Seismicity Associated with Geothermal Systems

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Geosciences

Abstract

Studying natural and induced seismicity associated with geothermal systems can provide information regarding the location and magnitude of hydraulic fracturing. Understanding the fracture system can aid geothermal exploration. In addition, seismicity can affect the output of a geothermal reservoir, and potentially be a seismic hazard to the surrounding area. This study focuses on two geothermal systems: the Raft River Geothermal System (RRGS) in southern Idaho and the Mt. Princeton Geothermal System (MPGS) in central Colorado. The seismic data analyzed for the RRGS is from the broadband sensors that are part of the EarthScope Project's Transportable Array (TA), while the seismic data from the MPGS is from broadband and short-period sensors from the IRIS PASSCAL Instrument Center. A significant increase in seismic activity was measured on the TA station L14A near the RRGS, indicating pump testing and production caused induced seismicity. At MPGS, local events were identified, possibly related to natural hydraulic fracturing caused by near-surface hot fluid movement.

Introduction

Geothermal energy

Better understanding the production of geothermal energy from geothermal systems (Figure 1) is currently of great interest due to the global energy crisis and global warming. We investigate how seismic activity associated with geothermal systems can provide information on the productivity of power generation.

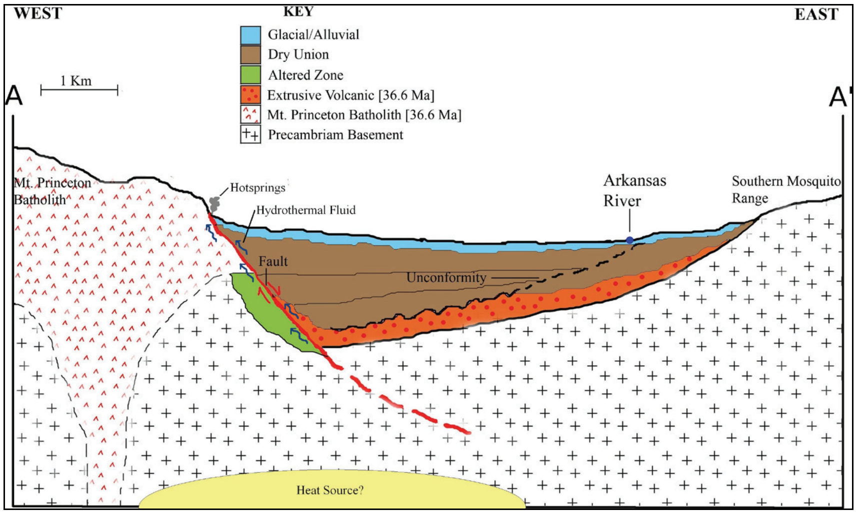

Figure 1. This figure shows a generic heat source and hydrothermal fluids moving along a normal fault system with a hot springs at the surface. This diagram is consistent with the proposed geothermal environment of the Mount Princeton Geothermal System. Not drawn to scale.

Seismicity

The two types of seismic activity considered for this research were induced seismicity and natural seismicity. Induced seismicity is ground motion generally associated with anthropogenic sources. For instance, people causing a change in the pore pressure of subsurface rocks by injecting water into or extracting water from a geothermal system. Pore pressure can also be altered by anthropogenic activities such as mining and the extraction of hydrocarbons and natural gases (Bommer, 2006). The presence of induced seismicity can lead to information regarding both the productivity and safety of a geothermal system. Induced seismicity can either increase or reduce permeability, potentially affecting productivity of a geothermal system. Induced seismicity can also cause temporary or permanent shutdowns of a plant, if it causes damage to equipment or creates seismic hazards.

As previously stated, induced seismicity is caused by changes in lithologic pore pressure. An increase in pore pressure associated with water injection in geothermal systems generally causes a decrease in the effective normal stress, resulting in shear stress. This decrease in effective normal stress occurs along already existing fractures (Cornet, 1995). Alternatively, extracting water, thereby reducing the pore pressure, is also correlated with induced seismicity. This type of induced seismicity may be explained by poroelastic stresses from changes in pore fluid distributions (Segall, 1989). Along with injecting and extracting water into the subsurface as a way of producing geothermal energy, pore pressure can be altered by activities such as mining and the extraction of hydrocarbons and natural gases (Bommer, 2006). The variety of ways in which induced seismicity may occur, many of which are related to alternative energy or the global economy, makes its study significant.

Natural seismicity occurs by natural means, for example movement along a fault due to strain caused by plate tectonics or the creation of hydraulic fractures due to water movement in the subsurface. The presence of natural seismicity can lead to information regarding the hydraulic fracturing in the geothermal system and monitoring of induced seismicity. Through analyzing clusters of events it is possible to determine where hydraulic fractures are occurring. There is a direct relationship between hydraulic fracturing and geothermal energy productivity. Also, implementing an array of stations before the start of geothermal power production will allow us to compare seismic activity before, during, and after the production of geothermal energy.

Geothermal Systems Considered

Two geothermal systems were considered as a part of this research project. The Raft River Geothermal System (RRGS), in southeastern Idaho, is operated by U.S. Geothermal Inc. and began production in January 2008 (U.S. Geothermal, 2007). Additionally, the Mt. Princeton Geothermal System (MPGS) is a geothermal system located in Chalk Creek Canyon, Colorado and is being carefully considered for geothermal exploration (Field Camp, 2009).

Raft River Geothermal System, Idaho

Introduction. The RRGS is located in a basin and range valley known as the Raft River Valley. The valley contains previously identified fault sequences that control the structural geology of the basin and the geothermal system. The basin has a Precambrian basement of quartz monzonite, overlain by Paleozoic metamorphics, such as schists and quartzites. Stratigraphically above the metamorphics are Tertiary deposits of primarily sedimentary rocks: gravels, alluvium, silt, and sand, along with volcanic sediments. The hydrothermal fluid in the RRGS is 140°C to 160°C. This is considered only a marginal temperature for a geothermal system. As a result, the Raft River Geothermal Power Plant uses a binary system where a secondary fluid with a lower boiling point than water is used. (Applegate, 2009)

Methods. Seismic data for this study was obtained by requesting data from the EarthScope project through the Incorporated Institutions for Seismology (IRIS) Data Management Center (DMC) using the WebRequest tool. The EarthScope Project focuses on installing numerous seismic stations across the United States (Figure 2) in order to gain a better understanding of the subsurface structure (EarthScope, 2009). Seismic data from two EarthScope Transportable Array (TA) stations show events before and after the start of energy production.

TA L14A and TA L13A are mapped relative to the RRGS in Figure 3. L13A is located approximately 50 km from the RRGS and L14A is located approximately 13 km from RRGS. The stations began acquiring data on julian day 199, 2007. Testing occurred at the RRGS from julian day 289 (October 16, 2007) to julian day 296

(October 23, 2007). A second phase of testing began on julian day 329 (November 25, 2009) and its end date is unknown. Production at the RRGS began on julian day 003 (January 3, 2008).

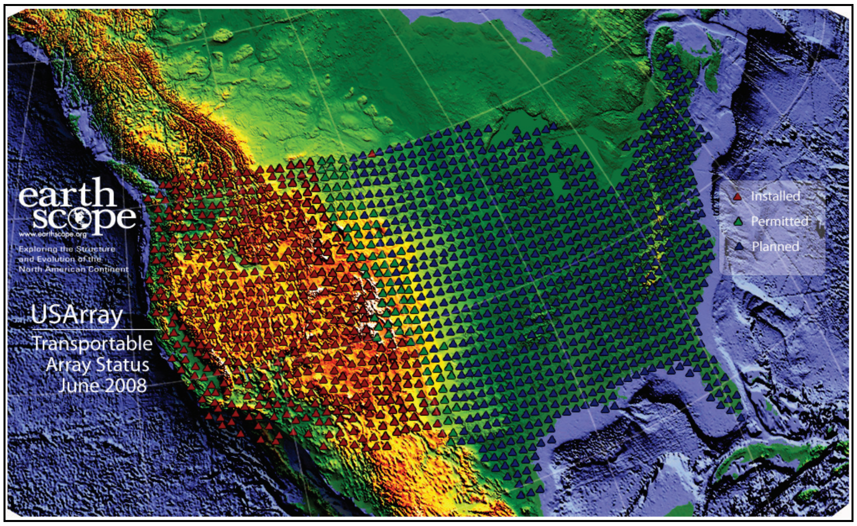

Figure 2. Map of the Transportable Array stations managed by the EarthScope project.

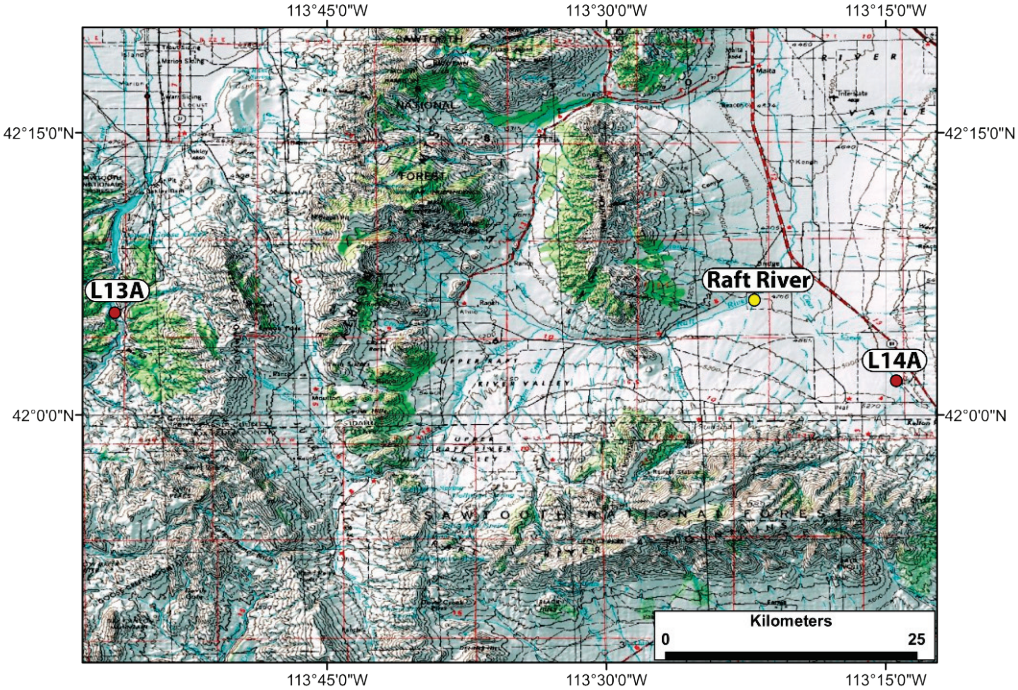

Figure 3. Map of the Raft River Geothermal System and the surrounding area, including the TA stations L13A and L14A.

Once the data was converted to the necessary format, the seismic analysis software PASSCAL Quick Look was used to scan the data (PQL, 2009). Events with amplitudes larger than 80 times the ambient noise were considered for both TA stations. The number of events that occurred between July 7, 2007 and April 3, 2008 were compared to determine if induced seismicity might be occurring near the RRGS. The station TA L13A is used as a control station because it likely does not detect small seismic events induced by the RRGS, whereas station TA L14A will. An example of a possible RRGS induced event can be seen in Figure 4.

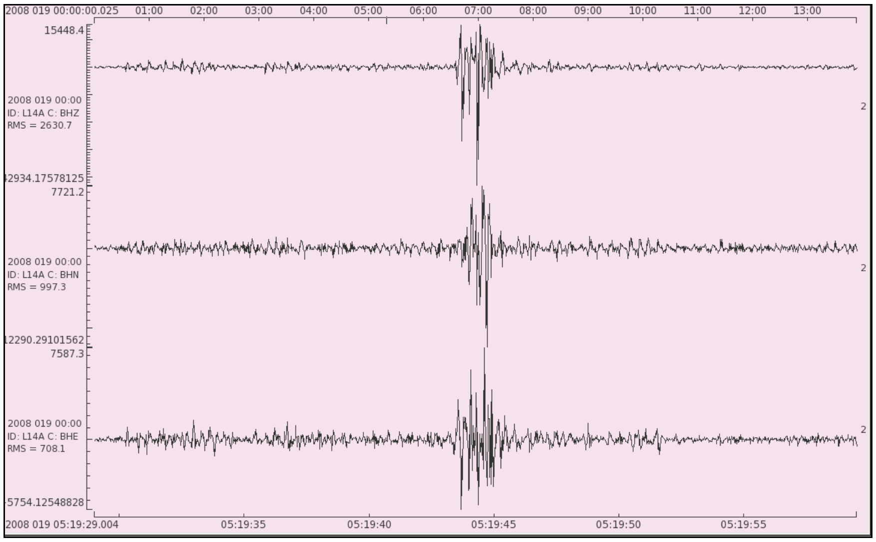

Figure 4. Example of an event at station L14A that may be induced by the RRGS.
A 3Hz-8Hz filter was applied to the data in this image.

Results. Figure 5 is a histogram with the number of events that occurred during a specific time on TA L14A and TA L13A. The y-axis is the number of events and the x-axis is julian days. Compared to TA L13A, TA L14A shows much more seismic activity. In addition, the increased seismic activity seems to correlate with pump testing and production. This could indicate that the seismic activity for station L14A is associated with the geothermal exploration.

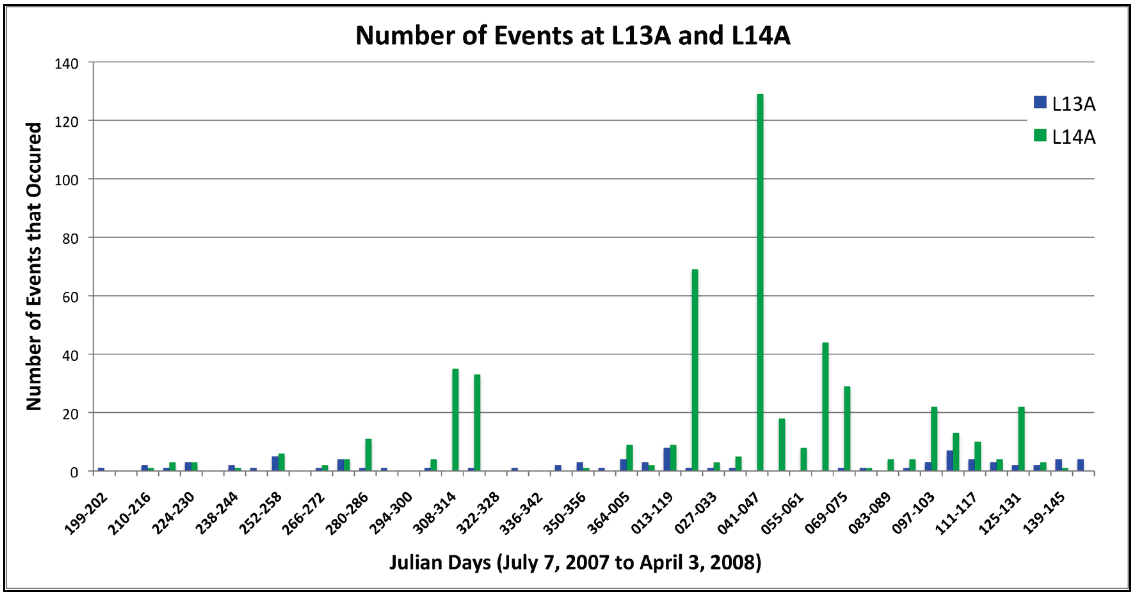

Figure 5. Number of events for TA L14A and TA L13A.

Conclusions. From the L14A histogram, it is apparent that there is little seismic activity prior to production at the RRGS, a small peak in activity during the testing phase, and a significant increase in activity during energy production. This is a strong indicator of induced seismicity present at the RRGS. The seismic activity seems to fit the criteria of local events; the wave forms of the events contain high frequencies. There is currently insufficient data for an analysis that includes determining the exact source locations of these events.

Mt. Princeton Geothermal System, Colorado

Introduction. The MPGS is a geothermal system that has been analyzed by Boise State University and Colorado School of Mines for the past five years in order to determine the geothermal characteristics of the area known as Chalk Creek Canyon, located at the foot of Mount Princeton, and how they fit the geologic structure of the Upper Arkansas Valley. The basement rock in the area of the Mt. Princeton Geothermal System is a granitic pluton that is estimated to be between tens to hundreds of meters below the surface. It is believed that the majority of the fluid movement is occurring within or near this granite. (Field Camp, 2009)

Contributors to the MPGS geothermal exploration acquired self-potential data in the Chalk Creek Canyon. This data suggests a shear zone in the canyon. The peak in the self-potential data suggests an area of fluid movement below the subsurface. This fluid movement is the basis for the proposed shear zone. It appears from these data (Figure 6) that there is a shear zone running parallel with the canyon (Richards, 2009). It is believed that the majority of the fluid movement is occurring within or near the granitic basement rock. Figure 6 shows the self-potential profile location with respect to the seismic stations and natural seismic events.

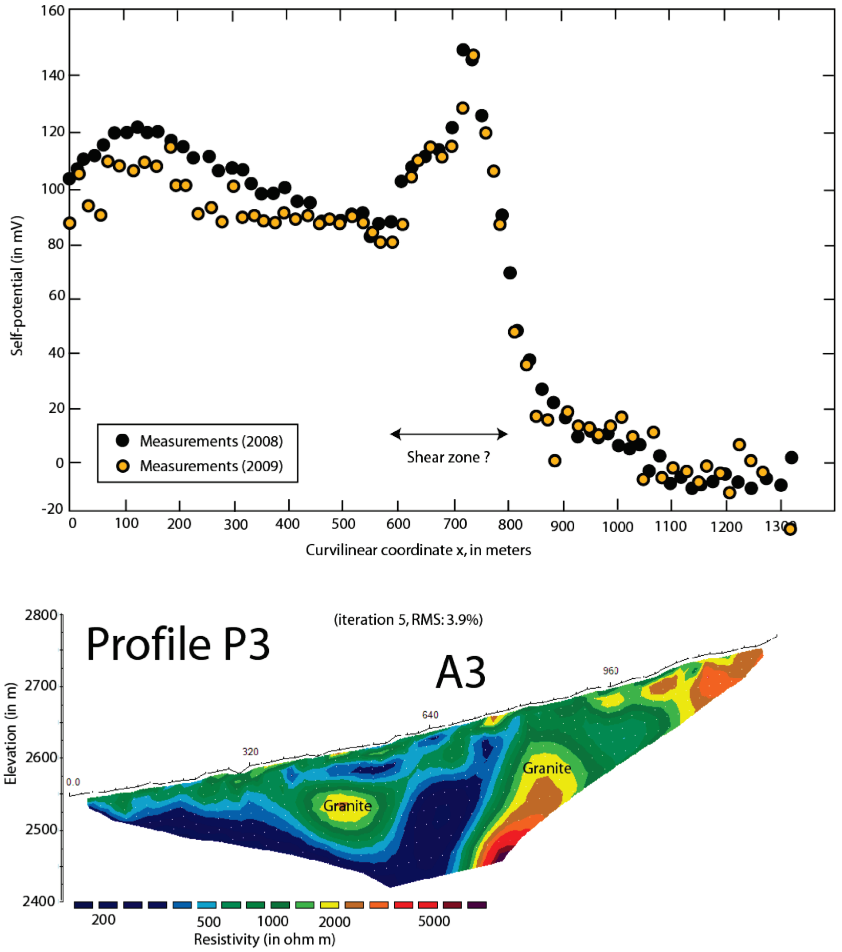

Figure 6. Self-potential data collected in Chalk Creek Canyon, CO. (Richards, 2009)

Methods. The passive seismic data were acquired by a network of seismic instruments from the IRIS PASSCAL Instrument Center. The data were analyzed by scanning for "unknown" events across multiple stations. An "unknown" event is one that is not noise and not a USGS archived regional or teleseismic event, making its source unknown (Figure 7). If an event was found on one station, but not a significant number of others, than it was likely noise (i.e. a vehicle driving by the station). If an event was found across multiple stations, but has a similar arrival time as a USGS archived event, than it is likely teleseismic and not one of the local events that we are interested in.

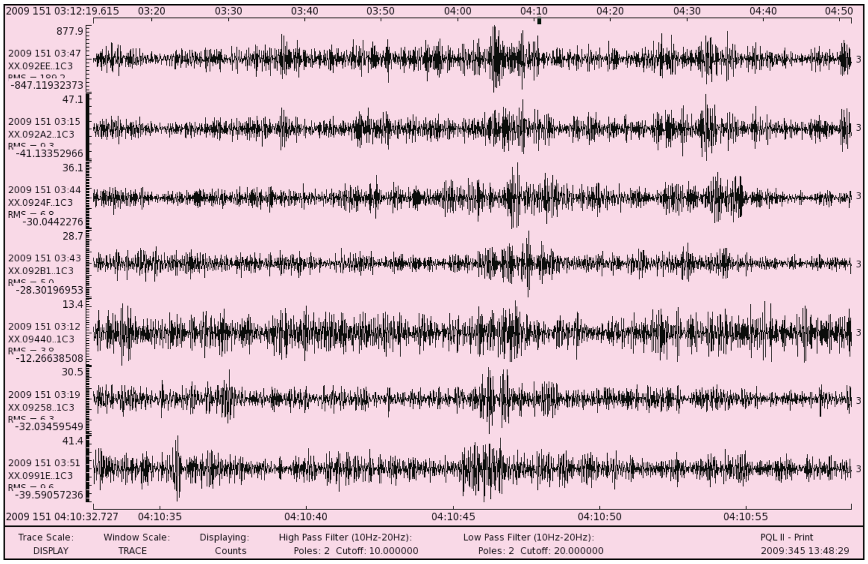

Figure 7. "Unknown" event. Traces show the vertical components of seven different stations.

Once several events were classified as "unknown," their parameters were entered in to a code written in SciLab to approximate their source locations. The code was used to optimize the locations of the events based on the event arrival times and an initial best location guess. The code assumes that the depths of the events are shallow, based on the local geology of the area, effectively reducing out source location problem to a 2D one.

Results. One night of data was analyzed for "unknown" events. On day 151 (May 31, 2009), nine "unknown" events were identified on at least seven of the thirteen stations in operation. The events that were identified were used in order to construct an event location map (Figure 8). Of those nine events, seven of them fell within a reasonable zone to be considered potential events associated with the faulting sequence under consideration for the MPGS. The two north-west trending faults are normal faults associated with faceted spurs and can be seen from surface deformation and active seismic sections. The north-east trending fault is inferred by the self-potential data discussed in Figure 5. These events were located using a surface wave velocity model of 0.5 km/s. The average normal misfit of the event locations was 0.03 seconds.

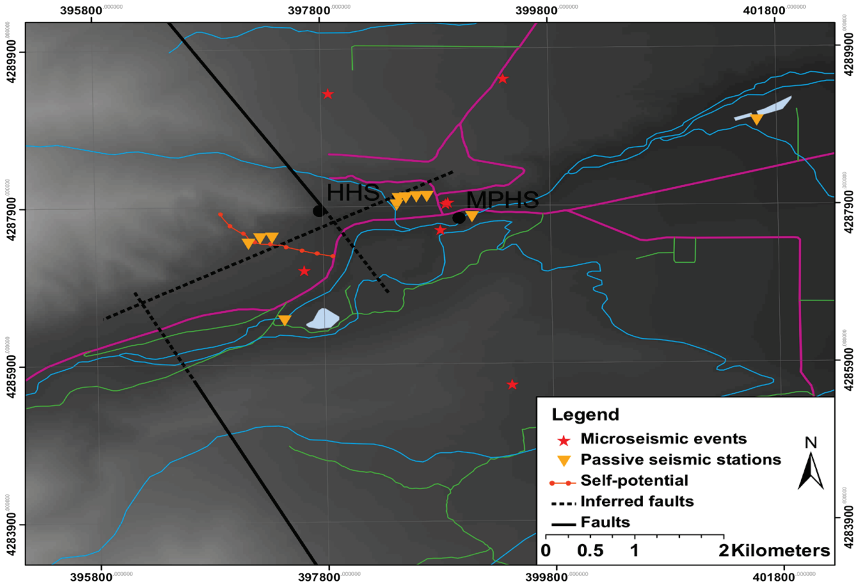

Figure 8. Map of the seismic stations and identified events relative to known faults in the valley.

Conclusions. Through identifying and locating "unknown" events in the proposed MPGS production area, we found local seismic activity. Based on faulting and surface geothermal expressions, we hypothesize these events are related to natural hot fluid flow in the near surface.

Other applications

Colorado debris flows. With the data collected from the MPGS, we also found that our seismic instruments have recorded several debris flows. Figure 9 is a seismic recording of a debris flow that occurred on June 2, 2009. From this unique data, in conjunction with video collected by the United States Geological Survey of the debris flow events, we may be able to learn more about the geomorphological events that occur in Chalk Creek Canyon, Colorado.

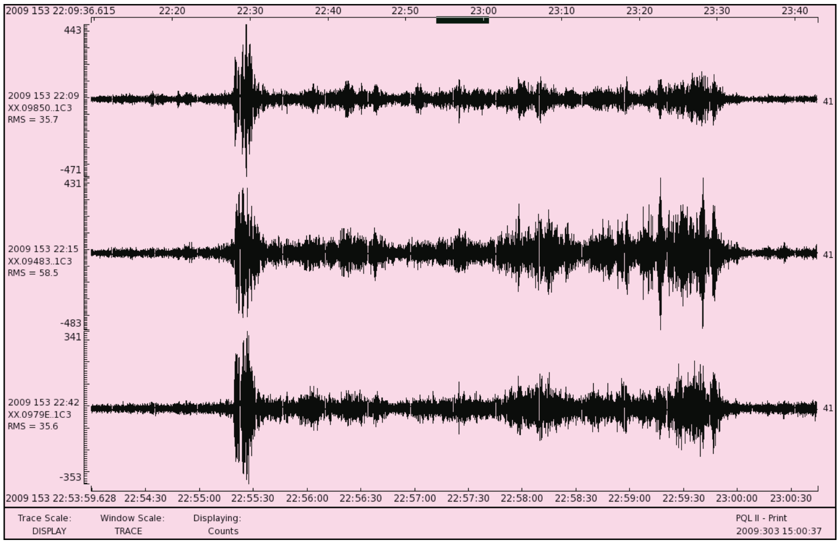

Figure 9. Debris flow event identified using the seismic data collected in Chalk Creek Canyon, Colorado.

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