ODP/IODP CORK Observatories: Designs and Geophysical Results since 1991

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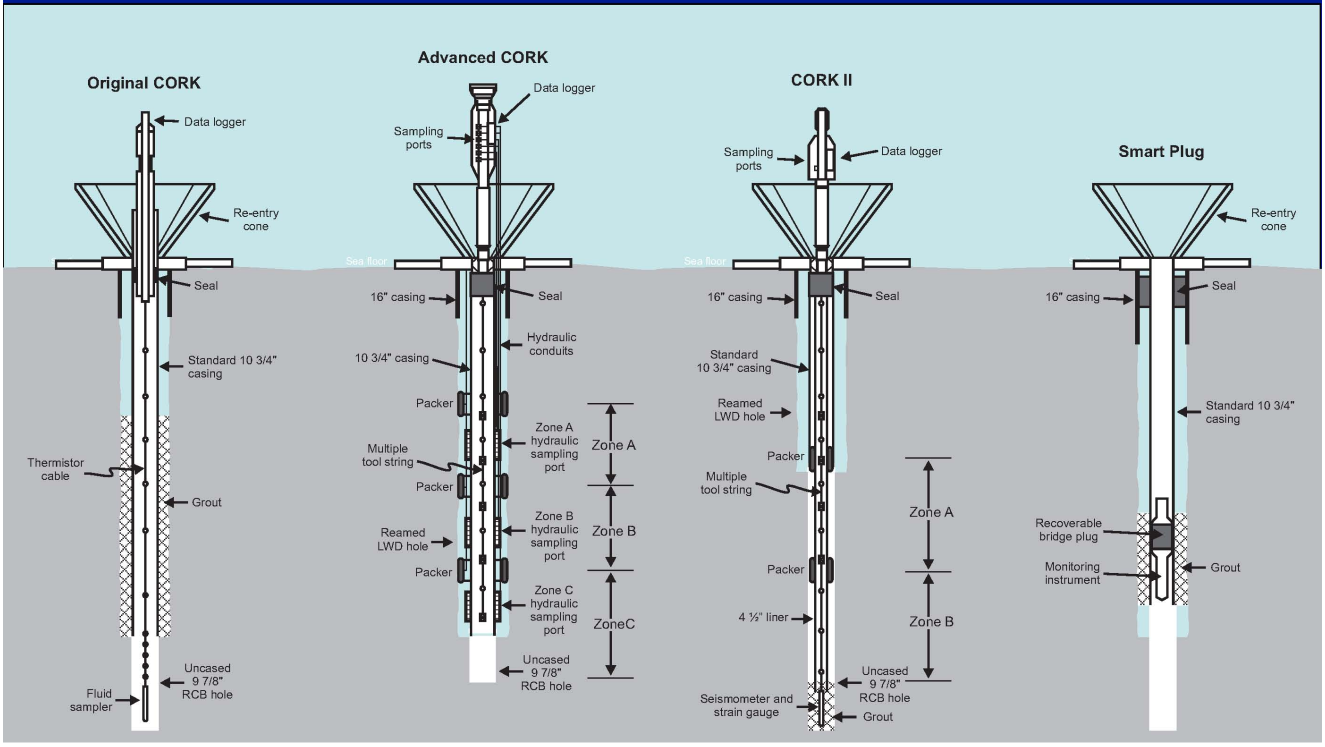
Since 1991, the Ocean Drilling Program (ODP) and Integrated Ocean Drilling Program (IODP) have instrumented >25 subseafloor boreholes with long-term sealed-hole observatories called Circulation Obviation Retrofit Kits (CORKs). As will be described by other speakers in this session, additional installations have been implemented or are planned during the first few years of the 2013-2023 International Ocean Discovery Program (also IODP), using D/V’s Chikyu and JOIDES Resolution. Understanding subseafloor hydrology and its relationship to hydrothermal and tectonic processes have been prime objectives of scientific ocean drilling since the late 1970’s. However, early experience indicated that holes that penetrated through marine sediments into underlying oceanic basement often allowed open exchange between formation fluids and ocean water, perturbing if not totally disturbing the in-situ hydrogeological state. This motivated the CORK approach to seal select holes and instrument them with long-term sensor strings and data loggers, to record the recovery from drilling disturbances to the in-situ state and monitor natural hydrologic, tidal, and geodynamic signals. A brief summary of the designs of the CORK observatories will be presented (attached image), starting from a 1989 concept sketch on a dinner napkin. The original design included a single seal at the seafloor, and later designs have allowed for separately monitoring multiple zones sealed by packers in a single hole. Also, legacy reentry holes can be retrofitted with less expensive “CORK-Lite” models deployed by remotely operated vehicles (ROVs). The sensor strings have always included pressure and temperature monitoring, and many have included self-contained fluid samplers driven by osmotic pumps (“OsmoSamplers”) that can be tuned for a variety of geochemical and microbiological sampling objectives. Typically, data and samplers have been recovered and/or exchanged at average intervals of ~1-3 years using manned or unmanned research submersibles. Installations to date have been in sedimented young ocean crust or in subduction settings. Important geophysical findings to date include documenting the following: (1) small pressure and temperature differentials associated with vigorous off-axis hydrothermal circulation in highly permeable young oceanic crust; (2) formation response to seafloor tidal loading; (3) formation pressure as a proxy for plate-scale strain in response to tectonic stresses and earthquakes; (4) vertical seafloor deformation associated with slow and rapid fault slip; and (5) temperature variations associated with volumetric strain within the crust and turbidity events and other oceanographic events at the seafloor.

Keywords: CORK subseafloor hydrological observatories, Ridge-flank hydrothermal systems, Formation pressure as a proxy for plate strain

Evolution of CORK Designs, 1991-2011

From single-seal original CORK to multi-seal ACORK and CORK-II to downhole single-seal memory "Smart Plug" and "Genius Plug"...



Changes in physical properties of the Nankai Trough megasplay fault induced by earthquakes, detected by continuous pressure monitoring

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One primary objective of Integrated Ocean Drilling Program (IODP) Expedition 365, conducted as part of the NanTroSEIZE project, was to recover a temporary observatory, termed the “GeniusPlug“ emplaced to monitor formation, pore fluid pressure and temperature within a major splay fault that branches from the main plate interface, at a depth of ~400 m below sea floor (mbsf). The instruments were installed in Dec. 2010 and recovered in April 2016, yielding 5.3 years record of formation pressure and temperature within fault zone. Here, we use the pressure timeseries, and in particular the response to ocean tidal loading, to evaluate changes in physical properties of fault zone induced by several regional earthquakes. To accomplish this, we quantify: (1) the amplitude of the formation’s response to tidal loading, defined in terms of a tidal loading efficiency, governed primarily by the formation and fluid elastic properties; (2) the phase lag between the ocean tidal signal and the measured response in the observatory, which is governed by a combination of formation hydraulic diffusivity and the relative compressibilities of the formation and sensing volume; and (3) pressure steps associated with earthquakes, identified in formation pressure after removal of the tidal signal. We observe essentially no phase lag, but in for many events we detect both pressure steps and transient decreases in loading efficiency. To reveal the cause of these changes, we investigate the effects of static and dynamic crustal strains. Changes in theoretical static volumetric strain and the associated expected pressure step for each event are calculated based on Okada (1992), and using a conversion from volumetric strain to pore pressure based on formation properties defined by laboratory experiments. We find that, there is no clear correlation between observed pressure steps and predicted static volumetric strain; furthermore, the predicted pressure steps are ten to hundreds of times smaller than observed. As a proxy for dynamic strains, we calculate the integrated “pressure energy density” over a 30 minute window for each event, and show a positive correlation with both step changes in pressure and changes in loading efficiency.
Most of the detected changes represent pressure increases and loading efficiency decreases. We speculate that disruption of grain contacts and subsequent pore collapse induced by dynamic strain produces changes of hydraulic properties in the fault zone. Alternatively, these changes could reflect exsolution of gas from pore fluids that drives pore pressures up while simultaneously reducing loading efficiency by increasing the compressibility of pore-filling fluids.
Finally, the observed amplitude response and negligible phase lag of the formation pressure response to ocean tidal loading, taken together, allow an estimate of the minimum hydraulic diffusivity of splay fault of 8.9×10^5 m^2/s.

Using giant piston coring within IODP to track past earthquakes in the sedimentary record along the Japan Trench

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“Submarine paleoseismology” is a promising approach to investigate deposits from the deep sea, where earthquakes leave traces preserved in stratigraphic succession. The concept of studying sedimentary event deposits for reconstructing past earthquake history and related impacts to the marine environment is increasingly being applied in various settings. However, at present we lack comprehensive data sets that allow conclusive distinctions between quality and completeness of the paleoseismic archives, as they may relate to different sediment transport, erosion and deposition processes vs. variability of intrinsic seismogenic behavior across different segments. Nevertheless, many recent studies, which are mostly based on conventional 10-m-long cores, demonstrate the potential of the research concept. With IODP opening its approach to include giant piston coring, a new horizon has opened up for multi-coring expeditions fully dedicated to the rapidly growing field of submarine paleoseismology. IODP is uniquely positioned to address the complex feedback mechanisms between earthquake shaking and its manifestation in the marine archive, decipher related mass fluxes from the shallow to the deep see and to eventually provide longer records to constrain earthquake recurrence far beyond historical catalogues.

Initially building on what sedimentary deposits were generated from the 2011 M9 Tohoku-oki earthquake, the Japan Trench is a promising study area to investigate earthquake-triggered sediment remobilization processes and how they become embedded in the stratigraphic record, and has thus been identified as a primary target for proposing giant piston coring within IODP. In this presentation we summarize recent results and available site survey data collected since the 2011 earthquake, comprising >50, 5-10m long piston and gravity cores from (i) trench-fill and graben-fill basin across the entire trench axis from 36° to 40.3° N (ii), the mid-slope terraces and (ii) from representative slope sites as potential source for sediment remobilization during earthquakes (2) nearly 2000km of high-resolution subbottom acoustic reflection data (Parasound) that reveals striking, up to several meter thick, acoustically transparent bodies interbedded in the otherwise parallel reflection pattern of the trench fill basins. Results from conventional coring covering the last ~1500 years reveal good agreement between the sedimentary record and historical documents in the central part of the margin, and shed new lights on earthquake-triggered, gravity flow-driven supply of significant amount of pre-aged carbon to the hadal environment. New cores retrieved from the southern and northernmost part of the Japan Trench during the recent R/V Sonne expedition SO251 confirm the presence of repeated thick turbidite sequences to be further tested for correlation to historic earthquakes along different margin segments. All these observations underpin the great potential for deciphering earthquake related processes from the stratigraphic record of the small deep-sea trench-fill and graben-fill basins in the Japan Trench, the longer-term record of which is only accessible by giant-piston coring and drilling, as proposed by IODP in Proposal 866.

Keywords: Submarine Paleoseismology, Japan Trench, Marine Geology and Geophysics, Event Stratigraphy, IODP

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Earth in Motion Through the Borehole Window

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The present knowledge of the solid Earth dynamics is largely built on remote-sensing observation data colleceted from the land surface or space combined with numerous lab experiments and modelings. On the other hand, scientific ocean drilling has been providing ground-truthing samples from the boreholes. Linking the two approaches is critically important for testing and verifying scientific ideas as exemplified by the hallmark DSDP achievement of verifying seafloor spreading in the beginning of the ocean scientifc drilling history. After nearly half a century, there still remains a wide gap between the two approaches in terms of the time and space resolutions and extents. To understand the "Earth in Motion," both approaches must advance to narrow the gap, since the target Earth is one. The remote-sensing community has evolved now that their sensor networks can be extended to seafloor and also to take advantage of the quiet borehole environment to capture the weak signal from below. Such signals include seismic, geodetic, thermal, or biological. The other direction in this effort is to achieve sampling from deeper into the mantle, for which *Chikyu* was designed and built. It is important that both the remote-sensing and ground-truthing communities benefit from the capabilities of *Chikyu.* First and foremost, the sampled rocks will ground-truth and bring unexpected discoveries on the physico-chemical framework of seafloor spreading. At the same time, we can utilize the deep vertical borehole into the mantle as an observatory, away from the atmosphere, ocean and crust to be the most sensitive station to mantle signals from local to global sources. We will show that a moderate modification to the current *Chikyu* specifications incorporating newly developing drilling technologies will enable us to conduct this grand experiment.

Keywords: Chikyu, mantle, Earth in motion, observatory, drilling