A06 Title: Use of outcrop analogues in fractured reservoir characterization – an example from the Dezful Embayment, SW-Iran

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Introduction:

Several giant oil fields in the Dezful Embayment in SW Iran (Figure 1) produce from the carbonates of the Asmari Formation (Late Oligocene - Early Miocene), where production depends strongly on the existence of fracture networks (e.g. Ogilvie et al, this volume). However, the fracture characterization is in some cases hampered by a limited dataset on static parameters derived from core and image logs. Seismic coverage is in general poor and consequently the structural definition is coarse. Also, well and core data in general do not contain information on important fracture characteristics like length distribution, crosscutting relationships and fracture density as a function of bed thickness or facies. Fortunately, outcrops of the Asmari Formation are found in close proximity to the giant oilfields. A detailed investigation of one of these outcrops – the Khaviz Anticline - was carried out to improve the database for different fracture parameters, and to improve the understanding of the relationships between deformation mechanism, structural position, lithology and the fracture systems. Ultimately, the aim of this study was to contribute to the generation of more realistic static geological models and dynamic reservoir simulation models.

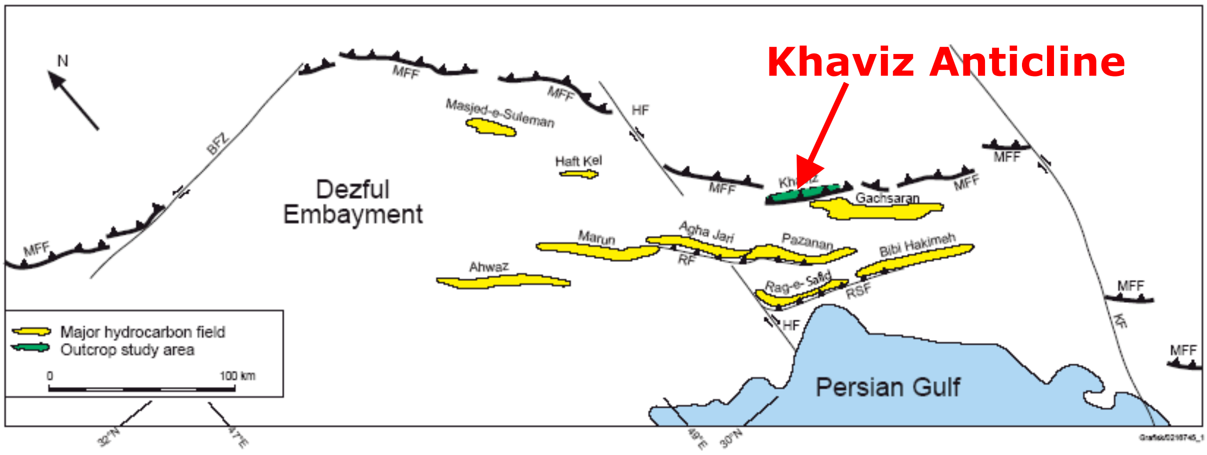

Figure 1. Main structural elements in the Dezful Embayment area with major oil fields and the location of the Khaviz Anticline. MFF = Main Frontal Fault, BFZ = Balarud Fault Zone, HF = Hendijan Fault, KF = Kazerun Fault, RF = Ramhormuz Thrust Fault, RSF = Rag-e-Safid Thrust Fault.

Geological Setting.

The ***Zagros Mountain Chain*** including the Dezful Embayment represents the northeast part of the Arabian Plate, and developed as a result of plate convergence, particularly during the Late Miocene-Pliocene orogenic phase (e.g. Hessami et al., 2001). The structural evolution has been controlled by a combination of thin-skinned tectonics above a main detachment zone and thick-skinned tectonics involving the crystalline basement by inversion of preexisting normal faults (e.g. Blanc et al. 2003). The ***Khaviz Anticline*** represents a typical Asmari Formation fold in this area, and has a very similar geometry and structural history to the major oilfields in the area. It is therefore well suited as an outcrop analogue.

Fracture Occurrence.

Measured fractures have been grouped into two major types based on their inferred influence on fluid flow behavior (Figure 2a): ***Diffuse fracturing*** describes distributed fracture populations, which in general contain several fracture sets with distinct spatial characteristics. Diffuse fractures are to a large degree stratabound. ***Fracture swarms*** are larger scale features, which dissect significant parts of the reservoir stratigraphy. In the Khaviz Anticline, fracture swarms are also represented by faults with displacements up to 150 metres, which are associated with relatively narrow damage zones with locally very high fracture frequency.

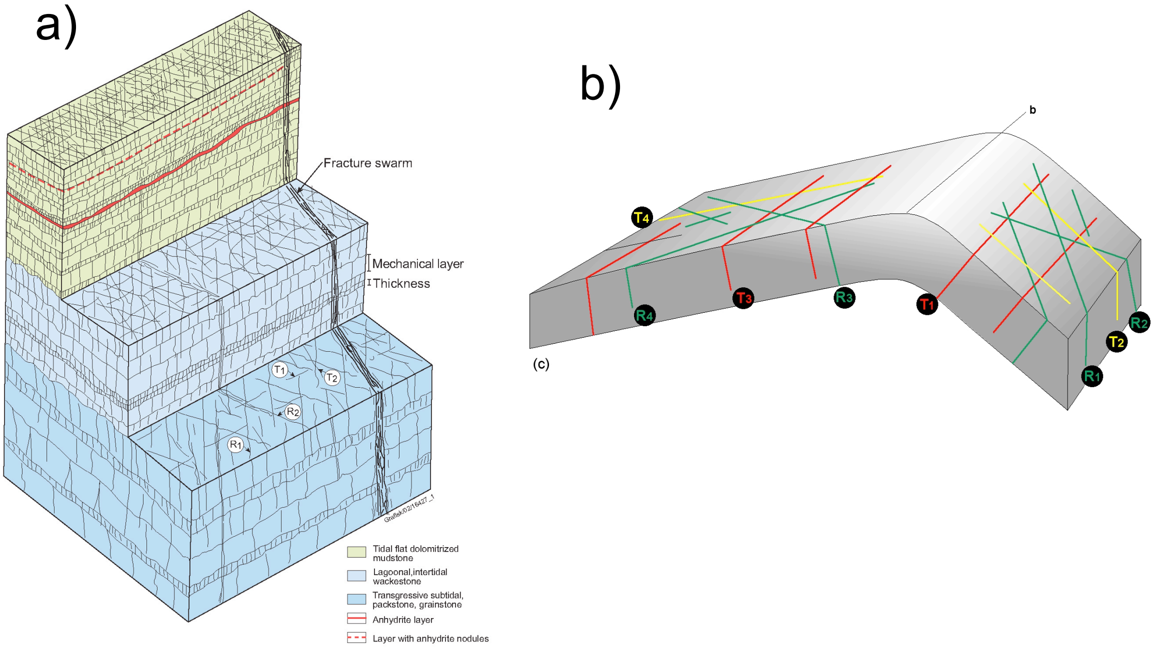

Figure 2. a) An ideal shallowing up cycle of the Asmari Formation with a typical fracture pattern in a forelimb of a Zagros anticline. b) Price's classification of fracture sets typical for asymmetric anticlines. Modified from Price (1966)

Diffuse fractures are in general sub-perpendicular to bedding, and have been subdivided into tensional **T fracture sets** and **R fracture sets** according to Price (1966) (Figure 2b). ***T fracture sets*** occur in one set sub-perpendicular to the axis of the fold (T2 in the forelimb and T4 in the back-limb) and one set parallel to the axis of the fold (T1 in the forelimb and T3 in the backlimb). ***R fracture sets*** develop as conjugate sets: R1 & R2 in the forelimb R3 & R4 in the back-limb. The T1/T3 fracture set is strongly dominating in the backlimb and in the crest area, with the T2/T4 fractures as the secondary set. In the forelimb there is a significant spread in fracture strike, and the R1 and R2 sets have higher frequencies.

Mechanical Stratigraphy.

To a large extent, the density and height of fractures in the Asmari Formation in the Khaviz anticline are controlled by the ***mechanical stratigraphy***. Here, the Asmari Formation is 378 m thick and can be divided into three depositional sequences. The lower 213 m thick Chattian Sequence comprises thick massive carbonate layers (up to 25 m thick). The Aquitanian (99 m thick) and Burdigalian (66 m thick) sequences are lithologically more varied and with well defined thinner layers with average layer thickness of ~ 1 m. Major fractures in Chattian sequence tend to be long and cut through large parts of the stratigraphy. In the overlying units the fractures tend to be stratabound. Fracture intensity in the Khaviz Anticline was to a large extent found to be controlled by texture. In general, mudstone has higher fracture intensity than wackestone to grainstone. This is in contrast to McQuillan (1973), which concluded that fracture intensity in the Zagros mainly was controlled by mechanical layer thickness.

Fracture formation.

We conclude that all the measured fracture sets formed more or less coevally, based on the lack of systematic termination or abutting relationships between different fracture sets. The main factors controlling the effective stress and fracture formation during the folding of the Khaviz Anticline are: plate-scale NNE-SSW contraction, orthogonal flexure folding, flexural slip folding, stress perturbation around active faults and fluid pressure variation. The resulting effective stress field responsible for the fracture generation in the Khaviz Anticline was in a continuous state of flux and varied through time and space.

Fracture modeling.

One of the key inputs into discrete fracture network models in this study has been the definition of fracture sets (Figure 2). The structural control on the different fracture parameters has then been used to guide the distribution of fractures in these models. Sets T1 and T3 have been related to outer arc extension during orthogonal flexural folding. First principal curvature, a function of the extensional strain perpendicular to the axis of the anticline during this outer arc extension, has been generated from the reservoir structural maps, and then rescaled to fracture density maps for these sets. The outcrop study indicates that R1 to R4 fractures are most frequent on the steep forelimb, and least frequent at the crest of the structure in accordance with e.g. Couples et al. (1998). R1 to R4 fracture sets also are the ones most likely to be controlled by flexural slip. Assuming a pin-plane through the crest of the structure, the amount of flexural slip will be a function of dip-magnitude. Dip maps from the structural reservoir maps have therefore been used to control fracture density of the R1 to R4 fracture sets.

Implications for recovery.

One of the most important factors for ultimate recovery and choice of IOR strategy in a fractured oil reservoir is the degree of capillary continuity, i.e. to what extent the individual fracture bounded blocks (matrix blocks) are in capillary communication. In the case of non-connected matrix blocks the spatial variation in the size, shape and orientation of the matrix blocks also contributes. These factors are a function of the mechanical layer thickness, structural dip and length/spacing of the fracture sets.

A case with relatively thin matrix block has been considered (Figure 3). In the forelimb position the R fracture sets dominate and consequently the top surface of the matrix blocks tend to be shaped as rhombs with the longest axis in the dip direction parallel to structural dip (Figure 14). In the backlimb and in the crest area, where T fracture sets dominate, the top face matrix blocks tend to be rectangular with the edges parallel and normal to structural strike. In the crest area, the inclination (dip-magnitude) will be significantly less than in the backlimb. If the matrix blocks in the different structural positions have the same volume, capillary pressure curve and all other matrix parameters, the ultimate oil recovery will be controlled purely by the shape and orientation of the matrix blocks. The column of the un-drained matrix (h) will be constant for the different cases and independent of matrix block orientation. On the contrary, the ultimate recovery will be variable and dependent on the orientation of the matrix blocks (Figure 3). For this particular block shape, the volume of capillary bound oil (green in figure) will be smallest and the ultimate recovery largest (in red) in the steep forelimb where the rhombic shaped blocks dominate. The ultimate recovery will be smallest for the rectangular/quadratic blocks in the crestal area, whereas the similar but more steeply inclined blocks in the backlimb will have an intermediate degree of ultimate recovery.

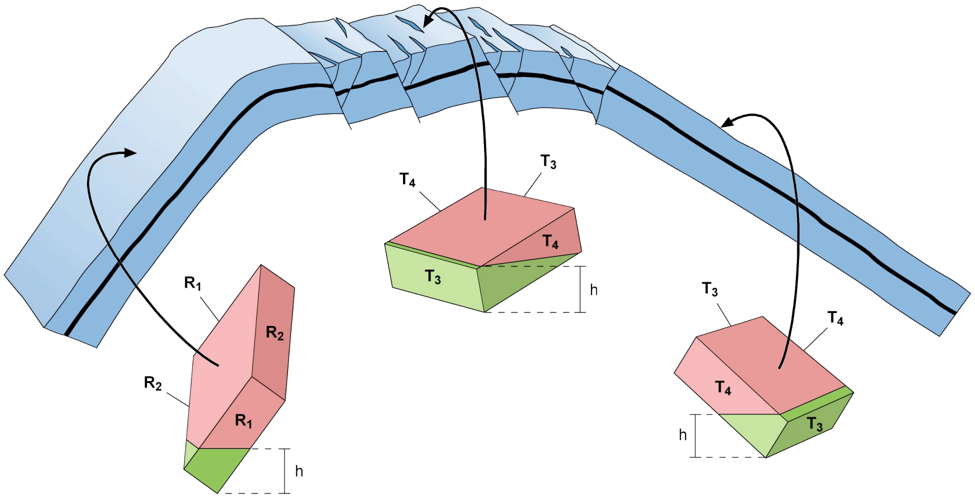

Figure 3. Schematic block diagram displaying the general structure of the Khaviz Anticline. Small blocks display the preferred shape and orientations of matrix blocks in different structural positions. Red represents the ultimate recoverable volumes in the matrix blocks and green represent un-drained volumes See text for discussion.

Acknowledgements:

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