THE GUADALUPE-CHUCHURE THRUST FAULT SYSTEM, FALCÓN BASIN, NORTHWESTERN VENEZUELA: NATURAL EXAMPLE AND ANALOG MODELLING OF A TRANSFER ZONE.

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INTRODUCTION

Analog modelling has become a relatively common practice in Structural Geology from the beginning of the last century. This technique aims to make models the closest possible to the geometry and/or mechanical behaviour of their natural equivalents. Nevertheless, experimental models generally simplify natural problems due to an unsufficient knowledge of the geological setting to be reproduced (precise geometry of rock masses and mechanical behaviour of rocks under stress) or to technical reasons (physical difficulties in reproducing mechanical parametres of rocks or their geometry). Consequently, diverse heterogeneities of nature are not taken into account. Therefore, if models are simplified versions of natural problems, the arisen conclusions should also reflect this fact. However, experimental modelling allows to study large-scale deformation in an original manner and to establish the relations between initial conditions imposed to a model and the geometry of generated structures, as well as their evolution during deformation.

The main objective during this study has been to reproduce the geometry of a segment of the Guadalupe-Mina de Coro-Chuchure thrust fault system that juxtaposes the today-inverted Oligo-Miocene Falcón basin and the Paraguaná high, in northwestern Venezuela. The comprehension of the geometry and origin of thrust faults associated with sedimentary wedges has deeply progressed due to analog modelling results but the compressive structures reproduced during most of those experiments did not try to comprehend the oblique deformations that very frequently perturb the lateral continuity of such structures in nature, such as: strike-slip faults, "en échelon" folds, thrusts or imbricated lateral connectors. These oblique zones to fold-and-thrust belts are classically described as tear fault zones (Harris, 1970; Harding, 1985), implying certain amount of strike-slip motion along certain faults. Several of such oblique structures have been identified along the Guadalupe-Chuchure thrust fault (Fig.1). Calassou *et al.* (1993) have been able to model analogically those complexly deformed zones by imposing, during modelling, several geometrical and mechanical initial conditions: variable thickness of sedimentary cover, offset thrust front, different friction law at thrust sole and variable angle between the maximum horizontal stress and the basin axis. Recently, Baby *et al.* (1993) have also modelled the last condition in order to explain transfer zones in the foreland basin at the foothills of the Bolivian Eastern Cordillera.

GEOLOGICAL SETTING

The north-vergent Guadalupe-Mina de Coro-Chuchure thrust system extends westward for some sixty kilometers in northwestern Venezuela from the town of Puerto Cumarebo to the village of Las Piedras

(Audemard, 1993), located south of Sabaneta (Fig.1). Its easternmost segment corresponds to the north-vergent arcuated Guadalupe thrust, located offshore along the northern coast of La Vela anticline. The associated La Vela brachy-anticline is bounded on the west by the Carrizal fault, that strikes N010°-N015°, and on the east by the NW-SE trending fault system that controls the eastern coast of the Falcón State (Fig.1). The thrust system front is disrupted twice by short left-lateral (tear) faults or complex zones that can offset it southward of few to about ten kilometers, such as east of Coro. There, the front jumps south, between the villages of Caujarao and La Vela, from the southern Carrizal fault tip to a north steeply-dipping monocline affecting the fanglomerates of the Late Pliocene-Early Pleistocene Coro formation (Fig.1). In between, the thrust plane does not outcrop, but its presence is underlined by a set of NE-SW trending "en échelon" folds that connects both segments (Audemard, 1993) (Fig.1). This geometry and the associated structures suggest the existence of a transfer zone. Further west, the second front disruption happens at the western end of the segment extending between Caujarao-El Isiro and San Antonio, SW of the city of Coro. (Fig.1). The San Antonio or Hatillo fault offsets it 2.5 km left-laterally, but the post-Pliocene slip is less than 1 km. Even further west, between San Antonio and Sabaneta, the thrust fault is located south of la fila Capote within the mudstones of the Middle Miocene Querales formation and along the valley of the small village of Chuchure (Fig.1).

ANALOG MODELLING

An experimental modelling approach was followed to reproduce those oblique stuctures observed across the main east-west trend of the Guadalupe-Mina de Coro-Chuchure thrust system. We only modelled its segment located east of Coro, though it corresponds to the most complex portion, comprising strike-slip faults and "en échelon" folds. Large sandbox experiments have been performed because they allow a 3-D analysis of structures after deformation (along-strike structural variations).

Many investigations, either theoretical or experimental, have proven that dry sand is an excellent analog of sedimentary sequences, because it is a brittle material that follows the Mohr-Coulomb rupture criteria (Hubbert, 1951; Byerlee, 1978; Dahlen, 1984; Krantz, 1991; Lallemand *et al.*, 1994). The sand used for building the models is made of well-rounded quartz grains of eolian origin. This dry non-cohesive sand is characterized by a 30° friction angle and presents a Navier-Coulomb rheology. Its density is about 1.6 gr/cm^3 and its granulometric sorting, smaller than 50 μm, is obtained after sieving. Thin horizontal markers have been intercalated within the sand fill and a coloured 10 cm x 10 cm reference grid was drawn on top of it in order to observe deformation.

The designed experimental apparatus tries to reproduce the basement geometry, whereas the sand fill represents the Oligo-Miocene sedimentary sequence of the Falcón graben before tectonic inversion, taking into account collected field geological data as well as previously published and interpreted seismic profiles. Then, the apparatus comprises three undeformable wooden blocks, sliding freely on a waxed P.V.C. table (Fig.2). The table is 1.20 m in width, thus allowing to study the along-strike structural variations away from free-face perturbated table edges. The wooden blocks were cut respecting the 60º dip of normal faults limiting the graben, and blocks have been placed on the table reproducing the geometric problem. The imposed analogies are: (1) NW compartment → Paraguaná high with rather thin sedimentary cover; (2) NE compartment → La Vela bay basin; (3) central compartment → deepest part of the Falcón graben; and (4) south compartment → southern margin of the Falcón basin.

MODELLING RESULTS

From the very beginning of the experiment, a wedge started to form normal to motion of the south block. This wedge comprised in-sequence imbricated structures. When approaching the differentiated geometry of the northern compartments, an important virgation developed. The thrust front prograded to a more northern position on the NE compartment (analog to basin of La Vela bay), where the basement is deeper (Fig.3a). The virgation formed right above the basement step, thus corresponding to a transfer zone.

During this experiment, common facts have been observed with Calassou *et al.* (1993)'s experiments: virgation develops right above basement jump (Fig.3a); thrust front progrades to a more external position where basement is deeper; for each thrust formed in the thick-sequence compartment (Fig.3c), two smaller thrusts form in the thin-sequence compartment (Fig.3b); complex structures affect the sedimentary fill above the basement step as observed in normal-to-wedge cross sections.

The experiment allows us to make the following analogies with the Guadalupe-Mina de Coro-Chuchure thrust system: (a) on surface, virgation is comparable to the one offsetting the thrust system front, southeast of Coro (Fig. 1 and 3a). Therefore, Los Médanos fault is responsible for such virgation because it vertically displaces the basement between the Paraguaná block (NW compartment) and the basin of La Vela bay (NE compartment); (b) the transfer zone of the Guadalupe-Chuchure thrust comprises a left lateral fault (Carrizal fault) and a set of "en échelon" folds located at the southern tip of this fault. The "en échelon" folds correspond to the folded structures observed in the parallel-to-wedge cross sections. Then, the Carrizal fault should be considered as a lateral ramp; (c) Comparing a NE compartment cross-section (Fig.3c) to a seismic profile across La Vela anticline interpreted by Cabrera (1985) (Fig.4), a close resemblance is observed. Let us recall that a large portion of the upper part of the La Vela anticline is already eroded. We also observe the fault plane where it dips about 30ºS, very similar to the dip of the modelled fault plane at depth. Model's backthrusts are equivalent to those of the natural example.

CONCLUSIONS

From the close similarities between the performed analog modelling and the natural example, we can conclude that the virgation of the Guadalupe-Mina de Coro-Chuchure thrust fault system, located southeast of Coro, is closely linked to the difference of Neogene sediment thicknesses between the Paraguaná high and the contiguous basin of La Vela bay, producing a typical transfer zone right above a basement step, in turn, generated by the Los Médanos fault (down-to-the-east normal fault). The transfer zone of this thrust system comprises a short lateral ramp (the left-lateral Carrizal fault) and a set of NE-SW trending "en échelon" folds, responsible for transport of the La Vela anticline to the north, in a more external position.

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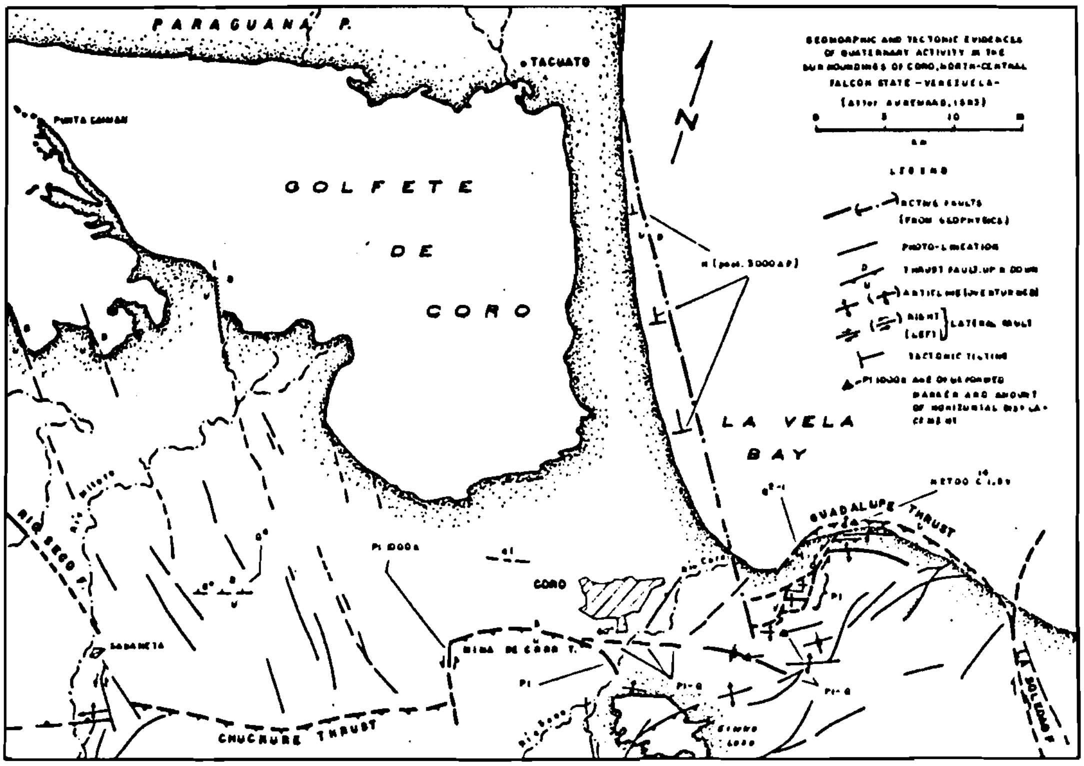
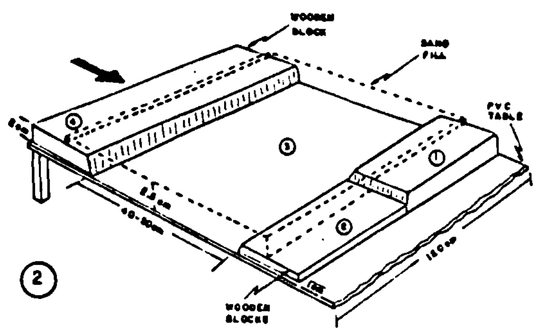
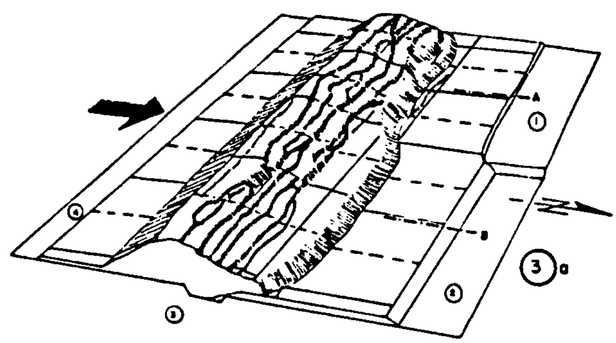
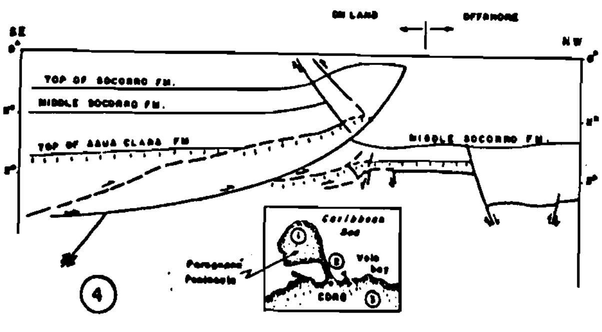


Fig.1 Neotectonic setting of northern Falcón State, near Coro, showing the Guadalupe-Mina de Coro-Chuchure thrust system and its virgations (after Audemard, 1993).







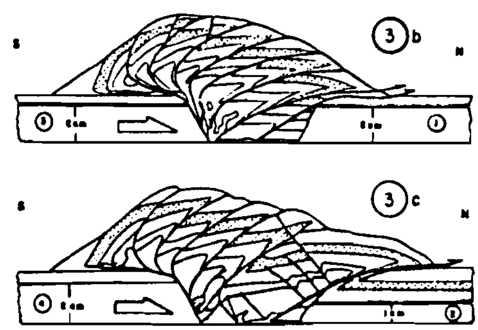


Fig.2 Apparatus used during analog modelling of transfer zone and graben inversion. **Fig.3** Final condition after deformation: a) bird-eye view of model showing transfer zone formation above basement step. Large arrow indicates kinematics imposed; b) NW compartment cross-section; c) NE compartment cross-section. **Fig.4** Interpreted seismic profile across the La Vela anticline (after Cabrera, 1985).