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Compressional intracontinental orogens: Ancient and modern perspectives

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A B S T R A C T

Compressional intracontinental orogens are major zones of crustal thickening produced at large distances from active plate boundaries. Consequently, any account of their initiation and subsequent evolution must be framed outside conventional plate tectonics theory, which can only explain the proximal effects of convergent plate-margin interactions. This review considers a range of hypotheses regarding the origins and transmission of compressive stresses in intraplate settings. Both plate-boundary and intraplate stress sources are investigated as potential driving forces, and their relationship to rheological models of the lithosphere is addressed. The controls on strain localisation are then evaluated, focusing on the response of the lithosphere to the weakening effects of structural, thermal and fluid processes. With reference to the characteristic features of intracontinental orogens in central Asia (the Tien Shan) and central Australia (the Petermann and Alice Springs Orogens), it is argued that their formation is largely driven by in-plane stresses generated at plate boundaries, with the lithosphere acting as an effective stress guide. This implies a strong lithospheric mantle rheology, in order to account for far-field stress propagation through the discontinuous upper crust and to enable the support of thick uplifted crustal wedges. Alternative models of intraplate stress generation, primarily involving mantle downwelling, are rejected on the grounds that their predicted temporal and spatial scales for orogenesis are inconsistent with the observed records of deformation. Finally, inherited mechanical weaknesses, thick sedimentary blanketing over a strongly heat-producing crust, and pervasive reaction softening of deep fault networks are identified as important and interrelated controls on the ability of the lithosphere to accommodate rather than transmit stress. These effects ultimately produce orogenic zones with architectural features and evolutionary histories strongly reminiscent of typical collisional belts, suggesting that the deformational response of continental crust is remarkably similar in different tectonic settings.

Contents

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1. Introduction

Conventional plate tectonics theory views orogenesis as the product of interaction between rigid lithospheric plates whose motions are modulated by forces originating in the underlying viscous mantle (e.g. Tackley, 2000; Schubert et al., 2001; Bercovici, 2003; Kearey et al., 2009). Orogenic settings are thus largely confined to plate boundaries and their immediate vicinity (e.g. Dewey and Bird, 1970; Bott and Dean, 1973). There is growing recognition, however, that deformation of the continental lithosphere may extend for considerable distances away from active plate boundaries. The formation and inversion of intracratonic sedimentary basins have been well-documented worldwide, with primary instances including the European Alpine foreland (e.g. Ziegler et al., 1995; Cloetingh and Van Wees, 2005) and the North American craton (e.g. van der Pluijm et al., 1997; Marshak et al., 2000). Detailed mapping of lithospheric stress orientations (e.g. Zoback, 1992; Hillis and Reynolds, 2000; Heidbach et al., 2010), and the detection of widespread intraplate seismicity (e.g. Kenner and Segall, 2000; Sandiford et al., 2004; Banerjee et al., 2008; Omuralieva et al., 2009) and dynamic topography (e.g. Mitrovica et al., 1989; Russell and Gurnis, 1994; Gurnis et al., 1998; Lithgow-Bertelloni and Silver, 1998; Sandiford, 2007) have also revealed that continental interiors continually undergo active deformation.

While these examples demonstrate that crustal deformation commonly occurs remote from plate boundaries, the existence of large-scale compressional orogens in such settings is comparatively rare. In the modern Earth, they are prominently represented by the widespread terranes of central Asia (Fig. 1A), including the Tien Shan and Altai (e.g. Molnar and Tapponnier, 1975, 1977; Abdrakhmatov et al., 1996; Yang and Liu, 2002; Cunningham, 2005; Buslov et al., 2007). In the ancient Earth, arguably the best examples are found in the Arunta Region (Alice Springs Orogen) and Musgrave Province (Petermann Orogen) of central Australia (Fig. 1B), which preserve a remarkable record of intracontinental deformation spanning the Neoproterozoic and Phanerozoic (e.g. Lambeck, 1983; Hand and Sandiford, 1999; Camacho and McDougall, 2000; Aitken et al., 2009a,b; McLaren et al., 2009; Raimondo et al., 2010). Despite their apparent incongruence with the notion of locally-derived tectonic forces, these orogenic systems involve levels of shortening, crustal thickening and exhumation comparable to their plate-margin counterparts. In order to comprehend their existence, therefore, the origins and characteristics of compressive stresses capable of producing significant intraplate mountain belts must be explained.

The intent of this review is to elucidate and critically analyse various hypotheses for the formation of compressional intracontinental orogens. It will begin with a discussion of the sources of stress in intraplate settings, and consider possible stress transmission mechanisms and their relationship to rheological models of the continental lithosphere. It will then investigate the means by which such stresses, once present, may be localised or amplified to generate significant crustal deformation. Finally, the characteristic features of intracontinental orogens will be addressed, along with their relationship to the proposed mechanical and thermal framework for mountain building. Throughout this discussion, specific insights will be referred to the intracontinental provinces of central Asia and central Australia, in order to highlight their relevance and provide appropriate context. Such inferences may also be relevant to analogous compressional intraplate terranes such as the Borborema Province, northeastern Brazil (e.g. Tommasi et al., 1995; Vauchez et al., 1995; Tommasi and Vauchez, 1997; Neves, 2003); the Sevier–Laramide Orogen, western North America (e.g. Livaccari, 1991;

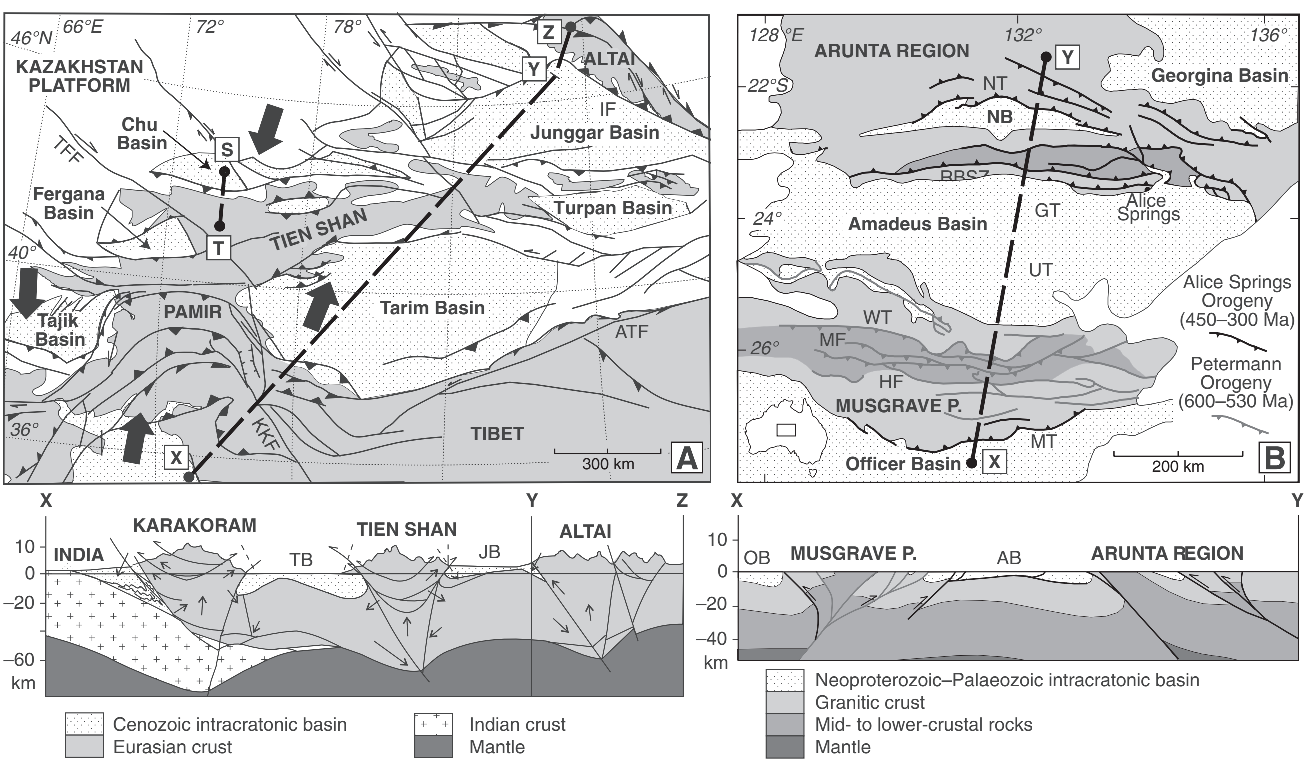

Fig. 1. (A) Regional map and cross-section (X–Y–Z) indicating the major structural features and lithospheric architecture across the central Asian intracontinental terranes, including the Tien Shan and Altai. Black arrows represent the direction of compression driven by the India–Eurasia collision. Line S–T represents the location of the seismic tomography profile shown in Fig. 12. Abbreviations: ATF, Altyn Tagh Fault; IF, Irtysh Fault; JB, Junggar Basin; KKF, Karakoram Fault; TB, Tarim Basin; TFF, Talas-Fergana Fault. (B) Regional map and cross-section (X–Y) of central Australia, showing key structural relationships of the Petermann and Alice Springs Orogens and the distribution of basement and cover regions. The Amadeus, Officer, Georgina and Ngalia Basins form dismembered fragments of the Centralian Superbasin (see Fig. 15B). Also shown are the locations of axial orogenic zones containing mid- to lower-crustal rocks. Abbreviations: AB, Amadeus Basin; GT, Gardiner Thrust; HF, Hinckley Fault; MF, Mann Fault; MT, Munyarai Thrust; Musgrave P., Musgrave Province; NB, Ngalia Basin; NT, Napperby Thrust; OB, Officer Basin; RBSZ, Redbank Shear Zone; UT, Uluru Thrust; WT, Woodroffe Thrust. Figure part (A) modified from De Grave et al. (2007); part (B) modified from Sandiford and Hand (1998).