

PS Reservoir Characterization by Integration of Outcrop Analog with In Situ Stress Profiling of a Fractured Carbonate Reservoir*

Jon Gutmanis¹ and Lluís Ardèvol i Oro²

Search and Discovery Article #42033 (2017)**

Posted March 13, 2017

*Adapted from poster presentation given at AAPG/SPE 2016 International Conference & Exhibition, Barcelona, Spain, April 3-6, 2016

See similar article [Search and Discovery Article #41387 \(2014\)](#)

**Datapages © 2017 Serial rights given by author. For all other rights contact author directly.

¹GeoScience Ltd, Falmouth Business Park, Bickland Water Road, Cornwall, UK (gutmanis@geoscience.co.uk)

²Geoplay Pyrenees Ltd, Nerets 10, 25620 Tremp, Catalonia, Spain

Abstract

This presentation describes a case history where outcrop information was used to help interpret the relationship between lithology, structure, and current tectonics in a challenging 'stress sensitive' reservoir setting. We describe firstly the methodology of building in situ stress profiles for wells and the benefits to be derived by integrating them with static fracture data, fluid type, and flow distributions; and secondly the value of studying representative outcrop analogs.

In situ stress profiles have been constructed from data acquired in deep exploration and appraisal wells in the Zagros petroleum province. The profiles used sonic and density log data, formation rock properties from core, pore pressure profiles, and leak-off data to estimate the magnitudes of the 3 three principle stresses (S_v , S_{Hmax} , and S_{Hmin}). The azimuths of S_{Hmax} and S_{Hmin} were obtained from induced fractures seen in the image logs.

Rock types in the drilled Tertiary-Cretaceous-Jurassic-Triassic sequence varied from very strong massive carbonates, through interbedded carbonates and mudstones, to weak mudstone dominated intervals as well as anhydrite dominated intervals. Consequently the models show large variations in stress regime and stress anisotropy with depth due primarily to this wide range in rock strengths and stiffness. A geomechanical zonation can be identified including intervals dominated by high stress anisotropy and strike-slip conditions; and other intervals of low stress anisotropy and normal conditions. This zonation is to a large degree mirrored by variations in both fracture intensity and azimuth as derived from image log interpretation. Observed patterns of fracture flow are consequently influenced by these conditions.

High quality analog exposures of folds in the Spanish Pyrenees record clear evidence for a similar geomechanical zonation within the ancient stress field, now 'fossilized' but seen in the deformation pattern. This is compared with, and used to interpret, the sub-surface information

described above. The geomechanical zonation developed by this approach may be incorporated in reservoir modeling and also in the planning of new wells both for stability and optimum fracture related production.

RESERVOIR CHARACTERISATION BY INTEGRATION OF OUTCROP ANALOG
WITH *IN SITU* STRESS PROFILING OF A FRACTURED CARBONATE RESERVOIR

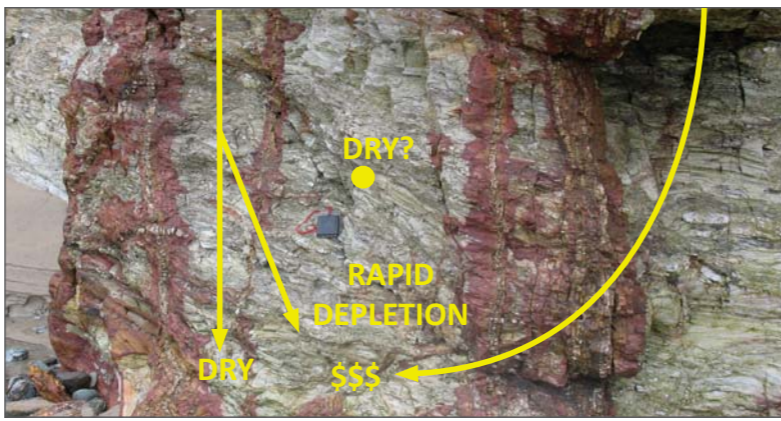


Jon Gutmanis- GeoScience Ltd and Lluís Ardèvol i Oró- Geoplay Pyrenees Ltd

Summary
At Hortonedá in the Spanish Pyrenees a mountain-scale outcrop of layered carbonates and marls shows heterogeneous fracture distributions and markedly different deformation styles which can be related to the mechanical stratigraphy. The outcrop is compared with an *in situ* stress profile prepared by analysis of well data from an exploration well in an active, stress sensitive thrust anticline in the Middle East. This demonstrates how rock properties, *in situ* stress, and fracturing can be closely coupled and suggests that an assessment of rock rheology should be included in fractured reservoir characterisation workflows when appropriate.

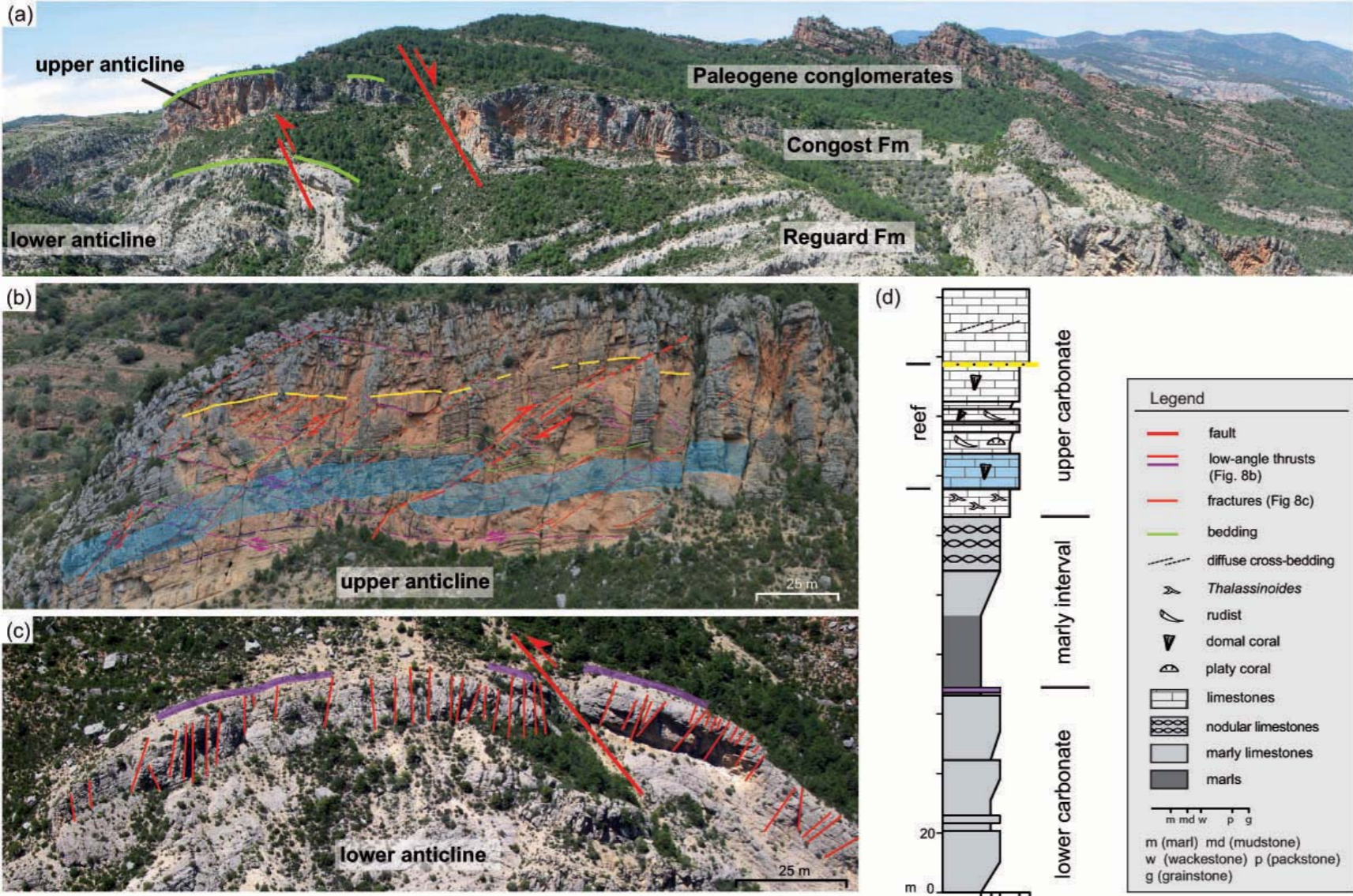
The challenge of fractured reservoirs

If the Fe-charged red volume in the outcrop photo (right) mimics the hydrocarbon distribution then vertical wells could completely miss it, as can wrongly-directed horizontal wells; perhaps the most productive trajectory should be deviated to maximize the intersection – but what deviation and what target? The heterogeneous fracture distribution, coupled with the often poorly understood charge history, can create major challenges for optimising and sustaining production in fractured reservoirs. This is compounded by the constraints posed by 1D well data and by the resolution limits of seismic acquisition.



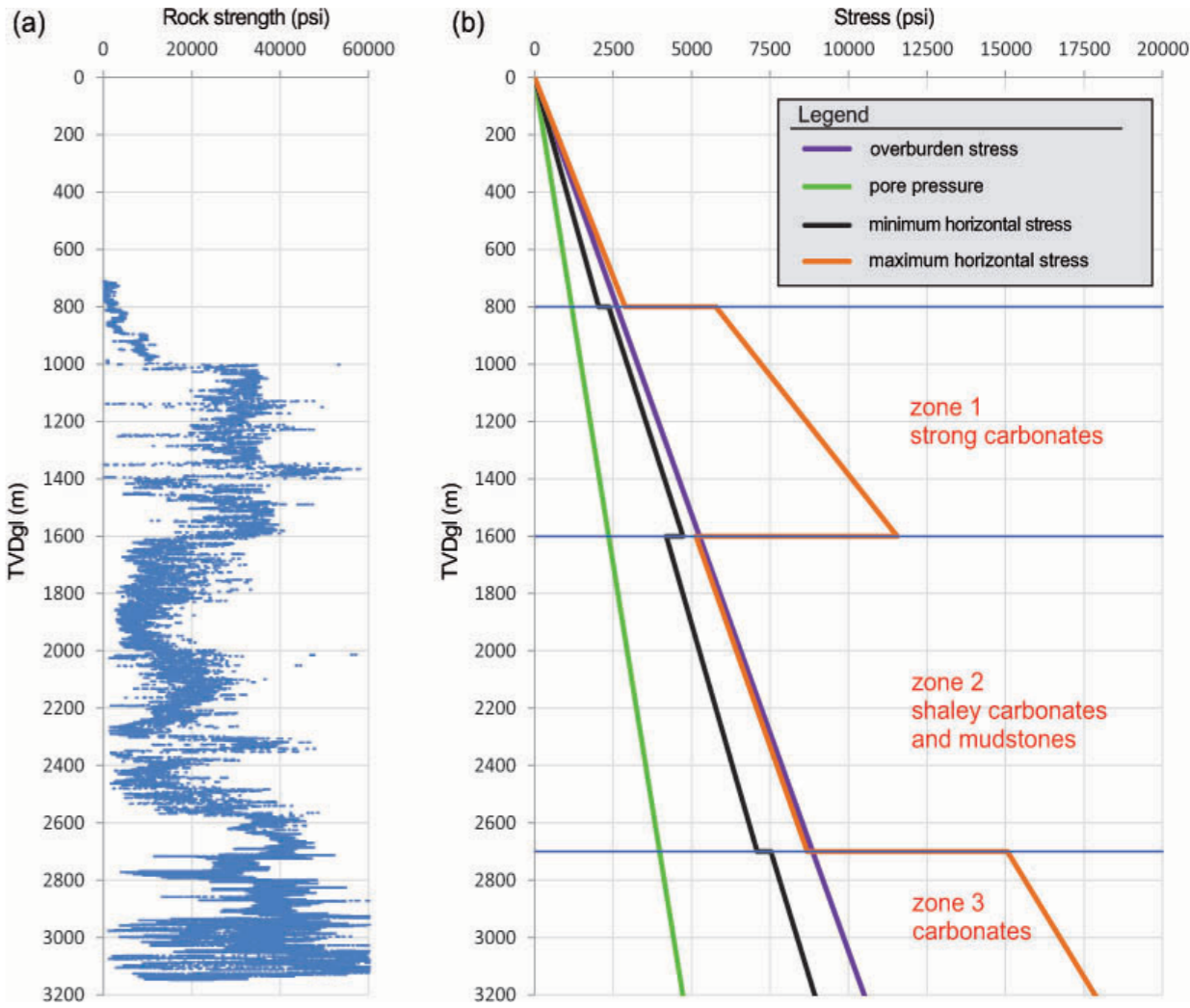
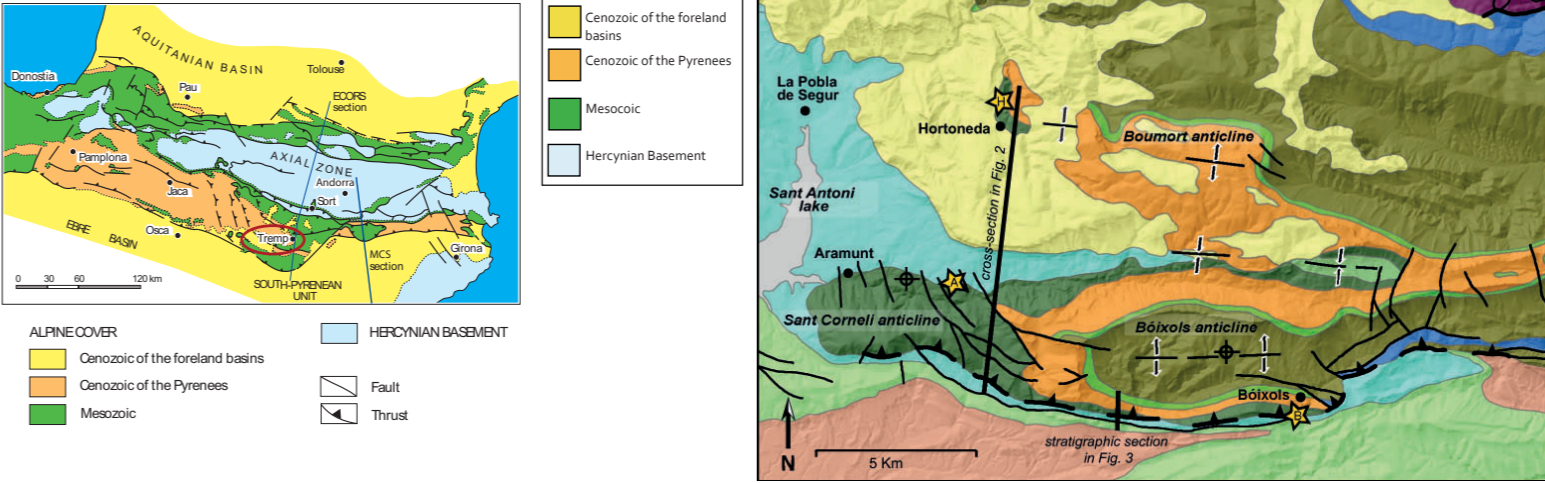
Hortonedá stratigraphy and geological setting

The Hortonedá exposure reveals, from base upwards, a thick section of Turonian marls and marly limestones overlain by 3 well-layered coarsening upward parasequences, followed by a marly interval which passes upward to a 75 m thick Coniacian limestone containing basal shoreface carbonates, patch reefs with 2 cycles of corals and rudists, and finally at the top grainstones with cross-bedding. Both the upper and the lower carbonate units are folded by anticlines but they have different geometries and degrees of shortening, as discussed below. Both are heavily fractured but with different fracture types and geometries: this reflects the different mechanical properties of the lithologies and the contrasting shortening mechanisms.



Location Hortonedá- near Tresp

The Cretaceous formations in the Tresp area of the Pyrenees South Central Thrust unit provide a range of excellent analog exposures. Formations include carbonate facies from reefal, to shelf margin and slope, as well as calc-arenites. They have been involved in a complex sequence of piggy-back thrusting and the outcrops reveal excellent examples of differing fold geometries, fault styles and fracture hierarchies – a natural laboratory for fractured carbonate analogs that is regularly used for field schools, especially for those currently working in the Zagros of Kurdistan.



This *in situ* stress profile was constructed by:

- integration of density logs from surface to derive overburden stress magnitude with depth (σ_v)
- processing of sonic and density logs to estimate rock strength with depth, calibration with core strength test data
- estimation of minimum horizontal stress magnitude (σ_{hmin}) with tectonic strain calibrated to leak off test data
- estimation of maximum horizontal stress (σ_{hmax}) by calibration to σ_v and σ_{hmin} together with observations of wellbore failure (breakout, induced axial fracturing)

A close coupling between rock strength, differential stress magnitude, and stress regime is seen. Fracture intensity is high in Zones 1 and 3 but much lower in Zone 2 (see below).

Contrasting mechanical stratigraphy and fracture patterns

At Hortonedá an upper massively bedded carbonate formation accommodated N-S shortening by an opposing system of low-angle thrusts whereas the highly layered micritic carbonate formation below responded by buckle folding and reverse faulting on its N limb. The upper structure has low limb dips and about 15% shortening, whereas the lower asymmetric anticline has steeper limb dips and a higher degree of shortening. The presence of a low-angle decollement between the two structures is implied.

Messages for Reservoir Characterisation

In Situ stress, rock properties and fold mechanisms are coupled. We should:

- Correlate litho-mechanical profiles with fracture types and distributions in well data
- Evaluate likely fold mechanism when reviewing fracture distributions predicted from curvature analysis or other forms of seismic interpretation
- Build a profile of *in-situ* stress magnitudes with depth to investigate the control on fracture intensities (FI) and orientations.

