## TN159 - Seismology Operations

### Motivation

The primary objective of the Keck funded experiment is to monitor the linkages between episodic deformation, fluid venting and microbial productivity at two plate boundary sites, the Endeavour ridge and the intersection of the Nootka Fault and Cascadia Margin. In order to monitor episodic deformation it is necessary to deploy carefully designed seafloor seismic networks to provide accurate locations and fault characteristics of local and regional earthquakes and to record other signals of interest such as volcanic tremor. Seafloor seismic data has been traditionally recorded with short deployments of autonomous narrowband ocean bottom seismographs (OBSs) that sink freely to the seafloor. While intermediate-bandwidth OBSs are now available, and advances in low power electronics have extended deployments to 1 year, all free fall OBSs are prone to poor coupling to the seafloor and noise generated by ocean currents. In order to overcome these problems, the Keck experiment is using two novel instrument packages that have been developed at MBARI, a broadband seismometer and a short period corehole seismometer both of which are deployed by ROV beneath the seafloor. These instruments should provide high-quality seismic data that will be equivalent to that expected of the NEPTUNE seismic network.

### Operational Objective

The operational objective of the seismology component of this cruise was to deploy a small network of well-coupled seismometers around the high-temperature vent fields on the central Endeavour Segment using ROPOS. The network was designed with an instrument spacing of ~3 km in order to accurately locate small crustal earthquakes beneath the vent fields. The network was to comprise one buried broadband seismometer and seven short-period corehole seismometers, five of which were to be deployed in holes previously drilled in basalt and two in concrete monuments deployed on sediments. All instruments were to be configured to be deployed to record data for one year. The goal was to deploy all the instruments on the first half of the cruise and to revisit the broadband in the second half to check that the automatic releveling and centering had worked as the newly buried broadband settled. The longer term objectives are to recover the date and refurbish this network next summer and to then sustain a seismic network on the Endeavour for multiple years until it becomes part or is succeeded by the NEPTUNE cabled seismic network.

### Instruments

The short-period seismometer [*Stakes et al.*, 1998] was developed by Geosense with support from and in collaboration with MBARI. It comprises three orthogonal 4.5 Hz Mark Products L-28 geophones in a 2.5”-diameter, 15”-long titanium housing which is designed to be deployed horizontally. A biaxial electronic tilt sensor is mounted adjacent to the geophones and two flashing LEDs are used during the deployment to indicate that the pitch and roll of the sensor are level within tolerances. For this cruise, these tolerances were set to ±5° for roll and ±7.5° for pitch. The sensor is connected by a 4-m cable to a 17" Benthos sphere that contains the logger and batteries. The seismometer has good response down to 1 Hz and samples at 128 Hz with the anti-alias filter conservatively set to 32 Hz.

The broadband seismometer [*Stakes et al.*, 2000] was developed collaboratively by MBARI and UC Berkeley and modified for deep water deployment with support from the Keck grant and MBARI. The sensor package houses a Guralp Triaxial Broadband Ocean Bottom system comprising a Guralp CMG-3T sensor with a flat response from periods of 360 - 0.02 s (50 Hz), a ±30° leveling system, a clock, and a digitizer. The sensor package is housed in a titanium sphere that was custom designed by MBARI for the Keck experiment in order to facilitate deployments in water depths up to 3000 m. On the seafloor the sensor is deployed within a buried and excavated PVC caisson and then buried by glass beads. The is sensor connected by a 20 m cable to a frame that holds 4 17" Benthos spheres; one contains the data logger and three contain lithium battery packs (the sensor power requirements are 1.8 W).

The Keck project is building 3 broadband systems and we had originally planned to deploy 2 broadband and 6 corehole instruments. However delays in the procurement of the broadband components limited the testing of the sensors and for this reason and because the deployment procedure was complex we decided to deploy only one broadband this year and to replace the other instrument with a short period sensor.

**Operational Summary**

All the seismology operational objectives were accomplished. The network was successfully deployed as planned and several waveforms were recovered from the broadband seismometer - the data quality is excellent. The details of the network are summarized in Table 1. The first seismometer deployed was a short-period sensor inserted in a concrete block (seismonument) at site C4 in dive R706 early on June 26. Since the sensor was preinserted in the concrete monument this procedure was relatively straight forward and required only half and hour of bottom time.

The next seismometer deployed was the broadband at site B11 and this proved to be very challenging. Prior to dive R706, we had recognized that there were problems with the serial connections to the broadband data logger through ROPOS. These are necessary to carry timing information and to enable two-way communications. The timing channels were working but the multiplexer on the ROPOS cage did not provide the streaming connections required by the broadband. This problem was solved by rerouting the communication channels through a single unused twisted pair in the tether between the cage and ROV and using an SHM-NPR ("Shalom Nippers") to get a dedicated two-way serial connection. However identifying the problem and implementing the solution took up a total of 18 hours during which we deployed moorings and collected CTDs.

The broadband deployment was planned for a single 24-hour long dive (R707) which started on the morning of July 27. ROPOS was deployed with the caisson, glass beads, and staples on a pallet hanging from the battery/logger frame which was in turn hanging from the cage. A dunk test had shown that it was necessary to rebalast the frame to account for the lighter weight of the logger sphere (relative to the 3 battery spheres). The sensor (ID # 1055) was carried down on the porch. The deployment procedure went fairly well. After releasing the packages from the cage we set down the seismometer which rolled down into a small depression. It took some time to clear the tag lines, we quickly found a suitable site to bury the caisson about 14 m from the logger frame. The burial process went well and took about 2.5 hours of vacuuming with periodic breaks to "sit" on the caisson. The seismometer was carefully deployed and oriented in the hole and one bag of beads was released into the caisson. We then hooked up seismometer and ROV to the data logger. The logger was working but the seismometer would not boot - it would repeatedly get half way through the process before aborting. Unplugging and replugging had no effect. We had no choice but to recover the sensor and terminate the dive after spending nearly 11 hours on the bottom. Immediately upon recovery, the sensor boot problems repeated themselves in the lab and we initially suspected that the sensor may have been damaged during the deployment procedure. However, later lab tests showed that the seismometer was booting successfully so there may be temperature related problems (there was no time for cold room tests at MBARI although Guralp did place the sensor in a cold room for two weeks to calibrate the clocks). Because the sensor cannot be safely opened on a rolling ship, it will not be possible to troubleshoot sensor #1055 until after the cruise.

After losing 4 frustrating days to bad weather, we returned to the broadband site (dive R708) late in the evening of June 31 with the backup sensor (ID #1047). Tests in the UC Berkeley vault had shown that this sensor was noisy. This may have been the result of a loose wire that was touching the housing, a problem that was fixed when the sensor as prepared for sea but there was no time to repeat the tests. Sensor #1047 also suffered from lost data packets in the UC Berkeley vault, a problem that might be specific to the long cables and telemetry system employed in the vault. Nevertheless, we had previously agreed that it was critical to the project to deploy at least one broadband this year and even if the noise and packet-loss problems persist the sensor would still return seismically useful data.

Dive R708 went well. It proved necessary to revacuum the caisson to fully insert the seismometer but before doing this we connected up the ROV to the data logger and seismometer and were relieved to find everything working. It was straightforward to deploy and orient the seismometer. The deployment of 7 bags of glass beads takes a long time (nearly 5 hours). The nozzles are fragile and difficult to open and it is often necessary to rip the bag and the process of stowing the empty bags on the caisson pallet is also time-consuming. However, after completing the process the sensor and caisson rim are completely buried. We insert 4 staples to secure the sensor cable near the caisson and then plug the ROV back into the logger. We successfully level and center the seismometer and collect good timing data but the compass (magnetometer) does not appear to be working. We leave the site after spending over 11 hours on bottom.

**Table: Seismic Network**

| Site ID | C1 | C2 | C3 | C4 | C5 | C6 | C7 | B11 |
|---|---|---|---|---|---|---|---|---|
| Location | Sasquatch | Main Field | Mothra | SE Flank | NE Flank | NW Flank | SW Flank | W Flank |
| [1]Sensor | SP | SP | SP | SP | SP | SP | SP | BB |
| Installation | Corehole | Corehole | Corehole | Monument | Corehole | Corehole | Monument | Buried |
| Site Description | Between Pillows | Attached Pillow | Detached Pillow | Sediment | Attached Pillow | Massive Flow | | Sediment |
| Latitude, N | 47º 59.704' | 47º 56.936' | 47º 55.443' | 47º 56.4004' | 47º 58.210' | 47º 58.782' | 47° 56.194' | 47º 57.5652, |
| Longitude, W | 129º 4.328' | 129º 5.925' | 129º 6.490' | 129º 3.6030 | 129º 3.356' | 129º 6.607' | 129° 8.454' | 129º 7.5222' |
| [2]Depth, m | (2158) | 2202 (2191) | 2285 (2279) | 2340 | 2340 (2330) | 2160 (2153) | 2381 | 2377 |
| Azimuth, ° | 103 | 220 | 040 | 062 | 182 | 148 | 320 | 0 |
| Hole Length, " | >=15 | 12 | 14.5 | - | 21 | 13.5 | - | - |
| [3]Hole Pitch, ° | $5.7^T/5.9^G$ | $5.2^T/6.2^G$ | $5.1^J/6.8^G$ | - | $3.7^J$ | $5.3^J$ | - | - |
| Distance Inserted, " | | 9-10" | 10" | - | 11" | 10" | - | - |
| Pitch < 7.5º | Yes | Yes | Yes | Yes | No (~8º) | No (~10º) | Yes | |
| Roll < 5º | Yes | Yes | Yes | Yes | Yes | Yes | Yes | |
| Dive # | | R709 | R711 | R706 | R713 | R713 | R715 | R707/R708 |
| Date Installed | | 08/03/03 | 08/03/05 | 07/26/03 | 08/06/03 | 08/06/03 | | 07/31/03 |
| Homer ID | 88 | 91 | 11 | 10 | 13 | 12 | 13 | 92 |

[1]Notation is as follows: SP, Short Period Seismometer; BB, Broadband seismometer. [2]Depths in parentheses are from Tiburon or Jason II on previous cruises. [3] Notation for superscripts following hole pitches is as follows: T, Tiburon; G, Maurice Tivey's Geocompass; J, Jason II.

The second short period was deployed in a corehole at site C2 in the Main field early on August 3 as the first task of dive R709. This process took 1 1/3 hours at the site and the main problem was that the hockey puck grip on the sensor rotated during the insertion process. Following a dive devoted to CanRIDGE objectives, the third short period seismometer was deployed in a corehole at site C3 in Mothra at the start of dive R711 early on August 5. This also took 1 1/3 hours.

The primary objective of Dive R713 on August 6 was to deploy two seismometers in coreholes on the NE and NW flanks (sites C5 and C6). It took some ingenuity to load two instruments on the ROV but the deployments go well and take about 1½ and ¾ hour respectively. The only problem is that neither sensor is within the ±7.5° pitch tolerance although the relevant LED will come on when the sensor is gripped by the manipulator indicating that they are close.

On August 7, a the CCGV Tanu was used to swap out members of the scientific party, including all the seismologists with the exception of Paul McGill. After this data, short period seismometers C1 and C7 were successfully replaced and the broadband was revisied to verify leveling, data collection and sample the data.

**Recommendations**

*Broadband Deployments*

1. Improve ballasting of the logger/battery frame so it falls horizontally and more slowly
2. Add hockey pucks to the center of the frame to facilitate the connection of the ROV plug
3. Devise a better (quicker) means of deploying the glass beads. Eliminate the valves and instead rip the bags. Devise a quicker means to stow them

*Short Period Deployments*

1. Neither the Tiburon or Jason II ROVs can drill horizontal holes because the horizontal thrust needed to apply pressure to the drill bit also pivots the ROV so that the drill bit points downwards. Pitches of up to 10° may be entirely acceptable but one might consider designing custom short-period sensors so that the orthogonal sensors are oriented horizontally and vertically for a hole pitching at ~7.5°.

**References**

Stakes, D., J. McClain, T. VanZandt, P.McGill, and M. Begnaud, Corehole seismometer development for low-noise seismic data in a long-term seafloor observatory, *Geophys. Res. Lett.*, *25*, 2745-2748, 1998.

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