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Analogue modelling of the influence of a rigid block in a strike-slip system: Comparison with the Domeyko Fault System, northern Chile

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Introduction

Strike slip faults are important structures in crustal deformation among different tectonic environments and have been largely studied in field approach and analogue modelling (Sylvestre, 1988; Richard et al, 1989; Ueta et al., 2000). The aim of this study is to understand the role of rheologic heterogeneity in the evolution of strike-slip faults by means of analogue modelling, with a hypothetical comparison to the Domeyko Fault System (DFS) between the Chuquicamata district and Sierra Limón Verde, just south of the city of Calama, northern Chile. The rheologic heterogeneity tested corresponds to the presence of a rigid block in a weaker environment along fault displacement, compared to the effect of the Sierra Limón Verde Palaeozoic crystalline block on deformation evolution and structural patterns along a segment of the strike-slip regional DFS. In the experiments the rigid block is modelled with a greater thickness of sand with respect to the surrounding material (Fig. 1).

Analogue modelling – Experimental procedure

The modelling techniques are similar to those usually applied in experiments on brittle-ductile systems at the Laboratory of Experimental Tectonics of the Geosciences department, Rennes University, and have been described in previous studies (e.g. Faugère and Brun, 1984; Vendeville et al., 1987; Davy and Cobbold, 1991).
Dry quartz sand with an angle of internal friction close to 30°, and a density of about 1400 kg/ m^3 was used to model the brittle behaviour. Silicone putty, a Newtonian fluid with a viscosity of about 10^4 Pa/s and a density of 1300 kg/ m^3 was used to model ductile levels. The experiment was constructed on a table with a mobile wall pushed by a screw jack driven at constant velocity by a stepper motor (Fig. 1). The dimensions of the experiment are sufficiently large to ensure that a large part of the model escapes boundary effects. Attached to the mobile wall was a horizontal rigid sheet, which created a linear velocity discontinuity at the limit of the sheet at the base of the experiment (cf. Malavielle, 1984; Allemand et al., 1989; Nalpas et al., 2003). The models consisted of 2 cm-thick silicone layers overlain by a 2 cm-thick sand pack (Fig. 1). The rigid block was represented by a square in the centre of the model with only 1 cm-thick silicone layer overlain by a 3 cm-thick sand layer. Experiments were carried out in the Laboratory of Analogue Deformation at the department of Geology, University of Chile.

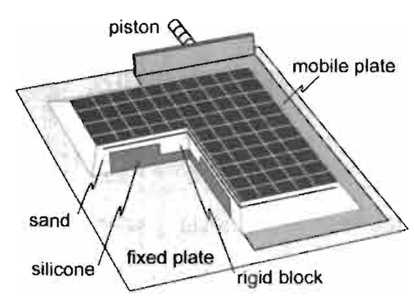

Figure 1: Experimental modelling design.

The sand pack was made of thin alternating coloured layers, which allow the identification of faults and folds on cross-sections. The displacement velocity was constant, 2 cm/hr. During experiments, photographs of the surface of models were taken at regular time intervals to study the progressive evolution of structures (Fig. 2). At the end of each experiment, the geometry of structures and their changes along strike were observed on serial cross-sections.

Results

For purposes of description and later comparison of analogue deformation characteristics to structural patterns along the DFS, deformation features are referenced by an arbitrary cardinal system, with N pointing to the right in figures 2 to 4. The linear velocity discontinuity represents a NS strike slip displacement through the middle of the experiment (Figs. 1 to 4). The rigid block is located at the centre and is the reference point for quadrant referencing with respect to the established N. The experiments allow the observation of general characteristics of the effect of a rigid block in the deformation evolution of a dextral strike-slip system. In the case of a sinistral system results would be identical, but inverted.

The most obvious effect of a rigid block along strike-slip dextral movement is the development of dextral strike-slip faults diagonal to the rigid block and principal NS discontinuity. These represent escape faults that accommodate deformation around the rigid block, in this case NW and SE of the block itself (Fig. 2a). These faults develop together and in response to clockwise rotation of the rigid block. Rotation also induces less important sinistral strike-slip and reverse faults NE and SW of the rigid block (Fig.2a).

With an increment of displacement (Fig. 2b and c) the deformation zone associated with the rigid block takes an elongated shape in a NW-SE direction, with an accordingly increment of rotation of the rigid block and of developing structures. The strike-slip faults are progressively transformed to reverse strike-slip faults as NS displacement is increased (Fig. 2b and c).

In addition to variation of displacements, variation of size and shape of the rigid block was tested (Fig. 3). These were done at 5 cm displacements. From these experiments the following observations are made. An increment of size of the rigid block from 5x5 cm^2 to 7.5x7.5 cm^2 causes a broader deformation zone associated with block rotation (Fig. 3b). For a larger block, 10x10 cm^2, the NS discontinuity cuts through the block (Fig. 3c). This indicates a limit at which it is easier to cut the rigid block than to produce rotation. Yet, if the shape of the rigid body is changed to a 10 cm diameter cylinder, resistance to rotation is less and strike-slip deformation is accommodated around the rigid body in a pattern similar to the smaller blocks, but

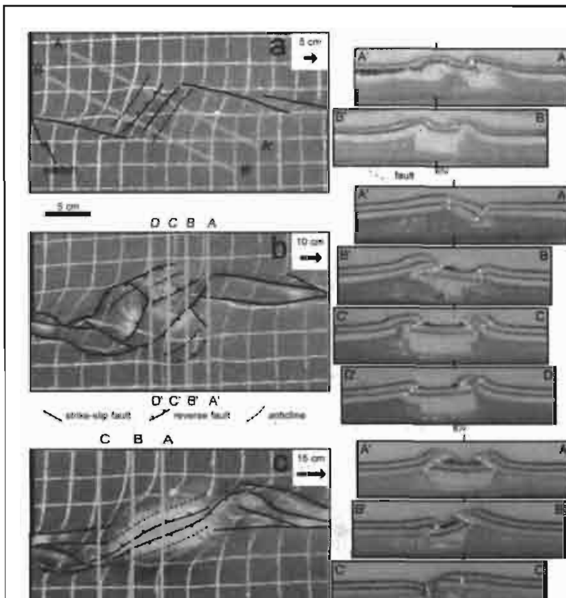

Figure 2: Surface views and cross-sections of 3 models with increasing NS displacement (a: 5cm to c: 15 cm).

with broader development of faults (Fig. 3d).

In consideration of strike-slip displacement documented for the DFS between El Abra and Sierra Limón Verde (Maksaev & Zentilli, 1988, Maksaev, 1990, Reutter et al., 1993, Lindsay et al., 1995, Tomlinson and Blanco, 1997, Dilles et al. 1997), initially dextral and later sinistral, one additional experiment was carried out. With the 5x5 cm^2 rigid block, initial 5 cm of dextral displacement were over displaced by later 5 cm of sinistral movement, this in order to observe the effect of pre-existing faults and deformation from a dextral system on to a sinistral system with a rigid block along the deformation zone. The inversion of displacement produced a reactivation of the initially formed dextral strike-slip faults to sinistral strike-slip faults, associated with an inversion of rigid block rotation. Strike-slip fault reactivation in opposed directions demonstrates that initial dextral slip associated deformation in presence of a rigid block will generate a fault geometry able to accommodate later sinistral strike-slip movement by reactivation and growth of pre-existing faults.

The Domeyko Fault System comparison

Fault geometry and deformation is comparable to that of the DFS just south of the city of Calama, II region, Chile. Such a geometry may have responded to the presence of a rigid crystalline block of Palaeozoic rocks (Sierra Limón Verde) along the southern end of this DFS segment. Initial 3 Km of dextral movement and some 32 Km of sinistral movement have been described and documented for this fault system (Maksaev & Zentilli, 1988, Maksaev, 1990, Reutter et al., 1993, Lindsay et al., 1995, Tomlinson and Blanco, 1997, Dilles et al. 1997). If the Sierra Limón Verde block is considered rigid, initial dextral movement associated faults would form as in the analogue experiments. Upon reversal of movement to sinistral, original dextral faults are reactivated to sinistral, accommodating deformation by growth of pre-existing escape faults. Such a hypothesis for the DFS south of Calama and Chuquicamata needs further study and corroboration, yet pre-existing dextral escape faults around a rigid block could accommodate large distances of deformation, as the 32 Km of sinistral displacement documented between the mines of El Abra and Chuquicamata (Maksaev & Zentilli, 1988, Maksaev, 1990, Reutter et al., 1993, Lindsay et al., 1995, Tomlinson and Blanco, 1997, Dilles et al. 1997), displacement which is progressively less just south of the Chuquicamata mine. Parallel sliver faults adsorb much of the more linear displacement from the north, in response to prior development of faults around the rigid block.

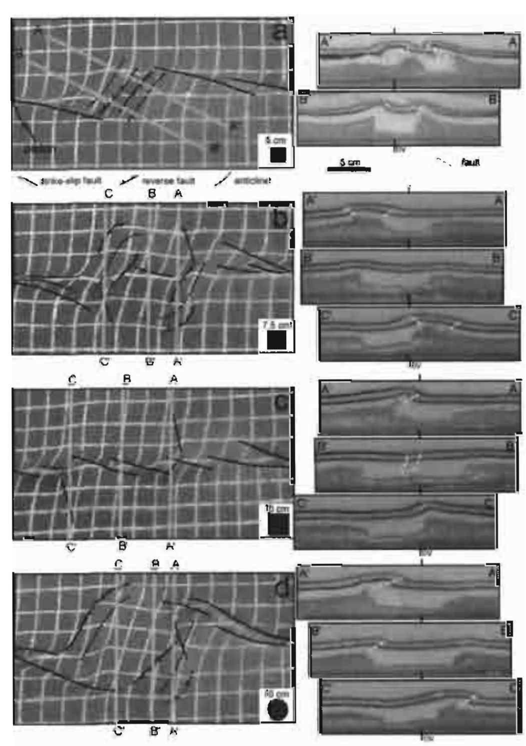

Figure 3: Surface views and cross-sections of 4 models with different size of rigid block.

Conclusions

The presence of a rigid block in a strike-slip fault system modifies the geometry of deformation (Fig. 4):

i) laterally to the rigid block and associated with the displacement strike-slip faults "en échelon" faults are developed; ii) if the size of the rigid block allows its rotation, it is clockwise in a dextral system and anticlockwise in a sinistral system, and iii) the rotation of the rigid block induces the creation of strike-slip fault systems around it, antithetic to the general displacement. The size of the rigid block is a key parameter in the evolution of the deformation: i) a small rigid block favours its rotation and deformation around it, and ii) a big rigid block is cut without perturbation of the general deformation. An increment of displacement generated: i) an increment of displacement along the faults; ii) an increment of rotation associated structures, and iii) a deformation around the rigid block associated with vertical rotation of the layers of sand. The inversion of the displacement sense produced: i) the reactivation and inversion of the movement on the faults, and ii) the inversion of the rotation sense of the rigid block.

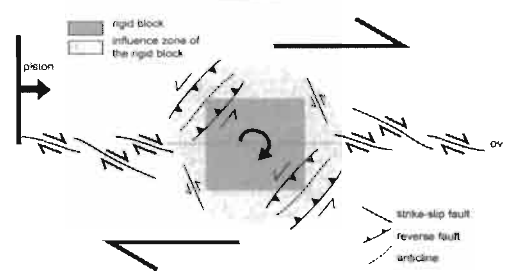

Figure 4: Schematic representation of the principal deformation characteristics around an rigid body.

The geometry of deformation along strike-slip systems with movement inversions, when considering a rigid body along the main deformation pathway, is comparable to the Chuquicamata – Sierra Limón Verde segment of the DFS, and may help explain large differences in total displacement, from few kilometres between the mentioned segment to 32 Km between the Chuquicamata and El Abra segment. Differential deformation along regional fault systems is a most expected feature in response to rheological differences associated with lithological heterogeneity, in this case a rigid crystalline body.

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