Buckling an orocline: Supplementary material

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Abstract

The scaling and experimental procedure are detailed. Experiments are detailed.

Introduction

Plate tectonic processes are characterized by very large spatial and temporal scales. Consequently, geological data often provide partial insights into their mechanics, and geodynamic modeling, using either experimental or numerical techniques, is routinely employed to better understand their development in space and time. The experimental modeling technique is particularly efficient to investigate three-dimensional phenomena (Davy and Cobbold, 1991; Bellahsen et al., 2003; Funiciello et al., 2003; Schellart et al., 2003; Cruden et al., 2006; Luth et al., 2010). However, in multiple experimental models, the rheological stratification of the lithosphere is simplified and the strength variations induced by the temperature gradient through the lithosphere are simulated using various analogue materials with different physical properties (Davy and Cobbold, 1991; Schellart et al., 2003; Cruden et al., 2006; Luth et al., 2010). A drawback of this simplification is that the mechanical properties are retained throughout the entire experiment regardless of temperature variations associated with vertical displacement.

Experimental modeling with temperature-sensitive analogue materials allows incorporating these temperature variations and their mechanical consequences (Turner, 1973; Jacoby, 1976; Jacoby and Schmeling, 1982; Kincaid and Olson, 1987; Chemenda et al., 2000; Rossetti et al., 2000, 2001, 2002; Wosnitza et al., 2001; Boutelier et al., 2002, 2003, 2004; Boutelier and Chemenda, 2008; Lujan et al., 2010). A conductive temperature gradient imposed in the model lithosphere controls the rheological stratification prior to deformation (Boutelier et al., 2002, 2003, 2004). During deformation, heat is naturally advected and diffused so that temperature and strength change with time in various parts of the model lithosphere (e.g. in the subducted lithosphere). However, due to the complexity of the thermo-mechanical analogue modeling technique, most thermo-mechanical models used a two dimensional approximation.

Methods

General setup

Scaling

The Buckingham or π-theorem provides a method for computing sets of dimensionless parameters from given variables, even if the form of the equation remains unknown. However, the choice of dimensionless parameters is not unique; Buckingham's theorem only provides a way of generating sets of dimensionless parameters and does not indicate the most physically meaningful.

Two systems for which these parameters coincide are called similar (they differ only in scale); they are equivalent for the purposes of the equation, and the experimentalist who wants to determine the form of the equation can choose the most convenient one. Most importantly, Buckingham's theorem describes the relation between the number of variables and fundamental dimensions.

In mathematical terms, if we have a physically meaningful equation such as

$$f(q_1, q_2, \ldots, q_n) = 0 \tag{1}$$

where the q_i are the n physical variables, and they are expressed in terms of k independent physical units, then the above equation can be restated as

$$F(\pi_1, \pi_2, \ldots, \pi_p) = 0 \tag{2}$$

where the π_i are dimensionless parameters constructed from the q_i by $p = n - k$ dimensionless equations of the form

$$\pi_i = q_1^{a_1} q_2^{a_2} \ldots q_n^{a_n} \tag{3}$$

where the exponents a_i are rational numbers.

For example consider the advection-diffusion of heat in a moving medium. the parameter to consider are length, l, velocity, u, time, t, temperature, T, and thermal diffusivity, κ. We have 5 parameters but only 3 independent dimensions since the dimension of u can be expressed as a combination of the dimensions of l and the dimension of κ can be expressed as a combination of the dimensions l and t. It is therefore only required to find $5 - 3$ dimensionless ratios of the 5 parameters. The ratio of the rates of advection and diffusion yields the Peclet number

$$P_e = \frac{ul}{\kappa} \tag{4}$$

and time can be included in the dimensionless ratio:

$$Const = \frac{ut}{l} \tag{5}$$

Table 1: Different quantities and qualities of T_{shell}

Heading	r_c (km)	T_{shell} (s)	t_{waves} (s)	$\mathcal{M}$	ω_c (rad/s)	P_{min} (s)	$P_{\text{min,Fe}}$ (s)	$P_{\text{min,NS}}$ (s)
Row	1.6×10^7	4×10^{13}	2×10^5	0.06	3×10^{-6}	2×10^5	40	2×10^{-3}
Row	9.7×10^3	3×10^8	10^6	0.002	4×10^{-3}	2×10^3	50	2.5×10^{-3}
Row	3.6×10^3	4×10^6	10^5	0.004	2×10^{-2}	-	-	-
Row	1.7×10^3	7×10^3	2×10^3	0.02	4×10^{-1}	-	-	-

Analogue materials

Particle Imaging Velocimetry

Principles

Cumulative displacements

Experimental results

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$$\int_a^b u \frac{d^2 v}{dx^2}\, dx = u \frac{dv}{dx}\bigg|_a^b - \int_a^b \frac{du}{dx} \frac{dv}{dx}\, dx. \tag{6}$$

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