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Seismic Characterization of the Newberry and Cooper Basin EGS Sites

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ABSTRACT

To aid in the seismic characterization of Engineered Geothermal Systems (EGS), we apply enhanced microearthquake detection and location techniques to two EGS systems: the Newberry EGS site and the Habanero EGS site in the Cooper Basin of South Australia. We apply the Matched Field Processing (MFP) seismic imaging technique to detect new seismic events using known discrete microearthquake sources. Events identified using MFP typically have smaller magnitudes or occur within the coda of a larger event. At the Newberry EGS site, 234 events were reported in the original catalog during a one year period including the first 2012 stimulation. MFP identified 202 additional events (an increase of over 85% more events). At the Cooper Basin Habanero EGS site, during a 12 day period including the start of the 2005 stimulation, 1238 events were identified in the original catalog and MFP identified an additional 123 events. This illustrates how MFP can be applied in conjunction with traditional earthquake detection techniques to enhance the official earthquake catalogs of EGS sites.

1. INTRODUCTION

A substantial fraction of seismic events can be excluded from official earthquake catalogs due to limitations in instrumentation and/or processing techniques. This can produce anomalously high detection thresholds that cause many microearthquakes to escape recognition entirely. Furthermore, the amplitude of microearthquake signals may be so small compared to the background ambient noise level that even a simple location procedure may be impossible for the event. However, both of these pieces of information are critical to enhance the utility of induced seismicity as a beneficial tool in reservoir management.

To mitigate these deficiencies and improve the spatio-temporal resolution of microearthquake activity at Engineered Geothermal Systems (EGS), we apply the empirical Matched Field Processing (MFP) method to continuous seismic data to detect and locate more microearthquakes than can be detected using only conventional seismic processing techniques. The MFP technique is different from established earthquake detection methodologies in that it is a template matching technique rather than an amplitude triggering technique (e.g., an STA/LTA algorithm). To perform MFP, we calculate the wavefield structure of a known event with high signal-to-noise ratio (SNR) across an array by estimating the structure directly from the previously observed seismic events. The templates would therefore contain both direct and scattered seismic energy. In choosing the master template events only the SNR is taken into consideration. No other magnitude, source mechanism or location criteria are taken into account.

The MFP technique breaks the waveform signals down into a large number of narrow frequency bands within the frequency passband of interest and performs the matching operation band by band. In this way, MFP attempts to suppress the sensitivity of traditional correlation matching operations to the source time function of the master template event. The trade off is that the origin times of the new events have errors up to a few seconds and therefore must be independently determined. Using this advanced earthquake detection method, we construct representative master templates from previously identified microearthquakes at two EGS sites (Newberry and Habanero) to identify new microearthquakes that had been previously missed.

2. NEWBERRY EGS SITE

The Newberry EGS site is situated on the western flank of the Newberry Volcano, a shield volcano in central Oregon. The EGS site is approximately 3 km from the caldera rim and is located on federal geothermal leases and National Forest Service lands in Deschutes National Forest. The Newberry EGS Project is a joint venture between AltaRock Energy and Davenport Newberry, and has received significant research and development funding through the Department of Energy (DOE) Geothermal Technologies Program (GTO). The AltaRock Energy Phase 2 Newberry microseismic network consists of 8 2-Hz 3-component Oyo Geospace HS-1 borehole geophones and 7 2-Hz 3-component Oyo Geospace HS-1buried surface geophones. The sample rate of the continuous data is 250 samples per second (sps) and the data is being recorded on Geotech SMART-24R dataloggers.

We use a merged combination of the Foulger Consulting Newberry earthquake catalog (Foulger and Julian, 2013) and the Lawrence Berkley National Laboratory (LBNL) Newberry EGS online catalog as the original earthquake catalog for this study. Between October 01, 2012 and February 18, 2013, the Foulger Consulting earthquake catalog is the authoritive catalog. Between February 19, 2013 and September 30, 2013, the LBNL earthquake catalog is the authoritive catalog. Combined there are 234 events reported during this time period. From this catalog, we identify 82 events that have high signal-to-noise ratios (SNR) on the seismic records in the frequency range of interest on at least four of the 3-component seismic stations. Templates are created for each of these high quality events and comparisons between the templates and the continuous data is stepped forward in time at 1-sec time intervals. Additionally for the Newberry EGS site, the frequency band over which MFP is performed is 10 – 20 Hz.

Using the above input parameters, the MFP method was able to identify 202 additional events. Newly detected events were given preliminary locations matching that of the master event that identified it (Figure 1). It is expected that new events would be within one wavelength of the master event.

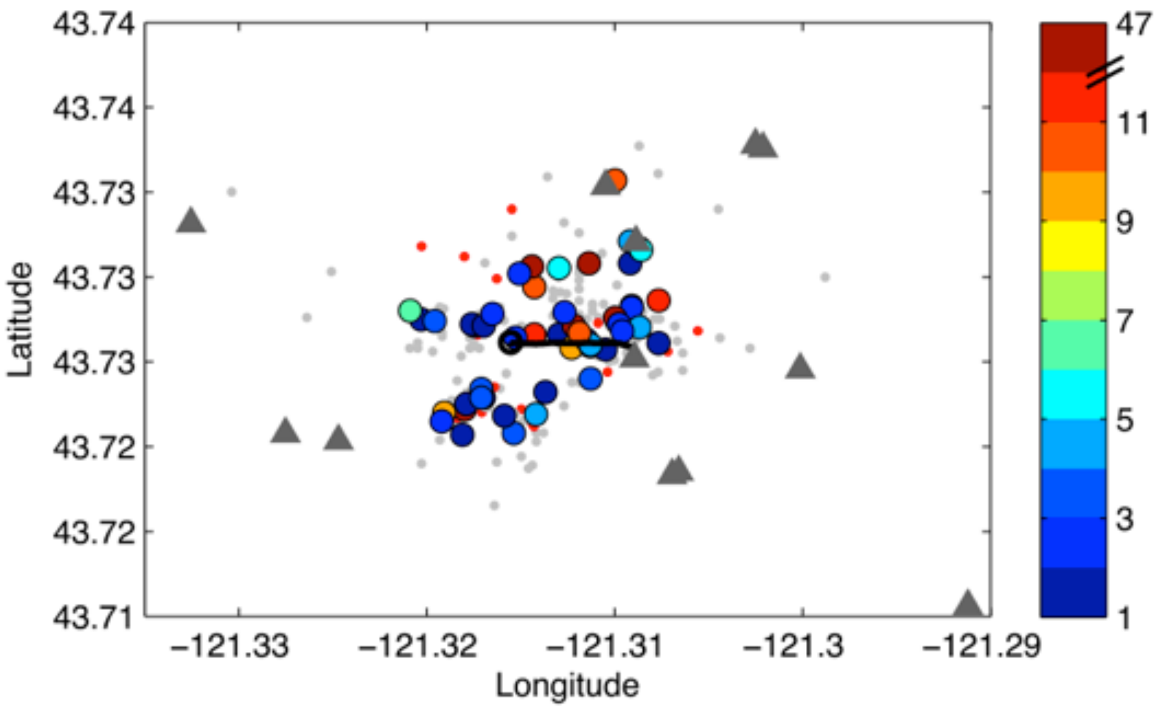

Figure 1: Map view of the Newberry EGS site seismicity. The location of the newly detected events are plotted as circles color coded to indicate the number of new events detected at each master event location. Master events that did not detect any new events are plotted as red dots. Original catalog events that were not used as master events are plotted as grey dots. Seismic stations are indicated by grey triangles. The surface location of the stimulation well is indicated by the black open circle and the black line indicates the deviation of the well with depth.

3. COOPER BASIN EGS SITE

The Cooper Basin in north eastern South Australia has been the site of several EGS projects. The Habanero EGS project near the town of Innamincka was developed by Geodynamics Limited and targeted a deep radiogenic granitic batholith overlain by approximately 3.6 km of sediments. The seismic network consisted of one deep high temperature instrument at 1780 m depth, two borehole instruments deployed between 240 – 370 m depth, and five near surface instruments installed between 80 – 130 m depth. The network recorded data at 500 sps on three-channel 24 bit Geotech SMART24 digitizers (Baisch et al., 2009; Soma et al., 2004).

In mid-September 2005, the second stimulation of the Habanero 1 well occurred. Over the course of 13 days, approximately 22,500 m^3 of water was injected to enlarge the stimulated reservoir area and enhance hydraulic permeability. To date we have analyzed 12 days of seismic data starting from 01 September 2005. This included several days of pre-stimulation seismic data which had very few seismic events. In the original catalog, 1238 seismic events occurred between 01 September 2005 – 09 September 2005. From this catalog of events, we identified 274 events that have high SNR on the seismic records in the frequency range of interest on at least four of the 3-component seismic stations. Templates are created for each of these high quality events and comparisons between the templates and the continuous data is stepped forward in time in steps of 1-sec. Based on a site-specific evaluation of anthropogenic and natural background noise sources at the Habanero EGS site, we chose 20 – 30 Hz as the frequency band over which MFP performed the template matching operation. This frequency band was relatively free of spurious noise sources.

From these 274 master templates, we were able to identify 123 more events that were originally missed in the earthquake catalog. Many new events were identified within the coda of larger events (Figure 2) or during times when one or more components showed glitches in the data stream, which may have caused the STA/LTA earthquake detection analysis to produce anomalously low values thereby invalidating potential new events.

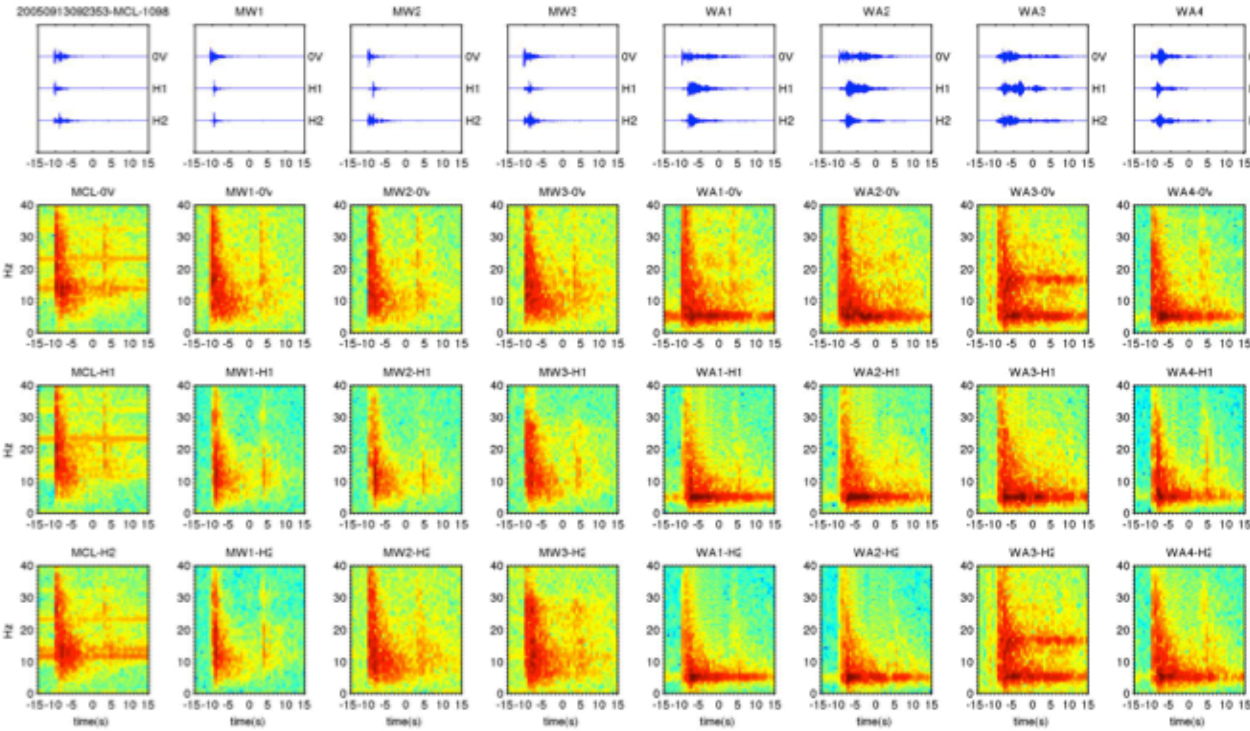

Figure 2: Example new event identified by the MFP method (starting at approximately +5 sec in the plots) that occurred within the seismic coda of a larger M1.5 event (starting at approximately -10 sec in the plots). Each column contains seismic data from one particular station. The first row contains waveform plots for each 3-component station. The second, third and fourth rows show individual spectrograms of the vertical and horizontal components between 0 – 40 Hz.

3. RESULTS AND CONCLUSIONS

The results from the Newberry EGS site and the Habanero EGS site show that the MFP advanced earthquake detection and location technique can provide enhanced spatio-temporal resolution of microseismicity occurring in subsurface reservoirs. Microseismic mapping is a key tool used to infer the geometry of the EGS resource and MFP can provide improved microearthquake identification even in difficult signal processing environments. Furthermore, this additional data can improve the statistical analyses of induced seismicity sequences, reveal critical information about the ongoing evolution of the subsurface reservoirs, and better inform the construction of models for seismic hazard assessments.

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