Decoupling in mechanically heterogeneous multilayered sandbox

Desacoplamiento en paralelepípedos de arena mecánicamente heterogéneos

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ABSTRACT

Analogue modelling has successfully simulated the progressive development of duplex formation in sandpack with intercalation of glass microbeads, whose coefficient of internal friction is significantly lower then that of the sand. A strong decoupling took place along this mechanical heterogeneity, which in turn defines two structural levels with different style of deformation.

Key words: *Analogue modelling, multilayered sandpack, glass microbeads, mechanical heterogeneity, decoupling, duplex.*

RESUMEN

Modelizaciones analógicas han simulado con éxito el desarrollo progresivo de duplex en paralelepípedo de arena que incluyen una intercalación de microesferas de vidrio, cuyo coeficiente de fricción interna es significativamente más baja que el de la arena. Un desacoplamiento pronunciado tuvo lugar a lo largo de esta heterogeneidad mecánica, la cual define dos niveles estructurales con dos estilos de deformación distintos.

Palabras clave: *Modelización analógica, multicapa de arena, microesferas de vidrio, heterogeneidad mecánica, desacoplamiento, duplex*

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Introduction

Analogue modelling provides a powerful tool to investigate the style of fold-and-thrust belt. In particular, décollement kinematics has been investigated with this method, although the geometry and rheology of analogue models necessarily simplify the complexities of the natural cases under investigation. In these cases, it is assumed that within a rock sequence involved in a fold-and-thrust belt, mechanical heterogeneity and decoupling are produced by stratigraphic variations. Nevertheless, in the analogue models, the vertical variations of mechanical properties are generally induced by silicone layers intercalated in an initial sandpack (e.g. Bonini, 2001 and references therein). Such Newtonian nongranular material is appropriate for simulating the rheology of evaporites, but might not be adequate when the décollement in the natural case is composed of shales, whose rheology, though very complex, can be expressed by the Mohr-Coulomb criterion (Weijermars *et al.*, 1993). Only very few literature can be found about models which include glass microbeads —a Mohr-Coulomb analogue material with a much lower coefficient of internal friction than the sand— to simulate natural rocks along which detachment can occurred (Turrini *et al.*, 2001; Kukowski *et al.*, 2002). In this paper, preliminary results describing the progressive deformation of sandpack with an intercalation of a layer of glass microbeads are presented. During compression, mechanical decoupling is created due to the intervening glass microbeads layer and different structural levels can be evidenced, together with the formation of duplex.

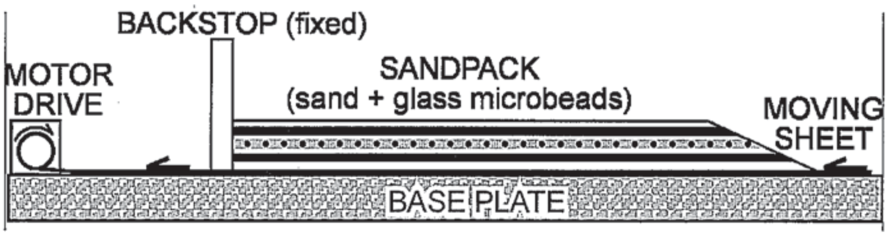

Fig. 1.- Simplified sketch of the experimental apparatus and model setting in cross section.

Fig. 1.- Esquema simplificado del aparato experimental y perfil del modelo inicial.

Model set up and experimental conditions

All the experiments were realized in the Analogue modelling Laboratory of the Geodynamic Department of the University of Granada. In the experiments, dry, rounded quartz sand with a grain size varying between 0.2 and 0.3 mm, were used in a natural gravity field to simulate the Mohr-Coulomb behaviour of competent sedimentary rocks undergoing brittle

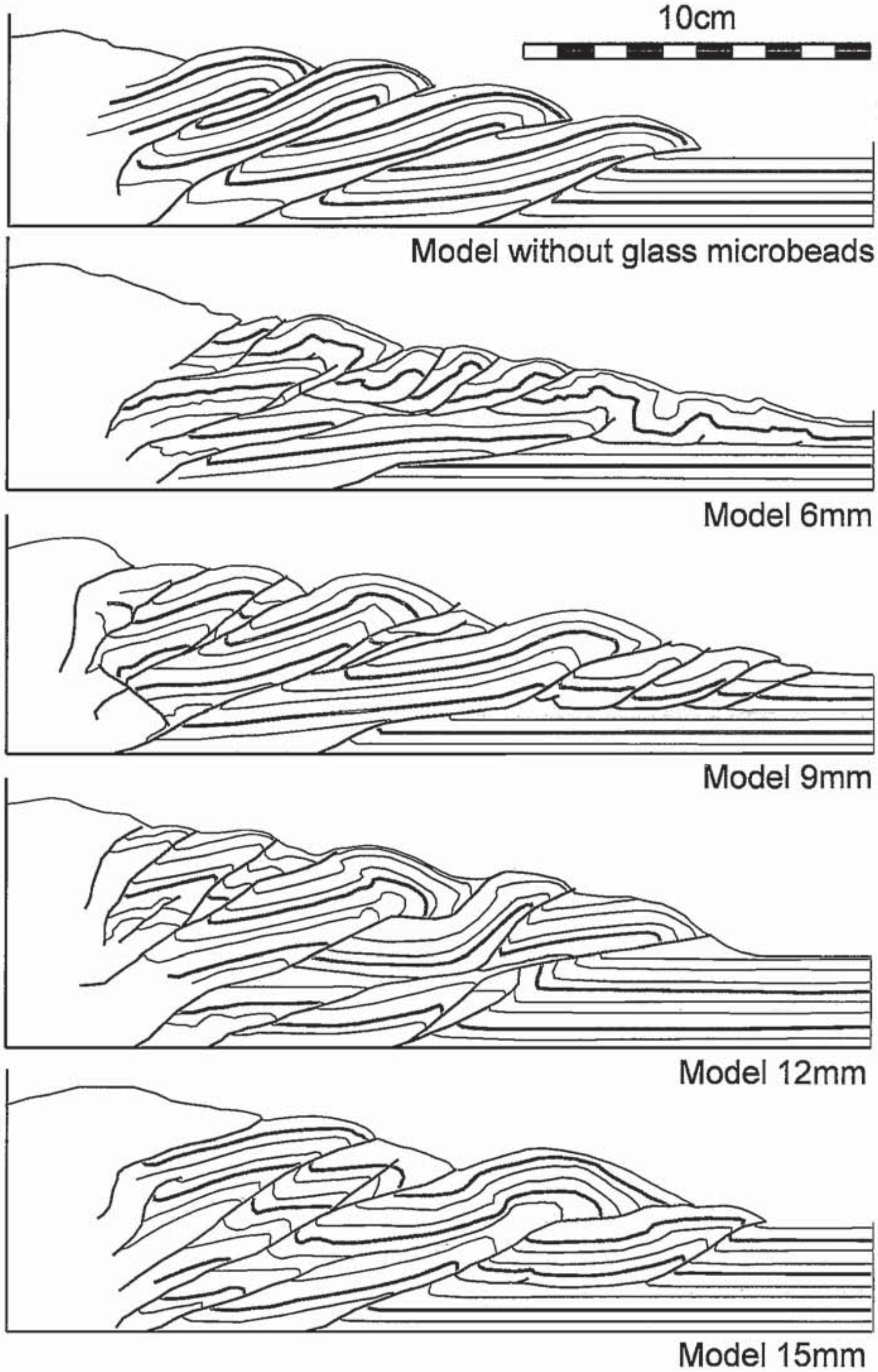

Fig.2 - Line drawing of cross-sections cut parallel to the tectonic transport direction at the end of the experiments (redrawn from photos). The glass microbeads layer in Models 6, 9, 12 and 15mm is highlighted by a grey pattern. The scale is the same for all the models.

Fig. 2.- Secciones cortadas paralelamente al transporte tectónico, al final del experimento (dibujadas a partir de fotografías). Las microesferas de vidrio aparecen con trama de grises en los Modelos 6, 9, 12 y 15mm. La escala es la misma para todos los modelos.

deformation at shallow crustal levels (e.g. Davy and Cobbold, 1991). Coloured sand was used to provide horizontal passive markers within the undeformed experimental multilayer. Glass microbeads were used to introduce a mechanical heterogeneity in the sandpack. They have a grain size of 0.2 -0.3 mm and show a coefficient of internal friction about 23%-30% less than that of sand (Shellart, 2000; Turrini *et al.*, 2001; Kukowski *et al.*, 2002). The experiments were performed in sandbox with two side walls which permit the observation of the progressive deformation (Fig. 1). A drafting film sheet floored the sandbox, and both the sand and the glass microbeads were sieved above the sheet. The drafting film sheet was pulled at a constant rate of 10cm/h by an electric motor, causing collision of the undeformed multilayer against the rigid, vertical backstop (Fig. 1). This forced collision induced the growth of a Coulomb wedge in the sandpack. Total shortening was approximately constant in all experiments, between 40 and 50% of the undeformed length of the sandpack. The changing geometry was recorded by time lapse photography of the sidewalls. After completion, each model underwent serial sectioning parallel to the shortening direction.

A series of experiments have been realized with an initial sandpack of 22cm wide and 60cm long. All the experiments included a 9mm thick sand layer at the bottom of the sandpack, overlaid by a 3mm thick layer of glass microbeads. The resultant geometry varied according to the thickness of the sand sieved above the microbeads. In the series of experiments presented in this paper, the uppermost sand layer thicknesses are 6, 9, 12, and 15mm (Models 6, 9, 12 and 15, respectively). Accordingly, the total thickness of the initial sandpack is 18, 21, 24 and 27mm, respectively.

Effects of mechanical heterogeneity on deformation style

Representative cross-sections of the finite deformation geometry of the thrust wedges are illustrated as line drawing in Figure 2. For comparison, in the upper part of the same figure, a cross-section of a model realized only with sand has been drawn. In this model, the evolution of thrust wedge growth is similar to that of a typical Coulomb wedge in which the foreland-verging imbricates were accreted in a piggyback fashion (e.g. Mulugeta, 1988; Liu *et al.*, 1992). By contrast, shortening of the models which include a layer of glass microbeads is strongly affected by this latter (Models 6, 9, 12 and 15mm, Figure 2). The presence of the mechanical heterogeneity defines two structural levels: a) a lower sequence where first-order imbricates detached at the base of the sandpack, and b) a roof sequence in which smaller, second-order imbricates and folds developed. Decoupling took place along the upper boundary of the glass microbeads level. Indeed, it can be observed in the frontal part of the models that the thrusts which affect the upper sequence are rooted along this boundary (in particular models 6, 9 and 15mm of Figure 2). Consequently, the lower sequence can be considered as a duplex: its lower thrust is represented by the detachment situated at the base of the sandpack, meanwhile its roof thrust is drawn by the upper boundary of the microbeads layer. It must be stressed that decoupling is more pronounced when the thickness of the upper sand layer is smaller. In Models 6 or 9mm, thrusts which affect the roof sequence are relatively more frequent than in Models 12 or 15mm. Moreover, in these latter, thrusts which cut the whole sandpack are more widespread, in a similar way to the model without mechanical heterogeneity.

Decoupling development

The progressive deformation of a representative model with mechanical heterogeneity is illustrated by line drawing for various amounts of shortening (t_1 to t_3 of Model 6mm, Figure 3) and by a plot of the distance of the deformation front from the backstop against shortening, for both the upper and lower structural level of the same experiment. Simultaneous folding and thrusting occurred in both levels, and deformation in the roof sequence is favoured by the push-from-behind effect of the lower frontal imbricate. When this latter develops and raises the frontal ramp, it actuates as a buttress and push the roof sequence, which is easily detached from the lower sequence due to the mechanical weakness enhanced by the glass microbeads. As shortening increases and the next lower imbricate develops, it produces not only the passive backrotation of older thrust sheets during the accretion of new material at the toe of the lower sequence, but also the passive folding of the duplex roof thrust (see frontal part of t_1 and t_3 line drawings of Figure 3).

Decoupling is also shown by the systematic monitoring of the distance of the deformation front from the backstop (Figure 3), for both lower and upper sequence. The plot corresponding to the lower part of the thrust wedge shows a typical saw-tooth shape, indicating that its growth occurred through first-order, abrupt widening pulses, separated by longer narrowing periods (Storti and Salvini, 2000). By contrast, the plot which corresponds to the upper structural level shows a less-defined saw-tooth shape, which reflects the more frequent development of second-order folds and thrusts.

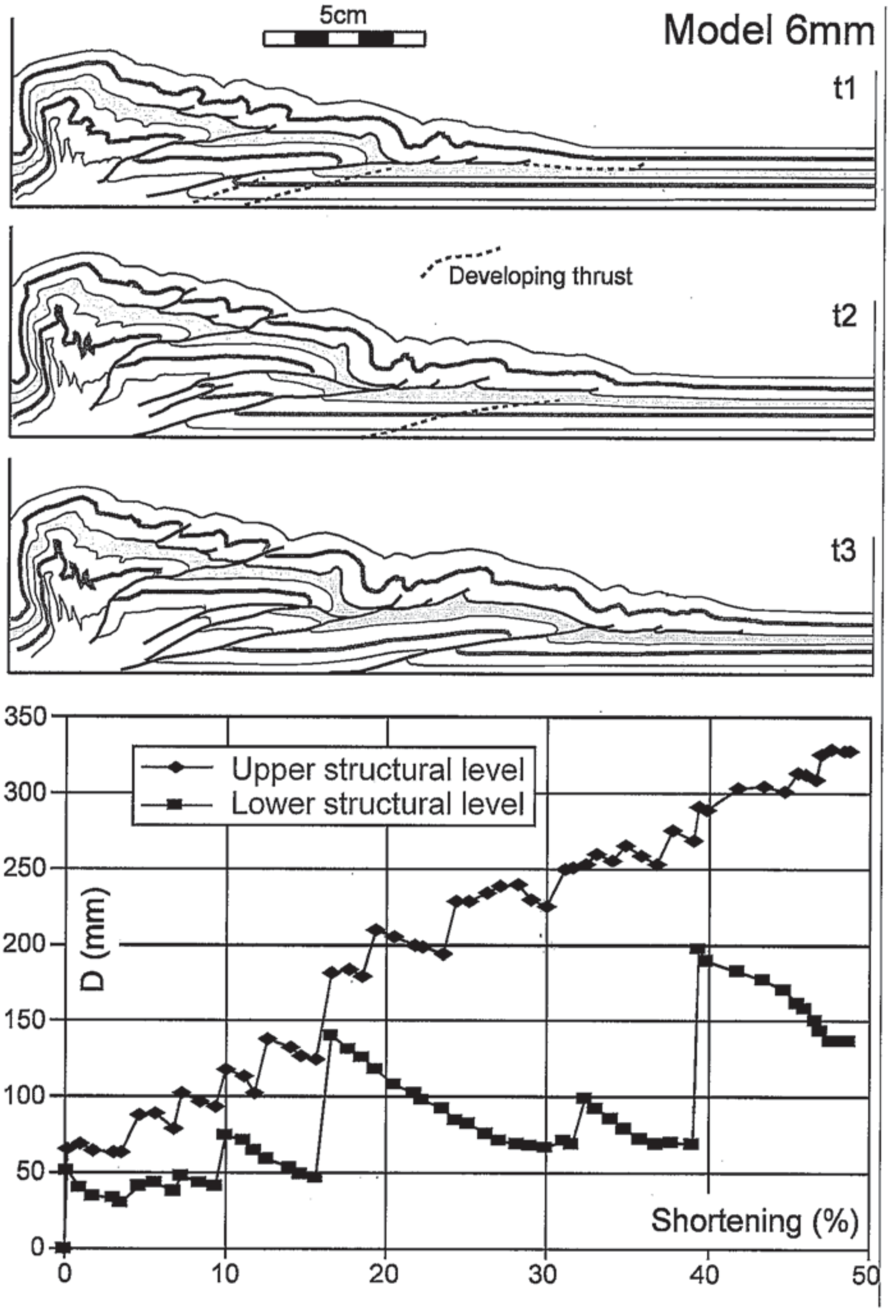

Fig. 3.- Line drawings of lateral view of the experimental apparatus for various amounts of shortening of Model 6mm. Plot: distance of the deformation front from the backstop (D) against shortening for the same experiment.

Fig. 3.- Dibujo del perfil lateral del aparato experimental para varias cantidades de acortamiento para el Modelo 6mm. Diagrama: distancia del frente de deformación al backstop (D) respecto al acortamiento, para el mismo experimento.

Concluding remarks

The sandbox experiments presented in this paper clearly show that within a multilayered sandpack, an intercalated layer of glass microbeads with a lower coefficient of internal friction than that of the sand, is sufficient to produce decoupling. The vertical strength variations, due to the contrast of the mechanical properties between both analogue materials, is a key parameter for producing detachment (Mulugeta, 1988). The models are similar to natural cases of fold-and-thrust belt in which the intervening material are shales, whose analogue in the experiments are the glass microbeads. This material permits to model a foreland-verging duplex, in contrast to the silicone, a viscous material which enhance more symmetrical structures, with the development of major backthrusts and no preferred vergence (e.g. Couzens-Schultz *et al.*, 2003). The very low coefficient of internal friction of the glass microbeads makes it an interesting material for analogue modelling, until now used very scarcely (Turrini *et al.*, 2001; Kukowski *et al.*, 2002). Nevertheless, in the very near future, a detailed study of their physical properties is needed for strength profile calculation and suitable scaling.

Acknowledgments

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