the Pre-Alpine and Alpine metamorphic processes. PT conditions of 560–580 °C and 10 kbar for Alpine metamorphism were calculated using exchange thermobarometry garnet-biotite and GASP barometry in metapelite and garnet-plagioclase-amphibole thermobarmtry in amphibolite. According to isopleths of garnet obtained using construction of pseudosection in thermocalc, the garnet started to crystallize at 530 °C at ca 7 kbar kbar having reached a maximum of 580 °C and 10 kbar kbar. The simulation was done for a time interval estimated according to the P-T path. Diffusion coefficient was calculated for Mn, Mg and Fe, where Ca was treated as dependent component. The advantage of such simultaneous calculation is that it allows subtle details of variations in compositional profiles to be interpreted and also considerably reduces the uncertainty in retrieved time scales that may arise from using only one profile. The retrieved time scales for Alpine metamorphism in this area imply ~2 Ma for the selected P-T path excceding 530 °C.

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Deformation and Exhumation of Magmatic and Metamorphic Rocks of the Pohorje-Kozjak Mts. (Slovenia): Constraints from Structural Geology, Geochronology

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The Pohorje-Kozjak Mts., NE Slovenia are built of several Cretaceous nappes, consisting from bottom to top of medium-grade metamorphic rocks, slightly metamorphosed early Paleozoic rocks (Magdalensberg series), and Permo-Mesozoic sediments. These rocks are covered by late Early Miocene (18–16 Ma) clastic sediments deposited in the rifting western Pannonian Basin. Pre-Tertiary rocks were intruded by granodiorite (tonalite), related pegmatite, aplite and lamprophyre dykes and subvolcanic dacite bodies and dykes (Márton et al. 2002).

Eoalpine subduction and nappe stacking resulted in very high (to ultra-high) pressure metamorphism of kyanite-bearing eclogites (Janák et al. 2003). The juxtaposition of mafic eclogites and continent-derived metasediments (micaschists, gneiss, marble) represents the first exhumation process but its kinematics is still poorly understood.

Most of the metamorphic rocks record prominent mylonitic microfabrics associated with penetrative foliation and stretching lineation. Well-developed kinematic indicators show top-to-the-(E)NE or -SW extensional shearing. Deformation progressively increasing upward toward a “phyllite” zone, situated at the top of the Alpine medium-grade metamorphic rocks. This zone also represents a break in degree of metamorphism while low-grade rocks or truncated Permo-Mesozoic sediments are in direct contact with medium-grade rocks. Thus the “phyllite” zone is regarded as a low-angle ductile mylonitic shear zone accommodating horizontal extension and vertical shortening (thinning).

Some magmatic rocks record oriented texture (foliation and locally mineral lineation), part of which is related to syn-magmatic, other part to post-crystallisation solid-state deformation. Dynamically recrystallised quartz, boudinaged biotite and non-deformed feldspars broadly place the deformation into the higher greenschist facies. This deformation induced the formation of strong magnetic fabric with maximal anisotropy axis trending mainly ~E-W.

Ductile deformation was associated with and followed by brittle normal faults and intervening tilted blocks of different size. Faulting could reactivate but often cut earlier ductile low-angle zones. The direction of tension varied from ESE-WNW to NE-SW, roughly parallel to ductile stretching lineation. Post-extensional compressional deformation could be related to Plio-Quaternary transpression.

All rocks suffered a regional, Pliocene to Quaternary ~30° counterclockwise rotation. The amount of CCW rotation almost compensated an earlier clockwise rotation in lamprophyre dykes but was much less then a much larger CW rotation in granodiorite. The preservation of more complex rotational history in granodiorite suggests relative chronology as younging from granodiorite to dacite.

Published Sm/Nd ages on garnets from metapelites (Thöni, 2002) give mid-Cretaceous (93–87 Ma) ages interpreted as time constraint of the high-pressure Alpine metamorphism. New thermochronological data show two major cooling events, which affected metamorphic rocks in different geographic and geologic position (Fodor et al., 2003a). In the northern Kozjak area muscovite K/Ar ages on medium-grade (102–96 Ma) and low-grade rocks (91Ma) and zircon fission track ages (27–22 Ma) show fast cooling immediately after mid-Cretaceous metamorphism and some thermal effects at the Oligocene/Miocene boundary.

In contrast, in the southern Pohorje area all thermochronological data (below ~350 °C) demonstrate Miocene cooling. Probably the oldest non-reset fission track ages of grains in Karpatian sediments show cooling of source rocks at 22–20 Ma (Sachsenhofer et al., 1998). Muscovite and biotite K/Ar ages (from 21 to 13 Ma), zircon and apatite fission track ages (19 and 10 Ma, respectively) indicate early to mid-Miocene cooling of metamorphic rocks. Identical K/Ar biotite, feldspar and hornblende ages of magmatic rocks (19–15 Ma) and fission track ages (18–15 Ma) demonstrate that the two rock types cooled together after magma emplacement and eventual hydrothermal-metasomatic alterations. Cooling ages of dacite are nearly equal true formation age while Karpatian sediments contain tuffs and are locally intruded with small dacite bodies. Granodiorite formation age remains questionable. However, granodiorite pebbles in Karpatian sediments give an upper time constraint and show fast exhumation for granodiorite (Fodor et al., 2003a). Thermal effect at early mid-Miocene is indicated by high vitrinite reflectance values and partially reset fission track ages from Karpatian sediments (Sachsenhofer et al., 1998).

Difference of cooling ages can be attributed to Miocene extension; the Kozjak Mts. seems to represent a major hanging wall fault block of a Miocene normal or oblique-slip fault, namely the Lovrenc fault. Early phase of Miocene cooling of the Pohorje can be connected to ductile extensional exhumation while low-temperature part was associated with brittle normal faulting. Kinematic directions did not change considerably during the deformation and cooling. Because of unclear timing, we have no exact data for tectonic regime for granodiorite magmatism. However, emplacement of all other magmas and their post-solidification ductile to brittle deformation also occurred in extensional settings. All deformation features are part of a prolonged Miocene extensional deformation.

The structural and thermochronological data suggest two ductile extensional exhumation events for the Pohorje-Kozjak rocks. The late Cretaceous event was responsible for extensional disintegration of the East Alpine nappe pile, including the Transdanubian Range ("Bakony") nappe of western Pannonia as the highest unit (Fodor et al., 2003b). Miocene exhumation is connected to extrusion tectonics, rotation and rifting of the Pannonian Basin; processes included the easternmost Eastern Alps and Western Carpathians. Magmatism are mainly related to Neogene extension, and contributed to heating at late stage of ductile to brittle tectonic exhumation.

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What Are the Tectonic Units in the Pannonian–Carpathian–Eastern Alpine Domain: Terminological Question or Key to Understand Structural Evolution?

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Tectonic units are three-dimensional rock bodies with distinct physical boundaries and unique structural characters including temporal evolution. One of the main tasks of structural research is to define boundary surfaces or zones (structural elements), describe their geometry, characterize kinematic nature and determine temporal evolution. On the other hand, the presence of certain rock formations, their special facies or paleogeographic similarities are not distinctive features, although they can occasionally be useful to establish or better characterise some tectonic units.

Tectonic units are evolving in time. Their boundaries can be shifted, their size can be increased or reduced. Frontal accretion,