Much of the world's oil reserves are held in fractured rocks so understanding the geometry of subsurface fracture networks can be critical in maximising oil recovery. **Xiang Yang Li** and **David Kerridge** explain.

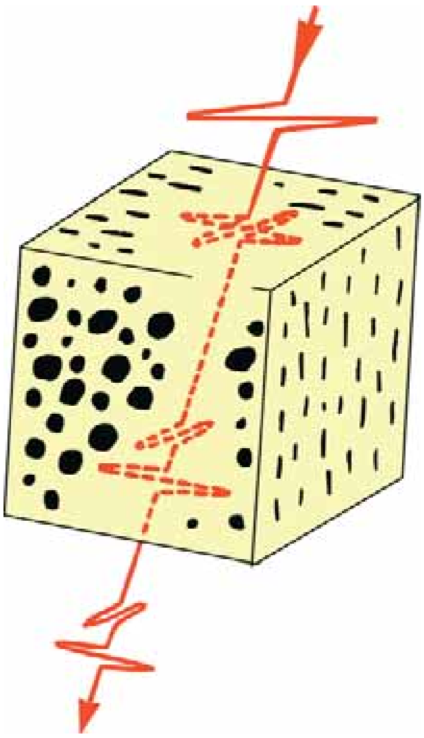
Mapping fractured reservoirs

About two thirds of the world's oil is produced from carbonate reservoirs. Carbonate rocks are brittle and, as a result, they are often fractured. The fractures tend to form clusters (also known as fracture swarms) and this is where oil often accumulates. Knowledge of the distribution of such fracture clusters is critical for the planning of hydrocarbon wells and for the successful development of carbonate reservoirs. The ability to map fractures remotely before drilling is, consequently, of considerable value to the hydrocarbons industry.

The BGS's Edinburgh Anisotropy Project (EAP) is a research consortium established in 1988 with the support of the oil and gas sector to investigate the potential for characterising reservoir properties using seismic data. In recent years, the EAP has developed a range of techniques involving the use of seismic data for remotely identifying fractures in rocks buried in the subsurface. Of these techniques, the use of P-wave (compressional wave) seismic data for fracture detection has attracted worldwide interest. Since 1999, this technique has been applied successfully to a number of North Sea oilfields with fractured carbonate reservoirs.

In 2002, after careful evaluation, the China National Petroleum Corporation (CNPC) commissioned the EAP to work on a collaborative project with scientists and engineers from its Geophysical Key Laboratory in Beijing. The main objectives of the project were to transfer know-how and technology to CNPC staff through technical training and joint project work and to bring the benefits to the CNPC's regional subsidiaries. Phase I of the project started in June 2002, and was completed in April 2004. Because of the success of the initial project, Phase II was immediately commissioned and is due for completion in 2006. Since the start of the project, EAP scientists have worked closely with their counterparts in the Geophysical Key Laboratory to understand the fundamentals of seismic wave propagation in fractured media and to develop practical applications.

Over the past ten years there has been a steady increase in using 3D seismic data to characterise fractures. This is critical for ensuring economic oil and gas production in rock formations which otherwise have a low permeability. If the fracture population in a rock has a dominant major orientation, seismic waves propagating in the rock will exhibit features diagnostic of the fractures. Seismic shear-waves exhibit a phenomenon called shear-wave splitting which, if observed, can be used to identify both fracture orientation and intensity. However, because shear-wave data are acquired relatively rarely, it is advantageous if P-wave data can be used to characterise fractures, as this is the most commonly available type of data collected by the oil industry.



When a shear-wave penetrates a fractured rock, the shear-wave splits into two waves travelling with different speeds. The fast wave is polarised parallel to the fracture plane, the slow wave is polarised perpendicular to it. The polarisation of the fast wave reveals the average alignment of the fractures; the time delay between the fast and slow waves indicates the intensity of fracturing.

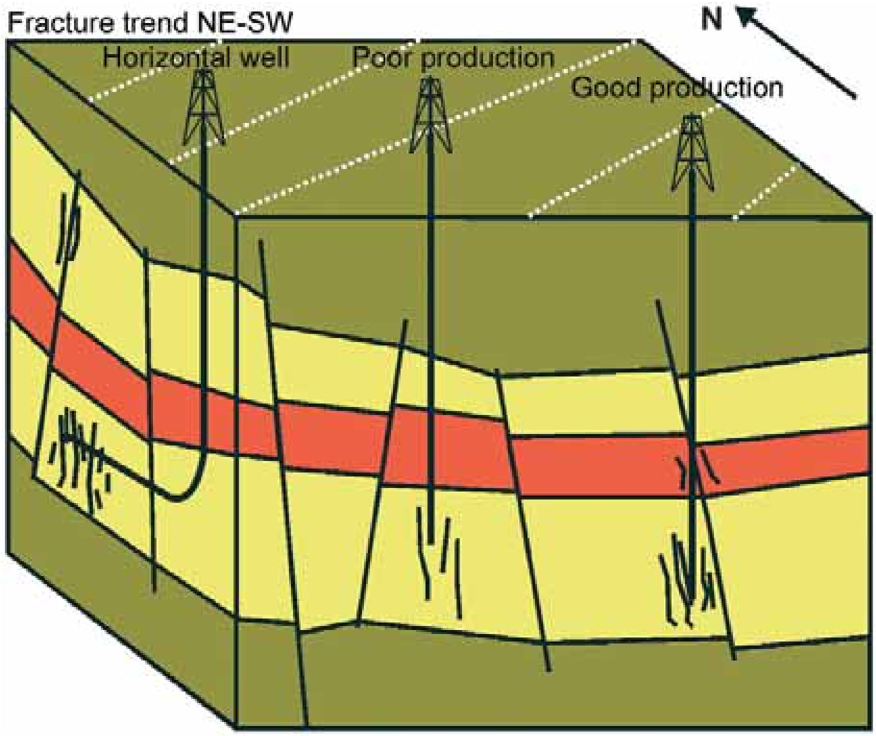
A number of measurable attributes of seismic P-wave reflections in the presence of aligned fractures show elliptical variations in the horizontal plane. The amplitude of the reflected wave is one such attribute. The long axis of the ellipse indicates the fracture orientation, and the ratio of the long to short axes of the ellipse is proportional to the fracture density or intensity. To generate the data needed for analysis, the reflected waves generated by a single seismic source must be collected by a 2D array of sensors at the land or sea surface. Fracture orientation and intensity maps can then be built from the P-wave data if the complete seismic survey provides reflection data over a sufficient area. This method of investigating fracture properties is often referred to as the azimuthal attribute analysis technique.

The P-wave technique has been applied to a range of areas throughout the world, including the North Sea, the Middle East and China. Analysis of data from a hydrocarbon field in China shows that, in this example, fracture patterns correlate quite well with the fault patterns in the area. We also see that along the faults the fracture intensity seems to increase, and there are concentrations of fracture clusters at the fault tips. These types of fracture maps provide helpful information during the planning of hydrocarbon wells. Additionally, fracture porosity and permeability maps, relevant to fluid flow, may be inferred from these results for input to reservoir modelling.

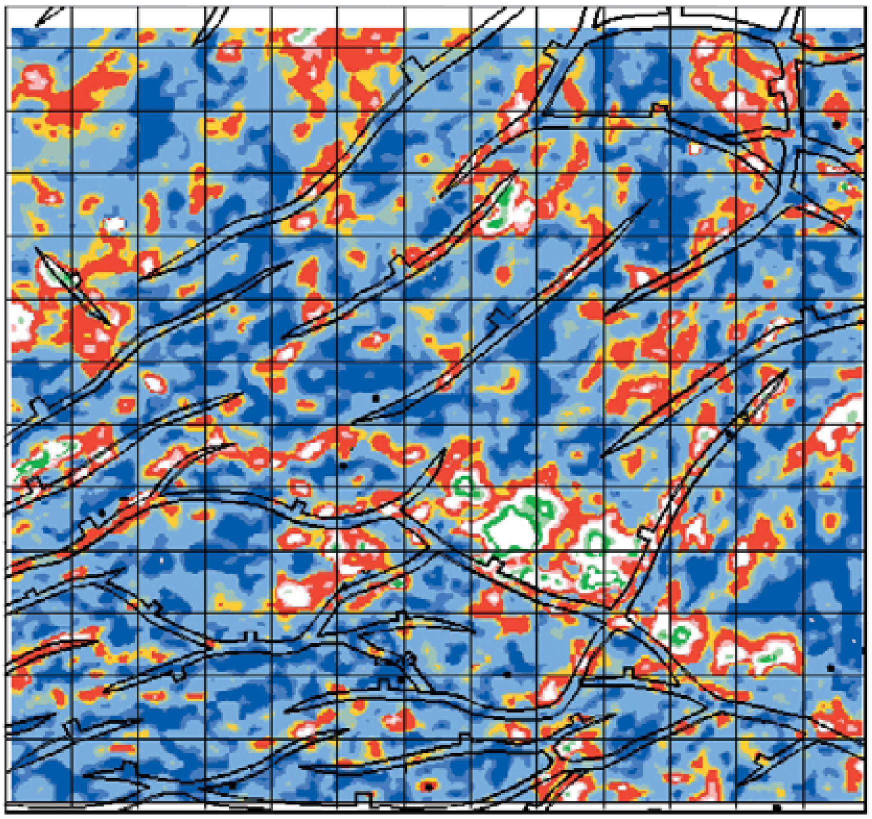
There is an ever-increasing demand for energy as the economy expands in China, which is now a net importer of oil. The CNPC is very interested in international collaboration for developing and transferring technology that can help to find residual oil and increase exploitable oil reserves in China. The collaboration with the EAP on characterising fractured reservoirs from seismic data is now one of the CNPC's flagship projects.

For further information contact:

David Kerridge, Edinburgh,
Tel: +44(0)131 650 0220
e-mail: djk@bgs.ac.uk



Successful drilling and well planning in fractured reservoirs requires knowledge of the distribution of fractures, as shown schematically for an onshore reservoir. The use of 3D seismic data is a key technology for fracture mapping.



An example of a fracture intensity map derived from 3D seismic data in China, over an area of about 5km x 5km. Red and white indicates high fracture intensity, which often corresponds to a rich accumulation of hydrocarbons.