Analysis of microseismicity using fuzzy logic and fractals for fracture network characterization

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Abstract

Microseismic (MEQ) event occurrence may be correlated with the fracture network at a geothermal field. If certain mechanisms are operative, cluster of the MEQ events should represent a connected fracture network. Drilling new EGS wells (both injection and production wells) in these locations may facilitate the creation of an EGS reservoir.

Here, we use fuzzy clustering to locate the fracture networks in the Geysers field. We show how the cluster centers move in time, representing fracture propagation or fluid movement within the fracture network. We also conduct fractal analysis to develop an accurate fracture map for the reservoir. Combining the fuzzy clustering results with the fractal analysis allows us to better understand the mechanisms for fracture stimulation and better characterize the evolution of the fracture network.

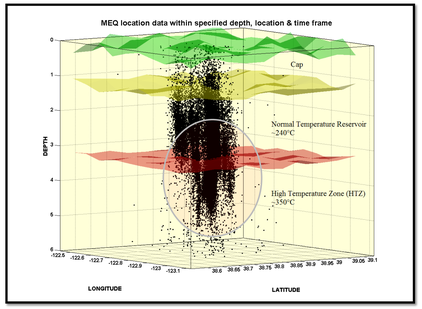


Figure 1 - 3D Distribution of microseismic events at The Geysers for the years 2006 to 2009

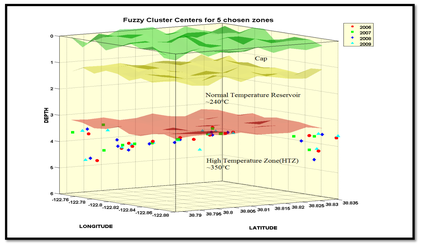


Figure 2 - Fuzzy cluster centers for all the years at the HTZ zone.

Fuzzy Clustering

Soft computing (fuzzy logic, neural networks, genetic algorithms) has been used extensively in geosciences and energy-related applications, yet few have been for exploration and exploitation of geothermal resources. Fuzzy clustering of the microseismic events in both discrete time windows and locations leads into accurate fracture map for the area. Careful review of the time windows of each specific location also demonstrates the fracture network propagation direction.

We consider four mechanisms to explain the occurrences of these MEQ events in a geothermal field. Those are the pore-pressure increase, the temperature change, the volume change due to fluid withdrawal/injection and the chemical alteration of fracture. Then, the area where the large number of MEQ events occur have a good correlation with of the fracture network in the geothermal field.

A viable geothermal reservoir, requires a large aerial distribution of fracture network. Clusters of the MEQs could represents a connected fracture network (Figure 1). Cluster centers show significant movement at the HTZ (Figure 2). Direction of arrows indicate the direction of movement of MEQ clusters over time. We believe this may represent the fracture network propagation direction (Figure 3). Large movements may be related to a faulting mechanism. Consequently, as it is shown in Figure 10, we have created a recommended drilling program for the injection and production wells, corresponding to the arrows with acceptable size and direction.

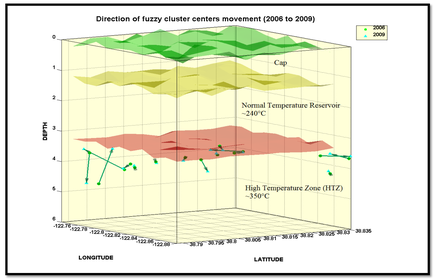


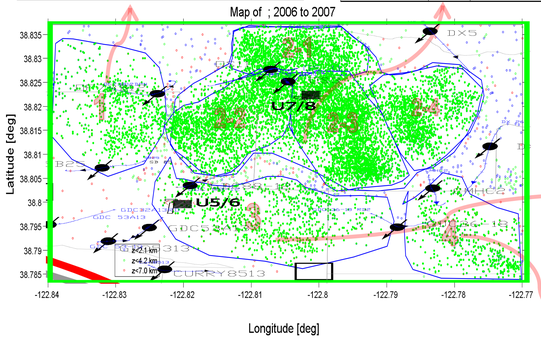
Figure 3 - Fuzzy cluster center movement from 2006 to 2009

Fractal Analysis

Name of Cluster	b-Value	Fractal Dimension	Number of events
Whole Study area	1.32	2.59	11487
(-.2-1.1)M		2.59	8433
(1.1-4.3)M		2.49	4032

Name of Cluster	b-Value	Fractal Dimension	Number of events
Region 1		2.23	698
Region 1 (-.2-1.1)M		2.22	537
Region 1 (1.1-4.3)M		2.18	199

Name of Cluster	b-Value	Fractal Dimension	Number of events
Region 2	1.36	2.65	8787
Region 2 (-.2-1.1)M		2.64	6541
Region 2 (1.1-4.3)M		2.53	3030



Name of Cluster	b-Value	Fractal Dimension	Number of events
Region 2-1	1.35	2.6	1556
Region 2 -1(-.2-1.1)M		2.53	1229
Region 2 -1(1.1-4.3) M		2.49	493

Name of Cluster	b-Value	Fractal Dimension	Number of events
Region 2-2	1.54	2.58	2404
Region 2 -2(-.2-1.1) M		2.49	1799
Region 2 -2(1.1-4.3) M		2.41	844

Name of Cluster	b-Value	Fractal Dimension	Number of events
Region 2-3	1.32	2.52	3326
Region 2 -3(-.2-1.1) M		2.51	2391
Region 2 -3(1.1-4.3) M		2.41	1220

Name of Cluster	b-Value	Fractal Dimension	Number of events
Region 2-4	1.15	2.27	1323
Region 2 -4(-.2-1.1) M		2.3	1006
Region 2 -4(1.1-4.3) M		2.1	419

Name of Cluster	b-Value	Fractal Dimension	Number of events
Region 3	1.32	2.55	860
Region 3 (-.2-1.1)		2.43	529
Region 3 (1.1-4.3)		2.44	404

Name of Cluster	b-Value	Fractal Dimension	Number of events
Region 4	1.16	1.73	477
Region 4 (-.2-1.1)		1.77	298
Region 4 (1.1-4.3)		1.87	219

Figure 4 – Seismicity map for 2006 events in the study area at The Geysers geothermal field. (Zmap)

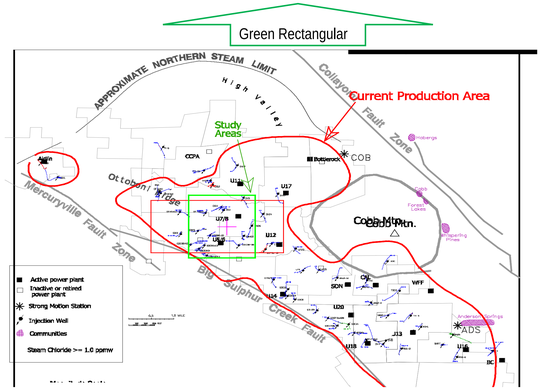


Figure 5 – The Geysers map and locations of the study areas. The map is modified from original one which is provided by Joseph Beall from Calpine

Seismicity has fractal structures in space and magnitude distributions, as articulated by the fractal dimension *D*, and the *b* value. The fractal dimensions are calculated using the correlation integral. And b-value is the slope of the frequency-magnitude relationship, and predicted by the maximum curvature method.

The results illustrate that the relation $D=2b$ between the *b* value and the fractal dimension *D* of fracture planes, is valid in the seismicity distribution at The Geysers geothermal field. Fractal dimension of 2.5 and b-value of about 1.25 on most regions of seismicity distribution also is another indicator of the induced seismicity at The Geysers as opposed to a tectonic event where fractal with fractal dimension of 2.

This result is further proof for our hypothesis that cluster of the MEQs represents a connected fracture network at The Geysers.

Conclusions

Fuzzy logic can be helpful in analyzing the MEQ data, especially when dealing with the weak events. As an example, fuzzy clustering technique was used to find the most likely and significant location of the fracture networks. The cluster centers may represent the locations of drilling new EGS well. These centers probably are the centers of the connected fracture network which is ideal for creating a geothermal reservoir.

The fractal dimension and b-value analysis also illustrate the behavior of the MEQ events at The Geysers. Comparing the fractal dimension and b-value of tectonic events with these events further prove that cluster of MEQevents could represent the connected fracture network.

The relationship between b-value and fractal dimension is also verified in this article with real data from NCEDC.

We are hopeful that our new findings can be tested by actual drilling. Once confirmed, hopefully such new applications of soft computing will find their use in the exploration and exploitation of geothermal resources in the future.

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