First evidence for ultrahigh-pressure metamorphism of eclogites in Pohorje, Slovenia: Tracing deep continental subduction in the Eastern Alps

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1 The first evidence for ultrahigh-pressure (UHP) metamorphism in the Eastern Alps is reported from kyanite eclogites of the Pohorje Mountains in Slovenia. Polycrystalline quartz inclusions surrounded by radial fractures in garnet, omphacite, and kyanite are interpreted to be pseudomorphs after coesite. Abundant quartz rods and needles in omphacite indicate an exsolution from a preexisting supersilicic clinopyroxene that contained a Ca-Eskola component. Geothermobarometry on the mineral assemblage garnet + omphacite + kyanite + phengite + quartz/or coesite yields peak pressure and temperature conditions of 3.0–3.1 GPa and 760°–825°C, well within the stability field of coesite, thus supporting the microtextural evidence for UHP metamorphism. This records the highest-pressure conditions of Eo-Alpine metamorphism during the Cretaceous orogeny in the Alps, implying a very deep subduction of the continental crust to at least 90–100 km depths. The new data are evidence for a regional southeastward increase of peak pressures in the Lower Central Austroalpine, indicating a south- to eastward dip of the subduction zone. Subduction was intracontinental; northwestern parts of the Austroalpine (Lower Central Austroalpine) were subducted under southeastern parts (Upper Central Austroalpine). The subduction zone formed in the Early Cretaceous in the northern foreland of the Meliata suture after Late Jurassic closure of the Meliata Ocean and the resulting collision, by a forward subduction shift to a Permian rift.

INDEX TERMS: 5475 Planetology: Solid Surface Planets: Tectonics (8149); 3660 Mineralogy and Petrology: Metamorphic petrology; 8102 Tectonophysics: Continental contractional orogenic belts; 9335 Information Related to Geographic Region: Europe; 9609 Information Related to Geologic Time;

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[2] Ultrahigh-pressure (UHP) metamorphism is an important type of orogenic metamorphism that over recent years has been recognized in many Phanerozoic collision belts [e.g., Liou et al., 1998; Chopin, 2003, and references therein]. In the majority of the well-established occurrences of UHP rocks, mineral indicators of UHP metamorphism are mainly preserved in metabasic rocks (eclogites) but also in metasediments. The main UHP mineral indicators are the polymorphs of silica (coesite) and of carbon (diamond) that are mostly preserved as inclusions within relatively robust minerals such as garnet, omphacite and zircon. Metastable survival of UHP phases during exhumation and decompression is invariably very limited. Thus it is often presumed from the microtextural observations that UHP phases were previously stable. Likewise, the polycrystalline texture of quartz after coesite is diagnostic but tends to disappear due to recrystallization during prolonged thermal annealing. Quartz rods have been observed in omphacite from eclogites of several UHP terranes. In all cases, SiO2 needles and rods in omphacite have been interpreted as exsolution products from a preexisting supersilicic clinopyroxene that contained excess silica at peak metamorphic conditions [e.g., Smith, 1984; Schmädicke and Müller, 2000; Katayama et al., 2000; Dobrzhinetskaya et al., 2002].

[3] This paper presents the first evidence for UHP metamorphism of eclogites in the Austroalpine units of the Eastern Alps, exposed in the Pohorje Mountains of Slovenia. Described here are the mineralogical and petrologic features of kyanite eclogites that are indicative of UHP metamorphism such as omphacite containing SiO2 precipitates and inclusions of polycrystalline quartz after possible coesite. This is supported by the thermobarometric results recording pressure and temperature conditions well within the coesite stability field. The finding of UHP metamorphism has profound consequences for unraveling...
the mode of continental subduction in the Alps during the Cretaceous orogeny.

2. Geologic Background

[4] The presently known UHP metamorphism of eclogites in the Alps, such as in the Dora-Maira Massif [Chopin, 1984] and Zermatt-Saas Zone [Reinecke, 1991], is of Tertiary age [Titton et al., 1991; Rubatto et al., 1998]. Metamorphic processes related to the Cretaceous, so called “Eo-Alpine” events in the Alps, have been recognized mainly in the Austroalpine units [e.g., Thöni and Jagoutz, 1992; Frey et al., 1999; Hoinkes et al., 1999]. In the Eastern Alps, the metamorphic grade of Cretaceous metamorphism in several places, such as Koralpe and Saualpe, reached eclogite facies [Miller, 1990]. This high-pressure metamorphism is commonly related to collision between the Austroalpine and another continental fragment after the closure of the Meliata-Hallstatt Ocean [e.g., Thöni and Jagoutz, 1992; Froitzheim et al., 1996].

[5] We have found evidence for UHP metamorphism in the eclogites of the Pohorje Mountains in Slovenia, which are located at the southeastern margin of the Eastern Alps in the proximity of the Periadriatic line (Figure 1a). The Pohorje Mountains are built up of three Eoalpine Cretaceous nappes [Mioc and Žnidarič, 1977; Fodor et al., 2003] which belong to the pre-Neogene, metamorphic sequences within the Austroalpine units of the Eastern Alps. The lowest nappe consists of medium to high-grade metamorphic rocks, predominantly micaschists, gneisses and amphibolites with marble and quartzite lenses. In the Pohorje area, south of the Ribnica trough (Figure 1b), it also contains several eclogite lenses and a body of ultramafic rocks. It is followed by a nappe composed of weakly metamorphosed Palaeozoic rocks, mainly low-grade meta- phyrules and phyllites. The uppermost nappe is built up of Permo-Triassic clastic sediments, mainly sandstones and conglomerates. This nappe stack is overlain by early Miocene sediments which belong to the synrift basin fill of the Pannonian Basin [Fodor et al., 2003]. The large magmatic intrusion in the central part of Pohorje is mainly of granodioritic to tonalitic composition. It was emplaced along the Periadriatic fault system in Oligocene to Miocene time [Altherr et al., 1995].

[6] Eclogites form bodies, lenses and bands of different sizes, usually several tens of meters thick [Hinterlechner-Ravnik et al., 1991a]. They are found within amphibolites, orthogneisses, paragneisses and micaschists, both north and south of the granodiorite body (Figure 1b). Eclogite lenses also occur in metatrunubites, at the northeastern margin of Pohorje. This metatrunubite body of 5 × 1 km size is mainly built up of serpentinitized dunite and harzburgite with garnet peridotite remnants [Hinterlechner-Ravnik et al., 1991b]. Field relationships between the eclogites and their country rocks suggest that eclogites are mostly associated with crustal rocks, i.e., gneisses and micaschists, being part of the continental basement.

[7] The age of metamorphism of the Pohorje eclogites is not very well known. Sm-Nd dating of garnet in the eclogite host rocks—gneisses and micaschists—yields a Cretaceous (93–87 Ma) age [Thöni, 2002]. This age is similar to that of the Koralpe and Saualpe eclogite facies metamorphism [Thöni and Jagoutz, 1992; Thöni and Miller, 1996; Miller and Thöni, 1997; Thöni, 2002]. Muscovite and biotite K-Ar ages (19–13 Ma) as well as apatite and zircon fission track ages (19–10 Ma) from the country rocks of eclogites and metatrunubites in the southern part of Pohorje are Tertiary [Fodor et al., 2002]. This suggests that the peak of metamorphism in the Pohorje eclogites was attained during the Middle Cretaceous, and final cooling and exhumation occurred in the Early to Middle Miocene.

3. Petrography and Mineral Chemistry

[8] Eclogites from two localities in the vicinity of the metatrunubite body near Slovenska Bistrica have been investigated (Figure 1b). The dominant rock type is weakly retrograded kyanite eclogite occurring as individual blocks of several meters size or as lenses and boudins within surrounding amphibolites, orthogneisses and paragneisses. The kyanite eclogites consist of garnet, omphacite, kyanite, and zoisite as major primary phases. Representative analyses of garnet, omphacite and phengite are given in Table 1.

[9] Garnet is nearly unzoned, with 48–53 mol % of pyrope and 19–22 mol % of grossular content in the core. There is only a slight decrease of Mg and Ca accompanied by an increase in Fe at the rims of garnet reflecting partial reequilibration during decompression. Inclusions in garnet are relatively rare; these are typically omphacite, rutile, kyanite and quartz.

[10] Omphacite occurs as large anhedral grains in the matrix or as inclusions in garnet and kyanite. The jadeite component of omphacite varies between 20–30 mol %. The most striking feature of matrix omphacite is tiny needles and rods of quartz. They display an orientation parallel to the c-axis, indicating exsolution from a pre-existing, more silicic clinopyroxene (Figures 2a and 2b). Microprobe analyses of these rods and needles confirm that they are essentially pure SiO2. The total cation deficiency and excess Al on the octahedral site suggest the presence of a Ca-Eskola component Ca0.5AlSi2O6. Integral analysis of omphacite together with SiO2 precipitates under a defocused electron beam (25–30 μm) yields even higher, up to 8 mol % of the Ca-Eskola component (Table 1), which was calculated from: Al(tot)-2AlIV-K-(Na-Fe3+-2Ti).

[11] Phengite, with up to 3.5 Si p.f.u., occurs sporadically in the matrix and as minor inclusions in garnet and omphacite.

[12] Quartz inclusions occur in garnet, omphacite and kyanite. Most of them are surrounded by radial fractures (Figures 2a and 2c). Some of these inclusions are aggregates of polycrystalline quartz grains (Figure 2d) which are rather similar to the PPQ (polycrystalline polygonal quartz) and MPQ (multicrystalline polygonal quartz) texture according to Wain et al. [2000]. These textures can be diagnostic but not unique to recovery after coesite breakdown. Small
grains of rutile are found as inclusions in garnet and omphacite.

[13] Secondary phases occur in the coronas, symplectites and fractures of the major primary minerals. The most typical are amphiboles between garnet and omphacite and symplectites of diopside + amphibole + plagioclase after omphacite, biotite + plagioclase after phengite and sapphire + corundum + spinel + anorthite after...
Table 1. Representative Microprobe Analyses of Mineral Compositions Used for Thermobarometry*

<table>
<thead>
<tr>
<th>Sample</th>
<th>PO6</th>
<th>JV03</th>
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<tbody>
<tr>
<td>Mineral</td>
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<tr>
<td>SiO₂</td>
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</tr>
<tr>
<td>CaO</td>
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<td>8.37</td>
</tr>
<tr>
<td>Na₂O</td>
<td>nd</td>
<td>0.03</td>
</tr>
<tr>
<td>K₂O</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>Total</td>
<td>100.28</td>
<td>100.31</td>
</tr>
</tbody>
</table>

*Analyses (in wt%) of garnet (Grt), clinopyroxene (Cpx), and phengite (Phe). Cpx* is integral analysis of omphacite including quartz rods. Garnet is normalized to 12, clinopyroxene to 6, and phengite to 11 oxygens. Abbreviations are as follows: bd, below detection; nd, not determined; Ca-Es, calcium Eskola.

5. Discussion

5.1. UHP Metamorphism

The evidence for UHP metamorphism in the Pohorje eclogites comes both from the microtextural observations and thermobarometric calculations. The presence of oriented quartz rods in omphacite indicates exsolution from non-stoichiometric Si₂O₆-rich clinopyroxene via the reaction 2 Ca₀.₅Al₂Si₂O₆ = CaAl₂SiO₆ + 3 SiO₂ [Smyth, 1980]. Such primary clinopyroxene would be stable at very high P-T conditions, as determined by experimental studies [e.g., Gasparik, 1986; Hermann, 2002]. We interpret inclusions of polycrystalline quartz in garnet, omphacite and kyanite, surrounded by radial fractures to be pseudomorphs after coesite. The preservation of coesite relics depends on many factors including the rigidity of the host mineral, the P-T conditions and path of metamorphic recrystallization, rate of exhumation and presence of fluids [e.g., Mosenfelder and Bohlen, 1997]. Our thermobarometric results show very high P-T conditions during the metamorphic peak, well within the stability field of coesite. Formation of sapphirine in coronas around kyanite indicates that high temperature conditions were maintained during decompression. If the eclogites followed a mainly isothermal decompression path, fracturing and access of fluids would occur at high temperatures, leading to a complete breakdown and recovery of coesite to quartz.

Our results are compatible with previous estimation of very high-pressure metamorphism in the Pohorje area. Hinterlechner-Ravnik et al. [1991a, 1991b] estimated a pressure of up to 3.6 GPa at 900°C for the garnet peridotite, but substantially lower pressure (<1.8 GPa) for the eclogites. Our results suggest, however, that even the eclogites occurring at the southeastern margin of Pohorje experienced UHP metamorphism (~3.0 GPa at 800°C).

The presence of UHP metamorphism in Pohorje bears important implications for the understanding of the Cretaceous orogeny in the Alps. The P-T conditions of Cretaceous metamorphism in Pohorje are the highest reported within the Austroalpine units of the Eastern Alps. Eclogites occurring northwest of Pohorje, like in the Koralpe and Sauvalpe area, record only high-P conditions of ~2.0 GPa at 700°C [Hoinkes et al., 1999]. This implies an increase in metamorphic grade toward the southeast. A reverse gradient with decreasing P-T conditions from the Koralpe (1.5 GPa; 700°C) to Pohorje...
(1.0 GPa; 600°C) reported by Tenczer and Stüwe [2003] from the metapelites is not consistent with our data obtained from the eclogites. We suggest that these metapelites may have equilibrated at lower P-T conditions during exhumation and decompression. Metapelites poorly preserve their true high-P assemblages [e.g., Proyer, 2003]. Actually, Tenczer and Stüwe [2003] also noted some discrepancy between their P-T estimates from metapelites and those obtained from eclogitic metabasites in the Koralpe and Saualpe. For these reasons, it is likely that there is a reverse gradient only from the Saualpe-Koralpe into the structurally higher Plankogel Complex [Gregurek et al., 1997; Kurz et al., 2002]. The contact of these units is tectonic, due to normal faulting in the upper part of a northward extruding wedge [Tenczer and Stüwe, 2003]. Further southeast in Pohorje, as the profile enters again the deeper structural level, the maximum pressures increase above the values for Koralpe and Saualpe.

5.2. Structure of the Austroalpine Nappes

In order to discuss the paleogeographic and tectonic implications, we have to shortly summarize the knowledge about the structure of the Austroalpine nappes.

They are elements of a Cretaceous-age orogen which were later, during the Tertiary, emplaced as a huge thrust sheet toward north on top of the Penninic and Helvetic nappes, derived from the Penninic Ocean and the European continental margin, respectively (Figure 4). The Austroalpine nappes form the Northern Calcareous Alps (NCA), comprising mostly Permo-Mesozoic sedimentary rocks, and basement-dominated units further south, between the southern border of the NCA and the Periadriatic line. The NCA are subdivided into the lower Bajuvaric nappes and the higher Tirolic nappes. The uppermost nappes are termed Juvavic (Lower and Upper). Mandl [2000] and Frisch and Gawlick [2003] have shown that the Upper Juvavic nappes are, in fact, southern parts of the Tirolic nappes, which were thrust out-of-sequence over more northerly parts of the Tirolic nappes. Leaving this out-of-sequence thrusting aside, the structurally highest parts of the NCA are the Hallstatt (Lower Juvavic) nappes, characterized by pelagic Triassic series. They come from the foot of the continental margin between the Austroalpine shelf to the northwest and the Meliata Ocean to the southeast. Higher units than the Hallstatt nappes are only very sparsely preserved in the southeasternmost part of the Northern Calcareous Alps. These comprise Triassic radiolarite and limestone, Jurassic sandstone and shale, and serpentinite, similar to the Meliata unit in the West Carpathians [Mandl and Ondrejickova, 1993]. It is generally assumed that a more extended oceanic thrust sheet from the Meliata basin once existed above the Hallstatt nappes but was eroded away during the Cretaceous.

Figure 2. Photomicrographs of kyanite eclogites. (a) Omphacite (Omp) with quartz (Qtz) inclusion surrounded by radial fractures and rods as SiO₂ precipitates. Optical microscope, plane polarized light. (b) Needles of SiO₂ in omphacite with orientation parallel to the c-axis of the omphacite. Backscattered electron image. (c) Radial fractures around a polycrystalline quartz inclusion in omphacite. Plane polarized light. (d) Polycrystalline polygonal quartz inclusion in garnet (Grt). Crossed polars.
South of the Northern Calcareous Alps, there are three types of Austroalpine nappes: (1) the Lower Austroalpine nappes, representing the continental margin between the Austroalpine and the Penninic Ocean to the northwest, (2) the Lower Central Austroalpine (lower level of the Central Austroalpine nappes in the sense of Trümpy [1980]), comprising basement with a scarce and only locally present Mesozoic sediment cover, in large parts affected by Cretaceous metamorphism up to eclogite facies, and (3) the Upper Central Austroalpine nappes with low-grade Variscan basement and unmetamorphosed Mesozoic cover remnants. These comprise, among other units, the Northern Grauwacke zone, Graz Paleozoic, and Gurktal nappe. (We suggest the terms “Lower Central Austroalpine” and “Upper Central Austroalpine” to replace the problematic terms “Middle Austroalpine” and “Upper Austroalpine”, respectively, of Tollmann [1959].) The eclogite-bearing, lowermost nappe of the Pohorje belongs to the Lower Central Austroalpine; the higher nappes of that area (weakly metamorphosed Paleozoic, Permo-Triassic sediments) to the Upper Central Austroalpine. The sedimentary rocks of the higher NCA nappes (Tirolic) locally rest with a transgressive contact on Paleozoic rocks of the Northern Grauwacke zone. Therefore the Tirolic nappes and the Upper Central Austroalpine are frontal and rear parts, respectively, of the same thrust system (Figure 5). Near the western end of the NCA, on the other hand, Mesozoic rocks of the lower NCA nappes (Bajuvaric nappes) rest with a transgressive contact on the northern border of the Lower Central Austroalpine Silvretta basement nappe [Rockenschaub, 1990]. This implies that the NCA are heterogeneous (Figure 5): the sedimentary rocks of the lower nappes (Bajuvaric) are connected with the Lower Central Austroalpine, and the higher nappes (Tirolic) with the Upper Central Austroalpine [Frisch and Gawlick, 2003].

5.3. An Intracontinental Subduction Zone in the Austroalpine Orogen

The understanding of the Austroalpine orogenic evolution has made significant progress in the last few years. Earlier, the Cretaceous metamorphism in the Austroalpine nappes had been related to the subduction of the more northwesterly located Penninic Ocean under the Austroalpine continent [e.g., Winkler, 1988]. Thöni and Jagoutz [1993], Neubauer [1994], Plasienka [1995] and Froitzheim et al. [1996], among others, developed a new picture where the metamorphism is related to the

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**Figure 3.** Results from geobarometry for kyanite eclogites (samples PO6 and JV03) using the assemblage Grt + Omp + Ky + Phn + Qtz/Coe and the Grt-Cpx Fe-Mg thermometer (abbreviations after Kretz [1983]). The quartz – coesite and graphite – diamond curves are calculated from thermodynamic data of Holland and Powell [1998].
collision of the Austroalpine with another continental fragment to the south or southeast (the “Pannonian plate” including the Bükk area [Plaštenka, 1995]). In this collision, after closure of the Meliata Ocean, the Austroalpine represented the lower plate. This view is now widely accepted. However, two questions still remain: (1) what was the orientation and geometry of the subduction zone that produced the Cretaceous eclogite facies.

**Figure 4.** Tectonic map of the Eastern Alps. Abbreviations are as follows: B, Bajuvaric; GN, Gurktal nappe; GP, Graz Paleozoic; K, Koralpe; NGZ, Northern Grauwacke zone; Ö, Southern Ötztal nappe; P, Pohorje; S, Saualpe; T, Tirolic. Modified after Neubauer and Höck [2000].

**Figure 5.** Stacking scheme of the Austroalpine nappes. Northwestward ascending thrusts define four nappe systems: Lower Austroalpine; Lower Central Austroalpine and Bajuvaric; Upper Central Austroalpine and Tirolic; Hallstatt nappes. Northwestern parts of the Tirolic cover nappes are derived from southeastern parts of the Lower Central Austroalpine basement (including Pohorje), as indicated by stippled arrow.
metamorphism and (2) is there an oceanic suture within the Austroalpine? The finding of UHP eclogites in Pohorje helps clarify these questions.

[24] The determined pressures of about 3.0 GPa indicate burial depth of close to 100 km and thus clearly require that the Lower Central Austroalpine crust was buried in a subduction zone under a mantle wedge (Figure 6). Such pressures cannot be reached in a thickened crust because the maximum crustal thickness in orogens is only about 70 km. The fact that the highest pressures are found in the southeasternmost part of the Austroalpine indicates a southeastward to southward dip of the subduction zone. The ca. 1.0 GPa pressure increase from Koralpe to Pohorje is equivalent to a southeastward increase in burial depth of about 30 to 40 km, over a horizontal distance of 50 km.

[25] Like all other eclogite facies remnants in the Austroalpine units, the Pohorje UHP rocks belong to the basement of the Lower Central Austroalpine. In the Koralpe, Saualpe, and Pohorje areas, the Lower Central Austroalpine basement does not carry remnants of its Permo-Mesozoic cover, which means that the cover has been sheared off from the basement when it entered the subduction zone, and has to be looked for to the Northwest. On the other hand, the Tirolic nappes have no pre-Permian substratum except in their most internal part where they locally rest with stratigraphic contacts on the Northern Grawacke zone. Therefore it may be assumed that the internal, high-pressure parts of the Lower Central Austroalpine nappes represent the basement on which large parts of the Tirolic Permo-Mesozoic sediments were deposited (Figure 5).

[26] Thöni and Jagoutz [1993] suggested that the Austroalpine eclogites represent the westward prolongation of the Meliata (Tethys) oceanic suture into the Alps, and that this suture extended still farther west between the Southern Alps and the Austroalpine. This view is based on the occurrence, in the Saualpe and Koralpe, of eclogitized gabbro bodies with MORB isotopic signatures. These gabbros have Permo-Triassic protolith ages of 290 to 240 Ma and they are interpreted to represent rifting processes preceding the breakup of the Meliata Ocean [Thöni and Jagoutz, 1993; Thöni, 1999]. Therefore the suture of the Tethys ocean was tentatively located in the Saualpe-Koralpe [Thöni and Jagoutz, 1993, Figure 6]. We do not share this view because the Meliata units are structurally above the Upper Central Austroalpine, whereas the Saualpe-Koralpe and Pohorje are below it (Figure 5). The vertical distance in the nappe edifice implies a horizontal distance in paleogeography. Instead, we assume that the gabbros represent intrusions in the thinned crust of a Permian rift [see also Schuster and Thöni, 1996; Schuster et al., 2001] northwest of the Meliata Ocean. This rift became the site of an intra-Austroalpine subduction zone when convergence across the Meliata suture went on after the Meliata Ocean had been closed (Figure 6) [see also Kurz and Fritz, 2003], for a similar interpretation). The site of the subduction was predetermined by the weakness resulting from the Permian rift. Toward west, the eclogite-bearing zone in the Middle Austroalpine continues to the southern border of the Ötztal nappe (Figure 4) [Hoinkes et al., 1991] and ends there. This suggests that the intra-Austroalpine subduction zone ended toward west, which requires a sinistral transform fault to take up the shortening from the subduction zone. The transform fault is a sinistral forerunner of the Tertiary-age, dextral Periadriatic line [Froitzheim et al., 1997].

5.4. Exhumation of the Austroalpine Eclogites

[27] The new findings have strong implications also for the exhumation mechanism of the Lower Central Austroalpine high-pressure terrane. Kurz et al. [2002] and Kurz and Froitzheim [2002] suggested that the Koralpe-Sausalpe eclogites were exhumed mainly by extensional unroofing in a core-complex mode. This assumption now becomes very unlikely because extensional unroofing from a depth close to 100 km would imply implausible amounts of stretching. Crustal extension during the Late Cretaceous did play a role in the exhumation of the Lower Central Austroalpine and affected also the Pohorje area. Fodor et al. [2003] documented that exhumation of Pohorje involved Late Cretaceous extensional shearing under ductile conditions and was finished in the Early to Middle Miocene by brittle normal faults. Extensional shearing and faulting can, however, only have accommodated exhumation from moderate, midcrustal depth. During the early and most important step of the exhumation from mantle depth to midcrustal depth, another mechanism must have been active.

[28] We tentatively suggest that the UHP rocks were initially exhumed by slab extraction [Froitzheim et al., 2003]. As discussed above, the Lower Central Austroalpine rocks were at peak-pressure time deeply buried under a lower crustal and mantle wedge belonging to the Upper Central Austroalpine. This substratum of the Upper Central

Figure 6. Hypothetical cross section of the Austroalpine orogen at circa 100 Ma. Pohorje eclogites are deeply buried in an intra-Austroalpine subduction zone. The exhumation of the eclogites was accommodated by later extraction (arrow) of the Upper Central Austroalpine lower crustal and mantle wedge. Dashed line delineates the slab that will be extracted.
Austroalpine is not present any more in the Alps, as the Upper Central Austroalpine now everywhere floats as allochthonous thrust nappes on the Lower Central Austroalpine. We suggest that the substratum was removed in a downward direction into the deeper mantle, thereby unroofing the buried Lower Central Austroalpine (Figure 6). The negative buoyancy of the Meliata oceanic slab, which was still attached to the Upper Central Austroalpine lithosphere, may have driven this removal or extraction.

6. Conclusions

[29] This finding of UHP eclogites in the Pohorje Mountains of Slovenia is new evidence for UHP metamorphism in the Alps. There are several important implications from our study:

[31] 2. The 3.0 GPa eclogites of Pohorje must have been subducted to depths of at least 90–100 km. This is considerably more than previous depth estimates (60–70 km) used for the thermal models [e.g., Willingshofer et al., 1999] of the Cretaceous continental collision in the Eastern Alps.

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