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Closure of the Paleotethys in the External Hellenides: Constraints from U–Pb ages of magmatic and detrital zircons (Crete)

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ABSTRACT

Paleotethys was a highly mobile oceanic realm pinching into the supercontinent Pangea between Gondwana and Eurasia in the late Paleozoic/early Mesozoic. Published Paleotethyan reconstructions reveal that the time of Paleotethys closure and the position of its suture are highly debated. We present new magmatic and detrital zircon ages, separated from pre-Alpine basement and Permian to Triassic cover rocks exposed in the External Hellenides of Crete. These age data reveal Variscan and Cimmerian docking of microplates along the southern margin of Laurasia and help to constrain the time of Paleotethys closure.

46% of detrital zircons from quartzite in the Variscan basement, are Pennsylvanian with concordant ages at 321 ± 2 Ma, 310 ± 3 Ma, and 300 ± 3 Ma. The basement is unconformably overlain by arc-related volcanics of the Tyros Unit, magmatic zircons of which yielded a concordant U–Pb zircon age at 285 ± 2 Ma. Thus, the metasediments of the basement, interpreted as former trench sediments, were deposited, metamorphosed and exhumed in latest Carboniferous to early Permian times (302–283 Ma). Magmatic activity during this late Variscan phase is also indicated by igneous boulders within Olenekian (meta)conglomerates of the Tyros Unit, which yielded concordant U–Pb zircon ages at 291 ± 2 and 310 ± 2 Ma. The late Variscan orogenic phase is attributed to the collision of the Gondwana-derived southern Minoan terrane (SMT) with Laurasia subsequent to northward subduction of Paleotethys lithosphere and Viséan collision of the northern Minoan terrane (NMT).

Magmatic activity ceased during the late Permian, but revived in the Lower Triassic as is indicated by felsic volcanics (249 ± 2 Ma, concordant U–Pb zircon) and by detrital zircons (242 ± 3, 240 ± 5 Ma, 237 ± 3 Ma concordant U–Pb zircon) of the Tyros Unit. At the same time the Variscan chain was exhumed and removed as is shown by the detritus in the Lower to Middle Triassic Tyros sediments, which includes high-grade metamorphic rocks and detrital zircons with U–Pb ages ranging from 280 to 335 Ma.

A significant change in the detrital components occurred in the Ladinian when the Variscan basement with its Permo-Triassic cover was thrust on top of clastic sediments, today represented by the Phyllite–Quartzite Unit s.str. The Phyllite–Quartzite Unit s.str. shows Cadomian and older – but no Variscan – detritus because of its position along the northern margin of the Cimmerian ribbon continent. Thus, in the eastern Mediterranean, Paleotethys was closed during the Ladinian and the related suture in the External Hellenides is situated between the Variscan basement (active margin in the north) and the Phyllite–Quartzite Unit s.str (passive margin in the south). Carnian crustal extension led to subsidence of the Variscan/Cimmerian chain, most parts of which merged below sea level. This is the reason why 90% of the detritus of the Carnian Tyros Beds are not related to the Variscan, but to the Cadomian and Grenvillian basement of the E-Gondwana derived Cimmerian ribbon continent.

1. Introduction

Rocks of the eastern Mediterranean realm were affected by Grenvillian, Cadomian, Variscan, Cimmerian, and Alpine orogenic events. Metamorphism and deformation related to these orogenic events destroyed fossils and affected isotopic systems relevant for constraining protolith ages of metasediments and metaigneous rocks. Moreover, the original position of sediments and volcanics is affected by thrusting and nappe emplacement due to subduction/collision and by extensional collapse of thickened crust. For these reasons, we are often dealing with fragments of lithosphere, the database of which is still incomplete and our understanding of its geological evolution is poor. This holds particularly true for the pre-Alpine events: There is little consensus on the regional plate tectonic development during late Palaeozoic–Triassic time. As no generally accepted tectonic reconstructions yet exist, it is necessary to

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return to the regional and local geology and examine the field-based evidence area by area through time to try to develop an internally consistent tectonic reconstruction (Robertson, 2012). Defining the original provenance of the pre-Alpine blocks along the northern margin of Gondwana remains the major tool in unraveling their movement between Gondwana and Laurasia.

In late Paleozoic/early Mesozoic times the Paleotethys formed a highly mobile oceanic ream that was wedging into the supercontinent Pangea between Gondwana and Eurasia. Progressive subduction of oceanic lithosphere and collision of intervening microplates led to the closure of the Paleotethys, whereas rifting caused the opening of a new oceanic basin referred to as the Neotethys. Rifting and microplate collision led to the formation of the Cimmerian ribbon continent, parts of which are today amalgamated within the External Hellenides, which consist of several nappes that were stacked together during the Alpine orogenic cycle. It is inferred that the Paleotethys in Greece and Albania had effectively closed prior to Late Permian time throughout the Balkan region, whereas it remained open in the Turkey–Iran area further east where it evolved into a Mesozoic ocean (Robertson, 2012).

The late Carboniferous (ca. 300 Ma) to late Triassic (ca. 200 Ma) was the time during which Pangea existed (Stampfli et al., 2013, and references therein). During this time, magmatic and orogenic activity is documented not only in the pre-Alpine basement of the External Hellenides (Peloponnese, Kithira, Crete; Seidel et al., 1982; Finger et al., 2002; Romano et al., 2004, 2006; Xypolias et al., 2006; Zulauf et al., 2007a; Xypolias et al., 2008; Zulauf et al., 2008, 2013), but also in the Cyclades (e.g. Henjes-Kunst and Kreuzer, 1982; Reischmann, 1998; Ring et al., 1999; Keay et al., 2001; Tomaschek et al., 2001; Ring and Layer, 2003; Chatzaras et al., 2013), and in Pelagonia (e.g. Mountrakis, 1984; Vavassis et al., 2000; Reischmann et al., 2001; Anders et al., 2007; Meinhold et al., 2008).

Palaeomagnetic studies show how the continental separation between Gondwana and Eurasia has evolved through time (Morris and Tarling, 1996). However, there are strikingly different views concerning the position and movement of intervening microplates through time. The most disputable topics include (1) the location and polarity of subduction of the Paleotethys lithosphere, and (2) the position of peri-Gondwanan terranes, such as Pelagonia, Sakarya, Menderes, or the different basement complexes within the External Hellenides.

Different tectonic models are currently proposed for the geodynamic setting of the late Palaeozoic/early Mesozoic units of the External Hellenides and adjacent domains (see review of these models in Robertson, 2012). One of these models is based on northward subduction and rifting of several microcontinents from Gondwana (e.g. Dornsiepen and Manutsoglu, 1994; Ricou, 1996; Robertson et al., 1996; Garfunkel, 1998; Dercourt et al., 2000; Dornsiepen et al., 2001; Garfunkel, 2004; Robertson et al., 2004; Robertson, 2006, 2008). The microcontinents drifted to the north and were accreted to Eurasia. The locus of rifting shifted northwards with time culminating in the late Triassic opening of the Pindos ocean.

In a specific model, suggested by Robertson (2008), the protoliths of metamorphic rocks, which are sandwiched between the Plattenkalk and the Tripolitza unit of eastern Crete (Phyllite–Quartzite unit of Creutzburg and Seidel, 1975), are restored as a discrete intra-continental rift basin within the northern margin of Gondwana, whereas those of western Crete are related to a distinct more southerly basin separated by a paleogeographical barrier.

Another model suggests that the Palaeotethys was located in a southerly position and was closed in late Triassic times within the South Aegean region (Stampfli, 1996, 2000; Stampfli and Borel, 2002; Stampfli et al., 2003; Eren et al., 2004; Stampfli and Kozur, 2006). Palaeotethys continued to subduct resulting in the development of Triassic accretionary complexes, volcanic arc units, backarc basins, and a late Triassic suture when Palaeotethys finally closed (Stampfli et al., 2001; Stampfli and Borel, 2002). This suture zone is mapped as running between the more northerly, Anatolide, and southerly, Tauride continental blocks in western Turkey, and through the Peloponnese and Crete in the south Aegean region (Stampfli and Borel, 2002; Moix et al., 2008). However, the existence of such a Late Triassic Palaeotethyan suture zone in Turkey is debated (e.g. Mackintosh and Robertson, 2009; Robertson, 2012).

The models invoking northward subduction are problematic as no evidence of a northward-dipping Palaeotethyan subduction zone has been identified in the south Aegean region, ruling out any juxtaposition of metamorphosed and unmetamorphosed units as a result of pre-Jurassic subduction–collision (Robertson, 2006). Evidence for northward subduction, however, has been found on Chios Island, which is regarded as the easternmost part of the Pelagonian zone (Meinhold et al., 2007).

Dornsiepen et al. (2001) and Robertson (2006) suggested that the pre-Alpine basement complexes of the south Aegean region represent exotic terranes that were emplaced from the central Mediterranean region by dextral strike-slip. However, this assumption is not in line with the fact that (1) structural and kinematic evidence for strike-slip is largely lacking in the basement of the External Hellenides, and (2) the crystalline basement complexes include detrital zircons which are similar to those of adjacent domains (Menderes, Levante, Cyclades; Zulauf et al., 2007a).

Late Palaeozoic-Early Mesozoic southward subduction of Palaeotethys and related opening of marginal basins (southern Neotethys) along the northern margin of Gondwana have been proposed by Şengör (1984). Southward subduction and collision of Gondwana-

Table 1
Locality, rock type and stratigraphic position of investigated samples.

Number of sample	Locality	Sample localities Co-ordinates	Rock type	Stratigraphic position	Protolith age
Do 500	Chimeney rocks W of two-nave chapell at Toplou	N 35°13′37.1″, E 026°13′06.0″	Metaconglomerate	Toplou beds, T5	Carnian
Do 501	Chimeney rocks W of two-nave chapell at Toplou	N 35°13′37.1″, E 026°13′06.0″	Metasandstone	Toplou beds, T5	Carnian
Do 502	pathcut W of two-nave chapell at Toplou	N 35°13′41.3″, E 026°12′58.7″	Dark quartzite	Toplou beds, T3	Carnian
Do 504	Akr. Tenta, south of Kokino Kava	N 35°13′21.2″, E 026°16′24.0″	Metasandstone	Toplou beds, T1	Carnian
32π	Rocks in olive grove 700 m SE of Petras	N 35°11′34.9″, E 026°07′09.1″	Quartzite	Tripokefala beds	Anisian
Do 515b	Chimeney rocks between Toplou and Vai, 1850 m NNE of Toplou	N 35°14′13,2″, E 026°13′21,3″	Felsic metavolcanic rock ('Weißquarzit')	?Chamezi beds	Olenekian
31TP	Rocks along the beach at Tripitos, between Sitia and Agia Fotia	N 35°12′00.2″, E 026°07′49.2″	Red metasandstone	Chamezi beds	Skythian
080908/1	Pathcut between OTE station and Linares	N 35°11′45.0″, E 026°01′25.4″	Volcanic pebble in metaconglomerate	Chamezi beds	Skythian
Do 524	Pathcut between OTE station and Linares	N 35°11′44.8″, E 026°01′24.9″	Granitoid pebble in metaconglomerate	Chamezi beds	Skythian
Do 511	Chimney rocks north of Mochlos	N 35°10′12.8″, E 025°54′28.1″	Metarhyolite layer inside metaandesite	Chamezi beds	Permian
Do 514	Pathcut north of Mochlos, eastern Crete	N 35°10′14.1″, E 025°54′21.6″	Quartzite	Pre-Alpine basement	
Do 505	Pathcut west of Messa Mouliana	N 35°09′34.0″, E 025°57′42.0″	Quartzite	Pre-Alpine basement	