From Variscan to Cimmerian Europe as revealed from case studies in the Bohemian Massif and the eastern Mediterranean

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The crust of Europe shows evidence for Cadomian, Variscan and Cimmerian orognic imprints. As these orogens developed in entirely different geodynamic settings, their crustal architecture, the amount of horizontal shortening and the crustal thickness differ significantly. The present paper will focus on the Variscan and Cimmerian imprints as exposed in the Bohemian Massif and in the Eastern Mediterranean.

The Variscan orogenic belt developed during the Devonian to Carboniferous collision of peri-Gondwanan terranes with Laurasia. The provenance of these peri-Gondwanan terranes has been revealed using the age of magmatic and detrital zircons (e.g. Dörr et al. 2015). Minoan terranes, which are widespread in the Alpine and Mediterranean realm, are characterized by Tonian zircons derived from NE Gondwana. Armorican terranes of central and western Europe rifted off from N and NW Africa and are free from Tonian and Mesoproterozoic zircons. Avalonian terranes are situated between the Iapetus and the Rheic sutures. They have Amazonian affinity and are characterized by Mesoproterozoic igneous activity. Before these peri-Gondwanan terranes were split off from Gondwana in early Paleozoic times, they underwent Cadomian (Andean-type) orogenic imprints at the northern margin of Gondwana, which did not result in large-scale continent collision and related exhumation of lower crust.

The Variscides, on the other hand, include large areas with exhumed deeply buried high-grade metamorphic rocks, which are characterized by partial melting, complex polyphase deformation and significant amount of finite strain. In contrast to the very-low grade metamorphic rocks of the External Variscides (e.g. Rhenohercynian or Moravo–Silesian Zone), primary structures like bedding are largely destroyed in the high grade rocks of the Internal Variscides and the kinematics of deformation structures like folds and boudins is difficult to constrain. Nevertheless, unraveling the evolution and kinematics of the Variscan Internides is possible in the Bohemian Massif, which is one of the largest outcrops of Variscan basement in Europe where both upper and lower crustal rocks are resting side by side. It was Franz Eduard Suess, who first recognized that the Tepla–Barrandian rocks were situated at a high structural level during the entire Variscan cycle and escaped Variscan metamorphism, while being surrounded by high-grade Moldanubian s.str. and Saxothuringian rocks. The lack of Variscan metamorphism makes the Tepla–Barrandian Unit an ideal candidate to obtain reliable kinematic data of deformations, which affected the internal part of the Variscides. These data suggest significant changes in the principal shortening directions, which are related to changes in the configuration and arrangement of the lithospheric plates and to major changes in the thermal state of the lithosphere (e.g. Dörr & Zulauf 2010; Žák et al. 2014):

(1) NW–SE shortening due to subduction/collision from ca. 390–345 Ma led to the closure of the Rheic ocean and to a doubly-vergent orogenic wedge with a crustal thickness >50–60 km.

(2) Radial extension from ca. 345–335 Ma was associated with a significant thermal turnover, exhumation of lower crust, and elevator-style slip along the Bohemian shear zone (BSZ), which governed the foci of mantle derived plutonism for >20 m.y. A minimum throw of 10 km was accommodated between 343 and 330 Ma causing the juxtaposition of the supracrustal Tepla–Barrandian unit (the “elevator”) against the hot extruding orogenic Saxothuringian/ Moldanubian root.

(3) N–S shortening at ca. 330 Ma led to a conjugate set of mylonitic strike-slip shear zones related to the closure of the Rhenohercynian ocean and to progressive docking of the collapsing wedge with Baltica. Dextral strike-slip occurred along NW–SE trending shear zones, such as the Bavarian Lode and the Elbe shear zone. Sinistral strike-slip was active along NE–SW trending shear zones as is well documented in the Mid-German crystalline rise (Odenwald).

(4) Subsequent extension at 325–315 Ma is indicated by the opening of E–W trending granitic dikes, which are widespread in the Moldanubain domain, and by the development of steep mylonitic normal faults.

(5) NE–SW shortening at 315–300 Ma is interpreted in terms of collision of Gondwana with the Variscan belt and Laurasia.

At 300 Ma Pangea had already been formed and — apart from the Paleotethys — all oceans of the Variscan realm in Europe had been closed (Stampfli et al. 2013). Orogenic activity continued along the northern active margin of the Paleotethys, which formed an eastward-opening wedge-shaped oceanic tract inside Pangea pinching out in the Iberian realm close to a Euler pole. Accretion of the south and north Minoan terranes to the southern margin of Eurasia occurred at ca. 320 Ma and at 300 Ma, respectively (Zulauf et al. 2015). Ridge subduction might have supported the formation of the late Carboniferous/early Permian Meliata rift. A significant thermal and magmatic event occurred close to 300 Ma as is documented at several places not only in the eastern Mediterranean but also in central and western Europe.

Magmatic activity in the eastern Mediterranean ceased significantly during the Middle Permian (ca. 270 Ma) when the Cimmerian ribbon continent rifted from the northern margin of Gondwana (Stampfli et al. 2013). This rifting event produced a new lithospheric plate, which included the remaining part of the Paleotethys, the Cimmerian ribbon continent and the northern part of the Neotethys. In contrast to the southern margin of Laurasia, the rocks of the Cimmerian ribbon continent are entirely free from Variscan-aged zircons.

Opening of the Neotethys and convergent movements along the southern active margin of Laurasia led to diachronic closure of the Paleotethys, which is regarded to have taken place after the Viséan in Morocco and during Roadian time in Sicily, Croatia and the Slovenian Southern Alps (Stampfli et al. 2013). Further to the east, Paleotethys was closed in Triassic times.

In the External Hellenides, revived early Triassic convergent movements along the southern active margin of Laurasia were related to magmatic activity and the formation of back-arc basins (e.g. Tyros basin). Back arc extension ceased in the Ladinian/early Carnian, when the Cimmerian ribbon terrane collided with the southern margin of Laurasia (Zulauf et al. 2018). This collision, referred to as the Eo-Cimmerian phase, was a 'soft' collision without major crustal thickening, as is documented from southern Europe to Thailand (Şengör 1979). In the eastern Mediterranean the closure of the Paleotethys led to a complete reorganization of the stress field. Crustal extension in the north led to subsidence of the accreted Cimmerian block resulting in the opening of small oceanic basins (e.g. Pindos ocean). Moreover, there was a striking facies change from siliciclastic rocks towards the Pantokrator-type dolomite, which is a characteristic rock of late Triassic Tethyan carbonate platforms.

It should be emphasized that the Apulian microplate was not part of the Cimmerian block since Permian times. The separation of the Apulian microplate from Gondwana is attributed to the Jurassic break-up of Pangea resulting in the opening of the Mesogean ocean, relics of which are undergoing subduction beneath the Aegean microplate still today.

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