

# REPORT OF THE SAFOD ENGINEERING SUBCOMMITTEE OF THE ADVISORY COMMITTEE FOR GEOSCIENCES, MARCH 30, 2011

## Subcommittee Members

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## A. Introduction

One component of EarthScope is the EarthScope Facility, part of which is the San Andreas Fault Observatory at Depth (SAFOD). SAFOD consists of an approximately 3 km deep borehole (Figure 1) to study, up close, the physical and chemical processes that control deformation and earthquake generation within an active plate-bounding fault zone. (Note: The activities associated with a pilot hole – drilled prior to the main hole – are not discussed in this report).

Through an integrated program of downhole sampling, measurement and long-term monitoring, SAFOD was designed to: 1) determine the structure and properties of the fault zone at depth, 2) utilize exhumed fault zone core to determine the frictional behavior, physical properties, and chemical processes that control faulting, 3) measure stress, permeability, and pore pressure conditions in situ, 4) characterize the three-dimensional volume of crust containing the fault, 5) directly monitor strain, pore pressure, and near-field seismic radiation during the cycle of repeating microearthquakes, and 6) observe earthquake nucleation and rupture processes in the near field.

Most of the elements of the integrated program noted above required building and installing a robust downhole instrument package (DIP) directly in the fault zone that could operate continuously at temperatures of 120 degrees C and fluid pressures of 30 MPa for extended periods. The DIP was to include multiple digital seismometers, accelerometers, and tiltmeters at several depths and a pore pressure sensor at the bottom of the hole. After completion of drilling Phase II drilling in 2005, it was discovered that the wellbore fluid was saturated with natural gas and lightweight hydrocarbons coming from the sedimentary formations east of the San Andreas Fault. The presence of hydrocarbons

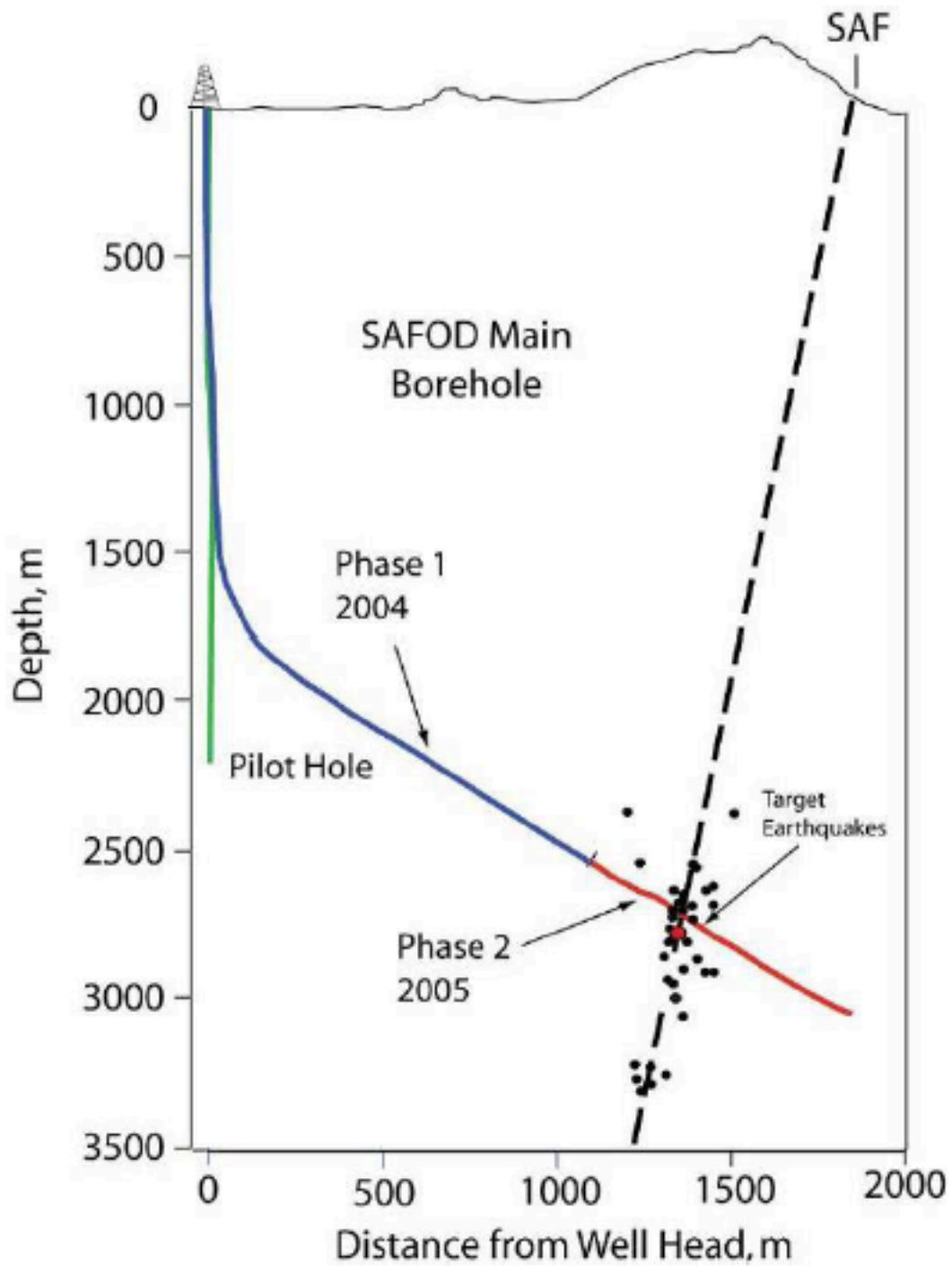


Figure 1 SAFOD Borehole

in the wellbore fluid created serious cable head problems in early deployments and testing of instruments between 2005 and 2007. An attempt to isolate the source of the hydrocarbons in the well was initially unsuccessful, although recent geochemical analyses suggest that, although the well is slightly over-pressured, hydrocarbons do not seem to be currently present at the DIP deployment depth.

Following the two years of testing, and with advice on the proposed DIP from the SAFOD Monitoring Instrumentation Technical Panel and experts from the IODP and ICDP, it was decided to house the instruments in a set of Pods in order to isolate the instruments from wellbore fluid (Figures 2 and 3). Pods 1, 3, and 5 contained seismometers and accelerometers and Pods 2 and 4 contained tiltmeters on a separate control line. Pod 5 also contained an EMI coil.

The DIP was installed (Figure 4) in September 2008 at the conclusion of the MREFC project. The DIP used what was considered the best design and equipment that fit within a budget that was much smaller than originally planned. An original budget of \$2.56M had been reduced to less than \$0.4M due to overruns in the core recovery portion of the program. Moreover, NSF informed SAFOD that no additional funds would be made available under MREFC. As such, considerable sacrifice had to be made to the original design, including eliminating portions of the instrumentation – most notably the pore pressure sensor and the preferred use of HT electronics that had been recommended by Sandia for longevity. Unfortunately, within two weeks of deployment, all elements of the DIP ceased functioning. In response, the SAFOD Engineering Subcommittee (henceforth referred to as “the committee”) of the Advisory Committee for Geosciences was established in August 2010 and charged with:

- a) Describing all prior temporary installations in the SAFOD main hole, and the “lessons learned” from each installation and applied to future installations;
- b) Reviewing the design and the installation process, including management of that process, for the downhole observatory installed in the SAFOD main hole in September 2008;
- c) Determining and summarizing the reason(s) that the September 2008 observatory ceased to operate;
- d) Recommending technical approaches that would give a reasonable likelihood for successful long-term operation of the originally proposed MREFC SAFOD downhole observatory; and

- e) Recommending technical approaches that would give a reasonable likelihood for successful long-term operation of the de-scoped SAFOD downhole observatory that was installed in the SAFOD main hole in September 2008.

The committee began its work when the DIP was removed from the well on October 7 and 8, 2010. Committee members were on site to observe the operation. Instruments were checked for operability before and after the DIP was removed from the well, with negative results in both cases. The DIP was trucked to UNAVCO headquarters in Boulder, CO, and then on to Houston, TX. The committee met in Houston November 29 to December 3 to observe opening of the Pods. Instruments were removed and bench tested for operability with continued negative results. Committee members assisted a Pinnacle engineer in examining the seismometer's electronic components and circuit boards. The seismic instruments were then left with Pinnacle in Houston for further testing, while the tiltmeters were sent to Pinnacle's San Francisco offices for a postmortem analysis by Pinnacle engineers.

**Figure 2 One of the Downhole Pods**





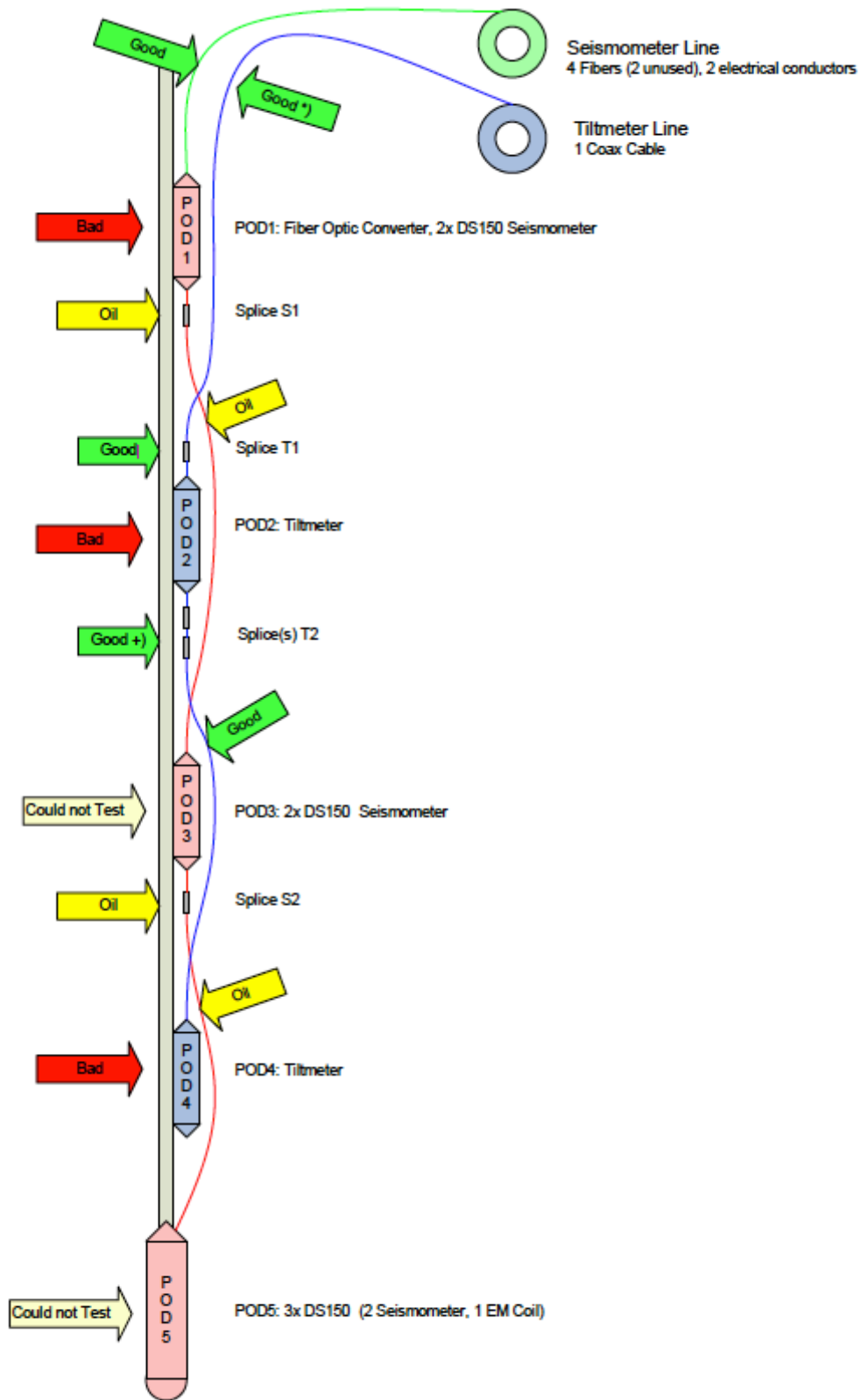


Figure 3 SAFOD DIP Showing the Two Separate Control Lines



Figure 4 Installing a Pod - Control Lines are Clearly Visible

## B. Prior Temporary Installations and Lessons Learned

A series of downhole instrument test deployments were carried out in the main hole (MH) between November 2004 and January 2007 prior to the final installation of the observatory (DIP). These prior deployments are designated as MH001 to MH017 in chronological order. Their purpose was two-fold: 1) to record a series of calibration shots and a few target earthquakes in order to guide the final phase of drilling and associated coring operations, and 2) to try out different types of sensors and clamping mechanisms under consideration for the eventual observatory deployment. None of these deployments tested instrument longevity, nor did they involve systems for isolating instruments and control lines from contact with the wellbore fluid/gas. It was not known that there would be a hydrocarbon (gas) problem in SAFOD when the original budget was prepared in 2003. Moreover, deployments on wireline using commercially available instruments that were designed for use in oil wells seemed a reasonable approach. However, once it was discovered that there was a gas problem, the cost to house the originally proposed DIP in an isolated system was prohibitive, given the limited budget. This led to the design approach utilizing “Pods” as a low-cost solution to help isolate the sensor packages from the wellbore fluid/gas. The Pod concept is discussed later in the report.

All of the MH001 to MH017 deployments were carried out on a standard wireline that was donated (used) by Oyo/Geospace, with the exception of deployments MH004 to MH006, which consisted of a passive 240 channel, 80 level, 3-component geophone array on a specialized cable (Figure 5) containing individual twisted conductor pairs. The array provided good data for low-amplitude signals. However, the clamping force was not sufficient to prevent crosstalk between the channels for higher-amplitude signals and the recording of target events.

Deployments MH007 (January 2006) to MH017 (January 2007) consisted of a series of tests with Pinnacle tiltmeters, Oyo/Geospace DS250 seismometers, and DS325/MEMS accelerometers, all with downhole electronics. Motor driven locking arms were also tested. Virtually all deployments lasted less than a few days to a few weeks due almost exclusively to failures of the cable heads (primarily electrical shorts) and invasion by moisture and wellbore gas. This resulted, early on (deployment MH008), in the replacement of Viton Duro O-rings with Kalrez O-rings. The latter are very resistant to gas. However, cable head failures continued. For deployment MH010 the side of the cable head

exposed to the wellbore fluid (wet side) was filled with Krytox, a high-density oil that is used as a water block in high temperature geothermal cable heads. However, failure occurred as the Krytox either leaked out or was displaced by wellbore gas. The Kalrez O-rings showed no sign of damage, although the cable above the cable head was seriously corroded. A decision was made to try potting the wet side of the cable head with a different grease and better Kalrez O-rings, which were more resistant at high temperature. While marginally better, failures continued from MH012 to MH016 (October 24 to November 9, 2006). These short deployments were for the purpose of recording test shots. A test on January 11, 2007 (MH017) involved filling the cable head with high temperature epoxy. The two DS250s used in the test failed a week and a half later. Failure was attributed to poor bonding of the epoxy to the feed-thru in the cable head, allowing water to enter and create a short between conductors.



**Figure 5 Downhole 240 Channel 80 Level Geophone Array**

Lastly, in addition to the many cable head failures, the portion of the wireline above the cable head was also a source of problems during the 2006 to 2007 deployments. Corrosion and embrittlement of the copper conductors by fluid and gases occurred, which made them hard to work with when reheading the cable. This corrosion/embrittlement probably originated from leaks in the cable head, as water and gas traveled up the wireline, so that the cable head and wireline problems were probably related. Upwards of 7000 feet of wireline were removed during reheading operations in an attempt to get to undamaged cable.

### C. Transition to the Pod Concept

The many tests described above suggested that instruments and control lines needed to be separated from the wellbore fluid and gas using metal-to-metal seals, as both gas and well water are highly corrosive and mobile at the bottom hole temperature of 120 degrees C and pressure of 30MPa.

As noted earlier, the original concept for the downhole observatory (DIP) as related to the scientific objectives was ultimately sacrificed due to budgetary constraints. The types and numbers of instruments were severely cut back, and so a final observatory design was apparently never completed. Instead, based on the testing and a recommendation from Pinnacle Technologies (principal contractor for the design and fabrication of the SAFOD observatory), and in order to isolate instruments from wellbore fluid, the Pod concept was adopted, in which the array of instruments were encapsulated within a 2<sup>nd</sup> pressure vessel with welded or metal-to-metal seals. Power and signal lines, encapsulated in ¼ inch stainless steel tubing, interconnected the Pods. The tubing entered the Pods via Swagelok fittings. The individual Pods were, in turn, fastened to the outside of 2-3/8 inch EUE tubing that would facilitate installation and retrieval, as well as allow other instruments free passage into the borehole through the inside of the EUE tubing. The final design consisted of two independent systems as noted earlier, one housing the tiltmeters at two different depths (Pods 2 and 4) and one housing the seismometers and accelerometers at three different depths (Pods 1, 3 and 5). An electromagnetic sensing coil was attached to the bottom of Pod 5.

The design to isolate instruments from wellbore fluid was the right approach, but did not adequately take into consideration temperature. For example, it does not appear that possible thermal degradation of the Mobil 1 (a synthetic oil used to fill the Pods) and its potentially caustic effects on interior components at elevated temperatures for extended periods was considered.

(**Note:** it was not clear to the committee why, in fact, the Pods were filled with oil. One response was that it added additional protection to any leaks of the wellbore fluid. However, unless the pressures inside and outside of the Pods were the same, and no void space existed inside the Pods (not the case), this would seem to be a fallacious argument.

As noted above, the design relied on metal-to-metal seals, both threaded and Swagelok or equivalent. On the order of two-dozen such connections existed on the final DIP, including those on the ends of the Pods. While there may be no other obvious alternatives, it is not clear how much care was taken in applying the proper thread compound and makeup procedures, which includes tightening each of the various connections using the appropriate torques and gap inspection gauges. Pressure testing did not appear to have been done on the complete system – only on partial components. However, in practice it would have been difficult to pressure test the completely assembled system, and as such, it would have been necessary to take extreme care and every precaution when each of the connections was made to ensure leak-free seals.

Because the entire DIP is approximately 300 feet long to accommodate vertical spacing between seismometers and tiltmeters, it was necessary to connect the Pods together in the field via splices between them (see Figure 3). The splicing was performed on the floor of the drill rig during DIP installation. Splices consisted of soldered connections of stripped ends with no additional strain relief, such as by twisting conductors together (Figure 8). The splices were housed in short sections of 3/8” tubes with Swagelok fittings at both ends (Figure 9). The committee felt that having splices was a design flaw, since the failure of a single splice could, under certain conditions, take out several all instruments in a string. An alternative would be to consider each Pod as an independent instrument, although arguably more costly.

Lastly, the committee noted that the metal-metal contact surface in a Swaged coupling is small and may be easily compromised during insertion into the wellbore, which is a rather rough handling process (see for example Figure 4). In addition to rough handling, each swaged connection can be compromised by dirt or debris between the cone and seat of each connection. It was not clear to the committee to what extent the attention to detail, as noted above, was an essential theme of the fabrication and installation process. The committee did note that the clamping of the ¼ inch tubing to the EUE tubing was a good idea, and had potentially reduced the chances of additional failures.



A project of this magnitude and complexity requires a full time manager who is familiar with all aspects of the instrumentation, construction installation, and data. That person should be independent of any contractors, and must ensure that all appropriate testing is carried out and everything is up to specification before deployment. He/she is the quality control specialist and responsible for careful and complete documentation of all aspects of the project. It was not clear to the committee that such an individual existed for this project. It appeared as if different elements of the project were in the hands of different individuals. Perhaps there was too much reliance on Pinnacle personnel and not enough “looking over their shoulders”. For example, some damaged or improper threads were missed, some design documentation was missing or incomplete, and torques on Pod end caps appear to have been variable and in some cases not up to spec. Moreover, one might be concerned that the Swagelok connections were not gauged according to specification either.

#### **D. Reasons the 2008 Observatory Ceased to Operate**

Listed below are the committee’s principal findings. It has not been possible for the committee to identify with certainty the sequence of events or exactly what happened during deployment and the several days thereafter that led to total failure of the observatory. One or more of these findings may have compromised the DIP. It is important to emphasize that all elements of the DIP failed within the first few hours to weeks following deployment, yet it remained at the bottom of the borehole at 120 degrees C for two years before being removed for assessing the reasons for failure. This has made it impossible in some instances to separate what may have happened early on versus what took place during the two years the DIP sat at the bottom of the borehole. As such, the committee has not attempted to make that distinction.

#### **The order of failure was as follows:**

1. The tiltmeter in Pod 4 lost contact with the surface before the DIP hit bottom. The failure was probably due to an open circuit that occurred during installation.
2. The tiltmeter in Pod 2 began to have problems shortly after deployment and stopped working two weeks later. It was found to be partially filled with oil during disassembly, suggesting a leak at one of the O-ring seals.
3. The seismic array arrived on the bottom fully functional, but problems began after several days. A perplexing pattern of noise developed with a 24-hour cycle (possibly due to ground loops).

4. Communication problems developed shortly thereafter.
5. Approximately 10 days after deployment, all communication was lost with the exception of the instrument in Pod 1. Several days later the last instrument went into a spasm of dropouts, spikes (Figure 6) and reboots. Dropouts can be indicative of cable issues due to leakage or to premature electronic component failure.

## Findings

- An examination of threads on the pod end caps and their female counterparts on the DIP by a professional tubing contractor concluded that: “There is evidence that the proper thread compound and makeup procedures (torques) may not have been used when assembling the connections. It is possible that this may have resulted in leakage, especially at the external shoulder seals.”
- The EUE crossover at the top of Pod 5 (male threads on the crossover into female threads at the top of Pod 5) may have allowed incursion of wellbore fluid and gas to enter Pod 5. The threads at this connection may not have been appropriate for the intended application (see item 1 below), thereby resulting in a fluid entry path. Within a few days the volume of fluid that entered Pod 5 was enough to cause electrical issues within the cable head, and in time, possibly allowed the migration of fluid/gas through the ¼ inch control tubing between Pod 5 and Pod 3, thereby compromising the cable head in Pod 3.

There were ways that the top of pod 5 could have been sealed against the borehole fluid:

1. The thread on the top end cap that connects to the EUE crossover could have been a gas-tight thread like all of the others used at every other connection. Instead it was a standard NPT pipe thread and unable to hold pressure.
2. The top of the end cap on Pod 5 that connects to the EUE crossover could have been terminated (inside) with a solid piece of metal. Instead it was open to permit filling of pod 5 with oil after assembly. The solid piece of metal was instead inside of the crossover.

3. The pipe thread connection between pod 5 and the EUE crossover could have been welded after it was made-up. This would also have prevented borehole fluid from entering through the pipe threads.

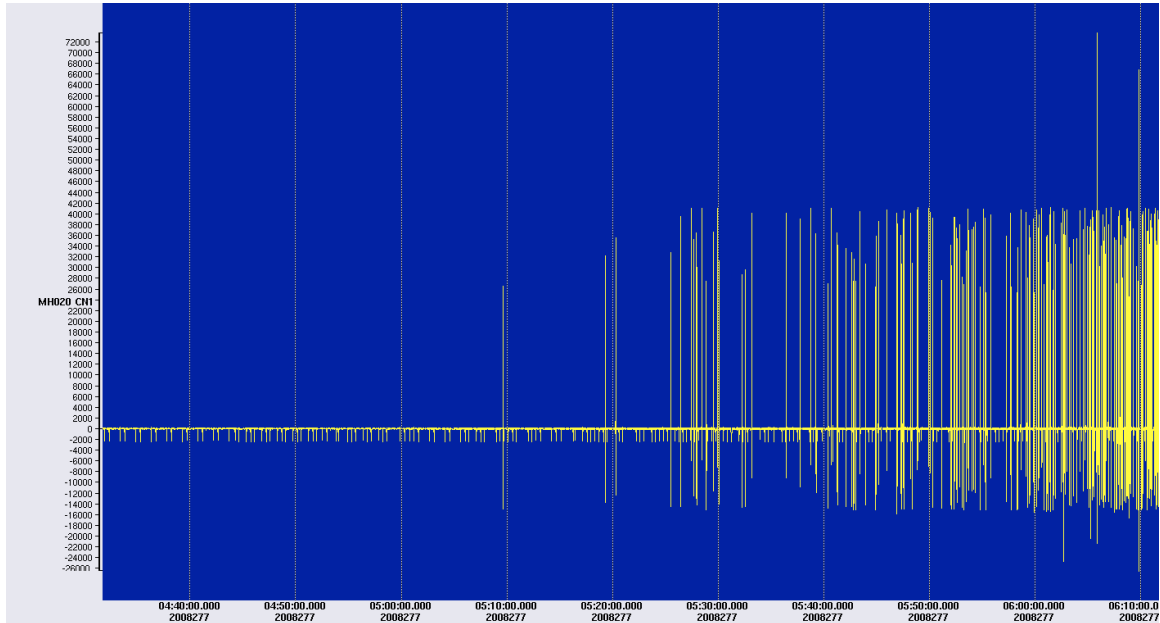


Figure 6 Spikes Developing in Seismic Data

- The Pods lacked sufficient internal barriers to fluid and gas flow. Internal Swageloks were used only for load bearing and not as internal seals, thus providing a path for fluid and gas to migrate from one Pod to another through the interconnecting ¼ inch control tubing. It appears as if fluid migrated into Splice S2 between Pod 3 and Pod 5.
- Chemical analyses on fluid samples from Pods 3 and 5 by Dr. William Stringfellow (UOP) indicated the presence of an aqueous phase in both Pods, clear evidence that wellbore fluid had entered these two Pods. However, the Pods contained only Mobil 1 oil suggesting no incursion of external (formation) oil. The aqueous phase was found to be three times

saltier than seawater and acidic. Such fluids are both conductive and highly corrosive, particularly under high temperatures and pressures.

- There was a lack of documentation regarding the DIP from Pinnacle, and a lack of documentation regarding the installation process and procedures.

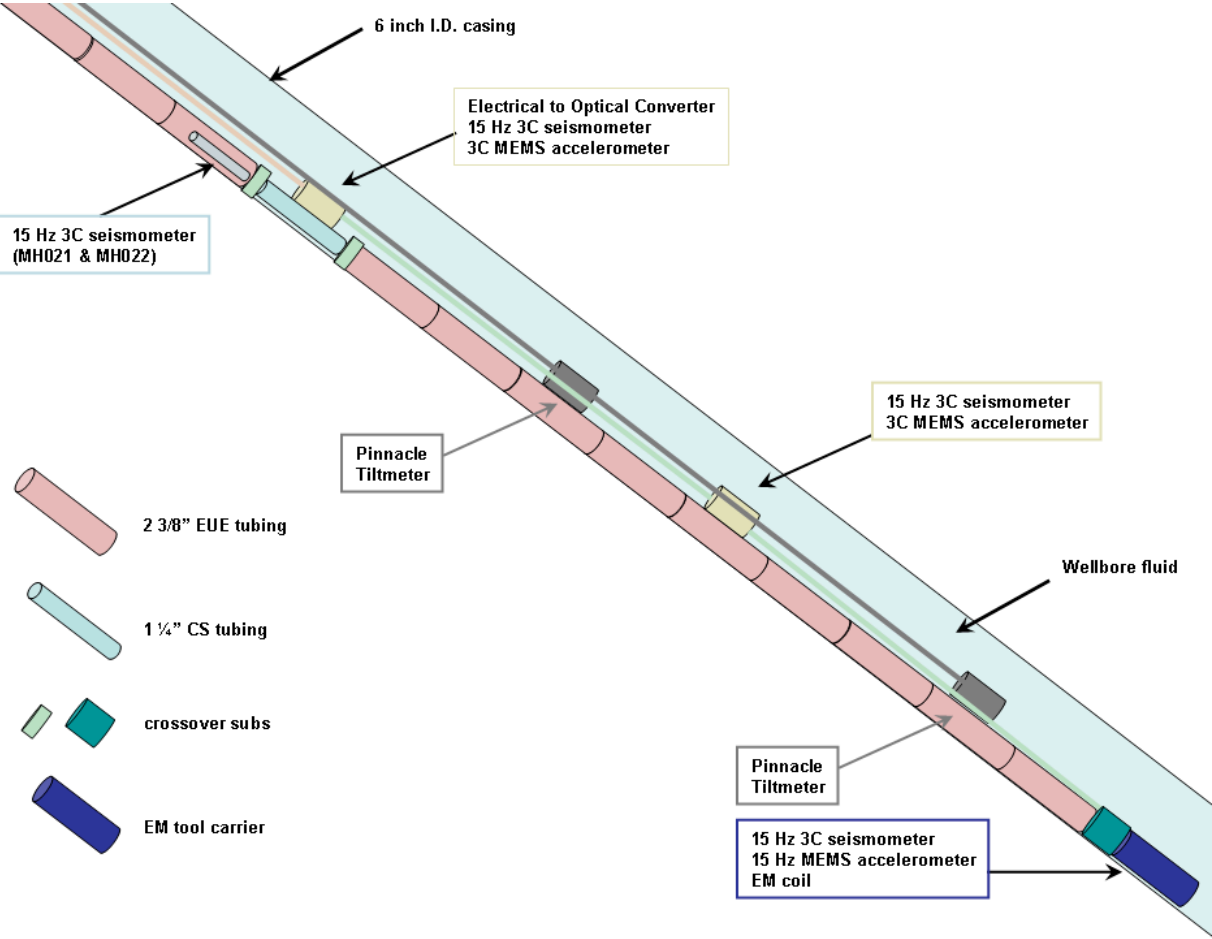


Figure 7 SAFOD Observatory Elements

- Splice S1 between Pod 3 and Pod 1 contained oil but not an aqueous phase according to conductivity measurements by Dr. Stringfellow. However, small amounts of water can dissolve in oil.
- Chemical analyses indicated the presence of volatile compounds in Pod samples, consistent with thermal oxidation (degradation) of motor oil. The committee was not able to determine if these volatiles would have a detrimental effect on seals, boots, and/or conductors, or whether these gaseous compounds could find their way around or through seals and/or feeds thru. Nor was the committee able to determine what effect, if any, the volatiles might have on electronic components and sensors.
- Chemical analyses of oil samples from the Pods were found to contain silicon grease, which might be an indication of seal failure. However, this hypothesis would depend on how the grease was used, since even under normal use, the grease could be exposed to the Pod oils in the cable heads.
- Most instrument circuit boards and many electronic components showed signs of corrosion, and occasionally minor traces of oil, suggesting the breakdown of seals.
- Examination of the electronics boards in the DS150s revealed many failed connectors, capacitors, transformers, voltage regulators, and possibly analog-to-digital converters and memory integrated circuits. Most likely these failures were caused by the long exposure time at elevated temperatures.
- In a statement to the Committee, Pinnacle engineers stated that the DS150s employed in the DIP would fail if put at 125 degrees C for any length of time. It appears as if the wrong instrument was selected for this application.
- A broken wire was found in Pod 4 tiltmeter. It is not clear if the break occurred before or during disassembly. Electronic components on circuit board were heavily corroded and some damaged.
- A broken wire was found in Splice S2 (see Figure 3). It is not clear if the break occurred before or during disassembly.

- Pod 2 tiltmeter was partially flooded with oil. Electronic components were heavily corroded and some damaged.
- Examination of the electronics boards in the tiltmeters indicated failed capacitors, connectors and microcontroller/memory integrated circuits. Due to the microcontroller failure, it was not possible to identify additional component failures such as signal conditioning circuits, analog-to-digital converters, etc. Also, all sensors and motors were no longer functioning. As with the DS150s, the failure of the electronic components and motors was likely caused by the exposure time at elevated temperatures.
- The Mobil 1 had migrated between Pods through the ¼ inch tubing, indicating that the cable heads were probably compromised in some cases.
- Electrical splices between Pods were poorly done. The exposed ends of the wires were placed parallel to one another and soldered with no mechanical connection (Figure 8). Individual splices within their protective steel tubes were not staggered. A broken brown wire was found to have occurred near splice S2 between Pods 3 and 5. Insulation materials around the soldered connections had badly deteriorated in many cases. This may have allowed conductive fluid that migrated along the ¼ inch tubing and into the splices to create short-circuits between individual splices.
- A cross-threaded Swagelok fitting was located at the top of Pod 4.
- Oversight and management decisions regarding the DIP design, fabrication, assembly, and installation appear to have been made largely by Pinnacle engineers. This is not a typical arrangement between a client and contractor. While Pinnacle may be a fine engineering company with considerable oil well instrumentation experience, they apparently have no experience with long-term deployments at elevated temperature and pressure. Moreover, the failures of all instruments over such a short period of time suggests that some decisions may not always have been the correct ones.



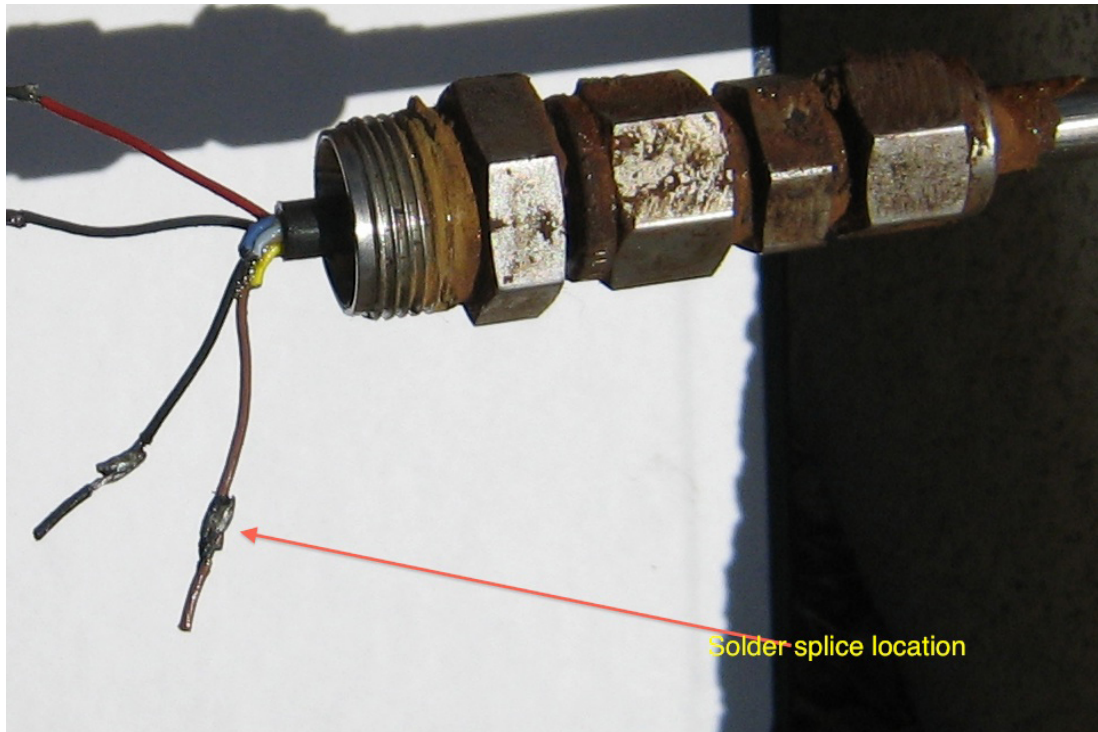


Figure 8 Poorly Soldered Splices



Figure 9 Splice Housing Between Pods 2 and 4

## E. Recommendations

The recommendations presented here cover items (d) and (e) in the charge to the committee. The committee did not see a reason to separate them since the issues regarding the originally proposed MREFC SAFOD downhole observatory and the de-scoped version installed in September 2008 have basically the same requirements, with the exception of the pore pressure monitor in the original version.

- ❖ The committee wishes to emphasize that the originally proposed MREFC downhole observatory remains an important scientific objective for the study of an active plate boundary fault and its seismogenic processes.
- ❖ A future observatory, whether the original or the de-scoped version, must be formulated, constructed, and deployed in stages, from simple to more complex systems over a multi-year time frame.
- ❖ The committee recommends that a future observatory be isolated from wellbore fluid via tubing filled with a benign fluid that reaches from the surface to the design depth. This installation could serve the wider community as a facility for testing developments in instrumentation for high temperature, high-pressure environments.
- ❖ A full-time, fully engaged project manager/engineer who understands both the project's technical details and scientific objectives must be brought on board to oversee the project and provide an interface between the scientists and the contractors. Moreover, this individual must be independent of all contractors, yet be able to work with them and listen to, but not necessarily accept, their advice.
- ❖ Detailed engineering drawings and notes regarding DIP components, assembly procedures, and test results must be part of the process.
- ❖ Specific to the SAFOD observatory and its environment, the project should engage the services of a metallurgical or materials engineer and an organic geochemist. The highly corrosive downhole conditions may require the use of specialized materials and engineering practice.
- ❖ The interplay between temperature, pressure, wellbore fluid/gas and time (the DIP remained in the well for 2 years following total failure)

made it difficult for the committee to identify the precise mode(s) of failure during the first few hours to days of deployment. The committee recommends that in the future, instruments that fail downhole should be removed immediately for inspection and testing.

- ❖ Preference should be given to DIPs that can be installed and removed inexpensively (i.e., without requiring the expense of some form of drill rig).
- ❖ The committee recommends that future DIPs abandon the use of motor oil unless it can be demonstrated that it has no effect on mechanical and electronic components at elevated temperature over time.
- ❖ The committee recommends the use of “qualified” hardware, electronics and sensors. Using conventional low temperature COTS (Commercial Off The Shelf) components for this application is not recommended. The only case where a conventional low temperature COTS system could be utilized would be if the system were wireline retrievable. The preference would be to select manufacturer-qualified components with data indicating the expected life at elevated temperatures. If no data are available, HALT (Highly Accelerated Life Test) evaluations should be performed to help qualify particular components. Qualified active components, passive components, sensors and pressure transducers are all available from a variety of sources that are well known, for example, to the geothermal research and testing community. Presently, no qualified tilt sensor is known and would require testing.
- ❖ While not trivial, hardware, electronics and sensors can be successfully designed for the SAFOD application, although compromises undoubtedly would be necessary. Hardware designed with metal-to-metal seals is common in high temperature/high pressure applications, including those with entrained gases. While elastomer seals work adequately in low temperature applications, long-term high temperature applications when combined with high pressure exceed their capabilities. Such applications should utilize metal-to-metal sealing mechanisms (e.g., C-rings) as the primary seals. However, even some metal-to-metal seals may be subject to corrosion over long deployment times in wells with acidic fluids, so careful selection of metals for seals and housings should be considered.

- ❖ The committee recommends a more detailed investigation of the success and failures regarding the electronic components and sensors. While unpowered during the two-year deployment period, many lessons can be learned and the results could lead to more robust future designs. It is extremely costly to perform long-term evaluations on electronic components and sensors and as such, it would be beneficial to the program to learn as much as possible from the exposed electronics and sensors.
- ❖ The committee recommends a more detailed investigation into the > 2 year deployment of the analog geophone tool using conventional 7 conductor wireline, and whether downhole analog tools might provide a potential alternative to tools with downhole electronics if longevity is a requirement.
- ❖ The committee recommends that further study be performed on the actual O-rings and feeds-thru (Figure 10) used in the DIP to determine if they maintained integrity (blocking fluid, gas, and volatiles) during the two years the DIP was in the SAFOD borehole. It would also be useful to perform various stress tests on Swagelok fittings to determine if they can hold up under the rigors of installation, as well as for long periods under corrosive fluid and gas conditions.

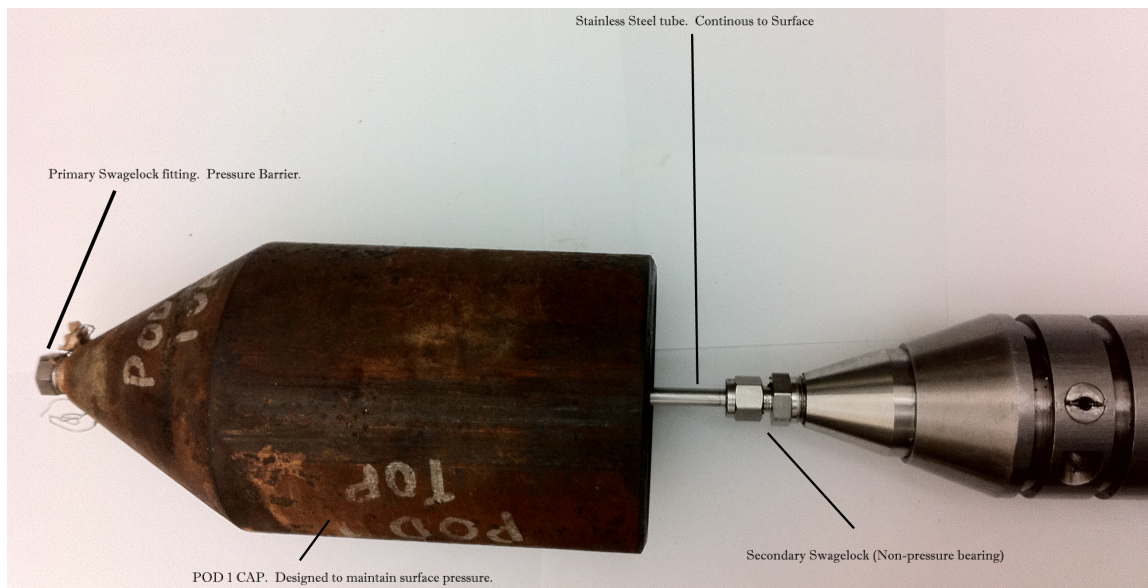


Figure 10A Pod Cap and Top of Cable Head.



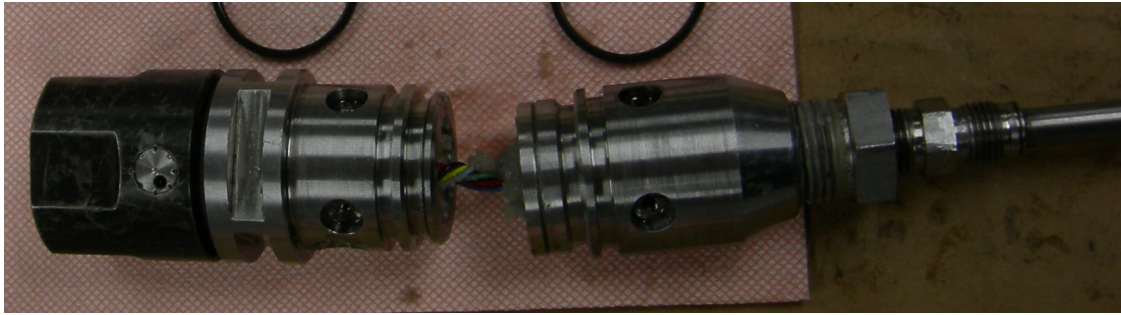


Figure 10B Cable Head Showing Feed Thru on Left and Cable Strain Relief (Bull Nose) on Right.

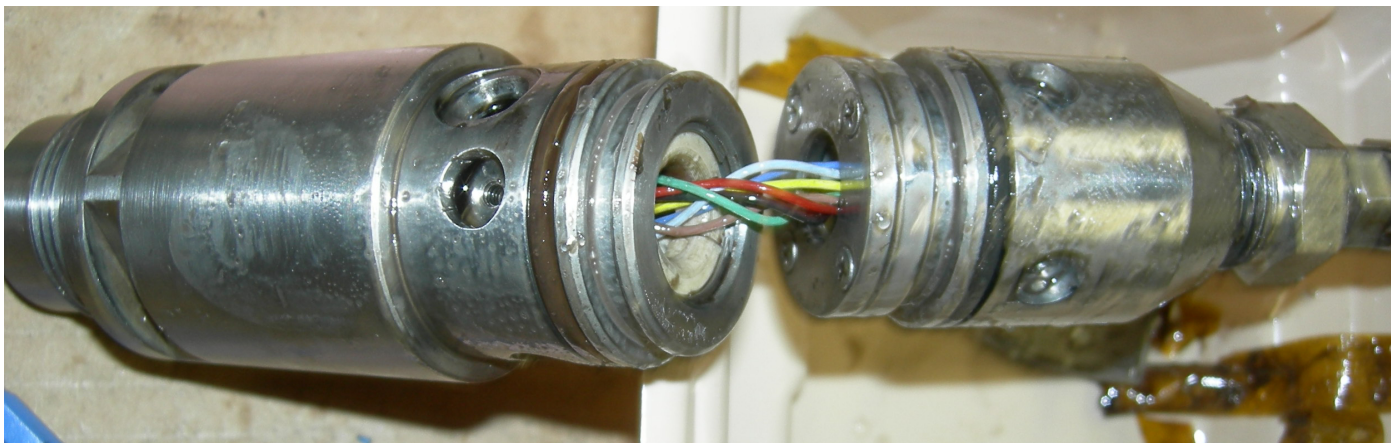


Figure 10C Cable Head Showing Wires from Bull Nose on Right and into Feed Thru on Left

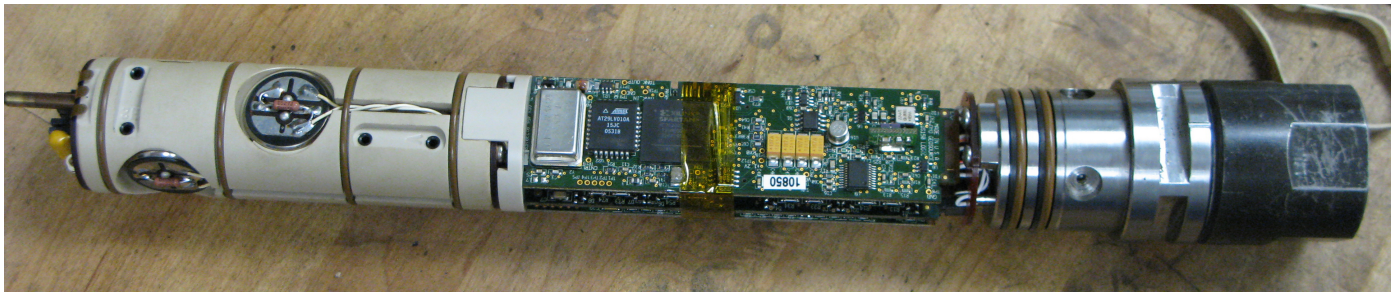


Figure 10D Seismometers on Left with Electronics in Center and Cable Head Connector on Right.





Figure 10E Cable in Upper Left Corner Connected to Instrument Housing in Lower Right Corner Through Cable Head in Center.

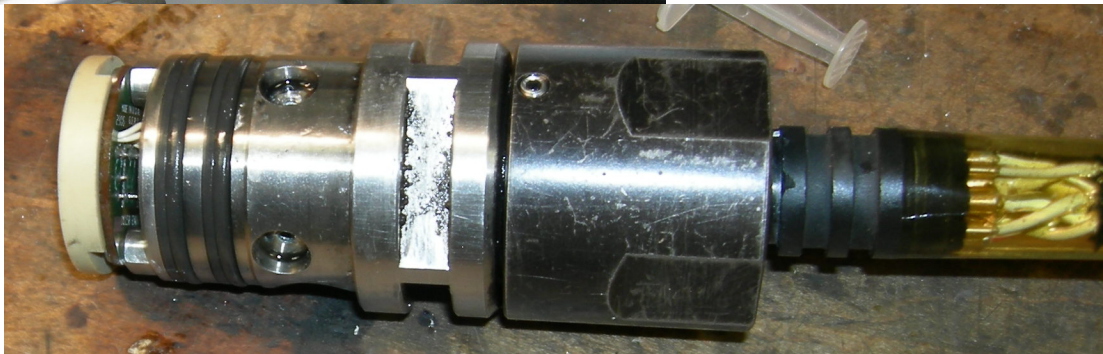
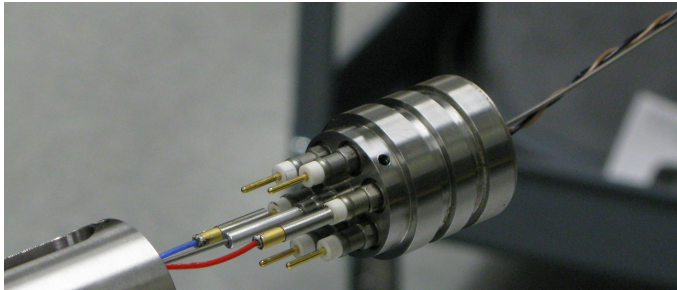


Figure 10F Two Examples of Feeds Thru.



## Glossary

- Cable head** The piece of hardware that terminates a multi-conductor armored communication cable (wireline) downhole, and connects the cable's armor (strength member) to the instrument housing and the cable's conductors to the internal electronics and sensors by way of a Feed Thru.
- C-ring** A gasket or ring based on the elastic deformation of a high temperature alloy with a "C" cross section.
- Crossover** A short segment of pipe or tubing (or solid cylindrical stock with threads) that connects two pieces of pipe or tubing that may have different functions and/or different thread types or sizes.
- DIP** Downhole Instrument Package (the 2008 SAFOD deployed observatory).
- EUE tubing** Tubing with External Upset Ends. The external upset ends provide additional thickness for strengthening connections.
- Feed-thru** The portion of the cable head that contains a set of conductors (pins) bonded to an insulator such as an epoxy or, in high temperature applications, a ceramic, that routes the electrical signals from the end of the wireline into the interior of the instrument housing. An example is the method by which current is carried from the socket of an incandescent light bulb into the inside of the bulb to block oxygen from reaching the filament.
- IODP** International Ocean Drilling Program.
- ICDP** International Continental Drilling Program.
- Kalrez O-rings** A family of O-rings composed of special low compression-set elastomers with good thermal and chemical resistance that can be used in the cable head to block wellbore fluid and gas from entering the internal electronics housing and coming in contact with electronics and sensors.

- Metal-to-metal seal** Any connection between two metal parts that prevents fluid or gas from moving through the connection. It can be a threaded coupling, a cone compression fitting such as a Swagelok fitting, a C-ring, or a welded connection.
- MREFC** Major Research Equipment and Eacilities Centers. An NSF program that provided funding for SAFOD.
- Potting** Encapsulating.
- Qualified** Has passed tests specifically for intended application.
- Reheading** Reattaching the cable head to the wireline.
- Swagelok** A type of tube fitting that employs a metal-to-metal seal to block the passage of fluid and gas between the inside and outside of the tube.
- Viton Duro O-rings** Similar to Kalrez O-rings but with somewhat lower compression-set and resistance to chemicals and elevated temperature.
- Wet side** The wellbore fluid side of the cable head. The dry side would be the internal electronics side.