FAULTS AND FOLDS DEVELOPED IN THE HANGINGWALL OF FLAT-RAMP SYSTEM: THE CONTRIBUTION OF THE PHYSICAL MODELING

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Intruduction

Since the first experiments, in the XIX century, physical modeling has been a useful tool to understand geological structures. Today it is employed not only for academic research but also in the industry. Such works improve the knowledge regarding the visualization, nucleation, development, geometry and temporal relationship between faults and folds developed in several geological environments.

In order to test the influence of the fault geometry on the architecture of the hangingwall block we developed a series of physical modeling experiments and analyzed the structures formed above fault segments with flat-ramp geometry due to orthogonal extension. The experiments were carried out in the Federal University of Rio Grande do Norte State (Brazil).

Experiment setup and procedures

We used a sandbox type apparatus to simulate an extensional tectonic event. Different geometries of the faults segments were tested. The flat varied from horizontal to gentle inclined (5º) orthogonally to the ramp strike and its width was kept constant in one model while variable along its dip in the others (Figure 01). In the ramp segment the only changeable element was its dip. The deformation was induced by a thin basal sheet simulating a detachment surface pulled at a constant velocity (0.04 cms^{-1}). The sedimentary pile represented by artificially colored sand was sieved in the apparatus. The syn-tectonic sedimentation was represented by adding new layers of sand at constant intervals of extension. One of the experiments was done without syn-tectonic infill. At the end of deformation, the model was cut in several sections, photographed, interpreted and treated in the 3D movies software.

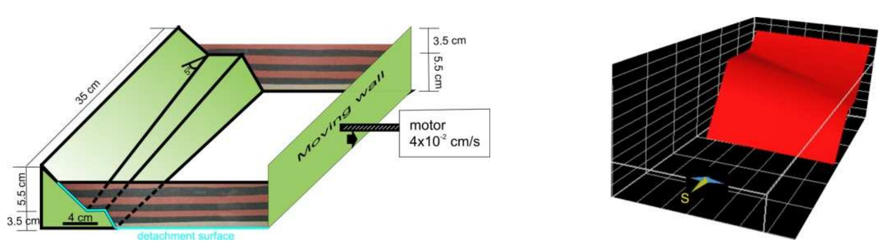

Figure 01- Example of one of the studied model. The flat is gently inclined and it shows a width variation (width decreases along the dip). The 3D geometry of the ramp-flat drawn in the 3D Movie software.

Synthesis of the Results

The model in which the flat segment is horizontal with a constant width – it has a less inclined ramp segment in comparison to the next models - is depicted in Figure 02. In this model, two sets of structures developed, viz. reverse faults and a pair of folds (anticlinal/synclinal). A sequence of reverse faults is nucleated in the interface ramp-flat (Figure 02).

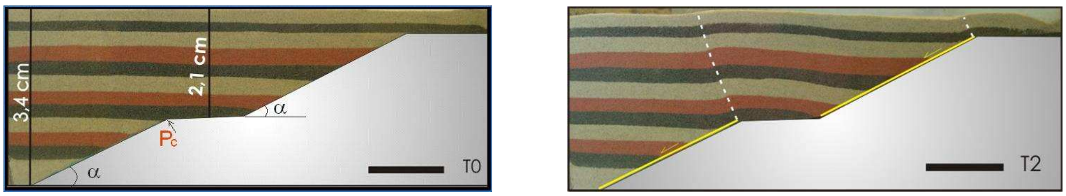

Figure 02- Sketch, modified from photography, showing the initial stage (T0) of the experiment with the flat horizontal and the beginning of nucleation of the first reverse fault (T2). Bar is 4cm, Pc is the site of nucleation of the reverse faults.

Initially the fault had a planar geometry that progressively changes to a more irregular geometry, ranging from slightly sigmoidal to completely curve (Figure 03). As the reverse faults are nucleated, localized compressive stresses, oriented parallel to bedding, generates an anticline (and an adjacent synclines) which is developed above the ramp-flat interface. Buckling process leads to distension in the top of the anticline and small collapse grabens developed. Between two adjacent reverse faults the sand layer, in the intermediate part of the pile, can be shortened and form small folds while pop-up like structures are formed in the upper part of it (Figure 03).

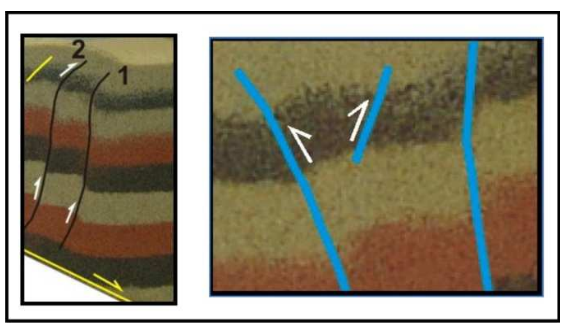

Figure 03 - Sigmoidal aspect of the reverse faults and the local development of pop-up structure. Note the layer-parallel shortening of the layer between two segments of faults.

Models with an inclined flat developed an anticlinal structure near the master fault while a conjugated syncline developed further away of it. The oblique synclinal (with respect to the master fault surface), varies from more tighten to more opened along its axis (up and down-dipping, regarding the flat inclination, respectively). The anticlinal has an inverse behavior, literally disappearing toward one side of the experiment (Figure 04).

In the upper part of the models, the syn-tectonic layers are affected by a domino-like normal fault system. Some reverse faults are nucleated in the interface between flat and ramp surfaces but their throws are less expressive than in the model where the flat is horizontal with an invariable width. Subordinated minor backward thrust is heterogeneously distributed in the model. With successive increments of deformation the early-formed faults and basal layers rotate so that the synthetic normal faults tend to a more horizontal position while the layers have a tendency to tilt toward the basal detachment becoming more vertical. The antithetic faults in their turn rotate to a vertical position. In some cases the rotation is enough to completely invert the kinematics, so they can show a pseudo reverse geometry. These data show that even a small change in the flat dip-angle adds complexities to the hangingwall architecture. The behavior of Baixa Grande fault in Potiguar Basin (NE of Brazil), as revealed by seismic sessions, is in agreement with the performed experiment.

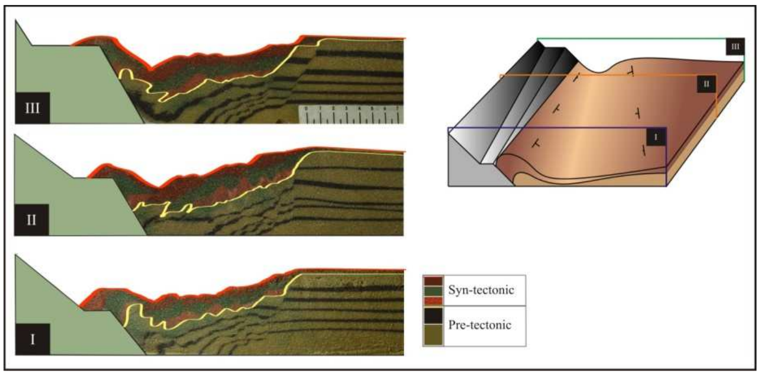

Figure 04- A tridimensional diagram representing the top of the pre-tectonic layers, showing a fault-parallel anticlinal and oblique synclinal. I, II and III are sections illustrating the several structural domains due to flat inclination.

Conclusion

The experiments have shown that variations in the geometry of the fault zone can greatly influence the hangingwall architecture. In fault zones with flat-ramp geometry, reverse faults and folds can develop regardless the geometry of the flat. However the geometry of the flat segment of the fault can be responsible for the intensity, geometry and distribution of such structures. Zones structurally more complexes are created in the hangingwall of models where the flat is inclined or displaying heterogeneous width. In such cases distinct structural domains are envisaged. The figure 05 shows these different domains in respect to the geometry of the synclinal/anticlinal.

The experiments, therefore, recommend caution when interpreting the evolutionary stage of a sedimentary basin based on structures "typically" associated with compressional events. Additionally, the anticlines as well as reverse faults (which may juxtapose layers of different rheological behavior) can serve as traps for fluids, and so, becoming important locus for hydrocarbon and/or underground water accumulation

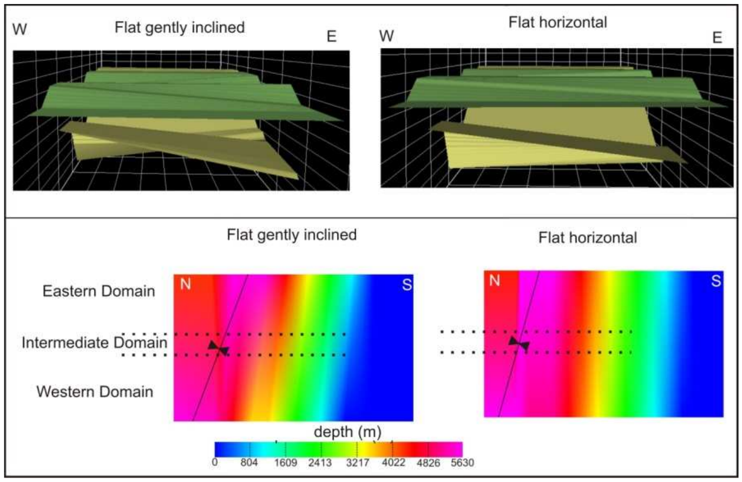

Figure 05- Geometry of the hangingwall sequence showing the geometry of the anticlinal and synclinal and the structural domains in the models in which the flat is inclined or have variation of its width.