Source Mechanism of Acoustic Emissions in Triaxially Loaded Granite

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1. General abstract

The development of brittle deformation and failure in rock is of importance in a number of fields, including seismology, the hydrocarbons industry and civil engineering. We can improve our understanding of this process by carrying out controlled experiments, where a rock is loaded to destruction in a hydraulic press. During this procedure high frequency sounds are emitted, termed 'acoustic emissions' (AE), thought to be produced by the initiation and growth of cracks on a microscale. By applying techniques from seismology, we can obtain useful information about the type of crack growth occurring and how it changes during the loading of the sample.

2. Technical abstract

During laboratory studies of brittle fracture in rock, high frequency pressure disturbances known as 'acoustic emissions' (AE) can be recorded (Lockner, 1993). Thought to be due to energy release during microcrack growth, AE events can be used as an indicator of internal damage. Moment tensor inversion (MTI) has been carried out for 16,311 AEs, recorded during the triaxial compressive loading of a cylindrical sample of red Aue granite. Events were then decomposed and classified into shear, tensile and mixed-mode sources. A shift in the dominant mechanism of cracking is observed between tensile sources, in the early stages of loading, and shear sources, during the later stages. The orientation and spatial and temporal variation of these sources can now be examined.

$$M = \begin{pmatrix} m_{11} & m_{21} & m_{31} \\ m_{12} & m_{22} & m_{32} \\ m_{13} & m_{23} & m_{33} \end{pmatrix} \quad (1)$$

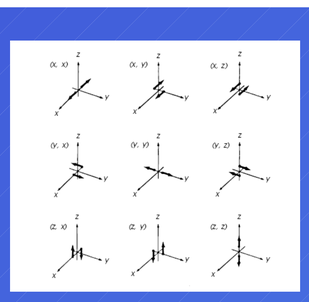


Figure 1 Moment tensor elements

3. Moment tensor inversion (MTI)

The source of an earthquake can be described in terms of the 'moment tensor', M (Eq. 1, Fig 1). This study utilises the SiGMA (Simplified Green's function for Moment tensor Analysis) technique, developed by Ohtsu (1991), to invert from P-wave amplitudes, for M (Fig 2). Once the elements of the moment tensor have been determined for an event, the source can be decomposed into different components, using eigenvalue analysis, and classified into different source types. Here, automatic decomposition is into double-couple (DC), isotropic and 'Compensated Linear Vector Dipole' (CLVD) parts (Knopoff & Randall, 1970) – see Fig. 3.

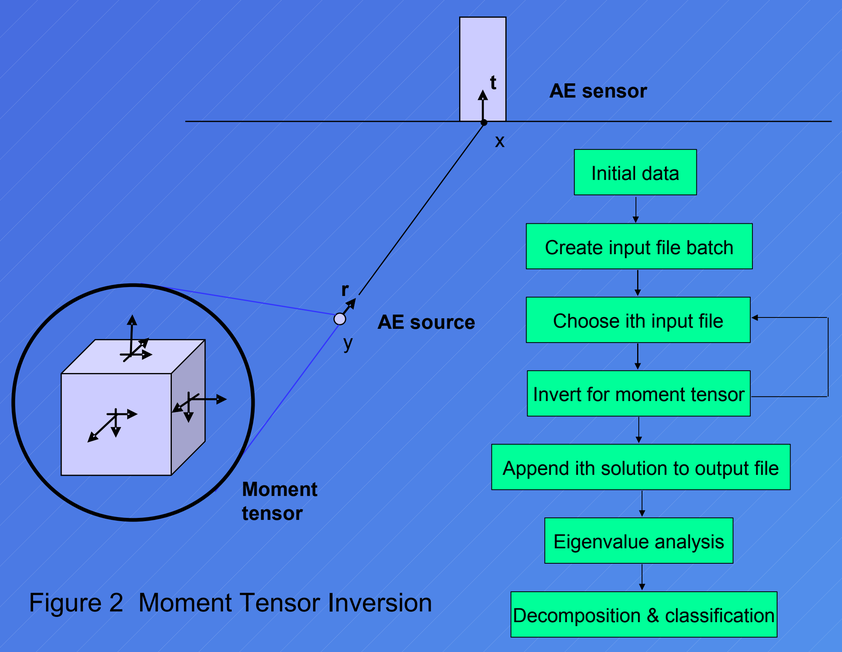


Figure 2 Moment Tensor Inversion

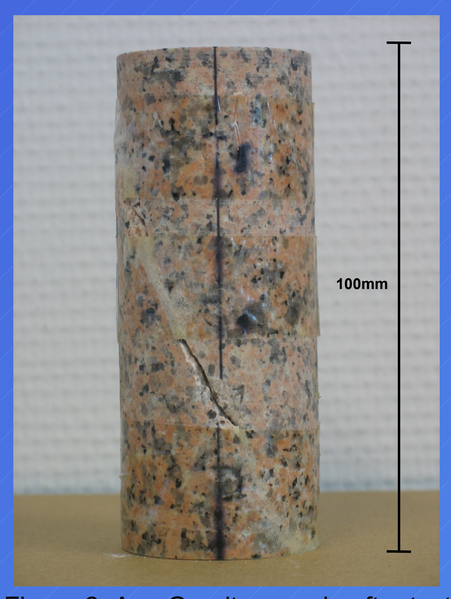


Figure 2. Aue Granite sample after test

4. Case study

MTI was carried out for 16,311 located AE events from a triaxial compression test on red Aue granite (examples in Fig.3). The confining pressure was 20MPa and 11 sensors recorded waveforms. Granite description:

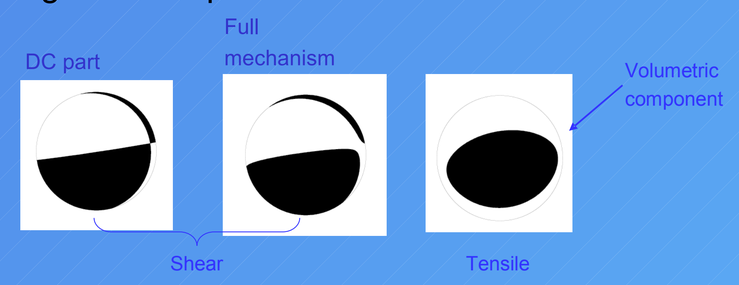
- 30% quartz
- 40% plagioclase
- 20% K feldspar
- 10% mica
- Grain size: 0.9-1.8mm
- Initial Porosity = 1.3%
- Poisson's ratio =0.17

5. Results

The resulting events classifications were then used to calculate the average percentage of each source mechanism, per 100 hits. These values were then plotted against time (Fig. 4). A further classification was introduced for those tensile sources for which the moment tensor trace indicated a net inward volume change.

- Initially tensile sources dominate
- Shear sources become dominant later
- Coincides with drop in V_{PH}

Fig. 3. Example focal mechanisms



- Decompose from eigenvalues
  ➡ X=DC, Y=CLVD, Z=ISO
- X>60% ➡ Shear
- X<40% ➡ Tensile
- 40%<X<60% ➡ Mixed-mode

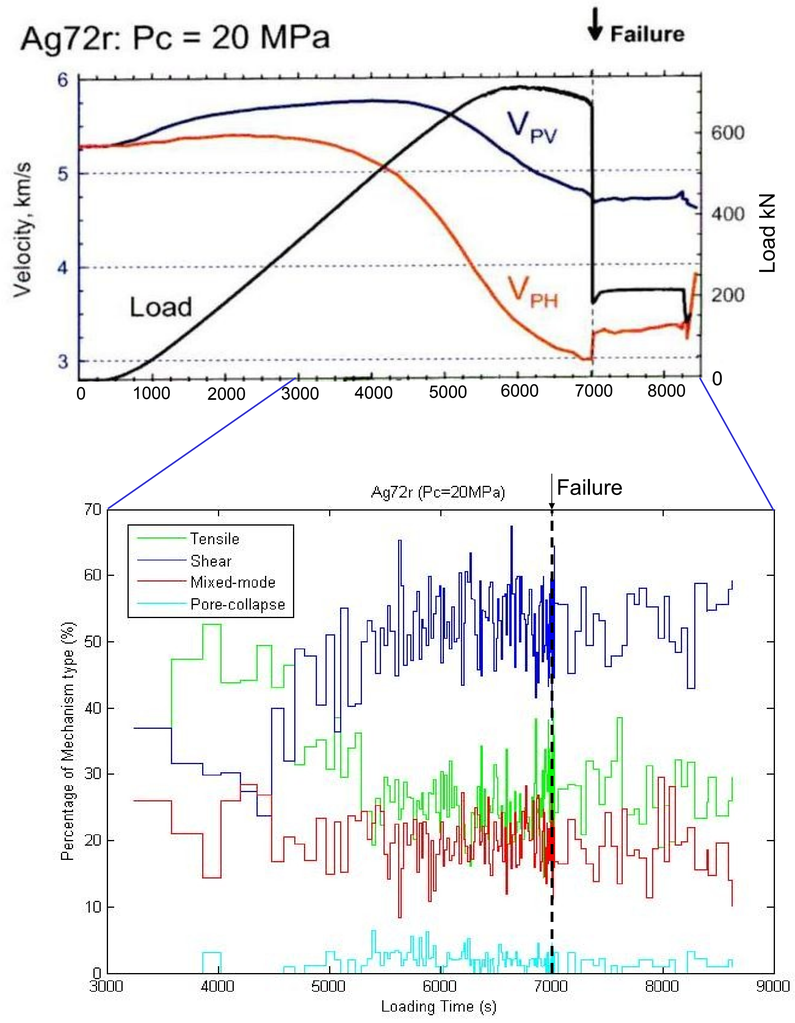


Figure 4 *Upper* – Load, horizontal (V_{PH}) and vertical (V_{PV}) P wave velocity as a function of strain during the test; *Lower* – relative proportions of tensile, shear and mixed mode failure inferred from the moment tensor inversion.

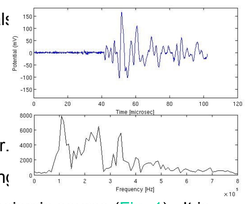
6. Conclusions

Microcracking produces AE during the brittle deformation of rock. Understanding the mechanisms involved will allow current damage models of time-dependent failure to be improved. Moment tensor inversion of AE events from triaxial compression of Aue granite indicates a change in dominant micromechanism at a coincident time as a drop in V_{PH}. This suggests a change in microcrack orientation may occur. Eigenvector analysis can now be used to investigate this.

Glossary

Damage: Microstructural changes which decrease the strength of a material, when subjected to unfavorable mechanical and environmental conditions (Kachanov, 1986).

Acoustic emissions (AE): High frequency acoustic signals produced by the release of energy during the growth of microcracks during brittle deformation of rock (right).



P-wave: A seismic body wave, which propagates by particle vibration in a compressional and dilational manner.

Moment tensor: A symmetric, 3x3 matrix (eq. 1) containing elements representing the nine force couples acting at a seismic source (Fig. 1). It is dependent upon the source strength and orientation.

Double-couple (DC): A source mechanisms consisting of two force couples acting orthogonally to one another. Such a mechanism is often used to represent earthquakes as there is no volumetric component to the source, only shear.

Compensated linear vector dipole (CLVD): A source mechanisms with a volumetric component such that the net volume change at the source is zero.

Granite: A coarse-grained igneous rock composed of >20% quartz and feldspar.

Quartz: A silica mineral, with composition SiO_2.

Plagioclase: A feldspar mineral of composition ranging from $NaAlSi_3O_8$ to $CaAl_2Si_3O_8$.

K feldspar: ($KAlSi_3O_8$) The general name for the potassium end-member of the alkali feldspar series.

Mica: Sheet silicates, with perfect cleavage and a platy habit.

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