The Variscan orogeny in the Austroalpine and Southalpine domains of the Eastern Alps

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by *Franz Neubauer*[1]

Abstract

Geochronologic data of metamorphic and magmatic rocks of different Austroalpine basement zones (Eastern Alps) are reviewed in relation to pre- and postorogenic sedimentation. A stepwise crustal consolidation due to metamorphism, uplift and postorogenic sedimentation was recognized ranging from Devonian to Permian times. The Variscan orogeny of the Eastern Alps is explained by stepwise accumulation of terranes due to oblique compression during Devonian and Carboniferous times which is followed by a transtensional stage (late Carboniferous to Permian). During transpression different microplates (terranes) were accumulated which show an individual pre-accumulation history each.

Keywords: Austroalpine basement, crustal consolidation, microplate, Variscan orogeny, Eastern Alps.

Introduction

In the Eastern Alps, pre-Alpine basement which suffered Variscan orogeny occurs in three distinct tectonic units (Fig. 1): The Austroalpine unit is closely related to the southerly adjacent Southalpine unit. Both units stay in contrast to the Penninic basement, which is related to the European foreland of the Alps.

The Austroalpine domain of the Eastern Alps is dominated by pre-Alpine basement rocks, the metamorphic state of which ranges from high grade metamorphosed complexes to more or less unmetamorphosed, fossiliferous sedimentary sequences. Evidence of a late Carboniferous Variscan orogeny within the sediments of the Austroalpine and Southalpine domains is known for a long time by angular unconformities (OESTREICH, 1900; SPENGLER, 1926; FENNINGER et al., 1974, 1976). In the crystalline basement, geochronological data show a more complex relationship because of a strong eo-Alpine metamorphic overprint and the widely scattered data (for a review, see FRANK et al., 1987; SASSI et al., 1985). Thus, models of the Variscan orogeny in the Eastern Alps are based mainly on data of fossiliferous sediments (FLÜGEL, 1978; SCHÖNLAUB, 1979).

Recent research yielded a lot of data (e.g. FRANK et al., 1987) favouring more complex models (FRISCH and NEUBAUER, in press; NEUBAUER, 1988). The aim of this paper is to review all these data from distinct Alpidic tectonic units in respect to their significance of the Variscan orogenic evolution. In detail, the main interests concern:

i) biostratigraphic data of pre- and postorogenic sedimentary sequences to date the orogenic movements in a more classic way;

ii) geochronologic data concerning the magmatic as well as the metamorphic evolution and their relationship to postorogenic sedimentary sequences;

iii) the structural evolution of some significant units.

In this paper, the data of basement units of the eastern Austroalpine domain are summarized because of the great variety of basement rocks in relation to metamorphic state as well as to lithology (Fig. 2). The zonation proposed

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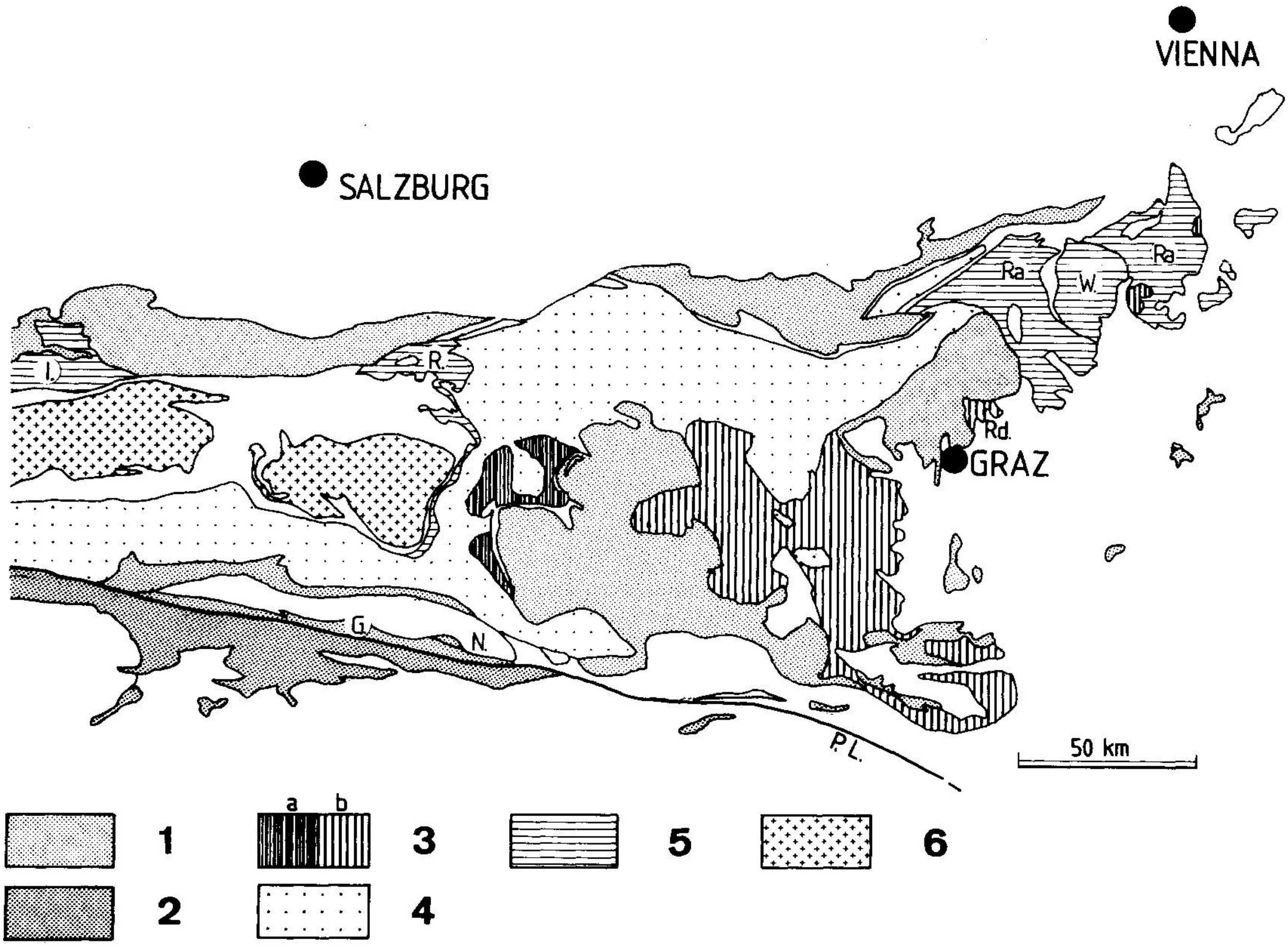

Fig. 1 Basement zones of the eastern Austroalpine region. 1 – Upper Austroalpine unit and related areas (G. – Gailtal crystalline complex; N. – Nötsch); 2 – Southalpine unit; 3a – Bundschuh-Priedröf-Einach unit; 3b – Korides (Rd. – St. Radegund crystalline complex); 4 – Murides; 5 – Lower Austroalpine units (I. – Innsbruck quartzphyllite; R. – Radstadt quartzphyllite; Ra. – Raabalpen crystalline complex; W. – Wechsel); 6 – Penninic basement.

follows the Alpine structural edifice (TOLLMANN, 1963, FRANK, 1987) with modifications based on basement studies (FRANK, 1987; FRISCH et al., 1984; NEUBAUER and PISTOTNIK, 1984). A diagrammatic sketch of basement zones involved in the Alpine orogen is shown in Fig. 2. In the present paper, those units are reviewed only, from which geochronologic data in combination with biostratigraphic data allow conclusions about timing of orogenic movements. Additional units in the more western Austroalpine region give further information about Variscan orogeny, e.g. the zone of the Ulten valley (GEBAUER and GRÜNENFELDER, 1978) or Ötztal (THÖNI, 1986). In the intra-Alpine region, it is difficult to separate the effects of the "Caledonian", pre-Devonian tectonothermal evolution ("Caledonian event") from the Variscan history. Thus the evolution from Devonian to Permian is regarded to be affected by the Variscan orogeny.

The chronostratigraphic framework from Devonian to Permian times follows the timescale calibration of ODIN and GALE (1982) and HARLAND et al. (1982) with the modifications proposed by ODIN (1986) and HESS and LIPPOLD (1986).

The term Upper and Middle Austroalpine follows the Austrian usage. The usage implies no preference for contrasting models of Alpine structural evolution.

The Upper Austroalpine and the Southalpine zone

The southern Upper Austroalpine zone is separated into three thrust sheets different in lithology of basement (NEUBAUER and PISTOTNIK, 1984), e.g. the Gurktal thrust system with the Murau nappe at the base, the Stolzalpe nappe at the hangingwall, the Ackerl unit, which has only local importance.

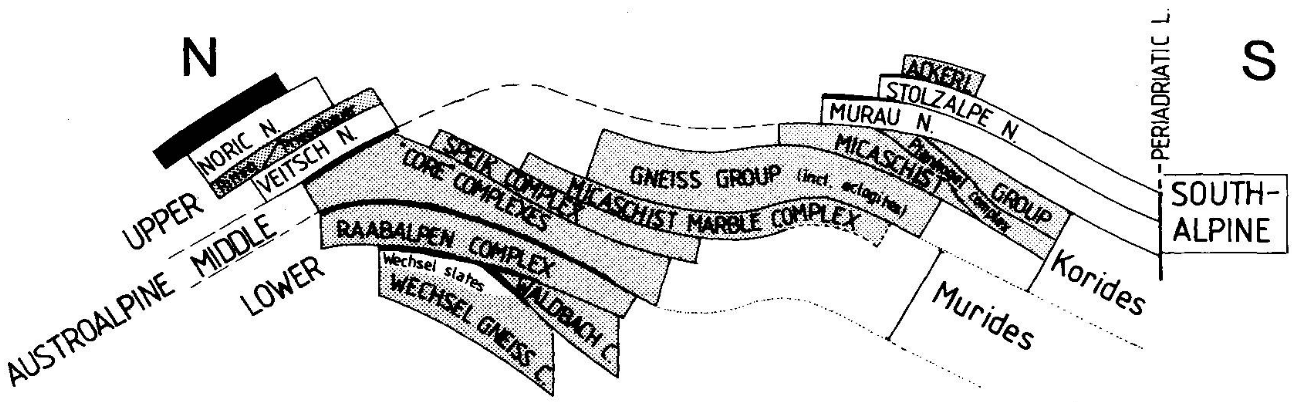

Fig. 2 Diagrammatic scheme for the Alpine structure in relation to basement zones of the Austroalpine domain.

The uppermost Austroalpine zone and the Carnic Alps

The sedimentary sequences of the Southalpine region (Carnic Alps, Karawanken) and of the Upper Austroalpine zone (Noric nappe of the Greywacke zone, the Stolzalpe nappe of the Gurktal thrust system, the Rannach-Hochlantsch-Laufnitzdorf nappes of the Paleozoic of Graz) show a similar geodynamic evolution as it is demonstrated by FLAJS and SCHÖNLAUB (1976), SCHÖNLAUB, (1982) and NEUBAUER and HERZOG (1985). The sedimentary sequences range from late Ordovician to the Carboniferous. The late Ordovician to early Devonian sedimentation is controlled by continuous subsidence on a shelf, intensifying the separation between swells and basins. The swell regions are dominated by carbonates, the basins by siliciclastic and volcanogenic sedimentation (FLÜGEL, 1977). Continuing subsidence and circulation in an open ocean are responsible of nodular limestones and lydites typical of early Carboniferous times (e.g., SPALETTA et al., 1982). The sharp change to siliciclastic flysch sedimentation is dated as intra-Visean in the Southalpine (AMEROM et al., 1983; HERZOG, 1983) as well as in the Austroalpine domain (NEUBAUER and HERZOG, 1985). The molasse-like overstep sequence is differentiated in facies and age north and south of the Periadriatic lineament. The Waidegg and Auernig formations of the Carnic Alps belong to the Stefanian with possible Westfalian precursors (SCHÖNLAUB, 1985b). The postorogenic sequence in the Stolzalpe nappe started with the Westphal C-Stefan (TENCHOV, 1978, and references cited therein) in the west, and with early Rotliegendes in the east (FRITZ and BOERSMA, 1987).

The age of the pre-Alpine metamorphism of the Southalpine unit has been proved only for the Brixen quartzphyllite situated below the Carnic Alps. DEL MORO et al. (1980) give evidence for a two-stage metamorphism (350 ± 3, 317 ± 16). The latter age is confirmed by HAMMERSCHMIDT and STÖCKHERT (1987). The younger metamorphic event coincides with the age of deformation of the Carnic Alps.

Thus, the age of deformation should be older than Westfalian B / C and younger than Visean. FLAJS (1967), MOSTLER (1973) and SCHÖNLAUB (1982) demonstrated a Variscan nappe structure within the Noric nappe of the Greywacke zone. The nappe pile is sealed by the angular unconformity at the base of the transgressive Permoscythian rocks (SPENGLER, 1926).

It is worth being noted that the fluviatile molasse sediments north of the Periadriatic lineament contain orthogneiss boulders which yielded intra-Devonian geochronological ages (FRIMMEL, 1986 a, b).

The Veitsch-Nötsch zone

The flysch-like early Carboniferous sediments of the first zone are contrasted by the Veitsch-Nötsch zone. For the Veitsch zone within the eastern Greywacke zone, NIEVOLL (1983) and RATSCHBACHER (1984) propose facies models of a shelf sequence strongly influenced by coarse clastic rocks which are rich in granitic pebbles. Biostratigraphic data are scarce, but demonstrate various time-levels between late Visean and Westfalian (RATSCHBACHER, 1984, and references cited therein).

A strongly metamorphosed basement slice has been found recently together with sediments of the Veitsch zone. A paragneiss has a U/Pb zircon lower intercept age of 391 ± 2 Ma, and an aplitic vein an upper intercept age of 363 ± 20 (NEUBAUER et al., 1987). Thus an intra-Devonian metamorphic and magmatic evolution is assumed. As reasonable, this basement slice is assumed to be the basement of the Carboniferous Veitsch sediments, although an Alpidic mylonite zone separates both units.

A sedimentary sequence similar in fauna, sedimentary facies and time of sedimentation is present at the locality of Nötsch, near the southern margin of the Austroalpine region. The age of sedimentation is reinterpreted recently by SCHÖNLAUB, (1985a) and ranges from late Visean to Westfalian. The conglomerates and a doubtful agglomerate ("Diabaszug") bear components of mylonitic granite gneiss, marble and amphibolites derived from a pre-Visean metamorphic hinterland (EXNER, 1983; own unpublished data).

The Middle Austroalpine units

The Middle Austroalpine unit is divided into two or three basement zones respectively,strongly differentiated by lithological and tectonometamorphic evolution:

i) The base of the Middle Austroalpine is composed of the Murides subdivided again into several units (Fig. 2).

ii) The hangingwall complex is called Korides. It is subdivided into the "Gneis-Gruppe" and the "Glimmerschiefer-Gruppe" including the ophiolitic Plankogel complex.

iii) The Bundschuh-gneiss complex and the Korides have the same structural position on the top of the Murides, but lithology and tectonometamorphic evolution show some essential differences.

Murides

The Murides consist of three complexes differentiated with respect to lithology (NEUBAUER, 1988, and references cited therein):

i) The "core" complexes appearing in some dome-like structures are composed of strongly deformed plagioclase gneisses, amphibolites and granitoid gneisses.

ii) The Speik complex is a strongly deformed and thinned ophiolite of unknown age.

iii) Micaschists and marbles ("Micaschist-Marble complex") on the top of the Speik complex remember to fossiliferous Silurian and Devonian sedimentary sequences of the Upper Austroalpine domain.

With respect to the assumption stated above, the age of metamorphism within the Murides should be younger than Devonian. The core complexes are overlain unconformably by sedimentary rocks (Rannach fm.) assigned to late Permian and to the Scythian by lithological arguments (for a review, see ERKAN, 1977). Besides some data favouring pre-Devonian tectonothermal and magmatic events in the core complexes (FRANK et al., 1976; SCHARBERT, 1981; own unpublished data), a lot of data fall into the range of 360-330 Ma (Fig. 3). In the Rennfeld area, a lower intercept model age of a tonalitic amphibolite is interpreted as an effect of a high-grade metamorphism producing trondhjemitic leucosomes by partial melting of plagioclase-rich amphibolites. The trondhjemites bear zircons with a concordant model age (U/Pb) at 353 ± 1 Ma. Similar trondhjemites are incorporated into necks between amphibolite boudins and should be intruded during stretching of amphibolites. A very elongated and thin augen gneiss body yielded a Rb/Sr errorchrone of 330 ± 30 Ma (FRANK et al., 1983). The augen gneiss shows relictic features of a porphyric granite which intruded into the zone of thrusting which displaced the Speik complex onto the top of the core complexes (Fig. 4). Similar features of a synkinematic granite intrusion were found in the Humpelgraben granite gneiss which shows a foliation formed by the separation of biotite and quartzofeldspatic layers. These layers were crosscutted by aplitic dykes derived from the same magma. The augen gneiss forms the top of the core complex, with some apophyses crosscutting the Speik complex and reaching also the hangingwall micaschists. Pegmatite concentrations within the micaschists and marbles were found in the continuation of the augen gneiss. Some coarse-grained pegmatitic muscovites yielded Rb/Sr model ages (e.g., 347 ± 2 Ma; FRANK et al., 1983) within the range of the augen gneiss errorchrone. Thus NEUBAUER (1988) argued for a

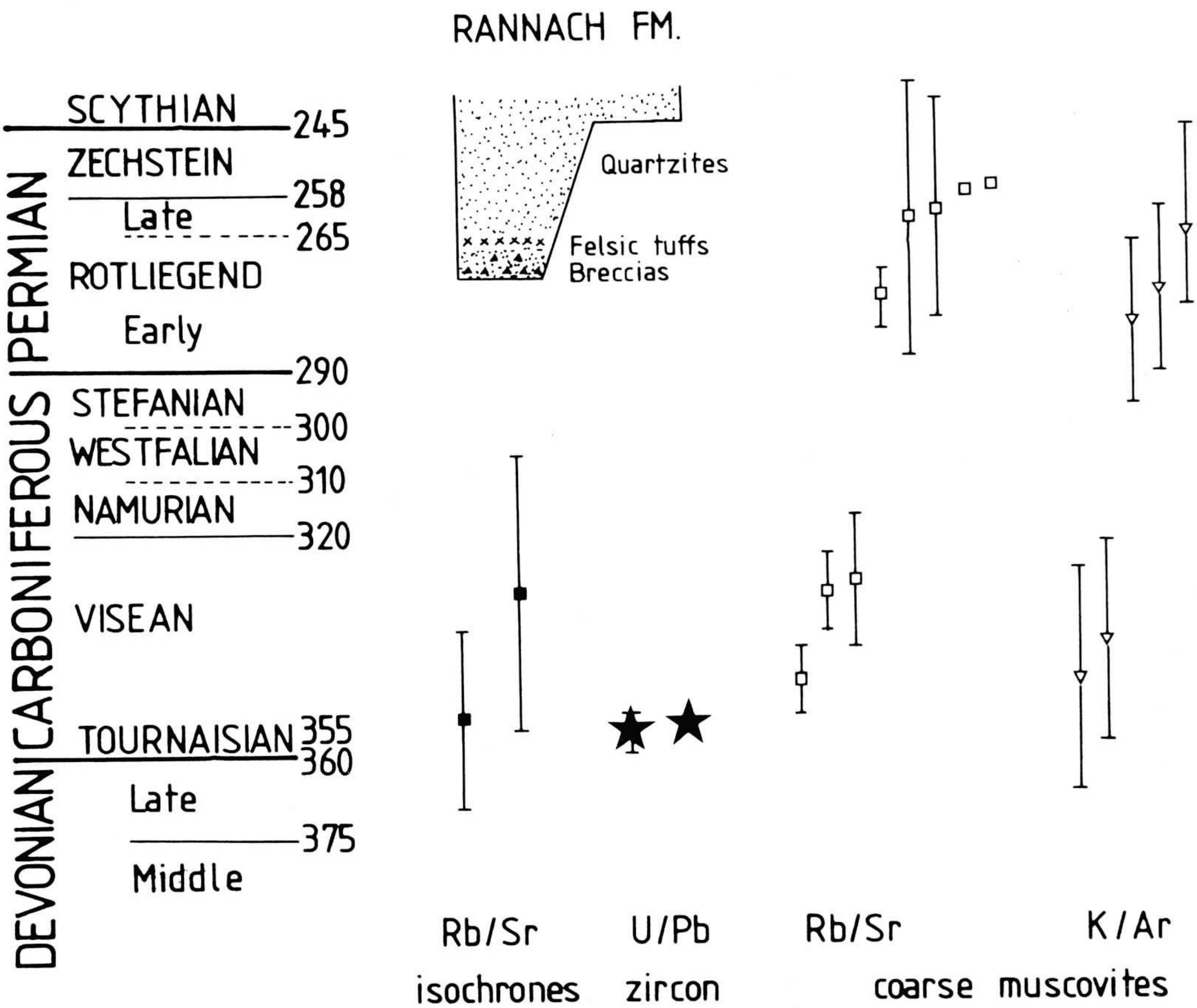

Fig. 3 Diagrammatic scheme of the Variscan evolution of the Murides. Data compiled from FRANK et al. (1976), FRANK et al. (1983), HEJL (1984), NEUBAUER (1988) and SCHARBERT (1981).

melt-enhanced thrusting of the ophiolitic Speik complex onto the core complexes during early Carboniferous times (Fig. 4).

In the Murides some scattered Rb/Sr model ages are found within the range of Permian time. On the other hand there are some volcanic layers within the Rannach formation which could be correlated to Permian volcanics elsewhere in the Alpine region. Thus an intra-Permian magmatic and thermal event and intra-Permian uplift is postulated for the Murides.

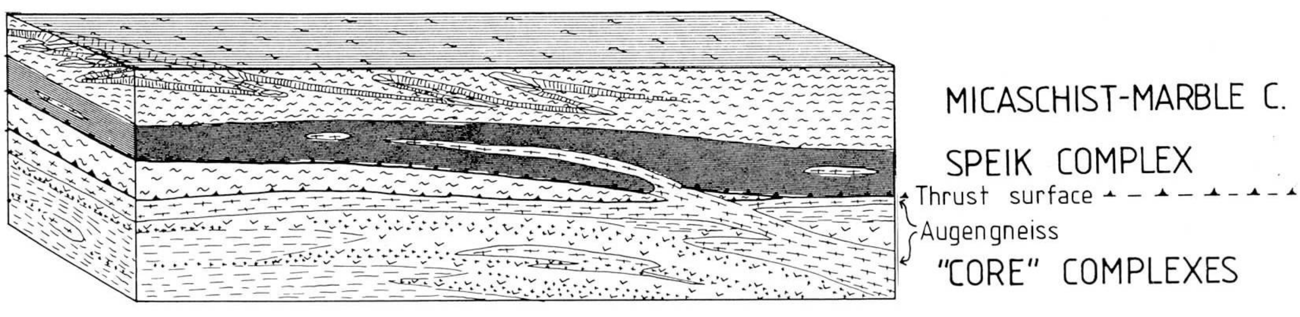

Fig. 4 Model for early Carboniferous deep-crustal thrusting in the Murides (modified after NEUBAUER, 1988).

The Korides

The most controversal age interpretations concern the Korides (Saualm and Koralm) of the Eastern Alps. In the Koralm and the Saualm, the gneiss group containing eclogites is thrusted onto the micaschists and marbles of the Murides visible also in some windows (WEISSENBACH, 1975). FRANK et al. (1983) proposed a multi-stage metamorphic evolution model with an earlier hT-metamorphism producing andalusite and a later hP-metamorphism which transformed andalusite into cyanite. The later metamorphic event is possibly related with eclogite metamorphism. MANBY, THIEDIG and MILLAR (pers. comm.) found some indications of a late Proterozoic age of eclogite metamorphism based on Sm/Nd data. However, a lot of Rb/Sr errorchrones as well as mineral data (Rb/Sr, K/Ar) give some arguments for probable Variscan events. The most

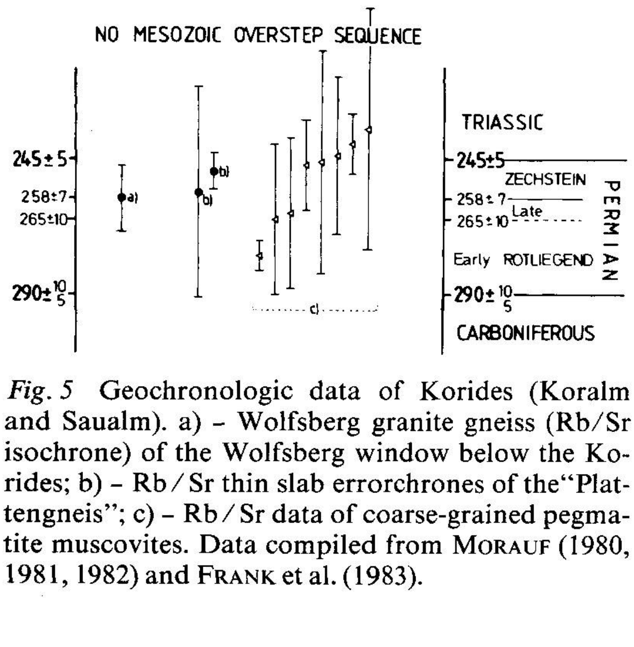

Fig. 5 Geochronologic data of Korides (Koralm and Saualm). a) - Wolfsberg granite gneiss (Rb/Sr isochrone) of the Wolfsberg window below the Korides; b) - Rb/Sr thin slab errorchrones of the "Plattengneis"; c) - Rb/Sr data of coarse-grained pegmatite muscovites. Data compiled from MORAUF (1980, 1981, 1982) and FRANK et al. (1983).

reliable Rb/Sr model ages of pegmatite muscovites (Fig. 5) favour a Permian age of isotopic closing which is indicated also by some thin slab errorchrones (MORAUF, 1982; FRANK et al., 1983). On the other hand, any Permomesozoic cover rocks are missing on the top of the Korides. Thus FRANK (1987) and KROHE (1987) argue for a deep-crustal position of Korides during late Variscan-early Alpidic times later upthrusted due to eo-Alpine tectonics.

The Bundschuh-Priedröf-Einach complex

The Bundschuh-Priedröf-Einach complex has the same-structural position on the top of the Murides micaschists like the Korides east of the Gurktal thrust system. It consists of monotonous paragneisses similar to some paragneisses in the Korides. But there is a significant difference in the lithology of inclusions: Mafic rocks like eclogites are completely missing in the Bundschuh region, on the other hand some bodies of muscovite-rich orthogneisses occurring here are not known in the Korides. The orthogneisses yielded Rb/Sr model ages of 373 ± 30 to 363 ± 27 Ma (HAKESWORTH, 1976; FRIMMEL, 1986 a, b). Further unpublished data of FRIMMEL (pers. comm.) favour a more older age of intrusion, whereas the Rb/Sr isotope systematics are strongly disturbed by an intra-Devonian metamorphism. A possibly similar body is the Villach granite-gneiss, from which a slightly older Rb/Sr model age is reported (GÖD, 1977; FRIMMEL, pers. comm.).This group of Silurian/Devonian orthogneiss data has some exclusiveness in the Eastern Alps except some data of the Greywacke zone (NEUBAUER et al., 1987) and muscovite granites in the Ötztal region (GRAUERT, 1981; SÖLLNER and HANSEN, 1987). The Bundschuh orthogneiss is strongly deformed under conditions of greenschist facies. The basement is covered transgressively by quartzites interpreted as Permoscythian (PISTOTNIK, 1976). Thus the deformation and metamorphism fall in the time between intrusion (early to middle Devonian resp. late Ordovician/Silurian according to unpublished data of FRIMMEL) and Permian. FRIMMEL argues for an intra-Devonian metamorphism from the geochronological point of view.

A late Paleozoic (or Alpine?) age of thrusting of the Bundschuh-Priedröf-Einach complex on top of the Micaschist-Marble complex is postulated, under the assumption that the Silurian-Devonian sedimentation age of the Micaschist-Marble complex is correct.

The Raabalpen crystalline complex

The Raabalpen crystalline complex has a structural position below the Middle Austroalpine unit, and is therefore assigned to the Lower Austroalpine unit. The monotonous lithology of this complex contrasts remarkably to all other basement units of the Eastern Alps. It consists of migmatitic paragneisses, micaschists somewhat transformed into phyllonites due to the Alpidic thrusting. The metasedimentary rocks include large sheetlike bodies of porphyric granite gneiss (Grobgneis) and little bodies of discordant medium-grained granite gneisses in its southern part.

The paragneisses suffered hT-metamorphism which is indicated by andalusite and sillimanite in migmatitic zones. The "Grobgneis" yielded a Rb/Sr isochrone of 320 ± 20 Ma (SCHARBERT in SCHÖNLAUB, 1979). A few Rb/Sr muscovite ages of the discordant granites fall into the range of the Permian. The Grobgneis shows no contact zones to the country rocks. Thus it is believed that the age of the metamorphism is principally similar to the intrusion of the Grobgneis. The discordant granite stocks should have an age younger than the migmatitic event. There is a possible relationship between granite stocks and volcanic rocks at the base of the cover series along the northern margin of the Raabalpen crystalline complex (Fig. 6). This cover series were assigned to the early Permian from the lithostratigraphic point of view.

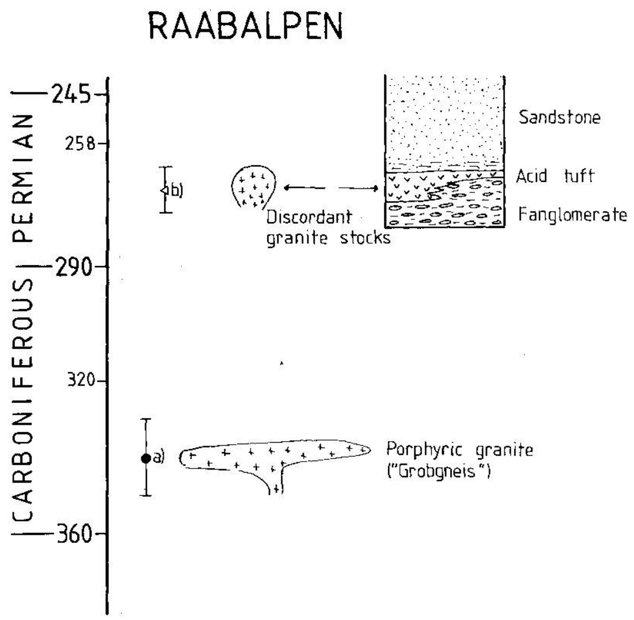

Fig. 6 Diagrammatic scheme of the Raabalpen crystalline complex and its sedimentary cover. Geochronologic data after SCHARBERT in SCHÖNLAUB (1979). a) – Rb/Sr isochrone; b) – Rb/Sr muscovite.

Discussion

The data stated above argue for striking differences in the timing of metamorphism and accompanying deformation taken as an indicator of orogenic events in different basement zones of the Eastern Alps. This is interpreted as step-wise consolidation of different Austroalpine basement units between Devonian and Permian times. The restoration of Alpidic structures due to the Alpine kinematics of the Eastern Alps in a rough way (for details, see NEUBAUER, 1988) yields an approximate conception of pre-Alpine, late Variscan paleogeography and orogenic zones. In this scheme, the position of basement units metamorphosed during different times yields an approximate state of the late Variscan structural zonation. The following orogenic zones are distinguishable (Fig. 7):

1) An external zone was deformed during late Carboniferous. It includes Paleozoic sediments of the Southalpine domain, the Noric nappe, the Paleozoic of Graz and the Gurktal nappe. Geochronologic data related to this event are known only in western part of the Southalpine basement.

2) An internal zone (incl. Murides, Korides and the Raabalpen crystalline complex) was deformed and metamorphosed during early Carboniferous. This zone includes a central batholitic zone flanked by metamorphic zones. The more internal part of the metamorphic zone (Raabalpen) shows mineral parageneses including andalusite and sillimanite which indicate a hT-metamorphism. In the more external metamorphic zone (southern Murides and Korides), kyanite is the common Al_2O_5-polymorph. This fact favours a geothermal gradient lower than that of the more internal zone. The age of metamorphism in this internal zone is early Carboniferous contrasting the sedimentation in the external zone.

3) A third zone (Bundschuh, Devonian metamorphics of the Veitsch zone) in an intermediate position was metamorphosed during intra-Devonian times.

A model for the Variscan orogeny has to explain the formation of the different metamorphic zones in terms of plate tectonics. The essential difficulties to reconstruct the Variscan history of the Eastern Alps are uncertainties in the interpretation of formation ages of pre-Alpine ophiolites (Speik and Plankogel com-

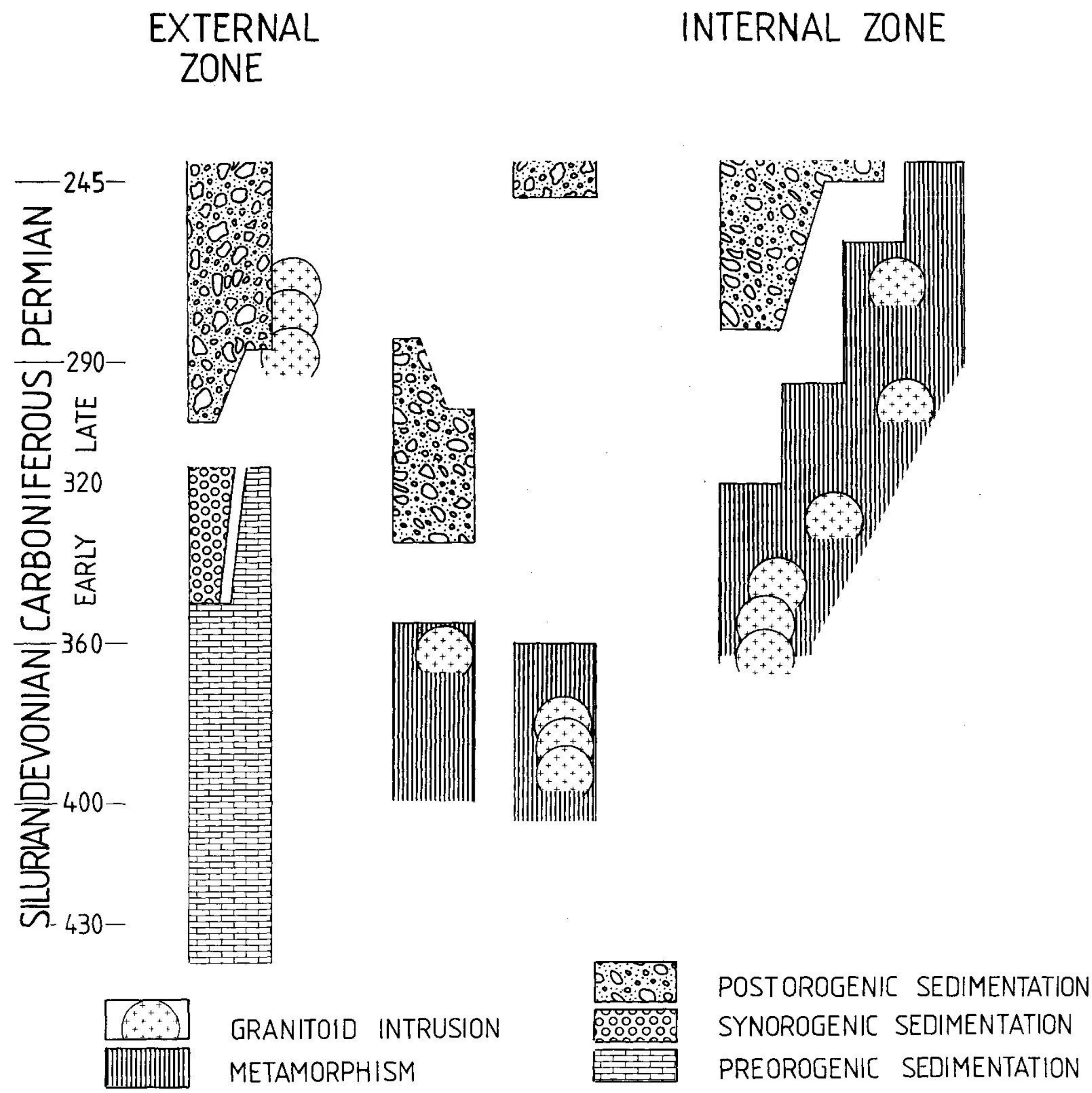

Fig. 7 Diagrammatic scheme for timing of metamorphism and orogeny in contrasting basement zones of the eastern Austroalpine region.

plex). Because of the occurrence of marbles and micaschists similar to fossiliferous Silurian-Devonian sequences together with ophiolitic rocks, Frisch et al. (1984) and Frisch and Neubauer (in press) argue for an early Variscan suture zone within the Korides of the Eastern Alps. This argument is contradicted by first Sm/Nd model ages (700 Ma; Manby, pers. comm.).

However, the essential result of this review is the contrast between sedimentation of the Upper Austroalpine and the metamorphism and magmatism in the Middle Austroalpine unit at the same time. This could be explained by convergence of two continental (micro-) plates with a possible intervening oceanic basin. This convergence started during Devonian times, whereas continuing subsidence due to rifting has occurred in the other region (e.g. models of Heinisch, Schlamberger, and Fritz and Neubauer, this volume). A first step of consolidation is the uplift of the intra-Devonian metamorphosed complex and the sedimentation of molasse-like sediments on the top of this complex during early Carboniferous time. At the same time thrusting occurred in the more internal zones of the Austroalpine units (Murides), whereas orogenic flysch-sedimentation occurred in the external zones. ROSSI and VAI (1986) show the shift of calcalkaline volcanism to alkaline volcanism within the flysch basin of the Southern Alps possibly due to transtensional movements. Similar large-scale strike-slip movements are also indicated by early Carboniferous Schlingen tectonics dated by GRAUERT (1981). A large-scale strike-slip component of movement could be an explanation for the position of the intra-Devonian metamorphosed crystalline complexes in the intermediate zone between the external, late Carboniferous formed zone and the internal zone formed during early Carboniferous (Fig. 8).

The external zone was deformed during late Carboniferous time. At this time some confined parts of the internal zone were uplifted as indicated by scattered cooling ages in eastern parts of Eastern Alps not considered in this paper (e.g., NEUBAUER and STATTEGGER, 1981). Strong evidence for late Carboniferous cooling and uplift is known from the western Middle Austroalpine domain (THÖNI, 1986).

The widespread scattered occurrence of Permian mica ages can be correlated to the regional uplift of the internal zone in an extensional regime due to buoyancy of previously thickened crust. Uplift and extension were accompagnied by widespread magmatism along the southern margin of the internal zone (e.g. plutons along the Periadriatic lineament and the related volcanism in the Southern Alps). Their composition ranges from granite to gabbro indicating a calcalkaline suite. The $^{87}Sr/^{86}Sr$ initial ratios of the more leucocratic rocks range between 0.7046 and 0.7157. These ratios indicate the strong involving of crustal rocks in the magma production possibly in a transtensional regime which rendered the uplift of the plutons.

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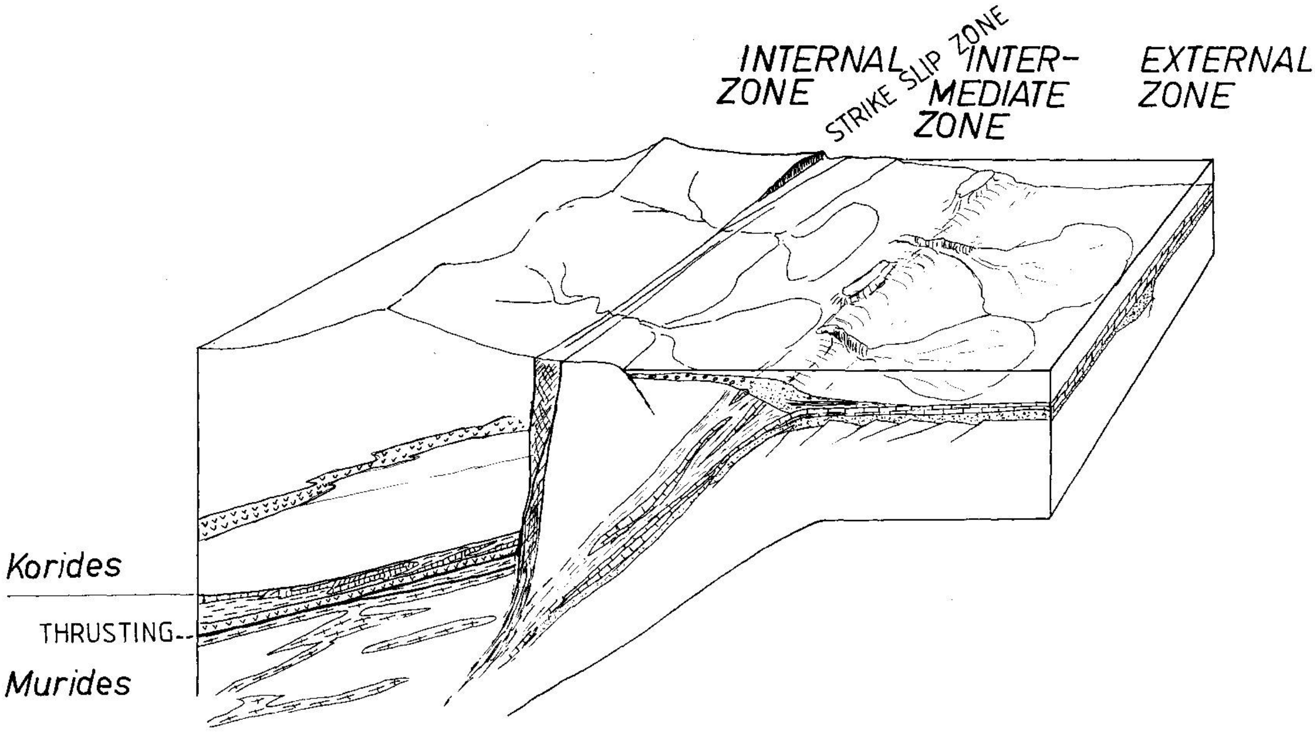

Fig. 8 Geodynamic model for mid-Carboniferous evolution of the Austroalpine and the Southalpine realms.

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