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STRESS CONTROL OF FRICTIONAL HANGINGWALL ACCOMMODATION ABOVE THRUST RAMPS

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ABSTRACT

Experimental models are used to study the stress control of frictional hangingwall accomodation above rigid flat-ramp-flat footwalls. Hangingwall accommodation involves shear or kink-band nucleation above the lower fault bend and migration of these as the hangingwalls climb over the underthrusting footwall. The kink-bands change shape and localise to thrusts as they migrate over the flat-ramp-flat footwall. When the shear stress to gravity stress ratio is low the thrusts reactivate to normal faults. With increase in the shear stress to gravity stress ratio reactivation of the kink bands was by tensile failure, at the upper fault bend. The models show that by changing the strength of materials deforming under otherwise similar conditions it is possible to study the geometry of frictional hangingwall accommodation, at different scales. In nature, hangingwall accommodation by thrust nucleation above thrust ramps and their subsequent normal reactivation may be anticipated in frictional sediments at shallow crustal levels, where temperatures and pressures are low.

KEY WORDS: stress control; frictional accommodation; thrust ramps.

1. INTRODUCTION

It is well-known that thrust faults with ramp-flat geometry can develop upon shortening of rheologically stratified multilayers. The flats commonly form along incompetent horizons while the ramps cut upsection in competent layers (Rich, 1934; Dahlstrom, 1970; Harris and Milici, 1977; Boyer and Elliott, 1982; Eisenstadt and De Paor, 1987, and others). However, the role of strength (involving both homogeneous and heterogeneous materials)in controlling the geometry of hangingwall accommodation is not well understood.

In this paper we investigate the role of strength in controlling the geometry of frictional hangingwall accommodation, above rigid footwalls. Previous experiments have investigated various aspects of the mechanics of frictional hangingwall accommodation. For example, Merle and Abidi, 1995 demonstrated the control on ramp accommodation of both friction along the ramp and erosion of the growing hangingwall. Bonini et.al (2000) studied the role of ramp inclination angle in hangingwall accommodation. Here, we investigate experimentally the role of strength in frictional hangingwall accommodation. This is necessary because strength is a fundamental property at shallow crustal levels in the crust and can determine the style of ramp-flat thrust accommodation.

2. THE EXPERIMENTAL MODELS

Model materials deformation and scaling

The experiments were performed at the Hans Ramberg Tectonic Laboratory, Uppsala University. Passively layered dry sand were sedimented and shortened in a Plexiglas squeeze box with dimensions (9.5 x 7 x 1.4 cm) by pushing a rigid block with a frontal ramp angle of 30°, at a constant rate of 1.8 cm h^{-1}. In the experiments the rigid indenter, represents either a thrust footwall or a pre-existing basement fault. After deformation, models were sectioned and photographed to study the internal deformation.

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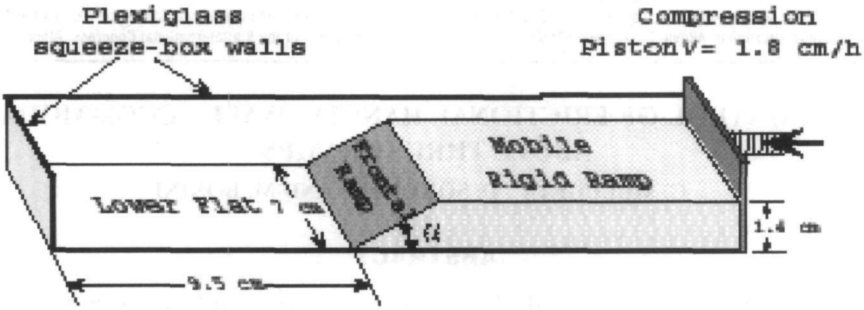

Figure 1. Model set up and definition of nomenclature used in the text. Arrow indicates the movement of the mobile rigid ramp.

The sand material used is intended to simulate the brittle behaviour of sedimentary rocks in nature (Byerlee, 1978) which exhibit Mohr-Coulomb material behaviour(eq.1).

$$\sigma_s=\mu\ \sigma_n+C \qquad (1)$$

where, σ_s and σ_n are the shear and normal stresses on the fault plane respectively, μ = tan f is the coefficient of internal friction, f the internal friction angle and C is cohesion. The cohesionless sand material consists of pure quartz sand with particle diameters less than 0.246 mm, a mean density (r = 1300 kg/m^3), coefficient of internal friction ($\mu\approx0.58$). To vary the strength the sand is made cohesive by impregnating with paraffin oil with cohesion C≈200 Pa. As in nature, in all models the flat-ramp-flat footwall provided a surface of low frictional resistance.

Here we non-dimensionalise the Coulomb equation by dividing the shear stress with the gravity stress (eq.2)

$$\sigma_s/h\varrho g = \mu+C/hrg \qquad (2)$$

where; $\sigma_n \approx \varrho gh$, r is density, g is the acceleration due to gravity and h is the thickness of the thrust sheet at the rear end.

Whereas, m has a small value in nature and experiments, in the range ($\mu\approx0.6\pm0.2$), the cohesive strength of frictional sediments can be significant at shallow levels in the crust and can vary within a wide range. Thus eq.2 may be approximated as:

$$\sigma_s/h\varrho g\approx C/h\varrho g \qquad (3)$$

Moreover, eq.2 can be used as a scaling parameter assuming that the cohesive strength to gravity stress ratios in models and nature remain invariant.

$$(C/h\varrho g)_{model}=(C/h\varrho g)_{nature}$$

$$h_m/h_n \sim C_m\varrho_n/C_n\ \varrho_m \qquad (4)$$

Where subscripts m and n denote model and nature, respectively.

In the experiments we vary the cohesive strengh of frictional materials to model different hangingwall accommodation styles, at different scales.

3. EXPERIMENTAL RESULTS

Cohesionless sand

In models using cohesionless sand $c/\varrho gh<1$, and at low values of bulk shortening, the model exhibits a flat-topped ramp anticline in cross-section (Fig. 2a), which progressively becomes more rounded with convex-upwards geometry. In these models, the shortening is accommodated by nucleation of a series of kink-bands at the lower fault bend (Fig.2). As the deformation continues, the earlier kink bands change shape, shear and localise to thrusts, as discussed previously by Mulugeta & Koyi (1992); while new ones nucleate serially at the lower fault bend. Similar structures were also reported in experiments performed by Colletta et al (1991), Merle and Abidi (1995), and Bonini et al (2000).

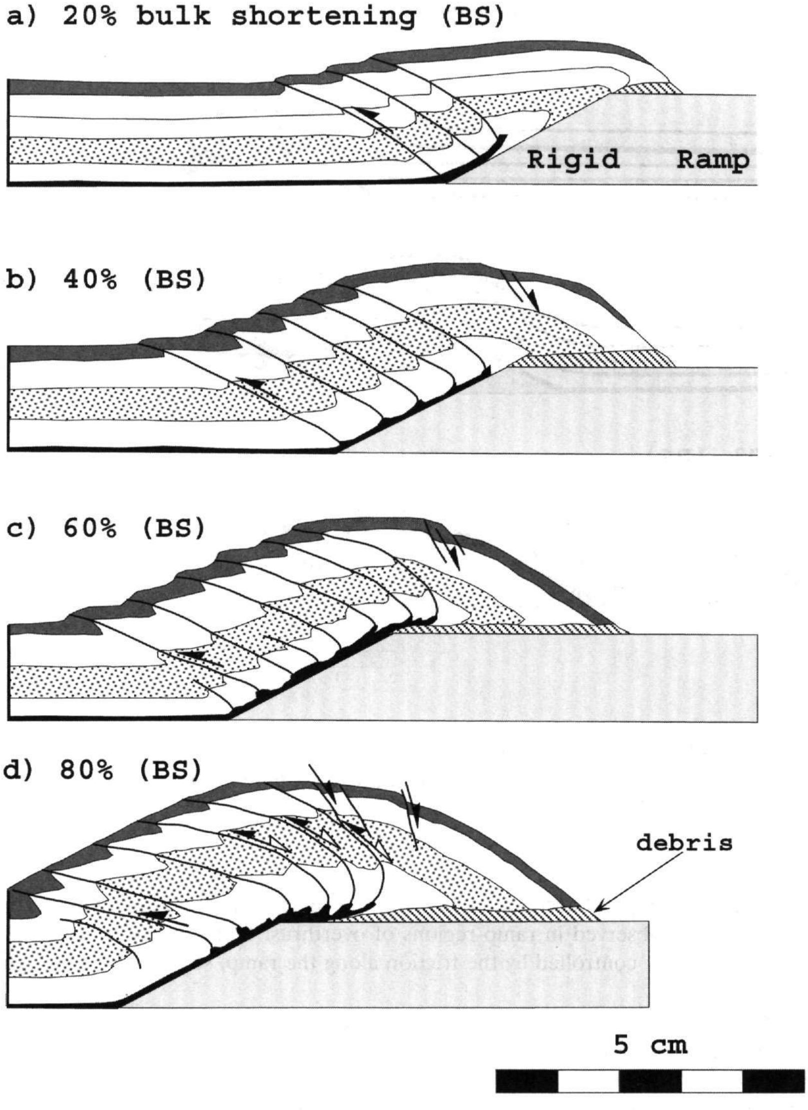

Figure 2. Cross-sections of experiments in cohesionless sand showing progressive frictional hangingwall accommodation.

Foreland-dipping normal faults start to appear at 40% BS (Fig.2c), partly reactivating older thrusts during extensional collapse of the hangingwall above the upper flat. The kink interlimb angles increase when the kinks or shear bands are re-utilised as normal faults (c.f. Mulugeta and Koyi, 1992).

Cohesive sand

By comparison, with increase in the cohesive strength to gravity stress ratio ($C/\varrho gh \approx 2$, Fig.3), a single shear band nucleates above the lower fault bend. This is then transported passively up the ramp until it reaches the upper fault bend where it becomes reactivated by tensile failure (Fig.3, c&d).

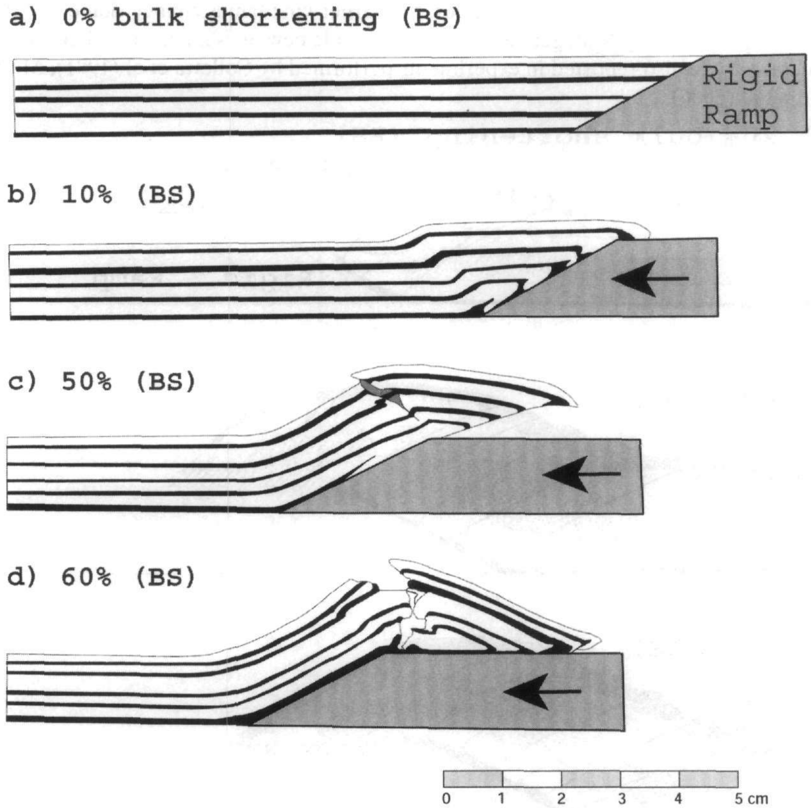

Figure 3. As in 2 but for cohesive sand showing extensional reactivation (at the upper fault bend) of a kink band which initially nucleated at the lower fault bend.

4. DISCUSSION

The style of frictional hangingwall accommodation in the experiments (e.g.Fig.2) can be compared to the convex-upwards curved faults observed in ramp regions of overthrust faults, in nature (e.g.Serra 1977). This geometry is presumably strongly controlled by the friction along the ramp, strength as well as homogeneity of the hangingwall.

In the models, the mechanism of kink band migration is quite different than that suggested by some kinematic models (e.g. Suppe 1983). For example, in the kinematic model the synformal axis remains spatially fixed at the lower fault bend while the anticlinal axial surface migrates along the rampuntil it reaches the top of the ramp where its position becomes fixed relative to the fault surface. By comparison, in the material models using cohesionless sand, both axial surfaces in a kink band migrate towards the upper flat and become curved (convex upwards) in the process. With increase in the shear strength to gravity stress ratio, for the same coefficient of basal sliding friction, the number of kink bands decrease and the reactivation of earlier kink bands (which nucleated at the lower fault bend) takes place by tensile failure at the upper fault bend (Fig.3). Thus, the model results show that kink band nucleation, migration and reactivation in nature and experiments requires assessment of the stress control of frictional hangingwall accommodation, above fault bends. For example, Bonini et al 2000 have discussed the geometries of various natural cases of normally reactivated thrust faults developing in the hangingwalls of ramps.

5. CONCLUSIONS

Results of scaled sand models shortened over a rigid ramp/flat footwall suggest that extensional reactivation of early back thrusts may be different depending on the shear strength to gravity stress ratio. Thus, this dimensionless parameter needs to be taken into consideration in any analysis of ramp-flat thrust accommodation.

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