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Reply to comment by J. Wickham on ‘‘Basin inversion and fault reactivation in laboratory experiments’’

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1. Introduction

The comments by Wickham (2007) raise a number of questions about the reliability of the experimental results reported in our paper (Del Ventisette et al., 2006) dealing with basin inversion and fault reactivation processes. We welcome his comments and appreciate the opportunity to clarify our interpretations and starting points of the modelling. It is well know that experimental models must necessarily include some simplifications. On the other hand, such models are useful for visualizing complex geological settings whereas full 3D numerical experiments are still difficult.

Wickham (2007) presents various combinations of dimensionless ratios of length (l^*), viscosity (η^*), density (ρ^*), gravity (g^*) and time (t^*) reported in Del Ventisette et al. (2006) to calculate the dimensionless ratios of fundamental units of mass (M^*), time (T^*) and length (L^*). We agree that the various combinations show different magnitudes of M^*, L^* and T^*, bringing Wickham (2007) to argue that the models fail to simulate natural deformation. More specifically, Wickham (2007) states in his conclusion section that ‘‘in the basin inversion system modelled by Del Ventisette et al. (2006), viscous materials with horizontal density gradients seem to be a central feature in the deformation, so gravity must be included in the scaling parameters’’.

2. Basic simplification principles

Scaling of gravity is a chief issue in physical modelling. In his pioneer work, Hubbert (1937) addressed this topic, showing that since a physical model and its prototype both form at the Earth's surface, they obey the same gravity acceleration, so that we are forced to set the gravity acceleration rate $L^*T^{*-2} = 1$, thereby $L^* = T^{*2}$, or $T^* = L^{*1/2}$. These relations imply that models using a reasonable length ratio would be deformed during an impracticable time span, while models operating in a realistic time span of deformation would have instead unfeasible infinitesimal dimensions. This seems to imply that no realistic physical models can be operated at the Earth's surface.

Following Hubbert (1937) and Ramberg (1967), this difficulty may be, however, circumvented by the consideration that the ‘‘acceleration, in terms of rate of change of velocity, but certainly not in terms of force per unit mass in a body-force field, of most tectonic processes is negligible except, for example, in earthquakes’’ (Ramberg, 1981). In other terms, inertial forces may be neglected in most tectonic processes. This can be shown by estimating the Reynolds number, which is the ratio between inertial forces (F_i) and viscous forces (F_v; e.g., Ramberg, 1981; Weijermars and Schmeling, 1986), $Re = F_i/F_v = \rho v l/\eta$, where ρ is density, v is the velocity, l is length, and η is the viscosity.

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In the models by Del Ventisette et al. (2006), a conservative estimate of this dimensionless ratio may be computed by considering a movement across the in-graben silicone viscous layer (with parameters $l = 0.16$ m; $\rho = 1060\ \mathrm{kg\,m^{-3}}$; $\eta = 10^3$ Pa s) equal to the applied shortening rate ($v = 2.7 \times 10^{-6}\ \mathrm{m\,s^{-1}}$) yielding $Re \approx 4.5 \times 10^{-7}$. This value is ca. 10 orders of magnitude lower than the critical value ($Re = 10^3$; see, e.g., Ramberg, 1967) separating turbulent flow from laminar flow where contribution of inertial forces is small. In nature, Reynolds numbers attain values that are more than 20 orders of magnitude lower than such a critical value. This suggests that inertial forces do not appreciably contribute to the motion. Though model and natural Re are usually dissimilar (thereby preventing a rigorous dynamic similarity), they may be considered to be basically comparable being both sufficiently small.

On this basis, it is argued that no significant error is introduced by ignoring the condition $L^*T^{*-2} = 1 = g^*$ and treating the ratios L^* and T^* as independent variables (Ramberg, 1981), thereby implying that $L^*T^{*-2} \neq 1$. Our modelling procedure has followed such a simplifying assumption, which has represented the basis of our model scaling. Under such conditions, some of the various combinations among fundamental units and dimensionless ratios computed by Wickham (2007, Tables 2–5) may be not strictly applicable. From this follows that the combinations in which the acceleration scaling ratio (such as g^*) has been substituted with L^*T^{*-2} are not appropriate for our simplified system. As an example, the relation $T^* = \rho^* l^{*2}/\eta^*$ (Table 3 in Wickham, 2007) has been obtained by substituting $g^* = L^*T^{*-2}$ in $T^* = \eta^*/\rho^* l^* g^*$, and this results in a scaling ratio of time that substantially differs from our calculation.

The scaling procedure that we have adopted is a method to perform analogue models in the Earth's gravitational field. Although such a scaling method deviates from a strict dynamic similarity, it does not seriously affect the studied process. This concept is corroborated by the impressive number of works conducted in normal gravity which show a remarkable similarity with geologic structures, and which have been successfully used for studying a large variety of complex geological processes. These conditions have been tested for both purely frictional (granular materials) and brittle–ductile models. We therefore imply that, in contrast to the conclusion of Wickham (2007), the undeniable correspondence between models and natural systems is not simply due to the accidental control on deformation exerted by dimensionless variables (angles, strain and coefficient of friction) but to the fact that, through a selection of model materials and boundary conditions, physical models may reproduce the geological processes at a sufficient degree of similarity.

3. Conclusion

We would like to regard the comments raised by Wickham (2007) as a stimulation to reduce modelling simplifications and to attempt using less simplified scaling procedures. Nevertheless, we are still strongly convinced that analogue modelling can provide a valuable input, in combination with numerical and analytical approaches, to the understanding of the complexity of geological and tectonic processes.

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