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IDENTIFICATION OF STRUCTURES INSIDE AN AE/MICROSEISMIC CLOUD IN A HDR RESERVOIR AND RELOCATION BY A MODIFIED COLLAPSING METHOD

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ABSTRACT

We present a new method to relocate microseismic events based on the concept of the "collapsing method". The collapsing method is a relocation technique which aims to find the simplest microseismic structure by reducing statistical uncertainties. We introduce the idea of estimating the original microseismic structures which have sizes comparable to the error ellipsoid. Three simple structures, point, plane, and line are allowed for in this new method. The original collapsing method implicitly assumed that all the original structures were points. The modified technique has been applied to microseismic events detected at the Fenton Hill HDR Field, NM, USA, and structures were imaged which show the feasibility of estimating precise structures inside HDR reservoirs.

1. INTRODUCTION

The acoustic emission/microseismic (AE/MS) method is considered to be one of the few methods available to measure HDR reservoirs which are typically created in deep and hot basement rock. The AE/MS method provides crucial information related to reservoir dynamics. The source location is necessary for these reservoir dynamics analyses. However, the locations contain an element of misfit owing to observational uncertainty in picking, local variations in velocity, and other factors. Because of these uncertainties and errors, the calculated locations are spread out from their true positions and are typically distributed like a diffuse cloud. Although it has been widely accepted that combined interpretation of microseismicity, logging, and geological information is key to understanding the physics in the HDR reservoir systems, the resolution of the microseismic mapping is often insufficient to allow this integration. Therefore development of mapping techniques which can locate microseismic events with increased resolution are needed.

Jones and Stewart (1997) presented a method for relocation using statistical optimization. In this technique the residual error in location is considered to be a kind of stochastic variable contaminated by white noise. This method is referred as the "collapsing method", and its effectiveness has been demonstrated by application to volcanic seismicity (Jones and Stewart 1997), microseismicity associated with the stimulation of an HDR reservoir (Jones et al. 1996), and natural microseismicity in a fault zone (Jones 1998).

The collapsing method can estimate structures which are larger than the typical error ellipsoids. The collapsing method always tries to collapse structures back to the simplest structure, i.e. a point structure. In this paper we investigate a new variation on the collapsing method which enables us to better estimate structures inside a microseismic cloud.

2. OUTLINE OF ORIGINAL COLLAPSING METHOD

In the original collapsing method Jones and Stewart (1997) made the observation that actual seismic locations have a simpler structure than that of the calculated locations. The calculated locations are contaminated by random noise which serves to make the locations spread out and so the observed structure becomes blurred, or cloud-like. The original collapsing method moves each location towards the point which has the greatest density of locations within the error ellipsoid of the original location. The procedure of this method is illustrated schematically in Fig.1 and consists of the following steps.

Step 1: Location of events by the JHD method.

After picking phase onsets a conventional location method is used e.g. the joint hypocenter determination (JHD, Aki and Richards 1980, Frohlich 1979). The location and origin times of all the events, station corrections etc. are optimized as far as possible. Ideally the residual errors after the JHD should follow a Gaussian distribution i.e. all systematic uncertainties have been removed and only random uncertainties remain.

Step 2: Calculation of error ellipsoids.

Confidence ellipsoids are calculated for each location via the standard error (Aki and Richards, 1980). For practical purposes the confidence ellipsoids are truncated at a specified confidence level, e.g. Jones and Stewart (1997) used 99.7% (which is 4.2 standard deviations for a Chi-square distribution with three degrees of freedom).

Step 3: Detection of target events

For a given microearthquake, termed the target event, all the events within its confidence ellipsoid are found and the centre of gravity is calculated.

Step 4: Movement of events.

The location of the target event is moved towards the centre of gravity. The magnitude of the movement of the location from its original position is calculated in terms of its own confidence ellipsoid.

Steps (3) and (4) are repeated for all the events in the cloud. This constitutes one iteration. The process is repeated until the distribution of normalized movements best fits the Chi-square distribution with three degrees of freedom.

Jones and Stewart (1997) illustrated the collapsing method by using a synthetic data set consisting of 1000 points perturbed from the original point using Gaussian statistics (Fig.2). The original point structure is obtained after five iterations.

3. DETECTION OF STRUCTURES INSIDE A MICROSEISMIC CLOUD BEFORE COLLAPSING

By moving locations towards the local center of gravity one assumes that all structures are point structures. We introduce the idea of estimating original structures before applying the collapsing, hence limiting the freedom of movement in the collapsing process.

We make the assumption that there are three possible types of original structures to which events may belong i.e. plane, line or point. Each location must have come from one of these three types of structure. The original structure (plane, line or point) for the target event is estimated by using the principal component analysis (PCA) of the locations which fall within the confidence ellipsoid of the target event. The distribution of locations within the confidence ellipsoid of the target event is normalized to remove the distorting effect of the non-spherical confidence ellipsoid of the target event. The ratio of the three eigenvalues which results from the PCA of the event distribution after normalization is used to decide which is the most probable type of original structure, point, line or plane. The movement of the target event is then structure-dependent, as shown in Fig. 3. The movements are as follows;

(1) Plane: The movements must be parallel to the shortest eigenvector of the distribution of events i.e. in a line perpendicular to the plane. The normalized movements are fitted to Chi-square distribution with one degree of freedom.
(2) Line: The movements must be perpendicular to the longest eigenvector of the distribution of events i.e. in a plane perpendicular to the line. The normalized movements are fitted to Chi-square distribution with two degrees of freedom.
(3) Point: The movement must be toward the centre of gravity of the distribution. The normalized movements are fitted to Chi-square distribution with three degrees of freedom. This is the same procedure as in the original collapsing method.

These new structure-dependent movement rules are included in procedures 3 and 4 in the original collapsing method.

4. SIMULATION

We evaluated the performance of this modified collapsing method to estimate original microseismic structures using two synthetic examples of microseismic locations, a plane and a line. All the events were initially on the structure, and they were moved by adding noise drawn from a Chi-square distribution with three degrees of freedom. The perturbed locations (left), relocated by the original (center) and new (right) collapsing methods are shown in Figs. 4 and 5. The original structure in Fig. 4 is a line from (0, 0, -1) to (0, 0, 1) and that in Fig. 5 is a circular plane in the y-z plane with radius of 1. It is difficult to detect the original structure by inspection of the perturbed locations, but structures very similar to the original structures were produced by application of the modified collapsing method. Relocation using the original collapsing method results in line and plane structures, the length, however, is less than half of the original. This scaling effect is a result of the assumption in the original collapsing method that all the events within the confidence ellipsoid of the target event were perturbed from a point.

5. APPLICATION TO FIELD DATA

The modified collapsing method was applied to microseismic data collected at Fenton Hill, NM, USA (House, 1987). We have selected a cluster of events which is referred to as "cluster-5" (Phillips et al. 1997), because various kinds of processing, including JHD and original collapsing, have been already applied to this cluster. The locations of the 727 events after JHD, the original collapsing and the modified collapsing processes are shown in Fig.6. The structure in the seismic cloud can not be clearly seen in the JHD mapping (left), but three semi-vertical planar structure are seen in the modified collapsing mapping (right). It is also seen in the mapping by the modified collapsing method, that more small scale structures appeared compared to the original collapsing method (center). The original collapsing method does resolve some structures, but the events are concentrated at the center and small scale structures are not seen. The seismic structure revealed by the modified collapsing method was consistent with the clustering mapping by Phillips and the stress condition (Phillips et al. 1997).

6. CONCLUSIONS

We have described the concept of a new relocation technique for microseismicity, based on the idea of the collapsing method. The original structure in the cloud is estimated by the principal component analysis of the locations around the target location. Event movements in the collapsing are restricted depending on the estimated original structures. Simulation showed that this method has a good ability to estimate original microseismic structure even when the size of the original structure is comparable to the confidence ellipsoid. The modified collapsing method was applied to field data from Fenton Hill, USA. Structures in the microseismicity associated with hydraulic fracturing were successfully imaged. The modified collapsing method preserves the advantages of the original collapsing method and has the potential to better resolve planar and linear structures, although at the cost of some additional complexity. The improved resolution of structures is very useful in increasing the understanding of the dynamic behaviour/structure of geothermal reservoirs.

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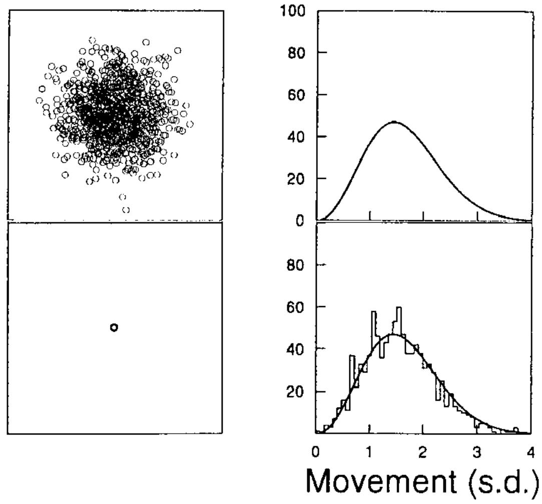


Fig.2 Collapsing of synthetic data set consisting of 1000 points perturbed from the original point using Gaussian statistics (Jones and Stewart, 1997)

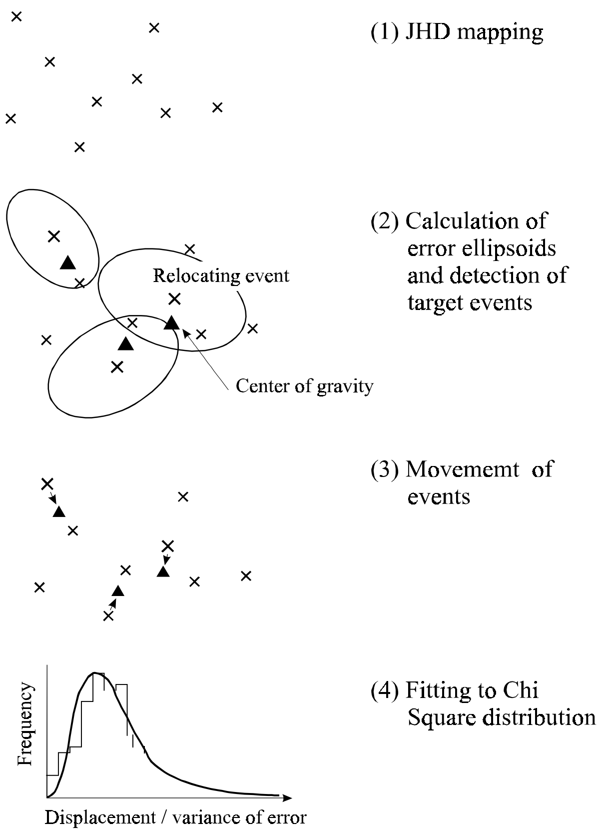


Fig.1 Concept of the original collapsing method.

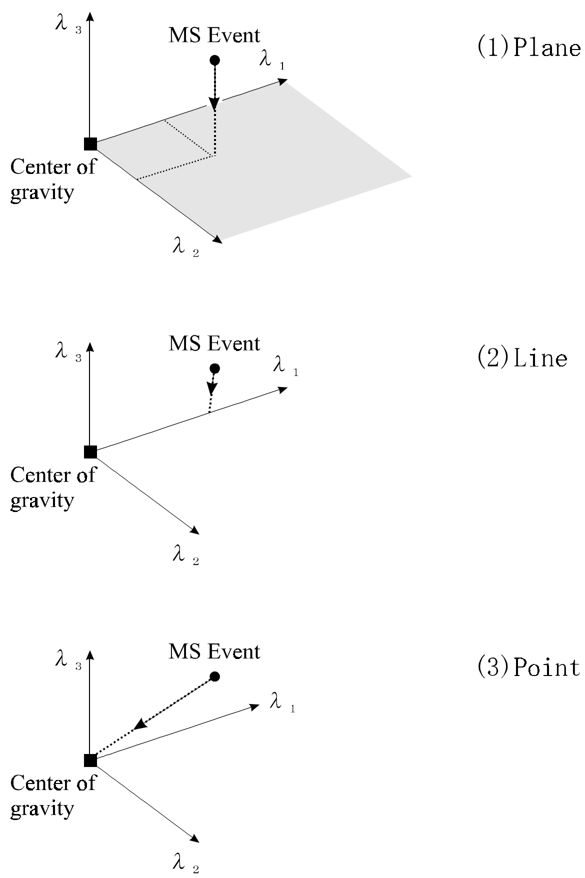
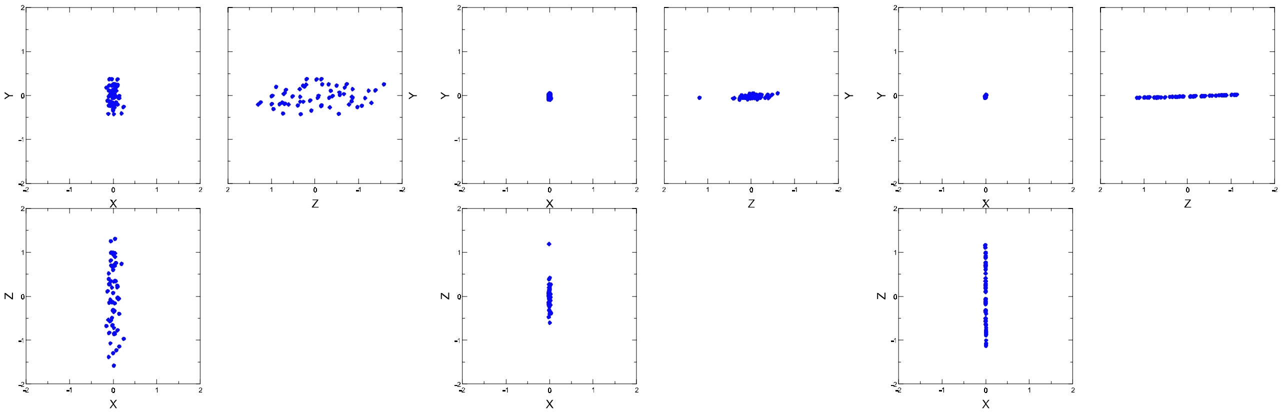
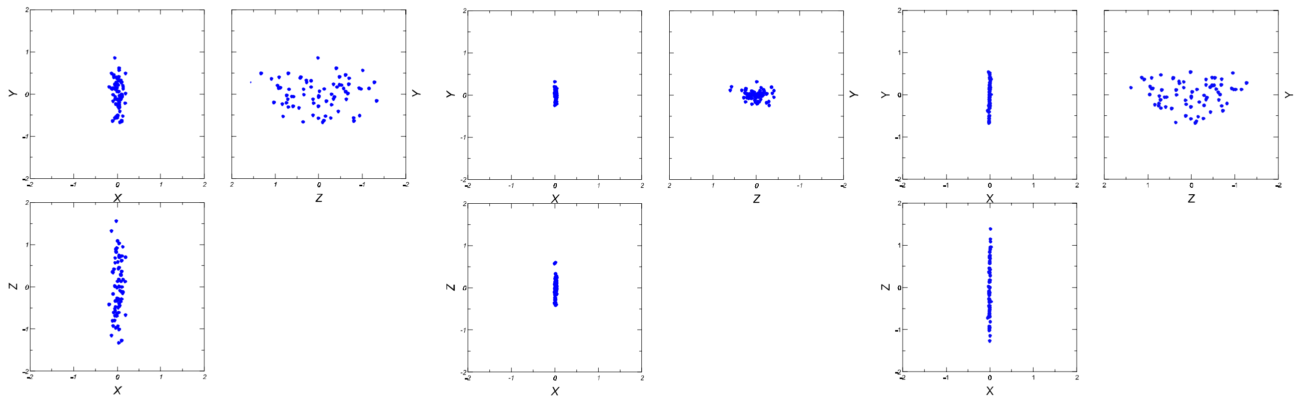


Fig.3 Freedom of movement in the modified collapsing method.



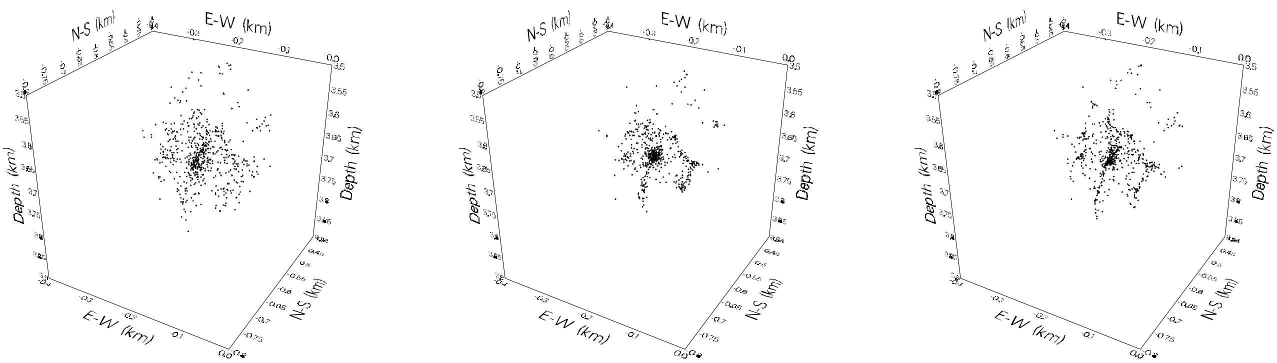
(a) Pertubated location (b) Original collapsing (c) Modified collapsing

Fig.4 Collapsing of synthetic microseismic locations (a line).



(a) Pertubated location (b) Original collapsing (c) Modified collapsing

Fig.5 Collapsing of synthetic microseismic locations (a plane).



(a) JHD (b) Original collapsing (c) Modified collapsing

Fig.6 Relocation of microseismic events in Cluster-5, Fenton Hill, USA.