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EVOLUTION OF LOWER AUSTROALPINE UNITS ALONG THE EASTERN MARGINS OF THE ALPS: A REVIEW

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Introduction

Lower Austro-Alpine tectonic units are widespread along the eastern margins of the Alps (Fig. 1, 2). These units contain various polymetamorphic basement complexes and Permo-Triassic cover sequences, the latter mainly exposed along the northern margin of these tectonic units (Figs. 1, 2).

Tatric Units

In the transition zone of the Eastern Alps to the Carpathians, a basement complex is exposed which belongs rather to the Western Carpathians than to the Alps because of distinct facies in Permo-Mesozoic cover formations (Fig. 1). The Tatric basement is composed of paragneiss, staurolite-bearing micaschist, quartzitic biotite phyllite, and greenschist which include carbonatic layers (Tollmann and Spendlingwimmer, 1978; Wessely, 1961). The paragneiss and micaschist are intruded by a granitoid pluton which includes two-mica granite, granodiorite and leucogranite comparable to the Bratislava pluton of the Little Carpathians. The phyllite is correlated by Tollmann and Spendlingwimmer (1978) to the Lamac Fm. of the Little Carpathians. In the Little Carpathians, the age of metamorphism is probably Devonian constrained by a Rb-Sr isochron of 380 +/- 20 Ma (Cambel and Kral, 1989). The Bratislava pluton gave an age of 347 +/- 4 Ma (Cambel and Kral, 1989). In contrast to the Raabalpen Complex, the Alpine metamorphism and penetrative deformation is weak.

Wechsel gneiss complex

The Wechsel gneiss complex occurs within the Wechsel window and some additional isolated windows (Fig. 2) in the transition zone of the Eastern Alps to the Neogene Pannonian basin (Tollmann, 1978) (Fig. 3). A detailed correlation between different windows is not done up to now.

The Wechsel gneiss complex (Fig. 4)consists of a thick package of monotonous albite porphyroblast paragneiss ("Monotonous Wechsel gneiss complex") and a structural higher complex which includes other lithologies like quartzites, epidote amphibolites, acidic orthogneiss, black schists and black paragneisses ("Variegated Wechsel gneiss complex") (Faupl, 1970, 1972; Neubauer, 1990, Vetters, 1970). The footwall boundary of the Wechsel gneiss is not exposed. The hangingwall is formed by a series of quartzphyllite-like rocks, the Wechsel phyllites and Permo-Mesozoic cover rocks. In other windows, the Variegated Wechsel gneiss complex is dominates with regard to the wide range of lithologies from albite porphyroblast gneiss, black quartzites and gneisses, and the thick leucocratic Wiesmath orthogneiss (Fuchs, 1962; Pahr, 1980). In the more northern windows, the monotonous albite porphyroblast gneiss is prevailing up to the Leitha Mountains.

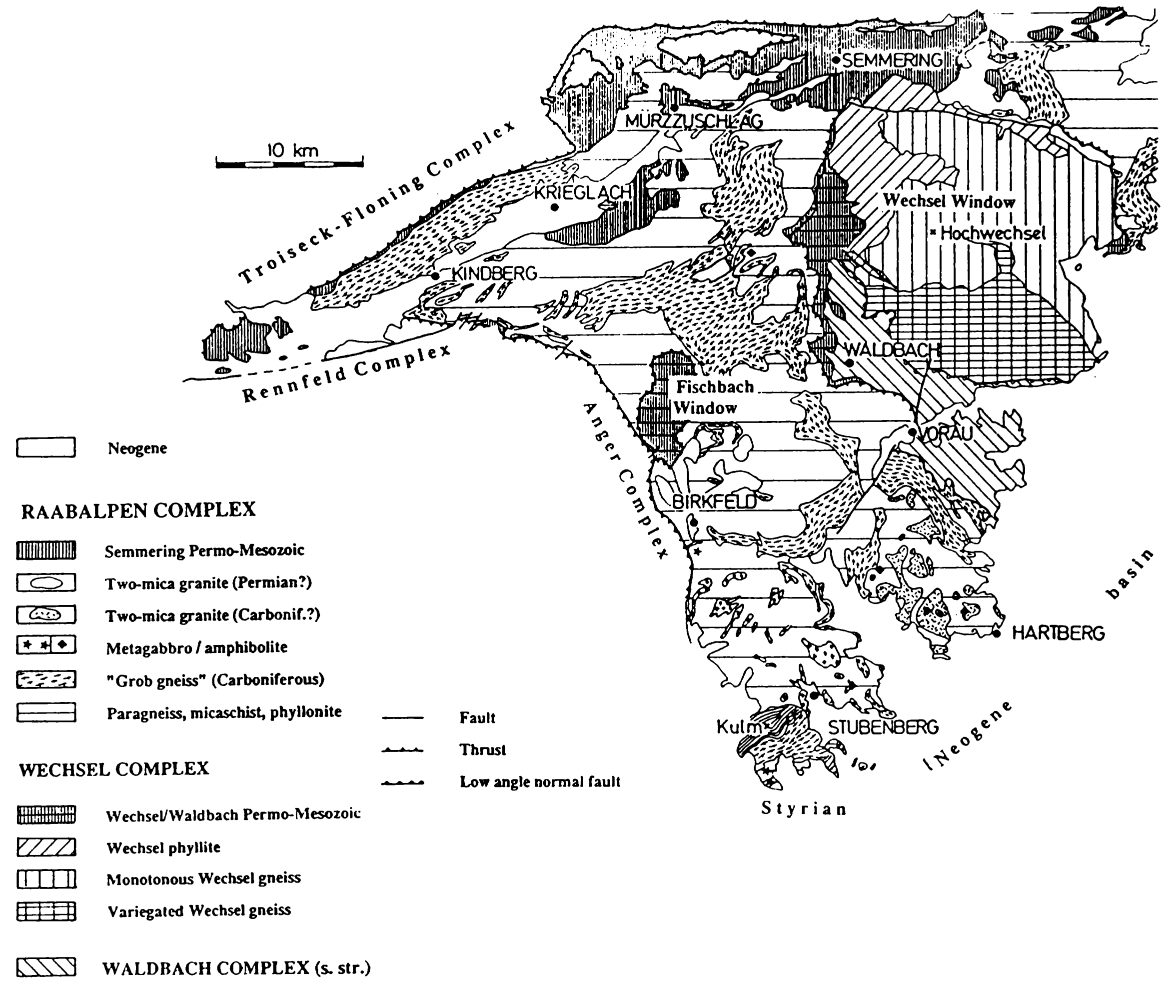

Fig. 1: Simplified tectonic map of the western part of Lower Austro-Alpine units along the eastern margin of the Alps.

The thick package of albite porphyroblast paragneiss exhibits petrographic and chemical features of somewhat altered graywackes and shales (Fig. 5; Neubauer, 1990). Based on major, minor, trace and rare earth elements, the mafic rocks have a mafic subalkaline chemistry comparable to that of a modern supra-subduction zone environment (Fig. 6). The sheetlike orthogneisses are strongly altered and have also some geochemical features comparable to those of suprasubduction zone environments. The protolith ages of all these rocks are uncertain.

Therefore, the Wechsel gneiss complex is interpreted as the product of an active continental margin (Neubauer, 1990). The essential arguments for this interpretation are the chemistry of igneous rocks, the presence of polycyclic, metasedimentary zircons in meta-quartz arenites, and the occurrence of massive Cu-sulphides at the hangingwall boundary of the Wechsel gneiss complex (Tufar, 1968).

The metamorphic overprint of the Wechsel gneiss complex is polyphase. Within the southern part there is evidence for a first epidote amphibolite facies stage later overprinted by retrogressive formation of albite porphyroblasts within higher greenschist facies conditions. Rb-Sr and 40Ar/39Ar ages with 380 - 370 Ma from phengitic white mica indicate an intra-Devonian age of a pressure-dominated metamorphic event (Müller et al., 1992; Dallmeyer et al., this vol.). The relationship of these white micas to the albite porphyroblast growth is uncertain. However, the metamorphism has been accompanied by polyphase folding suggesting approximately N-S compression within the present geographic framework.

The hangingwall boundary of the Wechsel gneiss complex to the Wechsel Phyllite is previously thought to be a possible primary contact. Recent investigations indicate that this boundary is a zone of ductile W to SW-directed thrusting or, more reliably, a ductile low angle normal fault

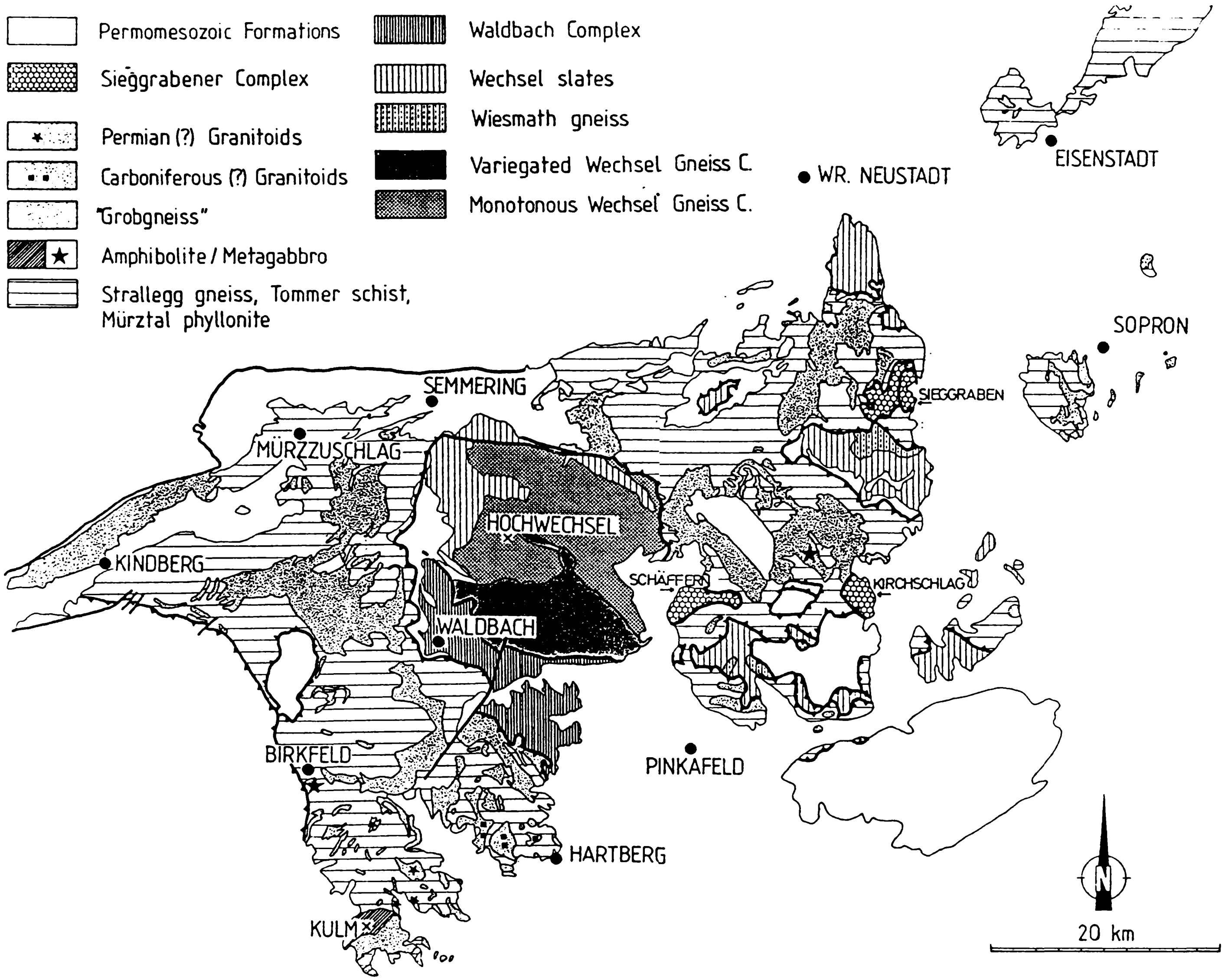

Fig. 2: Simplified tectonic map of the eastern part of Lower Austro-Alpine units along the eastern margin of the Alps.

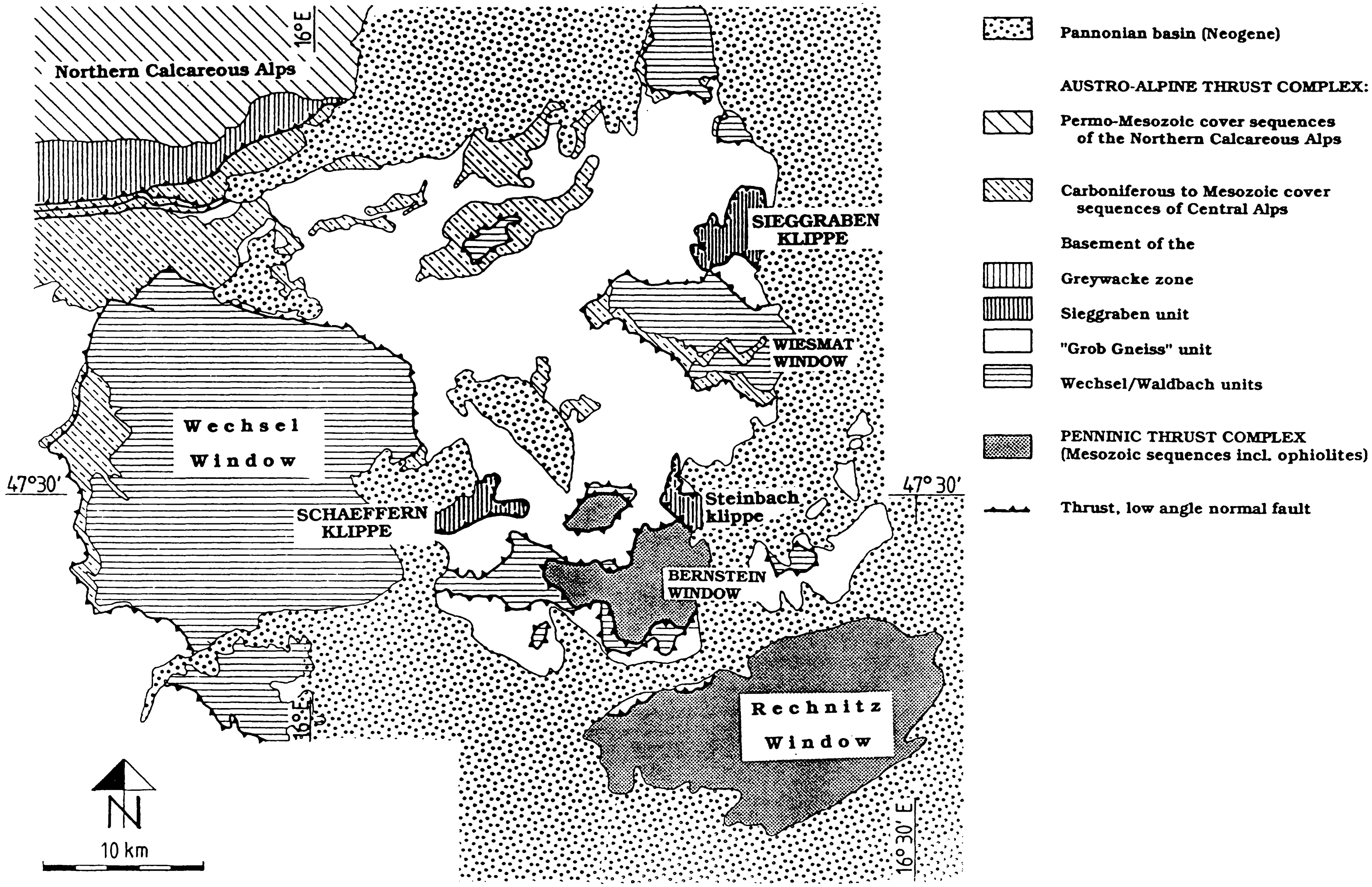

Fig. 3: Map of the Lower and Middle Austroalpine basement nappes at the eastern margin of the Eastern Alps (from Neubauer and Frisch, in press).

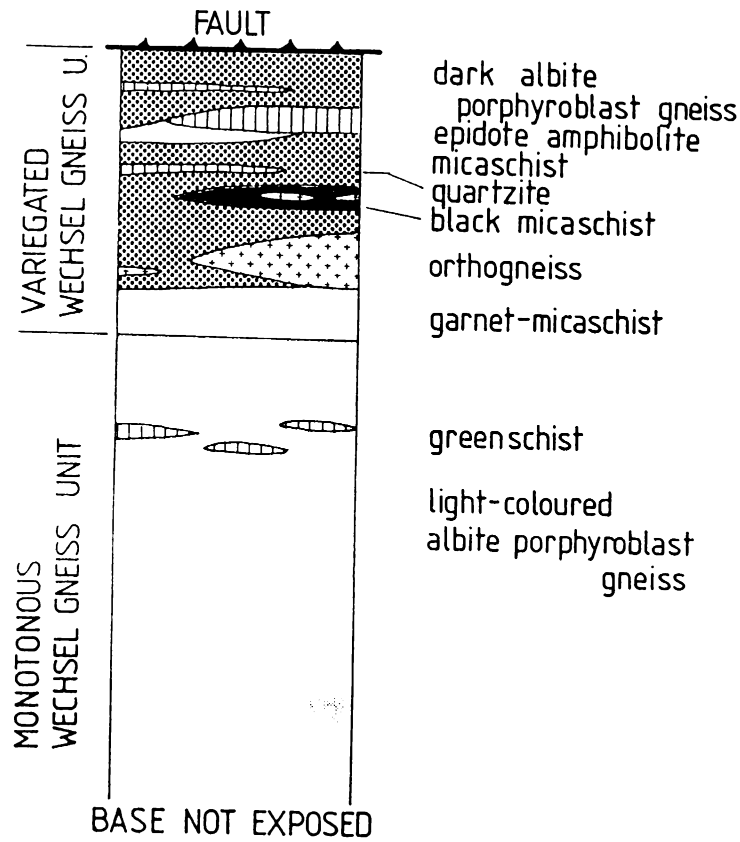

Fig. 4: Log of the Wechsel gneiss complex (from Neubauer, in prep.).

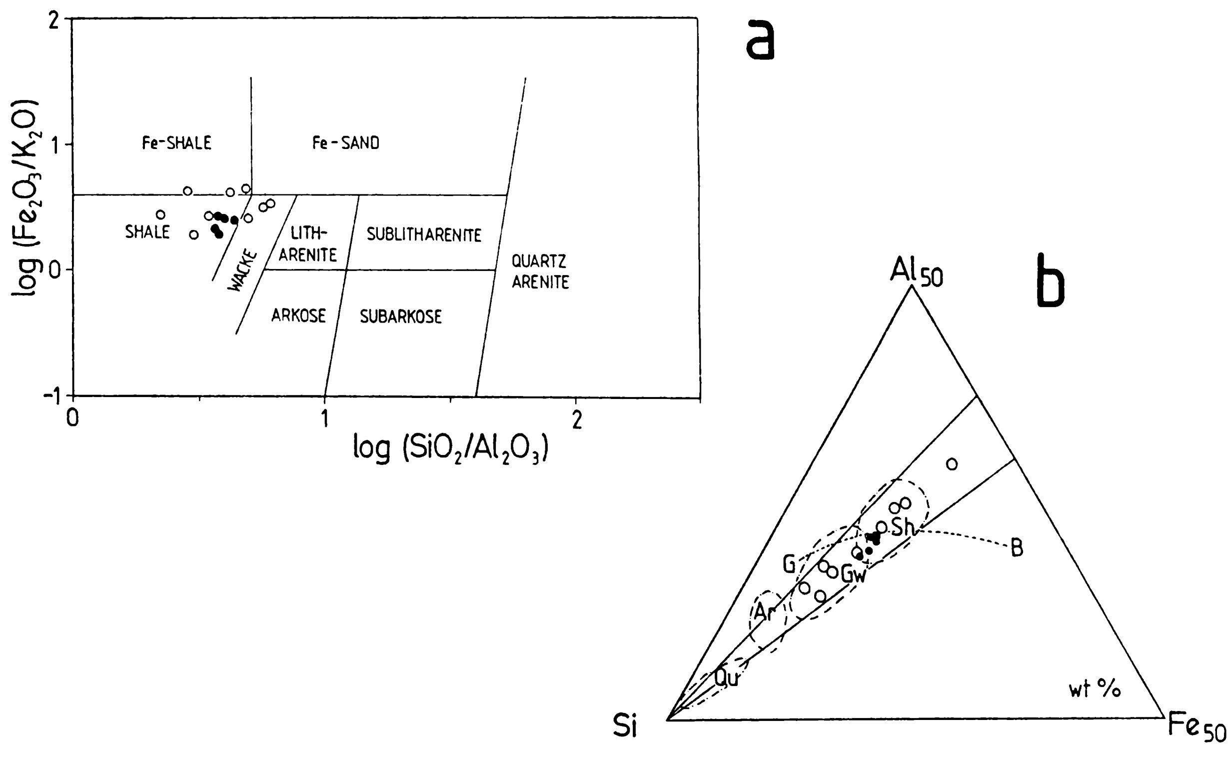

Fig. 5: Chemical discrimination of the Wechsel gneiss (from Neubauer, in prep.).

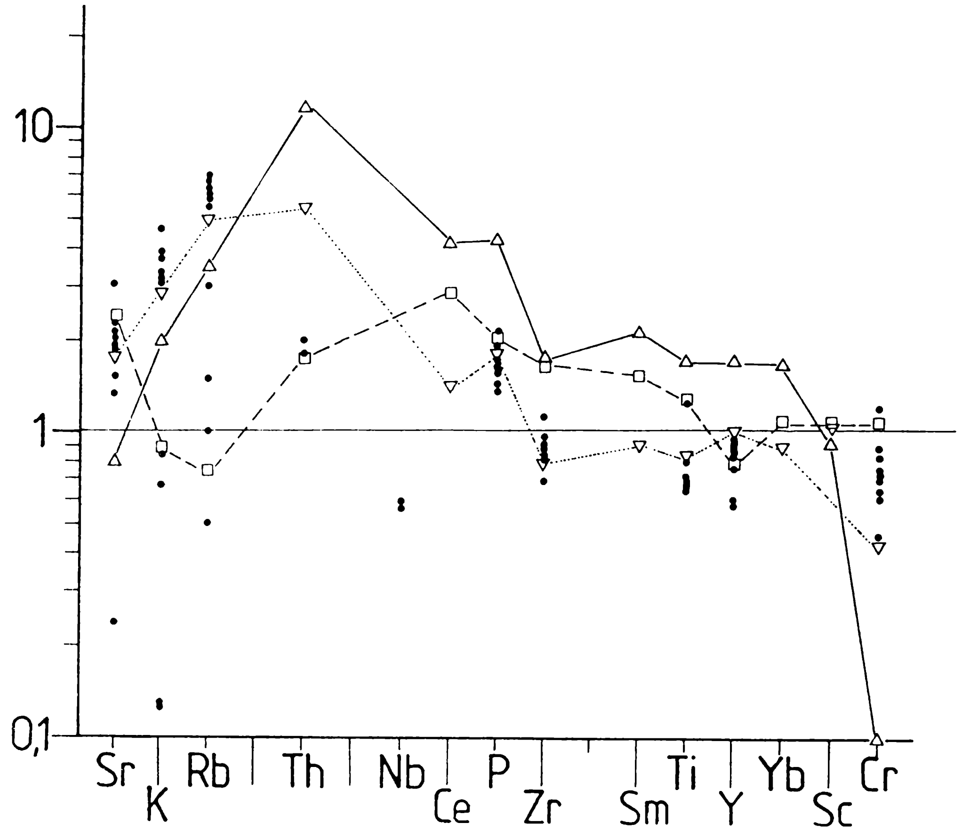

Fig. 6: Spider diagram of epidote amphibolites and greenschists from the Wechsel gneiss complex (from Neubauer, in prep.).

which indicates the emplacement of a Wechsel Phyllite nappe after raeching the metamorphic peak of the Wechsel gneiss complex (Neubauer and Pischinger, in prep.). A late Variscan age of retrogression (270 - 240 Ma, Late Permian) can probably be inferred from Rb-Sr ages of paragonitic white mica (Wechsel gneiss), Rb-Sr mineral isochrons (white mica - chlorite - whole rock) of the Wechsel Phyllite, and 40Ar/39Ar age spectra first increments at approximately 250 Ma. These ages may proof activity along the ductile fault mentioned above during Permian extension with ongoing subsidence and/or thermal influence by Permian volcanism.

The Fertörakos complex in westernmost Hungary has been correlated with the Wechsel gneiss unit by most authors (e.g., Kovach and Svinghör, 1981; Lelkes-Felvari et al., 1984). In that complex, amphibolites prevail besides phyllitic rocks and marble. A Rb-Sr age of a pegmatitic white mica is at 354 Ma (Kovach and Svinghör, 1981). These lithologies suggest major differences to the Wechsel gneiss complex.

Wechsel Phyllites

The Wechsel Phyllites occur within the Wechsel window and other comparable windows at the northeastern margin of the Eastern Alps. In the Wechsel window, the section comprises dark phyllites, black phyllites, volcanogenic graywackes and rare mafic schists and leucocratic metatuffites (Faupl, 1970; Vetters, 1970; Matura, 1990). In other windows, the Wechsel phyllites are accompagnied by the Wiesmath gneiss. The protolith age of the Wechsel phyllites is uncertain. Planderova and Pahr (1983) described mixed floras of sporomorpha which have a range from Silurian to earlymost Permian. These authors interpreted the protolith age of the Wechsel phyllite to be late Carboniferous to earlymost Permian. However, this age is unusual for quartzphyllite in the Eastern Alps and needs further proof.

Waldbach Complex

Along the southern margin of the Wechsel gneiss complex, the polymetamorphic Waldbach Complex is on the top of the former one, separated by a low angle normal fault. It consists of phyllitic micaschist at the structural base, intermediate orthogneisses (hornblende orthogneiss), various amphibolites, thin layers of garnet micaschists, ore-bearing black schists and quartzites, stratiform sulphides on the top of amphibolites (Faupl, 1972; Huska, 1970; Neubauer, 1983; Tufar, 1963). Limited petrographical and geochemical data suggest that major portions of amphibolites are derived from gabbros, hornblende gneisses from dacitic/tonalitic to granodioritic sequences. Therefore, these hornblende gneisses and amphibolites may represent an island arc magmatic sequence of unknown, pre-Alpine age. The widespread concordant polymetallic mineralization (Tufar, 1963) is in accordance with this interpretation. The pre-Alpidic metamorphic overprint reached amphibolite facies conditions, and locally, partial melting of rocks occurred (Faupl, 1972). Discordant pegmatites postdate peak conditions of pre-Alpine metamorphism and ductile deformation.

A relationship of the Waldbach crystalline complex to the Core complex of the Middle Austroalpine basement nappe is supposed because of comparable lithologies.

Although new grown staurolite, evidence for amphibolite facies conditions, can be locally observed within confining shear zones the Alpine metamorphic overprint is apparently within greenschist facies. Alpine deformation resulted in recumbent folds with E-W trending fold axes and related, steeply southerly dipping axial surface foliation fans. Confining shear zones operated within greenschist facies conditions during exhumation of the Wechsel Window.

"Grobgneis Complex"

The "Grobgneis" complex is exposed Northeast and West to the Wechsel window (Fig. 2). Other terms for this lithotectonic units are Raabalpen crystalline complex (west of the Wechsel window) or Eselsberg complex (east of the Wechsel window) (Flügel and Neubauer, 1984; Fuchs, 1965; Tollmann, 1978).

Metasedimentary and metavolcanic sequences

The "Grobgneis" complex is composed of migmatitic paragneiss (Strallegg gneiss), micaschist (Tommer schist), and phyllonite (Mürztal and Birkfeld quartzphyllites), respectively of minor intercalations like talc schists, clinopyroxene-bearing amphibolites, quartzites, kyanite-bearing quartzites and tourmalinites (Cornelius, 1952; Flügel and Neubauer, 1984; Moreau, 1981; Peindl, 1990). The age of deposition is uncertain but predates intrusion of various granites of Carboniferous age. Geochemical patterns of rocks surrounding the talc deposit Rabenwald argue for an evaporitic environment of the formation of country rocks (Moreau 1981).

The main metamorphic event is the pre-Alpine migmatitization of the metapelites in southern areas, and pre-Alpine amphibolite facies conditions within the stability field of staurolite in northern areas (Tommer micaschist). The intensity of (Early) Alpine metamorphism decreases from the amphibolite facies conditions in the southern areas of the Raabalps to a greenschist facies metamorphic overprint in the northern area.

The Strallegg Gneiss is a migmatitic, locally alumosilicate-bearing, biotite-rich paragneiss with a stromatitic foliation. Boudinage of the stromatitic foliation causes accumulation of leucosome in the necks being between the boudins (Peindl, 1990) indicating synkinematic anatexis.

The Alpine metamorphism causes a very strong change in the mineral contents of the melanosome: biotite is changed to sericite by the following reaction: biotite + K-feldspar + quartz + Tschermak-molecule = muscovite (Thompson, 1982). Well preserved Strallegg Gneiss occurs preferably in the southern part of the Raabalpen complex and in the area between Vorau and Birkfeld.

Amphibolites occur as metre- to decametre thick lenses within paragneisses and along margins of orthogneiss bodies. In the southeastern Raabalpen complex three amphibolite varieties occur:

(1) Clinopyroxene- and brown hornblende bearing amphibolites;

This group occurs always in combination with granitoids. This type is interpreted as being large xenoliths in the granites.

(2) Amphibolites and hornblende gneisses with brown hornblende but without clinopyroxenes occur within a few meters thick and a few hundred meters long lenses.
(3) Green and/or colourless hornblende-bearing amphibolites.
They are the retrograde metamorphic products of the two amphibolite types mentioned above.

Preliminary geochemical data of some further amphibolites from southwestern Raab Alps have geochemical signatures of continental within plate basalts based on low La_N/Yb_N ratios (ranging between 1.5 and 4), relatively high Nb and Th contents.

Although the Alpidic overprint reached regionally variable greenschist to amphibolite facies, the pre-Alpine mineral assemblages are well-preserved in some areas (Koller and Wieseneder, 1981). A recent estimate of the Alpidic metamorphic overprint of the southwestern area is 500 - 550^{0}C and 8 - 9 kb (Moine and others, 1989). Some stages of pre-Alpidic metamorphism may be recognized because of the relationship to Carboniferous and Permian intrusions (Peindl, 1990; Peindl and others, 1990). A first stage of metamorphism predates Carboniferous intrusions and reached partial melting in metapelites. The peak metamorphic conditions were reached after the intrusion of the muscovite-biotite granites by progressive decomposition of muscovite in granites to potash feldspar and sillimanite (Peindl, 1990). Therefore, the peak metamorphic conditions which can be described as localized granulite facies took place after intrusion of the first generation of two-mica granites between early Carboniferous and Permian.

Variscan plutonic suites

Granitoid gneisses are widespread within the "Grob gneiss" Complex. Recent field work and detailed Rb-Sr geochronologic work (see Tab. 2) exhibits an imagine of complex intrusional relationships. The most widespread rock, the "Grob gneiss", is a coarse-grained, porphyric, sheetlike granite gneiss which includes rare lenses of tonalite/diorite gneiss. Along margins of the Grob gneiss, well-preserved gabbros occur, e.g. the gabbros of Birkfeld and Landsee. Further metagabbros have been identified recently in the Kulm area at the southwestern margin of the "Grobgneis complex". The metagabbros of the Kulm may be of Permian age because they postdate the pre-Alpine metamorphism (see below). The Rb-Sr age of the "Grobgneis" is 338 +/- 12 Ma (Sr_0 = .7071 +/- .0006). A little body of fine-grained, porphyric hornblende to biotite metatonalite occurs in the southern area (Peindl, 1990; Peindl et al., 1990). The Rb-Sr age is 343 +/- 20 Ma with an Sr initial ratio of .7057 +/- .0003. A suite of isolated muscovite granite bodies is widespread in the southeastern Raabalpen crystalline complex. Further two-mica granite gneisses exhibit subsolvus granite mineralogy with often well-preserved discordant contact haloes to the country rocks. They are more differentiated in relation to the Grobgneis. A Rb-Sr isochrone of such rocks yielded an age of 326 +/- 11 Ma and a Sr initial ratio of .7068 +/- .0019 (Peindl, 1990; Peindl and others, 1990).

A further suite of isolated garnet-bearing muscovite-biotite granite gneisses occur in the area west of the former one (Fig. 2). The rocks yielded a Rb-Sr errorchrone of 243 +/- 12 Ma and a Sr initial ratio of ca. .7234 (Scharbert, 1990).

Detailed studies have been carried out in three regions: A detailed study about the "Grob gneiss" (Sassi, Zirpoli and Neubauer, unpubl. data), in the Masenberg - Hartberg section in the southeastern Raabalpen (Peindl, 1990) and in the Rabenwald - Kulm section of the southwestern ones (Moyschewitz, in prep.). Various granitoids and associated gabbros can be distinguished. The range of metagranitoids and metagabbros of the latter two areas in the Streckeisen diagram shows Fig. 7, the REE patterns are shown by Figs. 8 and 9. The location in the mol$Al_2O_3/(Na_2O+K_2O+CaO)$ versus SiO_2 diagram shows Fig. 10, the position in the log Rb versus log (Y + Nb) diagram Fig. 11, the position in the AFM diagram Fig. 12. Spider diagrams for the metatonalites and the Carboniferous two-mica granites are shown in Fig. 13.

(1) The **Grob gneiss** is a K-feldspar porphyroclasts-bearing augen gneiss. The size of the augen ranges between 1 and 15 cm. The modal composition is granitic, the groundmass consists of quartz, muscovite, plagioclase, some biotite, chlorite and epidote. Locally, there are intercalations of tonalitic/dioritic gneisses (Neubauer, 1983; Pahr, 1972). Geochemical data show the granitic composition of the Grobgneis. REE patterns (Kiesl et al., 1983; Peindl, 1990) show a strong enrichment of the light REE and a pronounced Eu-anomaly. A Rb-Sr isochron of the Grobgneis yielded an age of 338 $\pm$12 (Sr_0 = 0.7071 +/- 0.0006) (S. Scharbert, 1990).

(2) Some **Metagabbros** (Birkfeld, Landsee, Kulm, Pöllauberg) partly occur at the margins of the Grobgneis (Moyschewitz; in prep., Peindl, 1990; Schwinner, 1935). Some small lenses of

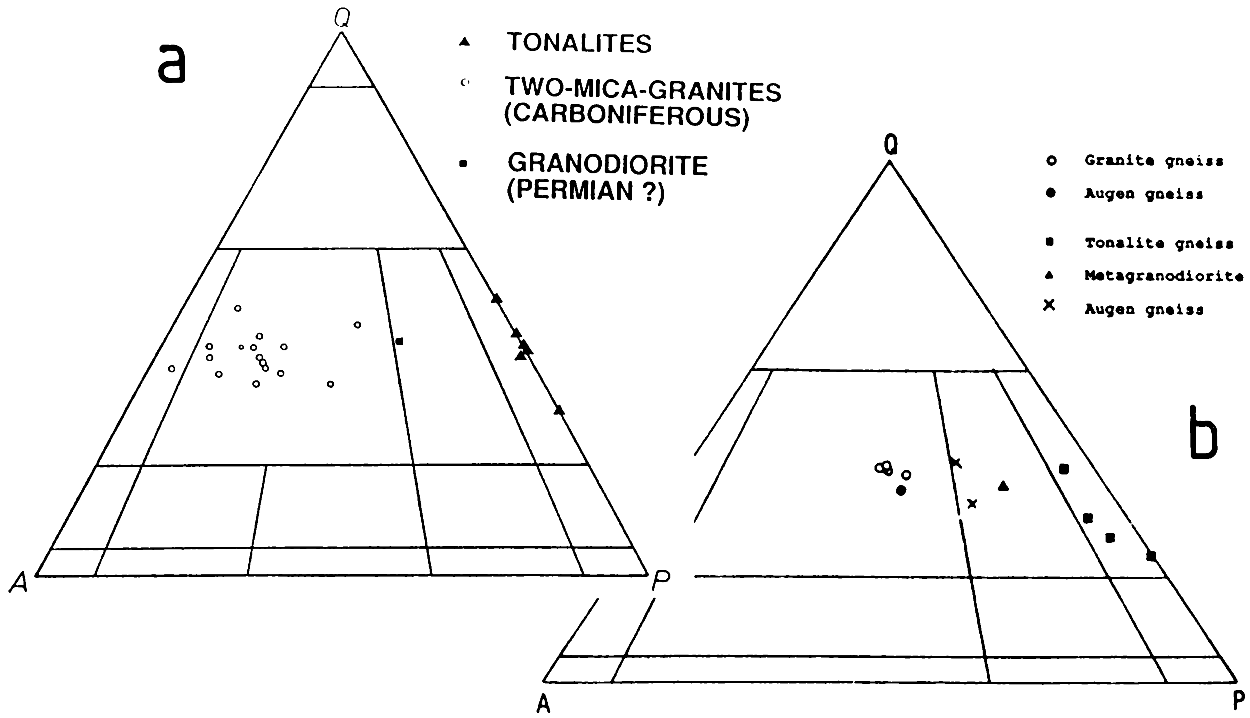

Fig. 7: Streckeisen diagram of the (a) granitoids in the area between Masenberg and Hartberg (Peindl, 1990), (b) granitoids and gabbros from the Kulm and Rabenwald (Moyschewitz, in prep.).

metagabbros can be found in the north of Birkfeld in the area between Ratten and Arzberg (Wieseneder, 1961), here called Eckberg Formation. This type often is completely altered to amphibolites which are to hardly distinguish from the amphibolites above mentioned. A small lens of a metagabbro with a very strong retrograde metamorphic imprint occurs 400 m SSE of the village Pöllauberg (Peindl, 1990).

(3) Small dykes of **metatonalites** not being connected with the Grobgneis occur only in one outcrop in the southeastern part of the Raabalpen (Peindl, 1990). Spider diagrams of the tonalites see Fig. 13. A Rb-Sr whole rock isochron yielded an intrusion age of 343 ± 20 Ma (Sr_0 = 0.7057 ± 0.0003) (Peindl, 1990).

Average modal composition:

	Hornblende-bearing	Biotite-bearing
Quartz	14 %	33 %
Plagioclase	34 %	45 %
Biotite	10 %	21 %
Hornblende	38 %	-
Accessories	4 %	1 %
	100 %	100 %

(4) **Two-mica granite gneiss**: The relatively fine-grained (maximum grain size about 5 mm) subsolvus-granites with varying modal compositions and textures appear in isolated bodies with sometimes clearly recognizable contacts with the country rock.

Geochemical features (Fig. 11) are similar to S-type syn-collisional granitoids. REE-patterns can be seen in Fig. 8.

Rb-Sr-dating (Peindl, 1990) yielded an intrusion age of 326 ± 11 Ma (Sr_0 = 0.7068 +/- 0.0019), see Fig. 15. Increasing temperature causes postintrusive desintegration of the magmatic muscovite, see below.

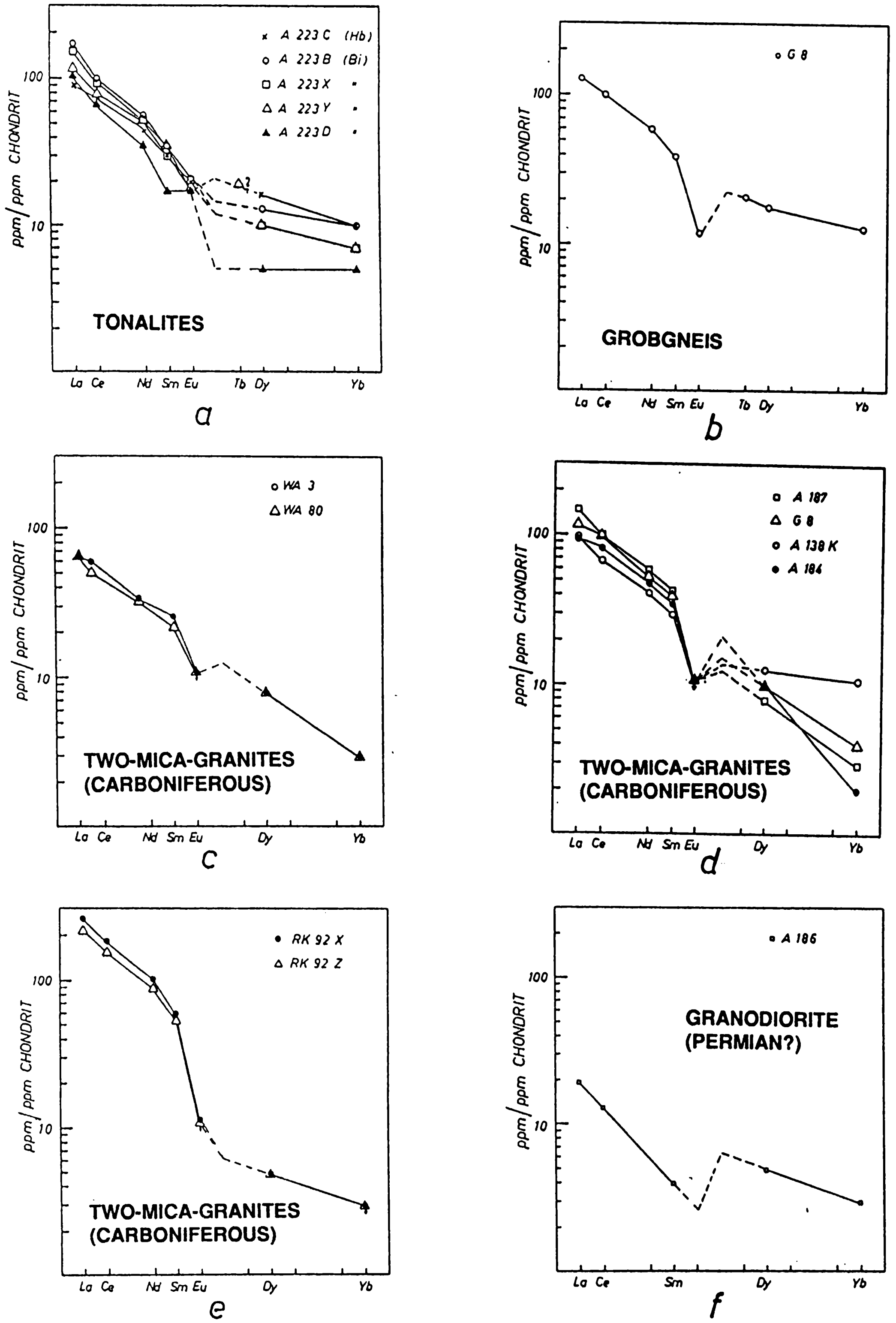

Fig. 8: REE patterns of the granitoids in the area between Masenberg and Hartberg (Peindl, 1990). (a) metatonalites; (b) Grob gneiss; (c), (d), (e) Carboniferous two-mica-granites; (f) Permian (?) granodiorite.

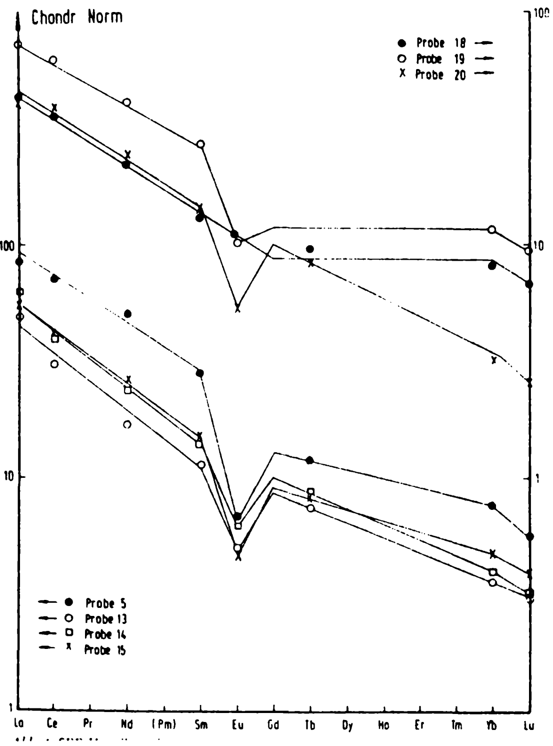

Fig. 9.: REE patterns of the Grobgneis (from Kiesl et al., 1983)

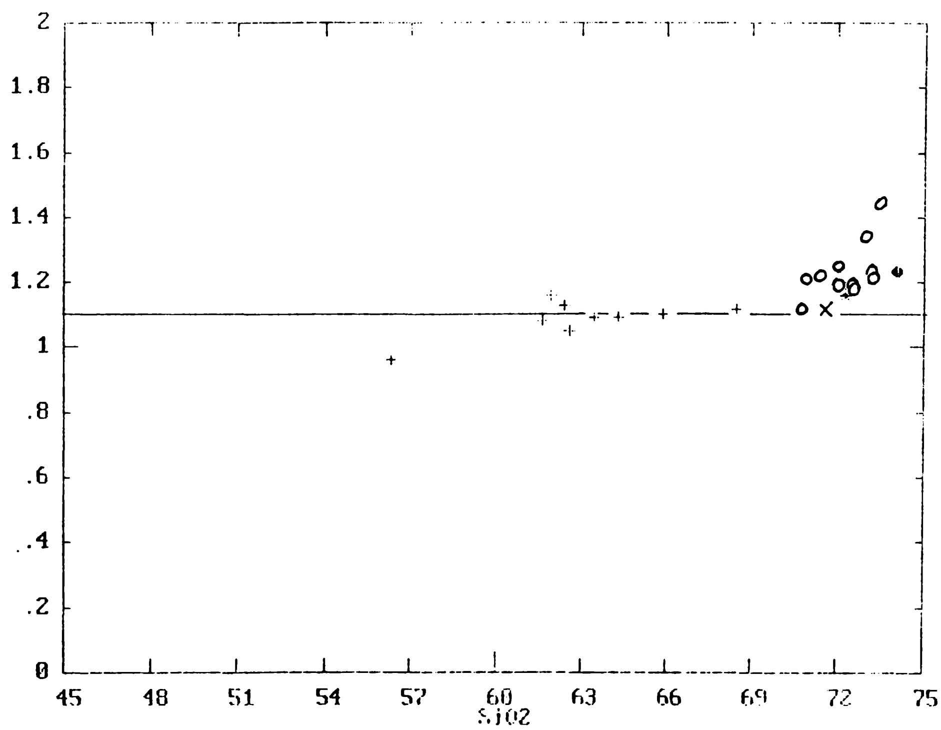

Fig. 10: Mol Al_2O_3/(Na_2O+K_2O+CaO) versus SiO_2 diagram (Chappell and White, 1974) of the granitoids and of two metagabbroes (filled squares). Crosses: metatonalites; x: Grobgneis; open circles: two-mica granites (carboniferous); asterisk: Stubenberg granite; filled circle: granodiorite (Permian ?).

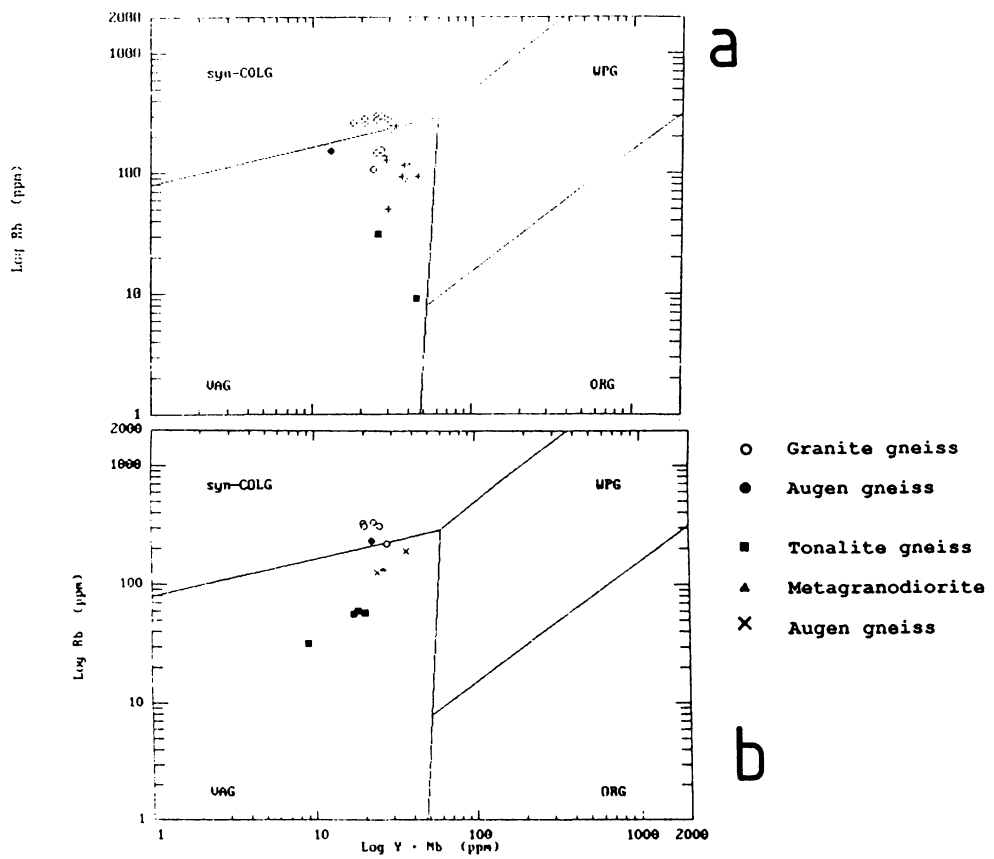

Fig. 11: Log Rb versus log (Y + Nb) diagram of Pearce et al. (1984) for the same rocks as in Fig. 7a, b. a) Granitoids from Hartberg - Masenberg; b) granitoids from Rabenwald - Kulm.

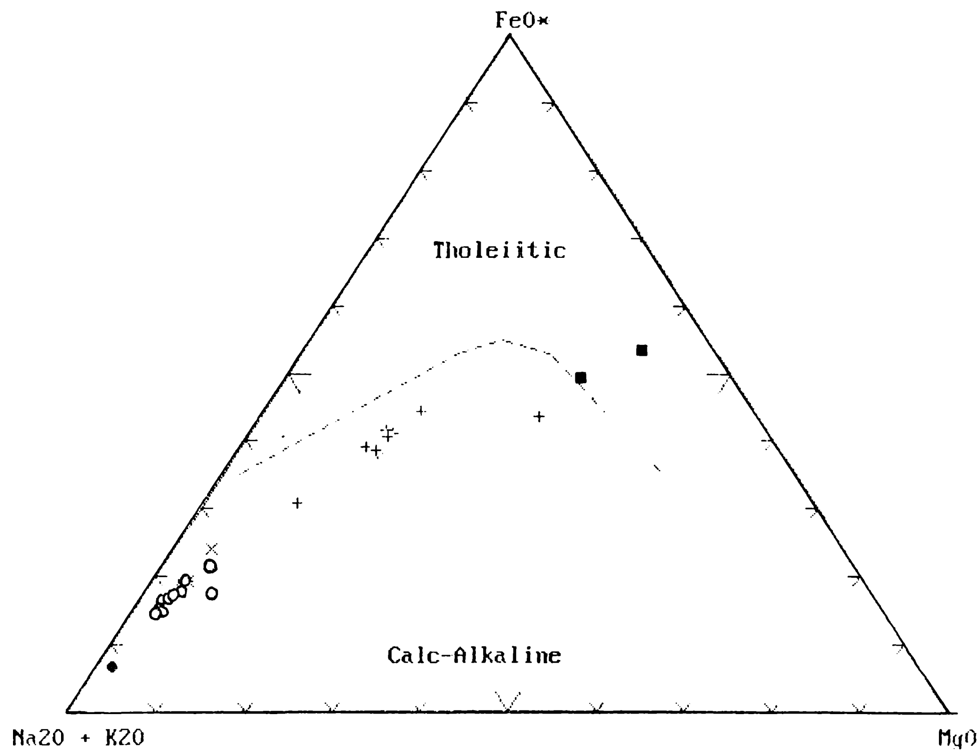

Fig. 12.: AFM diagramm of the same rocks as in Fig. 7a.

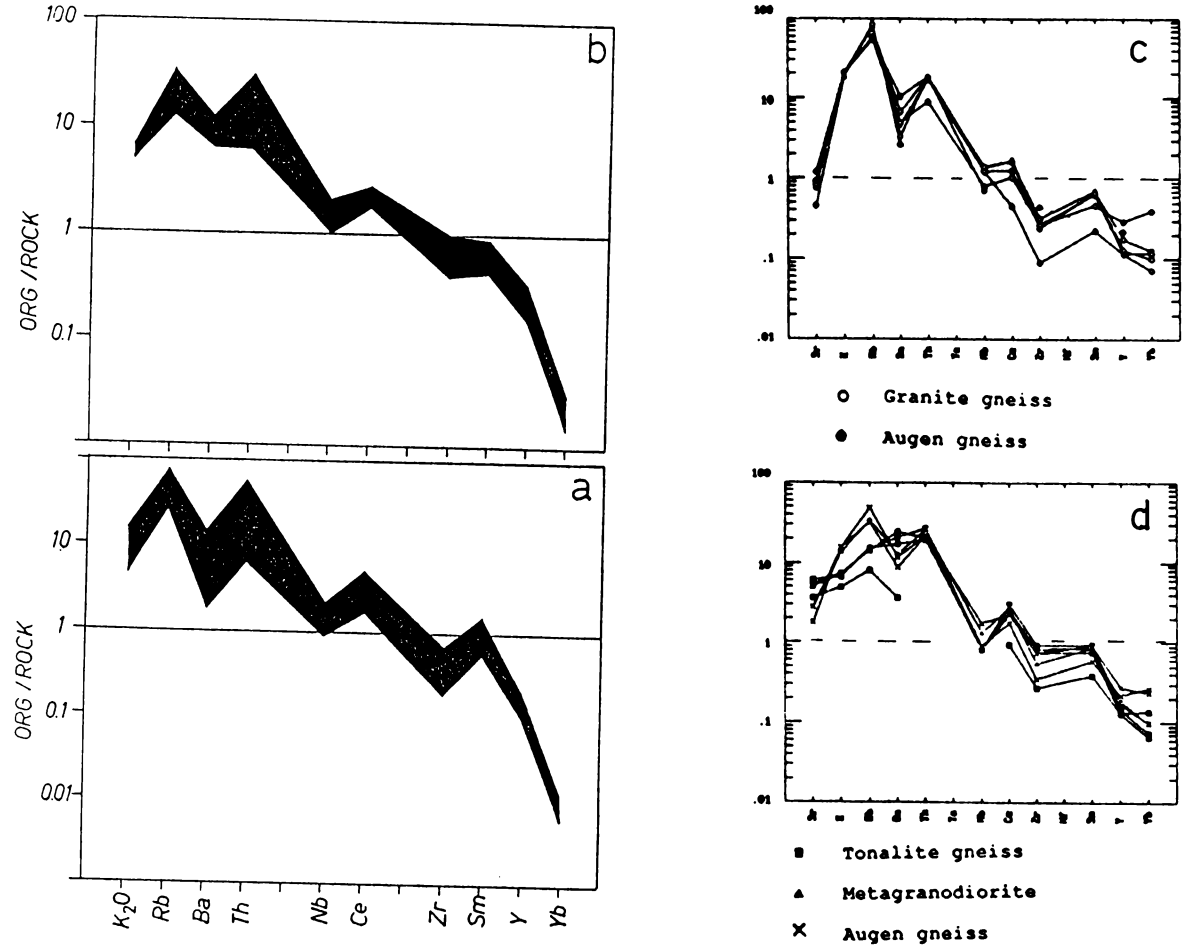

Fig. 13: Spider diagrams for the (a) Carboniferous two-mica granites, (b) metatonalites from the area between Masenberg and Hartberg, c) granites from the Kulm, d) granodiorites and tonalites from the southern Rabenwald. Normalization values from Pearce et al. (1984).

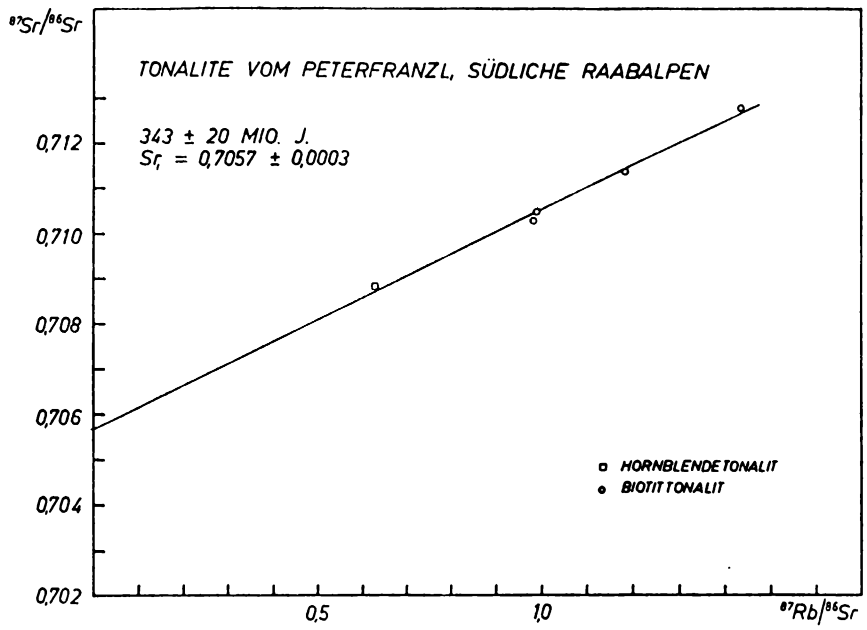

Fig. 14: Rb-Sr isochron of the tonalites (from Peindl, 1990).

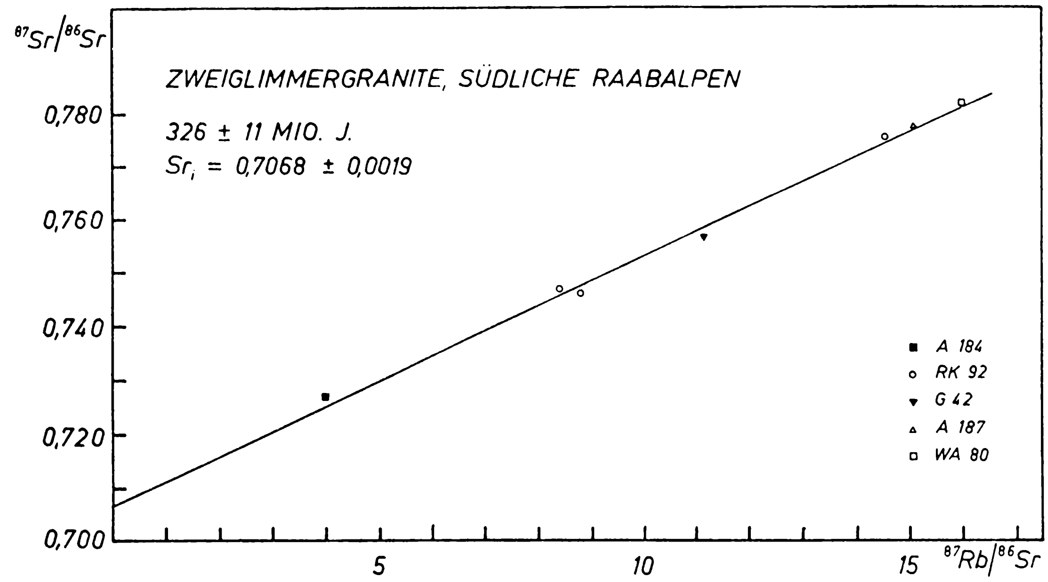

Fig. 15: Rb-Sr-isochron of the two-mica granites.

5) **Tonalite gneisses**, the **Buchkogel metagranodiorite** and biotite-rich augen gneisses of the Rabenwald/northern Kulm area, all with variable petrographic composition, are characterized by general calc-alkaline geochemical composition. High Al_2O_3 contents, highly fractionated geochemical patterns and low Sm/Nd ratios indicate limited crustal contamination.

(6) A **metagranodiorite** showing black patches occurs NW of Hartberg, at the southern slope of Wullmenstein. The black patches consist of magmatic muscovite with flakes of newly grown biotite.

There exists only one REE-analysis of this rock-type (Fig. 8) which yielded very low concentrations of the REE and a Th/U-ratio of 1 (Th = 2 ppm, U = 2 ppm). The content of Rb (153 ppm) and K_2O (5.58 %) is unexpected high. This rock type does not show the postintrusive high temperature metamorphism of the two-mica granites mentioned above. Similar rock types occur further in the W in the area between Rabenwald and the Stubenberg (Kiesl et al., 1983; Koller and Wieseneder, 1981). A Rb-Sr errorchron (S. Scharbert, 1990) yielded an age of these rocks of 243 ± 12 Ma (Sr_0 = 0.7234 ± 0.0017). The granodiorite from mount Wullmenstein is positioned exactly on this errorchron. A possible explanation for the genesis of this type is the contamination of a mantle-derived magma with crustal material.

7) **Two mica granite gneisses** and **microcline augen gneisses** form several bodies between Rabenwald and southern Kulm areas. Petrographic composition with high muscovite contents, high Rb contents ranging from 217 - 331 ppm, and the high Sr_0 ratio of 0.7234 mentioned above classify these granitoids as syn-collisional granites. The meaning of the errorchron is not really clear, but it is interpreted to show a possibly realistic, Permian intrusion age (S. Scharbert, 1990). Field relationships suggest that some of these two-mica-granite gneisses and the microcline augen gneiss may belong to the Carboniferous granitoids.

We interpret Early Carboniferous granitoids as syncollisional intrusions which are followed by late collisional I-type and H-type (hybrid) granitoids due to mixing of igneous and sedimentary sources. The Permian intrusions, granitoids and gabbros, are related to crustal extension, rifting and ongoing subsidence along the Tethyan margins. In addition, thin volcanic sequences in Permian cover sequences result from the same Permian plutonic/volcanic event.

Variscan P-T-path (Fig. 16)

The time of the migmatitization is unknown, but probably it happened at the time of the intrusion of the Carboniferous two-mica granites. Chilled margins in the granites and granite-dykes are missing, which is an argument for a higher temperature of the country rocks (migmatites). Arguments for a pressure of about 4 kb at the time of the anatexis/intrusion are (Peindl, 1990):

(1) the existence of sometimes slightly corroded magmatic muscovite in the two-mica granites (4 kb is the lower stability limit for muscovite in granitic melts (Hyndman, 1985)), and

(2) the existence of pseudomorphs of kyanite after andalusite in an contact aureole in the Waldbach valley.

The clinopyroxene-bearing amphibolites seem to be large xenoliths in the granites because of the following reasons:
Obviously following the reaction principle of Bowen, clinopyroxenes exist only in the central parts of the xenoliths. In the direction of the granite, the clinopyroxene disappears, brown hornblende can be found only.

A sign of the origin of the clinopyroxenes by a prograde metamorphic P-T-path is the appearence of hornblende with green core and a brown rim in one of these amphibolites. Consequently, this means an evolution from green hornblende to brown hornblende to clinopyroxene. In the clinopyroxene, there is growing brown hornblende. Finally, seams of green hornblende and of actinolite can be observed as the last step of the amphibolite growth.

Because there is a lot of biotite in the melanosome of the migmatites, the growth of the clinopyroxenes (far beyond the upper stability limit of biotite) can not have taken place in the vicinity of the migmatites.

A temperature rise follows the crystallization (dehydration) of the granites, which causes prograde replacement of magmatic muscovite by sillimanite + K-feldspar + quartz. Rare small green patches in the granites resulted from small frozen melts along grain boundaries and later grown green biotite (Peindl, 1990). Quartz grains beeing in these patches are corroded by the melt. If the

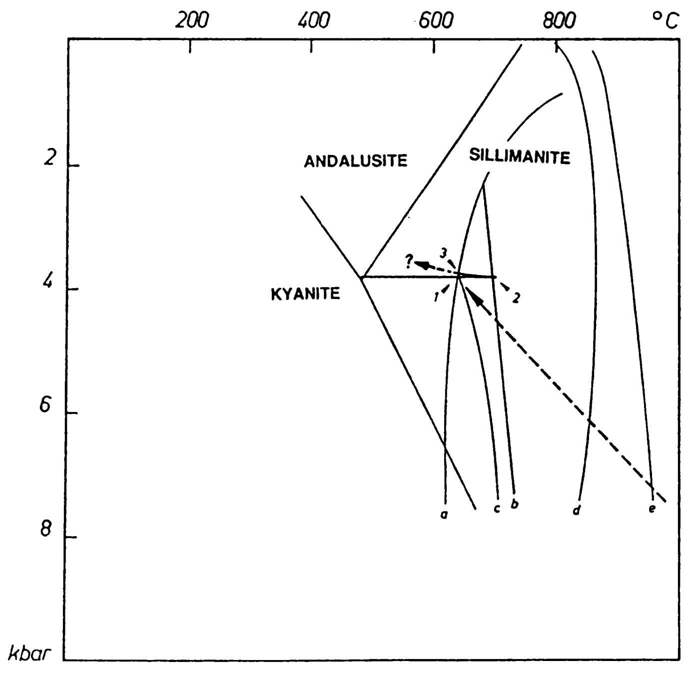

Fig. 16: Schematic Variscan metamorphic P-T-path of the southeastern part of the Raabalps (Peindl, 1990). Dashed line: P-T-path for the clinopyroxene-bearing amphibolites . Stages of evolution: 1: Anatexis of the migmatitic gneisses and intrusion of the Carboniferous two-mica-granites. 2: Increase of temperature, dehydration of muscovite, generation of H_2O-undersaturated liquids. 3: Intrusion of the Permian (?) granodiorite. Reaction curves: a: Anatexis of water saturated rocks. b: Anatexis of a water undersaturated rock. c: Upper stability limit of muscovite in a granitic liquid:muscovite + quartz + Na-rich plagioclase = alumosilicate + orthoclase + Ca-rich plagioclase + melt (Hyndman, 1985). d: Lower stability limit of biotite. e: Beginning of metamorphic growth of clinopyroxene (d, e after Wyllie, 1977).

tonalites/gabbroes intruded later than the two-mica granites, this could be the reason for the temperature rise. Otherwise, the volume of the tonalites/gabbros is much too small for releasing a sufficient amount of heat.

Before Triassic, but at latest at the Permian/Triassic boundary the granodiorite from the southern slope of Wullmenstein intruded. The muscovites are slightly corroded by the melt but they do not show any sign of a temperature rise following the crystallization of the magma.

Due to the strong overprint by the Alpine metamorphism, it is impossible until now to recognize the Variscan retrograde metamorphic P-T-path. Permo-Mesozoic sediments in the northern part of the Raab Alps proof the uplift of the Raabalpen complex at the end of the Variscan metamorphic P-T-path.

Permo-Triassic cover sequences

Permo-Triassic cover sequences are mainly exposed along the northern margin of the Tatric unit, the Wechsel/Waldbach units and the "Grob gneiss" unit (Semmering Group). The Semmering sequence commenced with the Alpine Verrucano Fm. (Permian ?) which consists of breccias, sericite schists and acidic tuffs as well as minor andesitic extrusive rocks (Tollmann, 1964, 1977). The Alpine Verrucano Fm. grades into the Semmering Quarzite of suggested Late Permian to Scythian age and greyish slates. Carbonate deposition started with rauhwacke (a gypsum-bearing yellowish limestone) and grades into light-coloured limestone and Anisian to Ladinian dolomite. Locally occurring dark slates and and coloured slates also including anhydrite/gypsum and dark dolomite belong to the Late Triassic. The Late Triassic sequence, called "Carpathian Keuper" (Tollmann, 1977), strongly differs from other Central-Alpine Triassic sequences.

The Wechsel/Waldbach cover sequence only includes basal Permo-Scythian and Anisian formations due to tectonic decapitation. This basal sequence is basically similar to the Semmering system (Faupl, 1970; Huska, 1970; Tollmann, 1977; Vetters, 1970).

Alpine Tectonic Evolution

The present tectonic structure of Lower Austro-Alpine tectonic units along the discussed section resulted from Cretaceous thrusting which led to the overriding of the Wechsel/Waldbach units by the nappes of the Semmering system. Thrust geometries with accumulated cover sequences in frontal recumbent folds along the northern margins of the Semmering System (Tollmann, 1964) and with basement only within southern areas combined with increasing metamorphic P-T conditions from North to the South which indicate a northward climbing of a basement-cover ramp. Metamorphic amphibolite facies conditions in the hangingwall nappe and in part upper greenschist facies conditions in the Wechsel/Waldbach nappes indicate an out-of-sequence thrust which brought up the Semmering nappes (Dallmeyer et al., this vol.). The internal structure of the Semmering system is dominated by splays of the basal master fault into mylonite zones which especially developed along Grob gneiss / paragneiss interfaces. These zones include broad mylonite zones with "white schists" which are mainly derived from orthogneisses due to access of hydrous fluids (Reindl, 1989; Prochaska, 1991). The direction of ductile thrusting varies over large areas (Fig 17). Limited data indicate top W to NW transport along northernmost Semmering areas, top N to NNE displacement in central portions (Reindl, 1991), and top N and NW displacement in southwestern areas (Moyschewitz, in prep.). Variations of the displacement pattern partly derived from ductile overprint within peak and decreasing metamorphic conditions which resulted from post-metamorphic extension. This later pattern mainly displays in E-W to NE-SW extension although detailed local studies monitor no preferred direction of extension (Peindl, 1990).

The exhumation of the dome-shaped Wechsel Window and probably of the Fischbach Window, both with a similar dome-like shape, ocurred in a two-step history. A first event probably followed Cretaceous metamorphism. Ductile to semiductile fabrics along western margin and semiductile fabrics along the eastern margin of the Wechsel Window record approximate E-W extension. In the interior, a weak flat-lying, widely spaced foliation is superimposed on earlier ones. The late foliation is related to folds with flat-lying axial surfaces due to subvertical shortening during extension. Semiductile shearing along E-W trending shear zones along northern and southern margins is apparently related to updoming. However, fission track data indicate that final cooling occurred during the Neogene (Dunkl, this vol.). Especially the northern portion of the Wechsel Window and

Permo-Mesozoic sediments are affected by brittle, ca. ENE trending folds. Related basins like the basin of Kirchberg am Wechsel proof the Neogene activity along these faults (Ebner et al., 1991).

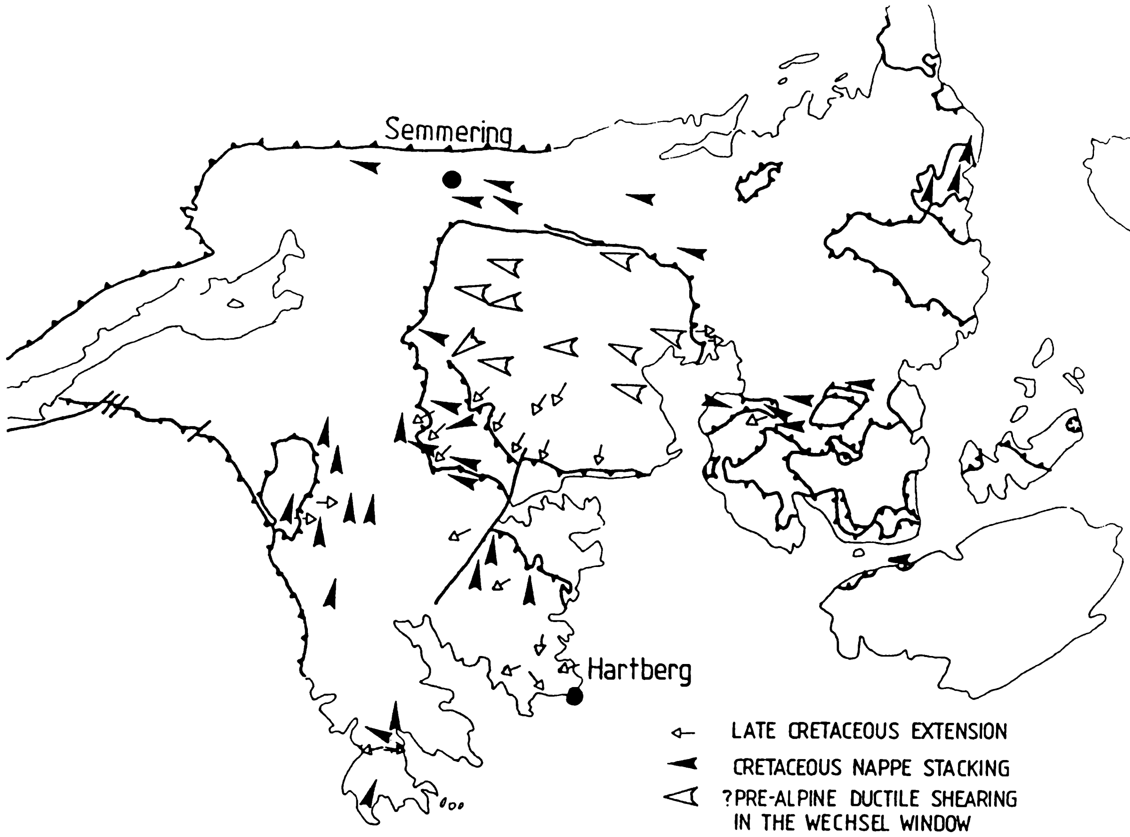

Fig. 17: Kinematic indicators in the Wechsel gneiss complex and Grob gneiss complex.

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