What is the Austroalpine mega-unit and what are the potential relations to Paleotethys Ocean remnants of southeastern Europe?

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Abstract: In Eastern Alps, basement units of the Cretaceous-aged Austroalpine nappe stack is considered to represent a relatively uniform continental mega-unit formed during the Variscan orogeny. Large new U–Pb zircon data sets from all, virtually Variscan and pre-Variscan, basement units east of the Tauern window reveal that the Plankogel Complex of the Saualpe is of oceanic affinity and contains Middle-Upper Triassic magmatic protoliths and detrital zircons excluding a depositional age older than Middle–Late Triassic. Based on these observations, we review Middle–Late Triassic palaeogeography and magmatic belts from both strands extending from Alps to western Turkey. We propose a new model with Triassic supra-subduction magmatic belts along margins of the Paleotethys Ocean as well as a model how the Triassic oceanic unit was emplaced within the Austroalpine nappe stack.

What is the Austroalpine mega-unit?

The Austroalpine mega-unit of Eastern Alps and Western Carpathians is a thick-skinned continental nappe stack of Cretaceous age. Its cover is considered to represent a uniform Triassic passive continental margin succession opening towards to Meliata Ocean in the S to SE during late Middle Triassic times (Fig. 1; Froitzheim et al. 2008; Schmid et al. 2008; Plašienka 2018). The basement, particularly east of the Tauern window, is considered to have formed during Variscan orogeny, mainly during early Pennsylvanian. The basement units are highly diverse and include pre-Variscan sedimentary and magmatic units (e.g., Neubauer & Frisch 1993), which are now intensely investigated by U–Pb zircon dating of magmatic protoliths. Based on literature data and new results, the Austroalpine mega-unit comprise several major units, which include: (1) fossil-bearing Early Ordovician to Early Pennsylvanian passive margin units formed along the northern Gondwana margin; (2) a magmatic belt with abundant Ordovician to Silurian granitoids; (3) a Late Devonian–Mississippian tonalite–granite belt due to Variscan subduction processes, (4) a zone of Middle Permian granite–gabbros (Grob-Gneiss Complex), which is interpreted to have formed by rifting and crustal thinning of mid crustal levels; and (6) (Neoproterozoic to) Cambrian magmatic arc successions (Neubauer et al., this volume).

Previous work on this basement demonstrated Permian tectonothermal processes (e.g., Schuster & Stüwe 2008; Thöni & Miller 2009) but no post-Variscan lithostratigraphic was known, and even not expected (Froitzheim et al. 2008).

The pre-Alpine Austroalpine amphibolite-grade metamorphic basement of Eastern Alps contains a number of ophiolitic sutures (Neubauer & Frisch 1993), which are poorly constrained in age. All of them have been considered to have formed not later than during Variscan plate collision during the Carboniferous. Major portions of this basement is then overprinted by Permian rift processes, which also include low-pressure rift metamorphism (Schuster & Stüwe 2008; Thöni & Miller 2009). As a result, the location of a Paleotethyan suture has not been considered to extend into the Alps.

Plankogel Complex of the Saualpe

Here we report preliminary results of an extensive U–Pb zircon dating campaign on the Plankogel Complex in Eastern Alps (Saualpe and Koralpe). The Plankogel Complex, a tectonic mélange, is composed of coarse-grained

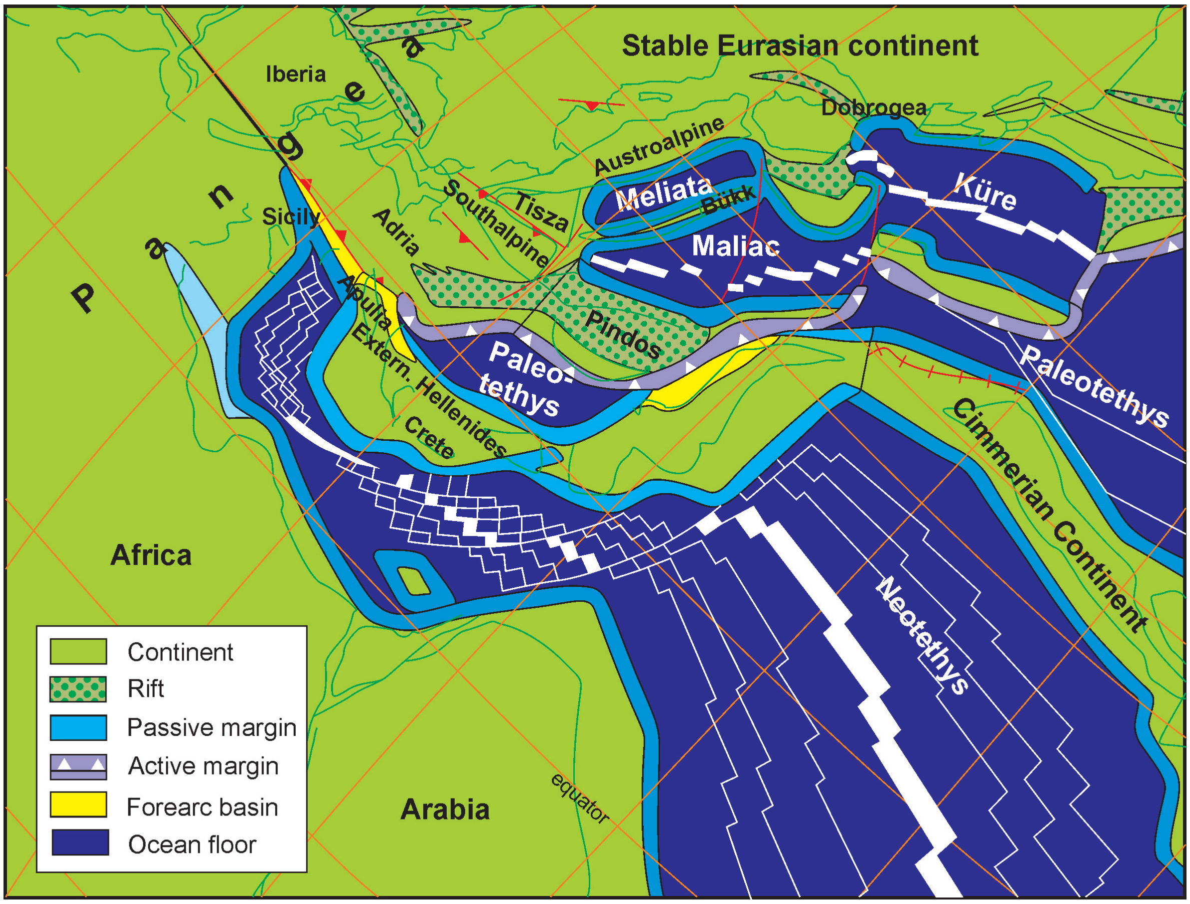

Fig. 1. Middle Carnian tectonic reconstruction for the western Tethyan realm (modified after Stampfli & Kozur 2006). Note the assumed Tethys rotation pole near Sicily implying increasing plate velocities towards E/SE. Note that it remains difficult, with this model, to explain subduction-related magmatic arcs.

garnet-micaschist as a matrix and plagioclase-rich biotite schist, within which hectometer-sized lenses of marble, Mn-rich quartzite, amphibolite and ultramafic rocks occur (Neubauer & Frisch 1993 and references therein). The marble was the host of a Mn-rich iron mineralization mined until ca. four decades ago. The amphibolites have a MOR-basalt geochemical signature (Neubauer et al. 1989). No protolith age were known up to now.

Metasedimentary rocks like the garnet-biotite-micaschist show a large population of Early–Middle Triassic, partly euhedral zircons implying an age of the sedimentary precursor rocks not older than Middle Triassic, and a significant Middle Triassic volcanic component. Zircons from the Mn-quartzites show a large Early Triassic volcanic component. The Mn-quartzite is interpreted to result from deep-sea Mn-rich cherts. Two amphibolites show late Permian/Early Triassic protolith ages.

As a whole, the dating results are entirely unexpected and require re-evaluation of the tectonic history of the Austroalpine units. Based on dating results, we conclude that the Plankogel Complex represents a Triassic ophiolite-bearing tectonic mélange with oceanic trench sediments and components from a deep-sea environment. The rich Permian to Middle Triassic volcanic components indicate, when calcalkaline, subduction of the Paleotethyan Ocean, and oceanic lithospheric elements were incorporated into the suspected trench sediments.

Western termination of Tethys

Here, we review the Triassic geodynamic setting of the western termination Tethys which is considered as an eastward opening huge bay of Panthalassa within Pangea (Fig. 1). All reconstructions since Şengör (1979, 1984) assume that the western termination of Tethys is represented by a northern Paleotethys Ocean subducting underneath Laurasia and a southern, new formed Neotethys Ocean separated by the Cimmerian continent (Fig. 1). For demonstrating these processes and paleogeograpraphy, we use the currently popular model of

Stampfli & Kozur (2006) (Fig. 1). As Pangea is stable from Permian to Triassic times, a rotation pole for Tethyan plate motion is postulated at the western tip of Tethys embayment close to Sicily. This peculiar geodynamic setting implies slow motion in the west and rapid motion in the east caused by a rotation at the western termination of Tethys Oceans near Sicily in the future Mediterranean. Geological relicts, e.g., potential arc magmatism, and ophiolite suites, mélanges, oceanic basalts, radiolarian-bearing silicalites related to the Triassic Paleotethyan evolution are preserved in southeastern Europe of the Western Paleotethyan domain (Bortolotti et al. 2013). However, the Triassic tectonic history of that area is largely unclear and disputed. E.g., few potential Paleotethys Ocean remnants appear in different mountain belts of southeastern Europe, and their relationship to Neotethys are under discussion. Open key questions are: (i) the existence of potential Middle–Upper Triassic arc magmatism, back-arc opening (Meliata Ocean), formation of microcontinents (e.g., Apulia, Adria as part of the Western Cimmerian microcontinent) as well as on back-arc ophiolite formation; (ii) temporal–spatial evolutionary and patterns of the different micro-continents/ or blocks and their tectonic setting in the Southeast European mountain belts; (iii) Triassic tectonic processes and geodynamics of the Southeast European (eastern Mediterranean) mountain belts at the western termination of the convergent Paleotethys Ocean with the main open question, rift vs. magmatic arcs.

Triassic tectonic processes at western termination of Tethys

In the following, models are discussed showing the interrelationships between Paleotethys and Neotethys and of intervening oceans (Fig. 2).

- Model 1 is the classical model as proposed by Şengör (1979, 1984): Paleotethys is subducting underneath the Eurasian continental margin. This implies there the presence of subduction magmatism, which was not identified in southeastern Europe.
- Model 2 (Stampfli & Kozur 2006) is similar but implies the rifting and short opening of a back-arc basin, in this case, the Dobrogea rift (Fig. 2).
- Model 3 (Bortolotti et al., 2013) separates Paleotethys and another ocean (TOFO=Vardar ocean), which is potentially a branch of Paleotethys. Note that this model does not exclude the Triassic opening and closure of the Dobrogea rift on the Eurasian margin. This model explains the magmatism in Dinarides/ Hellenides as rift magmatism in an overall extensional setting. Furthermore, the model does not include a subduction zone-related magmatism.
- Model 4 (Zulauf et al. 2018) explain magmatism in External Hellenides (e.g. Crete, and its extension in External Dinarides) as subduction-related magmatism of the Paleotethys Ocean and includes the Dobrogean rift as a sort of back-arc basin.
- Model 5, our own working hypothesis, implies two Paleotethyan branches, which were subducted during Triassic times underneath microcontinents.

As a major conclusion from all these models, revealing the nature of Triassic magmatism within the continental blocks is the key to understand the overall setting and to resolve the geodynamic setting. We tentatively assume, therefore, that the Triassic Dinaric–Hellenic magmatic belts representing supra-subduction magmatism. However, this model must be supplemented by future structural and paleomagnetic studies showing the kinematics of opening and closure of the oceanic systems (e.g. Muttoni et al. 2013), as well as the exact timing of these processes.

Discussion and open questions

We argue that the Plankogel Complex is a tectonic mélange containg significant remnants of the Paleotethys Ocean likely related to TOFO. Consequently, the location within the Austroalpine nappe stack needs explanation. We suggest, that the preservation is in immediate hangingwall of the Cretaceous-aged high-pressure wedge (Froitzheim et al. 2008) is due to a strong rheological contrasts between upper and lower plate allowing to indent subducted lower plate succession into the upper plate (Vogt et al. 2018)

The reconstructions and models result in several key questions, which need more detailed work in the future:

- What is the significance of Middle to early Upper Triassic linear magmatic belts like in Dinarides, Southern Alps and Bükk Mts. (Köver et al. 2019). Does they represent rift magmatism as now often postulated or does they result from subduction? Although these show a calcalkaline to shoshonitic affinity, these are even interpreted as related to continental rifting (Lustrino et al. 2019 for Southern Alps; Pe-Piper 1998 for External Hellenides).
- Did the remnants of Triassic Paleotethys Ocean subduct during Triassic times and is there any further evidence for Triassic trench deposits?

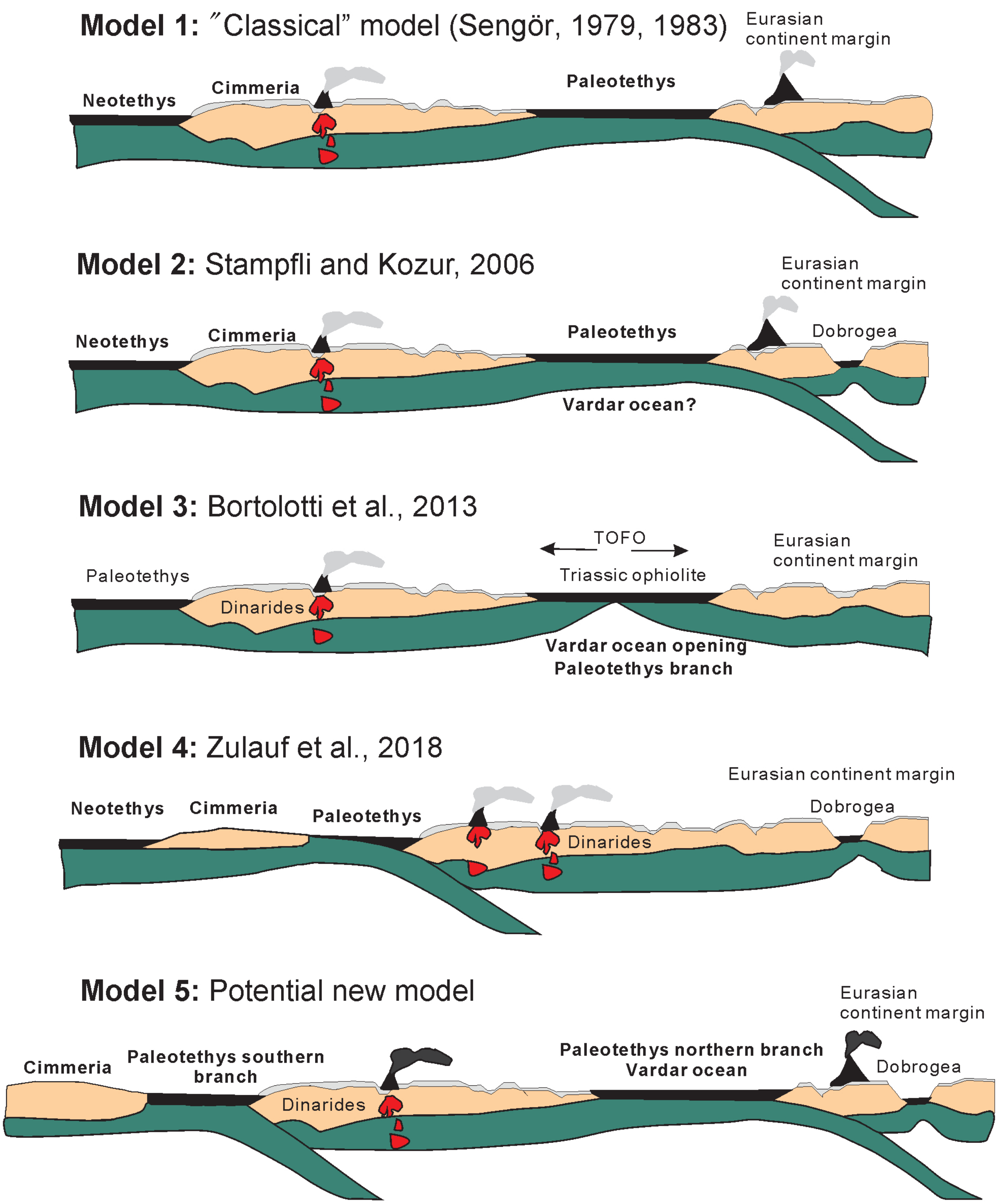

Fig. 2. Models of the Triassic tectonic evolution of Tethys. In all figures, the left side is S to SSW, the right side N and close to the Eurasian margin. For discussion, see text. TOFO=Triassic ocean-floor ophiolites (after Bortolotti et al. 2013).

- What is the relationship between TOFO/Vardar and other Triassic oceanic relics in southeastern Europe to the Meliata Ocean, which could be interpreted as a back-arc basin behind a continental pieces, which should carry linear subduction-related magmatic belts.
- Taking the currently popular tectonic model (e.g., Stampfli & Kozur 2006; Fig. 1), it seems impossible to explain Paleotethys closure and opening of Meliata Ocean in this sort of model when the Austroalpine mega-unit is separated from the potential Paleotethys

suture. Consequently, a new model is currently under development, which simplifies the ocean realms and explains the linear magmatic belts of the Southalpine, Dinaric and External Hellenides as magmatic arcs.

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References

Bortolotti V., Chiari M., Marroni M., Pandolfi L., Principi G. & Saccani E. 2013: Geodynamic evolution of ophiolites from Albania and Greece (Dinaric–Hellenic belt): one, two, or more oceanic basins? *Int. J. Earth Sci.* 102, 783–811.

Froitzheim N., Plašienka D. & Schuster R. 2008: Alpine tectonics of the Alps and Western Carpathians. In: McCann T. (Ed.): The geology of central Europe, Mesozoic and Cenozoic. Vol. 2. *Geological Society Publishing House*, London, 1141–1232.

Kövér S., Fodor L., Kovács Z., Klötzli U., Haas J., Zajzon N. & Szabó Cs. 2019: Late Triassic acidic volcanic clasts in different Neotethyan sedimentary mélanges: paleogeographic and geodynamic implications. *Int. J. Earth Sci.* 107, 2975–2998.

Lustrino M., Abbas H., Agostini S., Caggiati M., Carminati E. & Gianolla P. 2019: Origin of Triassic magmatism of the Southern Alps (Italy): Constraints from geochemistry and Sr–Nd–Pb isotopic ratios. *Gondwana Res.*, https://doi.org/10.1016/j.gr.2019.04.011

Muttoni G., Dallanave E. & Channell J.E.T. 2013: The drift history of Adria and Africa from 280 Ma to Present, Jurassic true polar wander, and zonal climate control on Tethyan sedimentary facies. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 386, 415–435.

Neubauer F. & Frisch W. 1993: The Austroalpine metamorphic basement east of the Tauern window. In: von Raumer J. & Neubauer F. (Eds.): Pre-Mesozoic Geology in the Alps. *Springer*, Berlin, 515–536.

Neubauer F., Frisch W., Schmerold R. & Schlöser H. 1989: Metamorphosed and dismembered ophiolite suites in the basement units of the Eastern Alps. *Tectonophysics* 164, 49–62.

Pe-Piper G. 1998: The nature of Triassic extension-related magmatism in Greece: evidence from Nd and Pb isotope geochemistry. *Geol. Mag.* 135, 331–348.

Plašienka D. 2018: Continuity and episodicity in the early Alpine tectonic evolution of the Western Carpathians: How large-scale processes are expressed by the orogenic architecture and rock record data. *Tectonics* 37, https://doi.org/10.1029/2017TC004779.

Schmid S.M., Bernoulli D., Fügenschuh B., Matenco L., Schefer S., Schuster R., Tischler M. & Ustaszewski K. 2008: The Alpine–Carpathian–Dinaric orogenic system: correlation and evolution of tectonic units. *Swiss J. Geosci.* 101, 139–183.

Schuster R. & Stüwe K. 2008: Permian metamorphic event in the Alps. *Geology* 36, 603–606.

Şengör A.M.C. 1979: Mid-Mesozoic closure of Permo–Triassic Tethys and its implications. *Nature* 279, 590–593.

Şengör A.M.C. 1984– The Cimmeride orogenic system and the tectonics of Eurasia. *Geol. Soc. Amer. Spec. Pap.* 195, 1–82.

Stampfli G.M. & Kozur H. 2006: Europe from the Variscan to the Alpine cycles. In: Gee D.G. & Stephenson R.A. (Eds.), European Lithosphere Dynamics. *Geol. Soc. (London) Mem.* 32, 57–82.

Thöni M. & Miller C. 2009: The “Permian event” in the Eastern European Alps: Sm–Nd and P–T data recorded by multi-stage garnet from the Plankogel unit. *Chem. Geol.* 260, 20–36.

Vogt K., Willingshofer E., Matenco L., Sokoutis D., Gerya T. & Cloetingh S. 2018: The role of lateral strength contrasts in orogenesis: A 2D numerical study. *Tectonophysics* 746, 549–561.

Zulauf G., Dörr W., Marko L. & Krahl J. 2018: The late Eo-Cimmerian evolution of the external Hellenides: constraints from microfabrics and U–Pb detrital zircon ages of Upper Triassic (meta)sediments (Crete, Greece). *Int. J. Earth Sci.* 107, 2859–2894.