沿聚合板塊邊界的伸張造山活動：自臺灣活動造山帶的啟發

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摘要

晚期脆性伸張作用是造山帶中普遍的特徵，但在造山過程中所扮演的角色仍存在爭議。它與地殼增厚、地形構造、盆地填充及岩石剝蝕抬升的時間關係決定是否為造山發育的主要因素，亦或者僅是造山發育過程所引起的近地表次生效應。本研究透過和平地區拉張脈中填充物的地球年代學結果及同碰撞沉積紀錄，研究臺灣弧陸碰撞活動的構造演化。岩石剝蝕抬升與磨礫層沉積的加速沉積時期與大約在 1.6Ma 脆性拉張構造形成的時期吻合。臺灣山地的地形起伏是在增厚造山帶的上部地殼轉為伸張作用而形成，且造山活動時造成的抬升是產生磨礫石的重要條件。因此，同碰撞脆性伸張構造被認為可能是促進剝蝕抬升和山地形成的因素。

關鍵字：伸張構造、年代學、造山作用 、剝蝕抬升

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Extensional mountain building along convergent plate boundary: Insights from the active Taiwan mountain belt

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ABSTRACT

Late brittle extension is a common feature in orogenic belts, and its role in mountain building processes is still the subject of debate. Its timing relationship with crustal thickening, the building of topography, basin infill, and rock exhumation are of key importance in determining whether it is a major factor in orogenic development or merely causes near-surface secondary effects. We examined this question in relation to the active arc-continent collision of Taiwan, studying its structural evolution by integrating new and critical geochronological results for tensile vein filling of hinterland metamorphic terrane with syn-collision deposition records. Acceleration of rock exhumation and molasse deposition was found to be coeval with the initiation of brittle tensile structures at ca. 1.6 Ma, which was long overdue as continental subduction started well before 6.5 Ma in central to northern Taiwan. The topographic mountain of Taiwan was thus constructed when the upper crust of the thickened orogenic prism turned extensional, as orographic elevation and relief are prerequisites for molasses production. Syn-collisional brittle extension is therefore proposed as a possible facilitator of both augmented extrusive exhumation and the formation of orography.

INTRODUCTION

Brittle extensional structures are observed in both active and ancient mountain belts, while their function in the structural and topographic development of these orogenic belts has been debated. In addition to inherited rift structures and post-orogenic normal faults that facilitate mountain collapse, syn- and late-orogenic extensional faults and shear fabrics have been well-documented in the hinterland of many orogenic belts as late overprinting structures (Malavieille, 1993; Crespi et al., 1996). Some of these are found, or thought, to have actually formed under a contractional regime as a result of dramatic footwall extrusive exhumation (Searle and Lamont, 2020), while tensile stress was considered to be responsible for others, and enabled extrusive corner flow to core complex-style exhumation of high-grade rocks in the footwall (e.g., Ratschbacher et al., 1989). A major challenge to understanding such extensional deformation is its timing in relation to the constructive phase of orogeny. Gravitational contrast due to overthickened crust (Platt et al., 2015) in regions of pronounced topographic and structural relief is often thought to be the cause (Long et al., 2015); the implication is that the normal faults are a late post-collisional feature that followed the establishment of orography and eventually led to the collapse of mountainous geomorphology (Dewey, 1988). For large-scale orogenic events, deep crustal or lithospheric reconfigurations have been proposed to cause shallow normal faulting during or even immediately before topographic rise, such as delamination of overthickened lithospheric root (Molnar et al., 1993) or lower crustal flow (Royden et al., 2008) in the formation of the Tibetan Plateau. Exact ages of these brittle extensional structures, relative to orogenic and orographic buildup, are usually unavailable due to the lack of datable mineral growths or methodological resolution. The ongoing mountain building of the Taiwan island, under a clear arc-continent collision framework (Suppe, 1981; Teng, 1990), serves as an ideal laboratory for examining the temporal relationships among normal faulting, orogenic shortening, crustal thickening, and topographic development. We analyze the deformational history of Taiwan with key geochronological constraints on a late brittle extensional system at the Hoping locality in the metamorphic hinterland, which are then integrated with regional thermochronologic and foreland sedimentation records to illuminate a direct correlation between the normal faulting and foreland molasse formation. Syn-orogenic, upper-crustal normal faulting is proposed to account for both hinterland exhumation and orographic relief buildup.

THE TAIWAN OROGENIC SYSTEM

Following total consumption of the South China Sea along the Manila Trench, the passive Chinese continental margin was incorporated into the subduction zone, causing shortening within the overriding Philippine Sea plate through forearc closure that caused the Luzon Arc to impinge on the evolving orogenic prism in the arc-continent collision (Malavieille et al., 2002). At present, the plate convergence is ~80 mm/yr in the northwest direction (e.g., Lin et al., 2010). Due to the obliquity between the northeast-trending Chinese continental margin and the near-longitudinal Manila subduction system, the Taiwan mountain building process propagates southward with a characteristic spatiotemporal correlation of orogenic development in which the southern, central, and northern parts of the island are currently in the initial-, full-, and post-collisional stages, respectively (Suppe, 1981; Shyu et al., 2005). Most of the island outcrops the bulldozed Chinese continental margin, from the frontal filled foreland basin (Coastal Plain) and fold-thrust upper margin cover series (Western Foothills) in the west, to the metamorphosed lower margin cover sequences (Slate belt) and basement (Tananao Metamorphic Complex) in the crest and eastern hinterland.

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