Cleavage fronts and fans as reflections of orogen stress and kinematics in Taiwan

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ABSTRACT

Recent observations of cleavage patterns, strain histories, and kinematics across the Taiwan mountain belt depict systematic orogen-scale variations with respect to the synorogenic divide and suggest that the pattern of cleavage development is a predictable consequence of orogen stresses and kinematics. In Taiwan, continental crust within the collision is accreted in the prowedge facing Asia, but is advected eastward into the east-verging retrowedge, where the most deeply exhumed rocks are exposed. Wedge mechanics predict a reversal in the direction of plunge of the principal compressive stress at the topographic divide between the opposing wedges. The observation of a single cleavage in western Taiwan suggests that the cleavage in the prowedge remains stable with respect to the stress orientation. In contrast, the existence of a second crenulation cleavage in the retrowedge is evidence for an abrupt change in stress orientation and unstable buckling of preexisting prowedge fabrics. Advection of a fabric across a topographic divide in a doubly vergent wedge provides an explanation for the occurrence of cleavage fronts and fans in natural systems such as Taiwan.

Keywords: cleavage fan, cleavage front, Taiwan, slaty cleavage, incremental strain.

INTRODUCTION

Deformation fabrics are systematically distributed across many active and ancient orogenic belts. At the scale of a mountain belt such as the Pyrenees (Choukroune, 1976) or Taiwan (Stanley et al., 1981; Fisher et al., 2002), cleavage patterns can take the form of a cleavage fan, fabrics on opposing sides of the mountain belt dipping toward an axial zone where cleavage is near vertical. Cleavage first appears in the foreland thrust belt along a front (Fourmarier, 1923, Holl and Anastasio, 1995), in some cases on each side of a mountain belt (Choukroune, 1976). The initial cleavage can be overprinted in the interior of the orogenic belt, resulting in a crenulation cleavage front (e.g., the Taconic allochthon; Chan et al., 2000). A cleavage orientation reflects specific stress and deformational conditions, and the common occurrence of regional-scale cleavage fans and cleavage fronts provides an important insight into orogenic stresses and kinematics of rock advection through the stress field.

In this paper we describe cleavage patterns across the Taiwan mountain belt, an active arc-continent collision where numerous studies have documented formation of multiple cleavages and fanning cleavage orientation across the mountain belt (Stanley et al., 1981; Fisher, 1999; Fisher et al., 2002) (Fig. 1). The Taiwan mountain belt is an active collision with convergence rates of 8.2 cm/yr (Yu et al., 1997) and erosion rates of 4–6 mm/yr (Willett et al., 2003; Dadson et al., 2003); there is widespread exposure of fabrics formed and exhumed since onset of collision in the Pliocene, thus permitting comparison to the modern tectonic context.

The mature north-central region of the Taiwan mountain belt is likely close to topographic steady state, where flux of material into the system by offscraping and underplating of continental crust is balanced by erosional removal of material from the surface of the orogen (Willett et al., 2003). In such a system, topography at long wavelength remains steady (Suppe, 1981; Willett and Brandon, 2002), permitting comparison between deformational fabrics and syntectonic topography. Based on this comparison, we argue that the cleavage forms in response to stresses consistent with topography, and that the fanning pattern and occurrence of a crenulation cleavage are reflections of kinematic motion of rock through this stress field.

DOUBLY VERGENT WEDGE TECTONICS IN TAIWAN

The Taiwan mountain belt can be described in the context of doubly vergent orogenic wedge models, in which crust from the continental plate is accreted into an orogenic wedge, which overlies a subducting plate (Willett et al., 1993) (Fig. 2A). Such an orogenic wedge develops a characteristic geometry in which the wedge tapers in both directions, reflecting a balance between gravitational stresses and basal traction from the underthrusting plates (Davis et al., 1983). Deformation associated with the accretionary flux maintains a low-taper prowedge verging toward the subducting plate, and a higher tapered retrowedge verging in the opposite direction. The crest of the mountain belt represents the transition between these opposing wedges. The topography of Taiwan is consistent with this model, with an asymmetric drainage divide that separates a northwest-facing, narrowly tapered prowedge from a southeast-facing, steeply tapered retrowedge. Crustal structure based on wide-angle seismic data across the Hengchun Peninsula in southern Taiwan shows the doubly vergent wedge structure of the young collision zone (McIntosh et al., 2005). Seismic profiles just south of Taiwan show active back-thrusting of the accretionary wedge over the forearc basin (Reed et al., 1992), and seismic tomography based on teleseismic data shows evidence for a subducting Asian slab in central Taiwan (Lallemand et al., 2001; Lin, 2002). In

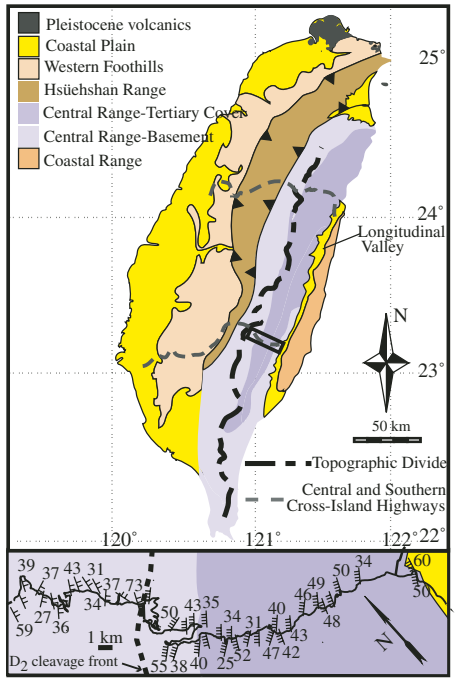

Figure 1. Top: Geologic map of Taiwan showing major tectonostratigraphic units, position of two cross-island transects, and drainage divide for Taiwan. Bottom inset shows map of cleavage orientations for Southern Cross Island Highway (two and four tick marks for slaty and crenulation cleavage, respectively).

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