GEO-SEQ Subtask 2.3.4: Microseismic Monitoring and Analysis

Status Report – March 1, 2011

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Executive Summary

LBNL's recent analysis of the microseismic data being acquired at well KB-601 has produced a new result of significantly more microseismic activity than previously estimated. During 2009-2010, there was background activity of 1 or 2 events per day with a notable increase during the spring-summer months of up to 20 or more events in a signal day (Figure 1). This level of activity warrants increased effort to obtain quantitative information, and supports plans for expansion of the microseismic monitoring.

Quantitative interpretation of these events, including locations, is still hampered by physically unrealistic data from some sensors and uncertainty in which sensors are being recorded and their depth. We now believe that some quantitative analysis will be possible, building upon LBNL's earlier work and analysis conducted by Pinnacle, and utilizing the sledge-hammer tests conducted in the fall of 2010 by the JIP. Current acquisition problems include electrical noise, lack of GPS clock timing, and the sensor uncertainty. To address the acquisition problems, we continue to recommend an active-source recording test with full 144 channel capability (or at least 48 channel). We also recommend a site visit for debugging and repair by a technician knowledgeable in the REF TEK recording system and microseismic acquisition.

Detection of Events

We have developed an event detection processing flow which has been successful in identifying more events than previous reports. We also have now applied this processing to the entire 2009-2010 data set. An important assumption in this processing and analysis is that the non-physical data seen on 3 of the 6 recorded geophones is due to equipment problems or incorrect wiring of the geophones. Since the uphole wiring has been checked, it seems likely that there are downhole wiring problems. We are now using only two geophones (from one of the three REF TEK data recorders) to identify seismic events. Additionally, we are using a spike removal algorithm along with a time-shifting algorithm (as first applied by Pinnacle) and an automatic event detection algorithm. Spike removal is necessary because of numerous noise spikes presumably electrical in nature. Time shifting (utilizing the electrical noise spikes) is necessary because the recording systems are not receiving GPS clock signals and are therefore drifting in time. Applying these processing tools to the entire data set, and then interactively quality controlling all events (i.e. visual check by geophysicist) has allowed us to develop confidence in the interpretation of these events as ‘real’ seismic events from the subsurface (see Appendix 1 for details). We have thus been able to develop a histogram of events over time. The resulting histogram for 2010 is shown in Figure 1, in which a significant increase in microseismic activity is seen from March to about July 2010, with often over 10 events per day (labeled as period B). Please note that this data is considered preliminary pending further quality control. Nonetheless, this level of activity is a significant increase from what was seen in the previously analyzed data (period A in Figure 1) and the large number of events allows more certainty in the interpretation of these as ‘real’ seismic events (as opposed to surface/cultural noise or electrical noise. We also have observed a significant increase in the electrical noise spikes beginning approximately in period C.

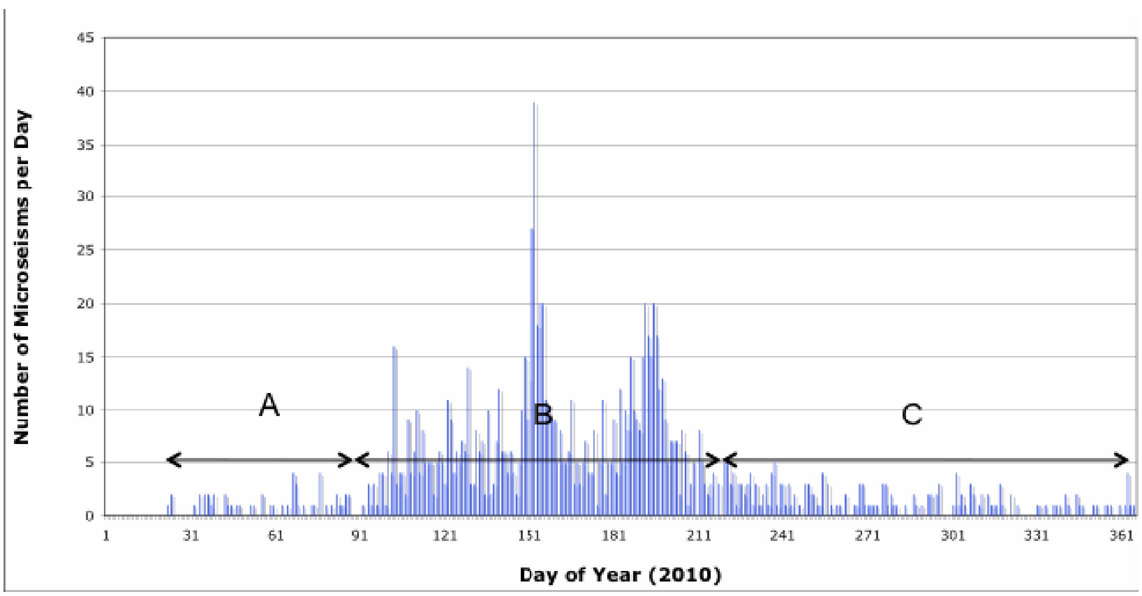

Figure 1   A preliminary histogram of microseismic events in 2010. Three distinct periods are identified: period A (approx Jan-March 2010) has low activity and corresponds to the initial data set used by LBNL and Pinnacle in previous reports; period B (approx. April-July 2010) has noticeably increased microseismic activity; period C (approx August-Dec 2010) has decreasing activity, similar to period A.

Summary and Recommendations

We now believe that there are many natural microseismic events being recorded (over 1000). Furthermore, the strong time-dependence of the number of events warrants further investigation. Quantitative interpretation of these events, including locations, is still hampered by some physically unrealistic data and uncertainty in which sensors are being recorded. We now believe that some quantitative analysis will be possible, building upon LBNL’s earlier work and analysis conducted by

Pinnacle, and utilizing the sledgehammer tests conducted in the fall of 2010 by the JIP. However determining the true sensor parameters (i.e. depth and component mapping to recorded data channels), as well as the true time base of each recording system, remains work in progress. While the Pinnacle analysis made significant headway, we have determined some remaining errors. We are currently using numerical modeling (2D finite-difference wave equation) to help understand the data and determine likely sensor parameters (see Appendix 2).

Current acquisition problems include electrical noise, lack of GPS clock timing, and the sensor uncertainty. To address the acquisition problems, we continue to recommend an active-source recording test with full 144-channel capability (or at least 48 channel). We also recommend a site visit for debugging and repair by a technician knowledgeable in the REF TEK recording system and microseismic acquisition.

Appendix 1: Microseismic Events

Shown below (Figures A-1 to A-4) are four example microseismic events, recorded on levels 1 and 2 (channels 1-6). In all cases the first arrival (P-wave) is seen predominantly on the vertical component, while the secondary arrival (S-wave) is seen on the horizontal components. Figure A-5 shows the spectral content of one event. The high frequency limit of the data is apparently controlled by the anti-alias filter (-3 dB at 125 Hz), suggesting that higher sampling rates could allow higher frequencies to be recorded.

Following the identification of over 1000 events, a histogram of events per day was made and is shown in Figure A-6. The change in number of events per day is notable, with a large increase in mid-2010.

As a test of the possibility of human induced (cultural) events, we generated a histogram of events for each hour of the day. No significant peak during daylight hours is seen, indicating that the events are natural in origin.

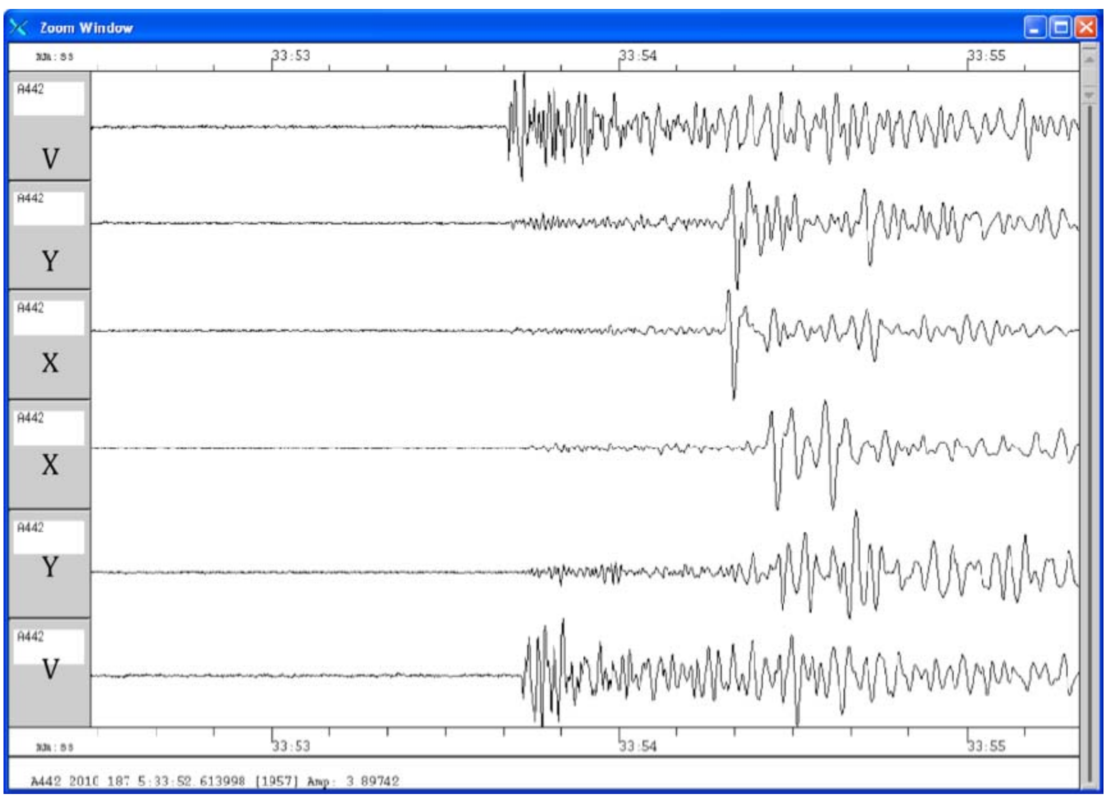

Figure A-1 Sample microseismic event.

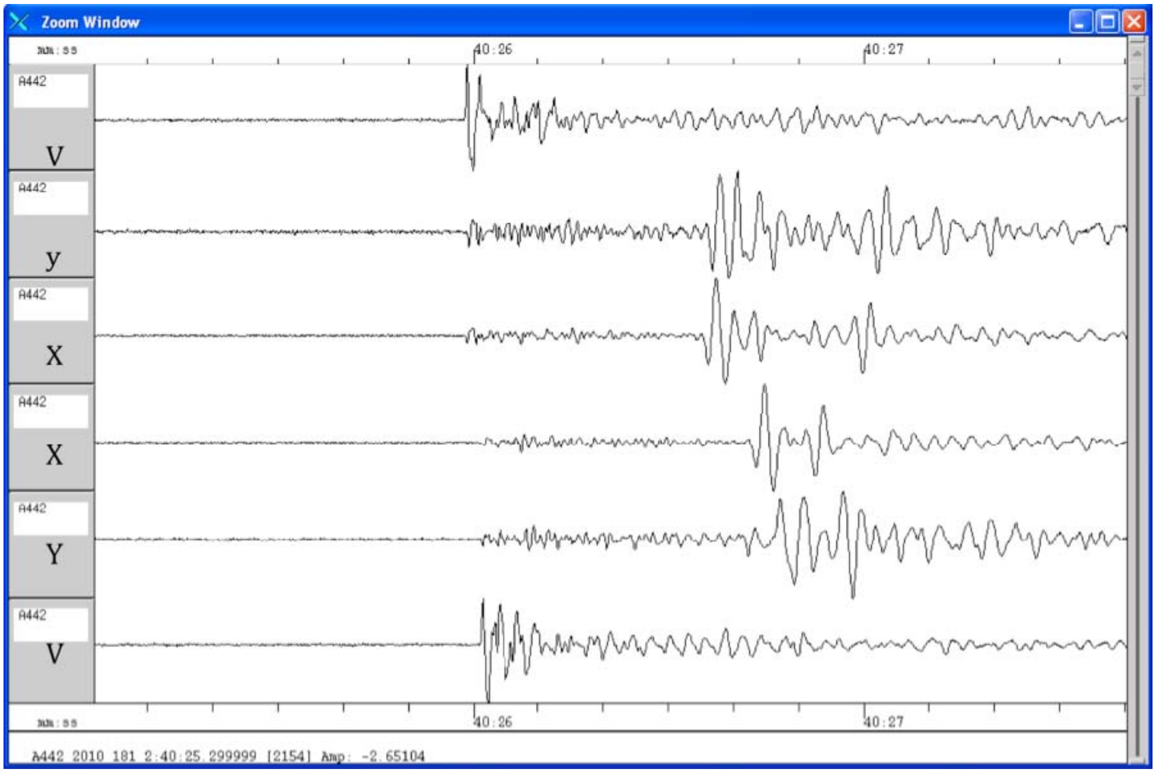

Figure A-2 Sample microseismic event.

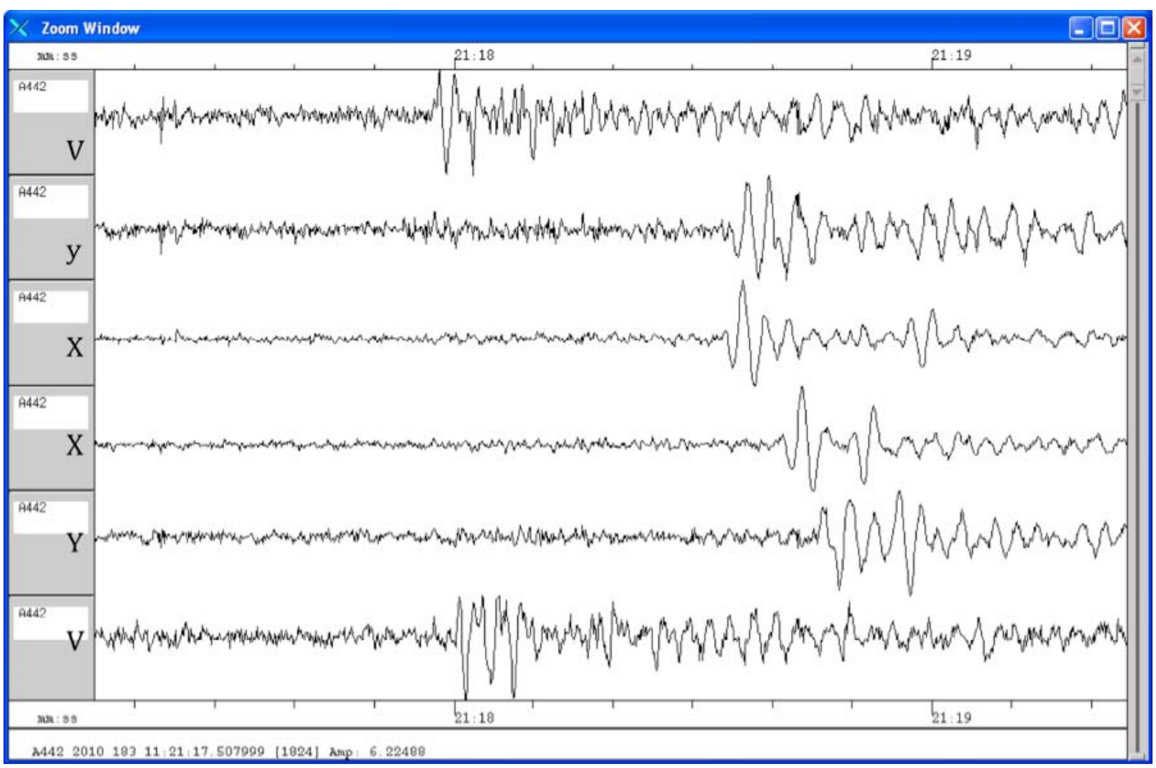

Figure A-3. Sample microseismic event.

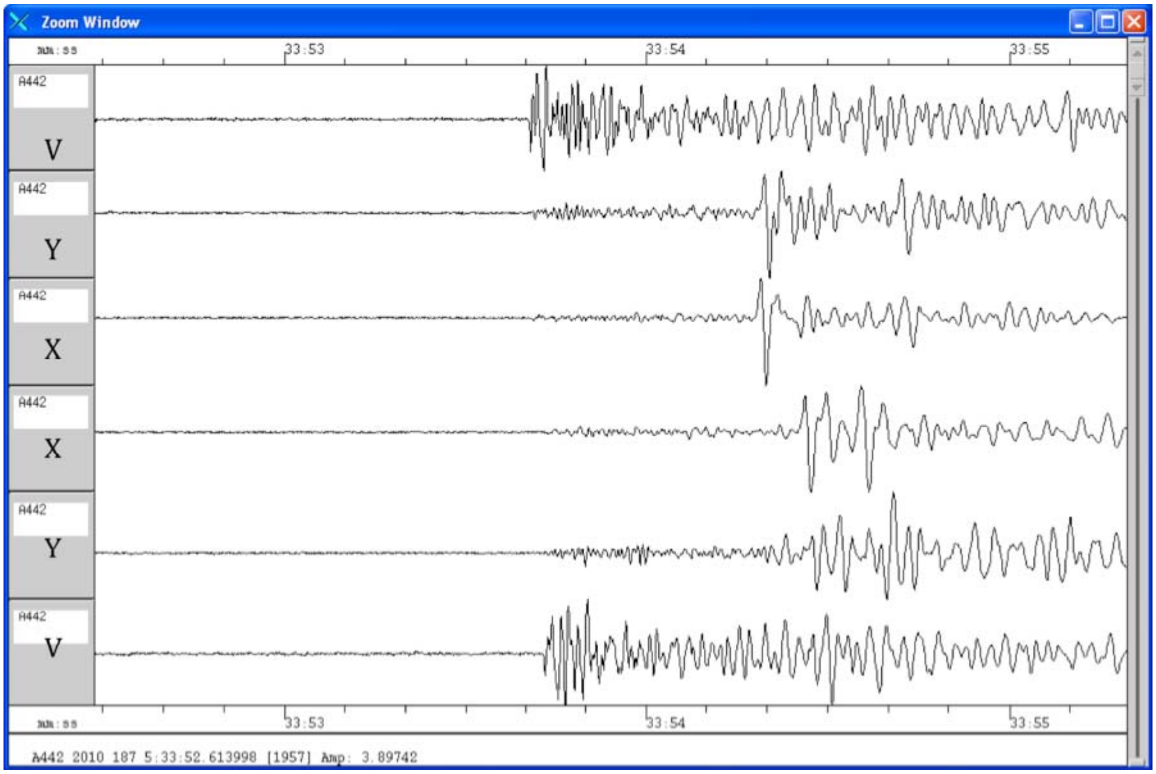

Figure A-4 Sample microseismic event.

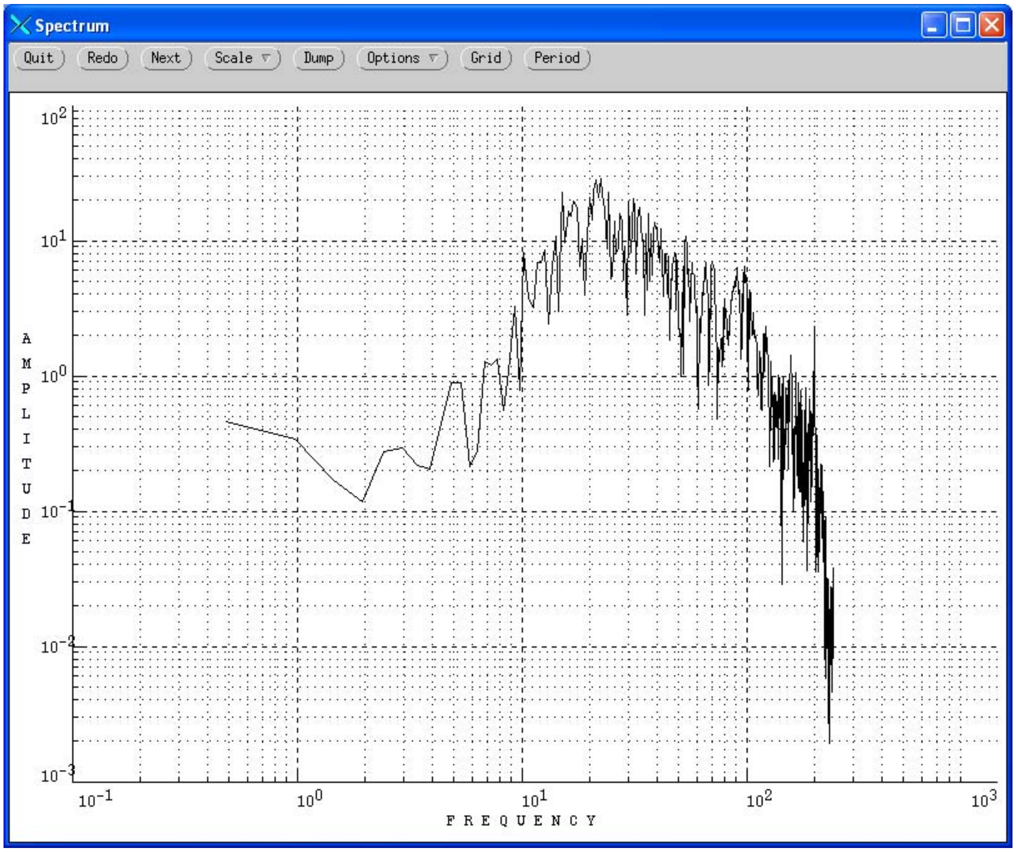

Figure A-5. Spectral content of a sample event.

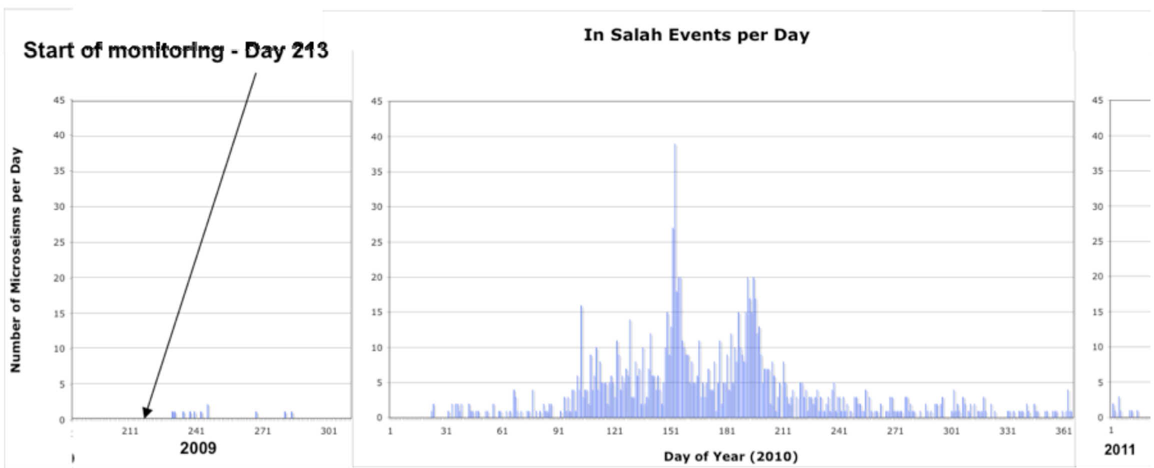

Figure A-6 Histogram of events per day over the available recorded data.

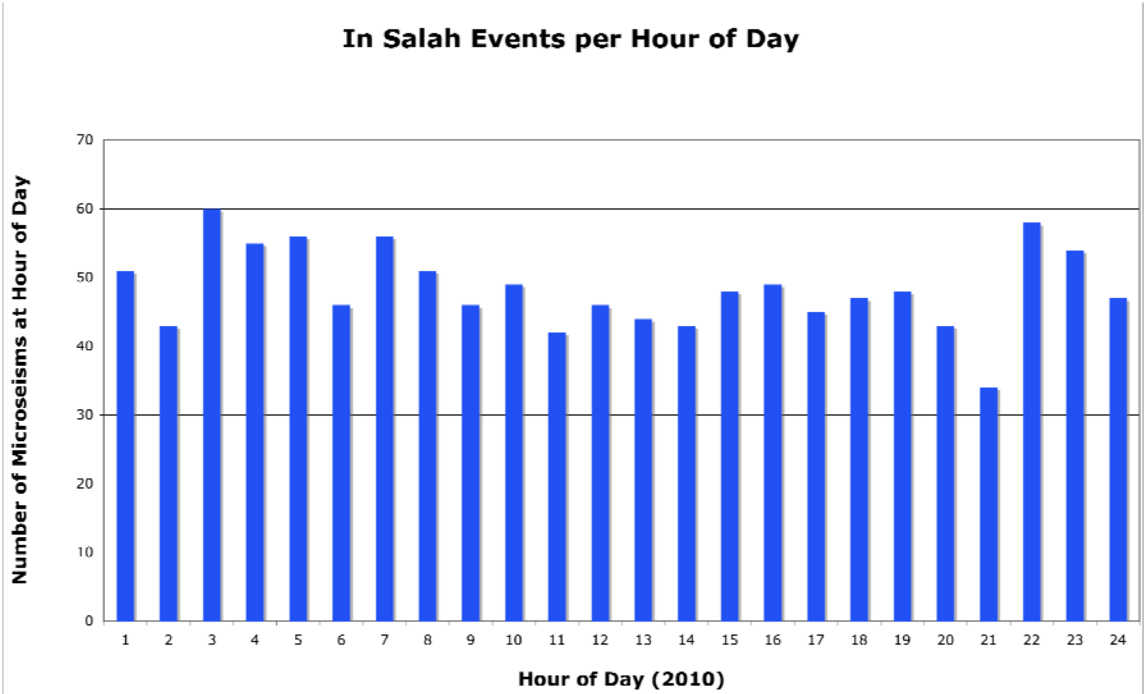

Figure A-7 Histogram of events recorded in 2010 for each hour of the day. Events due to cultural activity would be expected to peak during daylight working hours.

Acknowledgement:

This work was supported by the GEOSEQ project for the Assistant Secretary for Fossil Energy, Office of Coal and Power Systems through the National Energy Technology Laboratory, of the U.S. Department of Energy, under contract No. DE-AC02-05CH11231.

Appendix 2: Analysis note on microseismic sensors

A basis of these notes is Pinnacle's "Microseismic Precessing report for the In Salah CO2 Storage Project" from October 13, 2010 where orientations of the sensors were determined and several micro-seismic events were located. Since then LBNL has found that some of the channels had incorrect wiring assumptions and some data channels are likely displaced from their assumed positions. These notes aim to clear some of the issues.

1. Coordinate systems

In the Pinnacle report, the locations of the hammer calibration shots (HCS) are given in the right Cartesian system with Z- axis pointing up and X- axis pointing East (Figure 1).

Microseismic Processing
In Salah CO2 Storage Project
References

Location	X	Y	Elev (m)	Offset	GMT Start	GMT End
Kb-601	422054	3226927	454			
X01	422180	3226772	453	200	7:54	7:55
X02	422258	3226921	456	204	8:01	8:03
X03	422122	3227111	455	197	8:14	8:16
X04	421981	3227101	462	189	8:26	8:28
X05	421954	3226809	455	155	8:39	8:40

Table 1. Hammer Calibration Shots taken on August 7, 2010 (GMT).

Figure 1.

In geophone-channel assignment the report uses left handed Z-up reference system (Figure 2), which is rather confusing and needs clarification. It would be natural to assume that each 3C geophone accembly has right handed local orientation, but this needs to be verified.

Level	X	Y	Z
1 (top)	4	5	6
2	1	2	3
3	10 (no signal)	11 (no signal)	12
4	7	8	9 (inverted)
5	16	17	18
6 (bottom)	13 (no signal)	14 (no signal)	15

Table 2. Geophone to channel assignment. Left-handed Z-up reference system.

Figure 2.

The rotation angles for horizontal geophones are determined by Pinnacle in the right-handed system with Z- axis pointing down and X axis pointing North (Figure 3).

Level	Angle
1	-42.08
2	-33.15
3	n/a
4	-123.72
5	-3.23
6	n/a

Table 3. Geophone rotation of X axis with respect to North in degrees (positive is clockwise looking down). Note that the angle for levels 3 and 6 cannot be determined because the horizontal components are inoperative.

Figure 3.

In our analysis of the hammer shots, the first breaks of the vertical components are positive, which indicates that the vertical geophones are wired for downward positive voltage. Additionally, LBNL confirms Pinnacle's observation that channel 9 (level 4, Z- component) is reverse polarity from this standard.

2. Geophone Level

Our analysis of the first three recorded levels (3-component geophone locations) indicate they could follow configurations shown on Table 2 (Figure 2). However, levels 4-6 record phases from HCS as arriving simultaneously. The same is true for micro-seismic (MS) events. This is non-physical and can not represent 'real' seisimc data. Figure 4 shows traces recorded from HCS. Seismic arrivals for levels 4-6 have the same arrival times within the 2 ms digitizing time interval. The results of numerical modeling (Figure 5) give the estimates of at least 20 ms for arrival time differences between levels. Possible explanations are that either the geophones assumed to be located at levels 4-6 are in fact located at the same level, or there is some sort of cross-talk between data channels.

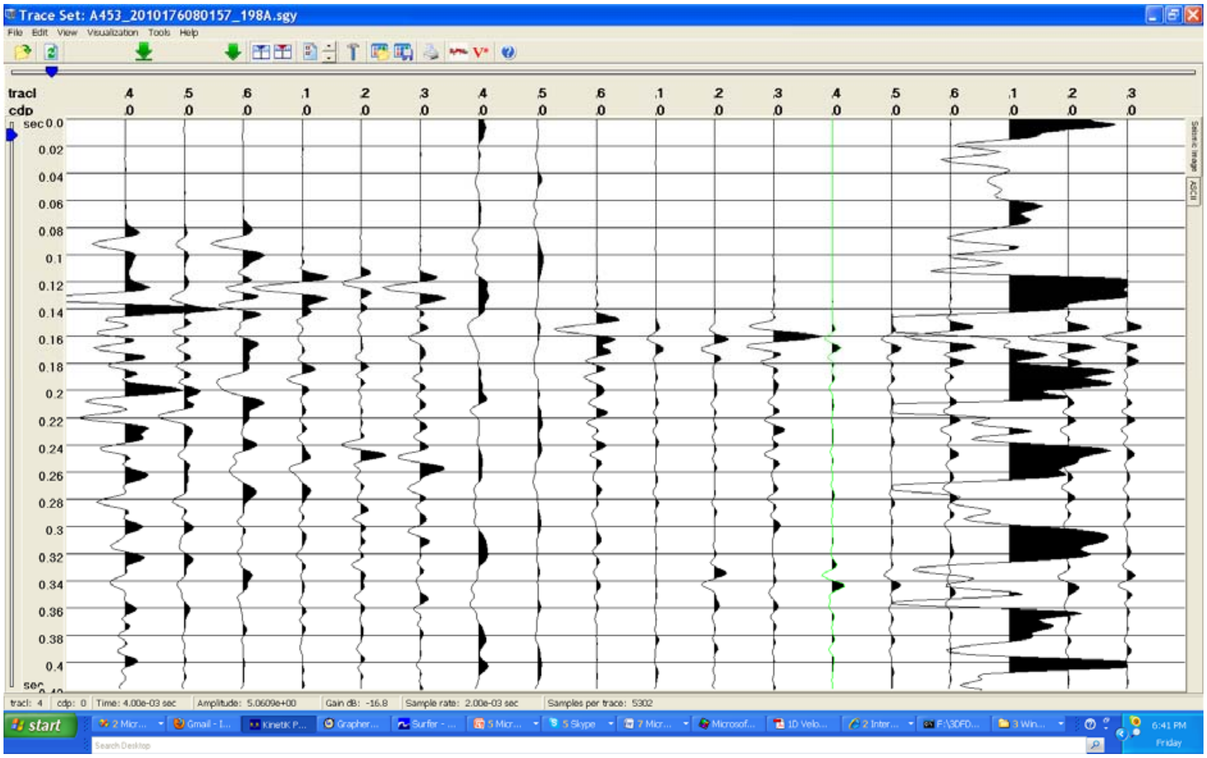

Figure 4. Microseismic event data. Field channel number listed on top, time in seconds, true relative amplitude. Note the same first arrival time on the levels 4-6 (traces 10-18, left to right).

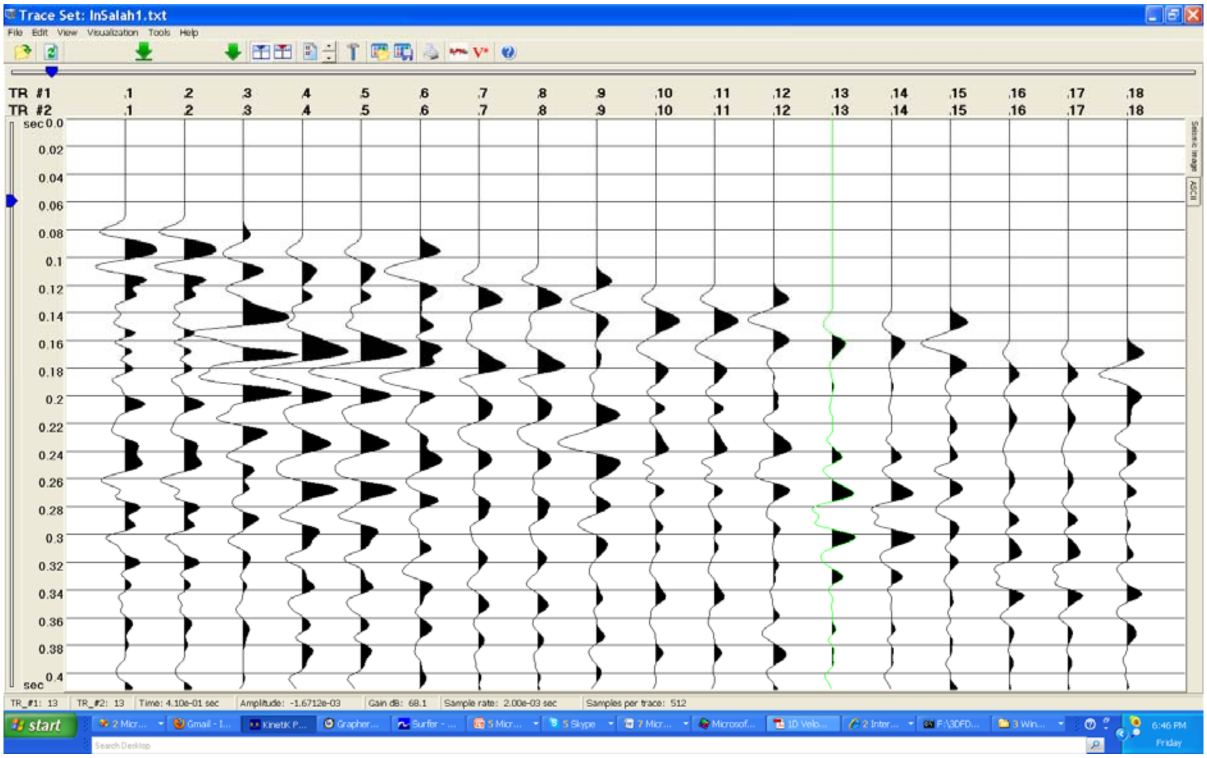

Figure 5. Finite-difference modeling of hammer shot from Figure 4. Geophone components are in order x,y,z for each level. Note the delayed arrival time for level 4-6 (traces 10-18, left to right)) as compared to Figure 4.

3. Geophone component to channel assignment

Visual analysis of traces indicates that the channels of level 2 follow ZYX sequence, not XYZ order as it was assumed in the processing. This can be illustrated by records both for HCS (Figure 6) and MS (Figure 7). Note that relative angle for x-components of levels 1 and 2 is just 9 degrees (Figure 3) so we expect similar response for the x- and y-component data from these two levels.

Hammer shot
A442_2010176081054_844A.sgy

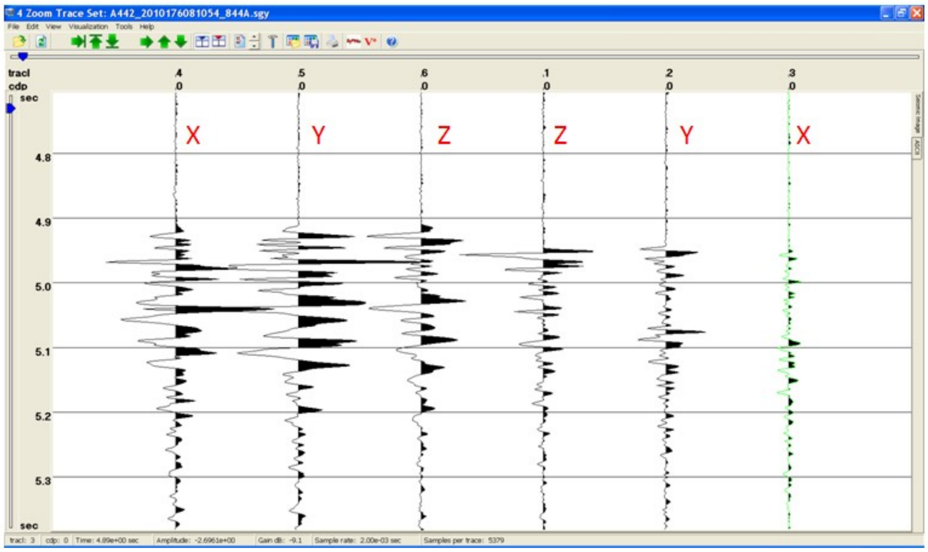

Figure 6. Components for levels 1 and 2 for HCS, inspection shows they have have different order. The interpreted components are as labeled. Note the similarity polarity and waveforms of the first arrivals for the pairs marked by the same orientation.

MS event
2010084140734_982.sgy

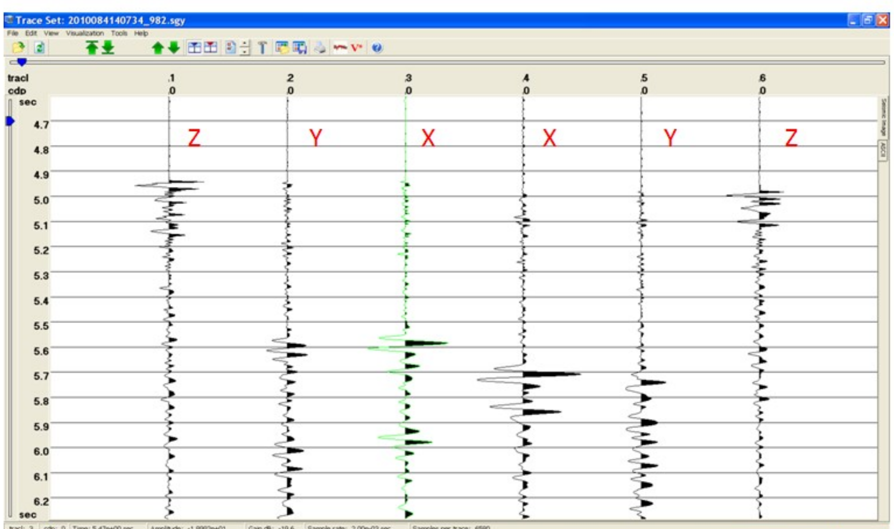

Figure 7. Traces for levels 1-2 for MS. Here first three traces belong to level 1 and traces 4-6 belong to level 2. Note same polarity and similar waveforms and amplitudes of the P and S arrivals for the pairs marked by the same orientation.

Following inspection of hammer shots and microseismic events, we have modified the channel assignments from the original wiring diagrams. The corrected geophone to channel assignment is given in the table in Figure 8. Since the component channel assignment has changed from the original wiring diagrams and the analysis in the Pinnacle report, we now conclude that the rotation angles for the horizontal components and event locations need re-evaluation. This will be in the next phase of work.

Level	X	Y	Z
1 (top)	4	5*	6
2	3	2	1
3	10 (no signal)	11 (no signal)	12
4 (bottom)	7	8	9 (inverted)
5 (bottom)	16	17	18
6 (bottom)	13 (no signal)	14	15

Figure 8. The corrected geophone to channel assignment. Channel 14 is working and "no signal" mark on Figure 2 is incorrect.

* Addendum: This channel is from geophone 10 m above