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Surface Seismic Monitoring Report Sulphur Mines Salt Dome Broadband Seismic Array

Report Period : December 1-15, 2023

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Using results from Nanometrics

Summary

- No seismic detections or locations were reported from December 1-15, 2023.
- All five broadband stations were operational from December 1-15.

Broadband Trillium Compact Seismic Array

Nanometrics (<https://nanometrics.ca/home>) operates and processes data for the broadband array. The broadband array was fully functional from December 1-15, 2023.

The broadband station locations are shown in Figure 1 and listed in Table 1. Figure 2 shows the broadband network amplitude over time from December 1-15, 2023 (background noise plot). The noisiest station during this time period is SUL01, followed by SUL02 and the quietest stations in this time period were stations SUL03 and SUL05.

The upcoming plan for the seismic network is to move station SUL01 approximately 2400 feet to the WNW (Figure 1, labeled SUL01 Trillium NEW LOC) and add an additional station to the west of the dome, SUL06 (labeled "SUL06 PROPOSED TRILLIUM"). The station moves will likely occur sometime in Q1 2024.

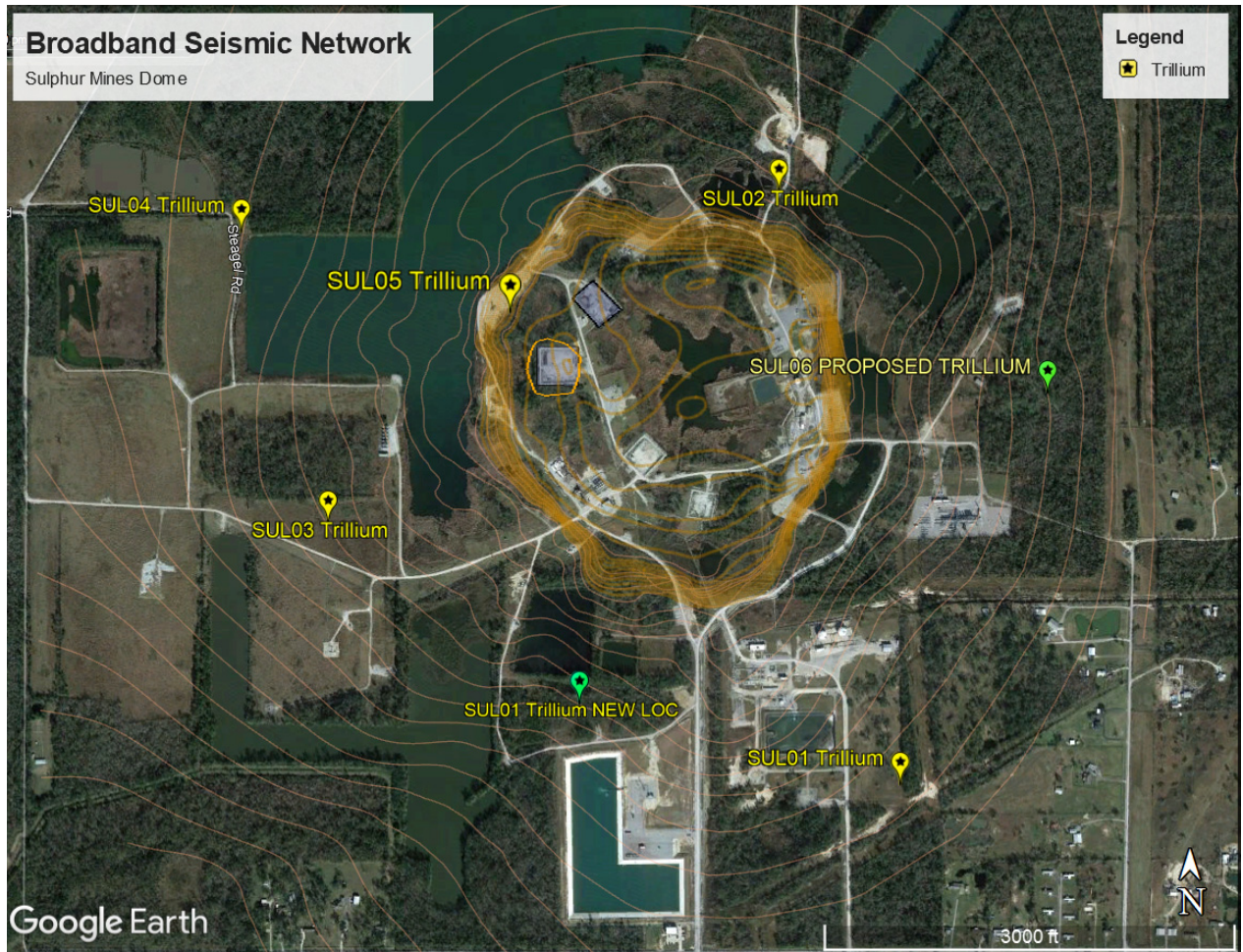


Figure 1. Google Earth map image showing the location of the broadband seismic (Trillium Compact Sensors, yellow symbols and labels) stations near and at the Sulphur Mines Salt Dome. The contours are the salt and cap rock elevations, the orange circle is the general outline of Cavern 7. Two new stations are shown in green symbols, SUL01 Trillium NEW LOC is the proposed approximate location for moving SUL01, and a new station SUL06 PROPOSED TRILLIUM is the approximate location for a new seismic station.

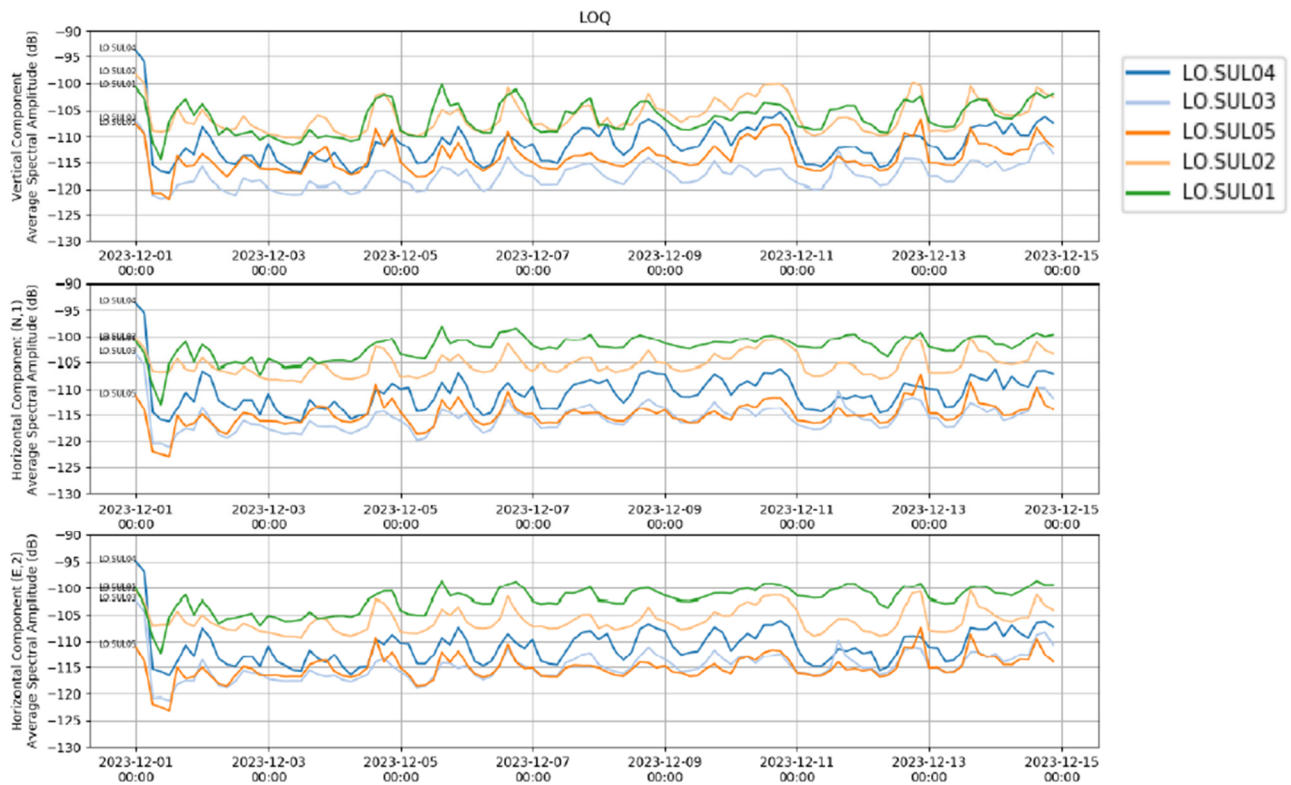


Figure 2. Average spectral amplitudes in decibels on the five broadband sensor from November 15-30, 2023. The upper plot is the vertical component, the middle and lower plots are the horizontal component (middle is north-south and lower plot is east-west component).

Magnitude Detectability. The magnitude detectability of the network for three representative noise periods is shown in Appendix 2. The modeling was updated to show the magnitude of completeness for three different attenuation values from high attenuation ($Q=100$) to lower attenuation ($Q=200$).

Appendix 1. Seismic Station Locations

Table 1. Seismic Station locations and operational dates at Sulphur Mines Dome (to December 1, 2023). Temporary Station locations and start and end dates provided by Westlake. Trillium station locations provided by Nanometrics.

Station	LAT WGS84	LON WGS84	Date start	Date end
Temp_1a	30.2575	-93.4123	1/30/2023	2/9/2023
Temp_1b	30.2534	-93.4135	2/9/2023	4/3/2023
Temp_2a	30.2570	-93.4097	1/30/2023	2/9/2023
Temp_2b	30.2555	-93.4132	2/9/2023	2/27/2023
Temp_2c	30.2547	-93.4138	2/27/2023	4/5/2023
Temp_3a	30.2533	-93.4091	1/30/2023	2/9/2023
Temp_3b	30.2563	-93.4146	2/9/2023	4/5/2023
Temp_4a	30.2486	-93.4123	1/30/2023	2/27/2023
Temp_4b	30.2507	-93.4121	2/27/2023	3/8/2023
Temp_4c	30.2506	-93.4100	3/8/2023	3/15/2023
Temp_4d	30.2503	-93.4119	3/15/2023	est 4/3/2023
Temp_5a	30.2502	-93.4156	1/30/2023	2/27/2023
Temp_5b	30.2507	-93.4153	2/27/2023	3/15/2023
Temp_5c	30.2504	-93.4140	3/15/2023	est 4/3/2023
Temp_6a	30.2532	-93.4166	1/30/2023	3/15/2023
Temp_6b	30.2529	-93.4161	3/15/2023	4/4/2023
Temp_7a	30.2547	-93.4161	1/30/2023	4/3/2023
Semi Perm S01	30.2453	-93.4073	4/4/2023	11/2/2023
Semi Perm S02	30.2571	-93.4098	4/6/2023	11/2/2023
Semi Perm S03	30.2536	-93.4091	4/6/2023	11/2/2023
Semi Perm S04	30.2470	-93.4213	4/5/2023	5/12/2023
Semi Perm S04_1	30.2506	-93.4204	5/12/2023	11/2/2023
Semi Perm S05	30.2564	-93.4224	4/5/2023	11/2/2023
Semi Perm S06	30.2532	-93.4167	4/5/2023	11/2/2023
Semi Perm S07	30.2547	-93.4162	4/5/2023	11/2/2023
SUL01 trillium	30.2452	-93.4071	9/13/2023	
SUL02 trillium	30.2570	-93.4099	9/13/2023	
SUL03 trillium	30.2504	-93.4203	9/12/2023	
SUL04 trillium	30.2562	-93.4223	9/12/2023	
SUL05 trillium	30.2546	-93.4161	9/13/2023	

Appendix 2. Broadband Array Magnitude of Completeness (M_c)

A magnitude of completeness, M_c , is the minimum magnitude locatable on a network. For the Sulphur Mines broadband array, Nanometrics modeled three M_c scenarios for the array based on three noise levels, high, median and low noise recorded from September 20 to 27, 2023 (Figure 3). The magnitude of completeness model assumes 4 stations are triggered to compute a location. The M_c events are modeled at 3000 ft depth, near the base of Cavern 7, using three different noise levels based on the noise recorded on the array. The percentile used are 10th (low noise), 50th (median noise) and 90th (high noise) (Figure 3).

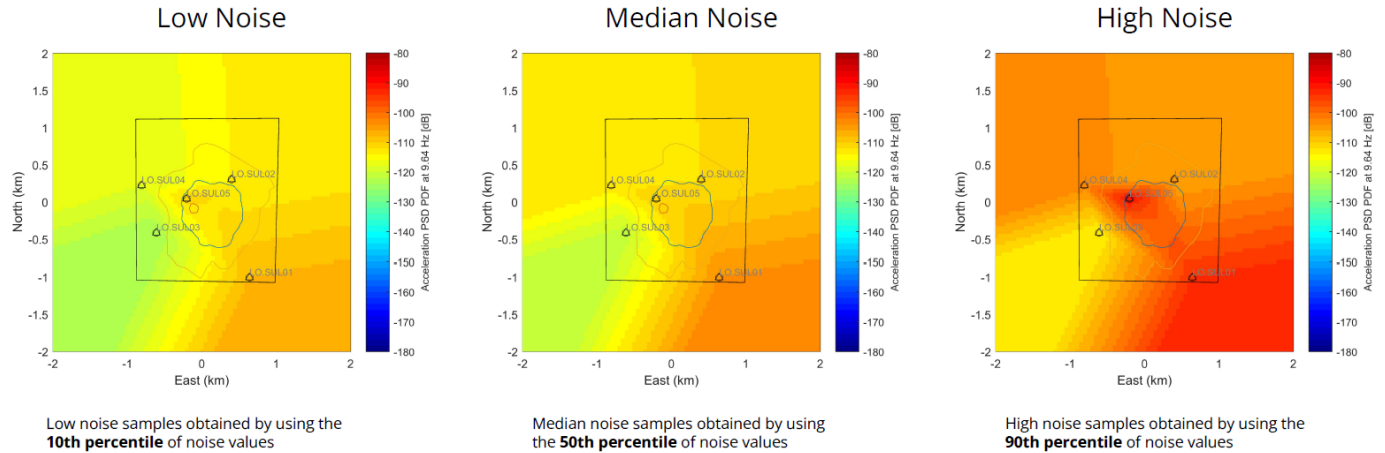


Figure 3. Map of the noise levels modeled for the magnitude of completeness figures. Left most is the low noise, middle median noise and right is high noise.

The map of the magnitude of completeness modeled by Nanometrics for the three noise levels is shown in Figure 4 for the Sulphur Mines dome area. The M_c will vary spatially (Figure 4) depending on the station geometry and the event dome location and depth.

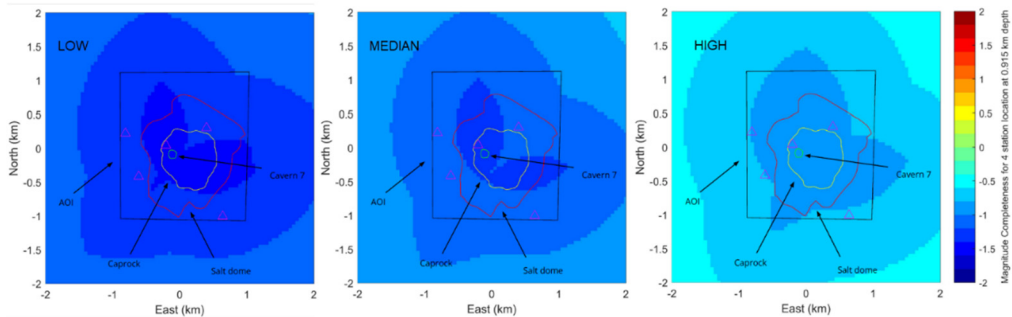


Figure 4. Modeled magnitude of completeness (M_c , lowest magnitude detectable) for the Sulphur Mines salt dome and vicinity using the broadband array. Three noise models are shown: the high noise model shown on the right, median noise level in the middle and low noise model on the left, as labeled. The outline of the Sulphur Mines dome and caprock and the outline of Cavern 7. The color bar shows the M_c values for each model.

Modeling with Seismic Attenuation. Seismic attenuation will result in a modification of the magnitude detectability across the array. If seismic attenuation is high, more energy is dissipated therefore is more difficult to record seismic waveforms on the surface. Figure 5 shows magnitude of completeness for the median noise level for three seismic attenuation values.

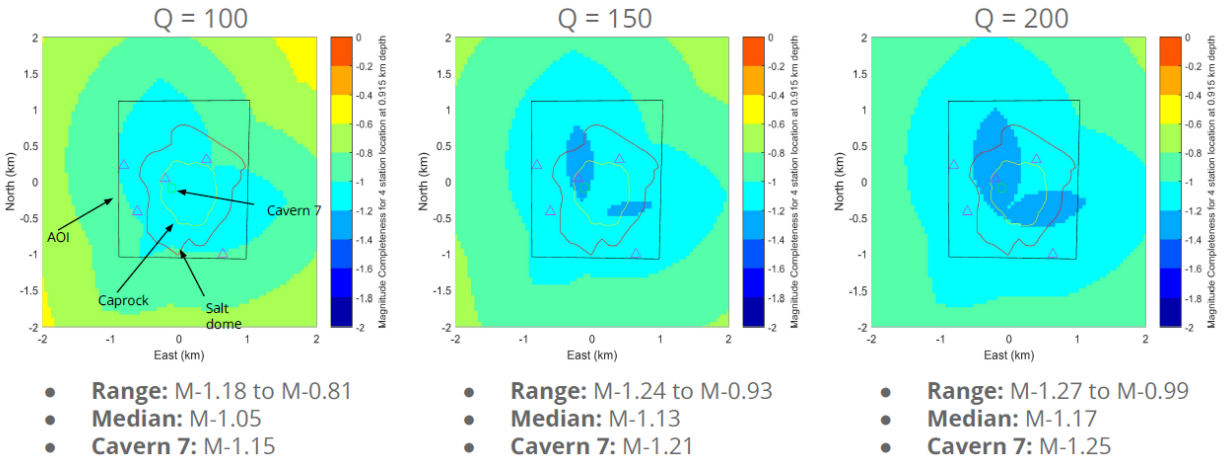


Figure 5. Modeled magnitude of completeness (M_c , lowest magnitude detectable) for the Sulphur Mines salt dome and vicinity using the broadband array for three different seismic attenuation values for a median noise level. The three seismic attenuation values are on the top of each plot: $Q=100$ (high attenuation, left most plot), $Q=150$ (medium attenuation, middle plot) and $Q=200$ (lower attenuation, right plot). The outline of the Sulphur Mines dome and caprock and the outline of Cavern 7. The color bar shows the M_c values for each model.

The modeling results for M_c computed by Nanometrics at Cavern 7 location at 3000 ft depth suggests:

- The low noise model shows a M_c of about magnitude -1.4
- The median noise level M_c is magnitude -1.3.
- For the median noise level and accounting for seismic attenuation:
 - With $Q=100$ seismic attenuations (highest attenuation modeled), the estimate is M - 1.15
 - With $Q=150$ seismic attenuation, the estimate is M -1.13
 - With $Q=200$ seismic attenuation (lowest attenuation modeled), the estimate is M -1.25
- The high noise level M_c is magnitude -0.9.