Journal of Structural Geology 31 (2009) 1074–1083

Contents lists available at ScienceDirect

Journal of Structural Geology

journal homepage: www.elsevier.com/locate/jsg

Constraining neotectonic orogenesis using an isostatically compensated model of transpression

Scott Giorgis*, John Tong[1], Robert Sirianni[2]

Department of Geological Sciences, SUNY-Geneseo, 1 College Circle, Geneseo, NY 14414, USA

ARTICLE INFO

Article history:
Received 29 May 2008
Received in revised form
12 February 2009
Accepted 13 February 2009
Available online 4 March 2009

Keywords:
Transpression
Strain
Isostasy
Erosion
Alpine fault
New Zealand
Central Range fault
Trinidad

ABSTRACT

Current models of transpression allow upward flow of material to compensate for shortening in the horizontal plane. We present an isostatically compensated model of transpression, where material is allowed to flow both upwards to create topographic relief and downwards to form a crustal root. Our model also incorporates the effects of erosion to more accurately examine the developing topography in orogenic systems. The modeling results suggest that topographic relief and crustal root thickness developed in transpressional orogens are most dependent on the magnitude of shortening, the initial thickness of the crust, and the density contrast between the crust and mantle. In contrast, the rate of convergence and final width of the deformed zone are relatively unimportant parameters in this model. Application to the Alpine fault system in New Zealand, a well-constrained active transpressional plate boundary, shows good agreement between topography-based model estimates of shortening and those derived from plate reconstructions. Application of our model to the Central Range fault zone in Trinidad suggests 2 ± 1 km of neotectonic shortening. The strain analysis approach presented here may be useful for isolating the effects of modern deformation in a region that has reactivated an ancient contractional belt.

1. Introduction

There is a well established interaction and feedback between landscape evolution and tectonic convergence (e.g. Willett, 1999; Willett and Brandon, 2002). In active mountain belts, an intuitive relationship exists between the amount of shortening and the topographic relief of an orogen. For example, the convergence along the Alpine fault (e.g. Walcott, 1998) that created the Southern Alps is much greater than that responsible for the rolling hills of the central Coast Ranges in the San Andreas fault system (e.g. Argus and Gordon, 2001). This relationship occurs throughout the San Andreas system where changes in the fault orientation along strike change the relative rates of convergent vs. strike-slip motion. Those areas that experience greater rates of convergent motion tend to be characterized by greater topographic relief; conversely, those areas dominated by strike-slip motion tend to have lower relief (e.g. Argus and Gordon, 2001; Spotila et al., 2007).

Obliquely convergent orogens such as the Alpine fault or the San Andreas fault zones are typically modeled as transpressional systems (e.g. Little et al., 2002; Teyssier and Tikoff, 1998). Transpression involves simultaneous strike-slip and convergent motion in a horizontal plane coupled with vertical elongation to compensate for the horizontal shortening (Fig. 1). In most models of transpression, vertical elongation is accommodated by movement of material upwards towards the Earth's surface (e.g. Sanderson and Marchini, 1984; Robin and Cruden, 1994; Thompson et al., 1997; Dewey et al., 1998). Application of transpression to the plate boundary scale leads to the development of topography, but this topography must be balanced by isostatic compensation (e.g. Stüwe and Barr, 1998). Additionally, the topographic relief created by convergence is continuously reduced by erosion, resulting in a feedback between isostatic and erosive affects (e.g. Stüwe and Barr, 1998). Therefore development of a quantitatively meaningful relationship between tectonic convergence and topographic relief requires a model of transpression that incorporates both isostatic compensation and erosion.

In this contribution, we present a model of transpression that links topographic relief and crustal root formation to tectonic shortening by incorporating both isostasy and erosion. We focus

* Corresponding author. Tel.: +1 585 245 5293.
E-mail addresses: giorgis@geneseo.edu (S. Giorgis), jjtong@gmail.com (J. Tong), rsirianni@ufl.edu (R. Sirianni).
[1] Present address: The Department of Geology & Geophysics, Texas A&M University, College Station, TX 77843-3115, USA.
[2] Present address: University of Florida, Department of Geological Sciences, 241 Williamson Hall, P.O. Box 112120, Gainesville, FL 32611, USA.

0191-8141/$ – see front matter
doi:10.1016/j.jsg.2009.02.003

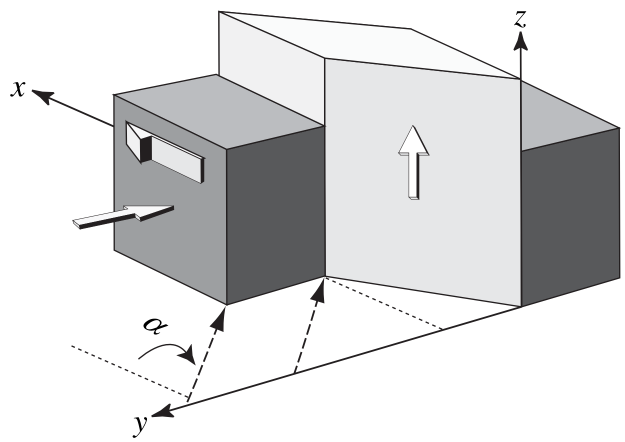

Fig. 1. Transpression results in wrenching parallel to plate margin (*x*-axis), shortening across shear zone (*y*-axis), and vertical extrusion (*z*-axis).

on transpressional settings because tectonic contraction is most often accommodated on obliquely convergence boundaries (e.g. Dewey et al., 1998). Moreover, the pure shear nature of convergence in transpression allows for the development of straightforward relationships between shortening, topography, crustal root formation, and erosion. Previous studies have developed more complex simulations of these relationships that include additional variables to model a variety of processes. For example, Beaumont et al. (1992) investigated the orographic effects of rain shadows. Koons (1994) examined the interaction of shortening, mountain building, and erosion in the context of a three-dimensional critical wedge. Willett (1999) explored the effects of climate, rock erodibility, and precipitation rate using a finite element model. Willett and Brandon (2002) examined steady vs. non-steady-state evolution of mountain belts. The model presented here complements these more complex investigations in two ways. First, these more complex models do not investigate the effects of isostatic compensation and erosion in oblique convergence using the simple kinematic framework of transpression. Second, our model provides a simple method for using widely available data sets (elevation and/or gravity) to generate first-order estimates of shortening in neotectonic, transpressional settings.

2. Numerical model

Fig. 2 outlines our approach to integrating isostasy and erosion into transpression. We begin with an initially undeformed block of continental crust. This crustal block starts at an isostatic equilibrium position governed by its initial thickness. The top of this block is flat and at an elevation equal to base level (i.e. sea level for many orogens). Shortening thickens the crustal block, which changes the equilibrium position. The increased thickness results in the formation of topographic relief and a supporting crustal root. The development of topographic relief in the orogen results in erosion. Lastly, removal of material from the deformed zone by erosion reduces crustal thickness, changing again the equilibrium position of the deformed crustal block. This four-step process – deformation, isostatic compensation, erosion, isostatic rebound – is used to investigate the progressive development of topography and crustal root thickness.

Although transpression involves three-dimensional flow, evaluation of isostasy and erosion can be accomplished with a two-dimensional model. In transpression, the amount of vertical elongation is solely a function of the amount of horizontal shortening (Sanderson and Marchini, 1984). Exclusion of the transcurrent component of deformation allows the model to only consider the two-dimensional contractional component of deformation. Moreover, modifications to include the effects of isostatic compensation and erosion are one-dimensional because only the vertical component of flow is altered by these factors.

A strict interpretation of our sequence of operations results in the material points rising first due to contraction, then sinking due to isostatic forces, and then lastly rising again due to isostatic rebound after erosion (Fig. 2). If we assume that isostatic equilibrium is reached instantaneously (see Section 5.4 for discussion), then in the natural world all of these processes operate simultaneously. The step-wise approach taken here only approaches the actual simultaneous nature of these processes if the steps are sufficiently small. In development of the model step sizes ranging from 1000 yrs/step to 100,000 yrs/step were investigated. The model results stabilized at approximately 20,000 yrs/step, indicating that artifacts due to the step-wise approach were no longer significant in this time frame. Further reduction to a 1000 yrs/step increases computation time, but did not change model results. All results presented here use a step size of 10,000 yrs/step or less.

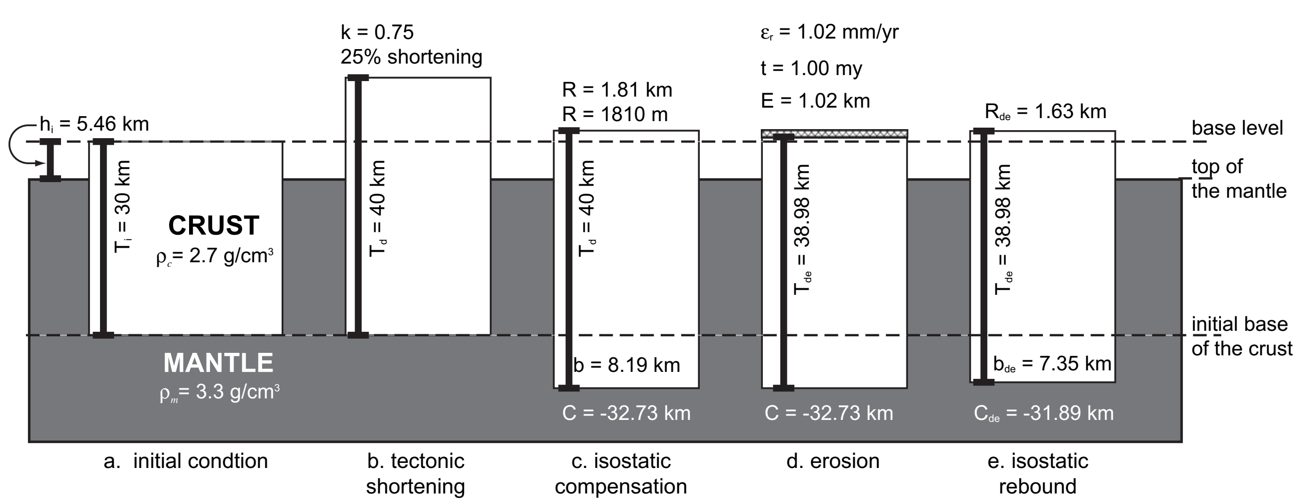

Fig. 2. Schematic diagram showing the four-step process used to incorporate isostatic compensation and erosion in transpression. See text for an explanation of variables.