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The Evolution of Reverse Faults in Forced-fold Analogue Experiments Using Wet Clay

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SUMMARY

The main objective of this project is to study the development and the architecture of extensional forced folds. Such structures usually develop above reactivated extensional basement fault. It is important to understand the evolution of reverse folds as they can trap hydrocarbons.
We used wet kaolin clay models to observe the development of forced folding and the associated faults. Many of the features seen in the analogue models can be identified also on seismic reflection data. Therefore, the analogue experiments were successfully used as a template to interpret the Jurassic extensional fault system from the Moesian Platform, Southern Romania.

Introduction

The purpose of this contribution is to study the development and the architecture of extensional forced folds. Forced folds typically develop above reactivated extensional basement faults (Withjack et al., 1990). Such structures are of economic importance as they can trap hydrocarbons (HC). Within a forced-fold, complex reservoir geometries may exist due to numerous small scale reverse faults that compartmentalize the structure. Thus understanding the evolution of the reverse faults through time is of importance in HC exploration. We have used wet kaolin clay models to study the development of forced folding and the associated faults. The modeling results have been compared to the extensional forced folds observed in seismic reflection data at Jurassic level of the Moesian Platform of Southern Romania.

Methodology

Analogue experiments were performed in the OMV Petrom Analogue Modelling Lab in Bucharest, Romania. We used wet kaolinite clay with 60 weight% water content (i.e. consistency of a tooth paste) for modelling. Wet kaolinite clay has been demonstrated to be a good analogue to consolidated sedimentary rocks (Cooke and Elst, 2012). We calculated that the modelling ratio between our analogue and nature is about 10^5 (i.e. 1 cm in model equals 1 km in nature). The device used for modelling was composed of three blocks that were about 15 cm across and followed the design of Withjack et al. (1990). Two moving blocks simulated the development of a graben along a fault dipping by 60^o angle. Initially the top of all three blocks were at level with the 4 cm thick undeformed wet clay on top. A set of experiments (~20) were carried out under the same conditions to make sure that our results are reproducible and representative. Side and top-view and images were captured during the experiment run and were compared with interpretation obtained from 3D seismic reflection data. The 3D seismic data was interpreted with Schlumberger's Petrel software.

Results

At the start of the experiments we see the progressive development of a large monocline that continues to amplify as the basement block subsides. The monocline is without any noticeable brittle deformation with all the basement fault slip being accommodated by ductile deformation in the clay. The monocline continued to amplify until about 1 cm of displacement. We run several models with various clay thicknesses and calculated that the average displacement needed for the first faults to develop is about 1/3 of the total thickness of the clay model. First faults to appear are the antithetic reverse faults typically at the lower part of the clay pie, close to the basement master fault. From this point onward in the experiment soon (i.e. few mm displacement) about 4-6 isolated high angle antithetic reverse faults appeared at the lower portion of the clay pie. These curved faults slowly kept propagating upward, until a synthetic normal fault emanating from the master basement fault did not cross-cut them so that some part of the reverse fault ended up stranded in the foot-wall (FW) block of this normal fault. Once the normal fault cut the reverse, the reverse faults ceased activity and were transported passively as part of the hanging-wall (HW) block of the new normal fault. This competing process of reverse faults forming first then cut by an upward propagating synthetic normal fault continued until the whole clay pie was cut by the synthetic normal fault. We have measured that the synthetic normal fault develops and cross-cuts the reverse fault at about the ratio between the total thickness of the clay pie and the amount of displacement reaches 1/4.

Many of the features seen in analogue models can be identified also on seismic reflection data. The small antithetic reverse faults are clearly visible on the seismic both in the HW and FW block of the synthetic extensional fault. The reverse faults have the same geometry as seen in the analogue model, sub parallel to each other and appear step-like structures (Fig. 1). The fault seal risk for prospects in the down-thrown block are dependent on the lateral continuity of both the reverse and normal faults. Important to note that the reverse faults rarely exceed the length of 0.5 cm (=0.5 km) laterally before being cut by the normal fault, as seen from top view images. In order to confidently postulate the

existence of the synthetic normal fault and thus a good seal for the prospect the total sediment package thickness-to-displacement ratio should exceed 1/4.
The fault system in the clay models strongly resemble to that observed on seismic data, such as the NNE-SSW Jurassic fault system on Moesia and was successfully used to simulate the development of these structures.

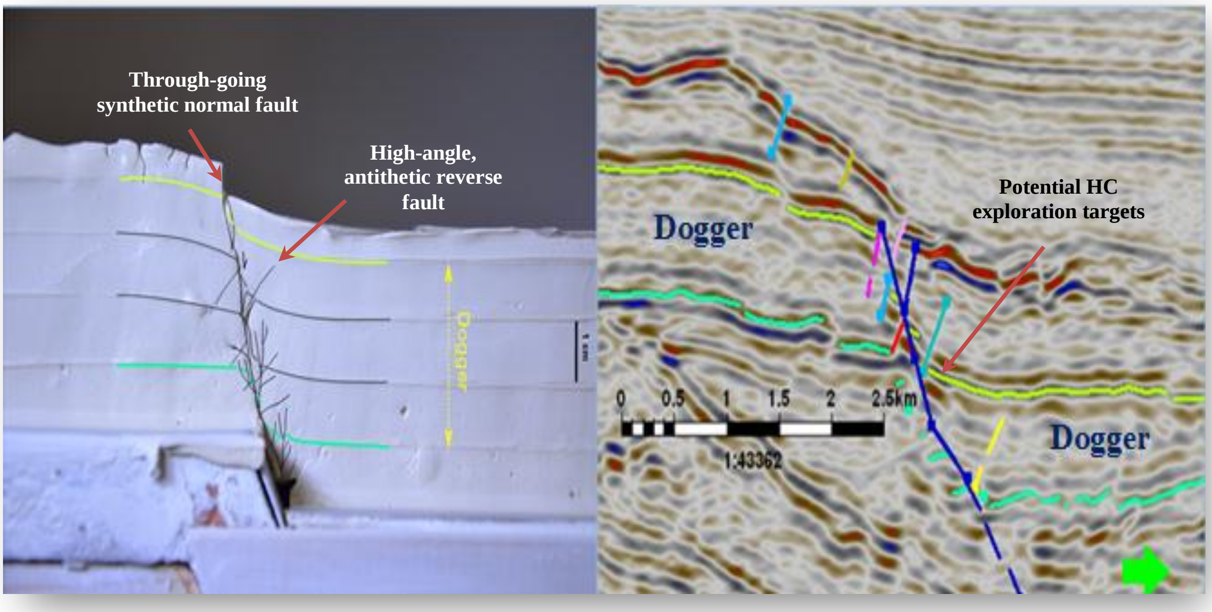

Figure 1. *Left: Side-view of the analogue experiment with the main faults traced over. Thickness of clay is about 4cm. Right: 2D seismic showing the Jurassic extensional fault from Mamu Block. Dark blue is the synthetic normal fault while the other colours represent the antithetic reverse faults.*

Conclusions

Analogue modeling of forced-fold was successfully used as a template and guide for seismic interpretation. It shows that the prospects within the downthrown block can carry a high exploration risk as they may be leaking up-dip along the segmented reverse faults that dissect the forced-fold structure. This risk is less where the synthetic normal fault has a large displacement as faults are less segmented.

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References

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