## **Preliminary Seismic Monitoring**

Kristine Pankow, Ph.D. University of Utah Seismic Stations

During Utah FORGE Phase 2A, the goals of Preliminary Seismic Monitoring were to: (1) install a local telemetered seismic network capable of magnitude of completeness (Mcomp) detection levels at **M** 0; (2) monitor seismicity at this Mcomp for a minimum of 30 days; (3) deploy a dense seismic network centered on the proposed drill site for ~30-days to collect additional data for seismic event detection and initial seismic velocity analysis; and (4) collect data appropriate to determine average shear wave velocity in the upper 30 m (Vs30) necessary for the PSHA work in Phase 2B. All of these goals were met in Phase 2A.

Installation for the local, five station, broadband, seismic network (Figure 1) was completed and data for all stations was telemetering by November 11, 2016. This network will remain operational through Phase 2B. For each of the five stations, a small hole is excavated and self-leveling concrete is poured to provide a level platform for the sensor. The sensor is covered to protect it from the elements and connected to a datalogger that sits next to the sensor on the ground surface (Figure 2). The stations are powered with solar and batteries, and connected to a cell modem for telemetry. The data is sent to the University of Utah Seismograph Stations (UUSS) where it is archived, and also transferred to the IRIS Data Management Center (DMC). The IRIS DMC provides a backup for the data storage and is a portal for open access to the raw waveforms. Visual daylong snap shots of the data are available as webicorders at

http://quake.utah.edu/station/heli/FOR[U,1,2,3,4].png (Figure 3).

At UUSS the data is integrated with data from the regional seismic network and fed into the UUSS Advanced National Seismic System (ANSS) Quake Monitoring Software (AQMS). Using Earthworm programs, picker and binder, new events are identified and automatically located. For events with magnitudes greater than 3.0 alarms are automatically sent to duty seismologist for timely review (within 30 minutes of origin time). For events smaller than typically detected with the regional seismic network and to achieve an Mcomp of 0, a subnet trigger specific to the Utah FORGE site has been configured. All events and triggers are reviewed by UUSS seismic analysts, and are submitted to the U. S. Geological Survey (USGS) Comprehensive Catalog (Comcat). Event details can be viewed on both the UUSS website and the USGS website (Figure 4).

From mid-November through January 20, 2017, 23 events (**M** -0.7 to 1.86) were detected and located (Table 1). These earthquakes locate primarily in the Mineral Mountains to the east-southeast of the Utah FORGE site with a few locating even further to the east (Figure 1). With one exception, all events locate at depths less than 5 km (relative to sea level). One event is deeper. The pattern and location of seismicity is consistent with what was documented in Phase 1. There had been

some concern that the windmills located near the Utah FORGE site might overwhelm seismic information. Figure 5 shows that at least in the frequency passband of local earthquakes this is not a concern. The waveforms recovered for these small earthquakes are generally of high quality (high signal-to-noise ratio).

The second part of preliminary seismic monitoring was to collect additional seismic data with a dense seismic array that could be used for additional seismic detection and for initial seismic velocity analysis. From mid-December (13<sup>th</sup> to 16<sup>th</sup>) through mid-January (13<sup>th</sup> to 15<sup>th</sup>), 96 three-component Nodal Seismic instruments (Figure 6) were deployed over the Utah FORGE site in two grid configurations (Figure 7). The grids were designed to optimize seismic detection and imaging beneath the proposed drill site. Figure 8 shows waveforms from the Nodal array for the **M** -0.66 2016-12-26 event (Table 1) originally detected with the broadband seismic network. A third array of three broadband seismometers was installed for one day (January 14) centered on FOR3 (Figure 1) in three configurations (10m, 30m, and 90m from FOR3). The data from the third array will be used to determine Vs30 at the Utah FORGE site. The data from all three arrays has been downloaded and backed-up for analysis in Phase 2B.



Figure 1. Map of seismic network (black triangles) and earthquakes detected during Phase 2A from November 10, 2016 through January 20, 2017 (red circles). Blue box, region enlarged in the inset image. Stations beginning FOR are part of network installed for the FORGE project. Stations TCRU, IMU, and NMU are part of the UUSS regional seismic network. Inset image, shows location of Utah FORGE footprint, nearby faults, and earthquakes, as a function of time from the installation of the network.



Figure 2. Seismometer installation. The seismometer is buried and enclosed in a temporary vault (orange water cooler). Solar panels are attached to a separate case that houses the datalogger and batteries.



Figure 3. Webicorder for 24-hour window beginning 10:00 local time January 26 for station FOR3. Red vertical bars show timing of potential seismic events.

## Recent Earthquake Map

Map contains earthquakes from the UUSS earthquake catalog represented with circle Earthquakes from other networks are represented with squares. Total: 126 | Largest: 3.3 | Smallest: -0.1 | Latest 2017/1/27 | Earliest: 2017/1/13 University of Utah ≈USGS ograph Stat Earthquake Hazards Program ← Latest Earthquakes M 0.5 - 18km ENE of Milford, Utah 2017-01-22 01:41:43 UTC 38.471°N 112.822°W 2.2 km depth Overview Regional Information Felt Report - Tell Us! Origin Interactive Map Interactive Map Review Status REVIEWED Magnitude Regional Information altLake City 0 0 0 0 0 01/21 18:41:44 MST 1 (1.4miles) UTAH Responses Felt Report - Tell Us! 0.5 md Depth 2.2 km Contribute to citizen science Technical Please tell us about your Time 2017-01-22 01:41:43.990 (UTC) Origin experience. Waveforms Contributed by UU<sup>2</sup> Citizen Scientist Contributions Contributed by UU<sup>2</sup> Contributed by UU<sup>2</sup> Download Event KML Contributors Search Nearby Seismicity 1. USGS National Earthquake Information Center, PDE L 2. University of Utah Seismograph Stations Last 2 hours Last 2 days Last 2 weeks Other Network ... 1 2 3 4 5 6 7

Figure 4. Event webpages. Left, from quake.utah.edu; Right, from earthquakes.usgs.gov. Detailed information about all events detected and located by UUSS are available at these two sites.

Origin		Latitude	Longitude	Depth <sup>1</sup>	Мс
_			_	( km)	
2016-11-18	21:36:38.560	38.493	-112.828	0.13	-0.01
2016-11-21	09:50:52.170	38.542	-112.565	3.50	1.16
2016-11-22	22:55:46.580	38.624	-112.542	8.74	0.83
2016-11-25	19:33:58.050	38.464	-112.789	3.81	-0.20
2016-11-26	02:24:15.740	38.545	-112.569	3.50	0.69
2016-12-01	01:36:32.040	38.486	-112.832	0.19	-0.70
2016-12-04	08:38:26.130	38.351	-112.441	4.97	1.86
2016-12-04	23:45:25.400	38.484	-112.848	-0.90	0.48
2016-12-07	14:10:06.470	38.467	-112.786	2.10	-0.23
2016-12-08	08:59:07.900	38.479	-112.834	0.29	-0.61
2016-12-18	14:24:36.740	38.483	-112.844	-0.52	-0.42
2016-12-18	23:30:28.300	38.464	-112.788	0.49	-0.19
2016-12-19	02:52:36.710	38.467	-112.791	-0.29	0.25
2016-12-24	12:17:09.340	38.466	-112.792	2.46	0.30
2016-12-25	02:09:40.550	38.484	-112.852	-0.30	-0.56
2016-12-25	15:19:34.840	38.584	-112.638	0.84	0.51
2016-12-25	23:22:16.850	38.485	-112.850	-0.89	-0.43
2016-12-26	00:54:37.870	38.478	-112.879	-0.15	-0.66
2016-12-31	06:32:36.920	38.573	-112.575	3.50	0.86
2017-01-01	05:16:21.740	38.469	-112.794	3.69	-0.33
2017-01-02	21:53:46.080	38.552	-112.650	0.31	0.49
2017-01-05	12:41:46.070	38.484	-112.469	2.73	0.95
2017-01-13	05:12:49.940	38.487	-112.853	0.04	-0.36

Table 1. Seismic events detected near Utah Forge Site

<sup>1</sup>Depths are reported relative to sea level. Negative depths reflect the high topography in the area.



Figure 5. Example waveforms from an **M** 0 earthquake located to the east of the Utah FORGE site plotted in distance from the event from bottom to top. FOR, broadband stations installed for the FORGE project. NMU, a short-period regional seismic station.



Figure 6. Nodal seismometers (right) are small stand-alone fully contained units. The units are charged, configured, and data downloaded using a special rack (left).



Figure 7. Location of the Nodal seismic instruments deployed in December and early January. There are two grids. The internal grid roughly centered on the proposed drill site has a spacing of  $\sim$ 600m. The outer grid  $\sim$ 4km.



Figure 8. Example vertical-component waveforms from the Nodal seismic network for an **M** -0.66 earthquake located to the east of the Utah FORGE site. The x-axis indicates the time starting at the earthquake origin time. Nodal stations labeled in the top right corner correspond to locations shown in Figure 7. "P" indicates the *P* arrivals.