration profiles from the seafloor to depth. Such a profile will be constructed postcruise for Site 1230.

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REFERENCES

Dickens, G.R., Borowski, W.S., Wehner, H., Paull, C.K., and the ODP Leg 164 Scientific Party, 2000b. Data report: Additional shipboard information for the pressure core sampler (PCS). *In* Paull, C.K., Matsumoto, R., Wallace, P.J., and Dillon, W.P. (Eds.), *Proc. ODP, Sci. Results,* 164: College Station, TX (Ocean Drilling Program), 439–443.

Dickens, G.R., Paull, C.K., Wallace, P., and ODP Leg 164 Scientific Party, 1997. Direct measurement of in situ methane quantities in a large gas-hydrate reservoir. *Nature,* 385:426–428.

Dickens, G.R., Wallace, P.J., Paull, C.K., and Borowski, W.S., 2000a. Detection of methane gas hydrate in the pressure core sampler (PCS): volume-pressure-time relations during controlled degassing experiments. *In* Paull, C.K., Matsumoto, R., Wallace, P.J., and Dillon, W.P. (Eds.), *Proc. ODP, Sci. Results,* 164: College Station, TX (Ocean Drilling Program), 113–126.

Fossing, H., Ferdelman, T.G., and Berg, P., 2000. Sulfate reduction and methane oxidation in continental margin sediments influenced by irrigation (South-East Atlantic off Namibia). *Geochim. Cosmochim. Acta,* 64:897–910.

Handa, Y.P., 1990. Effect of hydrostatic pressure and salinity on the stability of gas hydrates. *J. Phys. Chem.,* 94:2652–2657.

Hoehler, T.M., Borowski, W.S., Alperin, M.J., Rodriguez, N.M., and Paull, C.K., 2000. Model, stable isotope, and radiotracer characterization of anaerobic methane oxidation in gas hydrate–bearing sediments of the Blake Ridge. *In* Paull, C.K., Matsumoto, R., Wallace, P.J., and Dillon, W.P. (Eds.), *Proc. ODP, Sci. Results,* 164: College Station, TX (Ocean Drilling Program), 79–85.

Kvenvolden, K.A., Barnard, L.A., and Cameron, D.H., 1983. Pressure core barrel: application to the study of gas hydrates, Deep Sea Drilling Project Site 533, Leg 76. *In* Sheridan, R.E., Gradstein, F.M., et al., *Init. Repts. DSDP, 76:* Washington (U.S. Govt. Printing Office), 367–375.

Kvenvolden, K.A., and Kastner, M., 1990. Gas hydrates of the Peruvian outer continental margin. *In* Suess, E., von Huene, R., et al., *Proc. ODP, Sci. Results,* 112: College Station, TX (Ocean Drilling Program), 517–526.

Mayer, L.A., Pisias, N.G., Janecek, T.R., et al., 1992. *Proc. ODP, Init. Repts.,* 138: College Station, TX (Ocean Drilling Program).

Paull, C.K., Lorenson, T.D., Dickens, G., Borowski, W.S., Ussler, W., III, and Kvenvolden, K., 2000. Comparisons of in situ and core gas measurements in ODP Leg 164 boreholes. *Ann. New York Acad. Sci.,* 912:23–31.

Paull, C.K., Matsumoto, R., Wallace, P.J., and Dillon, W.P. (Eds.), *Proc. ODP, Sci. Results,* 164: College Station, TX (Ocean Drilling Program).

Pettigrew, T.L., 1992. The design and operation of a wireline pressure core sampler (PCS). *ODP Tech. Note,* 17.

Suess, E., von Huene, R., et al., 1988. *Proc. ODP, Init. Repts.,* 112: College Station, TX (Ocean Drilling Program).

APPENDIX

Time, Pressure, and Volume Measurements of PCS Deployments

Local time Hr	Local time Min	Elapsed run time (min)	Gauge pressure (psig)	Corrected pressure (psi)	Opening number	Gas release volume (mL)	Gas split number	Gas split volume (mL)	Cumulative volume (mL)	Notes
Core 201-1225C-32P										
3	30	0	Unknown						0	Rig floor; transducer leaked
3	53	23	4800						0	On ice
4	0	30	4450						0	
4	4	34	4350						0	
4	7	37	4300						0	
4	9	39	4250						0	
4	12	42	4200						0	
4	15	45	4170						0	
4	26	56	4100						0	
4	52	82	4030						0	
5	0	90	4010						0	Port stuck with broken transducer; no manifold connected
5	4	94	3620		C1				0	
Core 201-1226B-42P										
10	10	0	6208	6223					0	Rig floor
10	27	17	6425	6440					0	On ice
10	33	23	5709	5724					0	
10	37	27	5404	5419					0	
10	39	29	5311	5326					0	
10	41	31	5240	5255					0	
10	43	33	5187	5202					0	
10	45	35	5155	5170					0	
10	47	37	5129	5144					0	
10	49	39	5104	5119					0	
10	51	41	5085	5100					0	
10	53	43	5068	5083					0	
10	56	46	5047	5062					0	
11	0	50	5021	5036					0	
11	17	67	4954	4969					0	
11	20	70	4945	4960					0	
11	55	105	4915	4930					0	
12	31	141	4911	4926					0	
12	50	160	4907	4922					0	
13	44	214	4907	4922					0	
16	46	396	4941	4956					0	
16	49	399	4486	4501	C1				0	
16	50	400	2428	2443	C2	30	(G1)		30	
16	52	402	2436	2451					30	
16	53	403	2437	2452					30	
16	54	404	2438	2453					30	
16	54.5	404.5	1268	1283	C3	15	(G1)		45	
16	55	405	1269	1284					45	
16	56	406	1271	1286					45	
16	57	407	1273	1288					45	
16	58	408	399	414	C4	15	G1	60	60	
16	59	409	0	15					60	No warming
Core 201-1229D-10P										
12	30	0	Not measured						0	Rig floor; transducer leaked
12	37	7	420						0	On ice
12	40	10	262						0	Transducer leaked
12	42	12	184						0	
12	43	13	145						0	
12	44	14	128						0	
12	45	15	92						0	
12	47	17	47						0	
12	55	25	61						0	
12	56	26	51						0	
12	58	28	85						0	Broken transducer?
13	0	30	83						0	(pressure not correct?)
13	14	44	38						0	

Note: Only a portion of this table appears here. The complete table is available in **ASCII**.

Figure F1. Schematic of the ODP Pressure Core Sampler (PCS) highlighting the two pathways for sampling gas (adapted from Pettigrew, 1992). Top: release of gas from the port to the outer chamber. Bottom: release of gas from the port to the inner chamber.

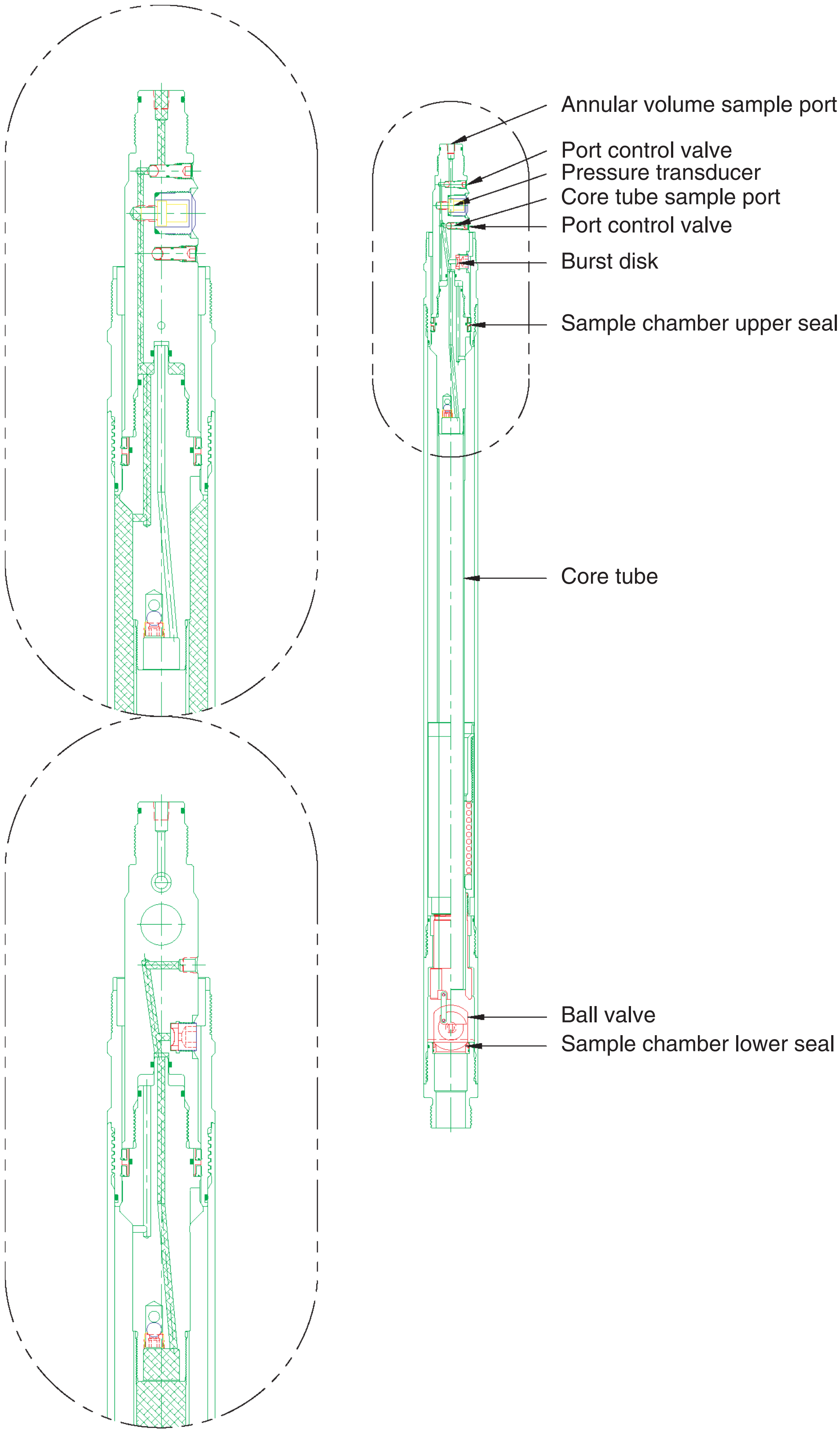


Figure F2. Photograph showing new cutting shoes used during PCS deployments. Left: Christensen auger shoe with carbide cutters. Middle: Rock Bit International (RBI) tapered auger shoe with PDC cutters. Right: RBI standard PDC cutting shoe.

Figure F3. Photograph showing the gas manifold system and degassing of the PCS in the laboratory during Leg 201.

Figure F4. Time-pressure plots for trial runs of the PCS. **A.** Core 201-1225A-32P. **B.** Core 201-1226B-42P. **C.** Core 201-1229D-10P.

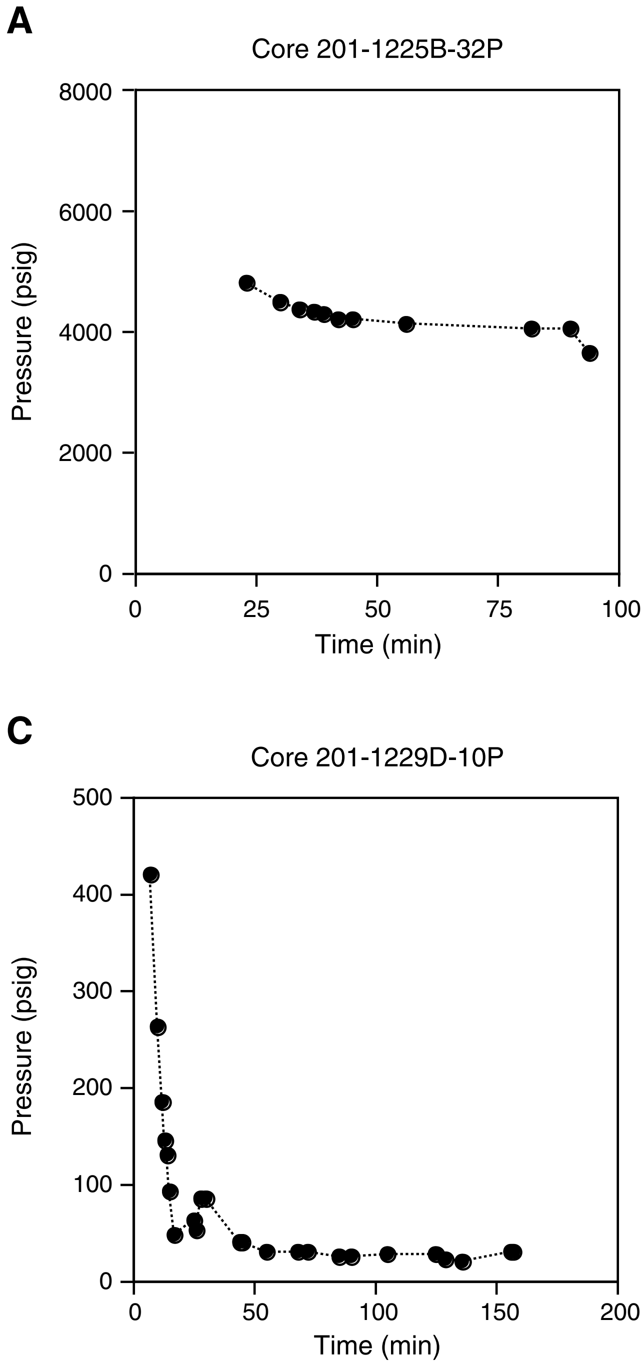


Figure F5. Time-pressure plots for PCS runs at Site 1230, Peru Trench. **A.** Core 201-1230A-7P. **B.** Core 201-1230A-16P. **C.** Core 201-1230A-20P. **D.** Core 201-1230A-25P. (Continued on next two pages.)

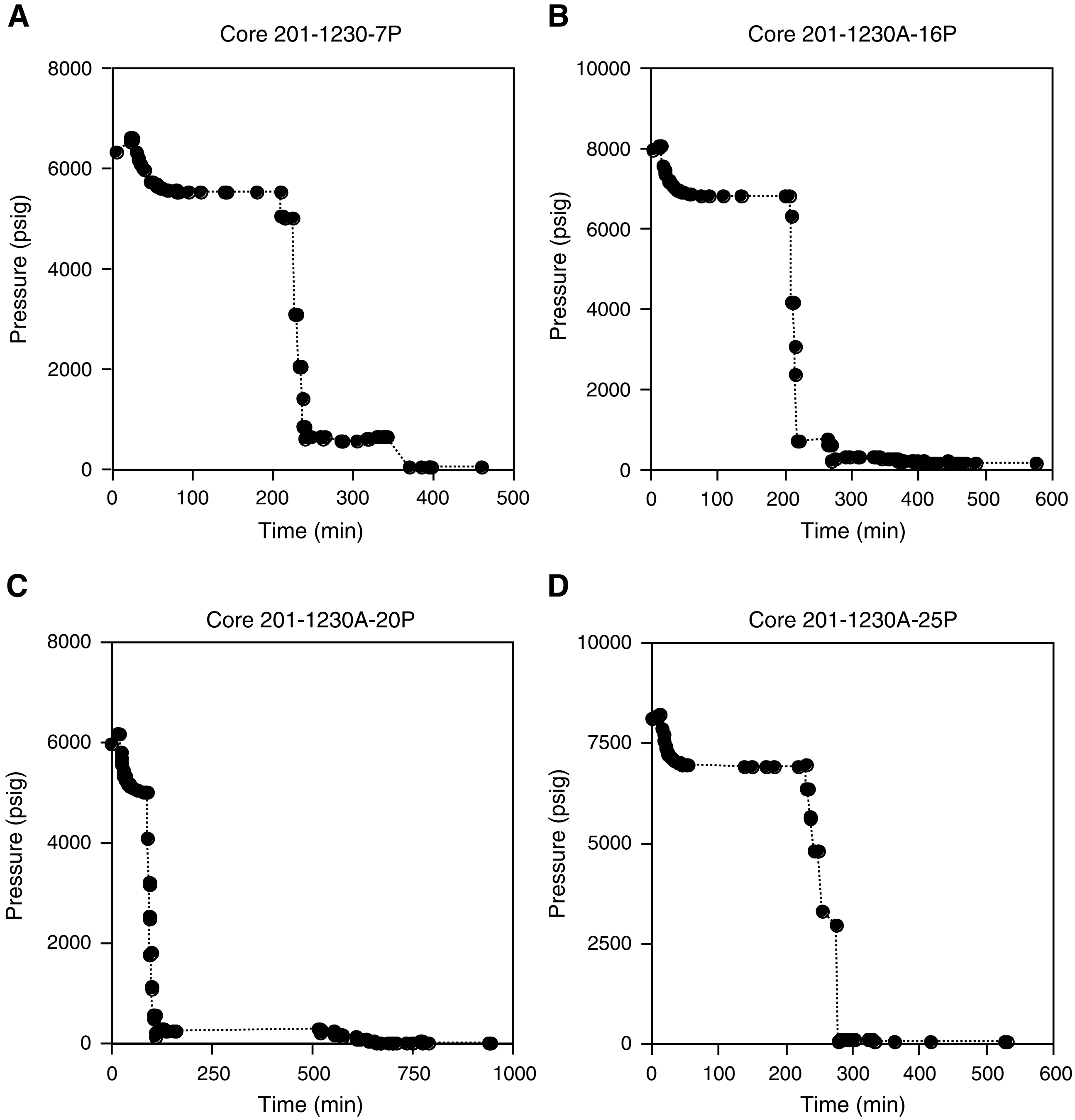
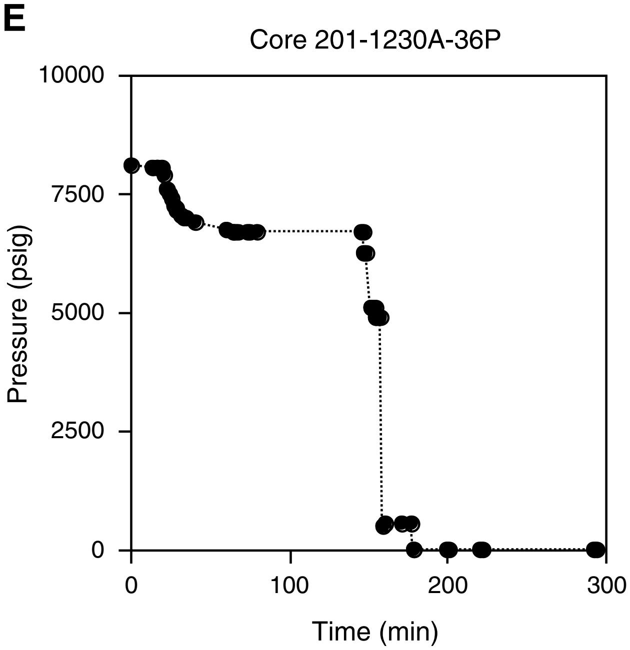
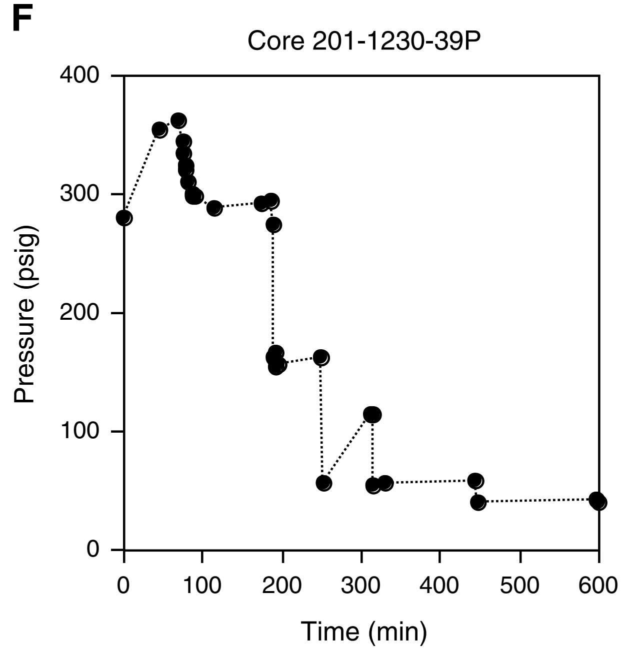


Figure F5 (continued). **E.** Core 201-1230A-36P. **F.** Core 201-1230A-39P. **G.** Core 201-1230B-4P. **H.** Core 201-1230B-10P. (Continued on next page.)

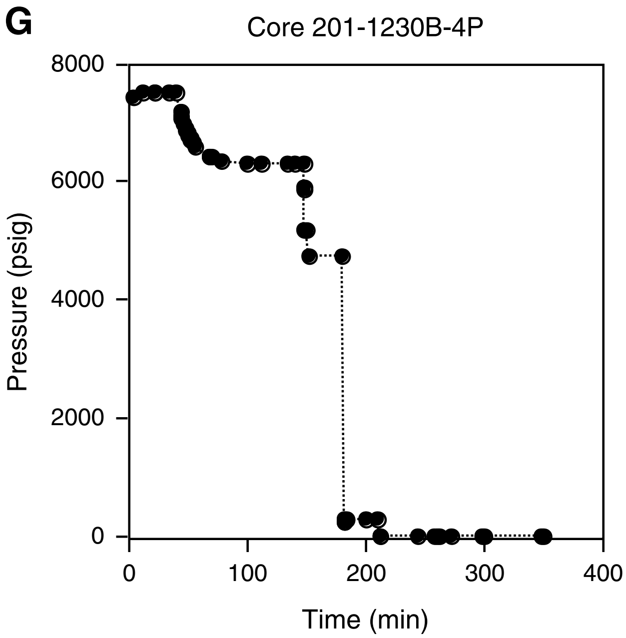
E



F



G



H

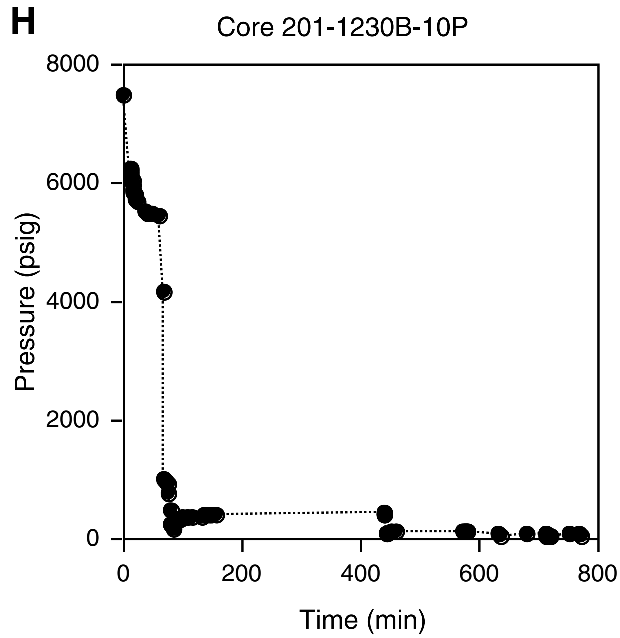


Figure F5 (continued). **I.** Core 201-1230B-14P. **J.** Core 201-1230E-5P.

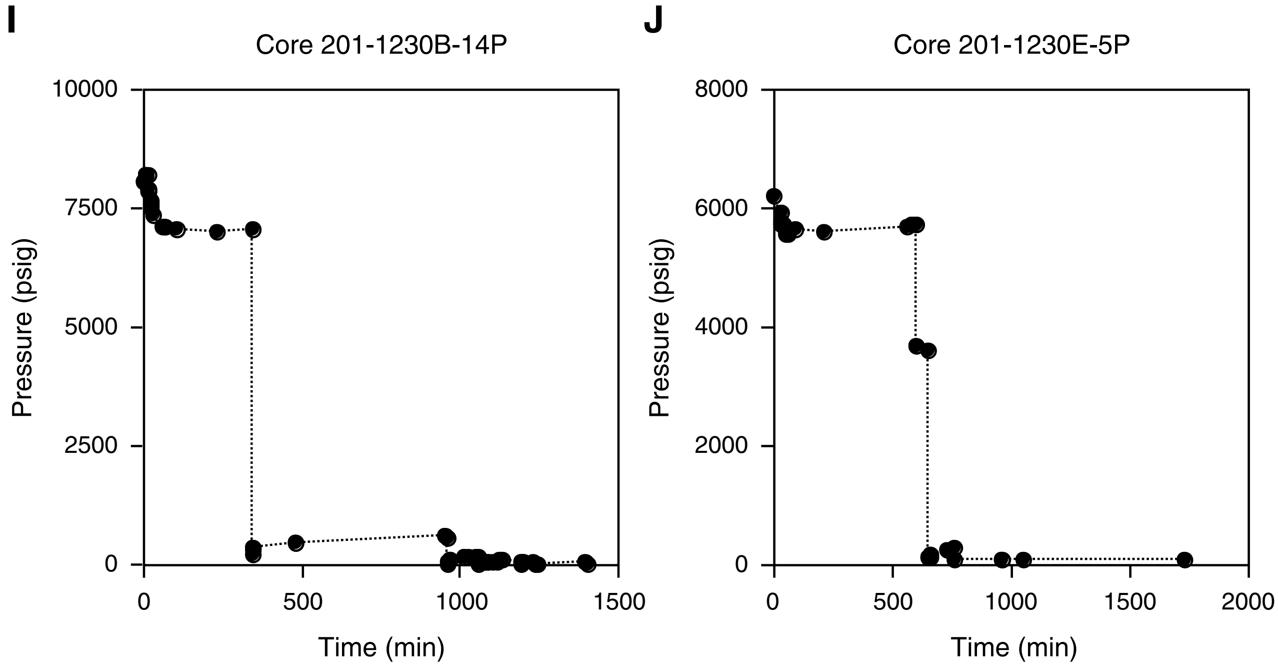


Figure F6. Volume-pressure plots for PCS runs at Site 1230, Peru Trench. **A.** Core 201-1230A-7P. **B.** Core 201-1230A-16P. **C.** Core 201-1230A-20P. **D.** Core 201-1230A-25P. (Continued on next two pages.)

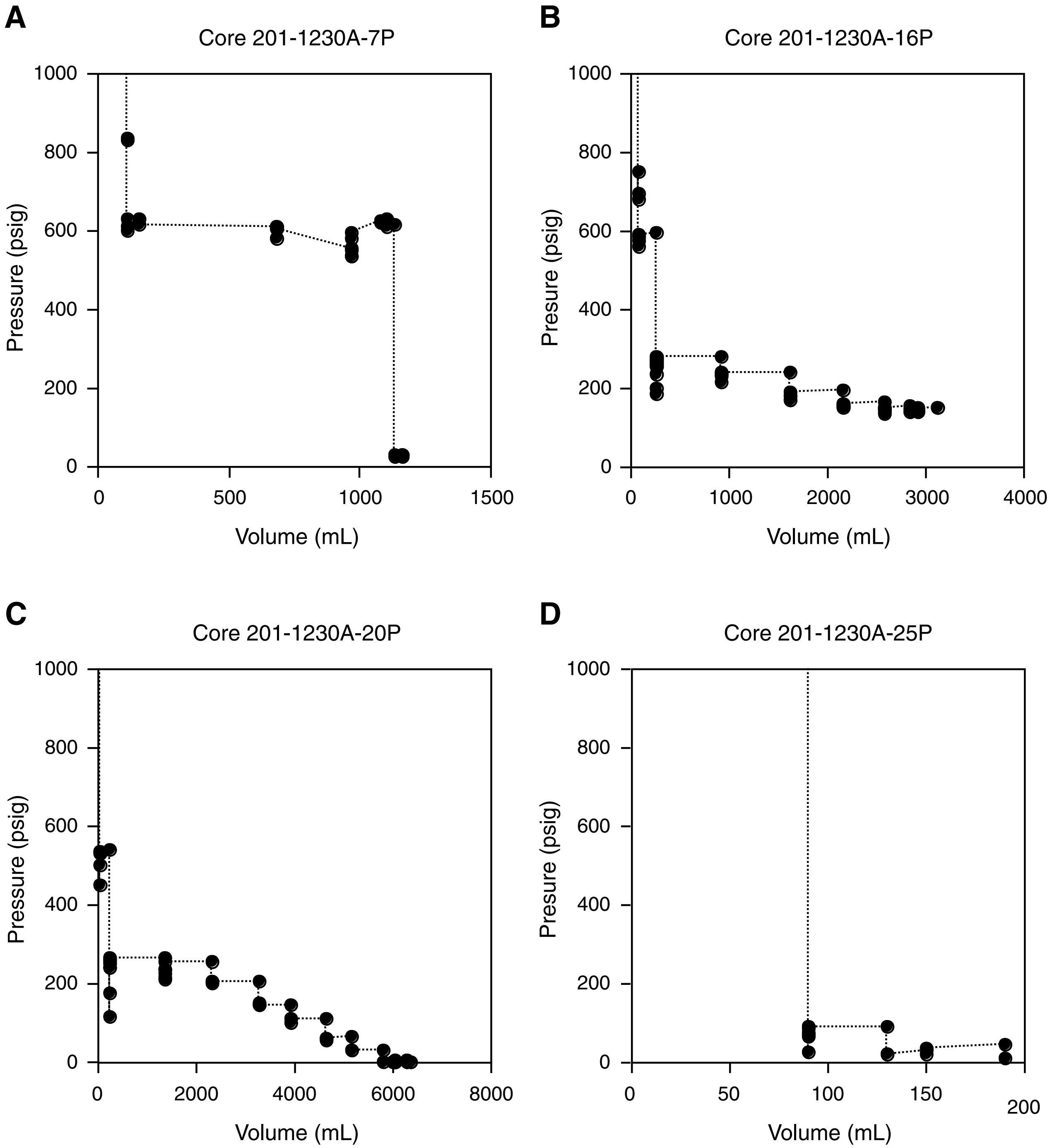


Figure F6 (continued). **E.** Core 201-1230A-36P. **F.** Core 201-1230A-39P. **G.** Core 201-1230B-4P. **H.** Core 201-1230B-10P. (Continued on next page.)

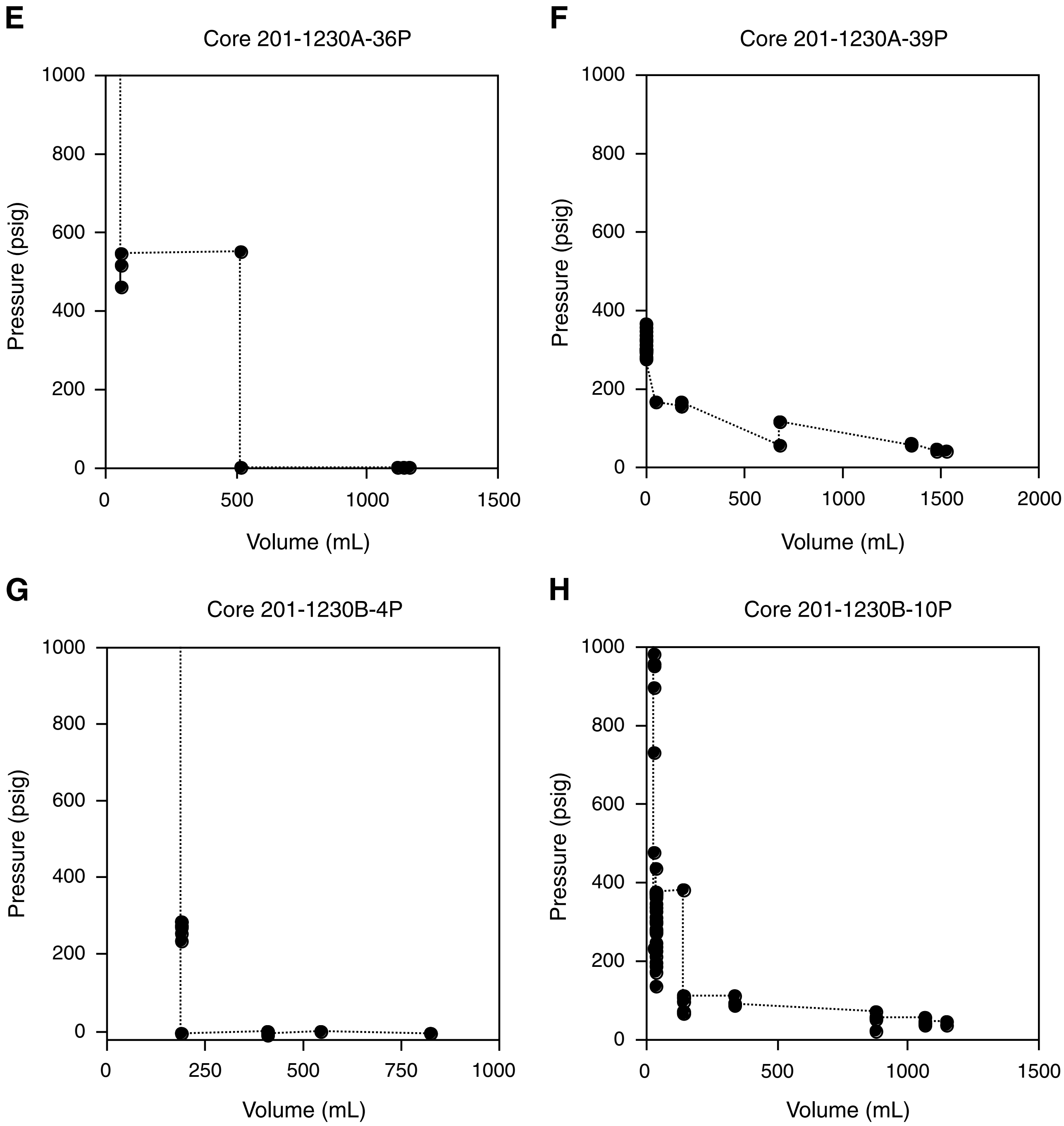


Figure F6 (continued). **I.** Core 201-1230B-14P. **J.** Core 201-1230E-5P.

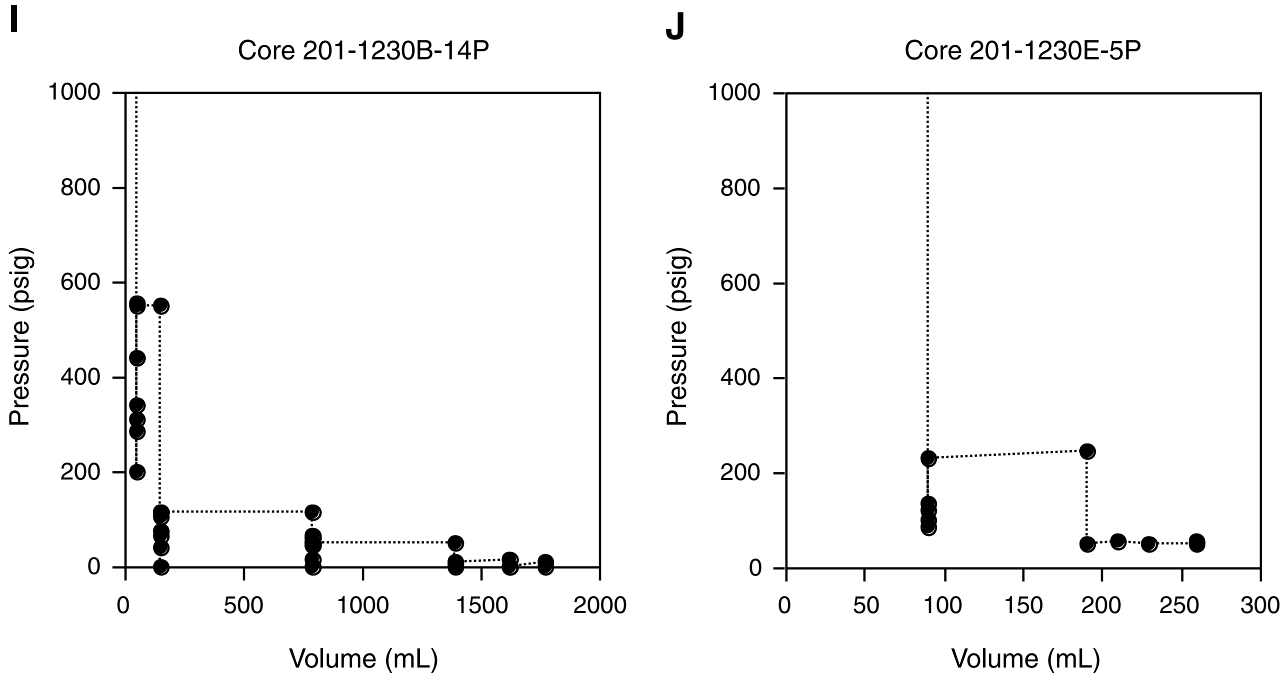


Table T1. PCS operations, Leg 201.

Hole	Core	Date (2002)	Cutting shoe[1]	Recovery time[2]	Core top depth (mbsf)	Recovered pressure (psig)	Corrected pressure[3] (psi)	Expected pressure[4] (psi)	Hydrostatic (%)	Length recovered[5] (m)	Total gas released[6] (mL)
1225A	29P	10 Feb	Chr	0530	262.2	1200[7]		5941	~20	1.41*	70
1225C	32P	13 Feb	RBI-t	0330	293.8	4800[7]		5987	~80	1.00	ND
1226B	42P	22 Feb	Chr	1010	378.0	6208	6222	5429	115	1.66*	60
1226E	21P	25 Feb	RBI-t	0230	378.0	0	14	5429	0	1.00	ND
1227A	15P	1 Mar	RBI-t	2140	129.1	0		837	0	0.00	ND
1228A	23P	5 Mar	RBI-t	1300	198.9	>35[7]		697	~5	0.07	60
1229D	10P	9 Mar	Chr	1230	77.8	420[7]		337	~125	0.86	2880[8]
1230A	7P	12 Mar	Chr	0330	52.3	6304	6292	7569	83	1.50*	1160
1230A	16P	13 Mar	Chr	0300	127.3	7940	7808	7679	102	1.05*	3110
1230A	20P	13 Mar	RBI-s	1515	156.8	5930	5944	7723	77	0.66	6350
1230A	25P	14 Mar	RBI-s	0425	196.8	8060	8067	7782	104	0.18[9]	190[10]
1230A	36P	15 Mar	Chr	0745	254.6	8086	8110	7867	103	0.43	1160
1230A	39P	15 Mar	Chr	2305	276.8	280	254	7899	3	0.62	1530
1230B	4P	17 Mar	Chr	0524	22.0	7400	7421	7524	99	1.00	825[11]
1230B	10P	17 Mar	Chr	1533	71.5	7450	7430	7597	98	1.00	1145
1230B	14P	18 Mar	RBI-s	0740	103.0	8030	8044	7643	105	1.62*	1765
1230E	5P	18 Mar	Chr	2300	34.0	6183	6143	7542	81	1.00	260[12]

Notes: 1 = cutting shoes shown in Figure **F2,** p. 12. 2 = ship local time. 3 = initial pressure after correcting final pressure to 14 psi. 4 = expected pressure assuming hydrostatic loading. 5 = some cores (*) collected a 1.00-m core under pressure and additional sediment in the extended shoe. 6 = total gas including air trapped in the tool during deployment. 7 = transducer not operating, pressure measured by gauge after potential loss of gas (air). 8 = entire gas volume consisted of air. 9 = maximum estimate of core length. 10 = an unknown amount of gas was lost at high pressure when the port clogged. 11 = total gas volume includes significant air (>100 mL). 12 = an unknown amount of gas was lost at low pressure. Chr = Christensen auger shoe with carbide cutters. RBI-t = Rock Bit International taped auger with polycrystalline diamond compact cutters. RBI-s = Rock Bit International standard with polycrystalline diamond compact cutters. ND = not detected.

Table T2. Composition of gas aliquots released from the PCS at Site 1230.

		Gas split		Gas concentrations							
Hole	Core	Number*	Volume (mL)	C_1† (ppm)	C_2† (ppm)	C_1‡ (ppm)	C_2‡ (ppm)	N_2‡ (ppm)	O_2‡ (ppm)	N_2/O_2 (ppm)	CO_2‡ (ppm)
1230A	7P	G10	290	894,599	ND	888,263	13	53,995	10,343	5	ND
1230A	7P	G11	110	926,475	ND	918,425	16	21,901	922	24	ND
1230A	7P	G13	50	543,753	ND	497,607	ND	17,563	2,411	7	ND
1230A	16P	G3	185	911,330	ND	904,526	32	4,270	898	5	ND
1230A	16P	G4	660	953,058	ND	949,518	33	714	319	2	ND
1230A	16P	G5	690	953,058	ND	949,519	33	714	319	2	ND
1230A	16P	G6	550	942,077	ND	939,084	19	1,072	347	3	ND
1230A	16P	G7	410	914,609	ND	909,365	16	14,742	2,147	7	ND
1230A	16P	G8	260	880,641	ND	874,291	18	43,986	7,308	6	ND
1230A	16P	G9	80	881,346	ND	866,884	18	44,237	7,584	6	ND
1230A	16P	G10	200	826,858	ND	822,154	21	102,132	16,454	6	ND
1230A	20P	G1	180	744,244	ND	734,219	58	167,070	37,715	4	ND
1230A	20P	G2	630	938,422	ND	ND	80	674	293	2	9,838
1230A	20P	G3	960	947,339	ND	931,693	80	591	184	3	6,030
1230A	20P	G4	930	947,167	ND	ND	79	592	137	4	4,510
1230A	20P	G5	670	929,254	ND	912,886	77	1,405	987	1	6,416
1230A	20P	G6	710	939,716	ND	922,880	72	1,327	127	10	8,964
1230A	20P	G7	510	934,807	ND	917,411	68	783	209	4	16,054
1230A	20P	G8	660	921,354	ND	904,865	70	1,421	60	24	34,657
1230A	20P	G9	170	886,660	ND	872,607	71	32,926	324	102	47,700
1230A	20P	G10	70	881,241	ND	866,141	73	32,922	341	97	54,799
1230A	20P	G11	220	869,129	ND	853,511	76	41,655	1,909	22	55,531
1230A	20P	G12	80	846,188	ND	ND	79	15,567	409	38	75,157
1230A	25P	G1	50	107,475	ND	144,895	11	407,485	100,386	4	ND
1230A	25P	G2	40	340,687	54	ND	55	171,138	36,247	5	2,938
1230A	25P	G3	20	505,060	51	668,083	67	24,436	635	38	1,712
1230A	25P	G4	40	926,842	ND	919,879	570	12,431	ND		35,929
1230A	36P	G1	30	6,452	ND	ND	ND	751,891	190,060	4	ND
1230A	36P	G2	460	920,916	ND	910,018	580	22,712	3,574	6	ND
1230A	36P	G3	600	936,947	ND	926,119	578	1,245	530	2	ND
1230A	36P	G4	20	927,083	ND	919,880	570	4,360	228	19	ND
1230A	39P	G1	130	928,439	ND	917,459	474	19,350	4268	5	ND
1230A	39P	G2	500	950,774	ND	940,066	479	966	,494	2	ND
1230A	39P	G3	670	943,460	ND	931,838	477	960	346	3	ND
1230B	4P	G0	150	2,984	ND	ND	ND	676	ND		ND
1230B	4P	G1	40	5,343	ND	ND	ND	76,879	15,343	5	1,017
1230B	4P	G2	220	133,008	ND	191,941	ND	345,907	56,643	6	2,357
1230B	4P	G3	135	280,815	ND	259,780	ND	336,831	52,228	6	4,305
1230B	10P	G2	195	885,772	ND	878,731	8	47,244	2,243	21	ND
1230B	10P	G3	535	895,825	ND	888,696	9	42,794	1,603	27	ND
1230B	10P	G4	190	847,186	ND	841,302	11	79,455	3,200	25	ND
1230B	14P	G1	100	901,275	ND	892,595	38	44,300	7,239	6	ND
1230B	14P	G2	640	945,934	ND	936,498	27	ND	ND		ND
1230B	14P	G3	600	936,232	ND	926,661	17	ND	ND		ND
1230B	14P	G4	225	902,128	ND	897,803	18	27,656	2,501	11	ND
1230B	14P	G5	150	909,206	ND	904,877	22	ND	ND		ND
1230E	5P	G1	70	14,529	ND	ND	ND	190,432	50,010	4	1,299
1230E	5P	G2	20	8,613	ND	ND	ND	536,883	141,130	4	ND
1230E	5P	G3	100	563,209	ND	557,719	9	293,682	64,590	5	ND
1230E	5P	G4	20	907,606	ND	901,368	19	39,198	2,232	18	ND

Notes: * = gas split shown in the "Appendix," p. 10. Gas concentrations were determined using different gas chromatography detectors: † = FID (flame ionization detector); ‡ = TCD (thermal conductivity detector). ND = not detected by automatic integration; this does not mean it is not present, especially for CO_2.