5. SPECIAL TOOLS[1]

Shipboard Scientific Party[2]

PACKERS

Introduction

Primary goals of ODP Leg 131 included obtaining the bulk permeability of, and pore-fluid samples from, sediments near the toe of the Nankai accretionary complex. The packer program was designed to assist in meeting these goals, through sealing and isolation of portions of drill holes, followed by testing and sampling. Mechanical, kinematic, and hydrogeologic models of accretionary complexes often require the specification of sediment permeabilities, but to date, such measurements have only been made on laboratory samples from these settings. On Leg 131 a rotatable drill string packer was intended to determine bulk sediment permeability and other hydraulic properties.

Pore fluids have been collected in this and in similar environments with *in-situ* probes (such as the WSTP tool) and by squeezing core samples in the laboratory, but these methods generally provide only small samples that are often contaminated with drilling fluid. On Leg 131 a new wireline sampling packer was intended to collect larger, less-contaminated samples. Due to operational limitations, principally hole instability, the wireline packer was not deployed. The description of its operation is retained here for general reference and to illustrate why it was included in the planned measurement scheme for the leg as described in the "Geological Background and Objectives" chapter (this volume).

Drill-String Packer

A packer can be defined as a device that hydraulically seals a portion of a borehole (Fig. 1). If this seal is maintained, the hydraulic properties of the formation within the isolated interval can be tested through controlled pumping of fluid into the isolated zone and careful monitoring of the resulting changes in pressure. Properties which can be elucidated through this kind of testing include pore pressure, transmissivity (from which permeability can be derived), and storage coefficient (which is closely related to bulk formation porosity).

The rotatable drill-string packer, previously run during Legs 110 and 123, is similar in principle to the TAM International straddle drill-string packer, which has been described numerous times elsewhere (e.g., Becker, 1986, 1988, 1989). Like the straddle packer, the rotatable packer is fully compatible with all logging operations. One major difference between the two tools is that the rotatable packer has a thicker-walled mandrill (strength member) that allows the tool to be torqued and compressed while made up as part of the drill string. This means that the tool can be in the bottom-hole assembly during limited drilling and spot-coring, and can be kept in the string during reaming and hole-conditioning operations. There are also differences between setting mechanisms and the "go-devils" (activation assemblies that are dropped down the drill pipe) that the two tools use, as described below.

The rotatable packer was recently modified for new inflation and deflation mechanisms. In the past, inflation of the packer resulted in the formation below the element being "charged" by a pressure pulse approximately equal to the setting pressure. In addition, deflation of the packer required locking out the heave compensator to break the drill string and insert a deflation go-devil. A new go-devil and rotatable-packer control sleeve now allow more controlled element inflation and locking, and a deflation-ball drop sub allows deflation without breaking the drill string.

Once the rotatable packer is positioned with the inflation element over the chosen packer seat, a 1 1/4-in. deflation ball is installed in a ball-drop subassembly (BDS) and an air hose, which is long enough to reach the drill floor during heave compensation, is connected. The BDS is then made up to the circulating head prior to activating the heave compensator. The new go-devil is deployed by free-falling it down the drill string and into the packer control sleeve. O-ring and polypack seals around the go-devil allow pump pressure to force the control sleeve to compress a spring, shifting both the sleeve and the go-devil downward relative to the packer. When the control sleeve shifts downward, the packer-element inflation port is opened to the drill string and several latch dogs in the go-devil lock it in place. Pumping inflates the element and continues until shear screws in the go-devil blow out, at a pre-set pressure, causing the inner assembly in the go-devil to shift downward. This allows (1) the packer element to be locked inflated with full pressure, (2) the go-devil deflation port to be aligned with the packer-element inflation port (with a deflation sleeve preventing deflation until later), and (3) piston-locking balls in the go-devil to be released in preparation for pressure bleed-off at the rig floor. When pressure is bled off, the compressed go-devil spring shifts a piston releasing the inflation latch dogs. A latch plug is then pumped into a catcher sub beneath the go-devil, opening the formation below the packer element for testing.

The go-devil carries recorders that monitor fluid pressure within the isolated interval. Fluid pressure is also monitored with gages at the rig floor, as the isolated interval is not shut-in, but the downhole records are more accurate. Fluid volumes and pumping rates are monitored and recorded for use in later data analysis.

After testing is completed, the packer is deflated by dropping the 1 1/4" steel ball into the drill pipe, by applying pressure to the BDS through the attached air hose. The ball falls into the go-devil and seals against a landing shoulder in a deflation sleeve. Rig pumping then causes deflation shear pins in the go-devil to fail, dumping the deflation sleeve into the go-devil catcher subassembly. This action opens the packer element deflation ports, allowing the fluid in the element to be vented back into the drill string. The go-devil and pressure gages are then recovered with a standard overshot. Resetting the rotatable packer requires retrieving and redressing the go-devil.

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[1] Taira, A., Hill, I., Firth, J., et al., 1991. *Proc. ODP, Init. Repts,* 131: College Station, TX (Ocean Drilling Program).

[2] Shipboard Scientific Party is as given in the list of participants preceding the contents.

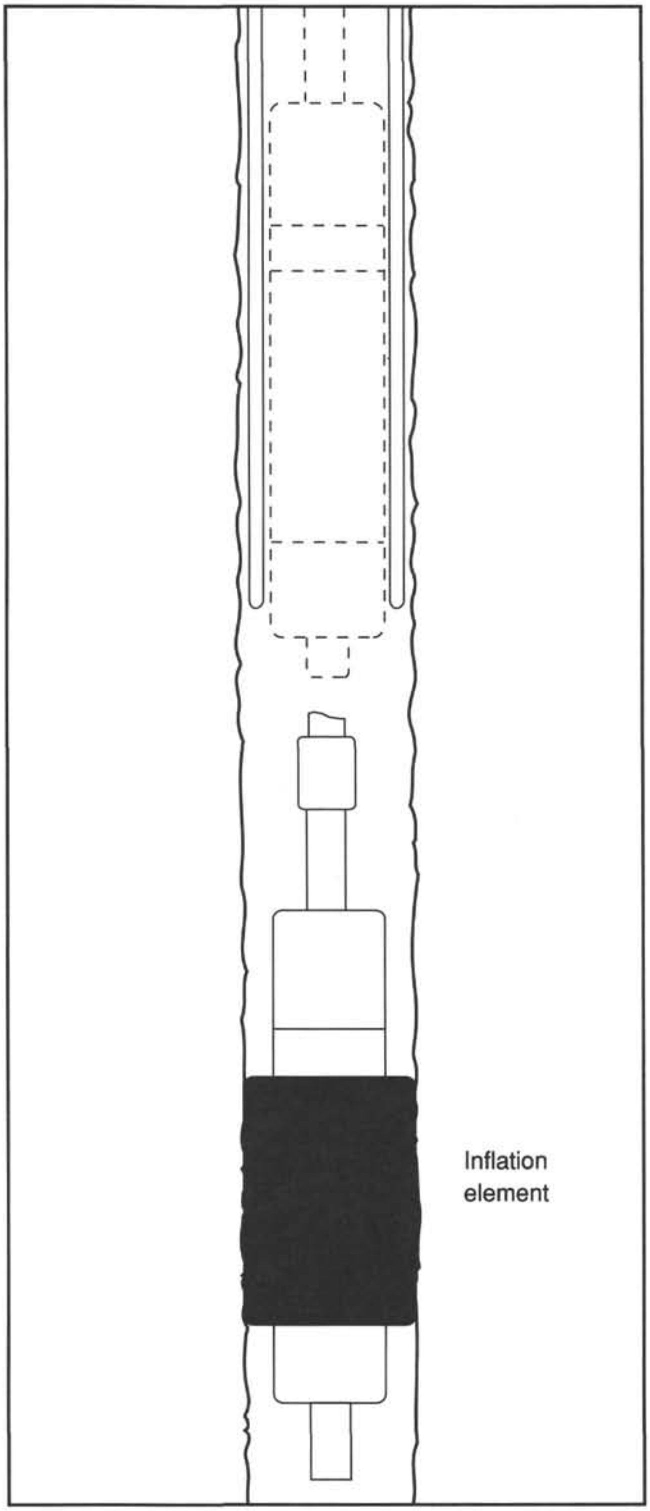

Figure 1. Sketch of an inflatable drill-string packer. A single inflation element isolates the formation between the element and the bottom of the hole for hydraulic testing.

Wireline Packer

The wireline packer, also designed and built by TAM International, is a discrete-zone, pore-fluid sampler. The tool is lowered down through the drill string and into the open borehole on the standard seven-conductor logging cable. Unlike a drill-string packer, which is actuated by dropping a go-devil and pumping through the pipe, the wireline packer is controlled by a surface computer in the downhole measurements laboratory. No hydraulic connection with the surface is required as the tool contains an electrically operated downhole pumping system. The wireline packer is a straddle tool, meaning that it has two distinct inflation elements. When inflated, the elements isolate a vertical zone approximately 1 m wide from which fluid is extracted (Fig. 2).

Because it must pass through the drill pipe and the bottom-hole assembly, the outer diameter of the packer is limited by the 3.80-in. inner diameter of standard ODP bottom-hole assemblies. The two packer elements will inflate to a maximum of 12 in. at a pressure of about 300-psi differential. Differential pressure is kept relatively low to prevent rupturing of the bladders in the packer elements, which are strained by high expansion.

Following packer inflation, fluid is drawn from the interval isolated between the packer elements and pumped out above the tool (Fig. 3). The pump has an output of about 1 gal./min. and a maximum drawdown of about 300 psi. Actual pump rates and zone pressures are controlled by the permeability of the formation. Zone and packer pressures and fluid chemistry (sodium, calcium, chloride concentrations, and Ph) are monitored and digitally transmitted to the surface continuously.

By monitoring the geochemical data in real time, the operator can determine when a reasonable concentration of "virgin" formation fluid is present in the system, and redirect fluid flow into one of four sampling bottles. The sampling bottles are similar in design to a syringe, each having a capacity of about 400 mL. Each bottle is equipped with a check valve to maintain fluid pressure following sampling. Once a sample is collected, the packers can be deflated and the tool moved to a new location. At the completion of the sampling program, the tool is drawn back up inside the bit and returned to the surface, where the samples can be removed for analysis.

LAST-I

The lateral stress tool (LAST-I) is designed for use in the sediment section of ODP holes, deployed on the end of the APC as a cutting shoe. The tool is used to measure *in-situ* variations in stress within sediment packages, such as the accreted sediment wedge at Site 808. LAST-I is hydraulically pushed into the seabed 5 m ahead of the bit. After placement, the tool is left in the formation for a minimum of 30 min. LAST-I measures *in-situ* effective stress at three locations in the same horizontal plane (120° apart), pore fluid pressure, and temperature. The cutting edge of the LAST-1 is designed to direct sampling disturbance inward toward the core barrel and to minimize disturbance along the outer walls of the tool. This strategy is the opposite of conventional coring and provides a better measure of *in-situ* stresses of the formation on the tool.

LAST-I (Fig. 4) is a passive sensor device that measures *in-situ* stress using strain gages that are bonded to the inside wall of thinned portions (diaphragm) of the cutting shoe. The thinner wall acts as a diaphragm and deforms under a differential stress. The outside of the diaphragm is loaded by the total lateral lithostatic stress, and the inside chamber of the membrane is ported to pore-fluid pressure. Consequently, the stress difference across each diaphragm is the effective lateral

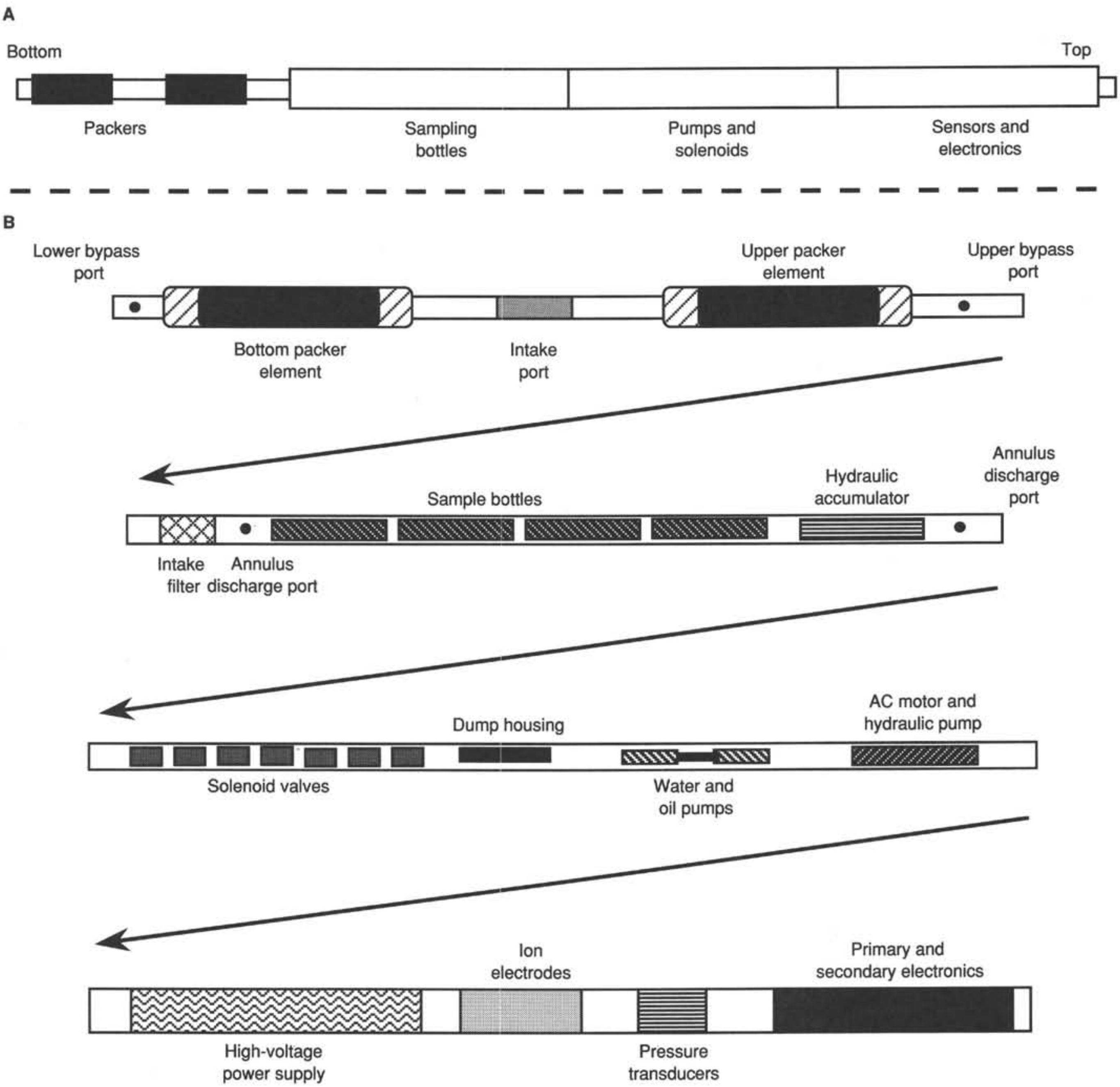

Figure 2. Schematic of the wireline packer. **A.** From bottom to top, the tool consists of four main subassemblies. **B.** Each subassembly is itself composed of several components. The packer subassembly includes the two packer elements that straddle the main intake port. This fluid is filtered at the bottom of the sampling bottle subassembly. This subassembly also contains two discharge ports for venting fluid above the packer elements and a hydraulic accumulator that allows fluid to be drawn. The pump and solenoid subassembly contains the valves that direct fluid flow and the motor and pumps that move fluid through the tool and inflate and deflate the elements. The dump housing allows fluid under pressure in the packer elements to be released for deflation. The upper subassembly contains geochemical, pressure, and temperature sensors and the downhole electronics.

stress that is measured with each strain gage. In addition, the absolute pore-fluid pressure is measured using a Sensotec type K pressure transducer with a 0–10,000 psi range and a + 0.15% full-scale nonrepeatability. Pore-fluid pressure is ported to the transducer and the membrane chambers via a polypropylene filter and fluid ports to the outside wall of the cutting shoe.

The tool is completely self contained and is programmed to take readings at user-specified time intervals that can vary throughout each run. Typically, one measurement from each sensor is recorded every 5 s after insertion into the seafloor. Three boards have been designed to fit into the wall of the tool. These are the power control board, amplifier, signal conditioning board, and memory/computer board. In addition, a thermistor is located on one of the boards. The tool is powered by six AA batteries that are changed for each new run. The data are recovered using a serial link to an IBM-compatible PC.

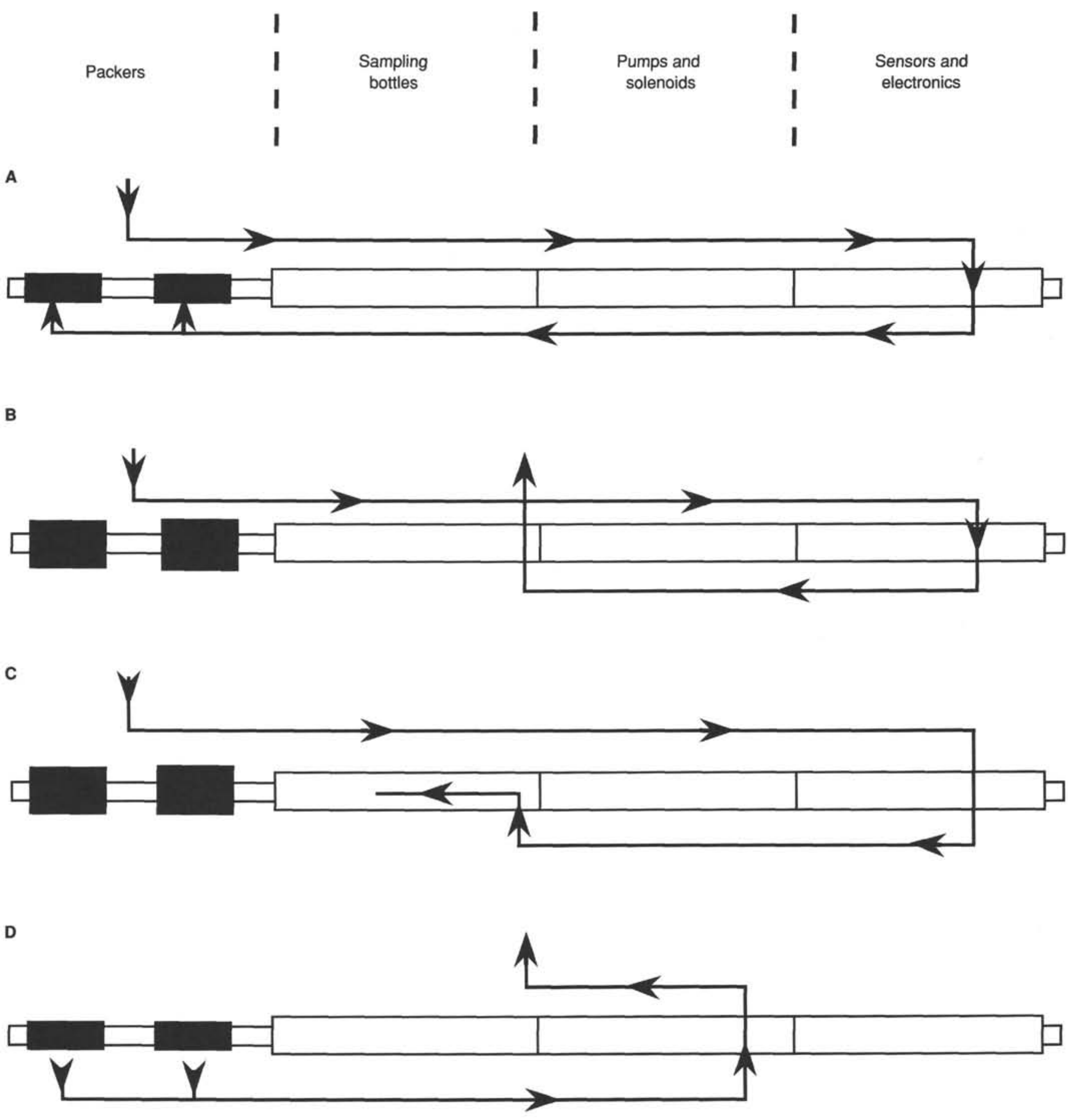

Figure 3. Schematic of fluid-flow paths during operation of the wireline packer. **A.** Fluid is drawn through the intake port between the two packer elements, passes up and down the length of the tool, then inflates the elements. **B.** Fluid is drawn from the isolated zone and dumped into the annulus above the elements until the sensors reveal that the fluid originated in the formation. **C.** Formation fluid is isolated in sample bottles. **D.** Fluid under pressure in the elements is dumped out into the annulus to allow deflation.

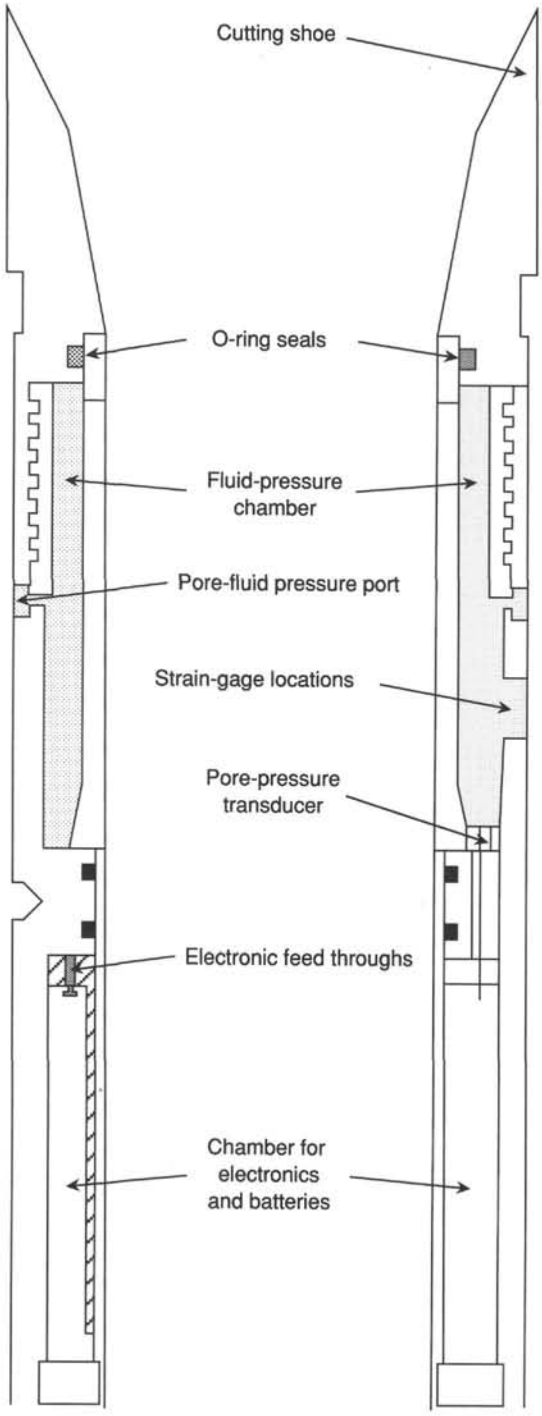

Figure 4. Schematic of the lateral stress tool (Last-I).

ONDO

The ONDO system is a long-term temperature monitoring system developed especially for ODP drill holes. "ONDO" means temperature in Japanese and also stands for "ODP Nankai Downhole Observatory." The objective of this experiment is to detect possible temporal variations in the temperature profile of a hole drilled into the Nankai accretionary prism. Such variations may reflect changes in the pattern or strength of fluid flows in the prism, especially along thrusts.

The ONDO system consists of three main components (Fig. 5): (1) thermistor cable, (2) recording package, and (3) acoustic transducer. The original thermistor cable is 800 m long and contains 19 thermistor temperature sensors at intervals of 40 m. Each thermistor has its own pair of lead wires to save as many sensors as possible if the cable is partly damaged. A pressure gage is mounted at the bottom end of the thermistor cable. The recording package is a cylindrical pressure housing in which a data logger and batteries are installed. The system has another pressure gage atop the recording package. The acoustic transducer is mounted at the top end of the system and is supported by a stainless-steel pipe.

The system is hung on the topmost part of the casing with landing pads, which stand on a niche grooved inside of the casing (landing subassembly in Fig. 5). The whole system is lowered from the *JOIDES Resolution* through the drill pipe, with landing pads folded. The landing pads open when they come out of the drill pipe, and support the system. The total weight of the system is about 1500 kg in the air and 900 kg in water.

The data logger measures temperatures at 19 points and pressures at two points once a day and records them in integrated circuit memories. The measurement range is 0° to 80°C for temperature and 0 to 10,000 psi for pressure. The resolution of temperature is 0.001 K at 0°C and 0.01 K at 80°C, and the accuracy is better than 0.1 K. The drift of each temperature sensor is expected to be about 0.01 K/yr. The resolution of pressure is 10 mm of water column. The capacity of the memories and batteries is large enough for over three years of operation.

The recorded data are retrieved with acoustic telemetering between the system and a surface ship (Fig. 5). Receiving an acoustic command from the ship, the system starts to send the data recorded during the term specified by the command. It may be difficult, however, to receive good acoustic signals at the sea surface because of the long distance, the high noise level at the surface, and the difficulty in keeping the ship's position. In such a case, the data are recovered through a pop-up type acoustic data logger (Fig. 5). The data logger is lowered to the seafloor near the ONDO system with the aid of an acoustic transponder set on the seafloor near the drill hole. The data logger communicates the command from the ship to the ONDO system, receives the data, and stores them in its own memory. After transferring the data, the logger is retrieved by using an acoustic command-based release system. The data are read out aboard ship.

If the hole is unstable, it must be cased down to a depth necessary to keep the hole condition good enough for deployment of the thermistor cable. At the present stage the top of the hole is open to seawater, because cementing the hole may damage the acoustic transducer and also make it impossible to retrieve the whole system. Therefore the pressures measured in the hole are nearly equal to hydrostatic. There is a possibility, however, that the hole may be sealed in the near future using the Japanese submersible "SHINKAI 6500."

ANELASTIC STRAIN RECOVERY

The anelastic strain recovery (ASR) technique measures the small component of time-dependent elastic strain resulting from the release of in-situ stress during the coring operation. If this strain tensor can be satisfactorily related to the total elastic strain, and if the elastic moduli are known or can be measured, the *in-situ* stress tensor can be characterized. A common assumption is that the rock sampled is mechanically isotropic. In this simple case, the principal stresses and strains have the same orientation, and their magnitudes are propor-

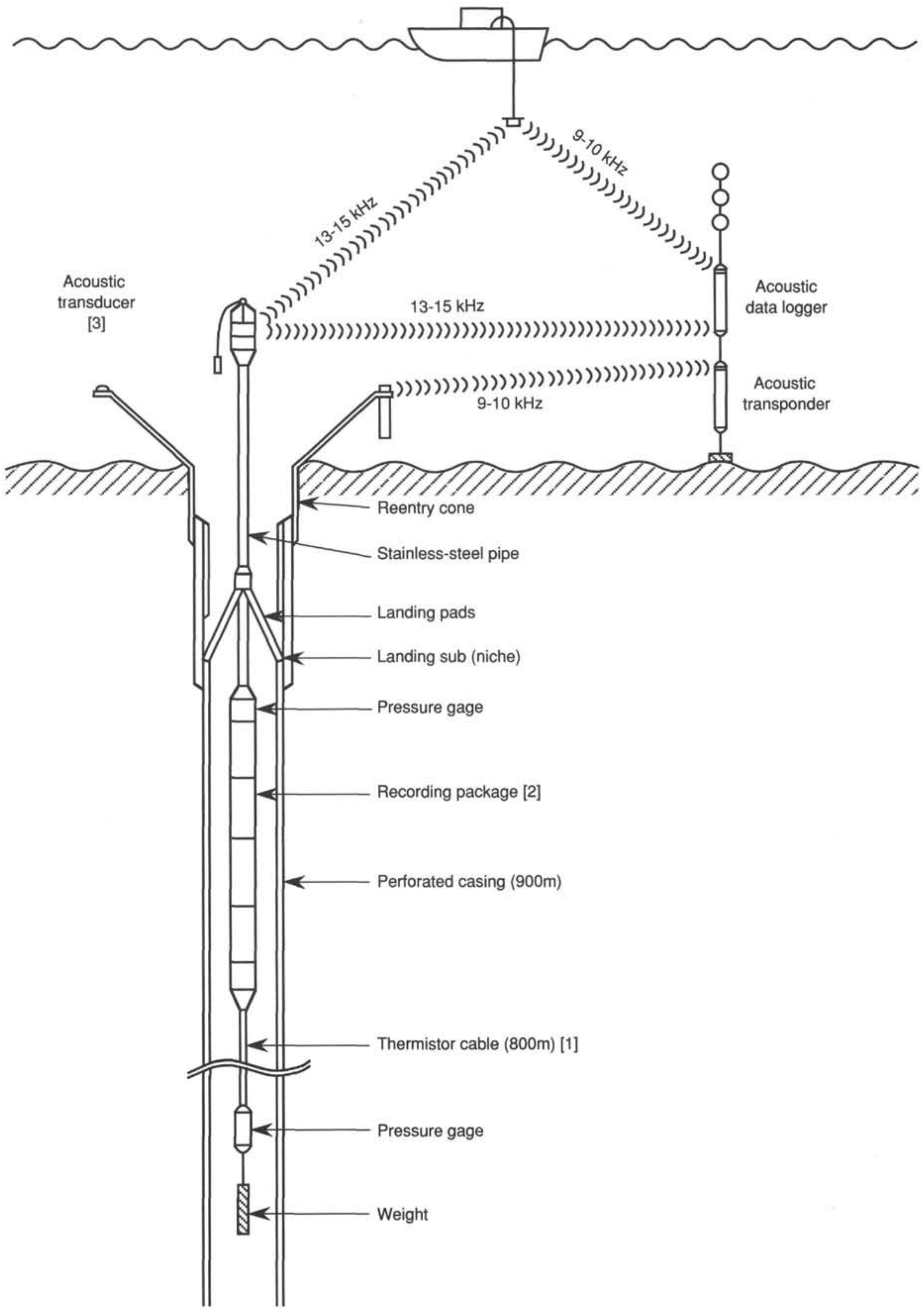

Figure 5. Schematic of the ONDO system.

tional. A more complicated but realistic assumption for the case of sediments is that these rocks are only laterally isotropic and have different elastic moduli in the vertical direction. Neither assumption can be applied to the toe of an accretionary prism because no principal stress is likely to be vertical and because deformation will have imparted an anisotropy that will most likely be orthotropic or even less symmetric.

Anelastic strain recovery studies have been carried out on igneous rocks (Wolter and Berkhemer, 1989) and on rigid (highly lithified) sediments (Teufel and Warpinsky, 1984), but not yet successfully on the less-rigid sediments expected in the Leg 131 drill cores. Moreover, the experiments to date have been on rocks for which the horizontal stresses were either less than or not much greater than the vertical stress. On the contrary, the maximum principal stress in the accretionary prism is expected to be subhorizontal and much larger than the vertical stress. Both of these factors will enhance the possibility that the cores will not be strong enough to resist failure during the coring operation and thus give erroneous or misleading results.

If successful, however, the anelastic strain recovery results will be of unique importance. These measurements are the only way presently known to determine the stress tensor where no principal stress is near vertical. Estimates of the magnitude and direction of the principal stresses in accretionary prisms may vary widely near the basal décollement and other large faults. Moreover, stress magnitudes are needed to test various mechanical models postulated for the behavior of accretionary prisms.

Because anelastic strain decays exponentially with time, measurements must begin as soon as possible after the core is cut. For the measurements in the apparatus employed during Leg 131, a 15-cm-long whole-round section of core, which is waxed to prevent desiccation, is placed in a framework holding seven linear variable-displacement transformers (LVDT's). Each component within this framework is an Invar ring, modeled after those used by Teufel and Warpinsky (1984). Invar rings have a very low coefficient of thermal expansion, thus removing the effects of temperature changes on the apparatus. Temperature changes of the core, from its *in-situ* to room temperature are monitored separately, using two thermistors; one mounted in the center of the sample and another in the surface wax.

Displacements on the LVDT's define the strain on three orthogonal planes, from which the three principal anelastic strains can be determined. These strains include the thermally-induced strains that must be removed. Displacements and temperatures are recorded every 15 min until the strains are dissipated. The core is then removed from the frame and preserved for mechanical testing onshore. This testing includes the determination of the coefficients of thermal expansion and elastic moduli in the directions of mechanical symmetry.

If the anelastic strain tensor that is measured is proportional to the total elastic strain, and if sufficient elastic moduli can be measured to construct the compliance matrix, then it is a simple task to calculate the anelastic stress tensor, which should provide the orientation and relative magnitudes of principal stresses. This tensor can be scaled up to total effective stress values by comparing the measured vertical effective stress (determined by integrating the sediment bulk density profile and subtracting the pore pressure at the sample location) with the vertical component of the anelastic stress tensor.

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