Extending a Continent: Architecture, Rheology and Heat Budget

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Extending a Continent: Architecture, Rheology and Heat Budget

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Preface

This book is the outcome of a Penrose Conference (8–12 October 2007) that examined processes that contribute to horizontal extension of continental lithosphere and the origin of oceanic basins. Over the last three decades, there has been a growing appreciation of the role of extensional tectonics in convergent orogens and **Wernicke**'s Introduction to this book provides a flavour of how this era changed our views on tectonometamorphic relationships in orogenic belts. This trend was initiated by the discovery of highly attenuated crustal sections in the Basin and Range province and the recognition that the attenuation was caused by regional-scale horizontal extension, as manifested by low-angle normal faults or detachments. Soon afterward extensional detachments were recognized as a global phenomenon in most orogens. The Aegean Sea is another well-known example of an orogen that has been extremely modified by large-scale continental extension. The majority of papers of this volume are devoted to the Aegean extensional province. Horizontal extension in the Aegean occurs directly above the Hellenic subduction zone and affects the forearc as well as the backarc region. Lithospheric extension in the Aegean is widely thought to be caused by slab rollback and started across the entire area rather abruptly at the beginning of the Miocene.

New research frontiers in the field of continental extensional tectonics are seen in the application of geodesy for addressing steady/non-steady-state behaviour of the lithosphere during extension. Ideally the emerging new results from this approach should be combined/compared with studies on deeply exhumed fossil extensional complexes. A key issue in the latter is to merge our understanding and gain more information on the exact timing of deformation with magmatic, metamorphic and tectonic microstructures. A general problem is that the new developments and achievements in numerical modelling far outstrip natural observations, stressing the importance of more and detailed field-based research in much closer interaction with numerical models than has previously been done.

The volume contains 11 papers. The opening contribution by **Wernicke** provides a historic view our ideas about large-scale tectonic contacts in mountain belts have changed over the years. Wernicke concludes that controversy still persists over the existence and mechanics of slip on shallowly dipping extensional detachments.

Boulton *et al.* address this issue. They summarize recent geological, experimental, and numerical research into the frictional behaviour of rocks. They posit that dynamic fragmentation in granular fault cores may result in low static and dynamic frictional strengths, thereby allowing faults to fail under low resolved shear stresses.

Marotta *et al.* report a 2D thermo-mechanical modelling study that aims at reducing the ambiguity on the geodynamic significance of Permotriassic high-temperature/low-pressure metamorphism, igneous activity and sedimentary records in the pre-Alpine continental crust in the Alps. The modelling predictions are compared with: (1) Peak PT conditions of Permotriassic metamorphism in the continental crust of the Penninic and Southalpine domains; (2) mafic intrusions and associated intermediate to acidic magmatism occurring mainly in the Austroalpine and Southalpine domains; and (3) structural and volcanic activity and coeval formation of sedimentary basins. The agreement between field data and model predictions supports the idea that large-scale lithospheric extension was responsible for the Permotriassic geological record in the Alps. The authors develop a model of bottom-up periodic strain localization at 5–10 Ma intervals that are comparable with volcanic pulses, episodic basin deepening, periodic sedimentary facies fluctuations and related episodic faulting.

Stern compares short- and long-term deformation in the Central Volcanic Region in central North Island of New Zealand. Both rotation and translation of the backarc can be described by observations of volcanic arc migration, GPS, geodesy and paleomagentism. Short- (10 years) and long-term (5Ma) measures of extension ($6–17\ \mathrm{mm\ a}^{1}$) and rotation (c. $6\ \mathrm{Ma}^{1}$) are surprisingly consistent. Heat flux in the Central Volcanic Region is of the order of 4.3 GW, which when averaged over the region of surface geothermal activity gives an effective heat-flow of c. $860\ \mathrm{mW\,m}^{2}$: a value many times greater than other backarc basins. Stern argues that other continental backarcs have histories of episodic and rapid extension, and that the central North Island is in one of these phases.

Tulloch *et al.* use high precision geochronology to reveal a strong episodicity in silicic magmatism in the interval between cessation of East Gondwana arc magmatism at 105 Ma and rifting of Zealandia at *c.* 83 Ma. They show that both 101 and 97 Ma groups of rhyolites and tuffs occur across the entire width of Zealandia from near the paleotrench to the continental interior, indicating distinct phases of widespread, near instantaneous, and subparallel, extension. The authors interpret these features to be most consistent with rifting being caused either by basal traction on a subducted slab that had been captured and pulled oceanwards by the Pacific plate, and/or southwestwards propagation of a <83 Ma oceanic ridge between Zealandia and West Antarctica.

Skourtsos & Kranis describe the geometry and the kinematics of normal faults exposed onshore along the southern part of the Corinth Rift in Greece, proposing that the southern margin is probably located further to the south of what it is considered to be. They explain the evolution of the Corinth Rift by the presence of a structurally lower detachment fault that soles northward into the estimated detachment zone beneath the Gulf of Corinth.

Thomson *et al.* tackle the controversial question over the origin of metamorphic tectonites in core complexes. The combine structural field data with robust geochronologic ages on mylonitization, fission-track and (U–Th)/He cooling ages and PT data to constrain the timing, kinematics and architecture of extension during exhumation of the Ios metamorphic core complex. Their work corroborates that large-scale extensional deformation in the central Aegean did not commence before the early Miocene.

Ring *et al.* use zircon and apatite fission-track ages from the poorly known Amorgos detachment system in the southeastern Aegean for discussing the role the Amorgos detachment played in the opening of the Cretan Sea basin. The authors argue that the Amorgos detachment is associated with the large-magnitude Cretan detachment and both detachments started moving in the early Miocene. Ring *et al.* also discuss aspects of shortening- and extension-induced normal faults and conclude that the inception of the Amorgos detachment did not result from large-scale horizontal extension of the lithosphere.

Seward *et al.* use a suite of new fission-track ages for revealing the timing of cooling/reheating of the metamorphic sequences on Naxos followed by cooling due to exhumation associated with extension along low-angle shear zones. They show that the late Miocene Naxos granodiorite was intruded into crustal levels where the temperature was already 300 °C as evidenced by the fission-track ages on zircon that are comparable to those obtained from higher temperature chronometers. Differential cooling of the pluton, identified through apatite fission-track ages, is related to either variable depth of emplacement and/or to progressive tectonic exhumation accommodated first by ductile shallow-shear zone and then by high-angle cataclastic faults.

Dilek *et al.* present new geochemical and isotopic data from the syn-extensional granitoid intrusions in the Menderes core complex in western Anatolia, and discuss their petrogenetic evolution in comparison to other late Cenozoic plutons in the Aegean region. Various degrees of partial melting of a mixed source including an enriched mantle lithosphere component and assimilated-melted lower and middle crustal components were responsible for the production of the magmas of these mostly metaluminous, high-K calc-alkaline granitoids. Partial melting of the subduction-metasomatized lithospheric mantle and the overlying crust are interpreted to be triggered by asthenospheric upwelling caused by lithospheric delamination. The authors argue that both slab retreat generated upper plate deformation and magmatically induced crustal weakening played a major role in the onset of the Aegean extension in the early Miocene.

Korja *et al.* describe a Precambrian example of a laterally spreading orogen with the help of large-scale seismic reflection surveys, structural field work and existing geological/geophysical data. As a result of the extensional deformation the exposed bedrock is characterized by networks of orthogonal shear zones and low angle fabrics typically found in deep, lower level sections of core complexes. The authors argue that decoupling of the upper, middle and lower crust during extension resulted in the formation of layered superstructure-infrastructure of the crust.

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