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Tectonic evolution of bi-directional extension in the W. Cyclades

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The Cyclades underwent contemporaneous bi-directional extension, with top-to-northeast movement on the NW-SE oriented E. Cyclades (Andros-Tinos-Naxos) dated to ca. 28 Ma (Oligocene) on Tinos and top-to-southwest movement on the parallel oriented W. Cyclades (Kea-Kithnos-Seriphos) dated to the lower Miocene (21-13 Ma) on Kea. Both sets of islands are characterised by a footwall overlain by a veneer of fault-rocks and/or hanging wall rocks. On Sifnos, an early top-to-northeast high-pressure movement was overprinted by top-to-southwest movement along discrete shear planes. On Kea, the geometry of the fault surface has been constrained only sporadically around the rim of the island, defining a periclinal form with a long-axis sub-parallel to the mean stretching and crenulation lineations, the mean fold-axis orientation and the mean azimuth direction of the foliation and of C'-planes. Mylonitic fabrics within mixed mafic-pelitic schists and calcite-mylonites are overprinted by brittle fractures. The zone of deformation narrowes from several tens of metres to possibly only a few centimetres of crush-breccia. These are all characteristics of metamorphic core-complexes, in which the fault surface is progressively exhumed. Models for the evolution of such structures, using either the initial low-angled fault geometry model (Wernicke 1985; Can. J. Earth Sci.) or the rolling-hinge model (Buck 1988; J. Struct. Geol.) cannot be easily applied since the two chains of islands, with their opposing extensional geometries are separated by only ca. 50 km in the direction of the extensional lineations, with no evidence of the isostatically required footwall uplift at the fault breakaway points. Instead, the model of Chéry (Geology 2001), developed for the Gulf of Corinth, is suggested for the Cyclades. In this, an initial high-angle fault causes a rotation of the local stress field at depth, allowing a low-angled detachment to form at the brittle-ductile transition zone (relatively shallow in a metamorphosed mudstone-limestone succession) dipping in the same direction as and having the same sense of movement as the initial high-angled fault. Essentially co-incident with this, a second major high-angle normal fault develops, conjugate (rift geometry) to the initial high-angle fault. With further extension, a series of conjugate faults form in and thin the upper crust in the footwall of the second high-angled fault. These faults rooted at the brittle-ductile boundary zone, with major block rotation leading to the initially high angle faults attaining a low angle. Throughout the W. Cyclades there are abundant outcrop examples of the interaction of conjugate high-angle ductile to brittle faults with creep on low-angled faults. As a result of thinning of the upper crust, the underlying lithosphere rises isostatically in a domal form. Overall, extension has opposing shear senses, giving 'top-to' movement in the same sense as the second major fault directly in the footwall of that fault (ie the low-angled fault here changes shear-sense), and 'top-to' movement in the opposite sense on the other side of the domed lower crust. Essentially, the upper crust is stretched over the doming lower crust/lithosphere. With cooling and isostatic subsidence, the area below the zone of maximum extension subsides below sea-level.