Kinematic evolution of strain partitioning in analogue brittle transpressional wedges

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Background

Strain partitioning is a well-documented phenomenon at obliquely convergent margins and continental transpression zones. Analytical derivations of its mechanics (Haq and Davis, in press; McCaffrey, 1992; Platt, 1993) have been tested numerically and by means of analogue models (e.g. Burbidge and Braun, 1998; Haq and Davis, in press; Vernant and Chéry, 2006). It was found that if the convergence obliquity θ (the angle between the plate motion vector and the normal to the plate boundary) exceeds a critical value θ_{crit}, displacement is partitioned into margin-parallel strike-slip and oblique-to-orthogonal thrust faulting at an angle α to the normal of the plate boundary. Furthermore, for a given convergence obliquity, the degree of strain partitioning (i.e. the fraction of margin-parallel displacement that is accommodated on a strike-slip fault) is a function of the friction on the fault surfaces in case of brittle - frictional rheologies.

For quartz sand with $\varphi=31^o$, θ_{crit} was derived to be 31-34 degrees (Burbidge and Braun, 1998; Haq and Davis, 2010), corresponding to a plate convergence angle of 56-59 degrees. According to some authors, the orientation of the slip vector on the thrust fault α is the same for all convergence obliquities and a function of the angle of internal friction φ and the dip angle of the thrust fault (McCaffrey, 1992; Haq and Davis, 2010). In the simplest case where the thrust fault is assumed to be horizontal, $\alpha = \theta_{crit} = \varphi$ (Haq and Davis, 2010).

Scope and method

In order to validate the applicability of these simple analytical results to progressively deforming transpressional wedges, improved observations of the fault kinematics in such systems are required. To this end, we ran a series of basal-driven transpressional analogue models with a brittle rheology at different convergence angles (4, 7.5, 15 and 30 degrees). In these crustal scale models, brittle rheology was represented by quartz sand (thickness 6cm, extent 120x60cm). Total displacement amounted to 50cm (24cm for the 30^o model). DPIV (Digital Particle Image Velocimetry) was used to record the displacement field at high spatial and temporal resolution (2 mm displacement increment). The progessive kinematic evolution of the models could be calculated and visualized by means of a directional derivative of this displacement field. In a next step, the slip vector on individual fault segments was extracted.

Results

Strain partitioning did not develop in the 30^o model for the applied amount of displacement and it was less obvious in the 4^o model due to its very high obliquity. We therefore focus on the results for the 7.5 and 15^o models, which show well-developed strain partitioning and a rather similar kinematic evolution.

Three different stages in the kinematic evolution of these models were defined by changes in the degree of displacement partitioning. A first stage of distributed strain with no visible faults at the model surface was followed by a second stage (2 - oblique wedge) in which a doubly vergent wedge formed, bounded by a pro- and a retro-shear with oblique displacement. With progressive displacement, the oblique displacement on these faults became locally partitioned towards the surface. During the third stage (3 - strain partitioning), strain was partitioned between a strike slip zone in the center of the wedge and reverse faults at the sides. The models show near-reverse displacement along both sides of the wedge in addition to strike slip displacement in the center. The retro-shear finally became inactive.

In a further analysis average slip vectors were extracted for individual fault segments, allowing a more quantitative analysis of fault slip evolution. It confirms the semi-qualitatively defined stages above. For the 15^o model (**Figure 1**) the initial faults defining the oblique shear lens have a slip angle of 15-30 degrees to the basal velocity discontinuity. In the strain partitioning stage, newly developed pro-shears show a rotation of the slip vector by ~40 degrees, changing from initially oblique (40^o on P1) to finally nearly orthogonal (up to 80^o on P2) to the plate boundary. Thus, for a constant convergence angle of 15^o, the slip vector on a single fault (P2) rotates by 30^o (from 50^o-80^o). The 7.5^o model shows a very similar pattern (**Figure 2**).

Discussion and conclusions

Strain partitioning in brittle analogue transpression models with a low convergence angle (7.5, 15^o) evolved only after sufficient displacement (see also Burbidge and Braun, 1998). In our models, the stage of full strain partitioning is preceded by stages of distributed displacement and a wedge with oblique slip faults. In this "oblique wedge" stage, the obliquity of the slip vectors parallels the applied displacement field. In contrast to the predictions from analytical solutions (Haq and Davis, 2010; McCaffrey, 1992), oblique slip is thus possible even for very high convergence obliquities, but it is a transient stage. During the "strain partitioning" stage, the slip vector at the frontal pro-thrust does not have a fixed orientation as predicted analytically, but progressively rotates towards a more margin-normal orientation. A similar progressive rotation of slip vectors has been recorded in the thin-skinned West Spitsbergen fold- and thrust belt (Braathen et al., 1997). The final angle is also more acute than $\theta_{crit} = \varphi$; instead of ~30 degrees it is ~10-15 degrees for both models. The rotation and final orientation of the slip vector may be due to a number of factors, which are not considered in the analytical models: ceasing activity of faults on the retro-side, which previously accommodated part of the margin-normal displacement; topographic build-up, increasing the vertical component of the stress tensor, or strain weakening on the pro-shears. Their relative importance is under investigation.

References

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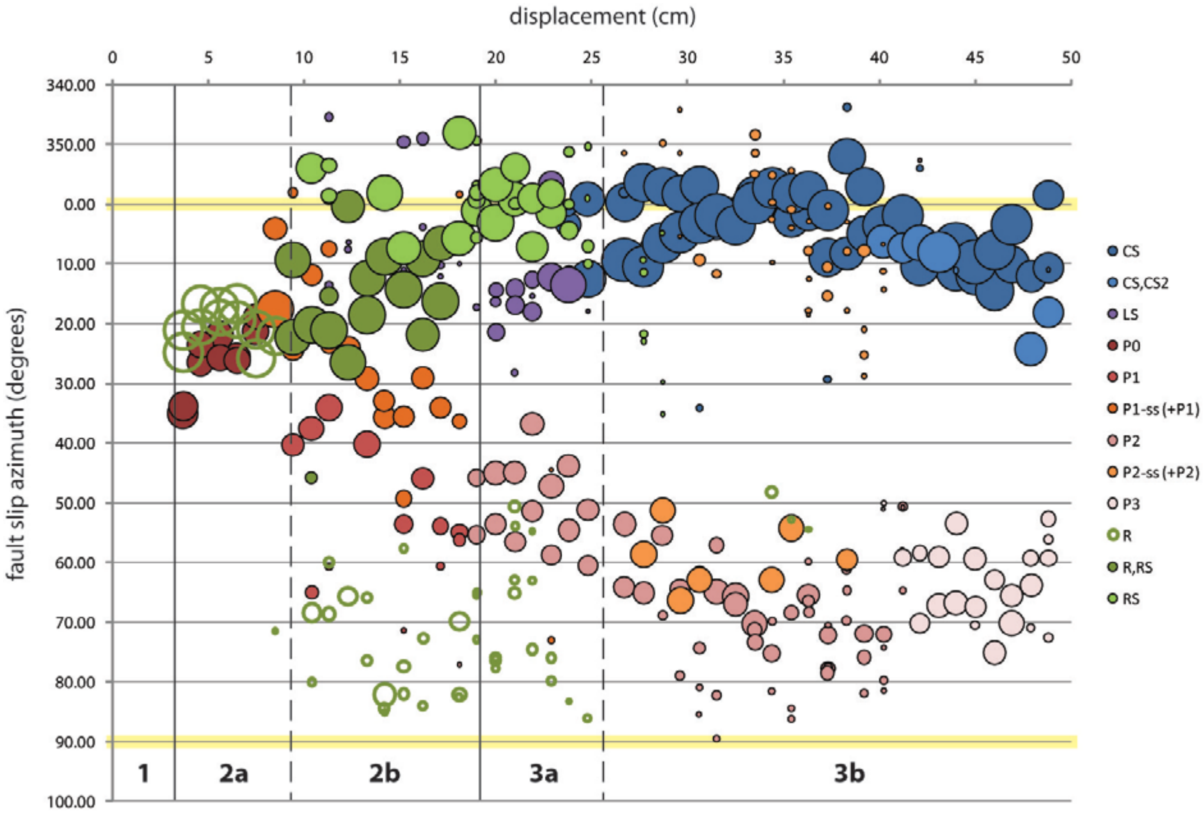


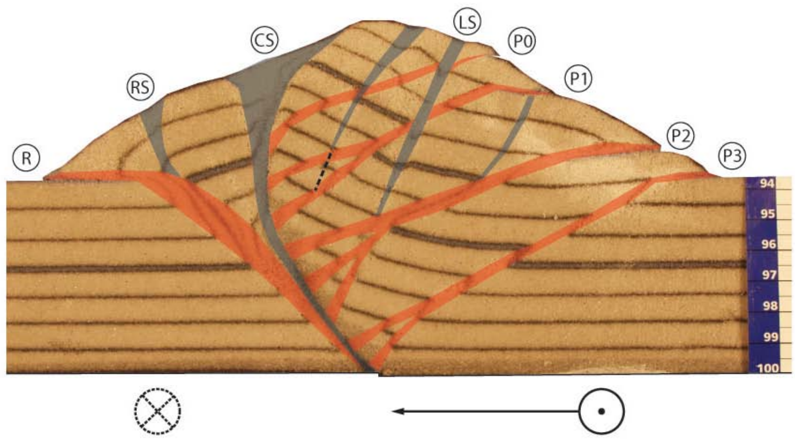
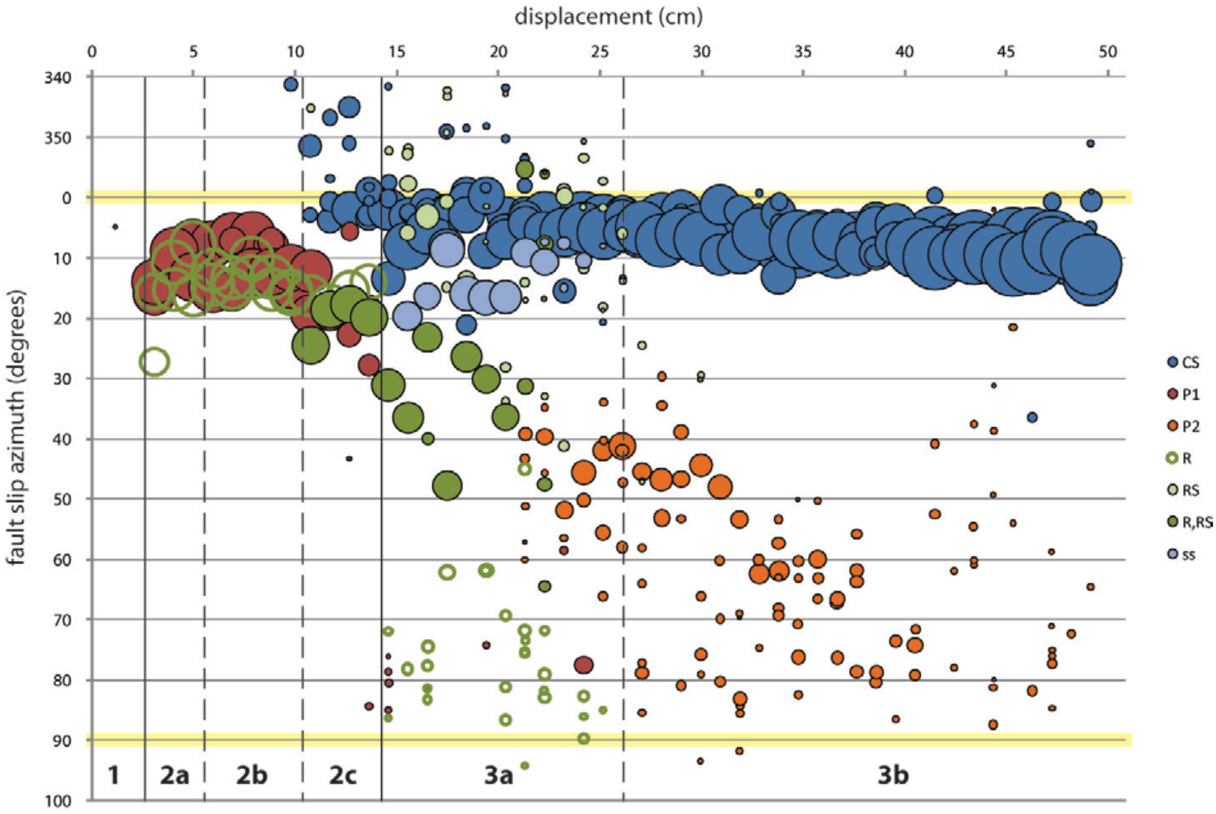


Figure 1

a. *Fault slip azimuth on different fault segments for the 15^o model. Horizontal axis shows the model displacement (in cm), vertical axis the orientation of the slip vector with respect to plate boundary, where 0^o corresponds to strike-slip and 90^o to orthogonal convergence. Bubble size corresponds to the magnitude of the slip vector. CS is the central strike-slip zone, P0-3 are pro-shears and R and RS are the normal and strike-slip branches of the retro-shear (see cross section in Fig. 1b). Kinematic stages 1-3 ("distributed strain", "oblique wedge" and "strain partitioning") are indicated.*

b. *Cross section of 15^o model*



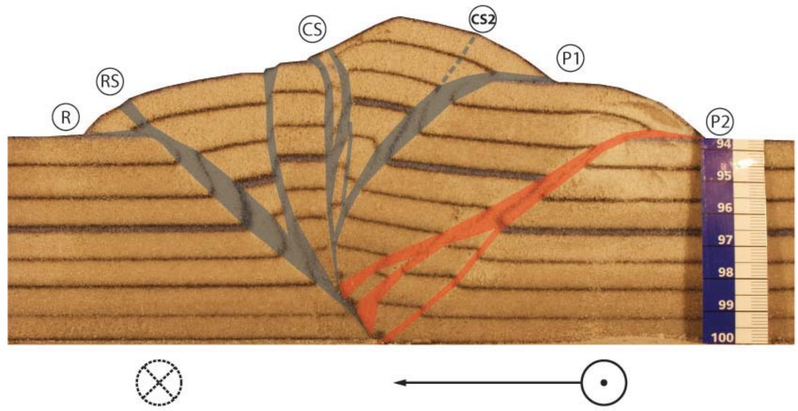


Figure 2

a. *Fault slip azimuth on different fault segments for the 7.5° model. See caption of Figure 1a.*
b. *Cross section of 7.5° model*