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Miocene core complex development and coeval supradetachment basin evolution of Paros, Greece, insights from (U–Th)/He thermochronometry

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ABSTRACT

The Aegean region of Greece hosts a series of crustal-scale extensional detachment systems that have accommodated the southward retreating Hellenic subduction zone. Extension has overprinted and dissected the Alpine nappe pile and locally exhumed Cordilleran-type metamorphic core complexes. On the island of Paros, a low-angle extensional detachment fault separates metamorphic footwall rocks from an unmetamorphosed sedimentary succession of the hanging wall. Basement orthogneisses were extensionally sheared in the footwall of the detachment until after 16 Ma (zircon U–Pb age of a slightly deformed granite), but pervasive ductile deformation had ceased by 7 Ma (zircon U–Pb age of an undeformed rhyolite dike that intrudes gneisses). Apatite and zircon (U–Th)/He ages from the gneisses confirm a period of cooling at rates >100 °C/Ma from 16 to 7 Ma. In the upper-plate, the basal sedimentary unit yields reset detrital apatite (U–Th)/He (DAHe) ages from 17 to 7 Ma and detrital zircon (U–Th)/He (DZHe) ages ranging from 270 to 18 Ma. DAHe ages from the stratigraphically higher fanglomerate units are reset to 10–7 Ma. The DZHe data have a primary thermal signature of 12–7 Ma, but preserve ages up to 113 Ma. The uppermost conglomerates exhibit completely reset DAHe ages of 15–9 Ma and reset DZHe ages from 10 to 8 Ma, with DZHe ages up to 104 Ma. Reset DAHe ages indicate late exposure of the footwall and constrain the depositional age of most sedimentary rocks on Paros to be from 14 to 7 Ma. Unreset DZHe ages preserve thermal signatures from the major Mesozoic–Tertiary tectonic events in the Aegean Region: [1] Cretaceous Pelagonian-type metamorphism; [2] Eocene peak HP metamorphism; and [3] Miocene Barrovian overprinting. Preservation of these signatures indicates long-term upper-plate recycling prior to syn-extensional deposition. The Paros supradetachment basin represents a classic inverted unroofing sequence deposited during progressive core complex exhumation in the Middle to Late Miocene.

1. Introduction

Sedimentary strata deposited in hanging wall basins spatially associated with metamorphic core complexes are commonly interpreted as supra-detachment basin fill without necessarily establishing a clear link between syn-tectonic sedimentation and progressive exhumation of the metamorphic core complex (MCC). Friedmann and Burbank (1995) investigated the anatomy of supradetachment basins in comparison to high-angle fault-bound basins (e.g., Gawthorpe and Leeder, 2000; Leeder and Gawthorpe, 1987) and pointed out distinct and diagnostic differences, such as basin thickness, subsidence history, spatial creation of accommodation space, the location of the depocenter, internal facies distribution, and detrital provenance of basin fill. As MCC development leads to the progressive exhumation of deep-seated rocks from upper to middle crustal structural levels with increasingly higher temperature deformation fabrics, inverted unroofing sequences recorded in the basin stratigraphy of supradetachment basins are often used to link the basin deposits to coeval footwall exhumation (e.g., occurrence of footwall mylonite clasts in the basin stratigraphy). However, while the presence of mylonite clasts might be a diagnostic sign, the co-genetic relationship of upper-plate rocks and MCC formation is often not as straightforward as the simple spatial juxtaposition might suggest and the superposition of basin strata of different ages and tectonic settings cannot be eliminated a priori.

While detrital U–Pb dating is the most widely used isotopic detrital provenance tool based on source rock crystallization ages (e.g., Gehrels, 2000; Ross and Bowring, 1990), the technique has limitations because it does not shed light on the upper-crustal thermal and tectonic history of the source terrane. Thermochronometry has become a powerful tool for constraining the thermal evolution and exhumation of footwall rocks in extensional tectonic settings (e.g., Foster and John, 1999; Stockli, 2005) and reconstructing the

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detrital provenance of extensional and contractional basins using source thermal histories (e.g., Bernet and Spiegel, 2004; Carrapa et al., 2004; Hodges et al., 2005; Najman et al., 1997; Reiners, 2005).

This study employs detailed bedrock and detrital (U–Th)/He thermochronometry to characterize the thermal and temporal development of the lower-plate rocks of the Paros MCC and to elucidate the stratigraphy and tectonic nature of the preserved hanging wall basin in one of the most classic areas for the study of back-arc extension and MCC development. The subduction and accretion-related contractional tectonics and subsequent back-arc extension of the central Aegean region of Greece have been a major focus and have helped shape many fundamental tectonic concepts (e.g., Dewey and Sengör, 1979; Jackson, 1994; Jolivet and Brun, 2010; Le Pichon and Angelier, 1979; Lister et al., 1984; McKenzie, 1978; Ring et al., 2010; Sengör and Yilmaz, 1981; Taymaz et al., 1991). Thermochronometry has been utilized in numerous studies to constrain the timing of extension and MCC formation on many Cycladic islands and shed significant light on their temporal, spatial and thermal evolution (e.g., Brichau et al., 2006, 2007, 2010; Grasemann et al., 2012; Philippon et al., 2012; Ring et al., 2003).

This study focuses on the detrital provenance and tectonic and genetic origins of the Paros upper-plate strata that are exposed on the E and NE sides of the island above the Paros Detachment (Fig. 1). The island of Paros has been the focus of structural (Gautier et al., 1990, 1993; Papanikolaou, 1977, 1980; Papp, 2007; Robert, 1982), litho- and biostratigraphic (Böger, 1983; Dermitzakis and Papanikolaou, 1980; Papageorgakis, 1968a, 1968b; Papp, 2007; Robert, 1982; Sánchez-Gómez et al., 2002) and geo- and thermochronometric studies (Altherr et al., 1982; Brichau et al., 2006; Engel and Reischmann, 1998; Hejl et al., 2003; Sánchez-Gómez et al., 2002). Despite decades of effort, the tectonic nature of the upper-plate strata, their stratigraphic correlation, their internal basin geometry, and their relationship to either early contractional or core-complex related deformation have been debated and remain unresolved (e.g., Papanikolaou, 1977, 1980; Sánchez-Gómez et al., 2002).

2. Tectonic evolution and Cenozoic kinematics in the central Aegean region

Extension in the central Aegean province has been ongoing since the latest Oligocene to earliest Miocene (Brun and Faccenna, 2008; Gautier and Brun, 1994; Gautier et al., 1999; John and Howard, 1995; Jolivet, 2001; Jolivet and Brun, 2010; Jolivet et al., 2010; Katzir et al., 2007; Keay et al., 2001; Ring et al., 2010). Cenozoic development and southward retreat of the Hellenic subduction zone (Brun and Faccenna, 2008; Royden, 1993) and the collapse of the Alpine Orogeny resulted in back-arc extension (e.g., Fytikas et al., 1984; Jolivet and Brun, 2010; Papanikolaou, 1993), which was accompanied by widespread plutonism and volcanic activity that followed the migrating arc southward (Papanikolaou, 1993; Pe-Piper and Piper, 2002). Total extension of up to ~580 km (Brun and Faccenna, 2008) has resulted in crustal thinning from an orogenic (>50 km) to an attenuated lithospheric thickness of ~26 km in the central Aegean (Papanikoloau et al., 2004) and is locally manifested by low-angle normal faulting and in some cases, MCC development (Brichau et al., 2007; Gautier et al., 1993; Jolivet et al., 2010; Lee and Lister, 1992; Lister et al., 1984). Regional, top to the N–NE, Holocene extension rates have been estimated to range between 12 and 60 mm/yr (Brun and Faccenna, 2008; Taymaz et al., 1991), although up to 2–3 cm/yr of geodetic movement has been reported between the Aegean region and stable Eurasia (Jolivet, 2001). The central Aegean currently behaves rigidly – perhaps due to microplate locking from rotation (McClusky et al., 2000; Taymaz et al., 1991) – and is largely aseismic (Fig. 1). Modern strain is partitioned into seismically active normal faults and strike-slip systems in the Northern Aegean and surrounding areas (Taymaz et al., 1991).

The current configuration of tectonostratigraphic units in the central Aegean resulted from extensional reorganization of the early Cenozoic Alpine nappe stack. The Cycladic basement rocks are variably deformed Variscan gneisses and schists, intruded by various Miocene plutons (Altherr et al., 1982; Bolhar et al., 2010; Dürr et al., 1978; Lee and Lister, 1992; Papanikolaou, 1989) and exposed on several islands as MCCs (e.g., Gautier and Brun, 1994; Lister et al., 1984). On Paros, zircon U–Pb dating of ortho- and paragneissic basement rocks yields typical Variscan igneous crystallization ages that range from 315 to 300 Ma, indicating that magmatism is broadly synchronous with Variscan metamorphism (Engel and Reischmann, 1998; this study) (Table 1, Appendix A).

Cycladic basement rocks are overlain by the Cycladic Blueschist Unit (CBU), which comprises metamorphosed early Mesozoic shelf sequences intercalated with metavolcanic rocks (Dürr et al., 1978; Negris, 1915–1919). The CBU can be further subdivided into Northern or Southern parts, based on lithostratigraphy and paleogeography (Papanikolaou, 1987, 1989). The Southern CBU is derived from bauxite-bearing carbonate platform sediments and directly overlies basement, whereas the Northern CBU is derived from a pelagic volcanosedimentary sequence, is overlain by ophiolitic material, and contains no exposed basement. In some cases, the Cycladic basement is regarded as part of the CBU (e.g., Dürr et al., 1978). Radiometric dating shows that the CBU underwent HP deformation during the Middle Eocene (e.g., Bröcker and Enders, 1999; Bröcker and Keasling, 2006; Bröcker and Pidgeon, 2007; Putlitz et al., 2005; Ring et al., 2010; Schneider et al., 2011; Tomaschek et al., 2003) and HT overprinting in the Oligocene–Miocene (Altherr et al., 1982; Andreissen et al., 1979; Duchêne et al., 2006; Wijbrans and McDougall, 1986, 1988).

The CBU is locally overlain by an upper tectonic unit, known in the Northern Cyclades as the Makrotandalon unit and in the Southern Cyclades as the Dryos/Messaria unit (e.g., Papanikolaou, 2009). These tectonometamorphic units are often exposed as heavily denuded rocks in extensional fault systems, with uncertain tectonic relationships with regard to the CBU and Cycladic basement. This upper unit is compositionally variable throughout the Aegean and can encompass a wide range of lithologies (Dürr et al., 1978; Papanikolaou, 1987). On Paros, the Dryos Unit comprises highly deformed metabasites, phyllites, calc-schists and low-grade marbles. The protolith origins and thermotectonic histories are not well-constrained, although Permian fossils have been recovered from low-grade marbles of the Dryos Unit (Papanikolaou, 1980).

2.1. Geology of Paros

Paros is unique among the central Cyclades in that it exposes a nearly complete succession of footwall rocks and hanging wall sediments (Fig. 2). In the footwall, Cycladic basement rocks of Paros are composed of highly deformed Carboniferous ortho- and paragneisses (Engel and Reischmann, 1998; Robert, 1982) and less-deformed, S-type granites (Altherr et al., 1982). At one location in the NW of the island, basement rocks are crosscut by clearly much younger and completely undeformed rhyolitic dikes (Hannappel and Reischmann, 2005; Papp, 2007). The ortho- and paragneissic basement complex is overlain by intercalated amphibolite-facies marbles, mica schists, and amphibolites of the Cycladic Blueschist Unit (CBU). On Paros, Miocene Barrovian-style metamorphism has pervasively overprinted any earlier high-pressure signature (Gautier and Brun, 1994), although relict blueschist assemblages have been identified from correlative units on the neighboring island of Naxos (Avigad, 1998). Overprinting relationships suggest at least three episodes of deformation, which may have developed as a continuous sequence during progressive shearing (Gautier et al., 1993; Papanikolaou, 1977; Papp, 2007).

A low-angle detachment fault separates the high-grade MCC footwall from the hanging wall sediments, which are mainly exposed along the coast in NE Paros (Fig. 2). The stratigraphically lowest