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Structural investigations along a low-angle normal fault zone (Kythnos, Greece)

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Abstract: Recent field investigations have revealed a high-strain zone in the south of Kythnos (Greece). Massive layers of ultrafine-grained Mn-rich calcitic mylonitic marbles and several generations of cataclasites hint at a high-strain event in the crust and are associated with a low-angle shear zone. We investigate fold-fault-relationships and deformation events preceding and post-dating normal faulting and compare the tectono-metamorphic history with adjacent islands in the Western Cyclades.

Keywords: high-strain shear zone, Kythnos, Aegean, low-angle normal fault

The island of Kythnos is situated in the Aegean Sea, among the Cycladic Islands south of Athens. Geologically it is a part of the Attic-Cycladic crystalline belt. Along with other Cycladic islands, Kythnos has undergone subduction-related high-pressure metamorphism associated with collision-related events during Alpidic orogenesis in the Eocene.

Recent geological and structural investigations have revealed a hitherto undescribed shear zone in the southern region of Kythnos Island.

Regional tectonic setting

The Aegean region is one of the seismically most active regions in Europe. The northward movement of the African plate and its subduction beneath the European plate represents a predominantly compressive regime. However, slab retreat related to the subduction zone at the Hellenic trench south of Crete leads to a southward extension of the Aegean microplate (Bohnhoff *et al.*, 2001; Jolivet, 2001).

In the Eastern Cyclades, metamorphic core complexes exhumed Miocene metamorphic rocks along N to NE directed low-angle normal faults (Lister *et al.*, 1984). South-directed kinematics involving a metamorphic core complex has been observed in the Western Cyclades on the island of Serifos (Grasemann *et al.*, 2004; Iglseder *et al.*, 2006). On Kea, exhumation occurs by means of a large-scale ductile-brittle shear zone involving low angle normal faulting (Müller *et al.*, 2007; Iglseder *et al.*, 2008; Voit, 2008).

Local geological setting and field observations

The rocks of Kythnos Island are commonly assigned to the Attic-Cycladic crystalline belt, a polymetamorphic terrane among the Hellenides. The island is dominated by metasediments-greenschists and albite-chlorite-mica schists intercalated with marbles – and a metagabbroic unit (De Smeth, 1975).

Evidence of Eocene to Miocene greenschist facies metamorphism is prevalent throughout the island. However, relics of an earlier, Eocene, high-pressure blueschist to eclogite facies metamorphic event are also preserved. In layers of ferro-manganoan metasediments (as described by Chrysanthaki and Baltatzis, 2003) garnets and sodium-rich amphiboles are present. Additionally the

metabasites show remnants of magmatic pyroxenes, which in conjunction with their texture seem to imply that these rocks have been less affected by the greenschist-facies overprint. The boudin-like lenses of metagabbroic rocks are commonly enveloped in layers of serpentinitic talc-schists with asbestos veins.

White mica K-Ar dating constrains the greenschist facies metamorphism at around 20-26 Ma (Schliestedt *et al.*, 1994). Geochronology of similar rocks on other Cycladic islands gives corresponding Oligocene to Miocene ages (Bröcker *et al.*, 2004).

Above, layers of epidote-, chlorite-, and albite-schist with intercalated marbles are followed by a conspicuously fine-grained calcitic and probably Mn-rich marble mylonite of up to 10 m thick (in other areas of the island this structurally higher position is occupied by coarse-grained impure marble). Adjacent to this ultramylonitic are various cataclastic layers ranging in deformation grade from protocataclasites to ultracataclasites. Both the underlying marble and the overlying quartzite acted as protoliths, and discrimination based upon compositional variation of the component material can be made. The structurally uppermost unit is a strongly brecciated and hydrothermally altered quartzite.

The island of Kythnos has been subjected to numerous ductile and brittle deformation phases. Most major units are found to be dipping shallowly to the NNE in more northern areas and to the SSW in the southernmost regions. Mineral and stretching lineations are found to strike fairly consistently towards NNE/NE.

The rocks of the greenschist-marble unit show penetrative schistosity and exhibit scc'-fabrics and shear bands both in outcrop and in thin section scale and indicate top to SW-directed deformation. Quartz and gneiss porphyroclasts also show geometries consistent with top to SW-directed kinematics. The schists and marbles show isoclinal folding with subhorizontal axial planes and SW-vergent fold axes.

A map-scale open-folding can be observed as the strata which lie mostly horizontal throughout the island are found to be dipping more steeply to the south in the southernmost regions. This open folding is depicted in the cross-sections drawn by De Smeth (1975).

A massive layer of ultrafine-grained mylonitic marbles at the southern tip of the island hints at a high-strain event in the crust. The ultramylonite is accompanied by cataclasites cutting discordantly through the existing structures. Compositional variations within the cataclasites enable us to distinguish between various generations of cataclastic material. The ultracataclastic layer represents a boundary between the marble mylonite and highly brecciated quartzitic rocks. The study of the quartz crystals in thin section has revealed an abundance of triple-junctions as a result of grainboundary area reduction. This foam structure formed by more or less static recrystallization or annealing stands in sharp contrast to the neighboring extremely fine-grained marble ultramylonites.

The lower unit and the ultramylonitic marble were further overprinted by NW-SE-directed compression (perpendicular to the direction of extension) which led to the folding of the ultramylonitic marble surface into an antiform. Within the marble, buckle folds and fault bend folds give evidence for this compressional event with a subvertical axial plane and an approximately NE-SW-directed fold axis.

Finally, the whole area under investigation was subjected to normal faulting due to further NE-SW directed extension. The high angle conjugated fault systems are often accompanied by iron- and barium-mineralization. The quartzites in particular are strongly overprinted by hydrothermal activity involving ore formation.

Discussion and conclusion

Due to wide-spread overprinting, the precise angle of the shear zone in south Kythnos is difficult to determine. To be classified as a low angle normal fault, the fault zone should exhibit a dip shallower than 30° (Axen, 2007). However the high shear strain that must have acted upon marble to thus reduce its grain size implies large displacement values. The highly fine-grained nature of the mylonitic marble or the partially rounded components in the ultracataclasite may have provided the means for reducing the apparent fault friction, thus enabling movement along an angle lower than the predicted 60°. Furthermore, the low angle normal fault can be correlated to similar major extensional shear zones in the Aegean region, as described on the neighboring islands of Kea and Serifos.

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