Pyrenees Hold Clues to Frac

Faults and fractures are often an important factor in determining hydrocarbon storage capacity and productivity in reservoirs such as tight carbonates, quartzites and basements. The use of reservoir analogues such as those found in Catalonia in north-east Spain can be key to the interpretation of fractured carbonates reservoirs in the Middle East and elsewhere.

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Photo: Jon Gutmanis

The potential importance of fracturing in reservoirs has always been recognised by the hydrocarbon industry. It is only in recent years, however, that the range and diversity of fracture structures and the roles they play in determining hydrocarbon storage capacity and productivity have become better understood. It is apparent that fracturing can be both advantageous and disadvantageous to field development, and field analogues can go a long way towards a clearer comprehension of the issues and challenges involved in this complex subject.

The region surrounding the town of Tremp, 150 km north-west of Barcelona in the Catalonian Pyrenees of north-east Spain, is one such analogue, with many outcrops displaying a multitude of fractures and faults. These vary in size from thin clay-rich planes known as stylolites, the product of rock dissolution as a result of pressure, to major displacement thrusts several hundred kilometres in length. Many of these fractures are the direct result of the great upheavals brought about by the

tured Carbonate Reservoirs

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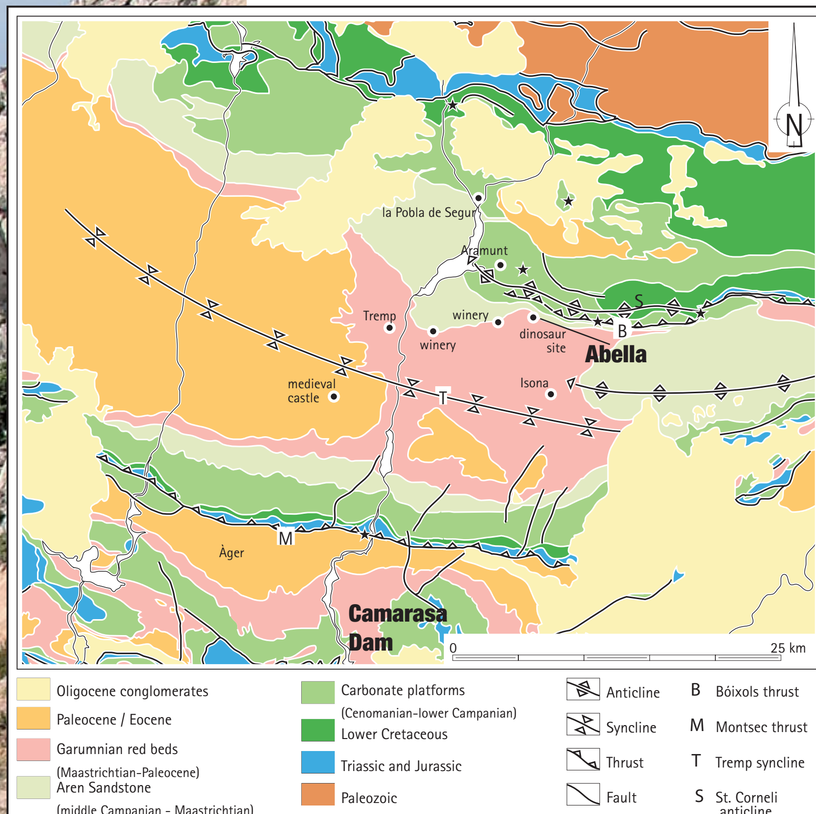

Geological map of the area in the region of Tremp in north-east Spain, where there are many good examples of fractured carbonates

Students on the Fractured Carbonate Reservoirs Analogues field trip examine the Upper Cretaceous Bóixols thrust, which passes through the village of Abella. The older Cenomanian and Turonian rocks can be clearly seen to have been thrust over the younger Santonian sediments. In the foreground the hanging wall anticline with a Lower Cretaceous core can be clearly seen. Houses have been built into the protection of the thrusted rock, which shows clear evidence of slickensides - parallel striations on rock surfaces caused by one rock mass moving across another along a fault plane – and also strong shear fabrics within the thrust plane itself.

collision of the Iberian and European plates and the uplift of the Pyrenees, and a study of these structures can shed much light on the performance of shelf carbonate reservoirs in many areas worldwide. This fascinating region has be used by UK oil industry consultants GeoScience Ltd, working with Catalonian colleagues at Geoplay Pyrenees, to demonstrate many of the features found in carbonate reservoirs and to support a methodology for fractured reservoir characterisation.

Key roles of fracturing

As is well known, most, rocks are fractured, and in fact 60% of hydrocarbon reservoirs worldwide have significant fracture components. Carbonate reservoirs, which contain as much as half of the world's hydrocarbons, form the majority of 'fractured reservoirs' and it is therefore vital that the industry gains a fuller understanding of these structural features in order to reduce risk in development decisions and to optimise production.

Photo: Jon Gutmanis

Close analysis of the area of the Bóixols thrust demonstrate many examples of fractures, from the major thrust itself to many small tension gashes concentrated in the footwall of the thrust. The latter probably record high fluid pressures required to allow the thrust plane to propagate. The manner in which faults like these interact in a hydrocarbon reservoir would have a huge effect on fluid flow and therefore on the reservoir potential of the rock. A similar 'damage zone' in a potential reservoir would increase the permeability of the rock.

Looking northwards towards the central zone of the Pyrenees near Tremp, folded Upper Cretaceous carbonates can be seen in the foreground, part of a South-directed thrust sheet, overlain by north-dipping layered Oligocene syn-tectonic conglomerates. In the distance are the Palaeozoic rocks of the central zone. This is a classic exposure for examining fold / fracture relationships

Photo: Jon Gutmanis

The Alinyà anticline, about 60 km east of Tremp, belongs to an eastern structural unit and was formed in the Eocene. A high degree of fracturing can be seen even from a distance, and closer examination shows that there is generally a greater degree of fracturing on the limbs rather then the crest of the anticline. This is very relevant for geologists seeking the optimum site for a well on an anticline in order to obtain the best possible permeability to ensure maximum productivity.

A fracture corridor is a narrow linear zone of relatively high fracture intensity compared to the adjacent rock. These corridors can be tens to hundreds of metres in length but they are generally hard if not impossible to observe in seismic surveying. Their importance to fluid flow and productivity is becoming apparent in many fractured fields. The Vilanoveta canyon exposes a long outcrop of Upper Cretaceous shelf margin calcarenites and reefal limestones, which demonstrate a high degree of faulting, including fracture corridors, particularly in the more bedded sediments. Close examination of a fracture corridor demonstrates clearly how the permeability properties of the rock are altered in the faulted zone.

Fractured reservoirs have a number of typical characteristics. One of them is high initial flow rates from wells, which can lead to overestimates of potential production. However, insufficient fracture connectivity to the wider reservoir can cause rapid depletion. Often, and especially in basements, they exhibit high reservoir columns, but the OWC can be hard to define, leading to uncertain reserve estimates. For these sorts of reasons fractured reservoirs were not, in general, the first choice for oil companies for many years, but as the economics of the industry have changed and technology has advanced, interest in these types of reservoirs has been increasing rapidly.

Fractures in reservoirs can play two key roles: they can be conduits, enabling and enhancing the passage of hydrocarbons, or they can be baffles, preventing or at least hindering the free movement of liquids and gasses. It is even possible for the same set of fractures to perform both roles at different times or pressures. We therefore need to be able to identify fracture types, origins, scales, connectivity and 'drivers', so we can ascertain if their presence in the reservoir will prove to be advantageous or disadvantageous and settle on the best development plan. The use of analogues, such as those found in the Spanish Pyrenees, is very important in assisting with this process.

Fractured carbonates in Northeast Spain

The geological and structural evolution of the Pyrenean basin is governed to a great extent by the convergence of the Iberian and Eurasian plates at the end of the Cretaceous, which reactivated Hercynian lines of weakness and defined much of the landscape through creating structures on both the macro and the micro scale.

Rifting in the late Palaeozoic and Early Mesozoic allowed the build up of various sediments, including red beds and evaporites, after which time the area developed as a shallow stable platform where a series of limestones, dolomites and marls were deposited in the Jurassic. These Jurassic dolomites can be seen in the region of the Camarasa dam, 30km south of Tremp, where they demonstrate, amongst other features, shallowing-up cycles and cross-bedding, and can be seen to be highly fractured and karstified with vuggy porosity, both important features for hydrocarbon reservoirs.

The area suffered rifting in the Early

Cretaceous, followed in the Early Late Cretaceous by a transition to a foreland structural setting, during which time there was extensive development of carbonate platforms. The region of Organyà, about 50km due east of Tremp, has excellent outcrops of Lower Cretaceous platforms up to 400m thick, separated by transgressive marls, grading distally into a succession of marls and organic-rich shales. The platforms are rimmed by a band of massive coral-rich limestone.

The region allows the geologist to clearly follow the passage of Upper Cretaceous platform carbonates through inner shelf deposition, with deepening-up cycles of sandstone, calcarenite and limestone; through shelf margin facies demonstrating marly limestones grading up into massive nodular limestones with coral-rudist buildups; and finally to outer shelf and slope marls, breccias and turbidites.

The sedimentary succession in this area culminates with further platform carbonates and deltaic clastics, deposited in an Early Eocene foreland setting, overlain by Late Eocene to Early Miocene syntectonic alluvial fan conglomerates.

Fracture History

Fracture development began during the initial rifting phase as sediments were buried, allowing stylolites and possibly hydraulic fractures to form. However, much of the fracture history is associated with the orogenic collision of the Iberian and Eurasian plates. This resulted in structural inversion and thrusting, causing the older Cretaceous carbonates to be juxtaposed against younger Upper Cretaceous carbonates, deltaic sands and continental red beds, as well as the Eocene foreland successions of shelfal limestones and deltaic clastics. These thrusts can clearly be seen at the village of Abella, 15km east of Tremp, where the Upper Cretaceous Bóixols thrust makes a clear mark on the shape of the landscape, and further south in the Terradets gorge where the Eocene Montsec thrust is seen. The movement and uplift associated with these thrusts and associated fold development lead to a high degree of fracturing in the Cretaceous carbonates. A wide range of structural features, from systematic joint sets to fracture corridors, faults and thrust planes can be seen at outcrop. In addition, complex vein sets can be observed in association with some of the thrust planes.

Acknowledgements:
GeoExpro Magazine would like to thank Lluís Ardèvol, Geoplay Pyrenees Ltd. and Jon Gutmanis, GeoScience Ltd. for their assistance with this article.