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PRE-MESOZOIC GEOLOGY OF THE MIDDLE AND UPPER AUSTRO-ALPINE METAMORPHIC BASEMENT EAST OF THE TAUERN WINDOW

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Introduction

In contrast to the Austro-Alpine basement west of the Tauern window, the eastern part is highly diverse. Its metamorphic grade ranges from nearly unmetamorphosed, fossiliferous Paleozoic sequences through low grade rocks in the so-called quartzphyllite units to medium and high grade metamorphic units in the "Altkristallin".

In this contribution we review fossil-free lithotectonic units of the Altkristallin of the Middle and Upper Austro-Alpine tectonic units which underwent pre-Alpine and/or Alpine, medium to high grade metamorphism (Fig. 1).

The lithotectonic units occur at different tectonic levels within the Alpine nappe edifice. Some of the major Alpine units are separated by Permo-Mesozoic rocks mainly along their northern margins. The following major Alpine basement nappes are distinguished (Tollmann, 1977):

* Upper Austro-Alpine nappes which include the crystalline Kaintaleck basement slices and the Ackerl complex,
* the Middle Austro-Alpine nappes which consist of distinct lithotectonic basement units, in particular the Muriden complexes, including the "Core", the Speik and the Micaschist-Marble complexes, and the Koriden gneiss complex, with its associated micaschist complexes, in particular the Plankogel complex,
* and the Lower Austro-Alpine units which include the higher "Semmering system" with the "Grobgneis" or "Raabalpen" unit (corresponding to the Tatric unit at the northeastern margin of the Eastern Alps) and the lower "Wechsel system" with the Waldbach and Wechsel gneiss complexes (see Neubauer et al., this volume).

Cretaceous metamorphism affected nearly all these Altkristallin rocks. It reached greenschist facies in most parts, and up to amphibolite facies and possibly eclogite facies in the central and southern part of the Middle and Lower Austro-Alpine units (Deutsch, 1988; Frank, 1987; Frank et al., 1987; Miller, 1990; Schimana, 1986; Dallmeyer et al., this volume). Therefore, pre-Alpine P-T paths have not yet been established in detail.

Lithostratigraphic units

We describe the different lithotectonic basement units from the Middle and Upper Austro-Alpine units. Geochronological data are presented in Table 1. Representative chemical analyses from various basement complexes are compiled for comparison in Table 1.

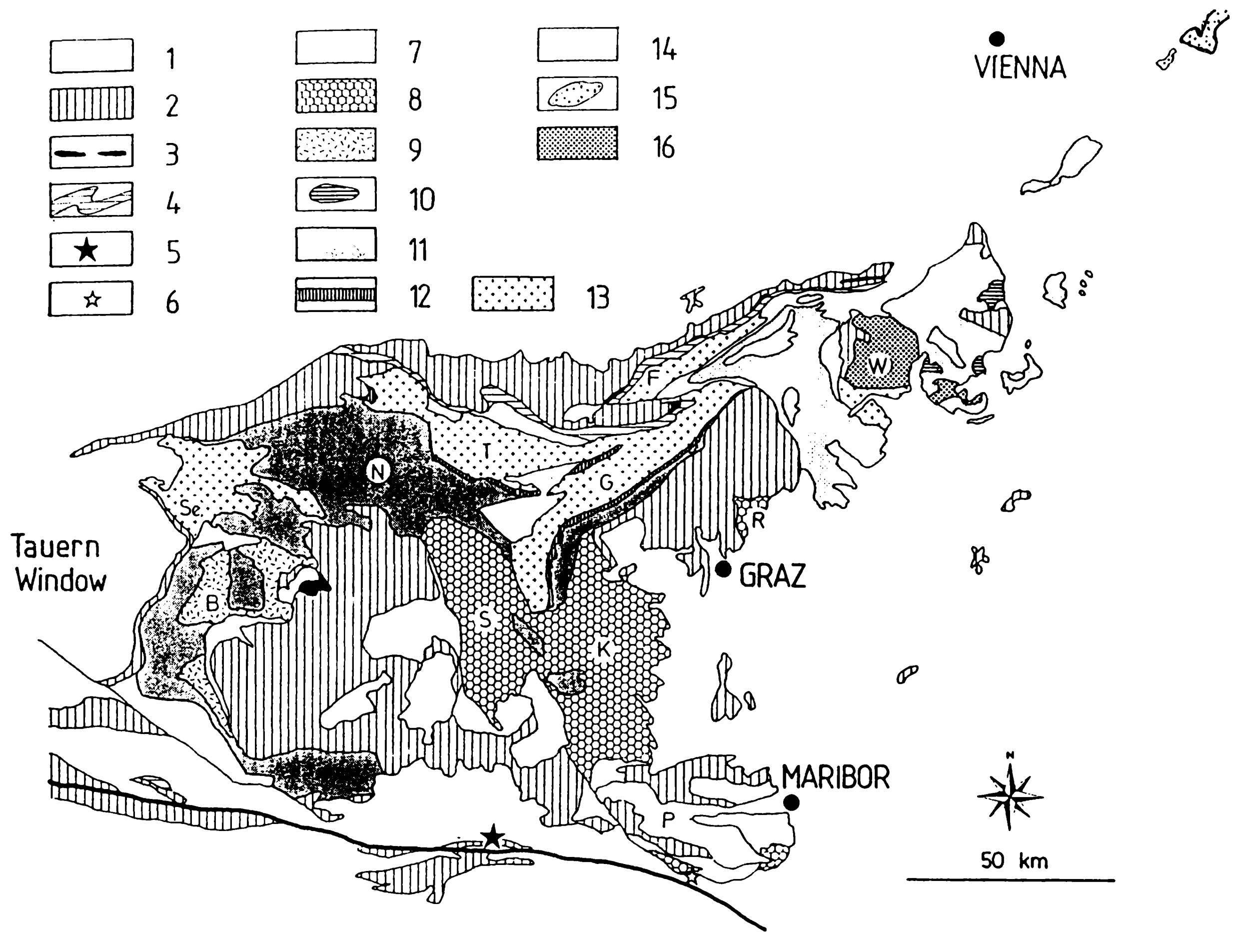

Fig. 1: Simplified map of Austro-Alpine basement units east of the Tauern window. Alpidic structures not shown. Legend: 1 - Permian to Cenozoic formations; 2 - fossiliferous Paleozoic formations and quartzphyllites; 3 - Kaintaleck slices and Ackerl complex (A); 4 - Carboniferous and Permian of the Veitsch nappe; 5 - Eisenkappel crystalline complex; 6 - Pohorje garnet-peridotite-granulite complex; 7 - Plankogel complex and related micaschist complexes; 8 - Koriden gneiss complex; 9 - Bundschuh complex; 10 - Sieggrabener complex; 11 - Micaschist-Marble complex; 12 - Speik complex; 13 - Core complex; 14 - "Grobgneis" complex; 15 - Tatric unit; 16 - Wechsel gneiss complex. Geographic signatures: B - Bundschuh; F - Troiseck-Floning mountains; G - Gleinalm; Gu - Gurktaler Alpen; K - Koralpe; L - Leithagebirge; N - Niedere Tauern; P - Pohorje mountains; R - Rennfeld; S - Saualpe; Sc - Schladminger Tauern; T - Seckauer Tauern; W - Wechsel.

Muriden

The term Muriden was created for basement units which differ from the Koriden and Raabiden (Raabalpen complex) (e.g., Kober, 1938). The Muriden complex contains three major lithotectonic units (Fig. 1, 2):

* the Micaschist-marble complex as the uppermost unit,
* the Speik complex and
* the "Core complex" which appears in structural domes or cores as the lowermost unit.

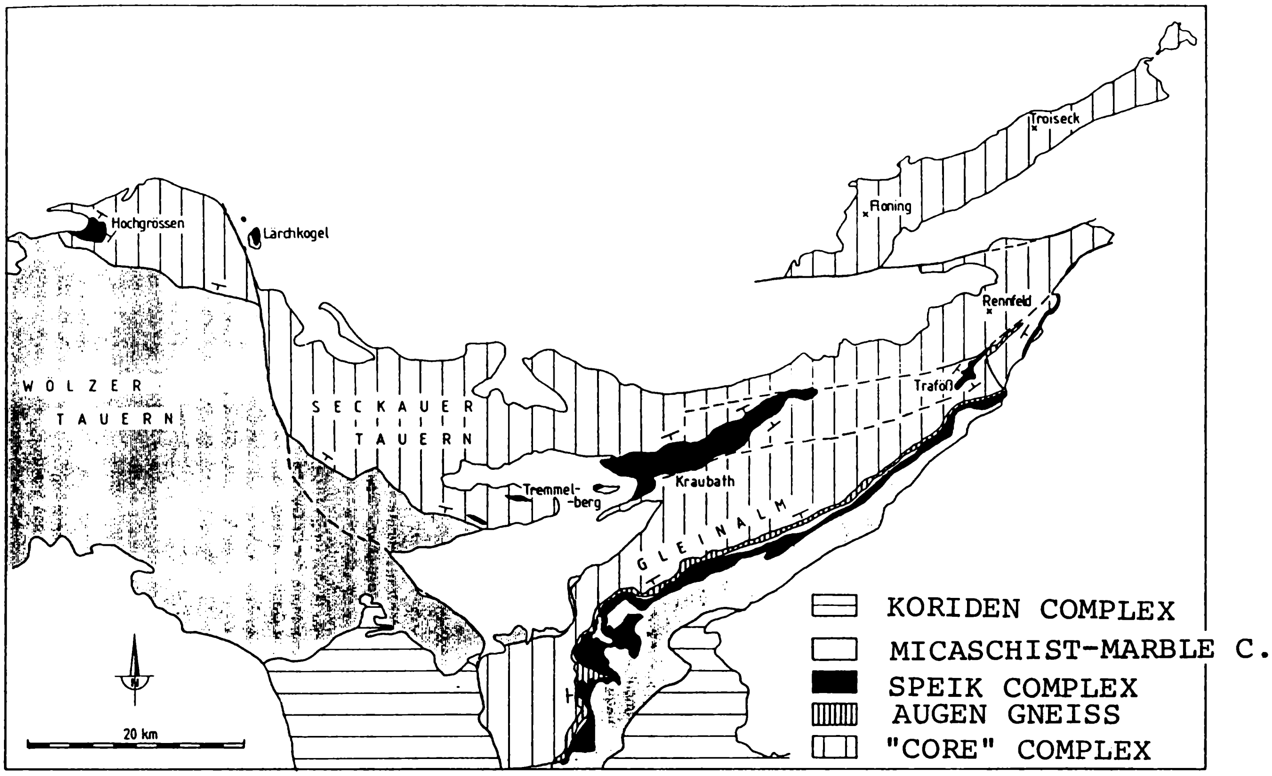

Fig. 2: Simplified geological map of the Gleinalm-Rennfeld-Mugel area which exposes Muriden complexes (modified from Neubauer, 1988a).

"Core complex"

The "Core complex", best studied in the Gleinalm and Rennfeld-Mugel areas, is also exposed in the Troiseck-Floning, the Seckauer Tauern and Bösenstein, and the Schladminger Tauern (Fig. 1).

In each locality, the "Core complex" consists of the following lithological units (see, for example, Fig. 2):

* A thick pile of strongly foliated biotite plagioclase paragneisses form the country rocks of all the other magmatic lithological units.

* Plagioclase orthogneisses appear in large cuppolas mantled by biotite plagioclase paragneiss.

* Large masses of various amphibolites are enclosed within plagioclase paragneiss and orthogneiss (Becker, 1981; Frisch et al., 1987; Haiss, 1991; Neubauer, 1988a; Schedl, 1981). The most common amphibolite type is a banded amphibolite which includes orthogneiss layers on the scale of centimetres to metres (Frank et al., 1976; Frisch et al., 1987). This amphibolite strongly resembles the leptinite-amphibolite complexes of Variscan basement massifs in western Europe (e.g., Santallier et al., 1988). The banded amphibolite is in close spatial relationship to the plagioclase orthogneiss (Fig. 2).

* A layered metatonalite complex ("metablastic amphibolites") is accompanied by ultramafic rocks, metagabbros and rare acidic rocks (Becker and Schumacher, 1970; Frisch et al., 1987); Neubauer, 1988a; Teich, 1987a, b).

* Major plutons of granitic, granodioritic and tonalitic rocks occur in all domes. A sheet-like augen gneiss forms the hangingwall boundary of the "Core complex".

The biotite plagioclase paragneiss contains thin marbles, calcsilicate rocks and garnet micaschists, which include manganese quartzites and carbonates (Paul and Neubauer, 1992), as marker horizons. The gneiss itself exhibits a locally well-preserved sedimentary layering which may reflect graded bedding of graywackes (Neubauer 1988a). Both the geochemistry and the zircon habitus suggest that the paragneiss may be derived from volcanogenic graywackes (Frisch et al., 1987; Haiss, 1991; Neubauer, 1988a). U-Pb zircon data suggest late Proterozoic to early Palaeozoic origin of the clastic zircons (Neubauer et al., in prep.). We interpret the plagioclase paragneiss sequence as graywacke prism on the margin of a magmatic arc complex which has been interrupted by sedimentation on an abyssal plane with pelites and siliceous, manganese-bearing rocks.

The plagioclase orthogneisses form a major pluton in the Gleinalm area (Fig. 2) with a Rb-Sr whole rock errorchron of 518 ± 50 Ma (Frank et al., 1976). Haiss (1991) found a U-Pb minimum age of approximately 500 Ma based on nearly concordant zircons. These rocks, in association with the banded amphibolites, were interpreted as a bimodal volcanic sequence (Frank et al., 1976). However, the dome-like form of the orthogneisses crosscutting other lithologies (Fig. 2), the rock distribution, the occurrence of amphibolite xenoliths and mappable discordant contacts between plagioclase orthogneiss and country rocks argue for a plutonic origin (Neubauer, 1988a; Neubauer, 1989b). The layering is the result of mylonitization and ductile shearing of both rock types after the intrusion of the orthogneiss protoliths into the amphibolites (Neubauer 1989b).

The amphibolites display a wide range of petrographic and chemical compositions. Because of intense ductile deformation, relics of magmatic mineralogy are preserved in only a few bodies. Well-preserved gabbros are mainly related to the suite of the "metablastic amphibolite", e.g. the Utschgraben meta-gabbro (Schatzmayer et al., 1990). These bodies contain relics of orthopyroxene and clinopyroxene (Hermann, 1972). In contrast, Haiss (1991) has described amphibolites which are derived from subalkaline basalts with an intraplate component. Other major amphibolite bodies show a more calcalkaline composition according to their major, minor, trace and REE chemistry (Fig. 3). Cumulate gabbroic rocks may form a major portion of the amphibolites as suggested by rare relict minerals, strong positive Eu anomalies, low Ti contents and other chemical features (Fig. 4). Gabbro-derived amphibolites dominate volumetrically within both the plagioclase paragneiss and the orthogneiss. All these data indicate different origins and variable ages of the amphibolites. Protolith ages of these amphibolites are uncertain. An unusual, highly differentiated garnet amphibolite yielded a U-Pb zircon age of ca. 425 Ma (lower intercept age; Neubauer et al., in prep.).

Some major amphibolite bodies exhibit migmatitic fabrics near contacts to country rocks (Neubauer, 1988a). Trondhjemite gneisses form leucosomes, hornblende felses the palaeosomes. The association is interpreted as result of partial melting of amphibolites (Neubauer, 1988, 1992). Nearly concordant U-Pb zircons at 353 ± 2 Ma indicate a Variscan age of trondhjemite formation, and, therefore, of high-grade metamorphism (Neubauer et al., in prep.).

The plutonic suite of the "metablastic amphibolite", a metatonalite, is widespread throughout the Core complex. It outcrops over a distance of 70 km mostly at the boundary between biotite plagioclase paragneiss and the banded amphibolite. The most prominent rock type of this suite is a medium-grained, massive plagioclase amphibolite or hornblende gneiss which includes lenses of metapyroxenite, metawehrlite, hornblendite, metagabbros and augengneisses which are derived from porphyric biotite granites. This augengneiss differs from the sheet-like augen gneisses at the hangingwall boundary of the Core complex. The plutonic suite is probably derived from more than one magma. The average metatonalite shows differentiation to more hornblende-poor types and to mafic and ultramafic cumulates. Own unpublished Sr isotopic data indicate contamination with radiogenic Sr of some metagabbros which are enclosed within the metatonalite. The trace element signature of the augengneiss is different from, and the REE contents are lower than, those of the metatonalite. The lower intercept U-Pb zircon age of the metatonalite is 356 ± 5 Ma (Neubauer et al., in prep.) which is interpreted as the age of Variscan metamorphism. The upper intercepts of the metatonalite near 3 Ga and of the augengneiss at 2.25 Ga indicate contamination by old, Archaean to Proterozoic zircons derived from continental crust during melt formation and magma rise. One of the augen gneiss lenses yielded a lower intercept U-Pb zircon age of ca. 425 Ma. A preliminary Rb-Sr errorchron with 390 ± 49 Ma contradicts the U-Pb zircon age of the metatonalite.

Most granitic, granodioritic and rare tonalitic and dioritic orthogneisses postdate formation of other lithologies. An orthogneiss from the Seckauer Tauern with unknown contact with the country rocks yielded a Rb-Sr age of 432 ± 16 Ma (Scharbert, 1981). A nearly concordant U-Pb zircon age (ca. 500 Ma) from a tonalite gneiss is interpreted as the minimum formation age (Haiss, 1991). Other

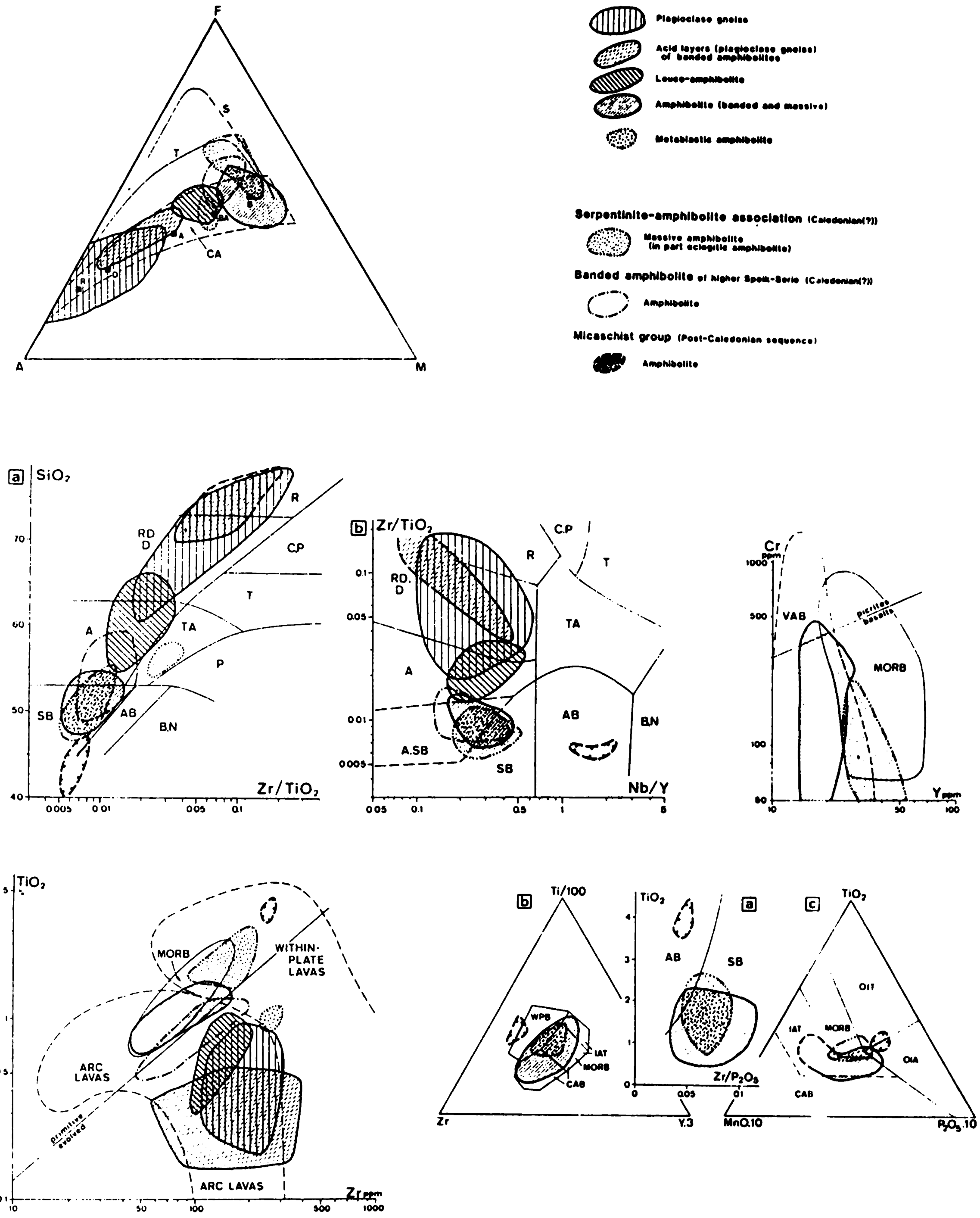

Fig. 3: Geochemical discrimination of amphibolites of the Murides units (after Frisch et al., 1987).

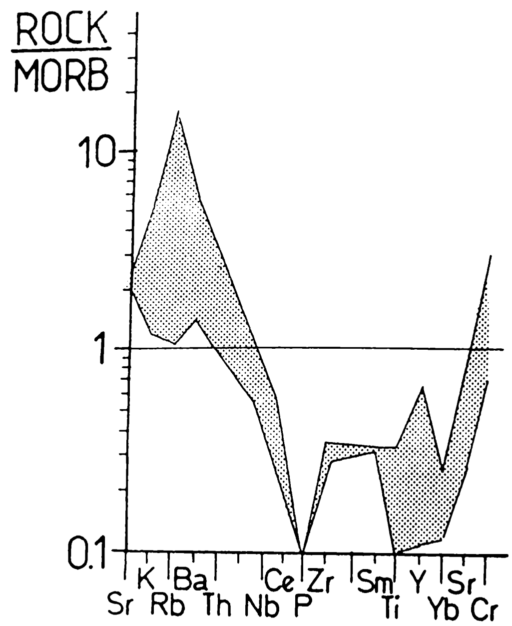

Fig. 4: Spidergram of a major metagabbroic amphibolite body from the "Core complex" (from Schatzmayer et al., 1990).

granitoids are fine-grained granite and granodiorite gneisses which form discordant plutons and sheet-like augengneisses (Neubauer, 1988a; Teich, 1979). A characteristic two-mica augengneiss forms the hangingwall boundary of the Core complex in the Gleinalm, Seckauer Tauern and Schladminger Tauern (Becker, 1981). The Gleinalm augengneiss yielded a Rb-Sr errorchron of 330 $\pm$ 30 Ma (Frank et al., 1983). The widespread granitoids in the Gleinalm and Rennfeld area are mostly mica-poor. Various flaser granite gneisses and two-mica granites like the Zinken granite occur in the Seckauer Tauern (Metz, 1976a; Scharbert, 1981). The Zinken metagranite yielded a Rb-Sr age of 354 $\pm$ 16 Ma (Scharbert, 1981) indicating an early Carboniferous age of intrusion. The source of early Variscan granitic rocks is uncertain because detailed investigations have not been made yet. The presence of white mica in some granitoids argues for a S-type origin.

We interpret the "Core complex" as a late Proterozoic to early Palaeozoic root of a magmatic arc which was flanked by sedimentary basins. The protoliths of the biotite plagioclase paragneiss may have formed in an arc-related basin which was later buried and intruded by mafic and acidic magmas. A major step in evolution is indicated by the most frequent age group in the range of 460 - 425 Ma which is exclusively related to magmatic rocks. Granites intruded during this period for the first time (orthogneiss in the Seckauer Tauern). Crustally-derived radiogenic Sr isotopic composition as well as Archaean and early Proterozoic memories in magmatic zircon indicate the presence of old continental crust underlying the "Core complex" during this time. Therefore, the subduction process ceased during this time by subduction of or collision with a plate composed of old continental crust which provided the Precambrian isotopic signature of the calcalkaline melts. We do not know whether there is a continuous transition of plutonism to the Carboniferous granitoids. The Carboniferous granitoids are related to final collision of the Core complex with other basement units of the Eastern Alps, e.g. the Speik complex.

Speik complex

The Speik complex (Fig. 2, 5) consists of a package of several hundred metres thick garnet amphibolites and banded amphibolites (meta-basaltic rocks), garnet-zoisite and plagioclase amphibolites (meta-gabbroic rocks), thin augengneiss or serpentinite lenses up to 20 kilometers in length, and rare metasedimentary rocks (El Ageed et al., 1980; Frisch et al., 1987; Haditsch et al., 1981; Neubauer, 1988a; Neubauer et al., 1989b). The complex is exposed along the southern

Gleinalm, at Kraubath, Trafößs and Hochgrößen. An eclogite occurrence is also reported from the Hochgrößen (Wieseneder, 1969; Richter, 1973). All these rocks are intensely foliated.

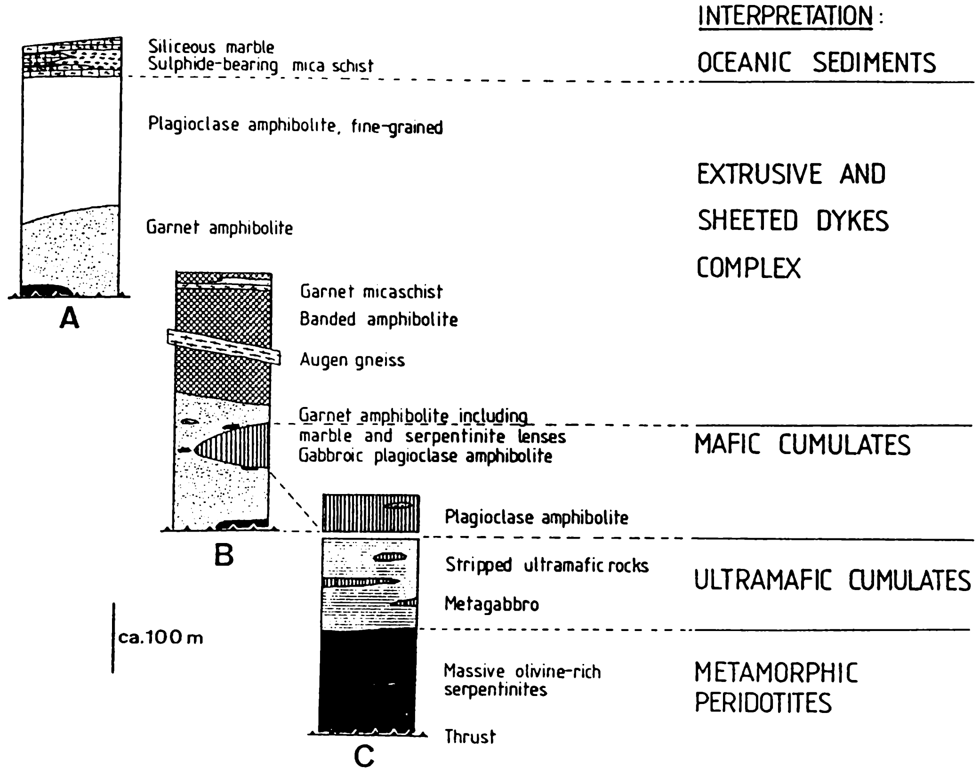

Fig. 5: Lithostratigraphy of the Speik complex (after Neubauer et al., 1989a).

Petrographic and chemical data provide evidence that the Speik complex contains all members of an ophiolite. Refractory ultramafic rocks are mainly exposed at Kraubath and Hochgrößen (El Ageed et al., 1980). Ultramafic and mafic cumulates are common within the Trafößs body (Neubauer, 1988a). The chemical patterns of garnet amphibolites of the southern Gleinalm are close to those of back arc basin ocean floor basalts (Neubauer et al., 1989b). Locally occurring sulphide-rich quartzites and impure marbles are interpreted as the oceanic sedimentary layer (Neubauer, 1988a).

The Speik complex has not yet been dated by geochronological methods. Its age is presumed to predate the Micaschist-Marble complex in the hangingwall for which a late Ordovician to Devonian age is assumed based on lithostratigraphic correlations (see below).

Micaschist-Marble complex

The Micaschist-Marble complex is widespread throughout the Middle Austro-Alpine basement (Fig. 1). It occurs along the southern margin of the Gleinalm, within the Niedere Tauern, and is again widespread southeast of the Tauern window and in the Kreuzeck Mts. south of the Tauern window (Becker, 1981; Hoke, 1990; von Gosen, 1989a) (Fig. 1). Feldspar-rich and quartz-rich micaschists dominate in the structurally lower part. The middle portion contains garnet micaschists, pale-coloured quartzites, thin amphibolites and black schists (Becker, 1981; Becker and Schumacher, 1970; Metz, 1976b; Neubauer, 1988a). Siliceous and pure marbles, which are also intercalated with biotite amphibolites, some garnet micaschist and sheet-like pegmatites, dominate the upper portion of the sequence (Fig. 6). The transition of micaschist to carbonates is characterized by calcsilicate rocks, and sometimes by scheelite-bearing tourmalinites and dolomitic marbles (Becker, 1977, 1981; Neubauer, 1988a; Raith, 1988).

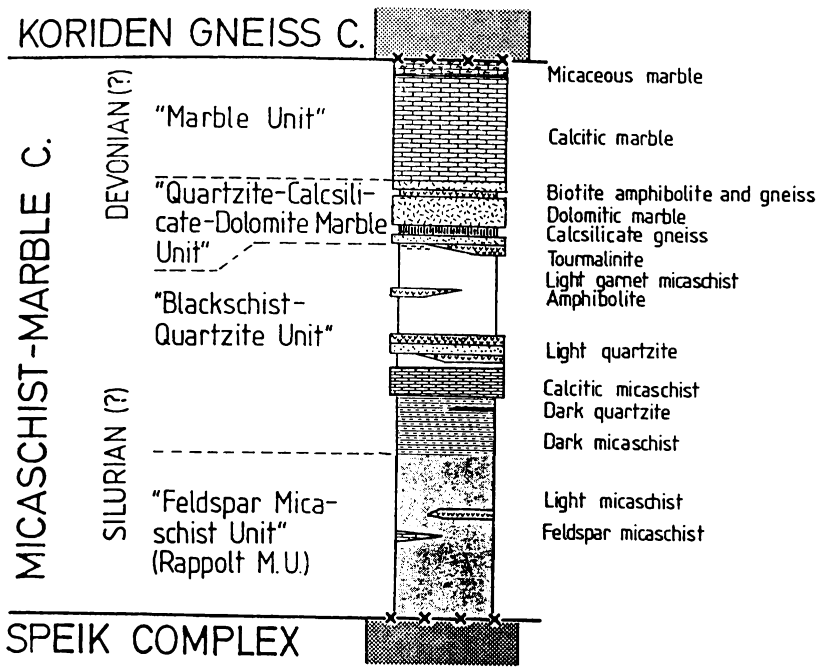

Fig. 6: Lithostratigraphy of the Micaschist-Marble complex, Gleinalm area (modified from Neubauer, 1988a).

Geochronological data of protolith ages are not available. The sequence can be correlated with the fossil-bearing late Ordovician to early Carboniferous sequences of the Eastern Alps: the micaschists are presumed to be of late Ordovician to early Devonian age, the marbles of mainly mid-Devonian age (Becker, 1977, 1981; Neubauer, 1988a).

The field relationship of the augengneiss in the lower Muriden complex and pegmatites in the Micaschist-Marble complex suggest cogenetic, early Carboniferous formation (Neubauer, 1989a). The Li- and Be-mineralizations of some pegmatites (e.g., Koller et al., 1983) classify them as highly fractionated melts derived from a major granite.

Pre-Alpine tectonothermal evolution of the Muriden

The Core complex, the Speik complex and the Micaschist-Marble complex have a common Variscan thermal history. The "Caledonian thermal event" is evidenced only in the "Core complex" by U-Pb zircon lower intercept data of the augengneiss within the metatonalite suite, and the garnet amphibolite between 450 and 425 Ma (Tab. 1). In addition, scattered paragneiss zircons are close to the discordia of this intercept (Neubauer et al., in prep.). The same age is found in an orthogneiss of the Seckauer Tauern (Scharbert, 1981). All these data indicate magma crystallization during this time. Evidence of deformation and metamorphism during this time span is lacking.

The superposition of both Speik and Micaschist-Marble complexes on the Core complex most probably predates peak thermal conditions of pre-Alpine metamorphism.Thrusting is accompanied by intrusion of granites, the protoliths of the augengneiss on top of the Core complex and within the Speik complex, into the zone of thrusting (Neubauer, 1988b; 1989a, b). Ductile deformation of hot granites and amphibolitic country rocks is attributed to large shear strain which caused the mylonitic fabric and the layering of gneisses and most banded amphibolites (which derived most probably from veined amphibolites). The fact that the augengneiss horizon climbs southwestwards from the top of the Core complex through the Speik complex into the Micaschist-Marble complex indicates top-to-the-

Koriden complex ("Gneiss group")

The Koriden Gneiss complex is exposed in the Koralpe (Beck-Mannagetta, 1970; Frank et al., 1983), Saualpe (Weissenbach, 1975) and Pohorje mountains (Hinterlechner-Ravnik and Moine, 1977)

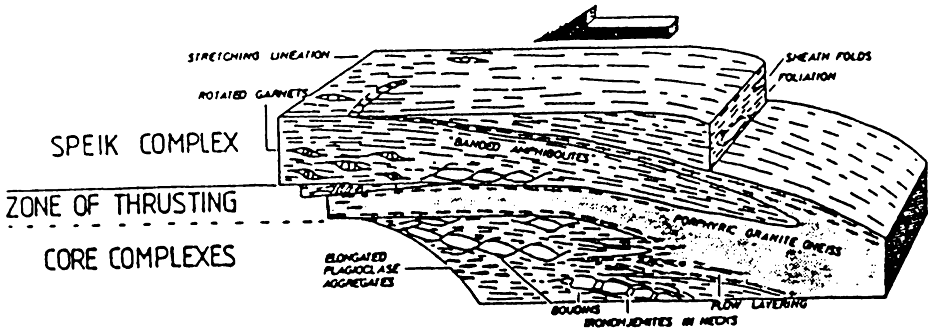

Fig. 7: Model for Variscan melt-enhancend emplacement of the Speik ophiolite nappe (modified from Neubauer, 1989b).

and consists of a thick sequence of kyanite-bearing paragneiss, paragneiss with kyanite paramorphs after andalusite, enclosing up to kilometre-sized lenses of eclogite and amphibolitic eclogite (Fig. 1). Intercalations of rare relics of metagabbro, marbles, manganese quartzites, calcsilicate rocks, and widespread pegmatites are observed (Hinterlechner-Ravnik and Moine, 1977; Raith, 1988; Weissenbach, 1975).

The age and evolution of the Gneiss group is the subject of lively discussion. The paragneiss is interpreted as metamorphosed graywacke and shale (Pacher and Riepl, 1978; Heritsch, 1980). The eclogites are derived from two different protoliths: Kyanite-bearing, low-Ti eclogites from gabbros (clinopyroxene-bearing cumulates), kyanite-free, high-Ti eclogites from N- and E-type MOR basaltic rocks (see, Tab. 2; Miller, 1990; Miller et al., 1988; Manby and Thiedig, 1988). The nature of the protolith and the metamorphic ages are uncertain. Manby and Thiedig (1988) and Manby et al. (1989) argued for late Precambrian eclogite metamorphism based on a Sm-Nd garnet-whole rock age of 693 Ma. Thöni and Jagoutz (1991) favour a Permian age of one of the gabbroic protoliths and an Alpine age of eclogite metamorphism. A pegmatite within the eclogite amphibolite, however, yielded a Permian Rb-Sr age (Scharbert, cited in Göd, 1989). Coarse-grained pegmatitic muscovite from pegmatite in paragneissic country rock yielded Rb-Sr ages in the range of 267 - 244 Ma (Frank et al., 1983; Morauf, 1981). These ages are considered to be slightly rejuvenated due to Alpine metamorphic overprinting under amphibolite facies conditions (Frank, 1987; Frank et al., 1987; Krohe, 1987; Rittmann, 1983). Rb-Sr thin slab isochrons of the mylonitic "Plattengneis" also gave intra-Permian ages (Frank et al., 1981, 1983) somewhat younger than U-Pb zircon ages (Paquette and Gebauer, 1989). Most workers agree that a Variscan metamorphic complex with low pressure characteristics (andalusite stability) was intruded by numerous pegmatites in late Variscan time (Becker et al., 1987; Frank et al., 1983; Göd, 1989). The crucial relationship of pegmatites to eclogites suggests a Permian or post-Permian age of eclogitization (for further discussion, see Neubauer, 1991).

East of the Wechsel window, the "Grobgneis" complex is overlain by several klippen of the "Sieggrabener complex" (Kümel, 1935) (for location, see Fig. 1). Their superposition on the "Grobgneis" complex is eo-Alpine in age. The Sieggrabener complex is composed of biotite-garnet paragneiss, kyanite gneiss, eclogite amphibolite, calc-silicate rocks, marble, and a large, kilometre-scale serpentinized peridotite body (Kümel, 1935; Richter, 1973). Most authors correlate the sequence with the gneiss complex in the Koralpe and Saualpe. The data base is poor. The chemistry of the eclogites to that of N-type MOR basaltic rocks (Kiesl and Weinke, cited in Koller, 1990) Garnet-clinopyroxene thermometry indicates a temperature of approximately 630^{o} C, and phengite and pyroxene composition a pressure of ca. 10 kb (Kiesl and Weinke in Koller, 1990).

The serpentinite body has in general a normative harzburgitic composition. It contains spinel pyroxenite and rodingite (Evren, 1972; Koller and Richter, 1980).

Rock	Method	Age (error)	Rb-Sr initial ratio (error)	Reference
Murides, core complex				
Plagioclase gneiss	Rb-Sr WR	518 (44)	.7044 (.7012)	Frank et al. (1976)
Orthogneiss	Rb-Sr WR	432 (16)	.71158 (.00235)	Scharbert (1981)
Garnet amphibolite	U-Pb z.l.	c.435		Neubauer et al. (in prep.)
Augen gneiss	U-Pb z.l.	c.425		Neubauer et al. (in prep.)
Metatonalite ("Metablastic amphibolite")	U-Pb z.l.	356		Neubauer et al. (in prep.)
Two-mica metagranite (Zinken granite)	Rb-Sr WR	354 (16)	.7047 (.0007)	Scharbert (1981)
Trondhjemite gneiss	U-Pb z.c.	353 (2)		Neubauer et al. (in prep.)
Augen gneiss	Rb-Sr WR	331 (25)	.7058 .0029	Frank et al. (1983)
	Rb-Sr mu	258 (1)		Frank et al. (1983)
Metagranite	Rb-Sr mu	331 (7)		Scharbert (1981)
Pegmatite	Rb-Sr mu	329 (12)		Scharbert (1981)
Pegmatite	K-Ar mu	347 (7)		Hejl (1984)
Pegmatite	K-Ar mu	340 (18)		Hejl (1984)
Biotite amphibolite	K-Ar bio	276 (15)		Hejl (1984)
Pegmatite	K-Ar mu	265 (14)		Hejl (1984)
Plagioclase gneiss	K-Ar mu	282 (15)		Hejl (1984)
Murides, Micaschist-Marble complex				
Villach orthogneiss	Rb-Sr WR	445 (44)	.7122 (.0014)	Frimmel (1988)
Wolfsberg granite	Rb-Sr WR	258 (11)	.7046 (.0028)	Morauf (1980)
Pegmatite	Rb-Sr mu	347 (6)		Frank et al. (1983)
Pegmatite	Rb-Sr mu	277 (1)		Frank et al. (1983)
Pegmatite	Rb-Sr mu	256 (30)		Jäger and Metz (1971)
Bundschuh area				
Bundschuh orthogneiss	Rb-Sr WR	372 (29)	.738 (.002)	Hawkesworth (1976)
	Rb-Sr mu	352 (4)		Frimmel (1986)
"Kaintaleck slices"				
Hornblende-garnet gneiss	U-Pb z.u.	2,530		Neubauer et al. (1989)
	U-Pb z.l.	516		
Paragneiss	U-Pb z.l.	391 (2)		Neubauer et al. (in prep.)
Aplitic orthogneiss	U-Pb z.u.	365 (20)		Neubauer et al. (in prep.)
Orthogneiss boulder	U-Pb z.u.	502 (6)		Neubauer et al. (1987)
Orthogneiss boulder	U-Pb z.u.	500 (20)		Neubauer et al. (1987)
Eisenkappel				
Karawanken granite	K-Ar hb	252 (9)		Cliff et al. (1974)
	Rb-Sr bio	232 (9)		Scharbert (1975)

Korides

Eclogite	Sm-Nd WR-gt	693 (39)		Manby and Thiedig (1988)
Micaschist	U-Pb zi.u.i.	1200 (60)		Paquette and Gebauer (1989)
"Plattengneis"	U-Pb zi.u.i.	2015 (49)		Paquette and Gebauer (1989)
	l.i.	297 (3)		
	Rb-Sr t.s.i.	256 (35)	.7158 (.0012)	Frank et al. (1981)
	Rb-Sr t.s.i.	249 (6)		Frank et al. (1983)
Metagabbro	Sm-Nd m.i.	275 (18)		Thöni and Jagoutz (pers. comm.)
Pegmatite	Rb-Sr WR	ca. 280		Scharbert, cited in Göd (1990)
	Rb-Sr mu	277 (5)		Frank et al. (1983)
	Rb-Sr mu	265 (25)		Morauf (1981)
	Rb-Sr mu	263 (25)		Morauf (1981)
	Rb-Sr mu	263 (25)		Frank et al. (1983)
	Rb-Sr mu	258 (16)		Morauf (1981)
	Rb-Sr mu	249 (16)		Morauf (1981)
	Rb-Sr mu	247 (15)		Morauf (1981)
	Rb-Sr mu	246 (16)		Morauf (1981)
	Rb-Sr mu	246 (32)		Morauf (1981)
	Rb-Sr mu	244 (26)		Morauf (1981)
Pegmatite (St. Radegund)	Rb-Sr WR	313 (18)	.7147 (.0010)	Neubauer and Stattegger (unpubl. data)
	Rb-Sr mu	308 (16)		Neubauer and Stattegger (1981)
	Rb-Sr mu	303 (65)		Neubauer and Stattegger (1981)

Tab. 1: Compilation of significant geochronological data of Middle and Upper Austro-Alpine basement rocks east of the Tauern window. Older data are recalculated with lambda = 1.42 x 10^{-11} a^{-1}. Explanation: WR - whole rock age, z.l. - zircon lower intercept age; z.u. - zircon upper intercept age; m.i. - mineral isochron; t.s.i. - thin slab isochron; mu - muscovite, gt - garnet, hb - amphibole, bio - biotite.

southwest shear. Because of the early Carboniferous age of the augengneiss, a Variscan age is presumed for thrusting (Neubauer, 1989a, b). The Speik complex is, therefore, considered by Neubauer (1988a) to be a large Variscan ophiolite nappe (Fig. 7) because of the Variscan age of granite emplacement into the zone of thrusting and the Variscan age of penetrative fabrics. The age of the Speik complex is assumed to be pre-Silurian. The metamorphic conditions are assumed to have reached the stability field of staurolite in the early Carboniferous.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Sample	R146	RF115	RF143	RF118	RF145	556	23	SK1	GE2	34	333b	GR-D	GR115
SiO_2	49.88	48.30	47.87	53.68	47.12	48.56	48.88	42.40	48.74	48.91	49.28	44.65	48.05
TiO_2	1.18	1.62	0.64	1.12	0.15	1.30	3.44	0.42	2.54	1.35	3.18	1.30	2.22
Al_2O_3	15.09	15.12	19.98	16.85	19.75	13.28	14.58	28.78	14.55	14.77	14.22	16.15	14.22
Fe_2O_3	2.02	2.99	1.03	1.29	0.45	2.10	1.48	0.80	1.27	1.26	2.07	11.04*	12.57
FeO	6.76	7.44	5.45	5.38	6.50	11.44	10.05	6.00	9.30	9.24	10.96	n.d.	n.d.
MnO	0.18	0.21	0.12	0.14	0.15	0.25	0.16	0.09	0.18	0.22	0.31	0.17	0.17
MgO	6.80	6.96	9.68	5.11	9.99	6.67	6.54	4.59	8.13	10.19	5.76	5.57	5.83
CaO	9.27	11.63	9.65	7.93	12.55	9.91	7.19	15.10	12.10	10.90	8.61	11.93	11.31
Na_2O	3.71	2.81	3.00	3.54	1.21	3.00	3.94	1.10	2.88	0.88	3.07	3.14	3.11
K_2O	0.10	0.31	0.47	2.08	0.13	0.20	--	0.06	0.09	0.15	0.21	0.42	0.52
P_2O_5	0.19	0.21	0.15	0.62	0.19	0.12	0.50	0.05	0.18	0.06	0.44	0.13	0.22
L.O.I.	2.78	1.74	1.71	2.23	1.64	0.48	1.00	1.07	1.23	1.18	0.46	4.69	1.24
Cr	180	200	143	116	135	72	372	248	206	282	54	111	175
Nb	<2	n.d.	n.d.	12	n.d.	n.d.	68	8	5	<5	45	<7	18
Ni	13	101	219	<5	81	54	123	59	73	149	29	74	125
Rb	6	2	16	73	3	<3	11	7	<4	10	7	12	11
Sr	366	183	255	766	232	112	554	271	182	98	347	291	368
Y	18	26	18	34	14	28	24	17	38	24	25	22	16
Zr	100	91	54	281	15	81	307	35	130	68	211	84	158

*Tab. 2: Representative chemical analyses of Austro-Alpine amphibolites. Major and minor element oxides in weight percent, trace elements in ppm. n.d. - not determined; * - Fe_2O_3 as total Fe.*
1: Epidote amphibolite from the Wechsel gneiss complex (own unpubl. analysis).
2: Plagioclase amphibolite from the "Core" complex with supposed calcalkaline basaltic origin (From Neubauer, 1988a).
3: Plagioclase amphibolite from the "Core" complex with supposed gabbroic origin (from Neubauer, 1998a).
4: "Metablastic amphibolite" (metatonalite) from the "Core" complex (from Neubauer, 1988a).
5: Metagabbro of the Speik complex (Neubauer, 1988a).
6: Garnet amphibolite of the Speik complex (from Schlöser, 1987).
7: Alkalic garnet amphibolite of the Micaschist-Marble complex (from Schlöser, 1987).
8: Low-Ti eclogite of the Koriden complex (Miller et al., 1988).
9: High-Ti eclogite of the Koriden complex (Miller et al., 1988).
10: Garnet amphibolite of the Plankogel complex (Schmerold, 1988).
11: Biotite amphibolite of the Plankogel complex (Schmerold, 1988).
12: Garnet-zoisite amphibolite of the Ritting complex (own unpublished analysis).
13: Amphibolite of the Frauenberg complex (own unpublished analysis).

Plankogel complex and accompanying micaschists

A package of micaschist units overlies the gneiss group along the southern margin of the Saualpe and Koralpe (Weissenbach, 1975; Kleinschmidt and Ritter, 1976) and in the Pohorje Mountains (Hinterlechner-Ravnik and Moine, 1977). The most prominent units are the Plankogel complex at the bottom and the Kräuping complex above it which in turn is structurally overlain by phyllitic micaschists.

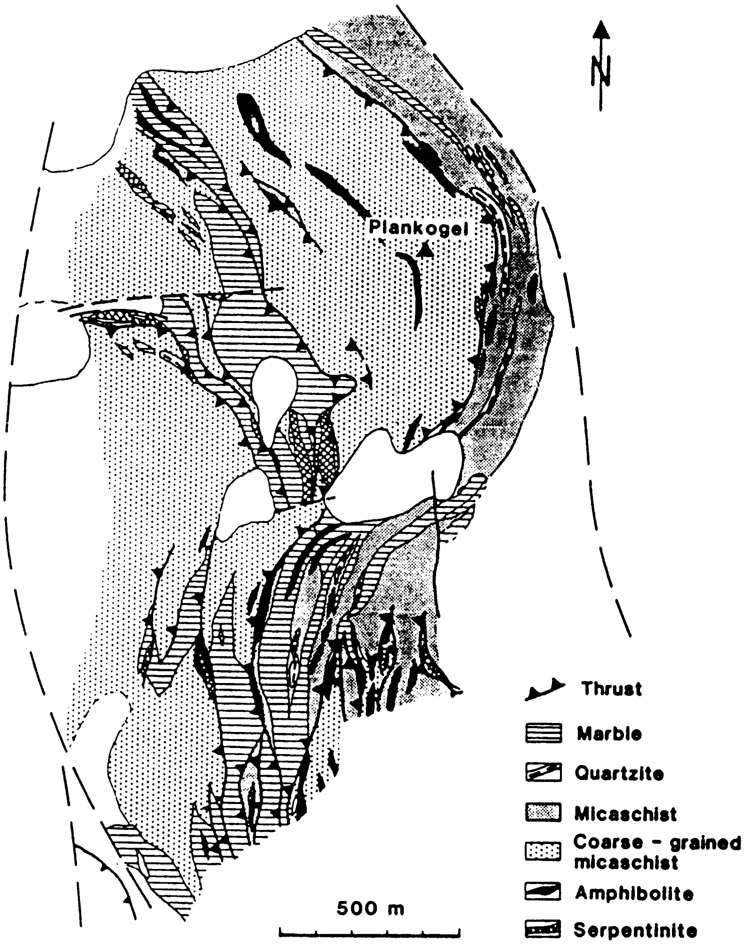

Fig. 8: Map showing the internal structure (ophiolitic melange) of the Plankogel complex (modified after Neubauer et al., 1989a).

The Plankogel complex consists of a staurolite-garnet micaschist matrix in which up to kilometre-sized lenses of marbles, amphibolites, manganese quartzites and ultramafic rocks are embedded (Kleinschmidt, 1975; Weissenbach, 1975). Schmerold (1988) subdivided the Plankogel complex into two subunits (Fig. 8, 9): (1) The "manganese quartzite unit" contains plagioclase and biotite micaschists, amphibolites with an alkali basaltic chemistry, silicate-rich marbles and manganese-bearing quartzites. This unit is interpreted in terms of an oceanic island environment. (2) The "serpentinite-bearing unit" is characterized by coarse-grained micaschists, serpentinites, amphibolites with an ocean-floor tholeiitic chemistry and pure marbles. The normative mineral contents of the serpentinites argue for harzburgite, lherzolite, olivine orthopyroxenite and olivine websterite protoliths (Schmerold, 1988). The Plankogelcomplex is interpreted as a an ophiolitic melange zone marking a pre-Alpine ophiolitic suture zone (Frisch et al., 1984; Neubauer et al., 1989b). Both protolith age and the age of metamorphism are uncertain.

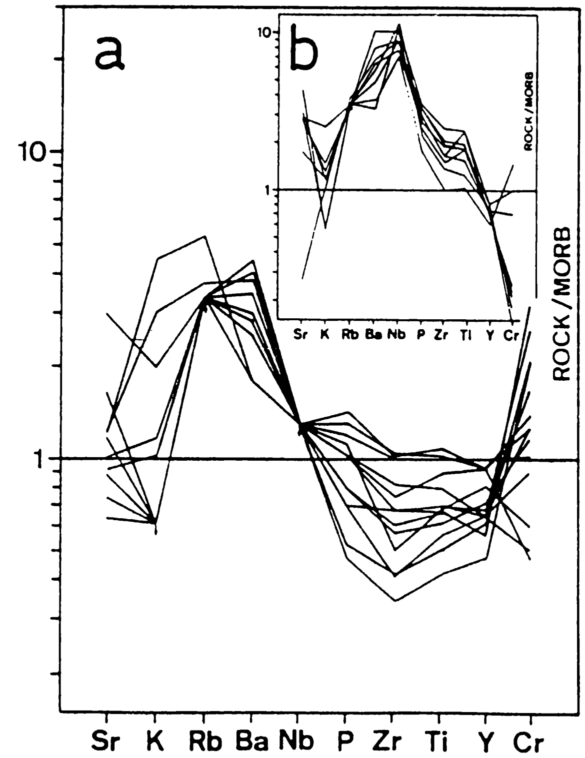

Fig. 9: Spidergram of Plankogel complex amphibolites displaying differentiation into two units with tholeiitic and alkali basaltic trends.

The Kräuping complex consists mainly of light-coloured micaschists, thin quartzitic layers and thick bodies of amphibolites (Weissenbach, 1975). The amphibolites have a predominantly alkali-basaltic chemistry (Schmerold, 1988).

Bundschuh-Einach complex

In the area between the Tauern window and the Gurktal thrust system, the Micaschist-marble complex is overlain by monotonous paragneiss (Einach-Priedröf complex) which contains lenses of Bundschuh orthogneiss (Fig. 1). The Einach-Priedröf paragneiss may be correlated with the gneisses of the Koriden because of their lithological similarities. The protolith's nature and age are unknown. The Bundschuh orthogneiss, a granitic to granodioritic gneiss, differs strikingly from other Austro-Alpine orthogneisses in its high content of muscovite, its high Sr_0 value of 0.738 and its Silurian/ Devonian Rb-Sr model age (Hawkesworth, 1976; Frimmel 1986a,b; 1988).

"Kaintaleck slices" and Ackerl complex

The "Kaintaleck slices" occur within the eastern Graywacke zone along 70 km of a thrust surface (Hauser, 1938; Cornelius, 1941). The thrust surface separates the lower Veitsch nappe with mainly Carboniferous formations (Ratschbacher, 1987) from the upper Noric nappe of Ordovician to early Carboniferous rocks. The structural thickness of the Kaintaleck slices does not exceed two hundred metres. In some areas these slices are intensely imbricated with footwall and hangingwall rocks (Neubauer et al., 1987). Lithology, geochronological data, geological relationships and structural position suggest that the Kaintaleck slices consist of various lithotectonic units (Fig. 10).

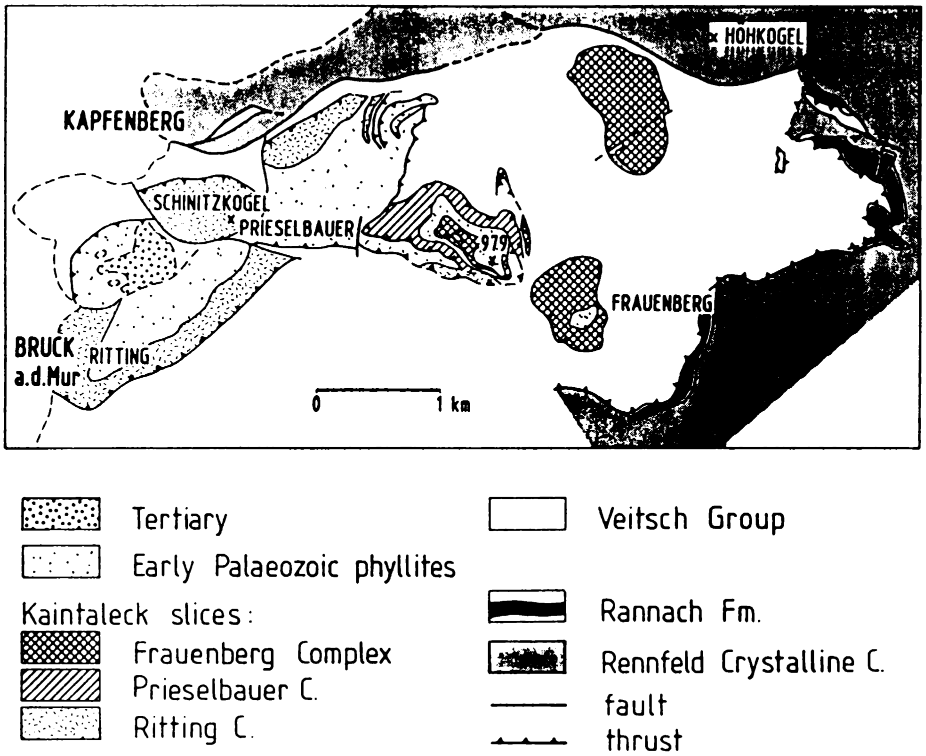

Fig. 10: Map showing internal structure of the Kaintaleck slices near Bruck/Mur (modified after Neubauer et al., 1987).

(1) The Ritting complex occurs near Bruck/Mur, at the Kaintaleck and west of Vöstenhof. It is composed of garnet-zoisite amphibolite, serpentinite, micaschist and thin marble layers. The chemistry of the amphibolites corresponds to tholeiitic basalts (Neubauer et al., 1989b). They contain a disseminated Cu mineralization. Chromite occurs in the serpentinites (Neubauer and Thalhammer, 1989). The protolith age of the Ritting complex is uncertain.
Amphibole concentrates yielded a disturbed total gas $^{40}Ar/^{39}Ar$ age which reflects post-metamorphic cooling prior to 420 Ma (Dallmeyer et al., this volume).

(2) The Frauenberg complex is mainly composed of paragneiss containing plagioclase amphibolite and marble lenses. The petrographic characteristics contrast with those of the Ritting complex. The amphibolites exhibit a mildly alkaline trend. A hornblende-garnet gneiss which is included in the plagioclase amphibolite contains numerous rounded zircon crystals with smooth surfaces which are interpreted as the result of high grade metamorphism. Pressure and temperature conditions are uncertain, but a high pressure event is indicated by the high pyrope content of garnet (ca. 40 mole percent pyrope). The zircons yielded a U-Pb upper intercept age of ca. 2.53 Ga and a lower intercept age of 516 Ma (Neubauer et al., 1989b). Because of the highly discordant pattern the upper intercept age is considered to be the protolith age, assuming an igneous source for the hornblende-garnet gneiss, and the lower intercept the late Cadomian age of metamorphism (Neubauer et al., 1989b). Brown, metamict zircons yielded a different upper intercept age of approximately 2.8 Ga. These zircons are interpreted as representing crustal contamination of the igneous source.

(3) The Prieselbauer complex is composed of migmatitic augen paragneiss and micaschists which include minor occurrences of amphibolite as well as concordant and discordant aplites. The paragneiss yielded a lower intercept U-Pb zircon age of ca. 391 Ma which is interpreted as the approximate age of metamorphism. A discordant aplitic vein yielded an upper intercept zircon age of 363 Ma which reflects the zircon crystallization within the protolith (Neubauer et al., 1987; in prep.). The Prieselbauer complex is interpreted as the basement of the Carboniferous sediments of the Veitsch nappe (Neubauer et. al., 1987).

The Ritting and Frauenberg complexes are transgressively covered by the Kalwang gneiss conglomerate which forms the stratigraphic base of the fossiliferous sequence of the eastern

Graywacke zone (Daurer and Schönlaub, 1978; Neubauer, 1985). Apart from various basement fragments such as amphibolites and serpentinites, trondhjemitic orthogneiss components dominate in the conglomerate. The orthogneiss is interpreted to derive from a source in a supra-subduction zone environment because of its geochemical patterns, especially those of the REEs. The U-Pb zircon upper intercept ages of two boulders from different localities are approximately 500 Ma (Neubauer et al., 1987). The predominance of the orthogneiss clasts suggest the presence of a major pluton in the hinterland of the conglomerates. This orthogneiss is not known from the Kaintaleck slices.

Recent mineral ages (Rb/Sr and 40Ar/39Ar muscovite and amphibole) of all three complexes resulted in ages ranging between 470 and 360 Ma with no significant difference between these three complexes. Therefore, a major Mid Paleozoic tectonothermal event affected major portions of the "Kaintaleck slices".

The Ackerl complex at the northwestern margin of the Upper Austro-Alpine Gurktal thrust system (Fig. 1) is another medium-grade metamorphic complex in a similar tectonic position to the Kaintaleck slices. The Ackerl complex is composed of staurolite-bearing biotite plagioclase gneisses, partly phyllonitized micaschists, rare amphibolites, acidic orthogneisses and quartzites (Neubauer, 1980). The Ackerl complex is derived from a thick clastic wedge with predominant graywackes and and basalts with within plate basaltic composition. Protolith ages are unknown. 40Ar/39Ar muscovite plateau ages with ca. 310 Ma record the Variscan metamorphic overprint (Dallmeyer et al., this volume). The Ackerl complex seemingly escaped a major Alpine metamorphic overprint.

Eisenkappel and eastern Gailtal crystalline

A small tectonic segment of crystalline basement rocks occurs immediately north of the Periadriatic lineament in the eastern Karawanken (Exner, 1972). It consists of a metamorphic sequence and the Karawanken granite pluton. The metamorphic sequence comprises biotite plagioclase paragneiss as the main lithology, with graphite-rich quartzites and gneisses, amphibolites and microcline orthogneiss (Exner, 1972; von Gosen, 1989a, b). Protolith ages and metamorphic history are unknown.

The Karawanken granite pluton is composed mainly of granite with subordinate granodiorite, diorite and gabbro as well as granodiorite dykes, pegmatite, aplite and lamprophyre dykes. The age of the pluton is poorly constrained. A K-Ar amphibole age (252 9 Ma; Cliff et al., 1974) and a Rb-Sr biotite age (232 Ma; Scharbert, 1975) reflect late Permian/ early Triassic cooling after intrusion.

Granite, diorite and augengneiss which are comparable to metagranitoids of the eastern Karawanken occur as tectonic slices along shear zones in the eastern Gailtal crystalline (Exner, 1985).

Garnet peridotites and granulites of the Pohorje Mountains

Although first described long ago, no attention has been paid to the granulites and associated garnet peridotites on the southern slopes of the Pohorje mountains in Slovenia. This unit is situated immediately to the north of the Periadriatic lineament in a comparable tectonic position to other Austro-Alpine granulitic and high-pressure ultramafic rocks (Frisch et al., 1990). A redescription of the Pohorje mountains was provided by Hinterlechner-Ravnik (1982, 1988) and Hinterlechner-Ravnik and Moine (1977). The metaperidotite-bearing sequence is composed of serpentinized dunite, harzburgite and garnet peridotite enclosed within eclogitic rocks. Kyanite-bearing eclogite typically associated with the garnet-peridotites suggests a relationship with the eclogite-bearing Koriden complex (Hinterlechner-Ravnik, 1982, 1988). The garnet peridotite suffered polyphase metamorphism: a metamorphic event with pressures higher than 12 to 15 kbar is postulated which was overprinted under amphibolite and greenschist facies conditions (Hinterlechner-Ravnik, 1988). Protoliths and metamorphic ages are unknown. The garnet peridotite and granulite have a position comparable to that of the garnet peridotites and granulites in the Ulten valley for which Variscan metamorphism is constrained by U-Pb zircon data.

Discussion

The medium- to high-grade metamorphic basement units east of the Tauern window exhibit a high degree of diversity with respect to their lithological composition, the age of granitoid intrusions, and metamorphism. The lithotectonic complexes have different positions within the Alpine nappe pile. During the early Alpine orogeny lithotectonic units accumulated in certain levels. This is espescially true for the Kaintaleck slices.

Protolith ages for the metasedimentary sequences are largely a matter of speculation. Several major groups of units are distinguished with regard to their tectonothermal histories according to their geochronological ages (Tab. 1):

(1) Rock units which were mainly affected by early Paleozoic magmatism and metamorphism (550 - 500 Ma) such as the Ritting and Frauenberg complexes, which escaped Variscan metamorphic overprint;

(2) rock units with Ordovician to Silurian, "Caledonian" ages (450 - 425 Ma) which were later affected by early Carboniferous metamorphism and intrusions;

(3) rock units which underwent Devonian metamorphism and magmatism (400 - 360 Ma), e.g. the Prieselbauer slice, the Bundschuh area and possibly the Tatric unit;

(4) rocks with early Carboniferous ages of metamorphism; these units are the most widespread;

(5) units such as the Koriden gneiss group for which the data base is uncertain or the lithological association is different from adjacent units, and whose history is not constrained by age determinations.

The geodynamic settings of most of these units appear to be different:

One set of units is regarded as the product of a late Precambrian/early Palaezoic subduction system. This system includes units derived from an ensialic magmatic arc such as the Core complex, and from ocean floor (Ritting and Speik ophiolite complexes) related to it. Some portions of this system suffered Cambrian metamorphism and accompanying deformation with subsequent uplift. Parts of the newly consolidated crust acted as the basement to an Ordovician to early Carboniferous shelf and rise sequences of a new sedimentary cycle. This is constrained by data from some Kaintaleck slices which show basement-cover relationship. The Micaschist-Marble complex is correlated by its lithostratigraphy to the fossiliferous late Ordovician to Carboniferous sequences. We interpret all units which contain this late Ordovician to Carboniferous cover sequence including its highly metamorphic equivalents as members of the Noric composite terrane (Frisch and Neubauer, 1989).

The Tatric unit, the Wechsel unit (see Neubauer et al., this volume), the Bundschuh-Einach complex, and major portions of the Kaintaleck slices define a completely different setting. Evidence of Devonian metamorphism and magmatism are not compatible with the evolution of a Devonian shelf and slope sequence in the Noric composite terrane. These units are, therefore, interpreted as parts of another terrane, the Pannonian terrane (Frisch and Neubauer, 1989), which formed a continental collisional belt in the Devonian as part of the West-European Ligerian cordillera.

The evolution of the other lithotectonic units is badly constrained. The Plankogel complex is interpreted to be the Variscan ophiolitic suture which separates the foreland sequences from Variscan metamorphic internides, especially from those of the Pannonian terrane (Frisch and Neubauer, 1989).

Geochronological data indicate an early Carboniferous climax of metamorphism and magmatism for the Murides, the Wechsel gneiss complex, and the Grobgneiss complex. S- and I-type granitoids of early Carboniferous age are widespread in the Grobgneis and Core complexes. These data suggest that the lower lithotectonic units within the Alpine nappe pile were involved in early Carboniferous plate collision which amalgamated different Austro-Alpine basement units. Burial, deep-crustal thrusting under the influence of melts, and uplift shortly after the metamorphic peak are the evolutionary steps recorded in this zone. The collisional event is also indicated by Visean flysch sedimentation in the Austro-Alpine/Southalpine foredeep (Frisch et al., 1990).

Only little evidence is available for the late Carboniferous evolution. Permian radiometric data obtained from pegmatitic muscovites, granite and gabbro intrusions, and Rb-Sr thin slab errorchrons are widespread. The meaning of these data is not clear. A reliable explanation is a major late Carboniferous to Permian rift event which resulted in intrusion of gabbros and formation of tholeiitic basaltic melts, high temperature/low pressure metamorphism in a regime of crustal thinning. The rifting led finally to formation of the Tethys. However, most mineral data were interpreted by previous authors as the result of partial resetting of Carboniferous ages by Cretaceous metamorphism. Well-documented magmatic activity, which is also preserved in acidic tuffs in Permian overstep sequences (see Krainer, this volume), indicates high heat flow within the Variscan crust, and the mineral ages may, therefore, reflect postmetamorphic cooling caused by crustal extension and uplift.

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