The resistivity and permeability of fractured rocks

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by
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ABSTRACT

The resistivity and permeability of fractures and faults
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Fracture permeability is necessary for the development of many unconventional energy resources, as they are often hosted in rocks with low primary permeability. The magnetotelluric (MT) method has previously imaged temporal resistivity changes associated with injection of conductive fluids into the subsurface. This thesis examines MT responses over two areas of the Otway Basin, Australia, to determine what characteristics of natural fractures can be imaged using MT. In addition, the resistivity and permeability of synthetic fractures and 3D fracture networks are modelled, to draw a link between the resistivity values that are measured and the permeability.

One dimensional anisotropic MT inversions in the Koroit region, Victoria, central onshore Otway Basin, delineate strong resistivity anisotropy at 2-3 km depth with a north-northwest strike. The anisotropy strike is consistent with that of known fracture networks in the Koroit region, and the groundwater at this depth is known to be saline. Thus, the resistivity anisotropy is interpreted as fluid-filled fractures and faults, reducing the resistivity in the north-northwest direction. In contrast, anisotropic inversions in the Penola Trough, western Otway Basin, reveal only minor anisotropy that is inconsistent with known fractures from coincident well image log and seismic data. Thus, an isotropic interpretation is consistent with the data here. Likewise, higher resistivities and lower permeabilities have been measured in wells in Penola, compared to Koroit.

The resistivity and permeability of synthetic fractures filled with an electrically conductive fluid change non-linearly as the fractures are incrementally opened. A percolation threshold can be defined, below which the permeability and resistivity are close to the rock matrix values. At the percolation threshold, the permeability increases by three orders of magnitude or more over an aperture change of < 0.1 mm. The resistivity change depends on the ratio of the rock to fluid resistivity but is generally less than the permeability change, and occurs over a wider aperture range. Similar characteristics are observed in 3D fracture networks except that in networks, percolation is controlled by both the fault network density and fault connectivity. Many sparse networks will not percolate no matter how open the faults are. When the fault density is sufficiently high, a percolation threshold can be defined in terms of the mean fault aperture. At the percolation threshold, a change in mean aperture of 0.02 mm changes the permeability by four orders of magnitude and resistivity by a factor of four. The percolation threshold does not necessarily occur at the same aperture for different flow directions, so fault networks near their percolation threshold commonly show anisotropy in both resistivity and permeability.

Therefore, not only are the MT responses in the Koroit region of the Otway Basin consistent with the presence of resistivity anisotropy due to pervasive open fractures and faults, but realistic fault networks can produce such anisotropic resistivities and permeabilities, with the amount of anisotropy highly sensitive not only to the density of faults in an area but also the degree of openness in the fractures themselves.

Thesis Supervisors: Graham Heinson, Simon Holford, Derrick Hasterok

STATEMENT OF ORIGINALITY

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