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Influence of early strike-slip deformation on subsequent perpendicular shortening: An experimental approach

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Abstract

We used sandbox analogue models to study the influence of previous pure strike-slip and transpressional structures on subsequent perpendicular compression. We performed also a brittle–viscous system in order to analyse the presence of a viscous basal level. Experimental results show that a previous pattern generated under pure strike-slip and transpressive regime causes the reactivation of structures with favourable orientation and the nucleation of oblique thrusts and non-rectilinear deformation fronts under compression perpendicular to the first fault system. The presence of a viscous basal level with the imposed strain rate, which does not favour the coupling between the viscous layer and cover, inhibits the reactivation of previous structures. Comparison with a sector of Northern Chile margin (24–25°S), located in the forearc trench-parallel region supports the experimental results.

Keywords: Strike-slip; Transpression; Analogue models; Reactivation; Andean forearc deformation

1. Introduction

Inherited structural features represent a key factor in controlling strain distribution and localisation of deformation (e.g. Holdsworth et al., 2001), as surfaces of pre-existing faults display lower cohesive strength and friction coefficient than intact rocks (Anderson, 1951). Since the last decades, the importance of reactivation processes to obtain deformation trends oblique to the expected fault orientation is well known (e.g. Ranalli and Yin, 1990; Tikoff and Teyssier, 1994; Casas-Sainz, 1993; De Paola et al., 2005). Numerous previous experimental studies have been performed in order to analyse reactivation of pre-existing structures or the influence of pre-existing faults on the new created fault pattern, and most of them have dealt with tectonic inversion (e.g. McClay, 1989; Brun and Nalpas, 1996; Keep and McClay, 1997; Dubois et al., 2002; Panien et al., 2005). In the last years, a wide range of different reactivation processes have been analysed in order to study different processes, such as transpressional reactivation of normal faults (Ustaszewski et al., 2005) or reverse faults (e.g. Viola et al., 2004), or reactivation of normal faults in extension (Bellahsen and Daniel, 2005).

When an area has experimented superimposed tectonic regimes, one of the hardest task is to discriminate how previous structures have contributed to the latest tectonic regime. In this work, we study the effect of pure strike-slip and transpressional faults in a final configuration with compression perpendicular to the previous fault system. Strike-slip to reverse reactivation can occur in nature under different scenarios: (1) when σ_1 experiences a direction change because of variations in plate convergence and/or slab retreat (e.g. Betic chain, SE Spain; Sanz de Galdeano and Buforn, 2005) and (2) if plate convergence does not vary, in the forearc of oblique convergence subduction margins due to changes in the strain partitioning into parallel strike-slip faulting and orthogonal

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thrusting (e.g. Chilean forearc). In order to validate the experimental results we have chosen a sector of Northern Chile margin (24–25°S) located in the forearc trench-parallel region that has registered strike-slip movements during the Eocene–Oligocene and perpendicular compression during the Neogene (Soto et al., 2005).

2. Experimental method

The experimental apparatus consisted of a large table (1.1 m × 0.8 m) on top of which lies a thin metallic plate linked to a computer-driven stepper motor (Fig. 1). Models did not present side walls in order to avoid sideways friction and were wide enough to allow a relatively large amount of deformation without edge effects. The mobile basal plate covered only one half of the table and had a rectangular shape for pure strike-slip deformation or forming a convergence angle (α) of 5° or 10° for transpressive deformation regime (Fig. 1 and Table 1). The moving boundary of this plate induced an asymmetric velocity discontinuity at the base of the models (e.g. Malavieille, 1984; Allemand et al., 1989), which localised the deformation in the covering sandpack (e.g. Richard, 1991b; Barrier et al., 2002). Models experimented two deformation stages: (1) pure strike-slip or transpression regime depending on the angle of the velocity discontinuity with respect to the bulk shear direction (i.e. convergence angle) (α) and (2) compression perpendicular to the previous velocity discontinuity. Reference model PN-04 was performed with a viscous décollement layer only in the central part of the experiment and only compressional motion (perpendicular to the velocity discontinuity) in order to compare how a previous fault system influences the resulting fault pattern with and without viscous décollement level. Two different setups have been used in analogue modelling in order to analyse the influence of a previous fault or fault network: (1) creating discontinuities by introducing a piece of cardboard or a metallic wire in the sandcake (Viola et al., 2004; Bellahsen and Daniel, 2005) or (2) subjecting models to two consecutive and different stages of deformation (e.g. Dubois et al., 2002; Ustaszewski et al., 2005). In this work, we have chosen the second case (i.e. performing two consecutive stages of deformation) due to the helicoidal geometry of strike-slip faults (i.e. Riedel faults) (Naylor et al., 1986), very difficult to simulate using a piece of cardboard or a metallic wire.

Simple sandpack models made of dry eolian quartz Fontainebleau sand (small cohesion, density $\rho = 1.493\ \mathrm{g\,cm^{-3}}$; Krantz, 1991) were made to simulate the brittle behaviour of the upper crust. Its deformation is considered as effectively time independent (Hubbert, 1937). Only models PN-04 and PN-05 presented a 30 cm long, 8 cm wide and 0.5 cm thick and 40 cm long, 8 cm wide and 0.5 cm thick, respectively, basal silicone putty layer. We used this layer, as in previous studies, to simulate the behaviour of a viscous detachment level (e.g. Vendeville, 1987; Cobbold et al., 1989; Richard, 1991b; Weijermars et al., 1993). The silicone putty used is a nearly Newtonian fluid with a density of $0.97\ \mathrm{g\,cm^{-3}}$ and a viscosity of 1×10^4 Pa s at room temperature for the deformation velocity of $4\ \mathrm{cm\,h^{-1}}$ used during the experiment. Models were scaled in terms of gravitational forces, rheology, and strain rates (Hubbert, 1937; Ramberg, 1981; Casas et al., 2001). The model ratio for length is 10^{-5} (1 cm in the model represents 1 km in nature); for stress, 10^{-5} (models are 10^5 times weaker than nature); for time 10^{-9} (1 h represents 100 000 years). All models run at $4\ \mathrm{cm\,h^{-1}}$. One-layer sandpack and two-layer (silicone-sand) models experimented 20 mm and 25 mm of dextral strike-slip component displacement during the first stage of deformation, respectively, and 10 mm of shortening during the second stage of deformation. In the reference model PN-04, we applied only 1 cm of shortening in compressional motion perpendicular to the velocity discontinuity.

During experiments, in order to analyse the progressive evolution of structures we took photographs of the surface of models at regular intervals. At the end of the two deformational stages, serial cross-sections perpendicular to the basal velocity discontinuity showed the three-dimensional geometry

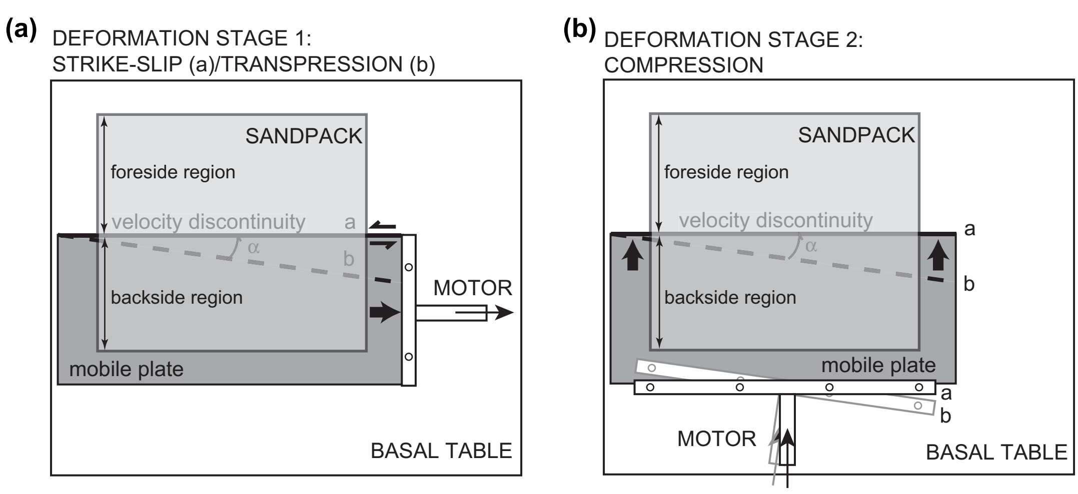

Fig. 1. Experimental apparatus. (a) Plan view of the apparatus during the first stage of deformation. Note the variation of the angle of convergence (α) from pure strike-slip faulting ($\alpha = 0°$) to moderate transpressive faulting ($\alpha = 5–10°$). (b) Plan view of the apparatus during the second stage of deformation, compression, which is perpendicular to the previous velocity discontinuity.