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2. CORK-II: Long-Term Monitoring of Fluid Chemistry, Fluxes, and Hydrology in Instrumented Boreholes at the Costa Rica Subduction Zone[1]

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ABSTRACT

Two boreholes were drilled on the Costa Rica subduction zone to study the geochemical fluxes and related processes associated with sediment compaction, dewatering, and alteration. The holes were outfitted with modified CORKs (CORK-IIs) that include instruments capable of fluid sampling and measuring flow rates, temperature, and pressure. Fluids are sampled continuously within the décollement zone and in the uppermost oceanic crust with long-term OsmoSamplers for both dissolved ions and gases. The major advantage of the CORK-II is that samples and data can be retrieved without disrupting the pressurized horizons by temporarily opening them to hydrostatic pressures during instrument exchange. This paper describes the concepts, design, and deployment of CORK-IIs in Holes 1253A and 1255A.

INTRODUCTION

Active fluid flow in convergent margins can have a profound effect on the shallow thermal structure and fluid content of the downgoing plate, the physical properties of the subduction zone interface, deformation style, and the transport of elements to the oceans, the volcanic

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arc, and the deeper mantle. Therefore, it is a major process for understanding the behavior of the seismogenic zone and the flux balance through the subduction zone.

Temporal hydrologic variations at convergent margins are likely intimately connected to the location, magnitude, and frequency of earthquakes as well as aseismic deformation in a subduction zone. In order to monitor those phenomena, two newly modified CORKs (called CORK-IIs hereafter) were installed for long-term sampling of fluids and gases as well as for monitoring of fluid pressure, temperature, and flow rate at critical horizons. Fluid sampling and physical monitoring is achieved by placing OsmoSamplers, temperature recorders, and ports for pressure measurements within a pressurized formation below a packer. In contrast to the initial CORK-II design, these installations monitor and sample processes only in the bottom section of a borehole, isolated from higher formations. An inflatable packer and a novel OsmoSampler seat inside the casing separate the lower hole from the upper portion of the cased borehole. The OsmoSampler seat was designed to maintain pressure within the pressurized horizon even during retrieval. This change was initiated to simplify estimates for fluid fluxes and to avoid the question of whether the entire cased borehole is chemically mixing (Wheat et al., 2000a) and to avoid pressure loss during sampler redeployments. Borehole OsmoFlowmeters were newly developed for this experiment to deduce relative rates and direction of fluid flow.

Significant design modifications to previously deployed OsmoSamplers (e.g., ODP Leg 168, Sites 1024 to 1027; Wheat et al., 2000a) improve the chances of recovering the OsmoSamplers in unstable formations and allow the samplers to be recovered and redeployed within pressurized horizons. Temperatures are continuously measured inside the OsmoSamplers using small autonomous data loggers (Pfender and Villinger, 2002). Pressure ports are located above and within the sealed interval, and pressures are measured with high-precision pressure gauges and recorded with a data logger located inside the CORK-II head, which sits inside the reentry cone at the seafloor (Shipboard Scientific Party, 2002b). The samplers are retrievable by wireline with the help either of a submersible or a remotely operated vehicle (ROV). Pressure data can be downloaded during submersible or ROV visits at the site by connecting a computer to the data logger via an underwater-mateable connector.

Leg 205 focused on the Costa Rica margin offshore the Nicoya Peninsula, building on ODP Leg 170 coring and logging at adjacent sites, and was designed to investigate the composition of the downgoing plate together with the thermal structure and hydrological activity across the Costa Rica margin (see the **"Explanatory Notes"** chapter, this volume). ODP Leg 170 drilling and heat flow studies (Kimura, Silver, Blum, et al., 1997; Silver et al., 2000) showed three distinct hydrological systems in the Costa Rica margin:

1. One system at Site 1039 is inferred to be in the uppermost oceanic basement beneath the sedimentary sequence on the incoming plate. This is based on the observations that in this region the basal sediments' pore fluid chemical profiles show a return to near-seawater concentration and isotope values for many tracers. Moreover, the surface conductive heat flow values are extremely low, ~10% of the expected value for the age of the oceanic basement.

2. At Sites 1043 and 1040, situated 0.5 and 1.6 km, respectively, arcward of the deformation front, a deeply sourced fluid flow system was sampled along the décollement and a shallower thrust fault.
3. A third system may be driven by compaction dewatering of underthrust sediments, with lateral transport of fluids trenchward, below the décollement.

Based on existing data from Leg 170 and coring results from Leg 205 (see the **"Explanatory Notes"** and **"Site 1254"** chapters, this volume), we identified zones of interest for fluid sampling and installed two CORK-IIs: one CORK-II in Hole 1253A, ~0.2 km seaward of the deformation front in the upper part of an igneous section, and one CORK-II in Hole 1255A in the décollement zone, ~0.4 km arcward of the deformation front. First observations of temporal variations of fluid and gas chemistry as well as pressure and temperature from CORK-II deployments of Leg 205 will be available once the fluid and gas samples have been recovered 1–2 yr postcruise.

In the following sections we will describe the individual components of a CORK-II system, with emphasis on the plumbing system for pressure measurements, the osmotic fluid and gas samplers, and temperature data loggers, and we will also explain the operational procedures for installment. In-depth discussion of some of the technical details and the design philosophy can be found in the "Explanatory Notes" chapter of the Leg 196 *Initial Reports* volume, during which ACORKs were deployed in the Nankai Trough (Shipboard Scientific Party, 2002a) (see the **"Site 1253"** and **"Site 1255"** chapters, this volume).

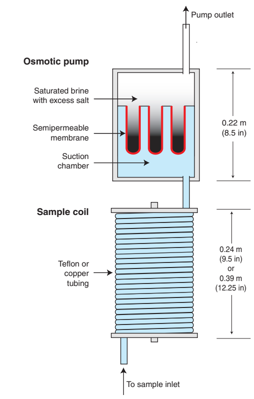
DESCRIPTION OF CORK-II COMPONENTS

OsmoSampler

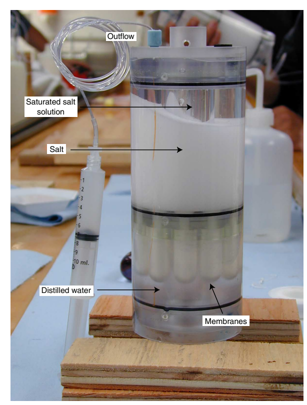
OsmoSamplers were designed and built to sample fluid continuously throughout the duration of each deployment. Significant design modifications to previously deployed OsmoSamplers (Wheat et al., 2000b; H. Jannasch, pers. comm., 2001) and those deployed at Sites 1024 to 1027 of ODP Leg 168 (Wheat et al., 2000a) allow the samplers to be recovered and redeployed within pressurized horizons. A newly developed OsmoSampler seat permits the OsmoSamplers to be replaced without losing formation pressure.

An OsmoSampler (Figs. **F1, F2**) consists of an osmotic pump originally described by Theeuwes and Yum (1976) and a sampling coil (Figs. **F3, F4**). The pump does not require any electrical power and has no moving parts. Flow within the pump is driven by the osmotic pressure gradient across a semipermeable membrane that separates solutions of different salinity. Membranes are chosen with an appropriate pore size to allow water to diffuse through the membrane while restricting the passage of dissolved salts. The difference in the salt concentration between the two solutions bounding the membrane drives a net diffusion of water, and thus flow, through the membrane from the fresher to the more saline side. The magnitude of the salt gradient, a function of the concentration difference and membrane thickness, controls the osmotic pressure and resulting flow rate. Rates of water flow across the membrane are dependent on membrane area, thickness, porosity, and number of membranes in the pump, as well as the osmotic pressure gra-

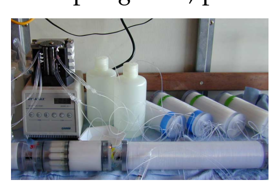
F1. Schematic of an OsmoSampler, p. 15.



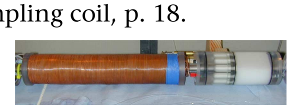
F2. Osmotic pump, p. 16.



F3. Osmotic pump and several Teflon sampling coils, p. 17.



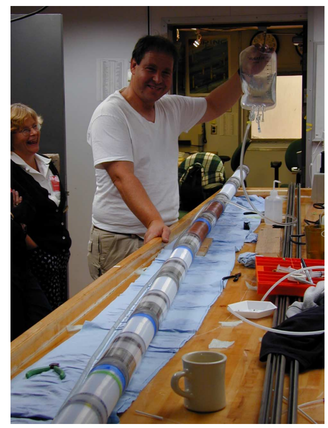
F4. Osmotic pump and a copper sampling coil, p. 18.



dient, temperature, and the diffusion coefficient of water. The osmotic pressure is maintained by keeping a saturated salt (NaCl) solution with excess salt on one side of the membrane while maintaining a solution with no salt (distilled water) on the other side. Housings of the osmotic pumps are made of acrylic because its thermal expansion coefficient is similar to that of water. A discussion of technical details can be found in Jannasch et al. (1994).

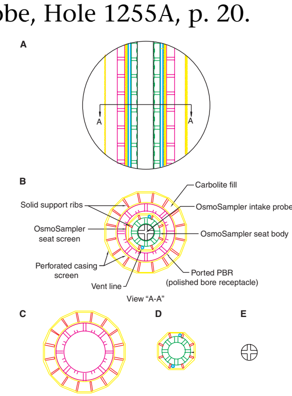
The osmotic pump draws sample fluid into and through a long spool of small-bore (0.8 to 1.2 mm inside diameter [ID]) Teflon tubing. The tubing is initially filled with degassed distilled water with the lower end open to the formation fluid to be sampled. Up to several hundred meters of Teflon tubing are wrapped onto spools that are then connected in series for long-term sampling (Fig. F5). Samples for gas analyses are drawn into copper tubing with an ID of 1.2 mm. Coils used during Leg 205 all contain ~300 m of Teflon or copper tubing with an ID of 1.2 mm for the fluid samplers and 0.8 mm for the flowmeter spools. Ten membranes deliver a pump rate of 4 mL per week at a temperature of 10°C. After retrieving the OsmoSamplers, the formation fluids are obtained by cutting the Teflon tubing into sections of desired length based on required fluid volume and desired temporal resolution, extracting the fluid, and analyzing it for chemical species of interest. Copper tubing is frozen, crimped, and cut. A vacuum line is then used to extract dissolved gases from the sample and partition those gases into several containers for future gas analyses. Typically, sections are cut into 1-m-long sections, which provide ~0.5 and 1.0 mL of sample from an 0.8- and 1.2-mm-ID tubing, respectively. Laboratory tests in which sample input alternated between seawater and modified seawater confirm that dispersion resulting from diffusion and peak smearing is not significantly greater than that calculated from molecular diffusion alone (Jannasch et al., unpubl. data).

F5. Assembly of an OsmoSampler package, p. 19.



The OsmoSampler packages for Hole 1255A (Leg 205) are capable of being recovered and redeployed without losing pressure within the sampling environment. This is accomplished with a new custom OsmoSampler seat, which has a plunger-seal design that is penetrated by a titanium sampling probe. The OsmoSampler seat is located within 4½-in casing (4½ in outside diameter [OD], 10½-lb/ft K-55 casing), which, along with the packer on the outside, completely seals the formation pressure. This seat has a 1½-in hole sealed with a plunger that can be pushed down by the sampling probe to expose a 12-in section of screen open to the pressurized formation. An inner screen on the OsmoSampler seat is located within the tightly fitting outer-perforated 4½-in casing, which is located below a packer (Fig. F6). The outer screen is 8 m long to concentrate any fluid flow within its depth range to the 12-in inner screen. The solid vertical support ribs keep flow from evading the casing and bypassing the OsmoSampler intakes. The outer casing is filled with Carbolite and should seal to the formation after its collapse (Fig. F6). Without an OsmoSampler (e.g., when the OsmoSamplers are being exchanged), the plunger is pulled up inside the OsmoSampler seat and isolates the pressurized zone from the overlying hydrostatic pressure.

F6. Sampling section of the intake probe, Hole 1255A, p. 20.



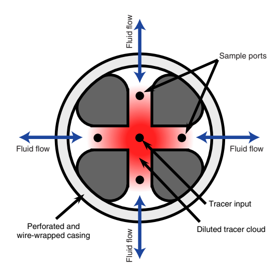
In this configuration, OsmoSamplers are encapsulated in a pressure housing that sits above the OsmoSampler seat and is rigidly attached to the titanium sampling probe. A total of nine 1⁄16-in OD tubes connect the various sampling ports within the probe to the OsmoSamplers within the pressure housing. The pressure housing is maintained at the pressure of the sampling zone by an additional 1⁄8-in OD pressure equilibration line that expels a pressure equilibration fluid within the pressure housing at the same rate as water is being sampled throughout deployment. This eliminates any pressure gradient that the OsmoSamplers would need to pump against. The chemistry of the pressure equilibration fluid was chosen to mimic that of the in situ pore fluid in the uppermost 50 m of the underthrust sediment (Site 1040 of Leg 170) plus 10% of the sum of the major component concentrations used (Cl, SO_4, Mg, Ca, K, and Na) added as NaCl. The overall density of the pressure equilibration fluid is ~3% higher than that of the average underthrust in situ pore fluid, and it is injected below the sampling horizons for fluid chemistry and flow rate determinations. This minimizes any possible mixing or contamination. Cesium is used as a tracer to quantify any mixing that may occur between the pressure equilibration and the formation fluids. Cesium was chosen as the tracer for this fluid because of its low concentration in seawater and the accurate and precise determinations of low Cs concentrations at nanomolar levels possible by inductively coupled plasma–mass spectrometry (ICP-MS). A concentration of 12.118 mM, equivalent to 2000 ppm Cs, was chosen (5.4×10^6 seawater concentration), which ensures analytical determination after dilution upon introduction into the sampling probe.

The OsmoSampler packages for Site 1253 also sample the pressurized formation but use a simpler pressure seal above two OsmoSampler packages that are suspended within the hole on a line with a sinker bar. This permits sampling at two depth horizons, but the seal will be broken during replacement of the OsmoSamplers. The upper OsmoSampler package directly below the plug seal is located within a section of screened pipe to ensure retrieval in case the hole collapses. This is similar to the CORK deployed at Site 1200 (Shipboard Scientific Party, 2002b), where OsmoSamplers were protected with a section of screened casing. This change was initiated because hole instabilities at ODP Sites 1025 and 1026 entombed OsmoSamplers that had been deployed there. The lower OsmoSampler package and the sinker bar hang near the bottom of the open hole below the screen. Two weak links (steel plates sewn together with ⅛-in polypropylene rod to avoid corrosion) located below each OsmoSampler package ensure that in case of collapse as much of the system as possible, and at a minimum, the upper OsmoSampler package, will be retrieved.

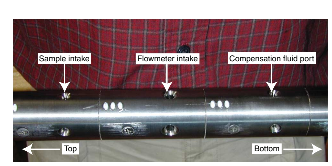
OsmoFlowmeter

An OsmoFlowmeter was incorporated into the titanium sampling probe for Hole 1255A (Leg 205). The flowmeter consists of two perpendicular ¼-in holes bored through the sampling probe. A tracer solution is added directly at the center, and four OsmoSamplers sample 1 cm away from the tracer input in each of the four branches (Figs. F7, F8) to determine both direction and flow rate of pore waters through the formation. The tracers are injected continuously from a coil connected to the brine output of one of the OsmoSamplers. Thus, the tracer is injected at the same rate as the intake of the four-membrane OsmoFlowmeter samplers (1.6 mL/week). These OsmoFlowmeters will measure the direction by presence and concentration of the tracer, and the relative flow rate will be calculated from the dilution factor. The directional flow will be limited to relative directions, since the true geographical orientation of the OsmoSampler package would require a compass.

F7. Schematic of an OsmoFlowmeter, p. 21.



F8. Intake configuration for OsmoSampler and OsmoFlowmeter, p. 22.



The tracer fluid consists of an artificial pore fluid spiked with rubidium and iodate (IO_3^-) tracers. Rubidium was chosen as the primary tracer because of its low concentration in seawater and ease of measurement by way of ICP-MS. Iodate was chosen as a redundant tracer because of its conservative behavior in pore fluids and ability to measure low concentrations colorimetrically.

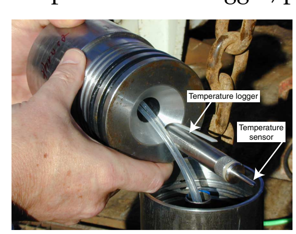
The bulk chemistry and, thus, density of the artificial pore fluid spiked with tracers was chosen to match that of the décollement and underthrust sediments at Sites 1254 and 1255 (Sites 1040 and 1043 of Leg 170, respectively). Interstitial water chemistry data obtained during Leg 170 were used to calculate an average pore water chemistry for both horizons. Chloride, SO_4, Mg, Ca, K, and Na concentrations in Hole 1040C of Leg 170 were averaged between the depths of 229.33 and 357.73 meters below seafloor (mbsf) for the décollement and between the depths 401.18 and 452.18 mbsf for the upper section of the underthrust sediments. These representative concentrations were used to estimate the mass of salt needed to add to the flowmeter output volume to produce the same chemistry and relative density as the Site 1254 pore fluids. This ensured that the artificial pore fluid would not sink or diffuse away upon injection. For the tracer compounds, higher concentrations than those in the pore fluid and seawater are desired so that they are not masked by the pore fluid concentrations and are measurable at high precision if diluted by fluid flow in the borehole. The following concentrations were thus used: 23.99 µM for Rb (~17× seawater) and 100 µM for IO_3^- (221.7× seawater). Even with 100× dilution of the tracers upon injection into the sampling probe, their concentrations can be determined with high precision.

The OsmoFlowmeter design assumes that the formation will collapse around the outer screen; otherwise, much of the pore fluid would flow around the outer screen. This collapse should be observable in the data. Solid vertical bars between the outer screen and 4½-in casing are intended to focus the flow from the 8-m section of screen to the 12-in section of inner screen and sampling area. The 4½-in casing under the outer screen (8 m long) is only perforated in the area of the inner screen (~12 in long). The tight tolerance between the inner and outer screens, as well as ¼-in flowmeter holes in the sampling probe, should further focus the flow. The holes for the sampling and pressure equilibration tubes are, therefore, only ⅛ in.

Temperature Data Logger inside the OsmoSamplers

Inside the end caps of the OsmoSampler housings, we installed a miniaturized temperature data logger (MTL) (Pfender and Villinger, 2002). The MTL consists of a 140-mm-long × 15-mm-OD cylindrical data logger housing with a thin-walled tip (20 mm long with an OD of 4 mm) containing the temperature sensor (Fig. F9). The pressure housing consists of high-strength corrosion-resistant steel and withstands a pressure equivalent of 6000 m water depth. Programming the logger and downloading the data are performed without opening the pressure case. A readout unit contacts the logger's tip and end cap with a voltage delivered by an RS232 interface from a PC. A high-strength plastic washer isolates the tip and main body to allow a two-point connection for data transfer.

F9. Temperature data logger, p. 23.



The electronics of the logger consist of a microprocessor, a 16-bit analog-to-digital converter, a real-time clock, and nonvolatile memory for up to 64,800 measurements. The sample interval can be varied from 1 s to 255 min. The complete system is powered by a standard 3-V lithium battery. A thermistor (interchangeability of 0.1 K) is used as a sensing element. The characteristics of the sensor provide a temperature range from –5° to +60°C and a resolution of 1 mK at typical deep-sea temperatures of 2°C. The absolute accuracy of the logger after calibration with a high-precision thermometer in a well-stirred water bath is <5 mK, which is adequate for the expected temperature fluctuations.

All loggers installed in the OsmoSampler packages have been calibrated in an absolute sense before deployment. They were programmed to take a measurement every 17 min, which allows recording of temperatures over a period of 2 yr. Only limited experience exists with long-term deployments of the MTLs. However previous deployments of over ~1 yr in shallow water in the Gulf of Mexico did not reveal significant problems with drift of the electronics or the internal clock. It is yet to be seen how long the batteries will last and how well the pressure housing will withstand corrosion over a period of 2 yr.

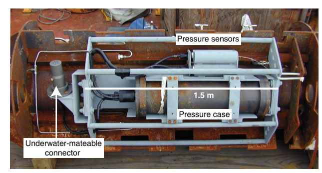
Pressure Sensors and Electronics

The package for pressure measurements and data logging is very similar to the one described in the "Explanatory Notes" chapter of the Leg 196 *Initial Reports* volume (Shipboard Scientific Party, 2002a). Therefore, we will describe it only very briefly. The package, designed to be removable and serviceable if required, weighs 115 kg in water and includes the data logger in its pressure case, two pressure sensors connected to the monitoring lines and one for monitoring seafloor pressure variations, an eight-pin underwater-mateable electrical connector, and interconnecting cables (Figs. **F10, F11**). The pressure sensors, manufactured by Paroscientific, Inc., employ matched pairs of quartz crystals, one sensing pressure and the second adding temperature compensation (Fig. **F12**). The total range of the sensors used during Leg 205 is 70 MPa (7000 m equivalent water depth). The actual pressure resolution realized is dependent upon the integration time of the pressure gauge, which is set to 10.7 s to achieve a resolution of 1 ppm (equivalent to 70 Pa). Absolute accuracy is limited by sensor calibration and drift. Experience from previous multiyear deployments shows that drift is typically <0.4 kPa/yr. This and an absolute calibration inaccuracy (~5 × 10^{-4} of total pressure or 23 kPa at the Costa Rica sites) are dealt with well by the intergauge hydrostatic checks both prior to final installation and later at times of submersible visits.

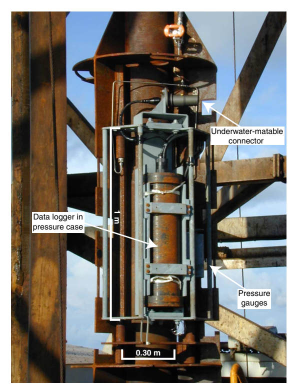
Temperature is measured with a thermistor mounted to the inside of the pressure housing of the data logger. Its temperature range is from 0° to 150°C, with a sensitivity of ~5.6 counts/mK at 2°C. Data are acquired during an interval of 1 hr, which is adequate to observe low-frequency temperature fluctuations at the seafloor with a sensor that has a large time constant resulting from its position at the inside of a thick-walled pressure case.

Sensors are activated at a user-specified interval, and data are recorded with a logger built by Richard Brancker Research, Ltd., of Ottawa, Canada. The logger has modular capability to store up to 32 channels of pressure and temperature data. Time-tagged pressure data are recorded in 8-MB-capacity flash memory. Logging rates are programmable at sampling intervals ranging from 10 s to 1 day. With three gauges being logged at 10-min intervals at Leg 205 sites and temperature being logged once an hour, memory capacity will provide 6 yr of

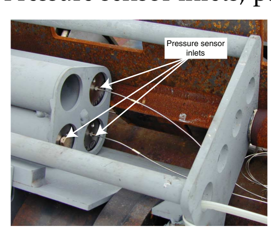
F10. Data logger bay of the CORK-II head, p. 24.



F11. CORK-II head bay with pressure sensor and data logger, p. 25.



F12. Pressure sensor inlets, p. 26.



operation. Data recovery and reprogramming of the logger is possible via a serial link and the underwater-mateable eight-pin connector. Power is supplied by lithium sulfuryl chloride battery packs at 7.4 V with a capacity of 360 A·hr, sufficient at this rate of logging for more than the shelf life of the batteries (15 yr). Logging can be extended beyond the life of the batteries by applying power from an external source through the underwater-mateable connector.

Packers

The inflatable packers used to seal the outside of the 4½-in casing to the formation are essentially identical to those used during Leg 196 except for diameter. They were constructed by TAM International, Inc., around standard-diameter 8.48-m-long casing sections. The elements themselves consist of 3-m-long steel-reinforced (vertical stave) nitrile composition rubber bladders, rated to 100°C and effective to 140°C in this application. The elements are attached to the casing core at the bottom of the packer and to a sealed sliding sleeve at the top. The sleeve rides on an annular volume through which the monitoring and packer inflation lines pass. The bladders are designed to expand from their ID of 8 in to a maximum of 14 in. A differential inflation pressure of ~150 psi (1 MPa) is required to overcome the rigidity of the elements. The bladders are filled using the ½-in inflation tube in the hydraulic umbilical. Flow is passed from the tube into a plenum that feeds the bladder of each packer through a pair of valves. The first valve is in an initially closed state and opens when a critical pressure in the plenum (relative to the local annular pressure) is reached, at which point filling begins. The inflation pressure is set by a shear-wire valve to a value of 600 psi that locks in an open position when activated. For the Leg 205 CORK-IIs, these valves were set too close when the internal pressure in the packer bladders rose to a total of 600 psi (4.1 MPa) relative to the local annular pressure (i.e., ~3 MPa above the pressure required to expand the packer itself).

To inflate the packer, the drill string is pressured up to 800 psi (5.5 MPa) and pressure is held for 30 min. After 30 min, the drill string pressure is increased to 1800 psi (12.4 MPa) and held for 10 min to activate the spool valves to connect the pressure sensors in the wellhead to the downhole screens (see discussion below). The last step consists of bleeding off the pressure through the rig floor standpipe manifold relief valve.

Screens

Hydrologic access to the formation was provided by 7.6-m-long screen filters on 11.68-m casing joints, manufactured by Houston Wellscreen, Inc. Granular fill is packed in a 2-cm annulus between the outside of a solid section of 4½-in casing and a screen formed of wire wrapped on radial webs (Fig. F13). The OsmoSampler is centered inside the screened section. The pressure monitoring line accessing the filter is terminated in a separate, smaller (2 cm OD × 1 m length) wire-wrapped screen located within the screened section. Carbolite, an aluminum oxide ceramic, was used for the filter fill, with a grain size of 400–600 µm, a porosity of ~30%, and a permeability of ~2×10^{-10} m^2. Laboratory experiments indicated that the Carbolite does not interfere with the fluid chemical data. The screen was wound with 0.085-in wire with a 0.01-in wire-to-wire spacing and provided an effective open cross section of

F13. Wrapped screen, p. 27.

15%. The design was intended to provide good hydrologic communication to the formation with maximum effective contact area and permeability while preventing sediment from invading and clogging the sampling or monitoring lines. The risk of clogging during installation was further reduced by having the monitoring lines closed to prevent flow through the screens. The monitoring lines open by the action of the spool valves following packer inflation, as described below.

Pressure Tubing

Transmission of pressure signals to the seafloor sensors is accomplished using thick-walled, 316-L stainless steel tubing of ½ in OD and 0.035 in wall thickness. One smaller diameter (¼ in OD, 0.03125 in wall thickness) line was provided for sampling fluids from screens in the horizon of interest. All lines, including the tube for packer inflation, are jacketed with polyurethane to form a single robust umbilical, provided by Cabett Services, Inc. Connections were made during deployment between the umbilical and the tubes leading through or from each packer or screen (Figs. **F14, F15**). In intervening sections, the umbilical was banded to the outside of the casing sections. A detailed discussion of the tubing dimensions chosen can be found in the "Explanatory Notes" chapter of the Leg 196 *Initial Reports* volume (Shipboard Scientific Party, 2002a).

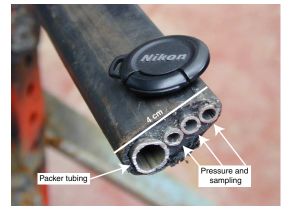
CORK-II Head Physical Configuration

The CORK-II head is a 30-in-diameter cylindrical frame fabricated from steel around a section of 11¾-in casing. It houses components in two of the three 120°-wide, 60-in-high bays that are bounded above and below by circular horizontal bulkheads and divided from one another by radial webs (Fig. **F11**). Two bays contain (1) the sensor/logger/underwater-mateable connector assembly on a demountable frame and (2) the spool valves, pumping/sampling valves, three-way pressure sensor valves, and geochemical sampling valve and port. The lowermost bulkhead is positioned ~16 in above the submersible landing platform that covers the reentry cone. Numerous cutouts on the vertical webs can be used as manipulator "handholds" for the same purpose. At the top of the CORK-II head is a small reentry cone for wireline tool delivery systems.

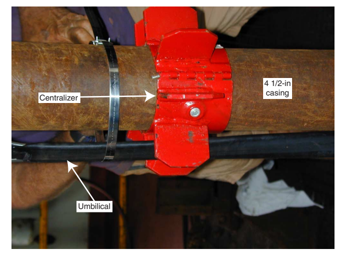
Plumbing at the CORK-II Head

At the CORK-II wellhead, the packer inflation line, pressure monitoring lines, and fluid sampling lines are all routed to several destinations (Figs. **F11, F16, F17, F18, F19, F20**). The packer inflation line is connected to the CORK-II running tool by a hydraulic hose terminated by a quick release with integral check valve. When the quick release is engaged, the integral check valve is held open, maintaining an open hydraulic circuit through the CORK-II running tool to the inside of the drill string. During deployment the packer inflation line and the internal voids of the packer body are thus allowed to fill and equalize pressure with the increasing hydrostatic pressure by way of the open quick-release check valve. After the assembly has reached the target depth, a wireline retrievable tool (go-devil) is used to divert all drill string flow and pressure into the packer inflation line. Once the go-devil is in place, the drill string pressure is increased inside the CORK-II running

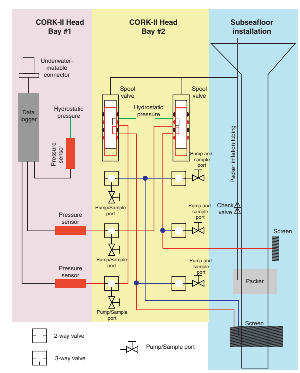
F14. Umbilical for packer inflation and sampling tubing, p. 28.



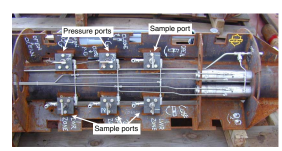
F15. Centralizer and umbilical strapped onto the 4½-in casing, p. 29.



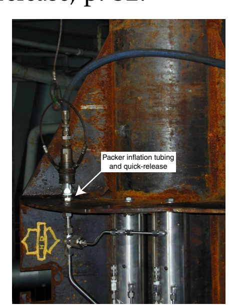
F16. Schematic of the plumbing system of the CORK-II, p. 30.



F17. CORK-II head plumbing and valve bay, p. 31.



F18. Packer inflation tubing and quick release, p. 32.



tool, thereby increasing the packer inflation line pressure. At a predetermined pressure (~800 psi), an "open" valve (integral to the packer) opens, allowing inflation of the packer element to occur. Once a predetermined packer element inflation pressure (~600 psi) has been reached, a "close" valve (integral to the packer) closes, preventing any fluid from either escaping or entering the packer element. The hydraulic hose quick-release check valve also acts as a redundant "close" valve in that when the quick release is disconnected from the CORK-II wellhead, the check valve automatically closes, preventing any loss of fluid or pressure from the packer inflation line.

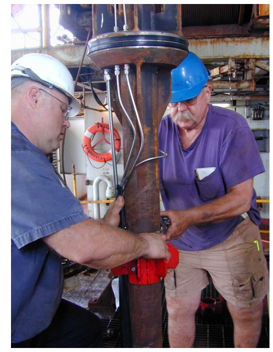
Another branch of the packer inflation line leads from the sliding sleeve valve to a manifold that passes the packer inflation line pressure to a bank of locking spool valves, one for each screen. Two positions of the spool valves, controlled by the packer line pressure, provide two different routings among screen lines, pressure sensor lines, and a local hydrostatic port. During deployment, drilling, and packer filling operations, lines from the screens are closed and lines from the pressure sensors are routed to a local hydrostatic port. Venting the sensor lines prevents damage to pressure sensors from any excess pressures that might be produced during drilling and packer inflation and allows a local hydrostatic calibration point to be established before the sensors are connected to the monitoring lines. Keeping the screen lines closed prohibits flow through the screens and minimizes the potential for infiltration of fine-grained material into the Carbolite-packed screens during installation. The spool valves are set to shift when the packer inflation line pressure reaches 1125 psi (7.8 MPa) (i.e., once the packer is inflated). Once they shift and lock, the spool valves close the hydrostatic port and interconnect the screen and pressure sensor lines for monitoring. The spool valves are designed to shift with no volumetric change so that no pressure pulse is generated that could potentially damage the pressure sensors.

A manual means for pressure sensor protection and calibration is provided by three-way valves plumbed into the pressure sensor lines downstream from the valved pumping and sampling ports described below. In their normal position, pressure from the screens (via the spool valves) is routed directly to the pressure sensors. In the second position, the sensor lines are opened to hydrostatic pressure and the screen lines are closed. Thus, these serve the same function as the spool valves but with manual control. The sensors can be isolated temporarily if pumping experiments are ever performed. Hydrostatic reference checks can be done at the time of any submersible or ROV visit, and the screen lines can be closed to prevent drainage of the formation if the logger/sensor unit is ever removed.

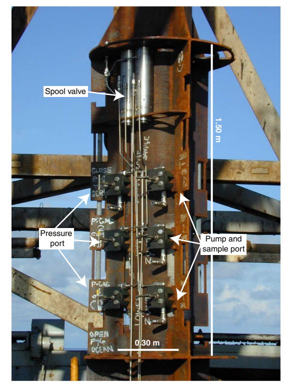
In addition to the lines leading from the screens to the spool valves and into the pressure sensors, there are also lines leading to valved pumping/sampling ports where fluid samples can be collected and pumping tests performed. One other pumping/sampling port leads from a local "T" junction in the sampling port bay to a monitoring line. If any pumping tests are ever carried out in the future, the three-way pressure sensor isolation valves would need to be switched to protect the sensors.

Before deployment of the CORK-II, all sampling valves and bleed valves on the wellhead are opened and the wellhead is lowered into the water to purge the hydraulic lines of air. The 1⁄16-in hydraulic lines connecting the pressure sensor control valves to the pressure sensors are filled with water prior to picking up the wellhead. Following immer-

F19. CORK-II head latch and seal, p. 33.



F20. CORK-II head bay with plumbing and valves, p. 34.



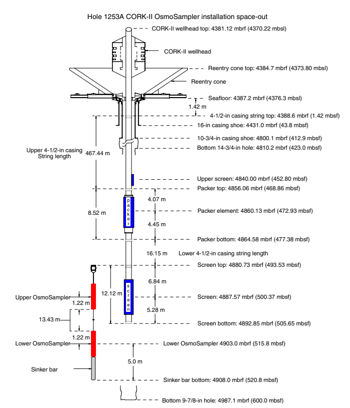
sion, the wellhead is raised back to the moonpool level where all valves are closed. Large rubber bands are then attached to the individual valve handles such that they would hold the valves in the closed position during the deployment. This is done to prevent the valves from partially opening during the deployment, as happened with the CORK-II valves deployed during Leg 196. With all hydraulic lines purged and all valves closed and after a last-minute inspection of the wellhead completed, the CORK-II assembly is ready to be lowered to the seafloor. In a final step, the CORK-II is latched permanently into the reentry cone and the packer is inflated, and the spool valves are shifted to connect the pressure sensors to the pressure ports in the screens.

CORK-II SETUP FOR ODP LEG 205 SITES

Site 1253—Oceanic Basement Site

Two OsmoSampler packages were deployed in Hole 1253A with the center of the upper one inside the screen at 500 mbsf and the lower one in the open hole at 516 mbsf (Fig. F21). A packer was set in the lower igneous unit at 478 mbsf. Two weak links were used in each OsmoSampler package in order to maximize chances of recovering at least the upper OsmoSampler (located within the screened interval) in case the hole collapsed around the lower OsmoSampler or sinker bar. First, the upper sampler was attached with a braided ⅜-in nylon rope to the latch/running tool assembly. Next, a sinker bar (3.7 m long; 131 kg weight) was attached to the lower OsmoSampler unit with a braided ⅜-in nylon rope and a weak link of 408-kg (900 lb) breaking strength. Another weak link with a breaking strength of 680 kg (1500 lb) was attached to the bottom of the upper OsmoSampler followed by 13.4 m of ⅜-in braided nylon rope. The lower OsmoSampler was then attached to the rope. The entire assembly (27.31 m overall length) was slowly lowered down the drill string in steps to prevent differential pressure from damaging the osmotic pumps and lowered further until the latch/running tool subassembly landed in the XN latch nipple on top of the 4½-in casing screen downhole.

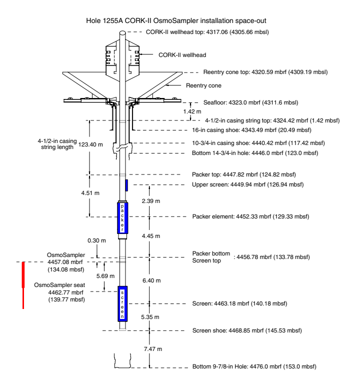
F21. Hole 1253A CORK-II OsmoSampler installation space-out, p. 35.



Site 1255—Décollement Zone Site

Installation of the CORK-II observatory, consisting of an OsmoSampler package with OsmoFlowmeter, started immediately after coring to 157 mbsf by assembling the 4½-in casing containing the screen and the packer element. With the casing shoe at 117.4 mbsf, the plan (Fig. F22) was to set the center of the packer at 129 mbsf and the center of the screen at 140 mbsf, in the middle of the geochemical anomaly as determined from Site 1255 data and Site 1043 results. The second pressure port inside a small screen was installed just above the upper packer. The final step was to attach the CORK-II head to the assembled casing string and lower the installation into the cased and open hole. No problems were encountered this time. Before latching the CORK-II head into the reentry cone, the OsmoSampler seat was deployed and latched, and then the OsmoSampler including the flowmeter was lowered slowly to allow proper equilibration of the samplers to ambient temperatures and pressures. Once the OsmoSampler was in place, the CORK-II head was latched, the packer was inflated, and the spool valves were shifted to start in situ pressure monitoring. The last step was the deployment of

F22. Hole 1255A CORK-II OsmoSampler installation space-out, p. 36.



the ROV platform before the drill string was decoupled from the CORK-II.

Visits of Sites 1253 and 1254 with Submersible *Alvin*

Because of the likelihood that the spool valves had not shifted and the packer had not inflated at the time of the CORK-II installation at Site 1253, a visit to the site was planned with the manned submersible *Alvin* in November 2002, ~1 month after the installation of the CORK-IIs. Data recovery operations at wireline-installed CORKs in Holes 504B and 896A, located on the southern flank of the Costa Rica Rift, had been fortuitously scheduled for this time. The proximity of the *Atlantis/Alvin* port call to the margin sites and efficiency of operations at the rift flank sites made the visit to the margin sites possible in the time allotted to that cruise. Participants in that program included K. Becker (chief scientist, Rosenstiel School of Marine and Atmospheric Science, University of Miami, United States), T. Pettigrew (ODP, College Station, United States), and E. Davis and R. Meldrum (both of the Geological Survey of Canada). Edited videos of both dives can be found in Figures F31, p. 73, and F32, p. 74, in the "Leg 205 Summary" chapter.

We prepared for the spool-valve problem at Site 1253 with two parallel solutions. The first would make use of a pump mated to the hydraulic connection at the top of the CORK-II assembly that accesses the packer-filling line (the very line that was believed not to have been pressurized when the packer-inflation go-devil failed to reach its landing point during deployment). This pump was designed and built by B. Carson and L. Holloway for formation testing in the CORKed Hole 949C in the Barbados accretionary prism. If this operation were to fail, a second approach would employ a stand-alone pressure sensor and data logger constructed by E. Davis and R. Macdonald that would be coupled to the redundant lower CORK-II formation-screen fluid sampling line that was plumbed to the seafloor through a valved port. This sensor/logger unit was equipped with an underwater-mateable electrical connector identical to that on the CORK-II unit itself to facilitate data downloading at the time of future site visits.

As it turned out, visual inspection of the CORK-II head at Site 1253 showed that both spool valves had indeed shifted (although the left-hand piston was ~¼ in above the level of the right) despite the go-devil never properly landing. The pump was coupled and run for 16.5 min as an ultimate precaution (this served to shift the left-hand spool valve fully down to the same level as the right), but following an inspection of the downloaded data, it became clear that the installation was successful from the beginning. The success was evident in the way of attenuated tidal pressure signals in basement and small, but well-resolved, average pressure differentials (several kilopascals) between the two basement levels separated by the packer.

The time remaining after operations at Site 1253 was just enough to allow for a visit to Site 1255 before the end of the dive. Because it is located at the bottom of a local topographic slope or in a local depression, the site was somewhat difficult to find using the sonar scanner on *Alvin*. Here two more mysteries awaited. First, despite the T-handles having been secured by rubber bands at the time of deployment, the top-left sampling valve was found to be rotated roughly 10° from horizontal. This brought back bad memories of Leg 196; the cause of this behavior remains unknown. Fortunately, in this instance, the rotation was insufficient to cause the valve to have leaked. The second mystery was that the formation pressure registered by the sensor connected to the deeper (OsmoSampler) level indicated leakage somewhere in the CORK-II plumbing until ~36 hr before the submersible arrived. Pressures at the sensor remained close to hydrostatic, and the tidal signal remained unattenuated relative to seafloor pressure until a time near the end of this first recording period, when the sensor pressure rose to a level somewhat higher than that observed in the upper interval (roughly 180 kPa) and displayed an attenuated tidal variation. It is with considerable confidence that we now look forward to the first real phase of data recording and first OsmoSampler recovery at both of these sites.

ACKNOWLEDGMENTS

The installation of the two CORK-II systems during Leg 205 would not have been possible without the expertise of the *JOIDES Resolution* core technicians "Bubba" J. Attryde and C. Bremner and the entire Transocean drill crew under the supervision of Captain T. Hardy and Offshore Installation Manager "Pepe" J. Estevez. Their dedication and hard work is gratefully acknowledged. We acknowledge the financial support of the National Science Foundation ([NSF] grants OCE 01-18478 for M. Kastner, OCE 01-18422 for H. Jannasch, and OCE 01-18918 for G. Wheat) and the German Science Foundation ([DFG] grant VI 133/4-2 for H. Villinger). The support of the U.S. State Department is greatly appreciated as they worked around the clock to get permission from Costa Rica on very short notice for *Alvin* dives in their territorial waters. Keir Becker generously shared his *Alvin* dive time to make inspection of the CORK-II installations possible.

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Figure F1. Schematic of an OsmoSampler. The system consists of an osmotic pump and a sample coil. The pump creates a pressure differential and flow across the semipermeable membranes that draw the fluid to be sampled into the sampling coil, which is initially filled with distilled water. The sample tubing consists of Teflon or copper for ion and gas samples, respectively.

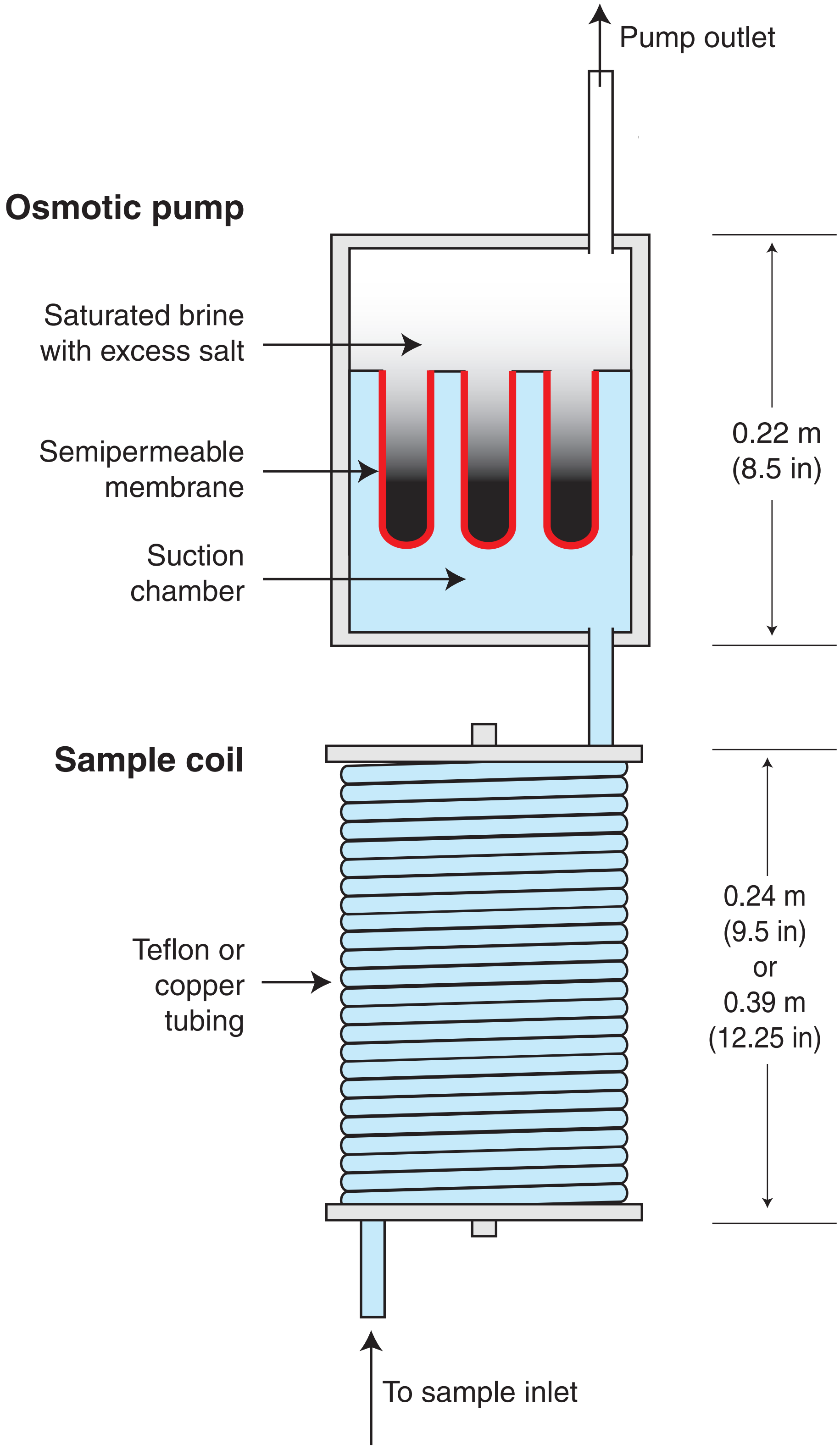

Figure F2. Photograph of an osmotic pump. The excess salt slowly dissolves throughout the experiment to keep the solution within the upper chamber saturated as brine is expelled through the outflow.

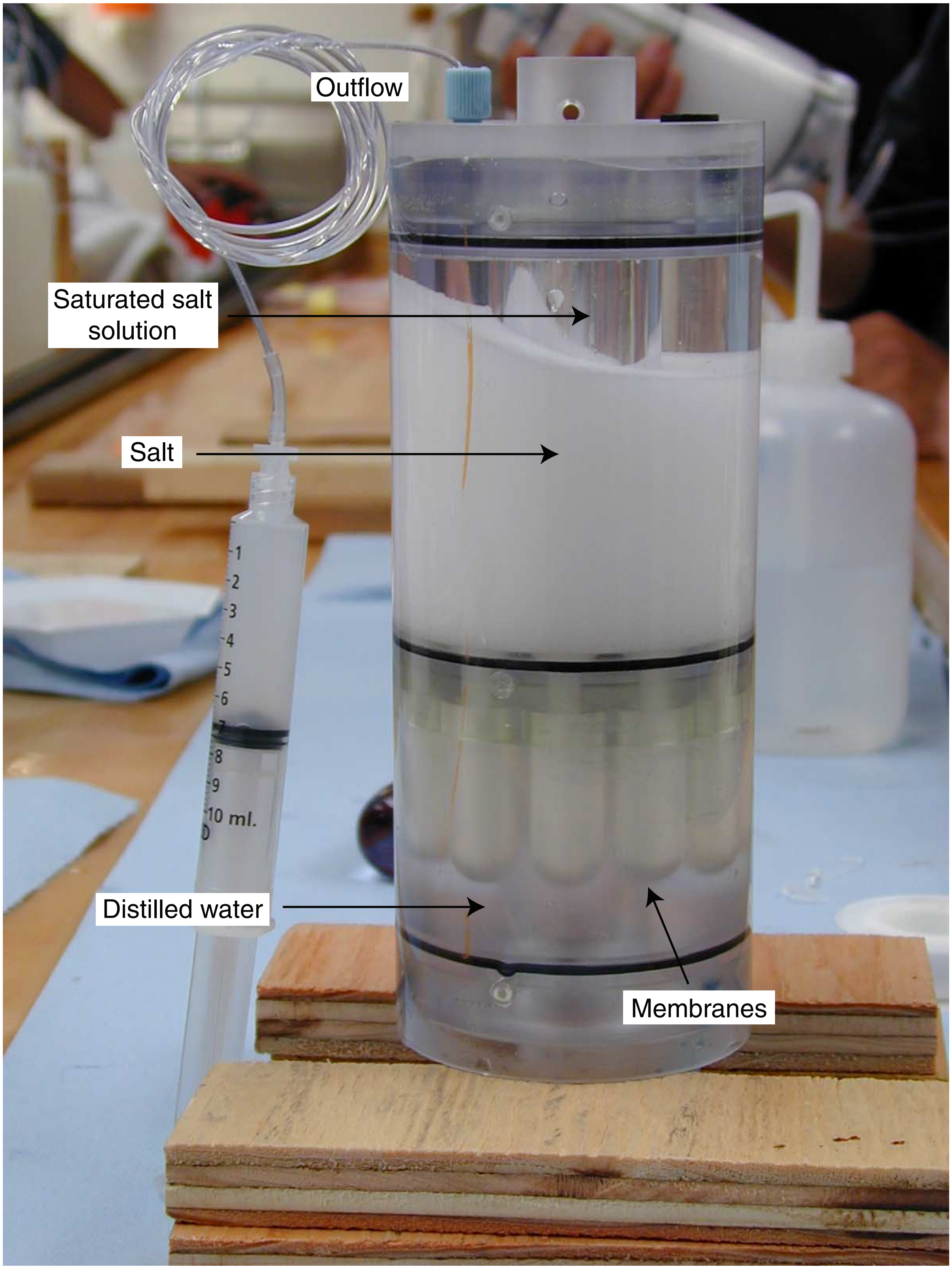

Figure F3. Photograph of an osmotic pump and several Teflon sampling coils being filled with distilled water by a peristaltic pump.

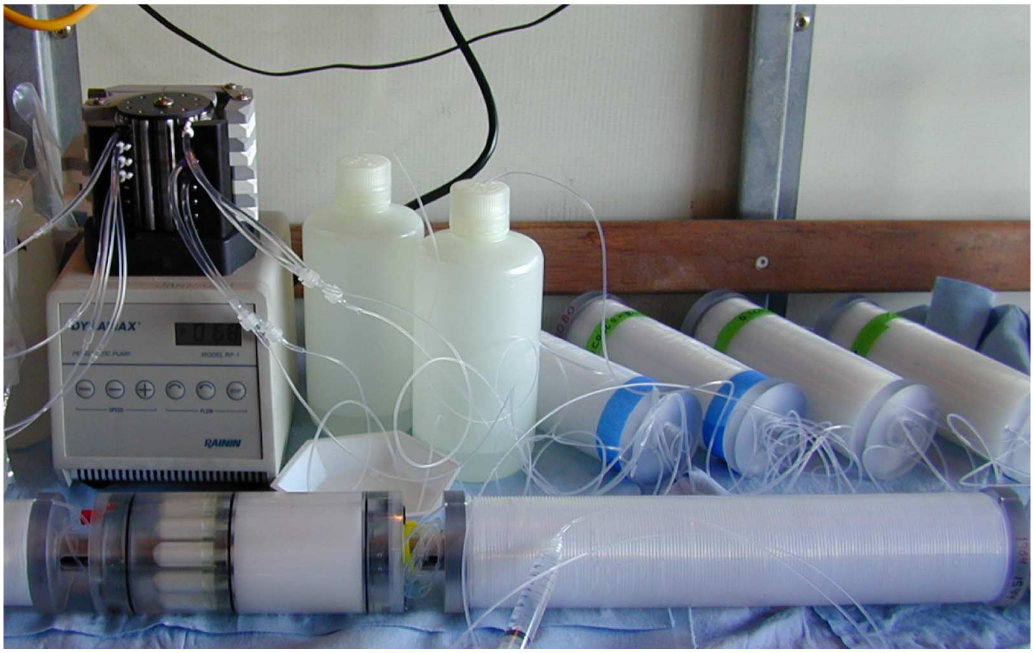

Figure F4. Photograph of an osmotic pump and a copper sampling coil.

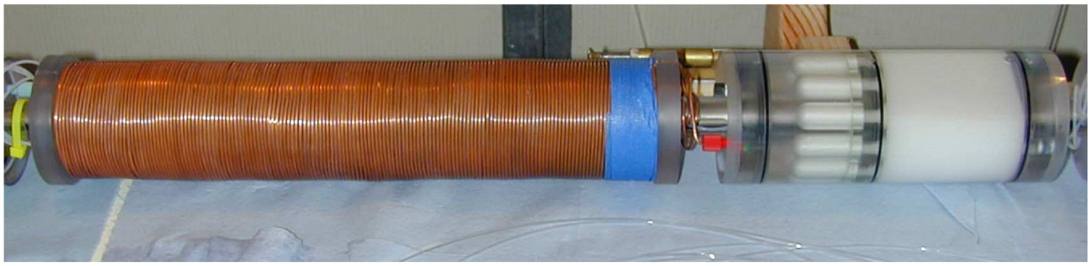

Figure F5. Assembly of an OsmoSampler package. (J. Morris, left, and H. Jannasch, right, are also pictured.)

Figure F6. Schematic of the sampling section of the intake probe from Hole 1255A. The two upper views show (**A**) vertical and (**B**) horizontal cross sections of the assembled 12-in-long screened section, where all samples are collected, flow rate measurements are made, and compensation fluid is reinjected. The lower view shows horizontal cross sections of the three separated components, (**C**) the perforated casing with the Carbolite-filled dual wire wraps, (**D**) the perforated OsmoSampler seat with a single wire wrap, and (**E**) the OsmoSampler package intake probe.

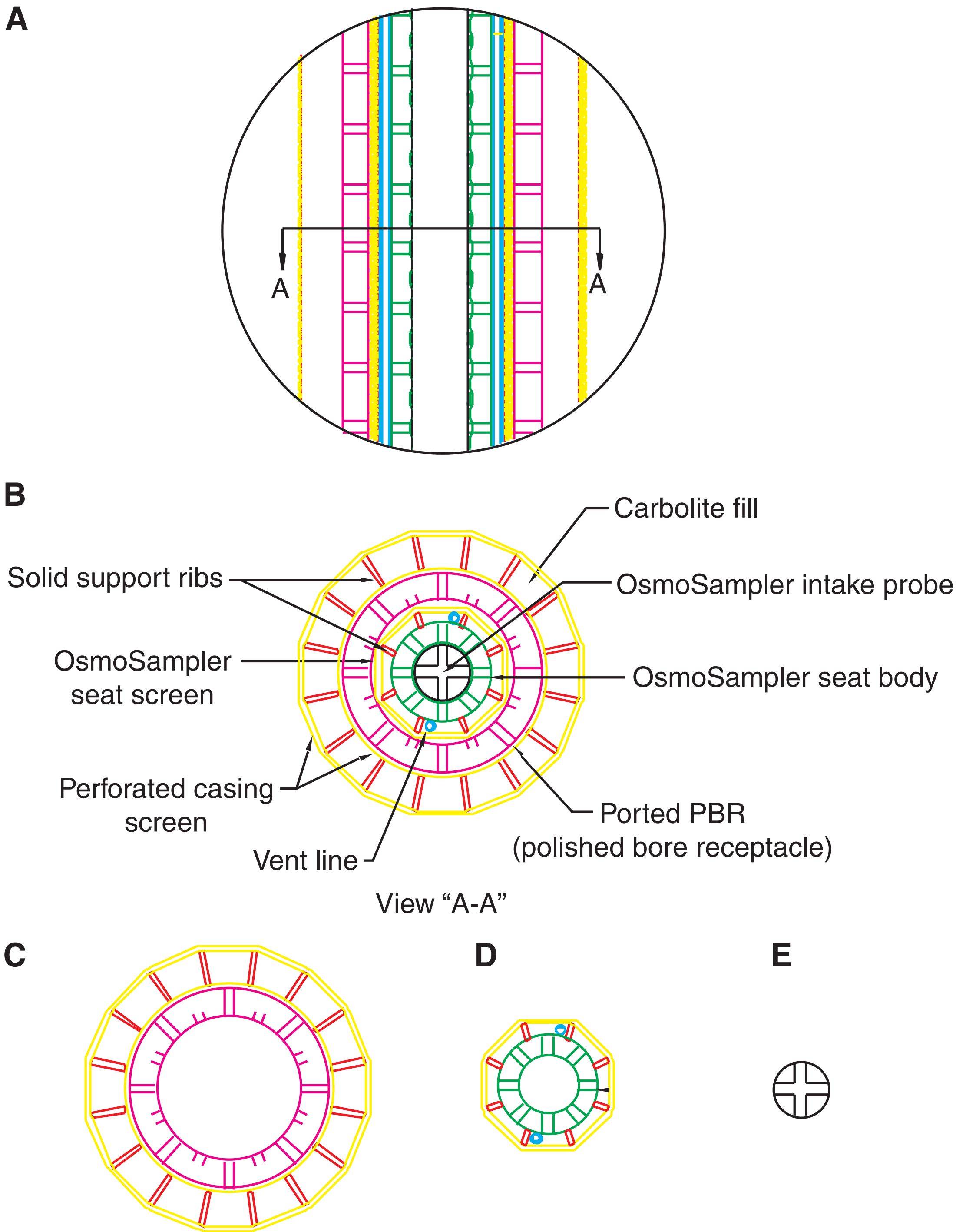

Figure F7. Schematic of an OsmoFlowmeter. Tracer fluid is injected at the center of the sampling volume at a constant rate that mixes with the naturally flowing pore fluids. The mixed fluid is continuously sampled at the four sampling ports. The varying amounts of tracer within these samples will be used to determine flow rate and relative direction.

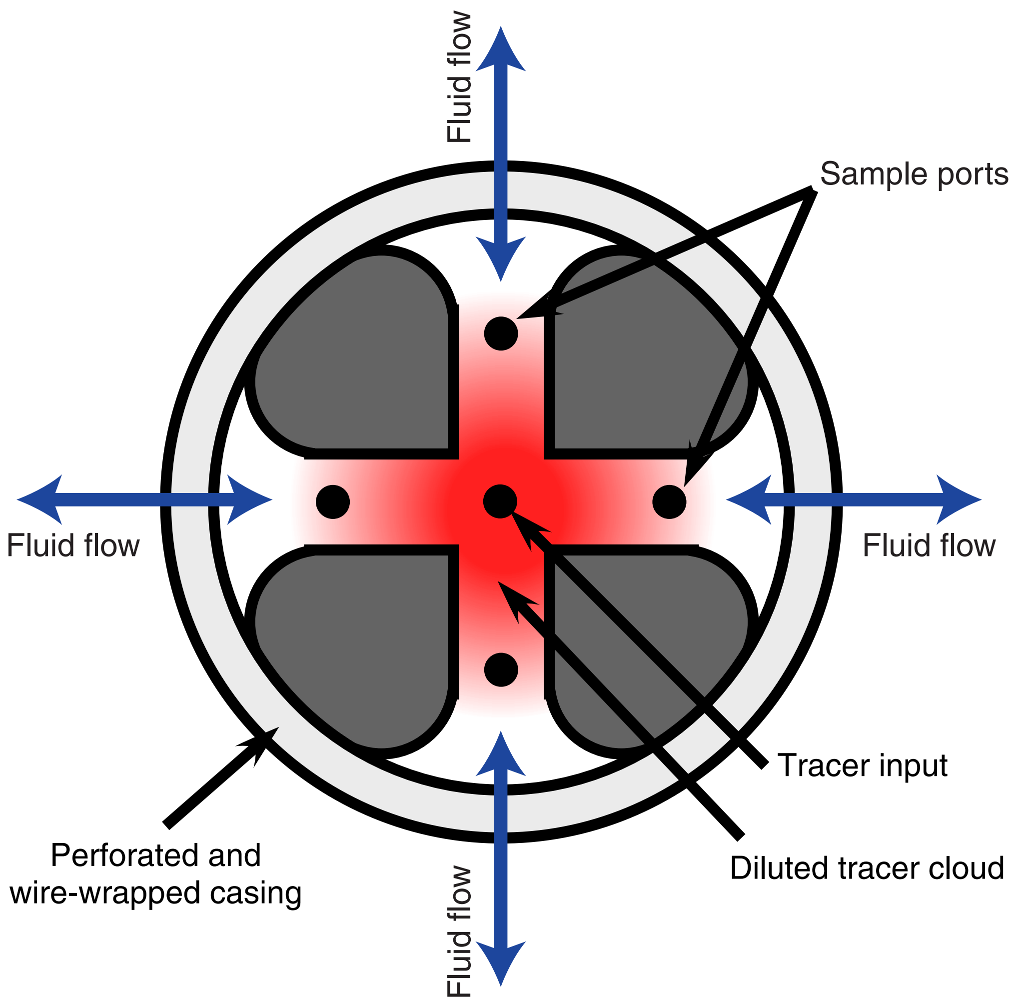

Figure F8. Intake configuration for OsmoSampler and OsmoFlowmeter in the sampling probe from Hole 1255A.

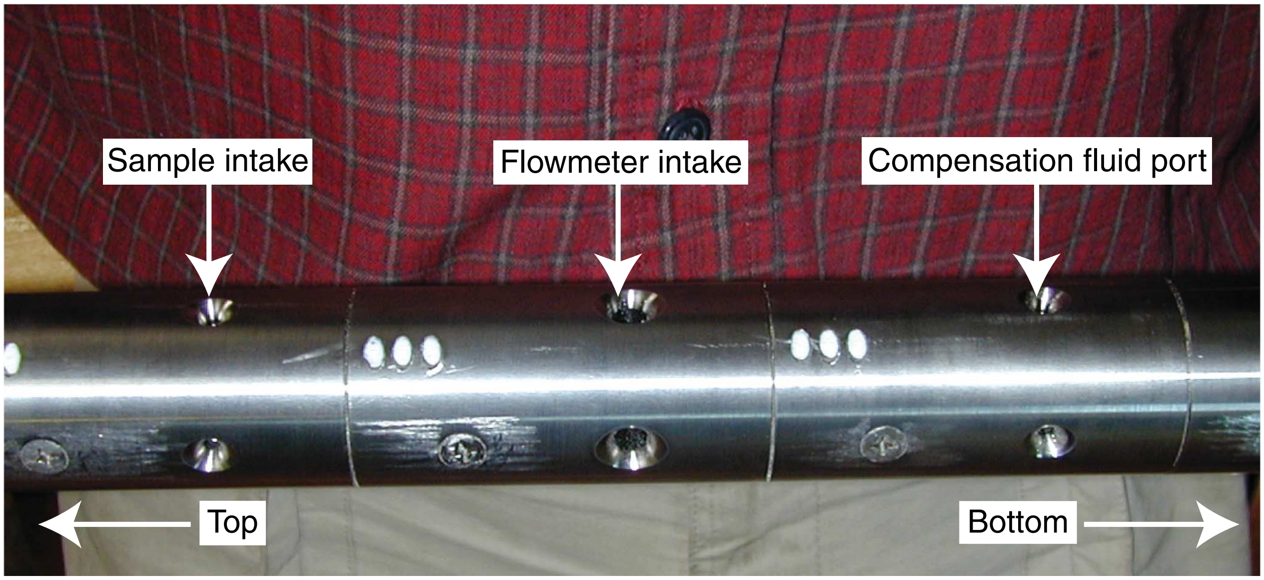

Figure F9. Temperature data logger inside the top end cap of the pressure housing of the Site 1253 OsmoSampler package.

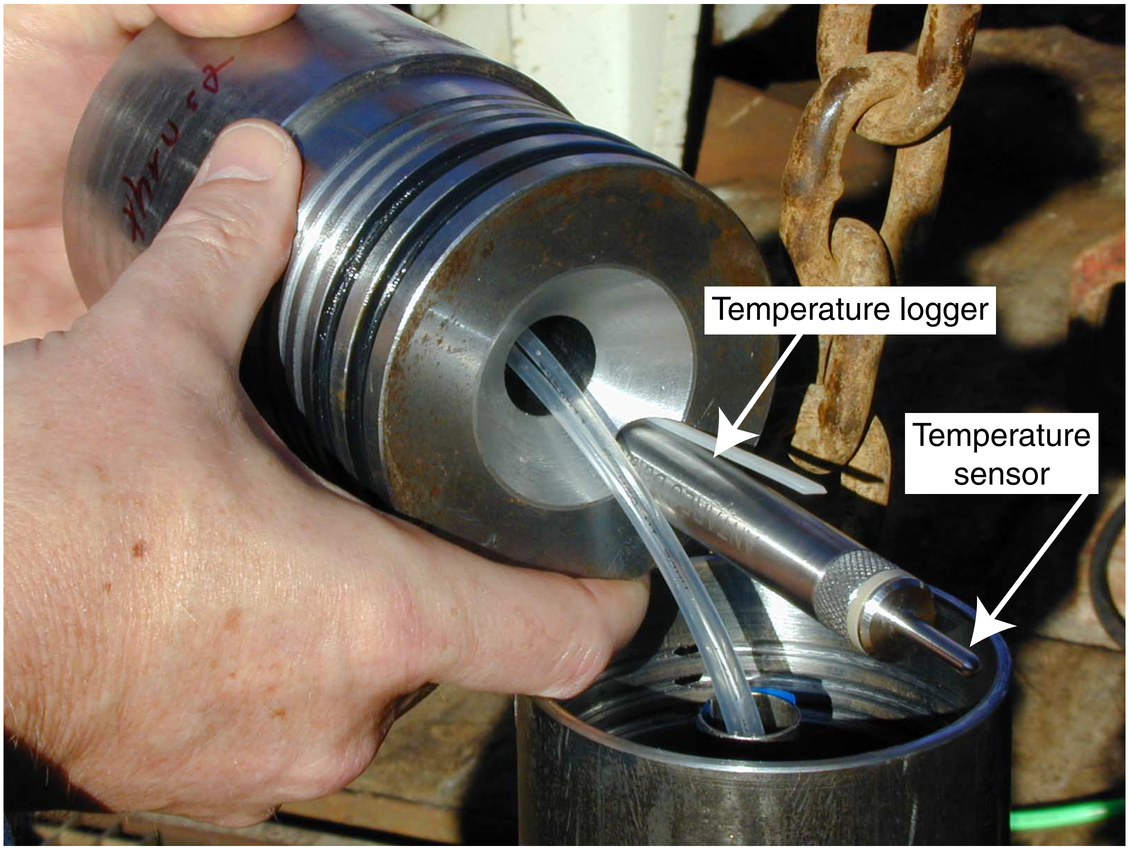

Figure F10. Close-up photograph of the data logger bay of the CORK-II head.

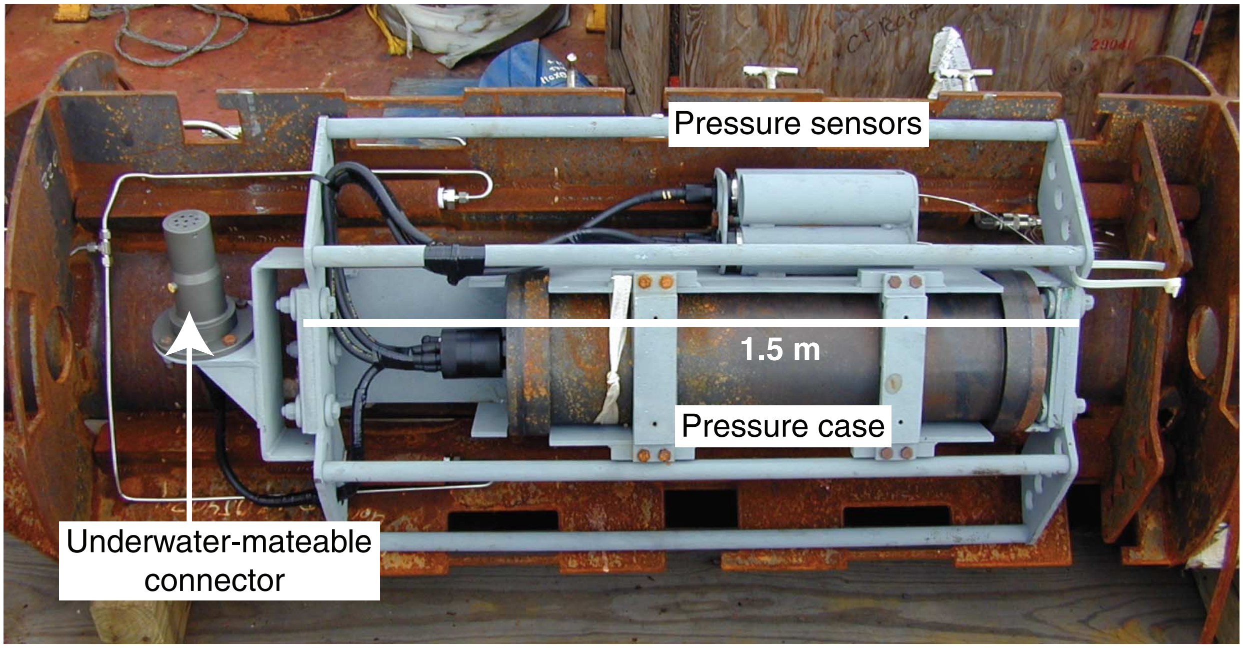

Figure F11. CORK-II head bay with pressure sensor and data logger.

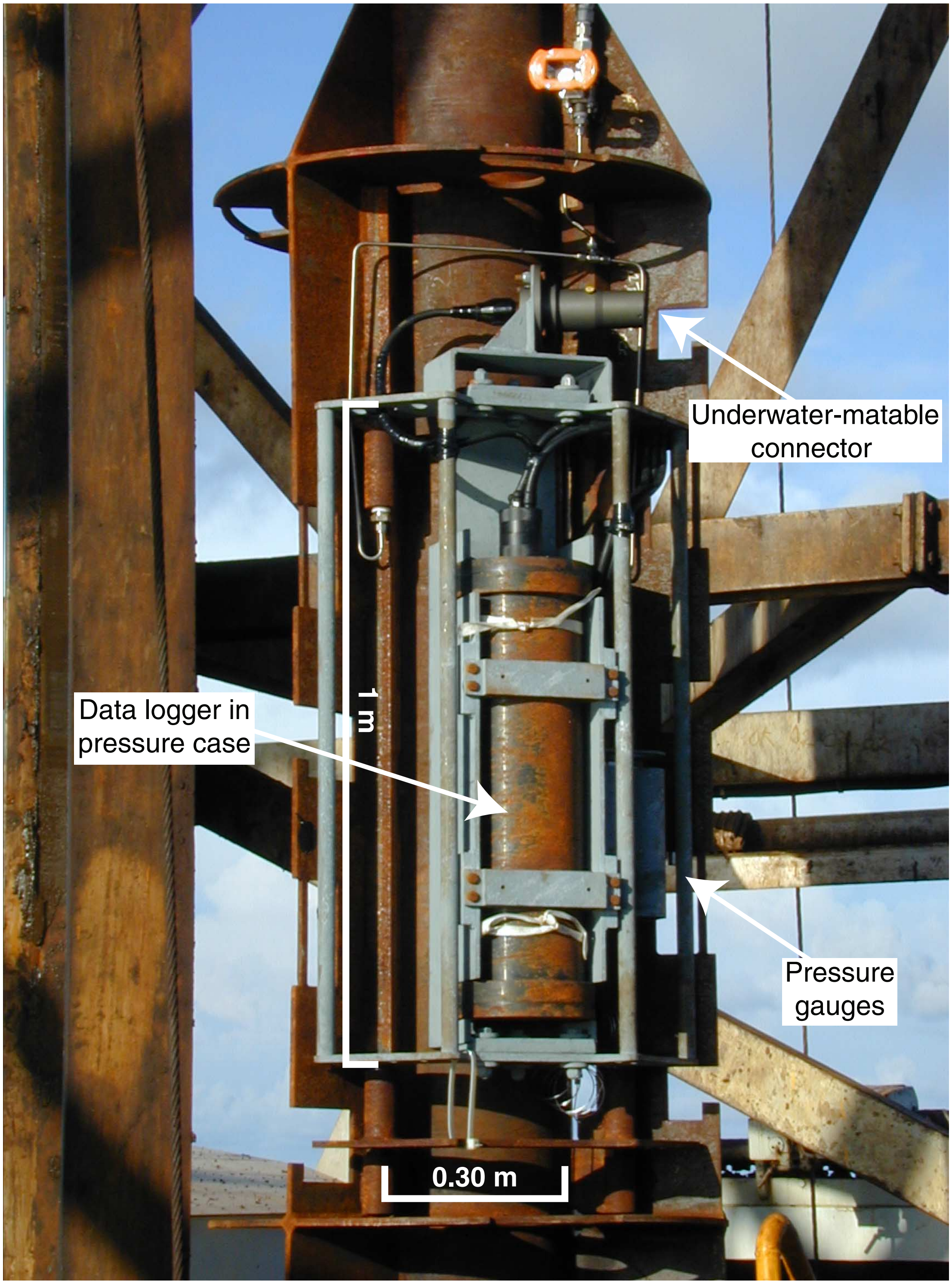

Figure F12. Pressure sensor inlets.

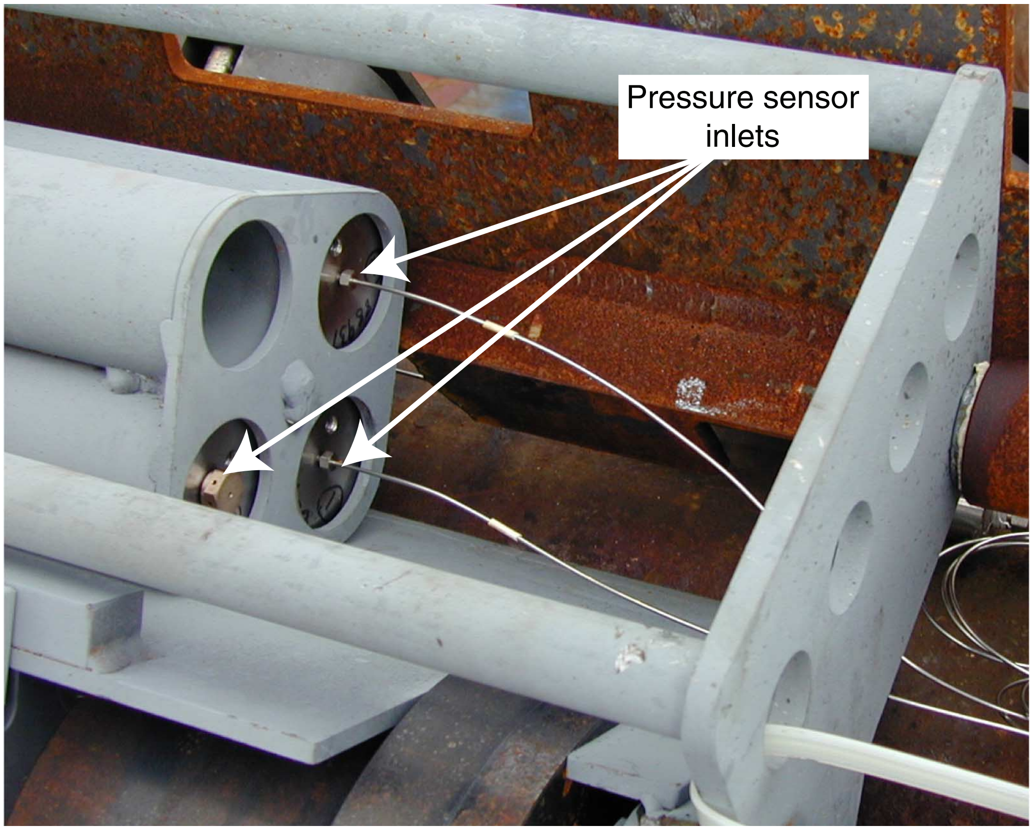

Figure F13. Close-up photograph of the wrapped screen.

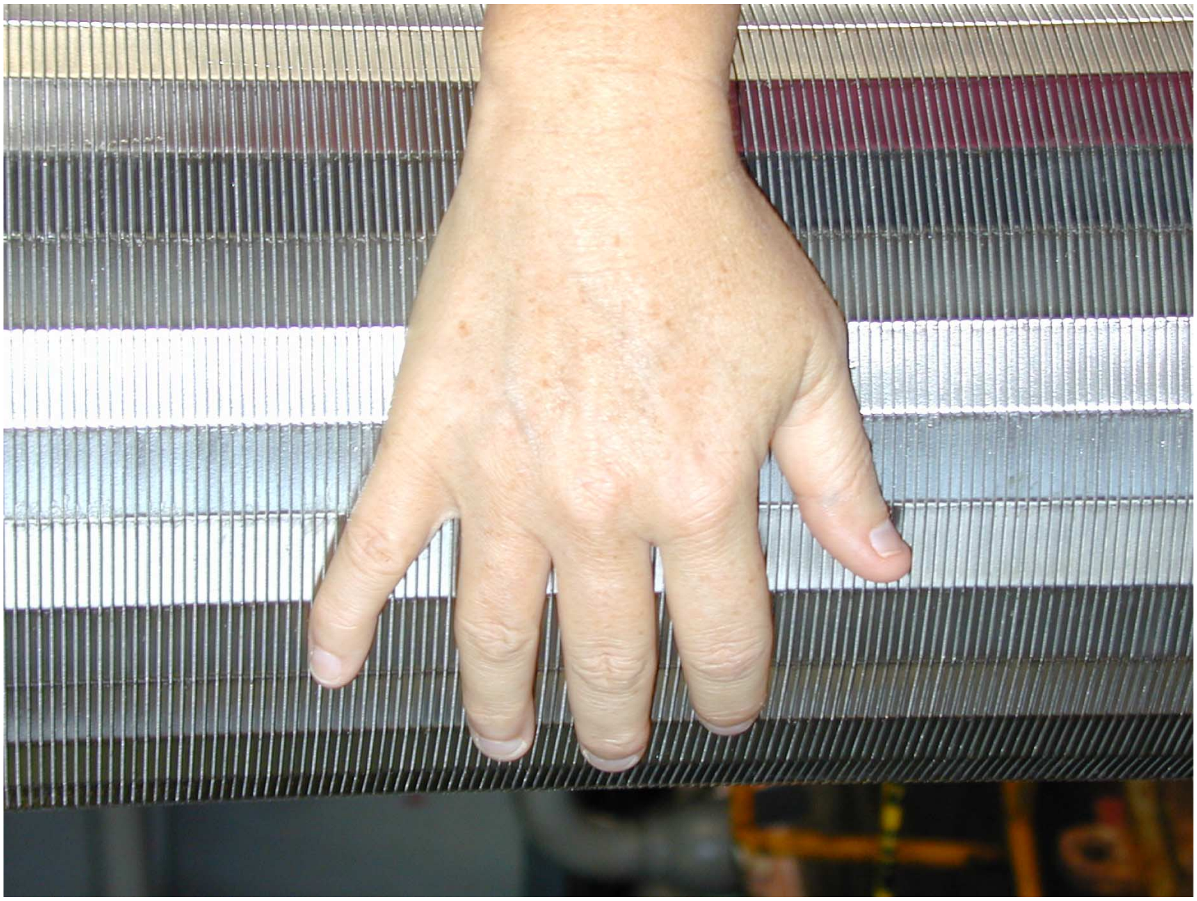

Figure F14. Umbilical for packer inflation and sampling tubing.

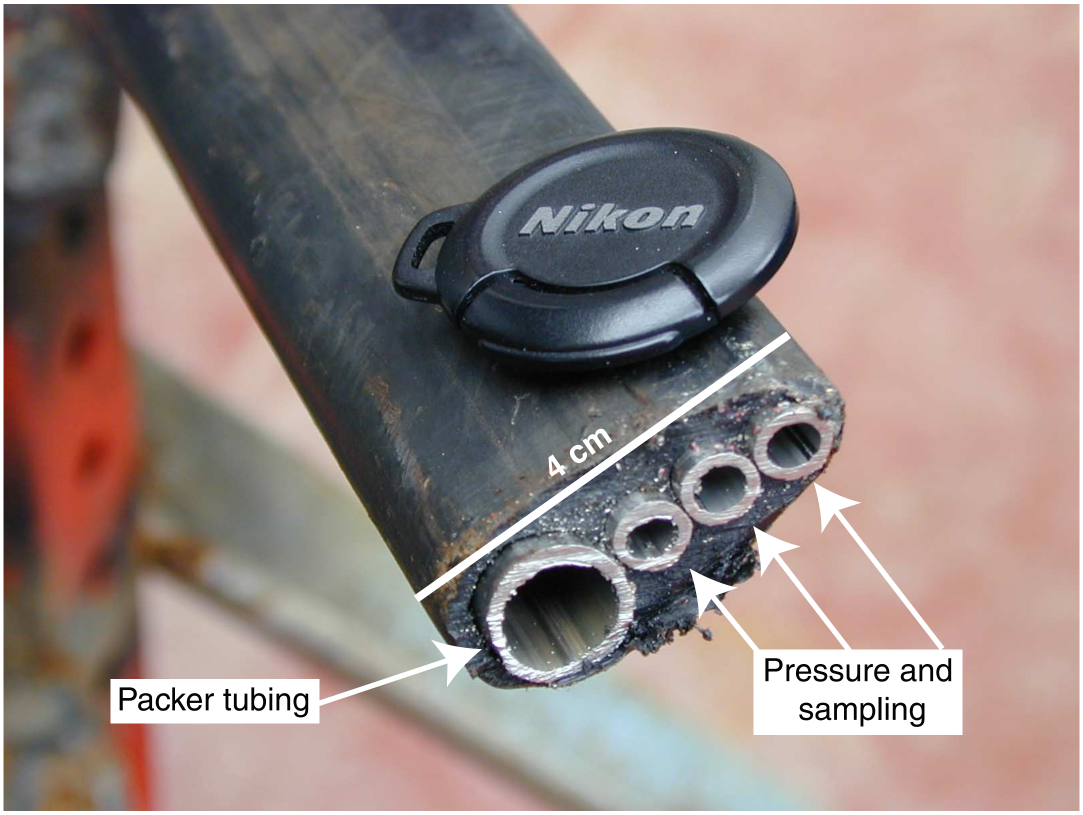

Figure F15. Centralizer and umbilical strapped onto the 4½-in casing.

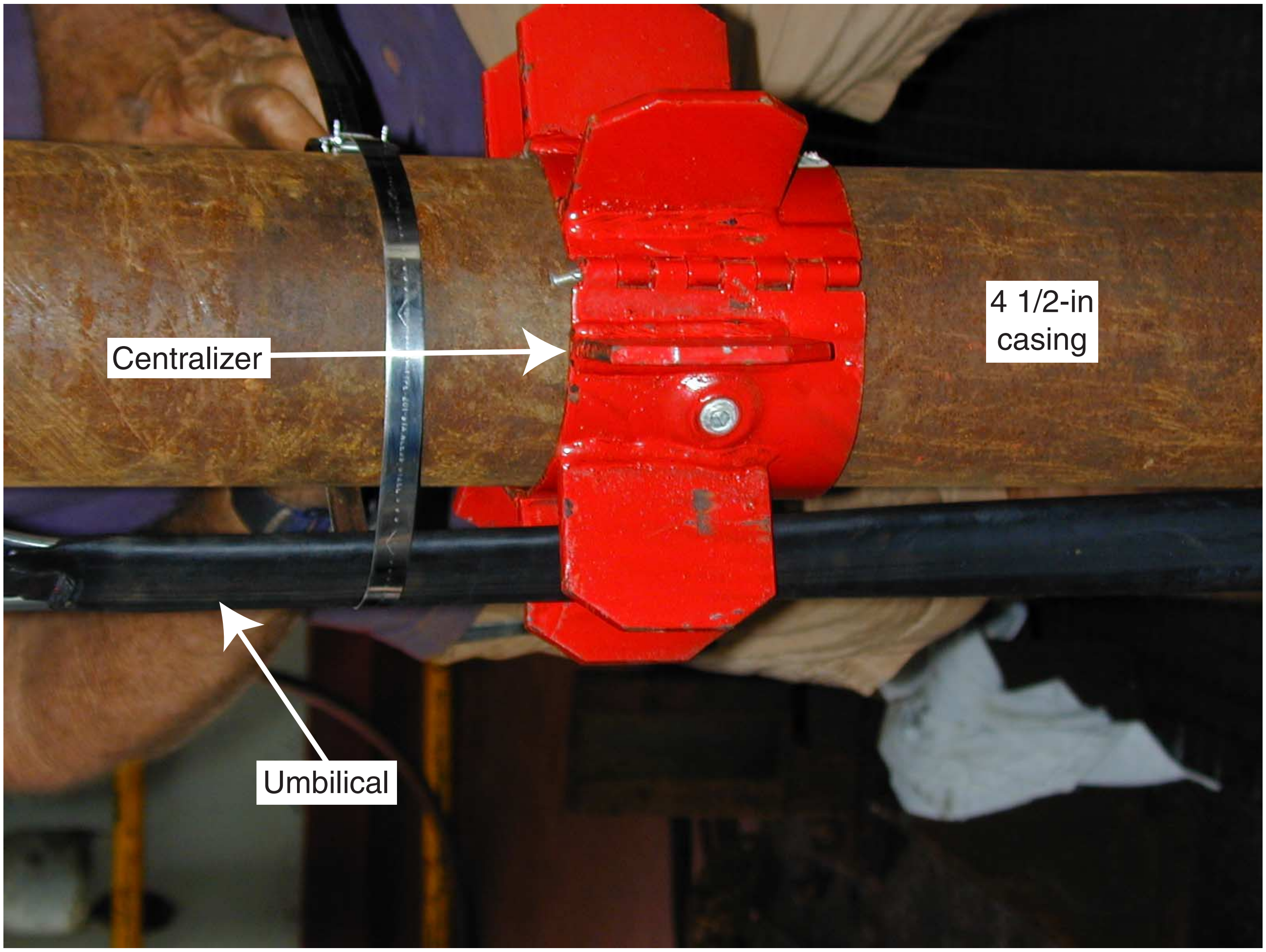

Figure F16. Schematic of the plumbing system of the CORK-II. During installation, the spool valves (black) connect the pressure ports to hydrostatic pressure to avoid pressure spikes that are potentially damaging the pressure sensors. After inflation of the packers, the spool valves are shifted (red) and connect the pressure gauge to formation pressures.

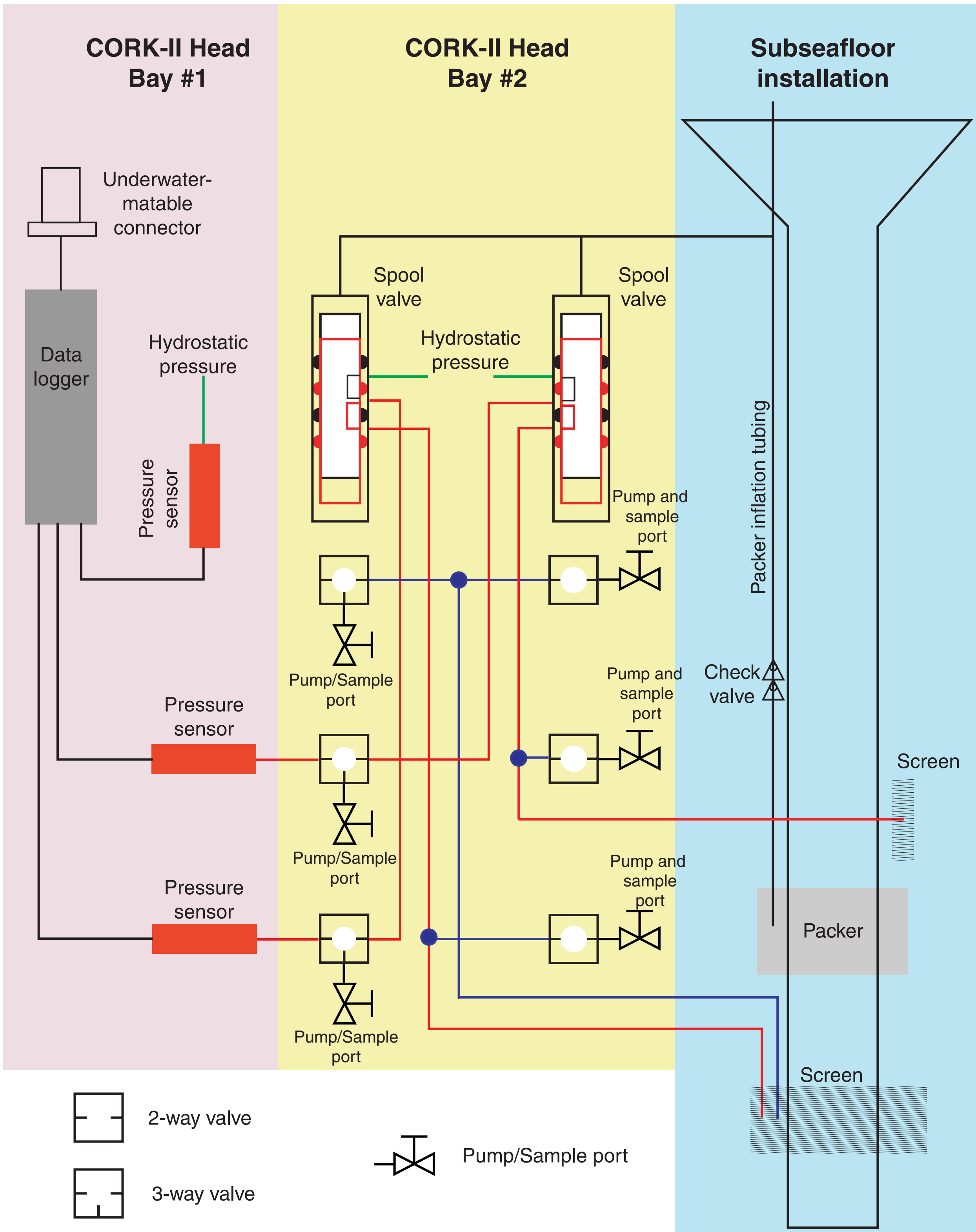

Figure F17. Close-up photograph of the plumbing and valve bay of the CORK-II head.

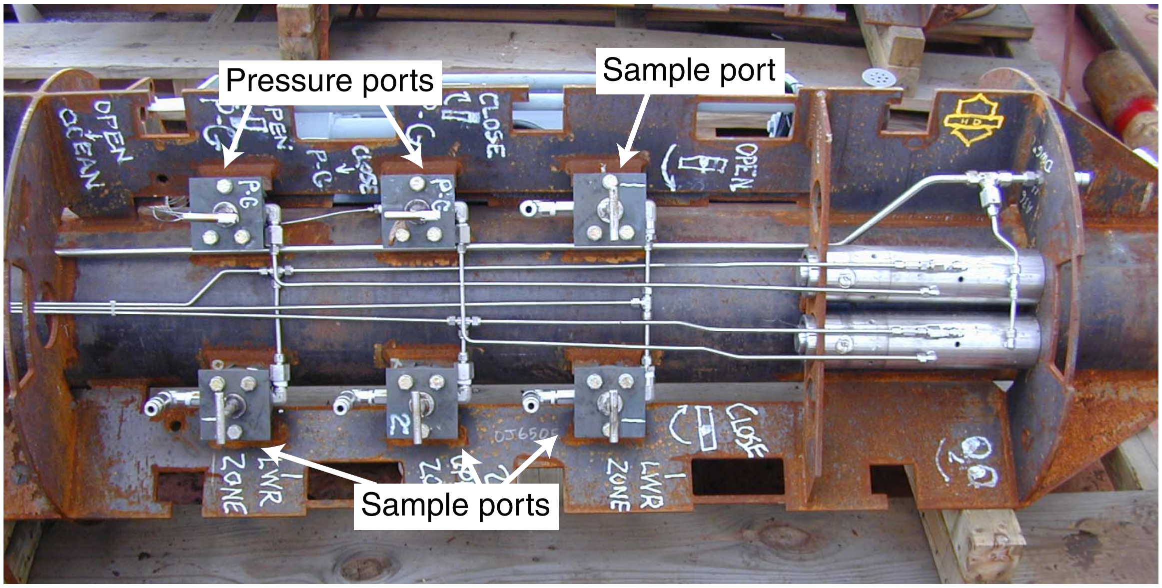

Figure F18. Packer inflation tubing and quick release.

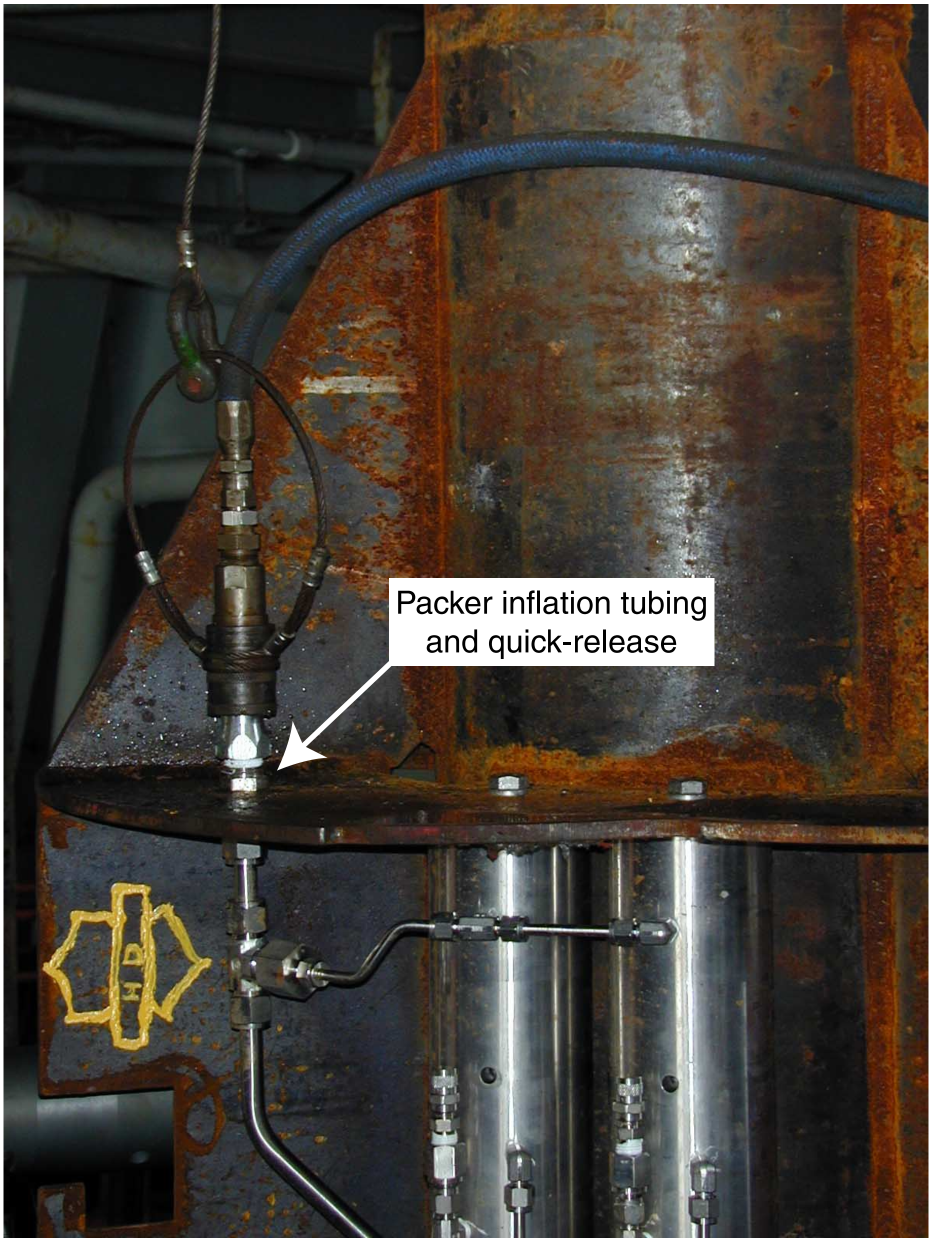

Figure F19. Latch and seal of CORK-II head.

Figure F20. CORK-II head bay with plumbing and valves.

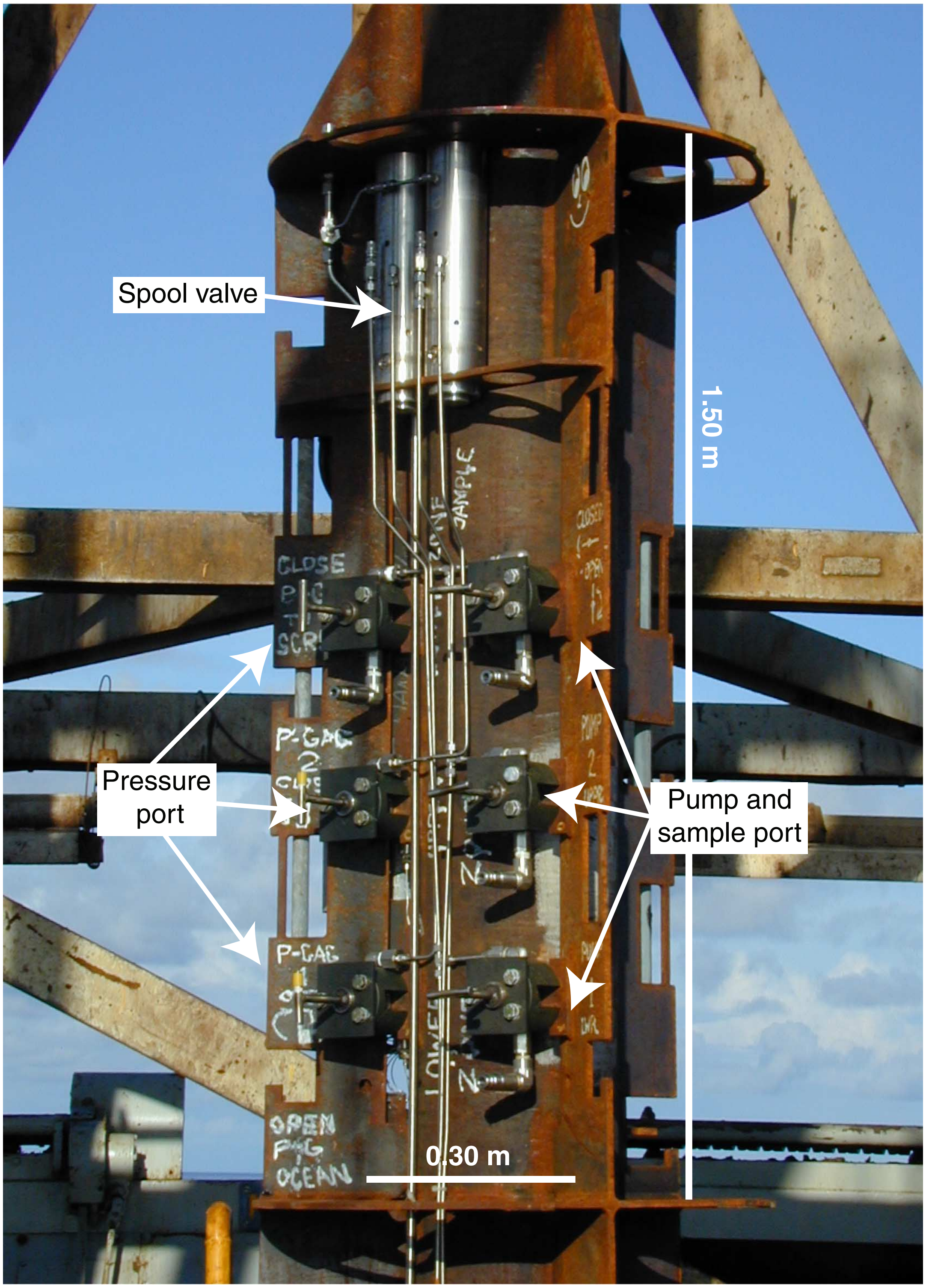

Figure F21. Hole 1253A CORK-II OsmoSampler installation space-out. mbsl = meters below sea level, mbrf = meters below rig floor, mbsf = meters below seafloor.

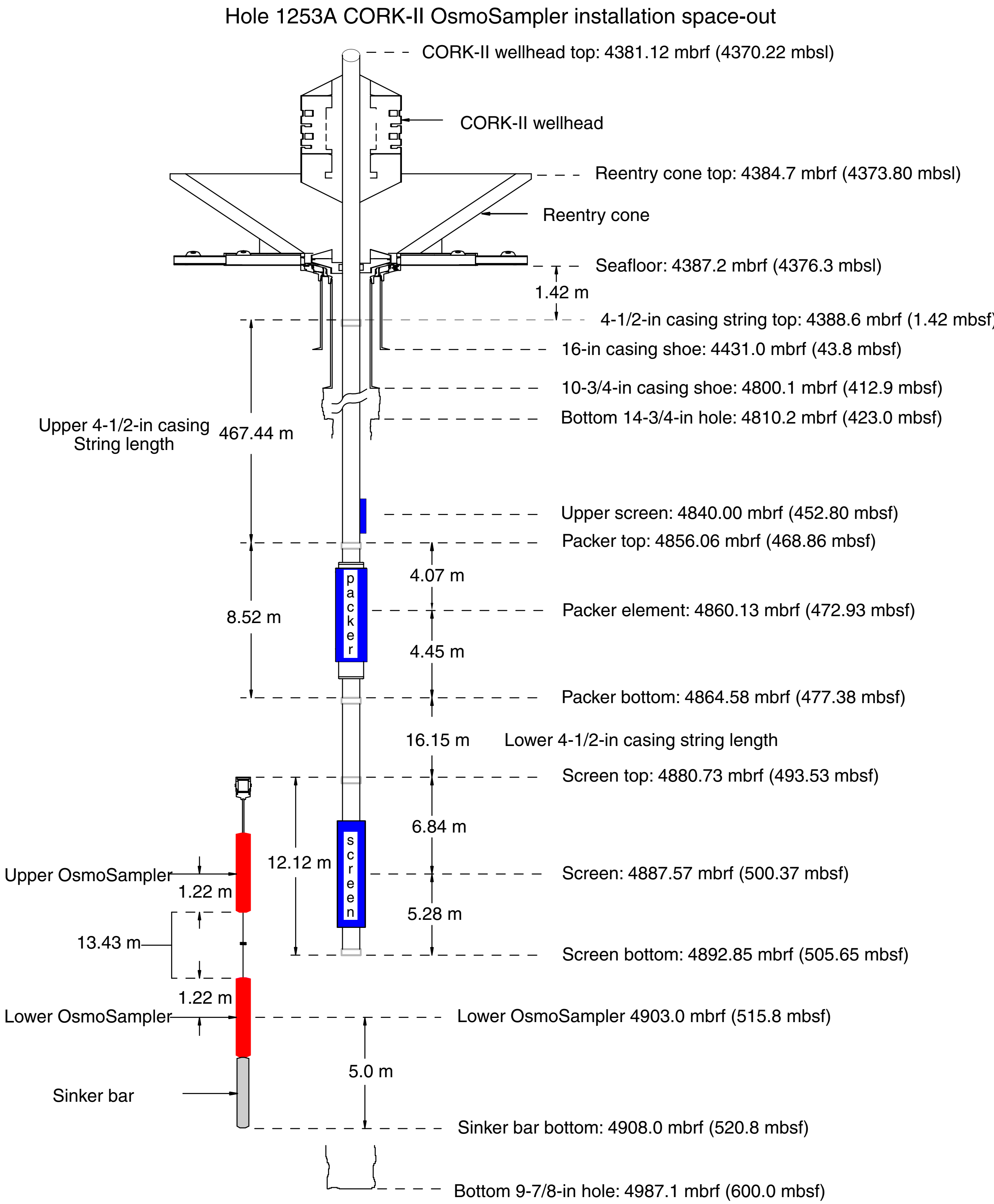

Figure F22. Hole 1255A CORK-II OsmoSampler installation space-out. mbsl = meters below sea level, mbrf = meters below rig floor, mbsf = meters below seafloor.