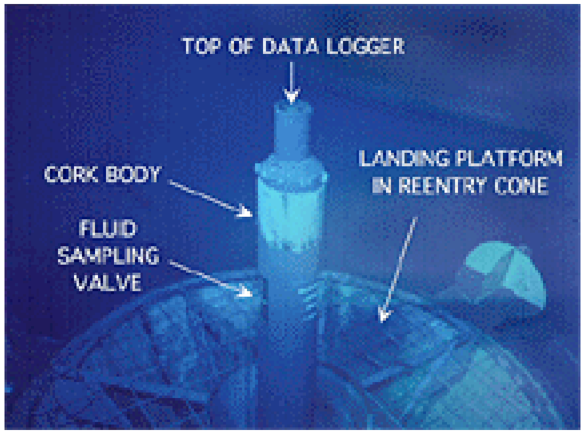
ADVANCED CORKS FOR THE 21ST CENTURY



REPORT OF A WORKSHOP SPONSORED BY JOI/USSSP

Science Workshop: 15-16 December, 1997, Scripps Institution of Oceanography
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I. Executive Summary

In late 1997, a JOI/USSSP-supported workshop was convened to outline the scientific objectives and general technical requirements for the next generation of ODP instrumented borehole seals or "CORKs" (Circulation Obviation Retrofit Kits). CORKs were initially developed in 1990-1991 for thermal and physical characterization of subseafloor hydrology, and 13 CORKs have been deployed to date in a variety of hydrologic settings. There is great interest in the potential of future CORKs for enhanced hydrological monitoring and testing, for sampling of subsurface fluids and microbiology, and for deployment of additional geophysical instrumentation hydraulically isolated beneath the seafloor.

The workshop was attended by 25 earth scientists and engineers representing a broad spectrum of disciplines, ranging among hydrogeology, seismology, geochemistry, microbiology, paleoceanography, and drilling engineering. Reviews of existing CORK technology and recent scientific results were followed by discussions of directions for future CORK science. Specific needs for future CORKs were then explored in the context of two generic hydro-lithologic sections representative of subduction complexes and oceanic crust. Discussions were focussed on settings most appropriate for CORK installations, i.e., where hydrogeologically active formations or structures can be intersected below naturally low-permeability sediments through which casing can be set.

Two key requirements proved to be common to the relatively diverse but interrelated disciplinary objectives for which future CORKs can make major contributions:

Of particular importance is the need for independently accessing multiple zones of the formation that are hydrologically isolated from one another. Current CORK technology allows monitoring of only the average conditions represented by either the full interval of open hole below casing or a single screened interval in a fully cased hole. Multi-level monitoring and sampling capabilities will open many new opportunities in all geologic settings, and will make much better use of ODP holes for hydrologic observatories.

Also critical for future CORK science is provision for wireline capability for servicing, reconfiguration of sensor packages, and possibly complete CORK deployment. This would reduce demands and dependency on the ODP drillship and provide greatly increased flexibility for both CORK science and other borehole science in ODP legacy

holes.

The CORK science workshop closed with presentation and discussion of conceptual notions for multi-level packer/sensor/sampler systems that could be deployed by wireline and with a non-riser drillship, the former for holes established in stable formations, and the latter for either stable or potentially unstable sections.

Determining the best technical ways to meet the objectives outlined during the main workshop was the focus of a follow-up meeting two months later, involving ODP engineers and a small number of scientists. This group was charged with outlining the most reliable and efficient means of completing holes, installing casing, and emplacing multi-level packer/sensor/sampling strings that will also provide flexibility for post-emplacement servicing and opportunities for installation of additional instrumentation. Following discussions of the scientific objectives developed at the first meeting and of the general constraints imposed by the hydrologically active lithologic sections most likely to be encountered, several options for multi-packer observatory strings were discussed. Two independent solutions emerged as having greatest promise in the way of being relatively simple and offering flexibility for servicing, recovery, and later use of holes:

The first is a **wireline multi-packer system** that would rely on a wireline control vehicle for deployment and recovery and will be pursued as a third-party development. This system would be suitable for use both in cased holes that have been perforated for hydrologic access through casing and cement, and in open holes extending below casing that are stable and have clean-caliper intervals where packers can be set. Packer elements, fluid conduits, and conductor wires for down-hole sensors and a televiewer would be integrated into a pre-designed string that will be installed in much the same way that a seismometer was emplaced recently in the ODP Ocean Seismic Network Hole 843B. Packers would be inflated with one or more submersible pumps. The number of packers, and hence the number of intervals accessed by the hydrologic conduits, would be limited to two or three primarily by the payload limitations of typical oceanographic cables.

The second solution is a **drillship-deployed multi-packer liner system** that could also be used in stable or cased holes, but it is intended primarily for unstable formations such as those common in accretionary prisms. This system would be assembled at the rig floor, and could be (a) inserted into a previously drilled, cased, cemented, and perforated hole or (b) drilled into the formation without rotation with a mud-motor and under-reamer. With the use of a free-fall funnel or drilled-in casing, it could also be installed in holes that have been drilled for logging with an LWD tool string. The multi-packer string would include porous, annular, screened "ports" that are individually connected to the seafloor up the outside of the liner for pressure monitoring, testing, and fluid sampling. Thermistors and other downhole sensors would be deployed down the inside of the liner, which would be completed at the bottom with either a pervious or impervious bridge plug, and at the top with a instrumented seal that could be removed by wireline. In this way, the full diameter of the liner will be available for other instrument installations after the hydrologic monitoring experiments have been completed. A full reentry cone and casing will not be required for these installations, and hence it is anticipated that they can be accomplished quickly and at modest cost.

The final workshop recommendation is that these two development efforts should be pursued in parallel and as expeditiously as possible. The likely hiatus in ODP CORK deployments until 2000-2001 represents an extraordinary opportunity to design advanced CORKs for the 21st century. The CORK design advances enumerated in the main workshop and engineering meeting are required to meet future scientific challenges in subseafloor hydrogeology, particularly to fulfill the promise of scientific ocean drilling for long-term in-situ monitoring of the fluid flow processes that are so pervasive and important in oceanic crust and sediments.

II. Introduction and Background

The CORK ("Circulation Obviation Retrofit Kit") hydrologic observatory (Davis et al., 1992; Davis and Becker, 1993) represents an important ODP innovation in the 1990's. Thirteen CORKs were deployed in 1991-1997 (Figure 1 ,Table 1), sited in three important hydrological type-settings on the deep seafloor: four in a sedimented ridge-crest hydrothermal system, four in accretionary complexes at subduction settings, and five in ridge-flank hydrothermal systems. For a visual indication of the impact of this experiment, one need look no further than the cover of the ODP Long-Range Science Plan, or the cover of the BOREHOLE workshop report, or the ODP section in the 1993-1997 RIDGE science plan. More substantively, the CORKs deployed to date have produced unique scientific results (e.g., Davis and Becker, 1994; Davis et al., 1995; Screaton et al., 1997; Becker and Davis, 1997; Becker et al., 1998; Davis and Becker, 1998), which have contributed significantly to the increasing emphasis on long-term observatories in the current ODP Long-Range Science Plan.

The first 13 CORKs all shared a similar basic design, which has been improved only incrementally over time: a drillship-deployed CORK body seals the hole at the reentry cone/upper casing, and a data logger/sensor string is deployed down the drill pipe into the CORK body and sealed hole (Figure 2). While this design has proven quite successful in achieving the hydrological objectives of the experiments carried out to date, it has certain limitations. Whereas manned or unmanned submersibles can recover data and conduct experiments at CORKs, only the drillship can perform major servicing, and the sensor packages have been limited to diameters that can be deployed down the drillstring. The former results in a dependence on a drillship that ranges over the world's oceans to serve other high-priority, competing scientific interests, and the latter limits the sensor packages and science that may be addressed with the CORK observatory. Both of these factors restrict access to CORKed holes for other post-drilling experiments; this is an important concern, given that a significant proportion of the limited number of ODP "legacy" reentry holes are now occupied by CORKs. Finally, a clear consensus emerged during the workshop that a single seal at the seafloor is not satisfactory when the hole penetrates more than one zone of interest, as is probably to be expected in most subseafloor hydrogeological settings.

With the next possible ODP CORK deployments not likely until 2000 or later, and an increasing emphasis on observatory science in the ODP long-range plan, the winter of 1997-1998 was an appropriate time to convene a workshop to consider both the scientific and technical requirements for the next generation of ODP CORKs. With support from JOI/USSSP, about 25 scientists and engineers attended the workshop, held at the Scripps Institution of Oceanography. The workshop agenda and list of attendees are included in Appendix II . The workshop began with a review of current CORK technology and science results, moved to a discussion of desirable scientific capabilities in future CORKs, with clear consensus on two basic attributes, and began to consider some engineering approaches to a new generation of CORKs. Two months later, five of the scientists in attendance at the main workshop travelled to ODP headquarters for a one-day meeting with ODP engineers to develop some conceptual designs for the next generation of CORKs, reaching clear consensus on two approaches to be pursued in parallel. The organization of this report follows a similar sequence: We first summarize current CORK design, capabilities, and results, then summarize the scientific priorities agreed upon for the next generation of CORKs, and finally describe the two conceptual engineering solutions arrived at in the engineering followup meeting.

III. Current CORK Design Summary

As noted above, the present CORK design incorporates two primary components: the CORK body that seals the reentry hole and the data logger/sensor string package which is deployed down the drill pipe into the CORK body, where the data logger seats with the sensor string suspended in the sealed hole. Acting together, the CORK seals and cemented-in casing serve to isolate the entire open-hole section beneath casing, or the perforated section in a completely cased hole. This design has been quite successful, and the entire package can be deployed efficiently during a single pipe trip requiring 24-36 hours total (assuming a stable reentry hole). The data loggers have sufficient battery power and memory for up to 5 years of operation, and data have been downloaded by utilizing manned submersibles and remotely-operated vehicles (ROV's) to establish underwater RS-232 connections. Basic sensor strings have incorporated pressure gauges above and below the seal and 10 thermistors at customized spacings down a cable extending through the sealed hole. The design also includes valving above the seal by which the fluids in the sealed hole can be accessed for either sampling or hydrologic testing of the isolated formation. Five of the CORKs deployed to date have also included modular "Osmosamplers" attached to the sensor string, as described below. Thus, the current CORK design incorporates provision for long-term monitoring of in-situ conditions, sampling of in-situ fluids long after any drilling disturbances, and active perturbation experiments in the sealed zone.

Development of the CORK experiment has been a cooperative effort among ODP-TAMU engineers and interested scientists led by the workshop co-convenors. Development and deployment of CORKs has been financially supported by a mixture of JOIDES co-mingled funds for the reentry cone and CORK body and national ODP funds for CORK scientific packages and post-drilling data recovery efforts. Costs are about $38k for the CORK body and $50k for the sensor package, with the latter varying with length of sensor string. (Reentry cones currently cost about $80k and reentry holes generally require about 4 days of shiptime to establish, but these investments benefit coring, logging, and other experiments in addition to CORK observatories.) To date, an American-Canadian consortium supported the development and costs of data loggers and sensor strings for 12 of the 13 CORKs deployed, with support from the U.S. National Science Foundation, the Geological Survey of Canada, and JOI/USSSP; a French instrument package supported by IFREMER was deployed in the CORK in Hole 948D.

Although the present CORK design has been very successful, it imposes several limitations on the CORK sensor package and on future use of CORKed holes. The CORK body is quite massive, as it must bear any stresses imposed by the drill string at the moment of deployment into the reentry cone, and it is expected to contribute toward balancing possible effects of overpressure in the sealed hole. The present design allows for recovery and even replacement of data loggers and sensor strings utilizing assets other than the drillship, but recovery of the CORK body and/or any major servicing require the drillship. To date, sensor packages have been recovered from two CORKs with the assistance of manned submersibles, but no attempts have been made at the more difficult operation of installing a new sensor package from a platform other than the drillship. The data logger and sensor package are limited to diameters less than 3.75" because they must be deployed down the drill pipe into the CORK body. This restricts the range of sensors that could be redeployed into a CORK body, regardless of the vehicle used to remove an original sensor package.

IV. CORK Science Results to Date

A. Long-Term Hydrological Monitoring

CORKs were originally envisioned primarily for long-term in-situ monitoring of basic parameters like temperature and pressure, after recovery of the hole and surrounding formation from the disturbances induced during the drilling process. Over twenty years of DSDP/ODP experience indicates that holes penetrating into active subsurface flow systems and left open commonly become hydrologic shunts to such systems (e.g., Hyndman et al., 1976). While important hydrological information can be gleaned from logs in such open holes (e.g., Becker et al., 1983), their value as study "windows" for the natural subsurface hydrogeology is limited. Thus, the acronym for CORKs ("Circulation Obviation Retrofit Kits") reflects the necessity of sealing the reentry hole to preclude open circulation between formation and ocean bottom water (Davis et al., 1992). With a CORK installed, the long-term monitoring includes three important aspects: (1) determining in-situ formation temperatures and pressures, after recovery from the disturbance induced by drilling; (2) monitoring temperatures and pressures for indications of chronic or periodic subsurface flow and hydrologic "events"; and (3) monitoring the attenuation and phase lag of the seafloor tidal signal as registered in subsurface formations. CORK results to date generally indicate that full recovery of borehole temperatures and pressures may require many months, and only a few possible hydrologic "events" have been captured in the data. The last aspect _ subseafloor tidal response _ was not foreseen when the CORK experiment was first proposed, but has proven to be quite diagnostic of formation properties (Wang and Davis, 1996; Wang et al., 1998; Davis and Becker, 1998).

In the years since the first CORK deployments, CORK scientists have published a number of short articles summarizing these observations; several of these articles are reprinted in Appendix I. More substantive peer-reviewed articles for further reference include Davis and Becker (1994) for Middle Valley CORK results, Davis et al. (1995) for Oregon Margin results, and Becker et al. (1997) and Foucher et al. (1997) for Barbados accretionary prism results.

B. Fluid Sampling Using CORKs

As noted above, the basic CORK design incorporates a valve at the seafloor, by which fluids sealed in the hole can be accessed. Sampling these fluids for the geochemical signal of formation fluids was identified very early as an important CORK objective. The original concept for fluid sampling from the CORK involved a single teflon tubing (_" O.D.) running from deep within the sealed hole up the sensor string to the seafloor valve. This simple plumbing within the hole was envisioned to allow formation fluids to be sampled at the valve without requiring flushing the full volume of the cased section of hole. However, this was abandoned after the first three CORKs because of a number of operational difficulties, including deployment problems (particularly in unstable formations at convergent margins).

More recently, five sensor strings (in Holes 949C, 1024C, 1025C, 1026B, and 1027C) have included self-contained, modular fluid samplers driven by osmotic pumps (Shipboard Scientific Party, 1995, 1997). Each of these units provides a continuous time-series sample, and allows formation fluids to be obtained even in holes that are "under-pressured" relative to local hydrostatic conditions. However, this approach requires recovery of the entire sensor package; this has not been attempted yet, but is tentatively scheduled for all but 949C in 1999.

Thus, directly sampling formation fluids remains an incomplete CORK objective, and the few results do not dictate a particular approach in future CORKs. To fulfill this objective, future CORKs should allow for multiple approaches: tubing from formation to seafloor valves, self-contained downhole samplers, and downhole chemical electrodes within the sensor string.

A recent, related development concerns the use of CORKs to access formation fluids for microbiochemical sampling. One of the CORKs installed in 1996 on the eastern flank of the Endeavor Ridge seals a hole (1026B) that was known to be producing warm formation fluids before CORK deployment (Fisher et al., 1997). When this CORK was revisited over a year later, it was clear from the recovered data that the formation had recovered from the drilling disturbance and remained capable of producing vigorous flow of 65_C fluids. J. Cowen and H.P. Johnson had prepared a microbiological scavenging filter for this situation; it was installed on the CORK sampling valve, and the valve left open for a year of formation fluid production through the filter. At this writing, results are being analyzed, but this clearly illustrates the potential of CORKs for microbiological sampling in fluids from ocean crust and sediments.

C. In-situ Hydrologic Testing Using CORKs

The seafloor valve which allows fluid sampling also enables use of CORKs for active testing to determine average hydrologic properties of the isolated formation in the vicinity of the hole. This requires use of pumps and sensors deployed by and operated from manned or unmanned vehicles, to perform relatively standard pressure pulse or "slug" test, injection tests, or flow (production) tests; to date such hydrologic testing has been conducted only from manned submersibles. This capability has been exploited at two CORKs in accretionary settings, where the in-situ pressure and stress fields may be strongly disturbed at the time of drilling and analogous experiments performed with drillstring packers are difficult both to conduct and to interpret (Screaton et al., 1995, 1997; Fisher and Zwart, 1996; see also Fisher et al. abstract reprinted in Appendix I). It has not yet been applied at CORKs in young oceanic crust, where in situ pressures are often closer to hydrostatic and drillstring packer experiments have in most cases been successfully conducted prior to CORK installation. Where the pressure field is strongly non-hydrostatic, e.g. as may occur at subduction settings, formation properties may vary strongly with fluid pressure. However, drilling at near hydrostatic conditions releases the in situ pressure near the hole and may even result in permanent damage to the near-field formation. Utilizing CORKs for post-drilling hydrologic testing allows formation properties to be determined after pressures have recovered from the drilling disturbance. Such tests can be conducted at a greater and more controlled range of test pressures and test durations than now possible with drillstring packer, to assess formation properties beyond the damaged zone and their variation with effective stress.

Recently, CORKs have also been utilized in two locations for opportunistic hole-to-hole hydrologic tests; the data have not been interpreted yet, but the potential exists for documenting formation properties on lateral distance scales much greater, and vertical scales much finer, than investigated with conventional testing at single holes. In the Middle Valley sedimented spreading center, the 1996 refurbishment of the original pair of CORKs was conducted such that the pressure signal of operations at one CORK site was recorded in the other CORK, already refurbished 1.6 km to the north (Davis and Becker, 1998). In the Barbados accretionary prism, the CORK installed at Hole 949C in 1994 was still sealed and clearly recorded pressure signals from nearby LWD operations in 1997.

V. Visions for Future CORK Science

The heart of the main workshop was a wide-ranging discussion of scientific objectives for future CORKs, along with basic implications for the design philosophy for a future generation of CORKs. The workshop agenda included four invited presentations summarizing current CORK capabilities as described above, with a special emphasis on enhancements desirable in future CORKs. These were followed by two invited presentations on some of the engineering and operational constraints and opportunities implicit in working within an ODP borehole, either from the ODP drillship or by wireline reentry control vehicle. These last two presentations are not summarized in detail in this report, as they were intended primarily as guides for exploration of scientific capabilities for future CORKs, and a much expanded discussion of engineering approaches two months later resulted in the conceptual designs for advanced CORKs presented below.

The workshop agenda then allowed for contributed presentations on particular scientific objectives for future CORKs. Several workshop participants spoke and some contributed abstracts for this volume. Speakers included:
J. Cowen on the potential of future CORKs as sampling and/or in-situ culturing mechanisms for subsurface microbiology;
P. Fryer on long-term monitoring systems analagous to and possibly complementary to CORKs, but at a smaller scale suitable for deployment in shallower core-holes made by conventional gravity or piston corers;
R. Harris on the potential of CORKs with detailed spatial sampling of temperatures in the shallow subsurface to resolve the signal of paleoclimatic changes in bottom water temperatures; and
D. Stakes on the role of sealed, instrumented holes within seafloor observatories long envisioned at active ridge crests and nearby ridge flanks, as outlined in the Active Processes Working Group Report of the 1996 workshop, "The Ocean Lithosphere and Scientific Drilling into the 21st Century."

The floor was then opened for an unrestricted discussion of scientific objectives for future CORKs, tempered occasionally by engineering, operational, and fiscal realities. This discussion culmininated in strong consensus on the following scientific capabilities and design philosophy for future CORKs.

Vital Scientific Capabilities for Future CORKs

(A) Enhanced Range of Sensors - Fluid Chemistry, Flow, Seismicity, and Strain.

As described above, the basic array of downhole temperature and pressure sensors in the present CORK has proven very useful in long-term monitoring to determine in-situ hydrological conditions and the formation response to seafloor tides. Some future CORKs might require similar simple sensor arrays in specialized configurations, e.g., CORKs for determination of paleoclimatic conditions, which would be best sited where subseafloor hydrology is relatively inactive. But most future CORKs will retain the basic definition as a hydrologic observatory, for which there is strong interest in an enhanced range of sensors beyond basic temperature and pressure gauges.

There was particular interest at the workshop in enhancing the capability of future CORKs for continuous monitoring of fluid chemistry and seismicity. Fluid chemistry may be more sensitive to in-situ hydrologic flow than temperature, so addition of monitoring capability for even the most basic chemical properties (conductivity, pH, Eh, specific ions) would greatly enhance the value of future CORKs as hydrologic observatories. While there are open questions concerning miniaturization and long-term stability of chemical sensors, incorporating them in future CORKs would require relatively minor modifications to the present data logger and sensor string designs.

Incorporating a capability to monitor seismicity simultaneously with hydrologic indicators would also represent a major advance in CORK science. In all the seafloor hydrologic type-settings, it is generally assumed that there are intimate linkages between tectonics and fluid flow, but the nature of these linkages is virtually undocumented. This is particularly important both in young oceanic crust, to determine the relationship between extensional tectonics and high-temperature hydrothermal circulation, and at compressional subduction settings, to determine the relationship between dewatering and the earthquake cycle. Adding hydrophones or seismometers to the current sensor string design would be straightforward, but major enhancements (building on present OBS capabilities) of the current data logging systems would be required.

To address complementary hydrological and tectonic objectives, there was also interest in incorporating more complex sensors and experiments in future CORKs, including in-situ flowmeters and strainmeters. These would probably require a more extensive departure from the current CORK sensor string concept than adding fluid chemical sensors and hydrophones as discussed above. The notion presented for an in-situ flowmeter involved a thermal source surrounded by a three-dimensional array of temperature sensors, some or all of which might be incorporated in or deployed against perforated casing at the borehole wall. Incorporating strainmeters could involve specialized instrumented casing or cementing a package in place within the open or cased hole.

(B) Enhanced Fluid Sampling and In-situ Microbiological Capabilities

As described above, the potential of CORKs for sampling in-situ fluids for geochemical and microbiological studies is great, but has barely been realized. Nevertheless, it was suggested at the main workshop that a network of redesigned CORKs could form the heart of a global program of mapping fluid fluxes in various seafloor environments _ and at the same time make a major contribution toward a global assessment of the significance of the deep, hot biosphere in ocean crust and sediments. Achieving these goals will require that future CORKs be as simple and flexible in design as possible. They should also allow parallel approaches to fluid sampling from a given interval, including: (1) self-contained samplers and in-situ filtering or culturing devices, analagous in installation and recovery requirements to the osmosamplers deployed on the sensor strings of some CORKs to date, and (2) multiple tubings of appropriate sizes running from the isolated zone to the appropriate manifolds accessible on the seafloor. The latter could include small-diameter teflon tubing (as presently utilized within the self-contained osmosamplers) running from formation to a seafloor manifold, there to be connected to an osmosampling system that is easily recoverable and replaceable without disturbing the CORK itself. It could also include separate larger-diameter tubing for larger-volume sampling, as required for microbiological studies and analyses of chemical species and isotopes for which updated osmosamplers will not provide sufficient fluids.

(C) Enhanced Formation Testing Capability

As described above and in the workshop abstract contributed below by E. Screaton and A. Fisher, the development of second-generation CORKs will provide the opportunity to significantly improve subseafloor hydrologic testing at accretionary margins and other geological environments. With the current CORK design, such testing is limited to a single downhole interval, accessed in accretionary settings through perforated/screened casing. Three key recommendations were made for enhanced formation testing capabilities in future CORKs, as follows. First, future CORKs should utilize downhole seals, allowing flexible isolation of particular zones of interest, rather than broad screened zones. Second, downhole flowmeters (as described above) could provide direct measurement of fluid migration rates. Third and most important, selected future CORK observatory sites should include more than one CORKed hole, allowing hole-to-hole hydrologic testing. Progressing from single-borehole tests to long-term formation tests utilizing source and observation boreholes will provide higher quality permeability estimates, will allow estimation of storage properties, and will provide valuable information on formation heterogeneity and anisotropy, all at a scale much more like that of natural circulation than achievable in single-well testing.

Design Philosophy for Future CORKs

Two Key Common Scientific Requirements for Future CORKs

As the discussion of disciplinary requirements for future CORKs proceeded, it became increasingly evident that they intersect in two common design features essential to achieving a significant enhancement of scientific capabilities in future CORKs: the need to isolate multiple zones in a single hole and the need to provide flexible access to the isolated zones. These two key features are developed further in the next section, in the context of generic future CORKs for two major hydrological type-settings, but some general comments are appropriate here.

A capability to separately isolate multiple zones would make future CORKs much more suitable for studying natural subseafloor hydrologic systems with heterogeneous permeability structures. Our understanding of subseafloor hydrology has advanced beyond a level at which assumptions of uniform, average permeability structures will yield major new insights. Borehole observations and remote sensing clearly indicate that heterogeneous permeability structures exist in virtually all subseafloor hydrologic type-settings; significant advances in our models of hydrology in such settings will require in-situ observations of properties and processes within each relevant zone, at appropriate lateral scales where possible.

Flexibility of access to these zones includes two particularly significant aspects. Most important, future CORKs should be designed to allow flexibility of servicing and installation of instrument packages, reconfiguration of experiments, and in some some cases complete deployment of the CORK itself, using assets other than the drillship (such as submersibles, ROV's, and wireline control vehicles) as much as possible. Second, as noted above, future CORKs should incorporate a capability for emplacement of a variety of sensors and fluid sampling devices within each zone. Downhole instrumentation for future CORKs may range from simple sensor strings for basic objectives (e.g., as described in the abstract contributed below by R. Harris) to more complex assemblies addressing the full range of objectives described above.

Other Important Factors

Several other general considerations are also important in the basic design of future CORKs. First, future CORKs should be designed to minimize possible conflicts among the many disciplinary objectives described above _ and this, along with operational and fiscal constraints, argues for a simple basic design that can be customized to best address specific CORK objectives appropriate for particular sites. Second, it should be emphasized that the mix of CORK disciplinary objectives will indeed differ from site to site. Carefully defining the objectives will require that all future CORK observatories are well integrated with programs of pre- and post-drilling site surveys, drilling, and post-drilling servicing _ much as all 13 CORKs deployed to date have been sited in hydrologically well characterized areas. While most CORK efforts in the future will be focused on specific hydrologic experiments (as they have in the past), it will also be important to consider CORK objectives during the planning of holes drilled for other purposes, e.g., paleoclimatology (see Harris abstract, Appendix I). This will provide the opportunity for CORK installations to provide thermal and hydrologic characterization in a wide range of ocean basin settings. It was also recognized that some ODP CORK sites would be appropriate for installation of complementary instrumentation on the seafloor and/or in small holes drilled or cored from platforms other than the ODP drillship (see Fryer abstract, Appendix I). Finally, not only are hardware and operational factors implicit in the design requirements for future drillship-deployed CORKs, but also serious consideration needs to be given to hole completion issues. The last includes a number of inter-related matters important to the success of future CORKs, such as minimizing formation damage, ensuring cement integrity, and methods for isolating multiple sampling intervals.

VI. Scientific Objectives for Generic Future CORKs

Following the general discussion of visions for future CORK science, objectives were considered in the specific context of lithologic "type" sections where future installations are most likely to be completed. For the sake of simplicity, these were reduced to two genre, one representative of continental margins and the other of the igneous oceanic crust (Figure 3). The first case treats an accretionary prism, although objectives for monitoring at a rifted or transform margin can be considered using this generic figure. Similarly, the second can be applied to various specific settings including mid-ocean ridges, ridge flanks, and old ocean basins. It should be noted that a feature common to both generic sections is the presence of a low-permeability hydrologic barrier through which a sealed section of casing can pass or in which a packer can be set, above any hydrologically active parts of the formation that are accessed with the CORK. In this way, the instrumented hole emulates well the nature of the formation and allows observations to be correctly representative of in-situ conditions once the perturbations associated with drilling have dissipated.

One conclusion reached immediately upon considering hydrologic objectives in context of the sections likely to be encountered is that discussed above: that it would be highly desirable to isolate multiple intervals in any given hole for monitoring, fluid sampling, and active experiments. As discussed above, current CORK technology provides only a single seal and allows only the average conditions (e.g., fluid pressure, fluid composition) to be determined for the entire interval of the hole that is open below casing or perforated and screened within the cased section. Clearly, holes could be used much more efficiently if there were a capability to access a number of levels in the sections penetrated. The number, spacing, and total depth (i.e., maximum temperature) of intervals that can be isolated will be limited by engineering constraints, and certainly more than one site will be required for many experiments. For these reasons, the examples shown in Figure 3 are at the same time composite and incomplete.

Another conclusion drawn was that it would be highly desirable to have the capability to carry out a number of monitoring experiments simultaneously in a given hole, some independent and others highly interrelated. In fact it may be possible that at some sites, all of the disciplinary objectives outlined in the previous section could be met in addition to the more "traditional" hydrologic ones. The potential for mutual benefit is obvious; for example, with holes instrumented with pressure gauges, fluid samplers, hydrophones, and a seismometer, questions about the linkages between seismic ground motion, pore pressure, and transient fluid expulsion could be addressed. Similarly, microbiological studies would clearly benefit from being conducted in a situation that is hydrologically and geochemically well characterized.

With these capabilities incorporated into advanced CORKs, it will be possible to investigate a number of questions that currently cannot be addressed. A few examples are imbedded in the generic sections shown in Figure 3 and are developed further below.

Continental Margins

In continental margin settings, occurrences of gas hydrates in the upper few hundred meters of sediments are common, particularly in accretionary prisms, and they are important for a number of reasons. Although no technology is available to recover them, hydrates are believed to represent a potentially large energy resource. Their formation and decomposition may contribute significantly to the global carbon budget and to the global greenhouse gas reservoir. Accumulation of free gas beneath hydrate layers can lead to a reduction of strength of the sediment matrix and the development of slope instability. Unfortunately, the mode of hydrate formation and the quantitative distribution of gas hydrates and gas in marine sediments are poorly constrained. Detailed monitoring observations and active experiments through a zone of accumulation of hydrate and gas can address these questions well. It will be possible to determine the temperature at the hydrate/gas phase boundary with great precision. Mechanical and hydrologic properties of the hydrate-bearing sediment matrix above and the gas-bearing interstitial fluid below the phase boundary can be determined from the response to tidal loading and seismic ground motion as a function of distance away from the boundary. Vertical pressure gradients coupled with determinations of permeability can provide constraints on the rate of fluid flow that may be responsible for gas and gas hydrate accumulation. And controlled heating experiments can provide constraints on the thermodynamics of hydrate dissociation and formation.

Another common and important process that can be studied at continental margins is faulting. Of particular interest are interplate subduction-zone thrust faults where the world's largest and most damaging earthquakes occur. Fault mechanics ranging from low (e.g., creep) to rapid (seismogenic rupture) rates are believed to be highly dependent on fluid pressure conditions; in turn, the generation of fluid pressures and the expulsion of fluids from accretionary prisms along faults and through permeable sediment may be influenced strongly by fault slip and ground acceleration. Pore-pressure conditions have been for the most part inferred from seismic observations. In two holes in the Barbados accretionary prism pressures have been observed directly with CORK and packer techniques, and high pressures have been confirmed. Little is known, however, about the details of the fluid pressure regime in the vicinity of the fault zone or elsewhere in the accretionary prism or underthrust section. Seismic monitoring, coupled with hydrologic monitoring spanning a range of depths across a subduction thrust interface, can provide a means of examining the spatial and temporal variability of tectonically generated pressure, of the transient response to external forcing at seismic, oceanographic, tidal, and barotropic frequencies (i.e., from periods of seconds to weeks), and of mechanical and hydrologic properties.

The same array of downhole access points that allow monitoring of pressure in the vicinity of a thrust fault will also allow spatial and temporal variations in fluid composition to be studied. Fluids expelled along faults from subducted or accreted sediments transport chemical constituents, both within the sediment section thereby assisting in sediment diagenesis and hydrocarbon concentration, and to the seafloor supplying nutrients to chemosynthetic animal communities. The composition of fluids can reveal the temperature, and therefore the depth of the source and scale of transport of the fluid. Contrasts in composition can constrain the degree to which fluids are "compartmentalized". Time-series records of fluid composition, coupled with coincident seismic and hydrologic monitoring, can help define the routes and rates of episodic fluid transport, and the ways in which tectonic and hydrologic processes are interrelated.

Definition of the hydrologic architecture of accretionary prisms will not be complete without determining the role of oceanic basement in the subducting plate. The extrusive part of young upper igneous crust is known to be highly permeable, and hence could serve as a "leaky aquifer" to drain the accretionary prism at its base, or to transmit water from great depth. Its potential role as a drain could strongly effect the mechanical behavior of the prism, possibly even controlling the position of the decollement.

The specific sequence of packers and monitoring/sampling intervals shown in Figure 3a is highly schematic, but serves to illustrate how all of these various parts of an accretionary prism might be instrumented. Short intervals are shown bracketing a thrust fault within the accretionary prism as well as a primary detachment fault, to monitor activity in the parts of the system that are probably hydrologically most active. Multiple short intervals above and below a hydrate/gas phase boundary and the primary detachment boundary allow hydro-mechanical properties and vertical pore pressure gradients to be determined. Broader intervals within the prism, the underthrust sediments, and igneous basement allow definition of the overall thermal, fluid pressure, and compositional regimes. And hole pairs or multiple holes will allow lateral gradients and transient events to be characterized.

Oceanic crust

Problems to be studied in the oceanic crust with advanced CORKs also will focus on fluids and fluid flow, in this case driven primarily by thermal buoyancy. Like accretionary prisms, the hydrologic structure of the oceanic crust appears to be highly compartmentalized, with permeability varying by many orders of magnitude through a typical section. Sediments form a low permeability cap over the very highly permeable, unconsolidated extrusive rocks of the uppermost igneous basement. Below that, intrinsic permeability decreases with depth, although faults may create zones of high fluid transmissivity, allowing fluids to access levels deep in the crust. In this context, multi-level CORK monitoring is again ideal for understanding the forces that drive flow, the detailed permeability structure, the routes and rates of flow, and the fluid compositional regime. Again, coupled experiments will be important. Multi-disciplinary observations will allow the sub-seafloor biosphere to be studied in context of the hydrologic, chemical, and thermal regime, and hydrologic responses to seismic ground motion, tides, and barometric loading to be understood.

A simple example of a single instrumented hole that addresses several questions about the hydrogeology of the oceanic basement is shown in Figure 3b . The degree of heterogeneity in parameters such as permeability and elastic bulk modulus characteristic of the igneous oceanic crust can be examined with multiple levels of observation, as can local pressure gradients that drive flow. Fully isolating deeper levels where permeability and porosity are low is the only means by which pristine formation fluids can be sampled and observations of temperature and pressure can be made that are unperturbed by the effects of conditions in the highly permeable, hydrologically active part of the crust lying above. As is the case discussed above with observatories in continental margin settings, pairs of holes or hole arrays would be necessary to determine lateral gradients and variability in properties. Isolating multiple vertical intervals in paired CORKs will be particularly valuable for determining the permeability distribution within basement.

Limits to what can be accomplished will be severe at sedimented ridge crest environments because of high temperatures, but much can be done in ridge flank and old ocean basin environments where conditions are much cooler.

VII. Design Recommendations for Future CORKs - Results of Engineering Meeting

Discussions at the Advanced CORK engineering meeting held at the Ocean Drilling Program on February 19, 1998 (see Appendix II for agenda and list of attendees) began with reviews of the science objectives and requirements that were established at the Advanced CORK science workshop two months earlier and the generic lithologies presented in the preceeding section. To allow engineering discussions to proceed efficiently, specific examples in each category were considered so that constraints could be placed "on the table" in the way of total penetration depths, number of isolated intervals, temperatures, and formational stability.

Typical Site Requirements

Barbados, Cascadia, and Nankai subduction zones provide good examples of accretionary prisms where much is already know about formational conditions, and where it is likely that advanced CORK experiments will be pursued. In some cases such as Nankai Site 808, Barbados Sites 948 and 949 (penetrating primary detachment fault boundaries), and Cascadia Site 889 (penetrating a hydrate/gas phase boundary), it may be possible to use existing cased reentry holes. In other cases, new holes are required. In cases of monitoring experiments at the level of thrust boundaries, hole pairs or multiple holes will be highly desirable. Six to eight packer elements isolating intervals as short as 20 m would be required in each hole. Penetration depths range to over 1 km, and maximum temperatures at the top of igneous basement range up to about 80_C at Barbados and 110_C at Nankai. Formation stability ranges from marginal (e.g., Nankai) to poor (e.g., Barbados); this is primarily a consequence of high fluid pressures and unstable lithologies.

Flanks of the Costa Rica Rift and the Juan de Fuca Ridge are likely sites for installations in ocean crustal settings. Again, excellent targets for monitoring are available in existing holes, such as at Sites 504 and 896 on the Costa Rica Rift flank, and proposals for new and for deepened existing holes on the Juan de Fuca flank are in preparation. Although Hole 504B reaches a total hole depth of 2 km, primary hydrologic targets there and at other locations lie in the upper 500 m or so of the igneous crust; temperatures at these levels should not exceed 100_C. If problems with formation instability (common in unconsolidated extrusive rocks in the uppermost igneous crust) are avoided during drilling, hole conditions will probably remain stable, although dimensional quality may be variable. High-quality logging data must be available for determining packer seating positions.

Conceptual Advanced CORK Configurations

With these formational constraints in mind, the group then moved to the practical objective of the workshop: outlining the means by which the primary scientific objectives could be met. No attempt is made to report the details of the discussion; instead, we simply summarize the results, which were felt to be realistic in light of the objectives, the formational constraints, and the desire to "service" (including retrieval and redeployment of instrument packages) any system by wireline control vehicle, ROV, or manned submersible to the greatest extent possible. Separate attention was given to systems deployable by wireline and by the drillship.

Wireline deployment

The capability to deploy a variety of instruments using wireline reentry has been recognized as an important priority since a 1987 workshop also sponsored by JOI/USSSP (Langseth and Spiess, 1987). The ability to deploy instrument strings and a borehole packer by wireline has been proven in operations during 1989 in 5 km of water at Hole 543A in the Atlantic Ocean (Stephen et al., 1989; Spiess et al., 1992) and during 1998 in 4.4 km of water at the Ocean Seismic Network Hole 843B (http://msg.whoi.edu/osn/OSNPE_intro.html), with a total of 4 hole reentries plus recovery of downhole equipment in both instances. This opens the door to a mode of multi-level CORK installation in existing reentry holes that would not require the drillship (Figure 4). All that would be required is a reentry cone, and either a cased hole with screened or perforated intervals, or a stable open hole below casing. Positions of packers would be determined on the basis of hydrologic objectives and, in the case of open holes, by where there were clean-caliper sections where good seals could be made. In the case of packers seated in casing, special efforts would have to me made to ensure proper isolation of the multiple zones, by means of squeezing cement at multiple levels through perforations, and via cement bond logs. Considerable reservations were expressed about the potential difficulties, costs, and risks associated with cementing integrity, however. Situations most ideally suited to wireline deployment are those where there are targets in stable open holes, such as in the oceanic crustal sections discussed in the previous section. In cases like these there are clear advantages to wireline deployment in terms of schedule flexibility and cost, particularly in the case of holes that already exist.

An instrument string deployed by wireline (Figure 4) would be different from one deployed by drillship only in detail. Multiple packers would be set (and later deflated) with a submersible pump. Hydraulic access for pressure monitoring, fluid sampling, and formation testing would be provided by multiple hydraulic lines with packer pass-throughs. Sensors at depth would be serviced by electrical wires also passing through packers; these could include seismometers, strain gauges, thermistors, flow meters, and chemical sensors. Installation would be guided with a camera included as part of the weight at the lower end of the tool string. Logging would be accomplished at the seafloor in a unit that could be serviced by wireline, ROV, or submersible.

A disadvantage of the wireline system is the small number of isolated intervals that can be established. This is due primarily to the limited payload of standard oceanographic cables; the maximum number is probably three. At sites where this number is sufficient and the hole quality criterion is met, however, wireline deployment should provide an excellent means of advanced CORK installation. And at any site, the flexibility afforded by a wireline system would allow periodic reconfiguration of the packer/sensor string, such that, after a reasonable time series is obtained with one configuration, the packer/sensor geometry could be changed to isolate and study different zones of the formation.

Drillship deployment

One of the greatest advantages of using the drillship for the deployment of an advanced CORK system is the capability to complete installations in relatively unstable formations. In holes already established for coring or logging operations (e.g., an advanced CORK system could conceivably make use of an LWD hole), an instrument/multi-packer string can be helped in by circulation. In fact, a string could be drilled in directly, much like a logging-while-drilling tool, with the use of an under-reamer and mud-motor. In this way, much of the expense of and time required for establishing a reentry cone and a cased, cemented, and perforated hole could be eliminated, and the risks associated with cementing the full length of casing in weak material (unconsolidated in the upper few hundred meters below seafloor, and in many instances overpressured at depth) could be avoided.

Conceptual sketches of drillship-deployed multi-level CORKs are shown in Figures 5-7. Figure 5 shows a system drilled directly into the ground with a removable under-reamer; Figures 6and 7show systems installed in cased holes that may be either pre-existing or new. While details like diameters of components may differ, in principle the systems are the same. The entire string, including the mud-motor and under-reamer where one is to be used, is made up at the rig floor as part of the bottom-hole assembly. As many screened intervals as required (a small number is shown for simplicity) can be made up at intervals determined from logging or coring. These are connected to the seafloor via rigid tubing or low-compliance reinforced hose passing through feeds through each of the packers and screens situated above. Once the system is in place, packer elements are inflated via a single hydraulic line or through the internal bore of the liner system, but possibly at pressures that can be regulated locally. Up to this point, the system is conceptually similar to that described above for wireline deployment, although there are effectively no limits imposed on the weight of packer elements and screens.

The major departure in design lies with the use of a continuous liner as a strength member and central core of the multi-packer/screen string. This serves multiple purposes: (1) It permits circulation or use of a mud-motor for washing or drilling in the system as mentioned above. (2) It provides a large-diameter (tentatively 6-7/8" i.d.) hole inside the packer/screen string for deployment of sensors or logging tools that do not require hydrologic connection to the formation (e.g., seismometers, thermistors), either at the time the packer/screen/liner is installed, or any time later by wireline. (3) If a permeable bridge plug is used at the bottom of the liner, a hydrologic connection is gained to the formation at the level below the lowermost packer. A seal within the liner at the seafloor would serve to make this part of the advanced CORK string essentially just like current CORKs. (4) As an option to fluid sampling via tubing external to the liner, sliding sleeves could be used for sampling or testing through the inner bore using a tool deployed by wireline.

Clearly, it would be possible to deploy a multi-packer/screen with a liner inside a fully cased hole, although no examples of a situation where this might be justified were conceived during discussions at the engineering meeting. A high-quality, continuous cement bond between casing and formation is difficult and costly to achieve and assess, as is the subsequent task of perforation to regain hydraulic access to the formation at selected locations. A washed- or drilled-in multi-packer/screen system eliminates the need for cemented casing as well as all of the associated risks.

One difference between the drilled-in and inserted systems arises from the constraints imposed by the internal diameter of the casing through which the system must pass. In the case of a drilled-in system or a new hole cased and drilled with an advanced CORK installation in mind, this constraint is roughly 12-1/4"; in cases where existing holes are to be instrumented it is typically 10-3/4" (i.e., the dimension of the casing) or less (the dimension of the drilled hole). Reduction in size of the multi-packer/screen string can be achieved, but at the expense of the final internal diameter of the liner. This will limit the maximum outside diameter of sensor packages as well as the size of any mud-motor that can be used for drilling if this is required. These trade-offs must be evaluated on a case-by-case basis. In some instances, the advantages of using a pre-existing hole will be greater than the disadvantages or risks associated with using a smaller, lower torque mud-motor and the disadvantages of having a smaller bore for post-emplacement sensors; in others, the opposite will be the case, and it will be preferable to start from scratch with the optimum-size hole.

At the seafloor, a landing module would serve a number of functions. It would be fitted with either a mud-skirt in cases where no casing or reentry cone were used, or a skirt compatible with whatever reentry cone might be present (e.g., a standard cone, or cone attached to a length of drill-in casing). A secondary funnel on the landing module would provide a guide for service operations and liner reentry by wireline, and a landing collar would accept a removable seal in which the data logger for sensors within the liner would be seated. The module would also house the termination of hydraulic lines accessing the screened ports. These would be fed to a pressure sensor/recording package as well as to valved ports for fluid chemical and biological sampling.

Summary

Many of the advantages of the wireline- and drillship-deployed advanced CORK conceptual designs are non-overlapping, and as a result, there was a clear consensus that efforts should be made to develop both capabilities. The flexibility and relatively low cost of wireline deployment is very attractive for those situations where there are existing holes or are to be holes drilled for other purposes, where the holes are stable, and where a small number of isolated zones is sufficient. In unstable formations there is no choice but to take advantage of the robustness and capabilities offered by deployment with the drillship. In addition, the liner configuration establishes a multi-disciplinary hydrologic monitoring experiment and at the same time creates a sealed legacy hole that can be used for any number of future experiments.

VIII. Conclusions and Summary Recommendations

The initial version of CORK, 13 of which were deployed by ODP in 1991-1997, has proven to be quite successful in fulfilling its promise as a basic in-situ hydrological monitoring, sampling, and testing observatory in a variety of subseafloor type-settings. But this very success has revealed shortcomings in the initial, massive, single-seal design, and at the same time spawned considerable community interest in enhanced capabilities for future CORKs. The purpose of the main workshop was to enumerate and prioritize the scientific capabilities deemed essential for future CORKs, and the followup engineering meeting focussed on the most feasible technical approaches to achieving these objectives.

Priorities for Scientific Capabilities for Future CORKs

There was considerable interest expressed at the main workshop in enhancing the disciplinary capabilities of future CORKs in three senses:
(1) expanded range of measurements related to subseafloor hydrologic monitoring, particularly for seismicity, fluid chemistry, fluid flow, and borehole strain;
(2) increased capabilities for fluid sampling, for both geochemical and microbiological studies, with in-situ samplers or culturing devices and with tubing(s) of appropriate size(s) running from isolated formation to a manifold accessible at the seafloor
(3) improved completions for active hydrologic testing, most important, provision for hole-to-hole hydrologic testing at scales similar to those of natural fluid flow.

Looking beyond these relatively straightforward enhancements of the basic CORK concept, the workshop came to strong consensus that major scientific advances with future CORKs requires that they share two essential design attributes:

(1) the ability to separately isolate multiple formation zones in a single hole; and
(2) maximizing the opportunities for servicing, instrument replacement, and even initial CORK deployment by wireline control vehicles, ROVs, and manned submersibles, and reducing dependency on the ODP drillship for installation and major servicing.

These two primary recommendations are highly consistent with those made a few months earlier at the CONCORD meeting for borehole observatories that might be installed with a riser drilling system. Fulfilling this vision will indeed involve major rethinking of the current CORK concept. There was strong consensus that any redesigned advanced CORK should also be as simple and flexible as possible, so each CORK can be configured uniquely to suit its specific hydrological setting or ancillary purpose in special cases like paleoclimatic monitoring. And finally, like CORKs to-date, future advanced CORKs must be deployed only in the context of the complete suite of pre-drilling site characterization, drilling, and post-drilling activities possibly including related seafloor and shallow subsurface monitoring stations.

Engineering Design Recommendations

This statement of scientific priorities for future advanced CORKs presents a broad and ambitious engineering challenge. Nevetheless, the engineering subgroup that met two months later quickly recognized that there are two viable, cost-effective basic design approaches that can fulfill this vision, and in fact should be pursued as parallel development efforts because they will be suitable in different settings of great scientific interest. These two complementary approaches are:

(1) A wireline multi-packer instrumented system that would rely on a wireline control vehicle for deployment and recovery and should be pursued as a third-party development. This system will be suitable for use in cased holes that have been perforated for hydrologic access through casing and cement, and in open holes extending below casing that are stable and have clean intervals where inflatable packers can be set.
(2) A drillship-deployed instrumented casing system that could also be used in stable or cased holes, but is intended primarily for unstable formations such as those common in accretionary prisms. This system would comprise a multi-packer liner string that would be assembled at the rig floor. This could either be inserted into a previously drilled, cased, cemented, and perforated hole, or drilled into the formation without rotation with a mud-motor and under-reamer.

The final and perhaps most important workshop recommendation is that these two development efforts should be pursued in parallel and as expeditiously as possible. The likely hiatus in ODP CORK deployments until 2000-2001 represents an extraordinary opportunity to design advanced CORKs for the 21st century. The CORK design advances enumerated in the main workshop and engineering meeting are required to meet future scientific challenges in subseafloor hydrogeology, and particularly to fulfill the promise of scientific ocean drilling for long-term in-situ monitoring of the fluid flow processes that are so ubiqitous and important in the ocean crust and sediments.
□

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X. Appendix I _ Selected CORK Reprints and Contributed Abstracts

Sorry, at present these are not available in this web version, but are printed in copies of workshop reports available from JOI.

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*Davis, E. and Becker, K., 1993, Studying crustal fluid flow with ODP borehole observatories, Oceanus , 36(4), 82-86.
#Becker, K., Foucher, J., and the ODPNaut scientific party, 1996, CORK string registers fluid overpressure, JOI/USSAC Newsletter , 9(1), 12-15.
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Screaton, E.J. and Fisher, A.T., Active hydrogeologic tests at sealed boreholes: Results from previous investigations in accretionary complexes and directions for the future.
Fryer, P., Ancillary studies at CORKed drill holes in ODP sites.
Harris, R., Documenting temperature variations in oceanic bottom water with CORKs.

XI. Appendix II - Workshop Agendas and Attendees

Main Workshop, Monday, December 15
8:15 Introductions, review of agenda
8:30-11:30 20 minute presentations, 10 minute discussions:
Becker CORK design overview
Davis CORK science overview

Kastner and Wheat Fluid sampling using CORKs
Screaton and Fisher Formation testing using CORKs
Pettigrew CORK engineering considerations
Spiess "Intervention" using ROV's
11:30 Discussion
12:00 Lunch
1:00 Contributions, discussion of science objectives for future CORKs
Examples of possible contributions/subjects:
Harris paleoceanographic applications
Cowen/Johnson subsurface biosphere
Fryer instrumenting gravity and piston core holes
Define and prioritize science objectives by close of day
6:00 Adjourn

Main Workshop, Tuesday, December 16
8:15 Discussion of engineering options to meet science objectives
Prioritize engineering approaches
12:00 Lunch
1:00 Wrap-up discussions: consensus on science objectives and engineering approach
3:30 Close for late afternoon/evening departures

Engineering Meeting, February 19
1. Review of recommendations from main workshop
2. Specific CORK experiments: objectives, old holes, new holes, number of holes, lithologic considerations, sensor/sampler/packer array configurations
3. Define "Advanced CORK" in these terms. Is it singular or plural, given the possibly wide variety of constraints imposed by item 2?
4. Servicing considerations, given CORK experiences to date, and secondary reentry considerations (nested experiments)
5. Approach to engineering solution(s), with parallel consideration of:
A. Wireline deployment/servicing capabilities
B. Drillstring deployment of all or part of system
6. Means of coordination of multiple design and development efforts
7. Distribution of tasks (ODP and third parties, in-house vs contract)
8. Cost estimates
9. Sources of funding for various components
10. Response to and coordination with JAMSTEC proposal for OD21 long-term monitoring system for legacy holes?

List of Attendees, Advanced CORKs Science Workshop, December 15-16, 1997

Keir Becker, RSMAS, University of Miami, co-convenor
Earl E. Davis, PGC, Geological Survey of Canada, co-convenor
Charles ("Buddy") Bollfrass, Ocean Drilling Program
Kevin Brown, Scripps Institution of Oceanography
James Cowen, SOEST, University of Hawaii
J. Paul Dauphin, National Science Foundation
Andrew T. Fisher, University of California at Santa Cruz
Patricia Fryer, SOEST, University of Hawaii
Joris M. Gieskes, Scripps Institution of Oceanography
Charles Golden, Scripps Institution of Oceanography
Robert N. Harris, RSMAS, University of Miami
Pierre Henry, Ecole Normale Supérieure
John Hildebrand, Scripps Institution of Oceanography

Miriam Kastner, Scripps Institution of Oceanography
H. Paul Johnson, University of Washington
Takeshi Matsumoto, JAMSTEC
Michael J. Mottl, SOEST, University of Hawaii
Tom Pettigrew, Ocean Drilling Program
Derryl Schroeder, Ocean Drilling Program
John G. Sclater, Scripps Institution of Oceanography
Elizabeth Screaton, University of Colorado (now at University of Florida)
Fred N. Spiess, Scripps Institution of Oceanography
Debra Stakes, MBARI
Hidekazu Tokuyama, Ocean Research Institute, University of Tokyo
Spahr C. Webb, Scripps Institution of Oceanography
Geoff Wheat, University of Alaska

List of Attendees, Advanced CORKs Engineering Meeting, February 19, 1998

Keir Becker, RSMAS, University of Miami
Charles "Buddy" Bollfrass, Ocean Drilling Program
Earl E. Davis, PGC, Geological Survey of Canada
Tim Francis, Texas A & M University
Mike Friedrichs, Ocean Drilling Program
John Hildebrand, Scripps Institution of Oceanography
Leon Holloway, Ocean Drilling Program
Brian Jonasson, Ocean Drilling Program
Derryl Schroeder, Ocean Drilling Program
Elizabeth Screaton, University of Florida
Fred N. Spiess, Scripps Institution of Oceanography
Mike Storms, Ocean Drilling Program

Table 1. Present status of the 13 CORKs deployed to date at 11 sites with JOIDES, NSF, GSC and IFREMER support. Data recovery vehicles: A=ALVIN, R=ROPOS, N=NAUTILE

<u>CORK, Location</u>
Deployment
Status and Comments

<u>858G, Middle Valley</u>
9/3/91, Leg 139
Data retrieved 9/91A, 9/92R, 9/93A;
Pressures indicated seal breached after 500 days

9/5/96, Leg 169
ReCORKed; data recovered 10/97A, scheduled 6/98A
Pressures indicated seal breached after 300 days

<u>857D, Middle Valley</u>
9/9/91, Leg 139
Data retrieved 9/91A
Logger damaged during Leg 146 cable replacement attempt

9/11/96, Leg 169

ReCORKed Leg 169; original logger yielded 1991-1992 data
Data recovered 10/97A, scheduled 6/98A

<u>889C, Vancouver Margin</u>
10/22/92, Leg 146
Damaged on deployment due to bad hole conditions and weather
Data retrieved 9/93A indicate severe sensor damage

<u>892B, Oregon Margin</u>
11/15/92, Leg 146
Data retrieved 9/93A, 9/94A, 10/95A
Temperatures indicated cable problem at 15 months
Acoustic modem tests, 1993, 1994
Logger recovered 1995 for inspection
Carson/Kastner geochemical expt. scheduled 6/98A

<u>948D, Barbados Prism</u>
6/29/94, Leg 156
Data recovered 12/95N; CORK body never sealed;
French instrument package recovered with flotation

<u>949C, Barbados Prism</u>
7/23/94, Leg 156
Data recovered 12/95N and 1/98N;
Seal and pressure xducer damaged in 1998 pump tests

<u>1024C, Endeavor Flank</u>
8/2/96, Leg 168
Good data recovered and acoustic modem installed 10/97A
Successful acoustic data download 6/98

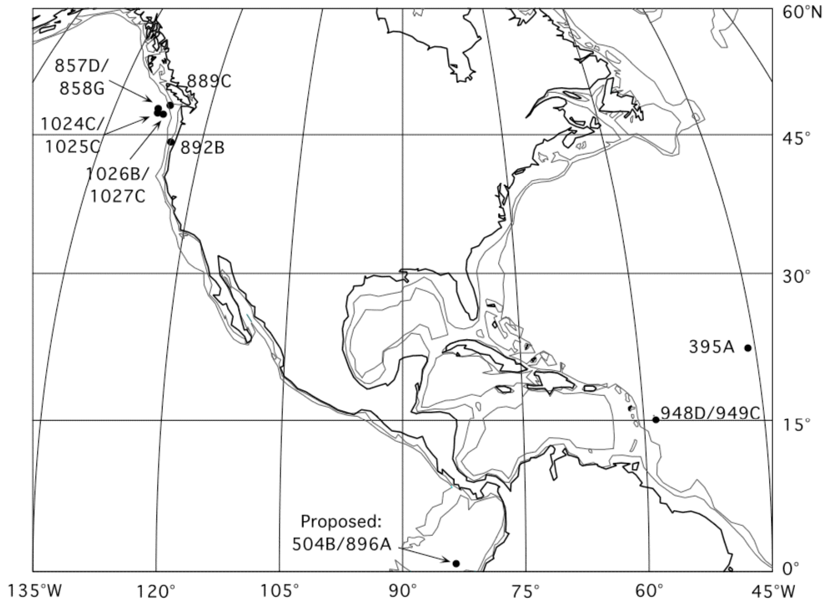
<u>1025C, Endeavor Flank</u>
7/30/96, Leg 168
Good data recovered and acoustic modem installed 10/97A
Successful acoustic data download 6/98

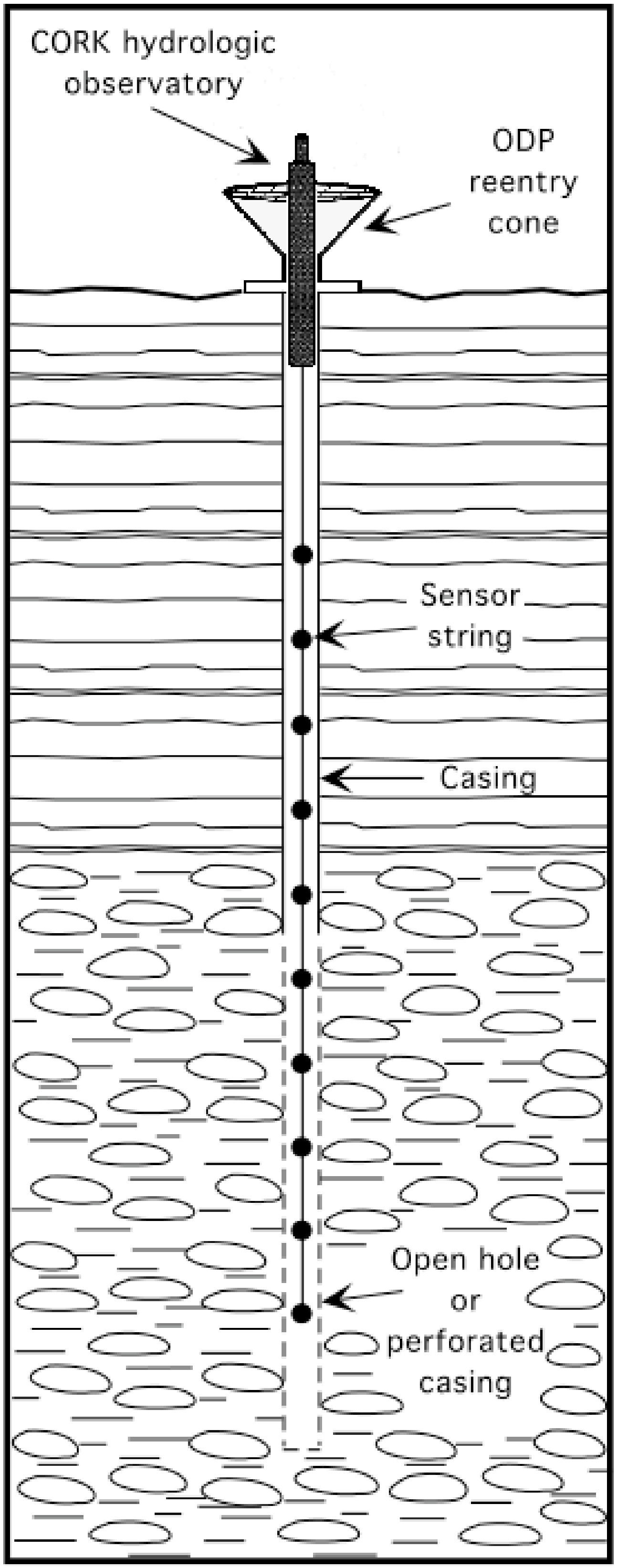
<u>1026B, Endeavor Flank</u>
8/7/96, Leg 168
Good data recovered 10/97A, scheduled 6/98A
Cowen/Johnson microbiological sampling experiment installed 10/97

<u>1027C, Endeavor Flank</u>
7/21/96, Leg 168
Good data recovered 10/97A
Data recovery scheduled 6/98A

<u>395A, MAR Flank</u>
7/31/97, Leg 174B
Good data recovered 1/98N

ODP CORK SITES, 1991-1997





CORK hydrologic
observatory
ODP
reentry
cone
Sensor
string
Casing
Open hole
or
perforated
casing

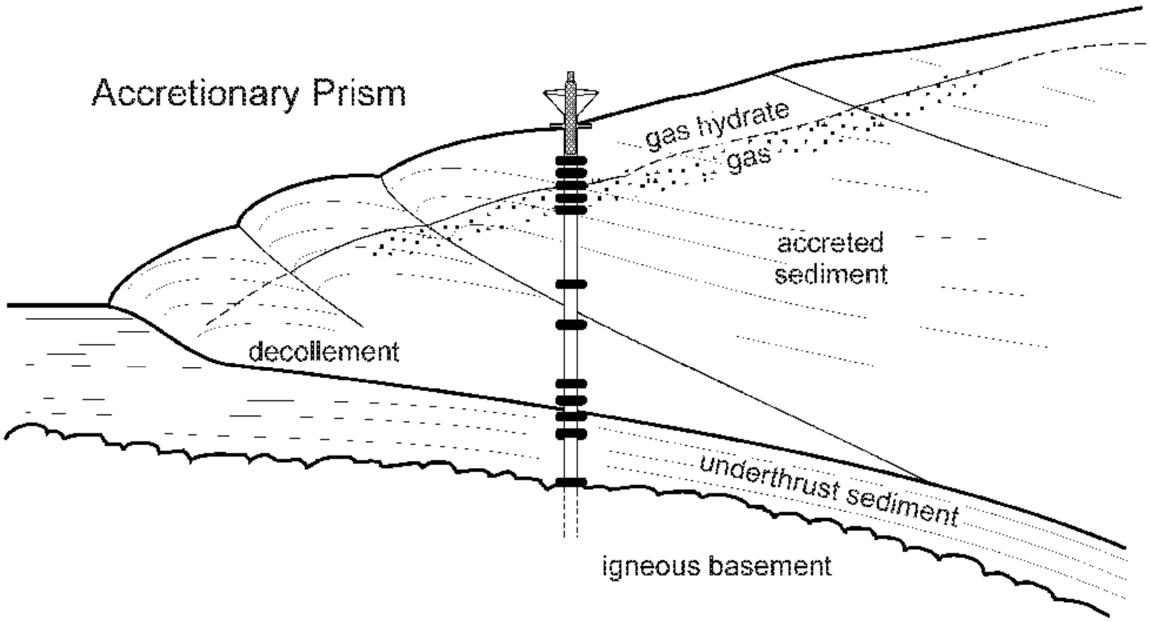
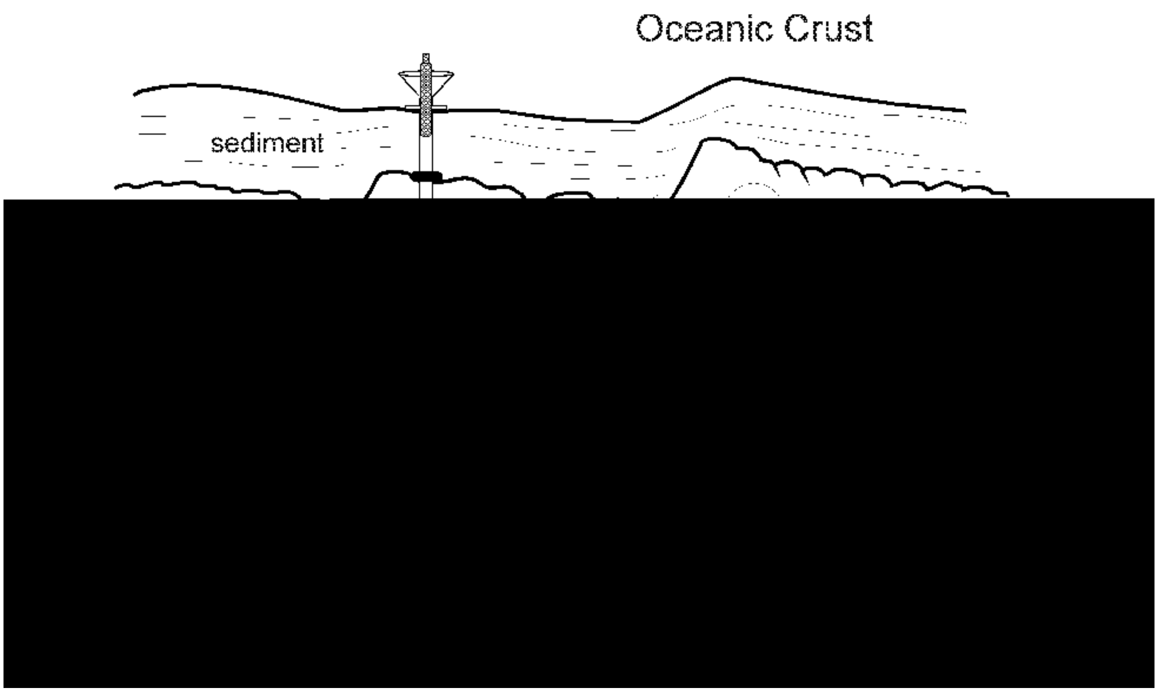
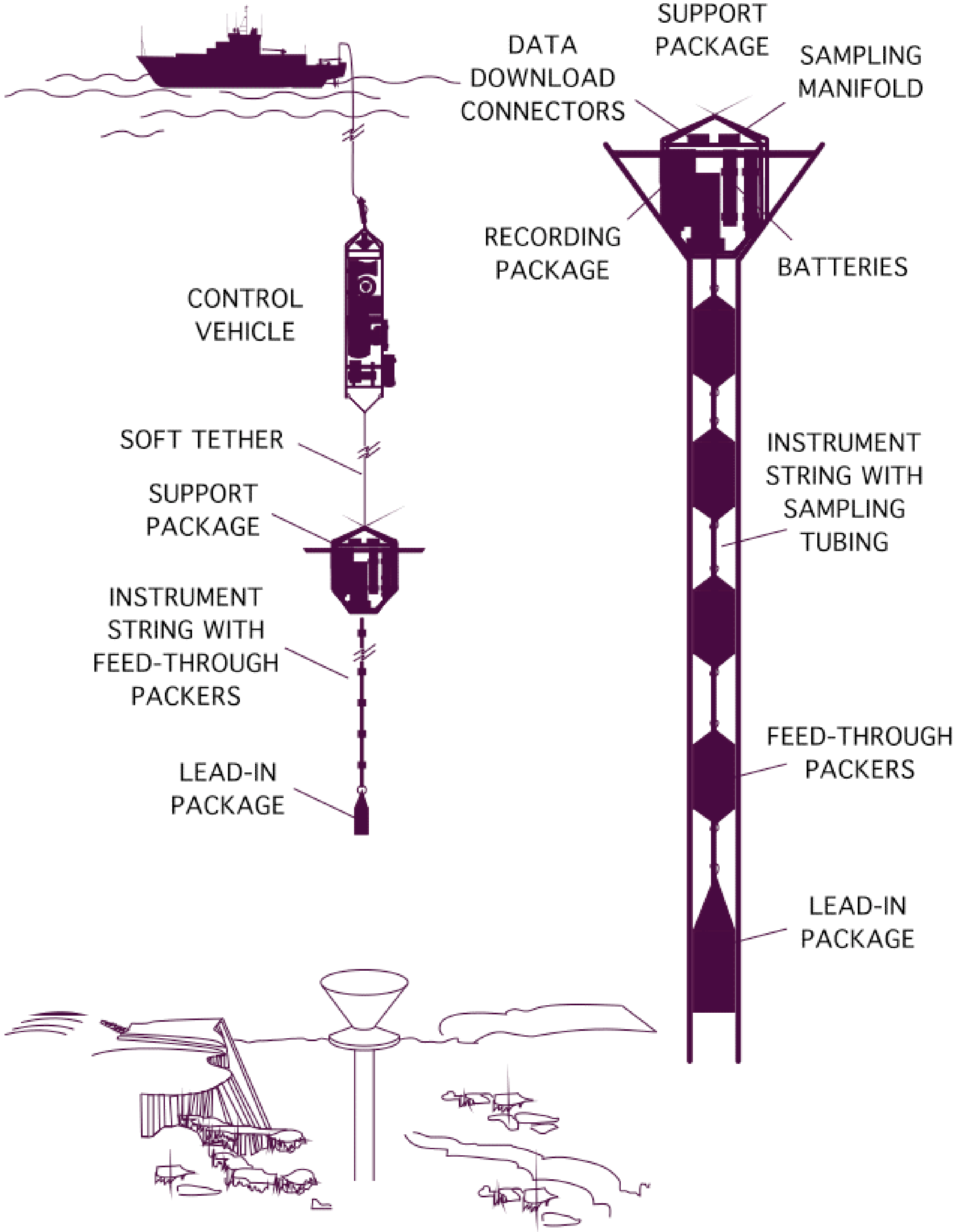


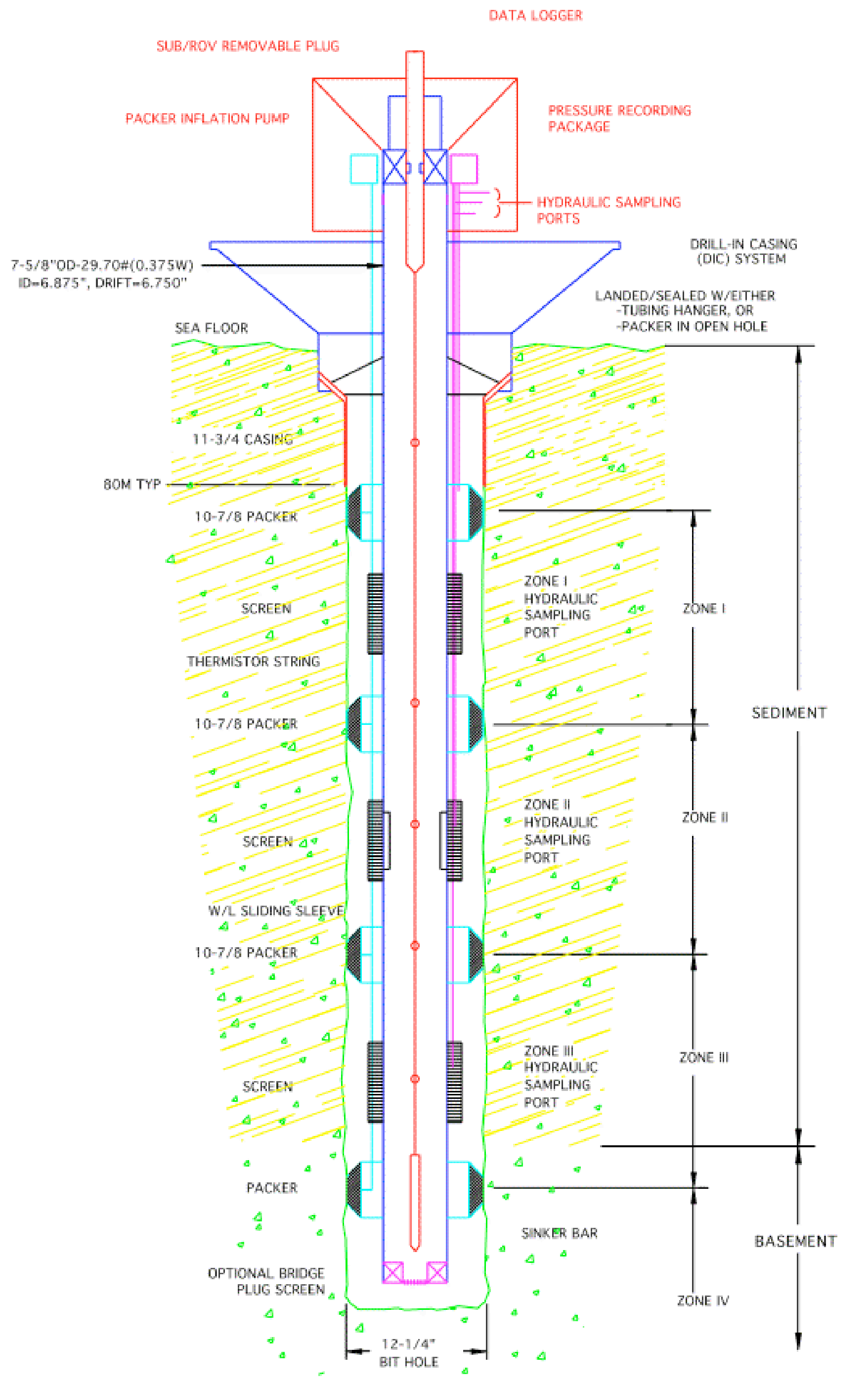
Figure 3. Generic Advanced CORK installations in (a) accretionary prisms and (b) oceanic crust.



[redacted]

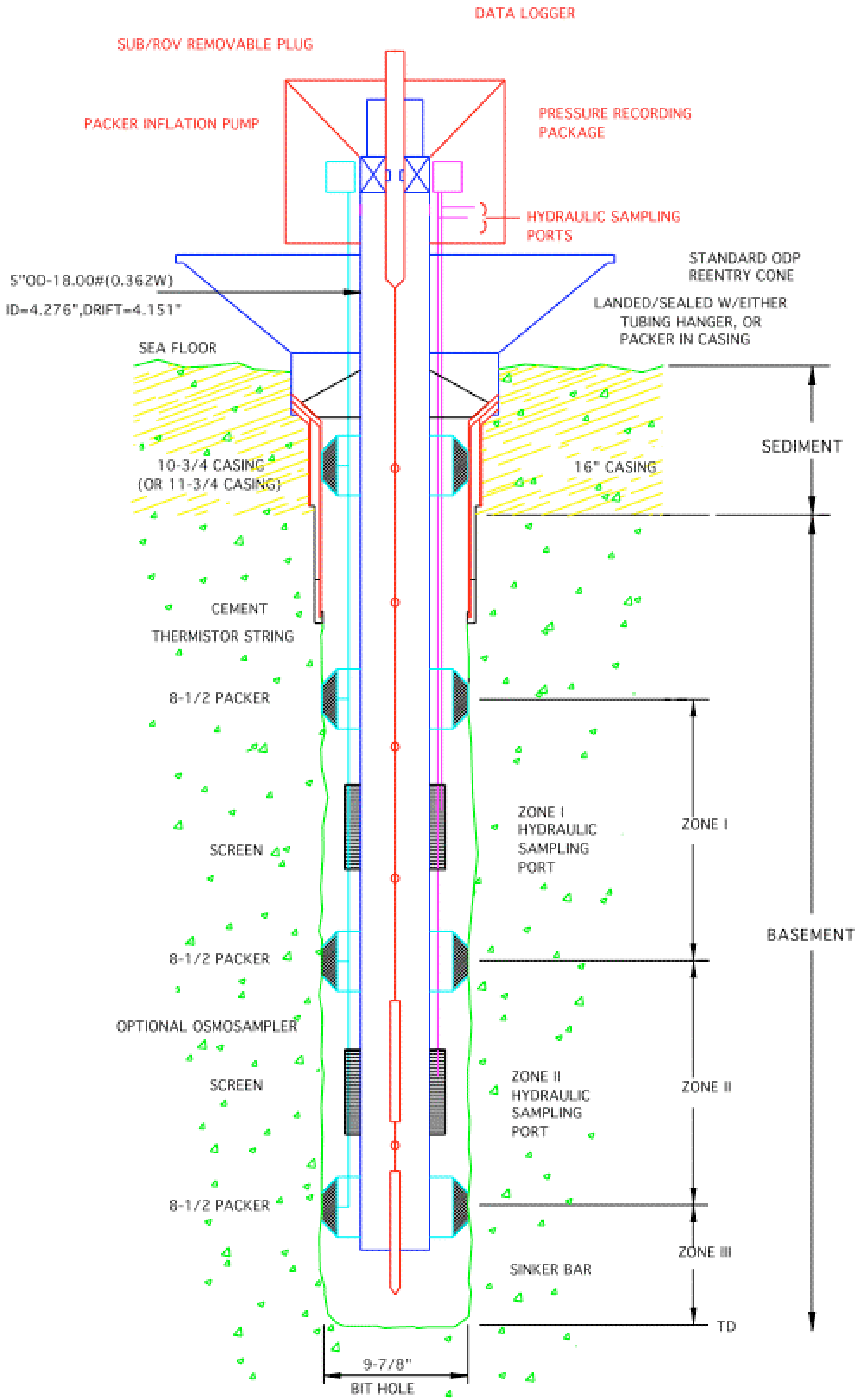

SUPPORT
PACKAGE
DATA
DOWNLOAD
CONNECTORS
SAMPLING
MANIFOLD
RECORDING
PACKAGE
BATTERIES
CONTROL
VEHICLE
SOFT TETHER
SUPPORT
PACKAGE
INSTRUMENT
STRING WITH
FEED-THROUGH
PACKERS
LEAD-IN
PACKAGE
INSTRUMENT
STRING WITH
SAMPLING
TUBING
FEED-THROUGH
PACKERS
LEAD-IN
PACKAGE

ADVANCED CORK II
DIC REENTRY HOLE FOR MULTIPLE ZONE OPEN (STABLE) HOLE ISOLATION



NOTE: CASING/TUBING SIZED FOR MUD MOTOR & UNDERREAMER

ADVANCED CORK II
FOR EXISTING BASEMENT REENTRY HOLE



ADVANCED CORK II

REENTRY HOLE FOR MULTIPLE ZONE CASED (UNSTABLE) HOLE ISOLATION