Microseismic Monitoring Report
Sulphur Mines Salt Dome
Borehole and Surface Seismic Arrays

Report Period : August 1-31, 2024
Report Date: September 9, 2024
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Using results from Baker Hughes and Nanometrics

Alert Level Status: Normal (Green)

1. **Summary Borehole Array Summary August 2024**

- 105 events were detected in August on the borehole seismic arrays located in PPG Well No. 006-X and PPG Well No. 020; 50 located microseismic events and 55 seismic detections. Six of the located events are likely perforations associated with workover activities in the PPG 04 and FEE 1031 wellbores.
    - 28 events are located in the proposed seismic monitoring AOI, 10 in the cap rock and the remaining in the salt dome and the salt dome flanks. Two of these events are likely associated with workover perforations performed in PPG 04.
    - Largest event in August was a magnitude -0.5 event on August 7 at 01:23:52 CDT, located on the NE flank of the dome at 5550 ft depth.

a. Borehole Seismic Arrays

Baker Hughes "Microseismic Services" group operates and processes data for the borehole seismic arrays located in PPG Well No. 006-X and PPG Well No. 020. The seismic array locations are shown in Figure 1 and the coordinates are listed in the Appendix, Table 2. The borehole arrays were fully functional in August 2024 except from August 30 15:00 to August 31 09:00 and August 31 11:00 to 15:00, the PPG 6x sensors 1, 2 and 3 were offline.

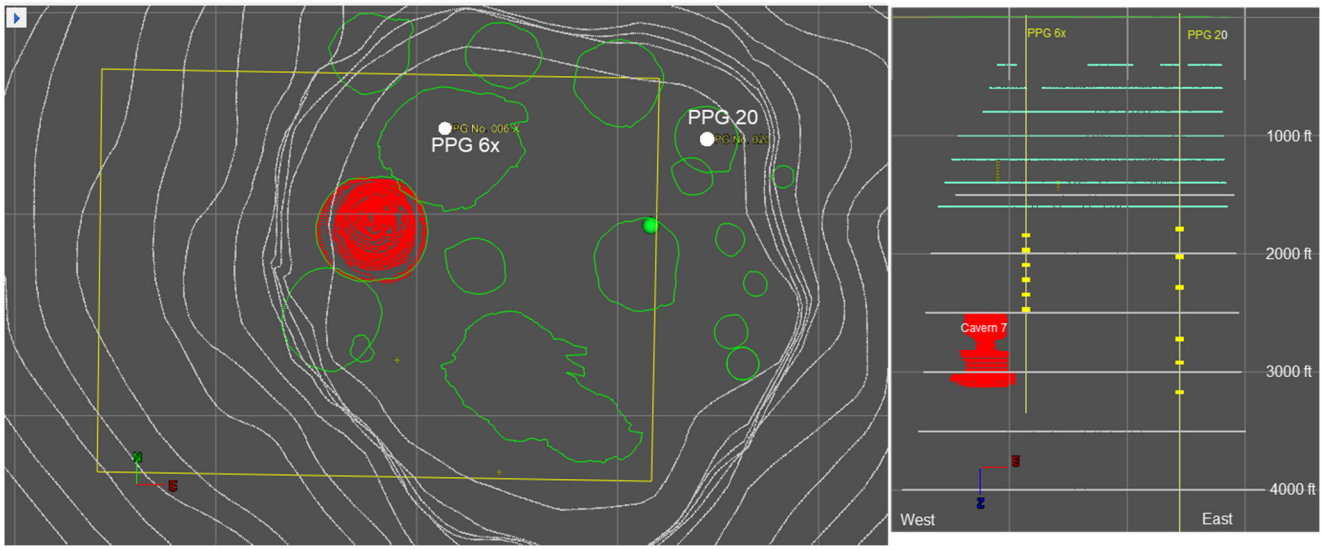

Figure 1. Map (left) and West-East cross section (looking from south) of the Sulphur Mines Salt Dome. The salt boundary is indicated by gray contour lines in map and side view. The borehole microseismic arrays are labeled and the various cavern are outlined in green in map view. In cross section the wellbores with the borehole array sensors are marked by yellow vertical line and yellow markers show the geophone positions in depth for PPG No. 006X and PPG No. 020. Cavern 7 is shown by a red sonar survey in both figures. The proposed AOI is indicated in map view by the yellow square. The grid is 1000 feet.

b. **August 2024 Microseismic Activity (using the borehole seismic arrays).**

105 seismic events were detected in August 2024 on the borehole seismic arrays. 50 events had waveform with good signal to noise to compute a location and magnitude, the August 2024 microseismic event catalog is listed in the Appendix in Table 4. The remaining event-detections are too poor quality to determine an event location or magnitude. The detections are classified as shallow or deep depending on the energy arriving along the array. Seismic energy arriving from below the array is classified as a "deep" detection and energy arriving from above the array as "shallow" detection. The August 2024 temporal distribution of located and detected microseismic events is shown in Figure 2. The largest number of located events in a day was five on August 24.

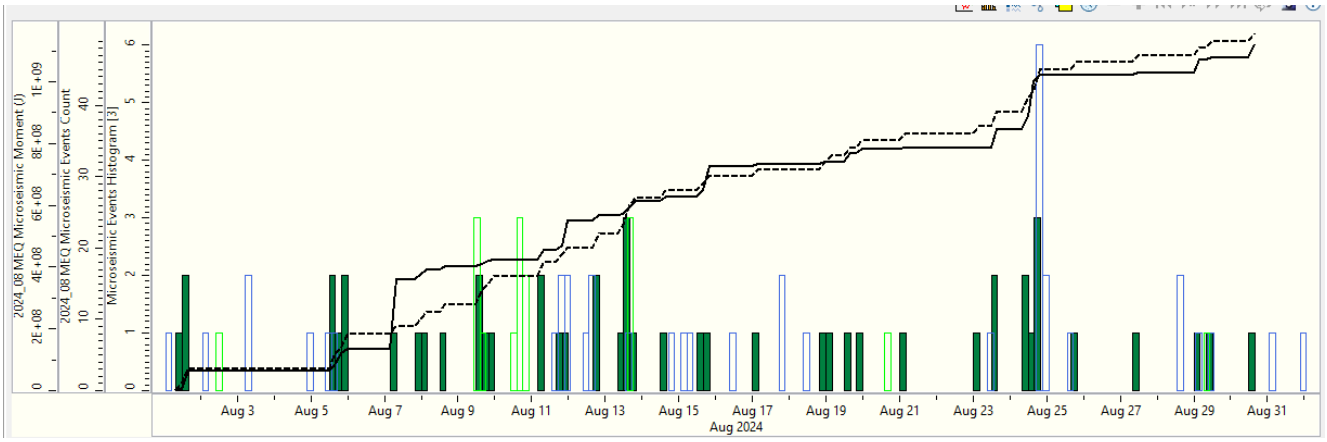

Figure 2. Temporal distribution of microseismic detections and locations in August 2024 recorded at Sulphur Mines salt dome with the borehole arrays. The histograms indicate the number of events in a four-hour time window. The event detections are unfilled boxes, where blue indicates a deep detection (seismic energy is emulating from below the seismic array) and green indicated is a shallow event detection (seismic energy is coming from above the seismic array). The located events time distribution is indicated by filled dark green boxes. Black line shows the cumulative seismic moment and the black dotted line is cumulative number of the located seismic events.

Caverns with proximal seismic activity in August are: PPG 06 (5 events); LGS 2 (3 events); PPG 2 (2 events) PPG 07, PPG 16, PPG 22 and BLM SS 01 with one event each (Figures 3 and 4). Workover activity in two wells resulted in six events likely associated with perforations, two events near PPG 04 and four events near FEE 1031, a flank oil and gas well. When a perforation is fired, it generates seismic waves that are recorded on the borehole arrays. Appendix Figures 1 and 2 show the location of the wellbore perforations and the associated event locations calculated using the borehole array data.

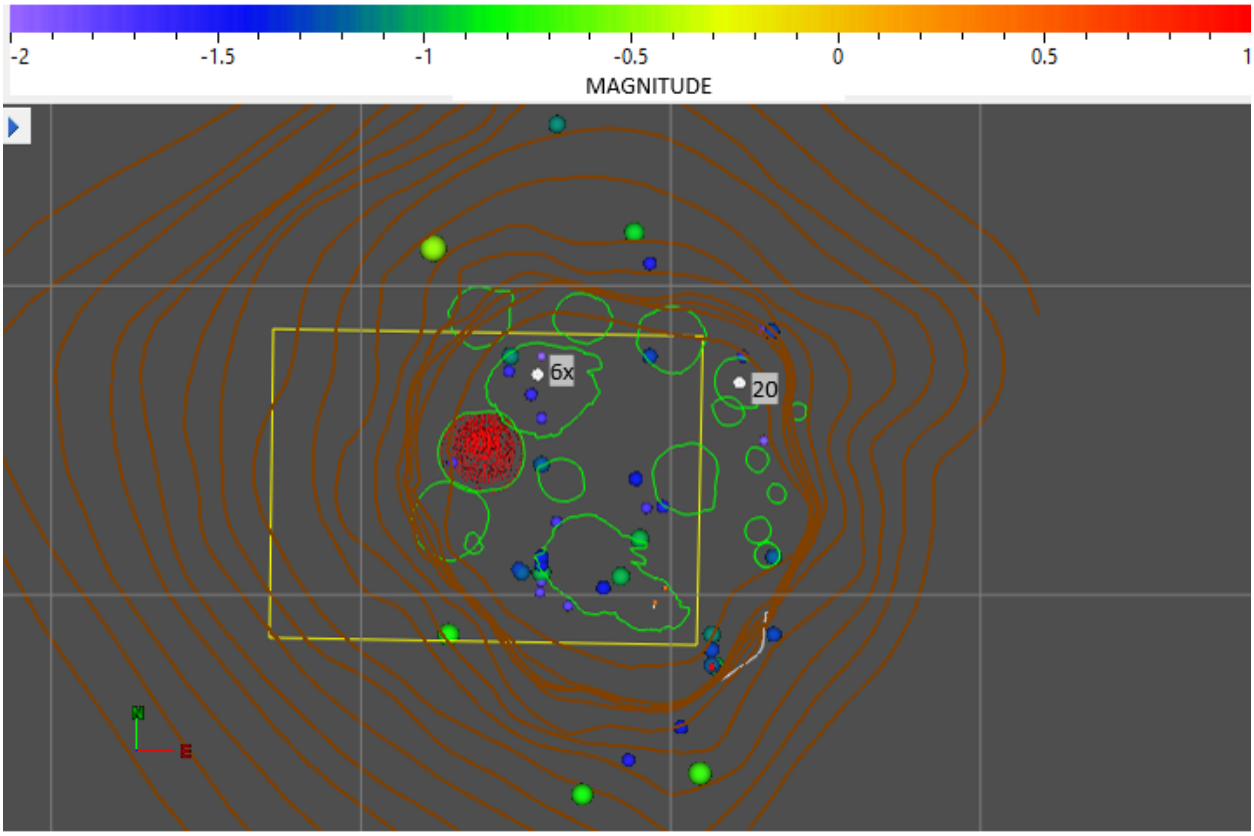

Figure 3. Map of the August 2024 borehole microseismic events colored and sized by magnitude. The locations and magnitudes were computed using data from the borehole seismic arrays in PPG No. 006X and PPG No. 020 (labeled). Grid is 2000 ft. The yellow box is the proposed AOI. The FEE 1031 wellbore is shown by thin gray line. The perforations related to workovers in PPG 04 and FEE 1031 are shown by the small orange and red dots.

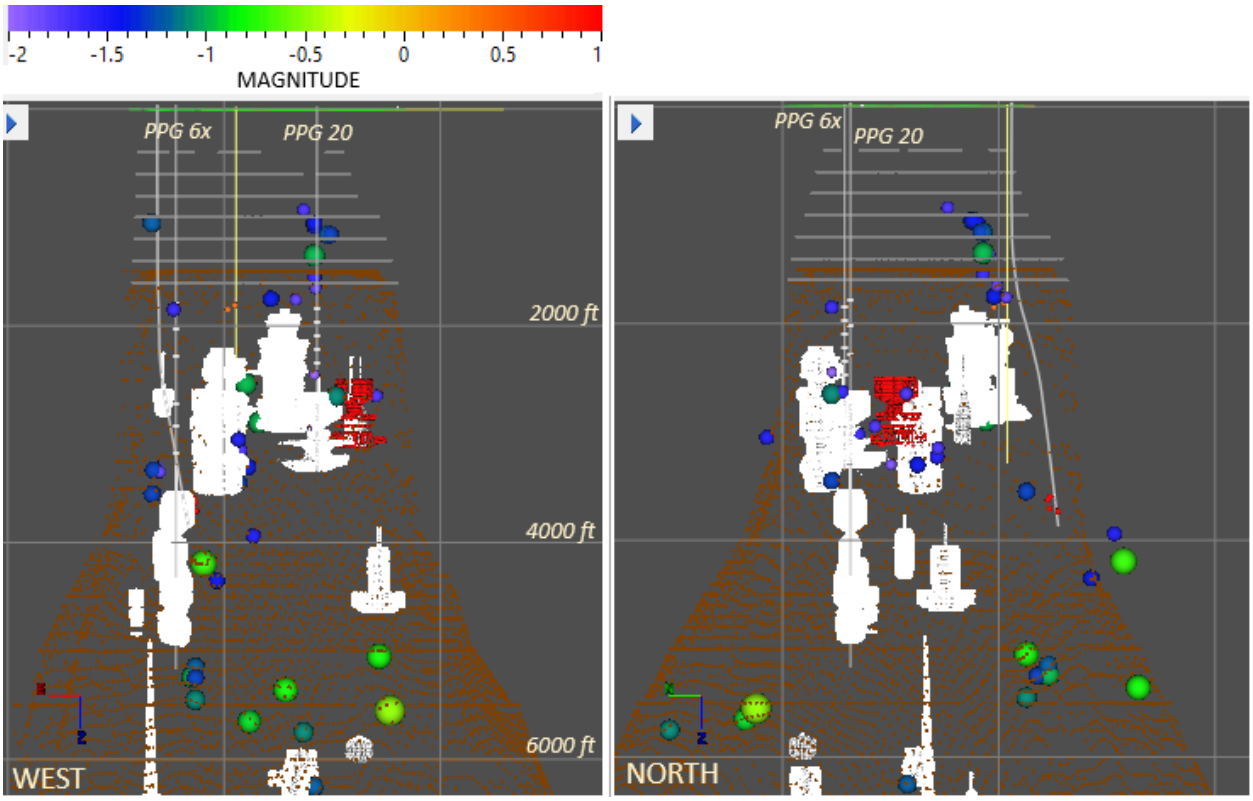

Figure 4. The August 2024 microseismic locations shown in depth view. The cross sections W-E (left), looking from south; and N-S (right), looking from west. The August microseismic events are sized and colored by magnitude. The salt (dark orange) and caprock (gray) boundaries are indicated by dots. The various salt caverns as mapped by sonar are shown within the salt. Geophone locations are indicated by hash marks, PPG 20 and PPG 6x well labeled. Fee 1031 wellbore indicated by gray line, the workover perforation locations shown by small red dots for FEE 1031 and orange dots for PPG 04. Cavern 7 is colored red. Grid is 2000 ft.

The June microseismic magnitudes range from -2.5 to -0.5 with a median magnitude of -1.4 (Figure 5). The largest event was a magnitude -0.5 event on August 7, 2024 at 01:23:52 CDT, located on the northeast flank of the dome at 5550 ft depth.

The depth distribution in August is from about 930 to 6250 ft subsea, with a median depth of 4000 ft subsea (Figure 5).

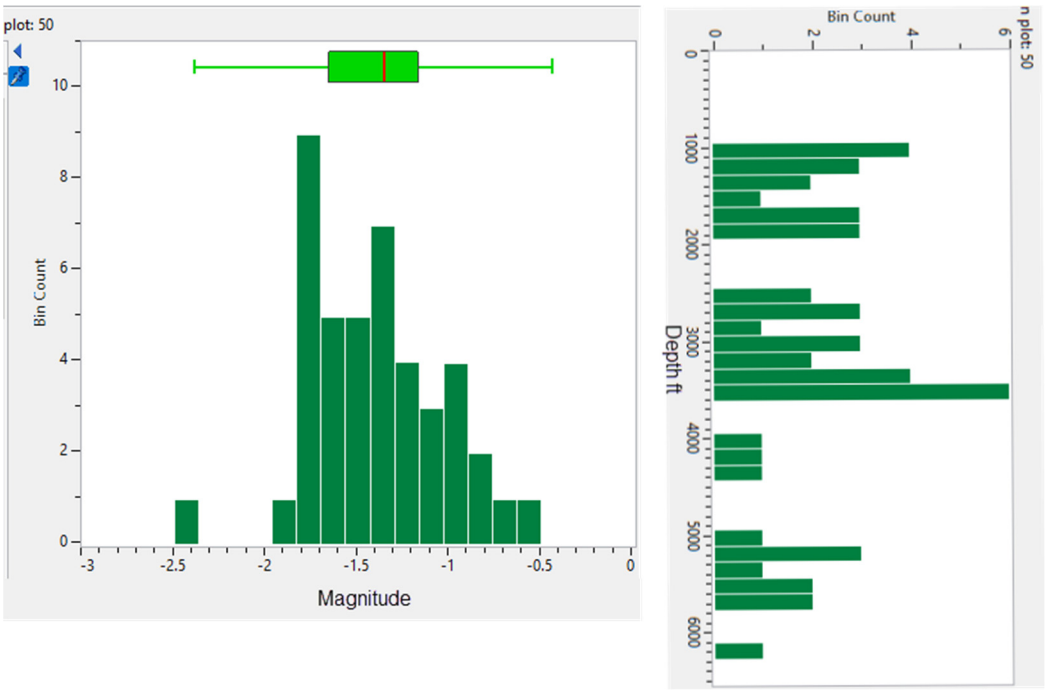

Figure 5. The microseismic magnitude distribution (left) and depth distribution (right) for activity in August 2024.

c. **AOI Microseismic activity using borehole seismic arrays.**

26 events (and two perforations) were located in the proposed AOI in August 2024 using the borehole arrays (Figures 6 and 7). Ten AOI events are located in the cap rock and three events are located on the dome flank. The remaining AOI events were in proximity to the caverns: LGS 02 (three events), PPG 02 (two events), PPG 07, PPG 16 and PPG 22 each had one event. There were five events near PPG 06 cavern, ranging from magnitude -2.2 to -1.1. Figure 8 shows the August seismicity near Cavern 6 in more detail, there are two events near top of the cavern, and two mid cavern depths. There is one small event located above the cavern, near the base of the deepest geophone in the PPG 6x array (Figure 8).

Additionally, two events associated with workover perforations in PPG 04 were recorded on August 9 and 17. Appendix Figure 1 shows in detail the location of the wellbore perforations and the associated perforation event locations, the August 9 perforation is located closer to the known perforation location than the August 17 perforation event.

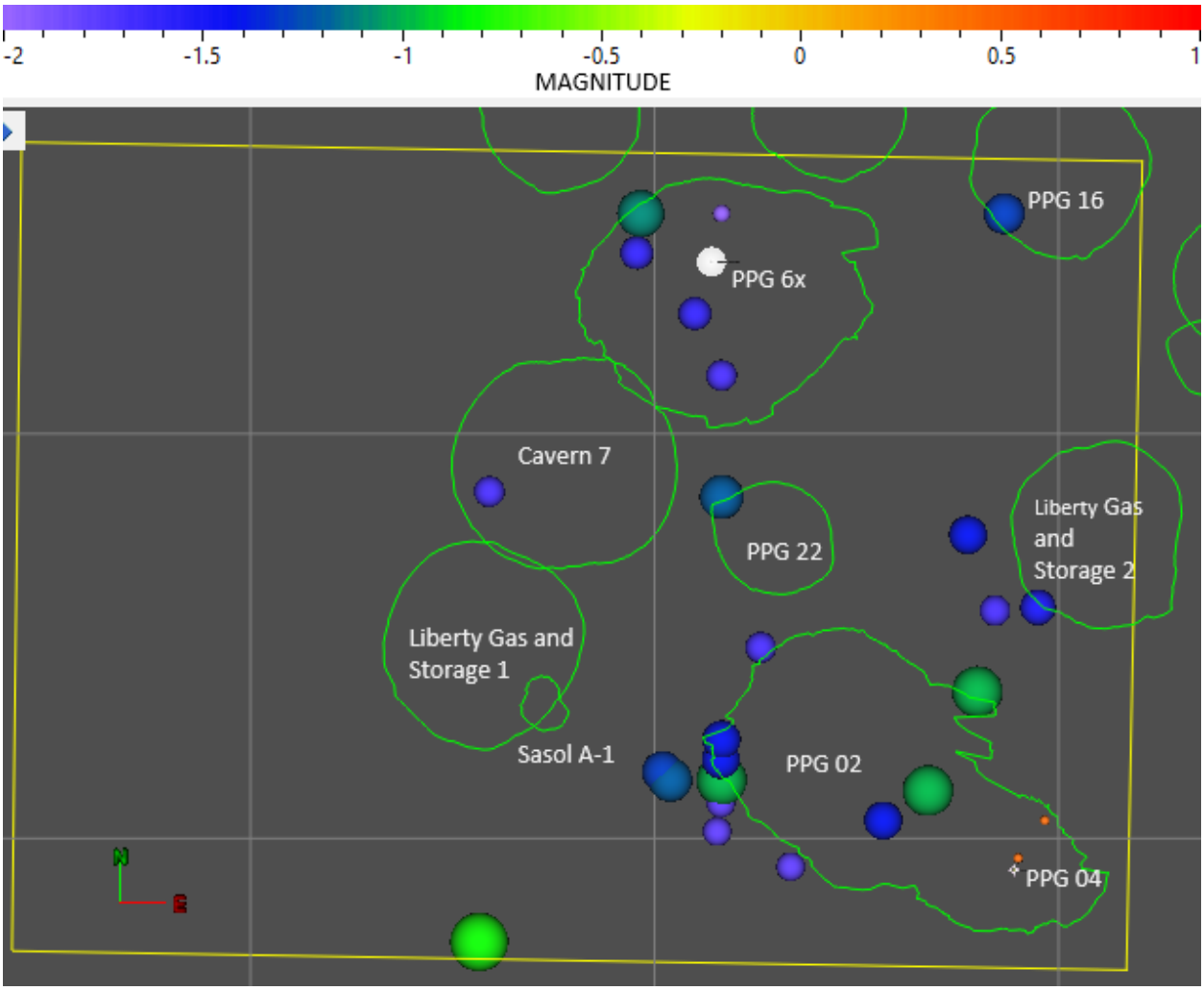

Figure 6. Map view of microseismic activity in August 2024 shown by colored dots in the proposed AOI (yellow box). The events are sized and colored by magnitude. The salt contours are shown by orange lines, cavern outlines by white lines. Grid is 1000 feet. The white dot indicates the PPG 6x borehole array location. The microseismic locations of the perforation shots in PPG 04 are shown by small orange dots.

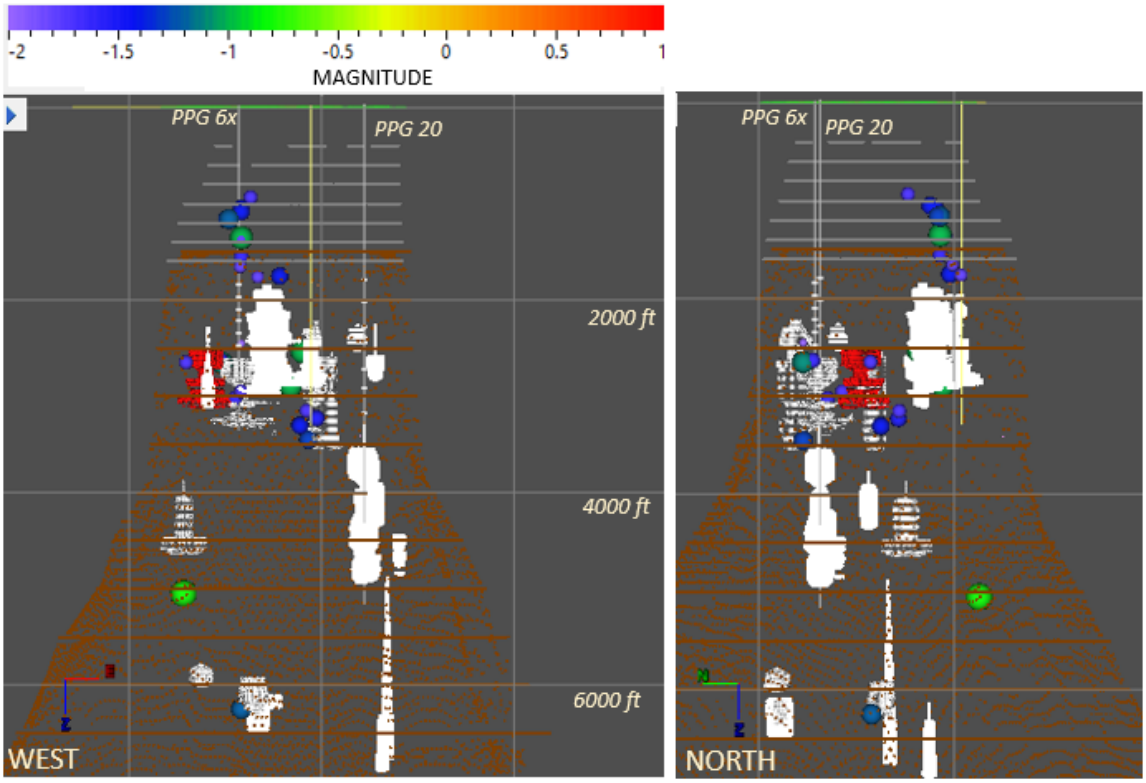

Figure 7. West–east (left) and north-south (right) vertical cross sections with the August 2024 microseismic events located in the proposed AOI with cavern sonars. Microseismic events are shown by colored dots, sized and colored by magnitude. Grid is 2000 feet. Salt boundary is shown in (orange), cap rock in gray.

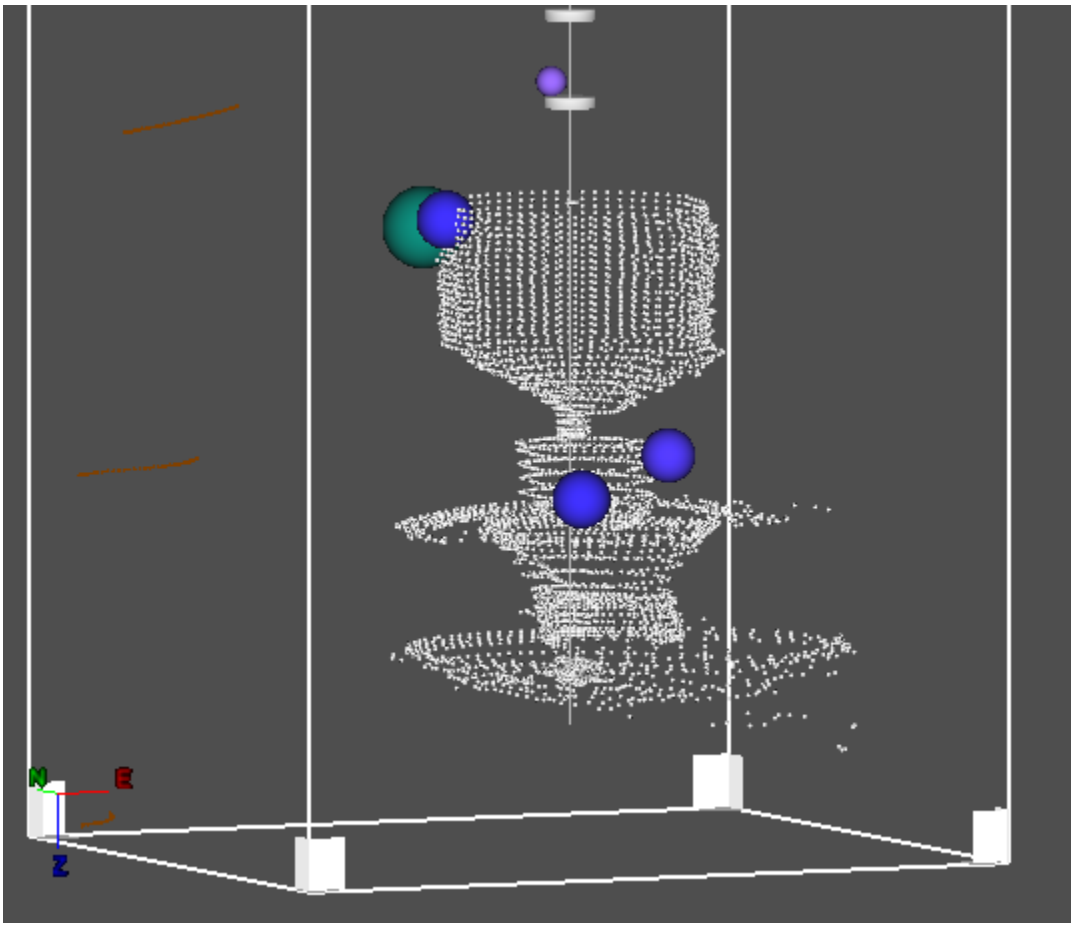

Figure 8. Perspective view of microseismic events near PPG 6 cavern in August. The while dots indicate the cavern 6 sonar, colored dots are microseismic events sized and colored by magnitude (the magnitude color scale is shown in previous figures). Hash marks above cavern are the geophone positions in PPG 6X wellbore.

d. Cumulative Seismicity since start of the borehole arrays

The cumulative seismicity located since the start of the borehole arrays in salt and cap rock is shown in Figures 9 and 10, the time progression of the events since mid-April 2024 is shown in Figure 11. In general, the seismicity is scattered through the Sulphur Mines dome. Events in the cap rock are generally scattered with some clustering on the SSW dome edge. The deep seismicity is mostly off the flanks of the dome, with some clustering in the southern flank.

There is very little seismicity observed near Cavern 7, the one small magnitude (-1.7) event near the upper part of cavern 7 in August has a poorly constrained location due to low SNR on PPG 20 geophones. This event occurred on August 13 at 06:46 AM CDT, when the injection rate in to Cavern 7 was reduced for a short period of time.

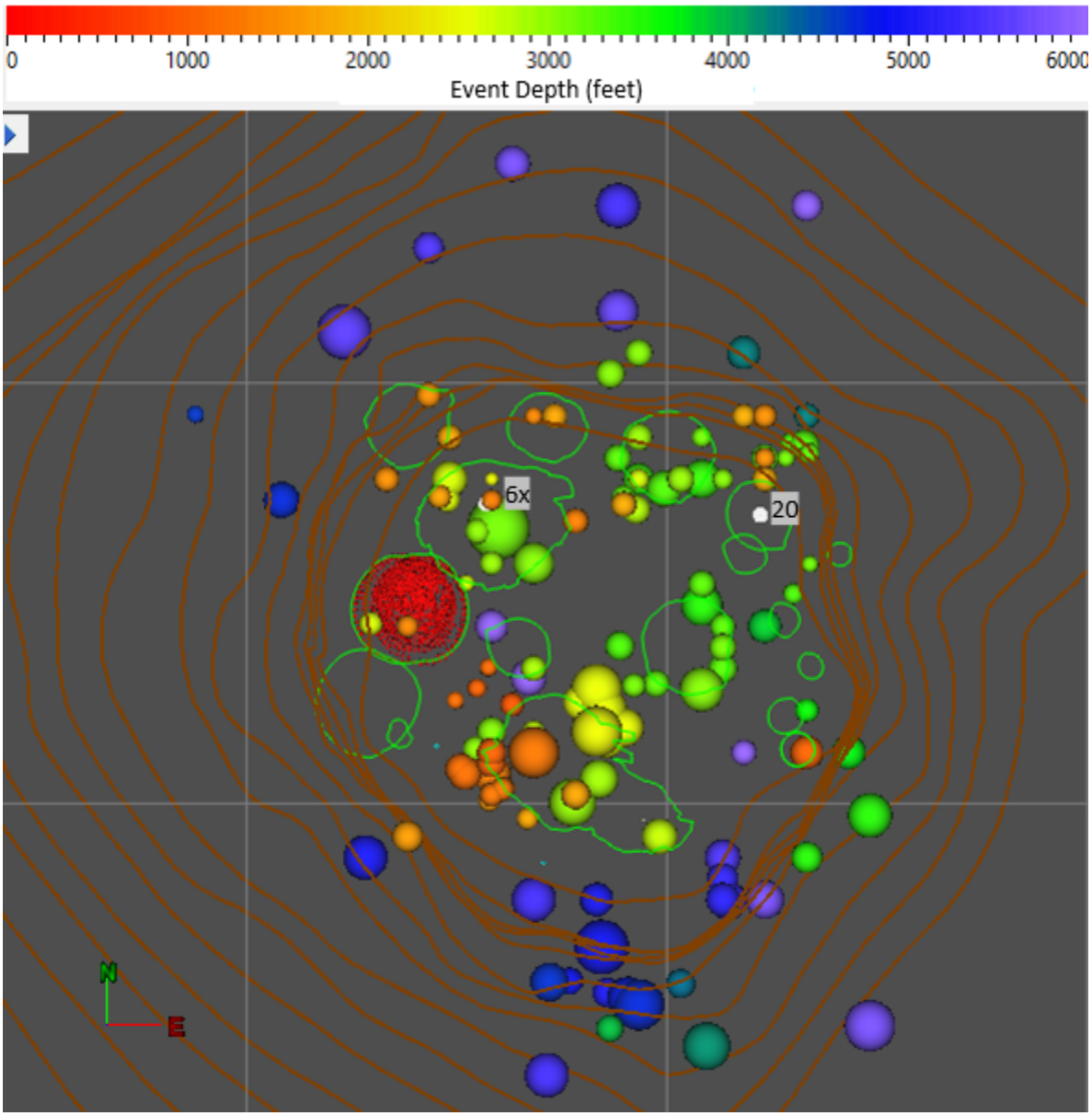

Figure 9. Map view of the cumulative microseismicity recorded from April 22 to August 31, 2024 using borehole seismic arrays (PPG 6-X and PPG 20 (labeled on map)) Events are sized by magnitude and colored by depth. Grid is 2000 ft. Cavern 7 is indicated by red dots and salt dome contours are shown by orange lines.

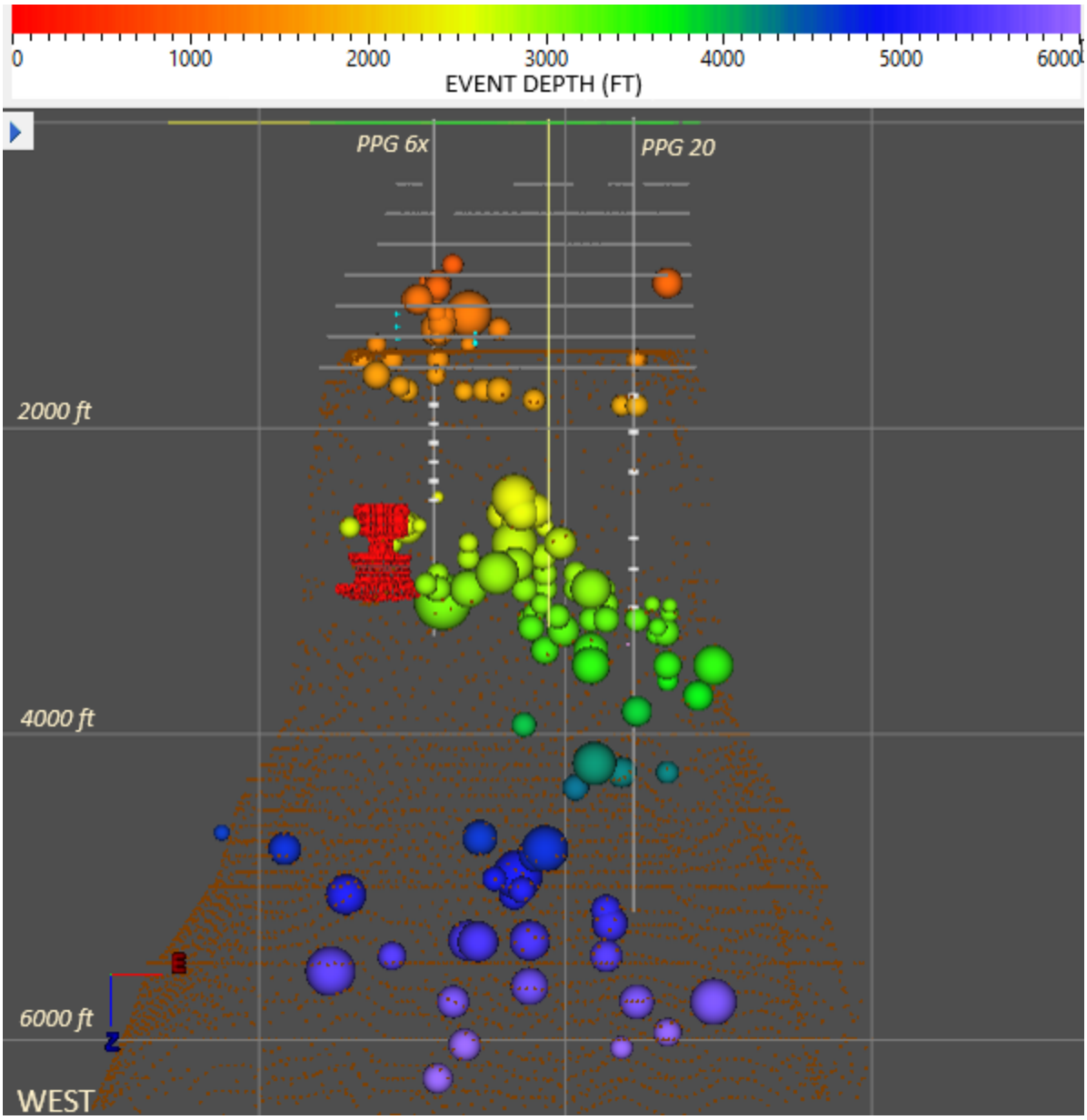

Figure 10. West-East side view of the cumulative microseismicity recorded from April 22 to August 31, 2024 using borehole seismic arrays (labeled PPG 6x and PPG 20). The microseismic events are sized by magnitude and colored by depth. Salt boundary is shown by dark orange dotted lines, cap rock by gray dotted lines. Grid is 2000 ft. . (The workover perforations in PPG 04 and FEE 1031 are included in this map).

Figure 11 shows the timeline of all the microseismicity starting in late April. There is an increase in both in number of events and the seismic moment (a proxy for energy) starting in late June. Since late June, the seismicity rate and energy appear to be consistent.

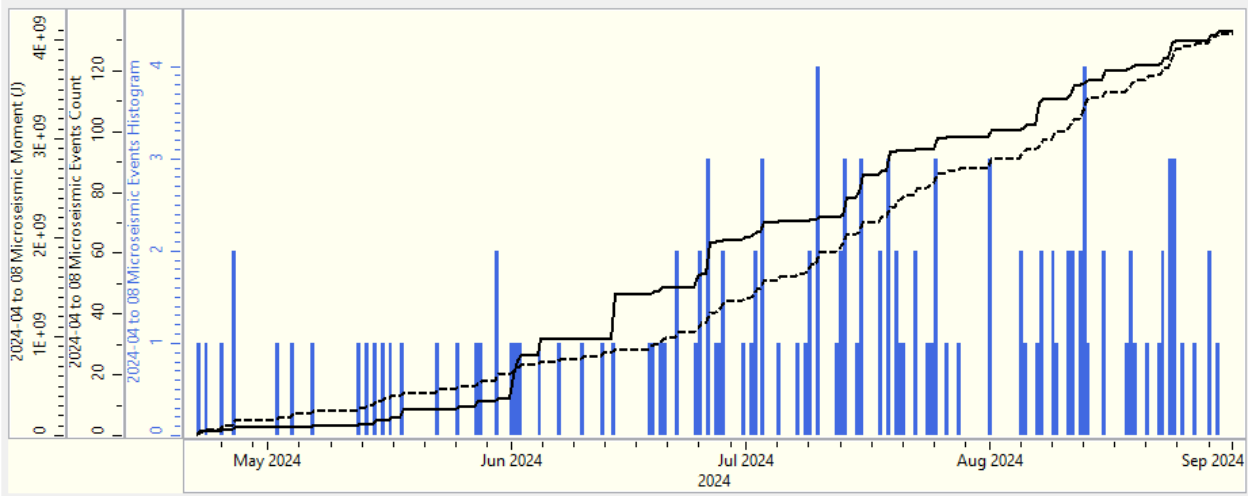

Figure 11. Time line of all microseismicity located at Sulphur Mines using the borehole arrays from April 22 to the end of August 2024. The histogram is the number of events per 12 hours, the black solid line is the cumulative seismic moment and the black dotted line the cumulative number of events.

2. Surface Broadband Seismic Array Summary

- Two events were located using the surface broadband array in August 2024. The August 20 event located NE of the salt dome was categorized as a possible man-made event, suggesting the event may be due to construction or some other work in the area. This event was not located on the borehole array. The August 30 event was co-recorded on the borehole arrays. (Table 4 and 5).
- The surface array was operational the entire month of August. Some data transfer latency was noted for SUL07 in August, no data was lost. The SUL07 station had a maintenance visit on August 28.
- Stations SUL03, SUL04, SUL05 and SUL06 continue to be the quietest surface stations, SUL02 and SUL07 continue to be about 5-10 dB nosier than the other stations.

a) Broadband Trillium Compact Seismic Array

Nanometrics (https://nanometrics.ca/home) operates and processes data for the broadband array. The broadband station locations are show in Figure 12 and listed in Table 3.

A co-recorded event on August 30 at 7:34:24 CDT has a surface array magnitude of -1.1, similar to the borehole array magnitude of -1.0. The surface array event location (Figure 13) differs from the borehole array location by 753 feet in easting, 160 feet in northing and 633 feet in depth.

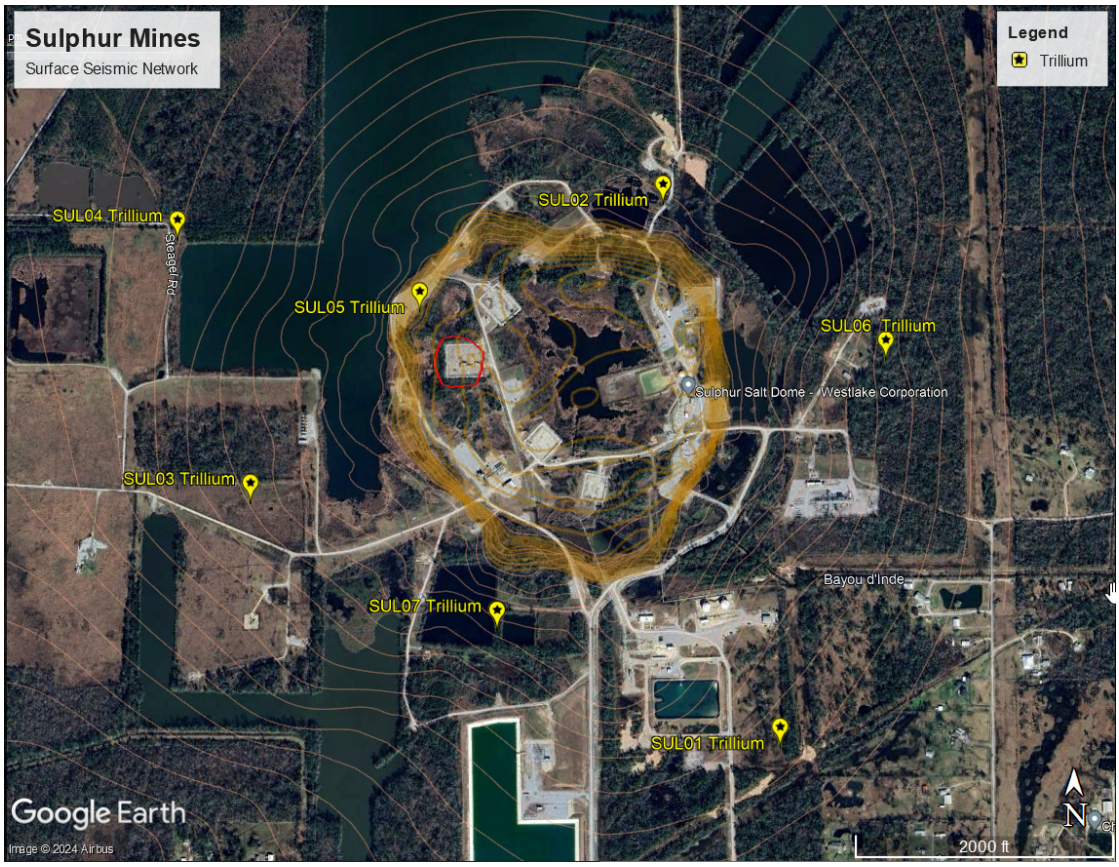

Figure 12. Google Earth map image showing the location of the six broadband seismic (Trillium Compact Sensors, yellow symbols and labels) stations near and at the Sulphur Mines Salt Dome. The contours are the salt and cap rock elevations, the red circle is the general outline of Cavern 7.

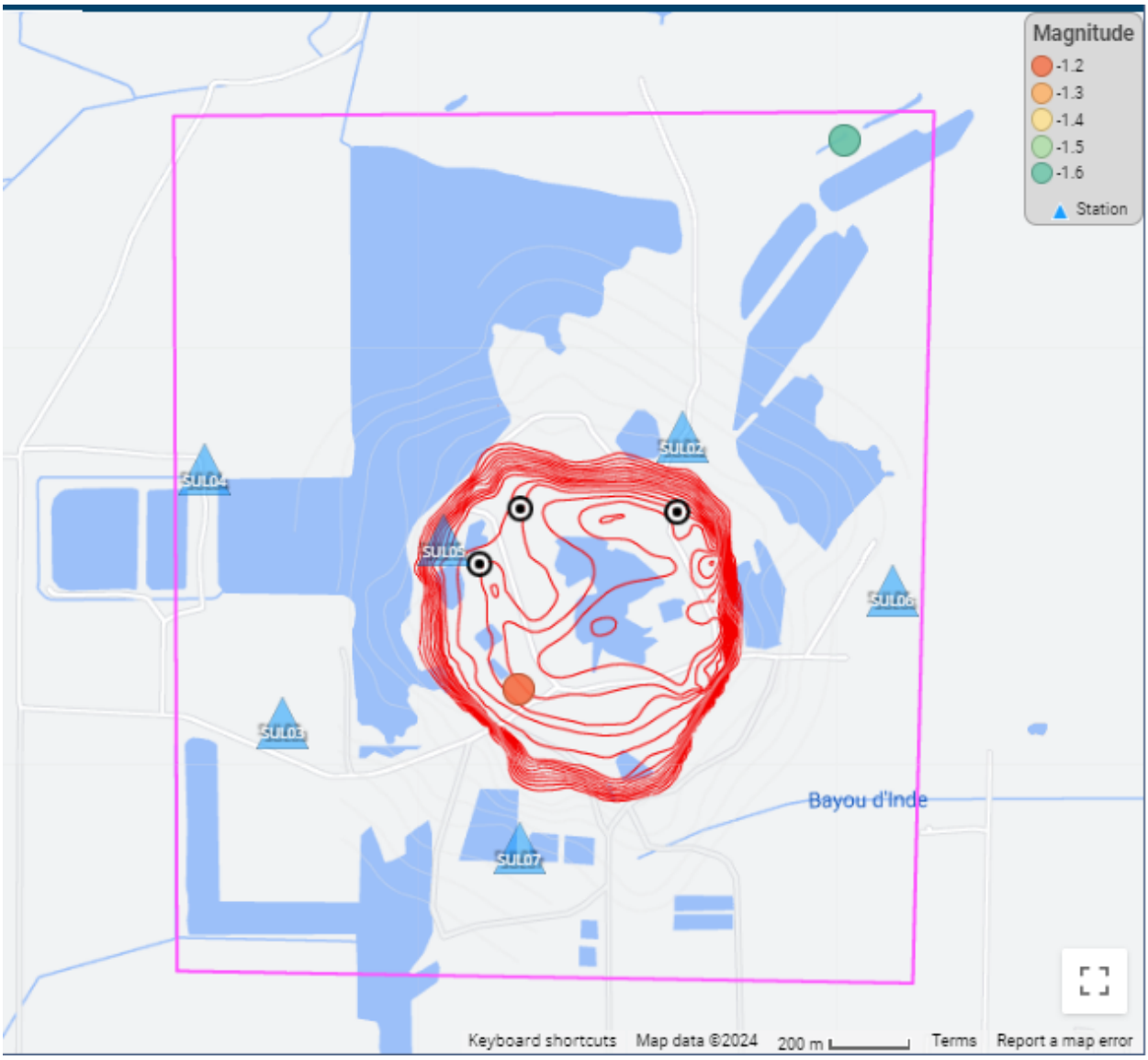

Figure 13. Map showing August event locations (colored dots) using the surface seismic array for the location. The salt contours are shown in red. Seismic stations are shown by blue triangles.

Appendix

Table 1. Proposed Microseismic Alert Level Criteria and Response for Sulphur Mines Dome.

Alert Status	Criteria	Response
Low (GREEN)	No events with magnitude ≥0.5 in AOI and/or Less than 30 MEQ per day in AOI with magnitudes ≥ -1	Once per week data processing, with previous monthly microseismic activity summary in the AOI is provided by the 15th of the following month to LDNR IMD.
Advisory (YELLOW)	Event with magnitude ≥0.5 and <1.0 in AOI and/or Count of MEQ per day ≥30 and <40 in AOI with magnitudes ≥ -1	Daily data processing M-F. Weekly reporting is provided LNDR IMD with activity summary from the previous week. Status remains active until seismic levels within the AOI reach "low"(green) level for 1 day.
Watch (ORANGE)	Event with magnitude ≥1 and <1.5 in AOI and/or Count of MEQ ≥40 and <50 with magnitudes ≥ -1 in AOI	Seven days per week data processing, 2x week reporting with activity for the previous days is provided via email and text message notifications to IMD. Status remains active until seismic levels within the AOI reach Advisory or Low criteria for 2 consecutive days.
Warning (RED)	Event with magnitude ≥1.5 in the AOI and/or Count of MEQ ≥50 with magnitudes ≥ -1 in the AOI	Seven days per week data processing, daily reporting with online meetings with stake holders as needed. The warning status level remains active until seismicity levels within the AOI reach a lower status level for 2 consecutive days.

Table 2. Borehole Sensor Locations

Wellbore	Sensor #	TVD SS	Northing ft	Easting ft
PPG 6x	Sonde 1	1844	1343141	583425
PPG 6x	Sonde 2	1969	1343141	583425
PPG 6x	Sonde 3	2094	1343141	583425
PPG 6x	Sonde 4	2219	1343141	583425
PPG 6x	Sonde 5	2344	1343141	583425
PPG 6x	Sonde 6	2469	1343141	583425
PPG 20	Sonde 1	1790	1344445	583372
PPG 20	Sonde 2	2025	1344445	583372
PPG 20	Sonde 3	2285	1344445	583372
PPG 20	Sonde 4	2720	1344445	583372
PPG 20	Sonde 5	2920	1344445	583372
PPG 20	Sonde 6	3170	1344445	583372

Table 3. Seismic Station locations and operational dates at Sulphur Mines Dome (to August 1, 2024). 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	
Semi Perm S02	30.2571	-93.4098	4/6/2023	
Semi Perm S03	30.2536	-93.4091	4/6/2023	
Semi Perm S04	30.2470	-93.4213	4/5/2023	5/12/2023
Semi Perm S04_1	30.2506	-93.4204	5/12/2023	
Semi Perm S05	30.2564	-93.4224	4/5/2023	
Semi Perm S06	30.2532	-93.4167	4/5/2023	
Semi Perm S07	30.2547	-93.4162	4/5/2023	
SUL01 trillium	30.2452	-93.4071	9/20/2023	3/12/2024
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	
SUL06 trillium	30.2535	-93.4043	3/12/2024	
SUL07 trillium	30.2477	-93.4141	3/12/2024	

Table 4. August 2024 Microseismic Event Catalog.

UTC time is used for monthly catalog time window.

						Uncertainties			
Central time	Easting (ft)	Northing (ft)	Depth (ft)	Mag. (Mw)	Surface Array Magnitude (Mw)	ΔEasting (ft)	ΔNorthing (ft)	ΔDepth (ft)	Cavity
08/01/2024 03:01:56	1344466	583544	1850	-1.6		277	777	388	Flank
08/01/2024 08:11:23	1343166	583144	2950	-1.7		315	869	385	AOI_PPG_06
08/01/2024 09:40:18	1343766	584344	5650	-0.9		818	2969	1268	Flank
08/05/2024 07:19:14	1343100	583297	3023	-1.6		322	1057	558	AOI_PPG_06
08/05/2024 08:26:56	1343566	582044	1750	-1.4		638	1637	1151	AOI_Cap_Rock
08/05/2024 13:03:46	1343166	582144	1350	-1.0		470	1690	763	AOI_Cap_Rock
08/05/2024 15:50:46	1344266	581546	3627	-1.2		968	2419	1260	Perf_FEE-1031
08/05/2024 16:35:32	1344289	581451	3734	-1.2		1099	2386	1529	Perf_FEE-1031
08/07/2024 01:23:52	1342466	584244	5550	-0.5		908	2741	1251	Flank
08/07/2024 15:30:04	1344666	582244	1050	-1.2		421	1600	700	Cap_Rock
08/07/2024 21:01:15	1344666	581744	3550	-1.3		856	2090	1447	Flank
08/08/2024 07:29:17	1344259	581531	3708	-1.3		1023	2375	1378	Perf_FEE-1031
08/09/2024 07:38:14	1343155	582017	1651	-1.8		437	1756	1026	AOI_Flank
08/09/2024 08:24:23	1343166	582144	1550	-1.6		456	1653	958	AOI_Flank
08/09/2024 13:47:14	1343900	581951	1812	-1.2		383	1679	637	Perf_PPG04
08/09/2024 15:16:05	1343164	582087	1360	-1.8		476	1741	840	AOI_Cap_Rock
08/11/2024 02:02:41	1342956	583447	2631	-1.6		338	697	380	AOI_PPG_06
08/11/2024 02:02:59	1342966	583544	2650	-1.1		343	655	390	AOI_PPG_06
08/11/2024 13:02:18	1343866	583544	3450	-1.3		422	1091	565	AOI_PPG_016
08/11/2024 18:47:47	1342566	581744	5050	-0.8		966	2820	1732	AOI_Flank
08/12/2024 13:11:04	1343164	582195	1080	-1.4		458	1768	1151	AOI_Cap_Rock
08/12/2024 13:56:18	1343166	582244	1050	-1.4		452	1717	1041	AOI_Cap_Rock
08/13/2024 06:46:32	1342591	582857	2647	-1.7		402	1045	815	AOI_PPG_07
08/13/2024 08:30:34	1343263	582472	930	-1.7		399	1604	954	AOI_Cap_Rock
08/13/2024 09:36:32	1343020	582165	1158	-1.3		439	1794	901	AOI_Cap_Rock
08/13/2024 10:29:43	1343043	582132	1159	-1.8		441	1824	928	AOI_Cap_Rock
08/13/2024 14:06:17	1343039	582145	1157	-1.2		439	1802	901	AOI_Cap_Rock
08/14/2024 07:30:55	1344270	581525	3598	-1.3		965	2346	1174	Perf_FEE-1031
08/15/2024 10:51:12	1343166	582844	6250	-1.2		993	3456	1682	AOI_PPG_22
08/15/2024 11:17:05	1343429	580709	5358	-0.8		1014	3786	1915	Flank
08/16/2024 22:01:13	1343966	582044	1850	-1.5		366	1668	608	Perf_PPG04
08/18/2024 16:39:57	1343728	580931	3939	-1.5		1295	3149	1969	Flank
08/18/2024 22:47:51	1344592	583712	3347	-1.8		404	705	580	Flank
08/19/2024 09:01:12	1343266	585044	5750	-1.1		932	3314	1596	Flank
08/19/2024 15:55:04	1344652	583704	3332	-1.3		421	739	579	Flank
08/20/2024 22:51:07	1344602	582998	3301	-1.9		374	771	412	BLM Sul Stor 01
08/22/2024 19:27:44	1343337	581930	1758	-1.8		412	1779	1169	AOI_Cap_Rock
08/23/2024 07:13:35	1344291	581537	5240	-1.0		858	2923	1358	Flank
08/23/2024 07:14:03	1344266	581544	5150	-1.2		859	2912	1336	Flank
08/24/2024 06:09:56	1344266	581644	5250	-1.3		901	2848	1298	Flank
08/24/2024 06:10:04	1344266	581744	5450	-1.1		874	2925	1373	Flank
08/24/2024 07:05:50	1344189	580846	4193	-0.7		862	3263	1953	Flank
08/24/2024 14:35:25	1343866	584144	3050	-1.5		354	1579	951	Flank
08/24/2024 14:36:17	1343776	582750	3304	-1.4		373	1386	669	AOI_LGS_02
08/24/2024 14:36:22	1343843	582563	3149	-1.7		354	1510	1003	AOI_LGS_02
08/25/2024 11:29:48	1343166	583544	2450	-2.5		277	544	316	AOI_PPG_06
08/27/2024 05:24:18	1343949	582571	3229	-1.5		366	1301	531	AOI_LGS_02
08/28/2024 22:34:23	1343677	582118	2891	-1.0		387	1756	852	AOI_PPG_02
08/29/2024 05:59:44	1344066	581144	4350	-1.4		728	2943	1409	Flank
08/30/2024 07:34:24	1343799	582363	2536	-1.0	-1.1	318	1438	872	AOI_PPG_02

Table 5. August 2024 Microseismic Event Broadband Surface Seismic Array Catalog

Date/Time CDT	Easting ft	Northing ft	Depth ft	Magnitude Mw	Depth error (ft)	Horizonal error (ft)
08/20/2024 14:51:30	1345841	586701	722	-1.5	131	354
08/30/2024 07:34:24	1343047	582203	1903	-1.1	886	652

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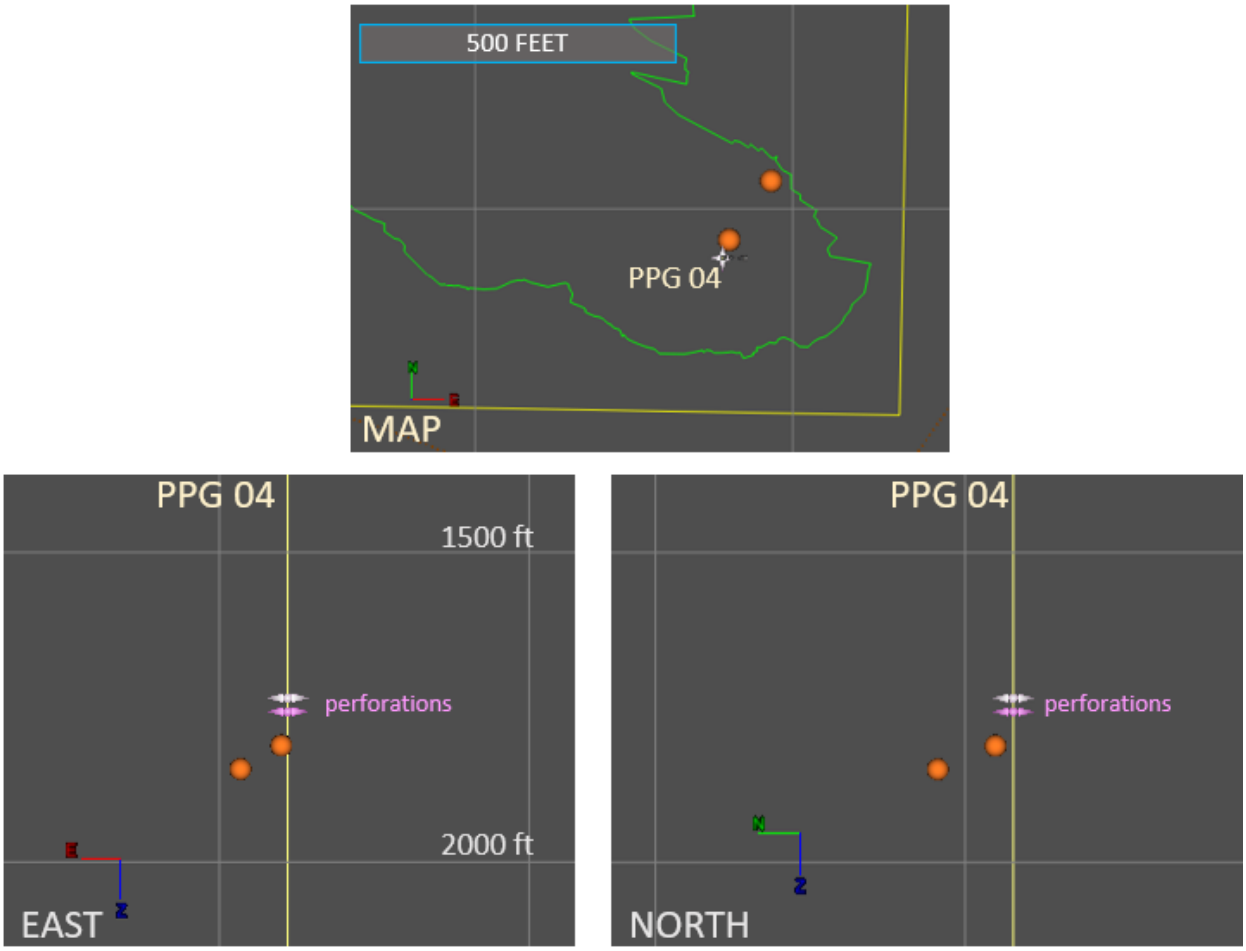
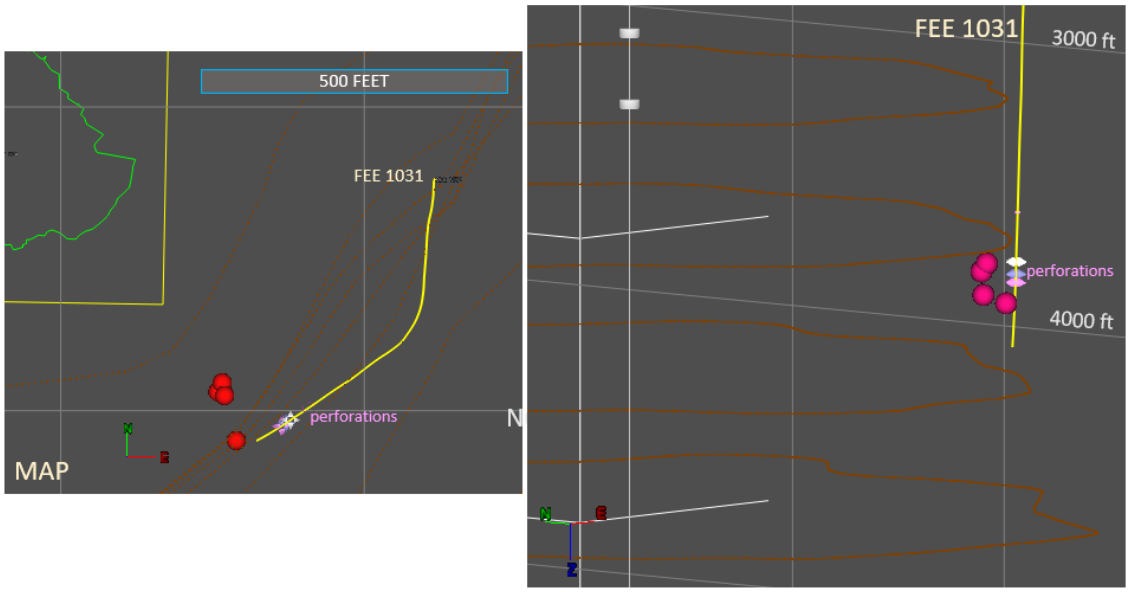


Appendix Figure 1. Top figure is map view and lower figures are east-west (left) and north-south (right) cross section views showing the PPG 04 wellbore and the perforation locations performed during a workover in August, as labeled. The orange circles are the location of the perforation shots using the borehole arrays. Grid is 500 feet.



Appendix Figure 2. Map (left) and a perspective view (right) of microseismic events suspected to be associated with perforations in the FEE 1031 well (yellow line) during workover activities in August 2024. These events are classified as perforations in the microseismic catalog. The orange lines are salt dome contours. Grid is 500 ft in map view and 1000 ft on the perspective view.