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Early Paleozoic and Variscan Events in the Austroalpine Rennfeld Block (Eastern Alps): A U-Pb Zircon Study

FRANZ NEUBAUER*), WOLFGANG FRISCH**) & BENT TAUBER HANSEN***)

10 Text-Figures, 1 Table

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Steiermark
Rennfeld-Kristallin
Ostalpin
Variszische Orogenese
Metamorphose
Magmatismus

Contents

Altpaläozische und variszische Ereignisse im oberostalpinen Rennfeld-Block (Ostalpen) anhand von U-Pb-Zirkon-Untersuchungen

Zusammenfassung

Basierend auf Geländebeziehungen und konventionellen U-Pb-Zirkonaltersdatierungen wird eine mehrstufige präalpidische magmatische und metamorphe Entwicklung im Rennfeld-Kristallin der Ostalpen nachgewiesen. Paragneiszirkone sind nahezu konkordant und zeigen an, dass die Sedimentation nicht vor dem späten Proterozoikum stattgefunden haben kann. Im Gegensatz dazu zeigen obere Schnittpunktalter des Rennfeld-Metatonalits und von Augengneisen eine vererbte präkambrische Komponente mit einem möglichen Alter von bis zu 3 Ga. Ein metamorphes Ereignis mit Anatexis fand zwischen 470 und 420 Ma statt, wobei vermutlich auch Granite (Vorläufer des Augengneises) intrudierten. Ein zweites magmatisch/metamorphes Ereignis im späten Oberdevon bis frühen Unterkarbon (ca. 367–353 Ma) produzierte Trondhjemite durch Aufschmelzung von Amphiboliten. Subkonkordante Zirkone mit einem Alter um 353 ± 2 Ma werden als Bildungsalter der Trondhjemite interpretiert. Das Schmelzereignis wurde vermutlich durch die Intrusion des Rennfeld-Metatonalites verursacht, dessen Zirkone mit einem unteren Schnittpunktalter als Kristallisationsalter der Zirkone interpretiert werden.

Die klastischen Zirkone in den Paragneisen zeigen eine juvenile Magmenproduktion im obersten Proterozoikum oder untersten Paläozoikum an. Das mittelpaläozoische thermale Ereignis (ca. 470–420 Ma) wird von Intrusionen gefolgt, welche sich wahrscheinlich über einer Subduktionszone längs eines aktiven Kontinentalrandes vor der variszischen Kollision kontinentaler Platten bildeten.

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*) Univ.-Prof Dr. FRANZ NEUBAUER, Institut für Geologie und Paläntologie, Universität Salzburg, Hellbrunner Straße 34, A-5020 Salzburg, Austria; Fax: ++43-662-8044-621; e-mail: franz.neubauer@sbg.ac.at.

**) Univ.-Prof. Dr. WOLFGANG FRISCH, Institut für Geologie und Paläontologie, Universität Tübingen, Sigwartstraße 10, D-72026 Tübingen, Germany.

***) Prof. Dr. BENT TAUBER HANSEN, Institut für Mineralogie, Universität Münster, Corrensstraße 24, D-48149 Münster.

Abstract

Based on field relationships and a conventional U-Pb zircon study the Austroalpine crystalline basement exposed in the Rennfeld region of the Eastern Alps exhibits a multi-stage pre-Alpine magmatic-metamorphic evolution. Nearly concordant zircon ages from a paragneiss suggest that sedimentation of the protolith of the paragneiss occurred not before late Proterozoic times. In contrast, upper intercepts of zircons from the metatonalite and augengneiss monitor Precambrian memories up to 3 Ga. A major metamorphic event between 470 and 420 Ma reached anatexis and resulted in strongly disturbed Pb isotopic systems. Furthermore, the protolith of an augengneiss likely intruded during this event. A second anatectic event occurred in the Early Carboniferous (ca. 367–353 Ma) and produced trondhjemites (subconcordant zircon age of 353±2 Ma) by partial melting of amphibolites due to overheating during intrusion of the Rennfeld metatonalite (353 +7/–10 Ma lower intercept zircon age). Clastic zircons in paragneisses infer a zone of juvenile magma production in the uppermost Proterozoic or lowest Paleozoic and a mid-Paleozoic tectonothermal event which was followed by intrusions (ca. 367–353 Ma) associated with steep thermal gradients above a subduction zone in an active continental margin setting that predates Variscan continental plate collision.

1. Introduction

Attention was focussed on the evolution of the basement in the circum-Mediterranean Alpine mountain belts during the last fifteen years (e.g. FLÜGEL et al., 1987; FRISCH et al., 1990; VON RAUMER & NEUBAUER, 1993). The progress in understanding the Alpine tectonic development and the increasing number of geochronological data constraining pre-Alpine magmatic and metamorphic events within these belts allowed more insights in the Variscan and pre-Variscan evolution.

Much progress was achieved by application of the U-Pb method on zircon and the Sm-Nd method on whole rock samples and minerals that enable to look behind the Alpine metamorphic overprint (SÖLLNER & HANSEN, 1987; EICHHORN et al., 1995, 1999; MILLER & THÖNI, 1995; MÜLLER et al., 1995; SCHALTEGGER et al., 1997; KLÖTZLI-CHOWANETZ et al., 1997; THÖNI, 1999 and references). So, for instance, Late Proterozoic and Early Paleozoic magmatic processes of a subduction-related environment are now well-known in the Penninic basement of the Eastern Alps (VON QUADT, 1992; VAVRA & HANSEN, 1991; GEBAUER, 1993; KÖPPEL, 1993; EICHHORN et al., 1995, 1999; for a review, see NEUBAUER, 2002). In the Austroalpine basement, these early processes remain poorly constrained although some data argue for similar processes in Late Proterozoic and Early Paleozoic times (e.g., FRANK et al., 1976; HAISS, 1990; MAGGETTI & FLISCH, 1993; MÜLLER et al., 1995; SCHALTEGGER et al., 1997). In contrast to Penninic domains, an intra-Ordovician tectonothermal event and an overprint by Variscan metamorphism are well established for the Austroalpine zone (SCHARBERT & SCHÖNLAUB, 1980; FRANK et al., 1987; SÖLLNER & HANSEN, 1987; THÖNI, 1999). Granitoids formed in the Ordovician (460–440 Ma) and in the Carboniferous and Permian (360–260 Ma) (FRANK et al., 1987; STILLE & BULETTI, 1987; PEINDL, 1990; FINGER et al., 1997). In contrast, protolith age data of the widespread mafic rocks in the Austroalpine unit are scarce and controversial (MANBY & THIEDIG, 1988; THÖNI & JAGOUTZ, 1992; MILLER & THÖNI, 1995; THÖNI, 1999). A further problem arises with the apparent non-record of subduction-related magmatism that predated Variscan continent-continent collision (BONIN et al., 1993; FINGER et al., 1997; SCHERMAIER, et al., 1997).

In this paper, we present results of conventional multigrain U-Pb dating of zircons carried out in the Rennfeld block, which is a part of the widely distributed „gneiss-amphibolite association“ (FRISCH et al., 1987; NEUBAUER & FRISCH, 1993) within the Austroalpine basement complex of the Eastern Alps (Text-Fig. 1). Conventional multi-grain U-Pb dating of zircons was performed between 1985 and 1986 with methods which are replaced by refinements (single grain dating, abrasion of zircons) not available at that time. However, these data still represent good results which constrain both timing of polyphase pre-Alpine metamorphic events and subduction-related magmatism in the Austroalpine unit, and allow more precise insights in the timing and nature of Early Paleozoic and Variscan accretion processes of Gondwanan tectonic elements to the Laurussian continent.

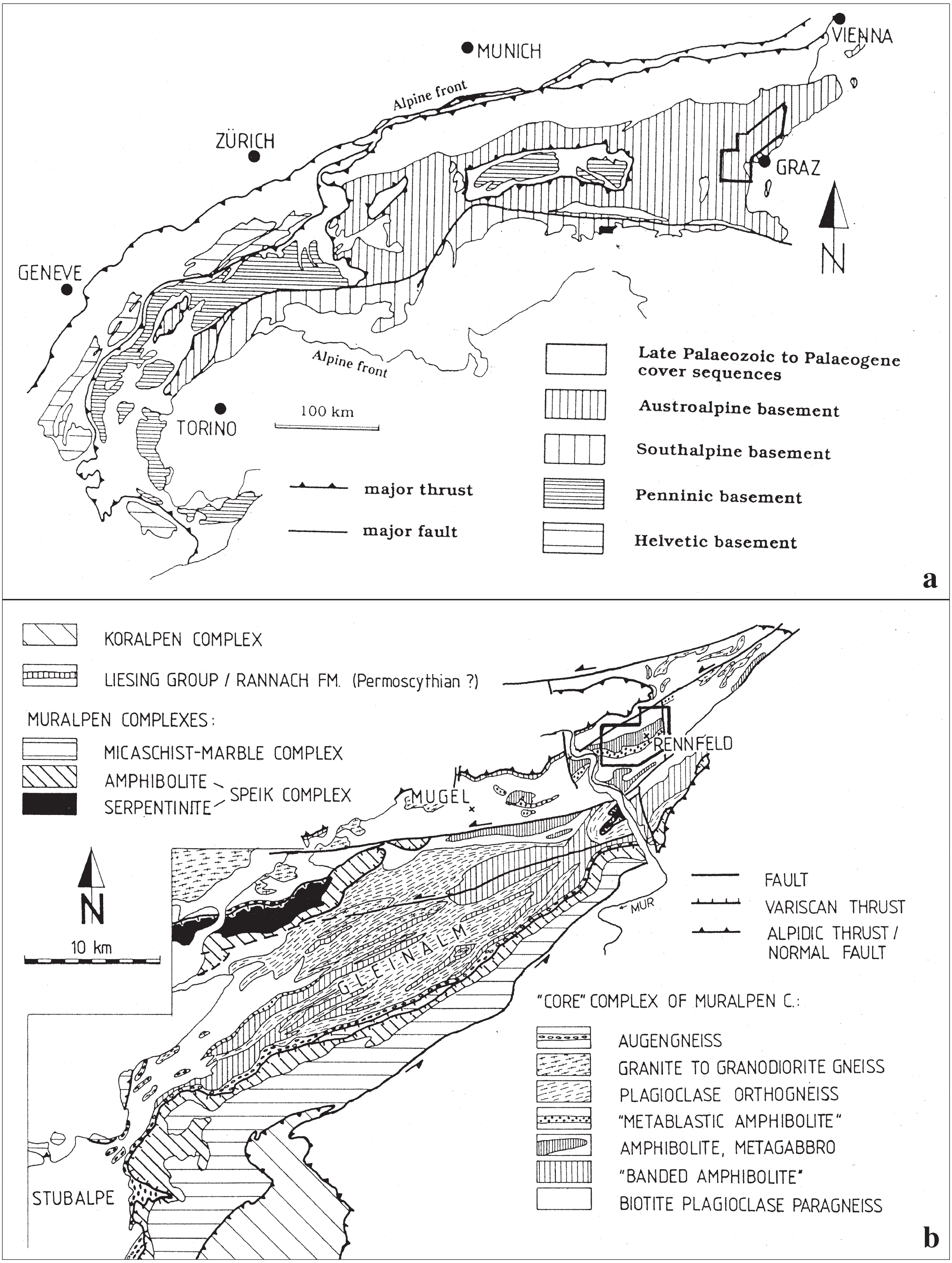
2. Field Relations

The Rennfeld block shows similar lithology, structure, and evolution as the adjacent Gleinalm region about which more details are known (FRANK et al., 1976; FRISCH et al., 1987; NEUBAUER, 1988; NEUBAUER & FRISCH, 1993) (Text-Fig. 1b). Both blocks are separated by a multiply activated fault zone of Late Cretaceous to Miocene age (NEUBAUER et al., 1995). The Rennfeld block mainly consists of generally N-dipping migmatitic paragneisses (Mugel paragneiss) and amphibolites (Text-Figs. 1b, 2). Distinct plagioclase-rich amphibolites, which show different mineral proportions, grain size, and texture, are intercalated to form a pile in the upper portions of the sequence. Lenses of marble, garnet micaschist, biotite-plagioclase gneiss, and garnet amphibolite are also intercalated. Meter-scaled nebulitic trondhjemite gneiss-hornblendefels lenses at the base of the plagioclase amphibolite pile suggest a genetic relationship to the migmatization process of the migmatites below (Text-Fig. 3a). The trondhjemite is therefore interpreted as the product of partial melting of the plagioclase amphibolites, leaving restitic hornblendefels behind (NEUBAUER, 1988).

The middle portion of the gneiss-amphibolite sequence is intruded by the Rennfeld igneous suite and minor granite bodies, which both suffered medium-grade metamorphism and have largely conformable contacts to the country rocks (Text-Fig. 2). The Rennfeld suite is a layered intrusion mainly made up of metatonalite and metadiorite (the „metablastic amphibolite“ of older literature [NEUBAUER, 1988]). The metatonalites and metadiorites contain plagioclase megacrysts (0.5 to 1 cm in diameter) in a matrix of amphibole, biotite and quartz. The tonalite/diorite body comprises lense-shaped metre- to dekametre-scaled inclusions of a wide compositional range (wehrlite, pyroxenite, hornblendefels, different types of hornblende metagabbro, granitic augengneiss). Based on petrographic, geochemical and Rb-Sr isotopic data NEUBAUER (1988, 1992) noted the calcalkaline character of the suite and reported a Rb-Sr whole rock errorchron of 390±49 Ma for the Rennfeld tonalite/diorite.

While the encountering gneiss-amphibolite association experienced two pre-Alpine medium-grade metamorphic events, the Rennfeld intrusive complex was only affected by the second event (NEUBAUER, 1988).

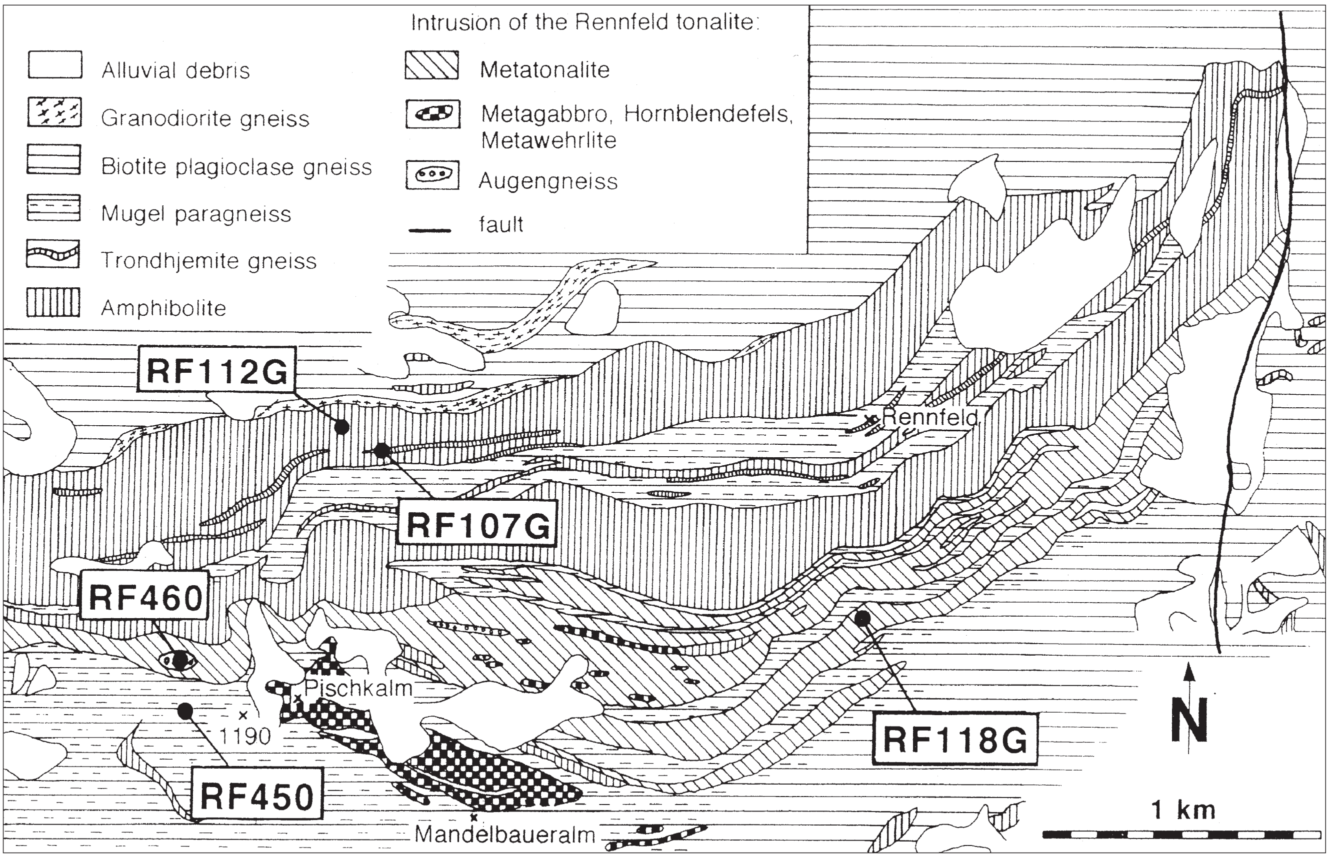
The paragneisses show evidence of three distinct episodes of metamorphism. The first metamorphic event led to the formation of migmatitic rocks with leucosome veins that are strictly parallel to the schistosity (Text-Fig. 3b). Trondhjemite and hornblendefels lenses in the basal plagioclase amphibolite probably formed during a second



Text-Fig. 1.
Location of the Gleinalm and Rennfeld blocks within the Alps (a) and simplified geological map of the Gleinalm and Rennfeld blocks (b).

Table 1.
U-Pb analytical data of zircon concentrates from the Rennfeld block (Eastern Alps).

Fractions	Sample weight	Concentrations			Isotopic ratios				Apparent ages (Ma)		
	(mg)	U (ppm)	Pb_{com} (ppm)	Pb_{rad} (ppm)	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{235}U}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{235}U}$	$\frac{^{207}Pb}{^{206}Pb}$
Paragneiss RF450											
(1) 57-80 µm, red	3.3	250	0.11	17.5	4891	0.0718	0.562	0.05677	447	453	483
(2) 80-100 µm, red	5.8	282	0.10	19.0	9916	0.0697	0.537	0.05585	435	437	447
(3) 100-125 µm, red	5.1	238	0.06	15.9	10328	0.0687	0.532	0.05614	428	433	458
(4) 125-160 µm, red	3.4	222	0.04	14.8	7096	0.0689	0.528	0.05562	429	431	437
(5) >160 µm, red	3.0	246	0.11	16.3	6438	0.0685	0.528	0.05587	427	430	447
Garnet amphibolite RF112G											
(1) 63-80 µm	5.8	64.4	0.05	7.73	1504	0.0739	0.602	0.05907	460	479	570
(2) 80-100 µm	4.0	36.6	0.09	4.25	304	0.0728	0.575	0.05731	453	461	504
(3) 100-125 µm	6.2	60.5	0.08	6.25	1662	0.0712	0.569	0.05802	443	458	531
(4) 125-160 µm	11.7	42.8	0.05	5.03	3148	0.0739	0.587	0.05755	460	469	513
(5) >160 µm	10.9	46.4	3.71	9.28	76	0.0754	0.610	0.05862	469	483	553
Metatonalite RF118G											
(1) <40 µm	2.45	588	1.25	35.6	3120	0.0575	0.444	0.05607	361	374	455
(2) 40-63µm	2.4	577	0.86	34.9	1837	0.0571	0.435	0.05522	358	367	421
(3) 63-80 µm	7.4	588	1.30	35.6	2232	0.0575	0.442	0.05576	360	372	443
(4) 80-100 µm	10.5	539	0.17	32.6	6061	0.0576	0.452	0.05691	361	379	488
(5) 100-125 µm	5.85	575	0.12	35.8	8403	0.0594	0.509	0.06211	372	418	678
(6) >125 µm	4.25	397	0.04	25.3	6757	0.0606	0.514	0.06143	380	421	654
(7) 125-160 µm	1.8	304	0.23	19.0	2842	0.0600	0.4892	0.05914	376	404	572
Augen gneiss RF460											
(1) <40 µm	3.0	512	0.39	34.2	4042	0.0706	0.555	0.05700	439	448	491
(2) 40-63µm	5.95	652	0.33	44.2	7684	0.0705	0.564	0.05809	439	454	533
(3) 63-80 µm	13.8	584	0.76	41.1	3357	0.0724	0.594	0.05951	450	473	586
(4) 100-125 µm	3.4	592	8.14	42.8	360	0.0757	0.670	0.06412	471	520	746
Trondhjemite gneiss RF107G											
(1) 100-125 µm	2.3	180	0.43	9.72	1254	0.0562	0.416	0.05361	353	353	355
(2) 125-160 µm	6.6	137	0.31	7.40	1438	0.0563	0.418	0.05378	353	354	362
(3) >160 µm	9.0	142	0.22	7.63	2098	0.0561	0.416	0.05374	352	353	360



Text-Fig. 2.
Simplified geological map of the Rennfeld region (after NEUBAUER, 1988) and sample locations for U-Pb zircon geochronology.

anatectic event (Text-Fig. 3a). Second generation irregular and discordant leucosome veins crosscut the veins and the schistosity of the first event (Text-Fig. 3b). These first two events are of pre-Alpine age because corresponding structures are cut by overlying Permian and Mesozoic cover successions (NEUBAUER, 1988). The third metamorphic event was within greenschist facies conditions and led to retrograde overprint concentrated in shear zones during the Cretaceous metamorphic period (HANDLER, 1994; NEUBAUER et al., 1995; DALLMEYER et al., 1996, 1998). This metamorphism also affected the Permian to Mesozoic cover rocks which occur along the northern margin of the Rennfeld basement complex (Text-Fig. 1b). ^{40}Ar/^{39}Ar and Rb-Sr mineral dating of Permian to Mesozoic cover successions and lithologies of the overlying Graywacke constrain a late Cretaceous age of metamorphism (102 to 90 Ma; HANDLER, 2994; DALLMEYER et al., 1996, 1998). In the adjacent Gleinalm basement area (FRANK et al., 1976, 1983; NEUBAUER et al., 1995), Rb-Sr, K-Ar and ^{40}Ar/^{39}Ar dating of muscovite/sericite revealed Late Cretaceous cooling between c. 95 and 80 Ma following Early Alpine epidote amphibolite facies metamorphism.

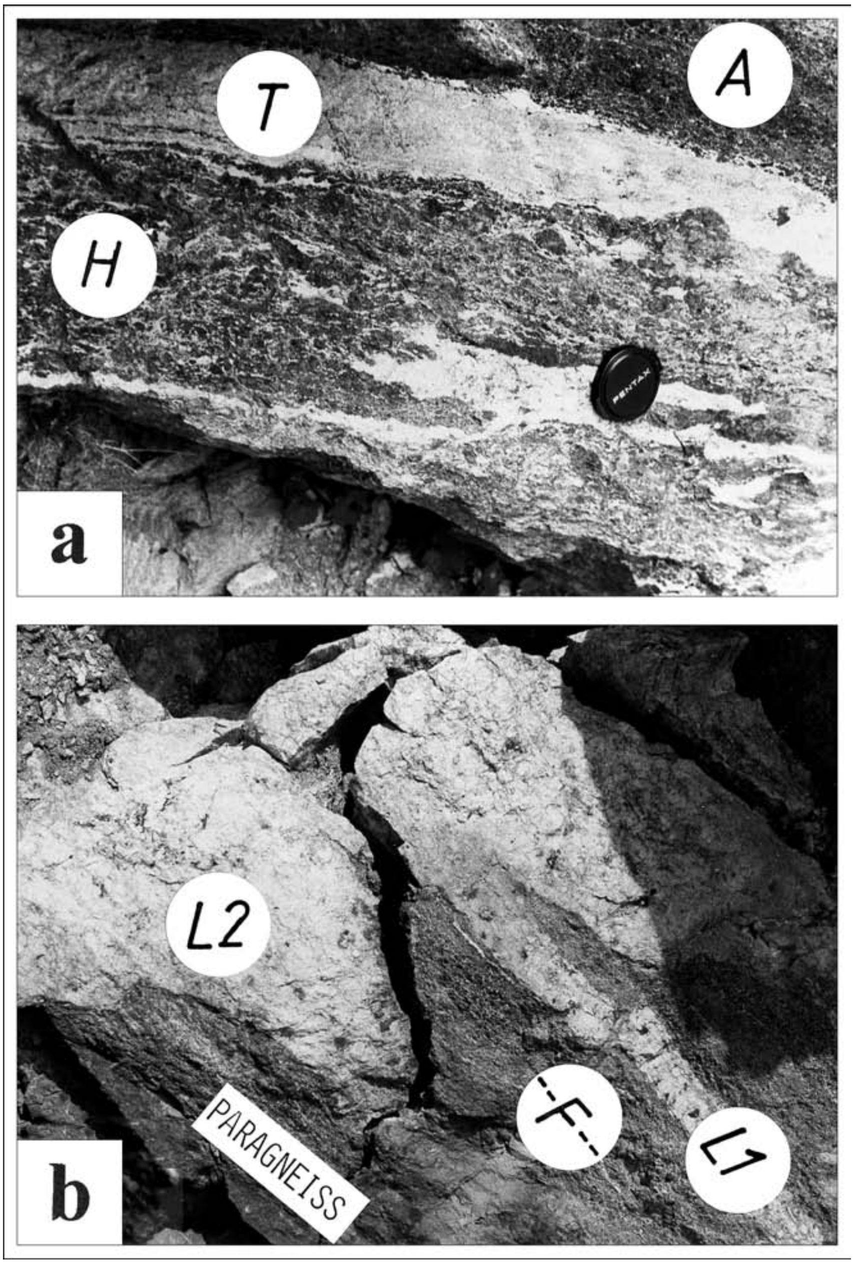
Further geochronologic studies in the adjacent Gleinalm block yielded the following results: Felsic plagioclase gneiss gave a 518±48 Ma Rb-Sr whole rock age (recalculated with the IUGS-recommended decay constant of 1.42 $\times 10^{-11}$ a^{-1} [STEIGER & JÄGER, 1977]) which is interpreted to represent Cambrian magma formation (FRANK et al., 1976). This date was confirmed by U-Pb zircon dating indicating an age of >500 Ma for magma formation (HAISS, 1990). Rb-Sr whole rock dating of a sheetlike granitic augengneiss body along upper margins of the amphibolite-gneiss sequence gave an age of 331±25 Ma (FRANK et al., 1983). Rb-Sr muscovite ages from pegmatites coincide within limits of confidence with the augengneiss Rb-Sr whole rock date (FRANK et al., 1983).

This study presents results of a conventional U-Pb study on zircon from five samples of a limited area in the Rennfeld block (for sample locations, see Text-Fig. 2): migmatitic paragneiss (sample RF450), garnet amphibolite (RF112G) and trondhjemite gneiss (RF107G) (both enclosed in the plagioclase amphibolite layer), Rennfeld metatonalite (RF118G), and augengneiss (RF460) forming a lense within the Rennfeld metatonalite.

3. Analytical Techniques

Concentration of the zircon crystals was achieved by means of a Wilfley table, a magnetic separator, and heavy liquids. The zircons were separated by hand-picking after size, colour, turbidity and shape. The isotopic analyses were performed in the Geochronologisches Zentrallabor, University of Münster, Germany. 1–10 mg aliquots of different zircon fractions were dissolved following the standard low contamination procedure after KROGH (1973). U and Pb concentrations and Pb isotopic compositions were measured using a NBS-type Teledyne mass spectrometer. The mass fractionation of lead was corrected linearly 0.12 per cent per amu. The Pb isotopic data (Tab. 1) were corrected for initial Pb and analytical blank. The isotopic composition of the common lead in the zircons was corrected after the age-related model of STACEY & KRAMERS (1975). An analytical total blank of ca. 0.1–0.5 ng was measured during the analytical work.

The IUGS-recommended constants (STEIGER & JÄGER, 1977) were used for age calculation. The calculation of errors and error propagation of ^{206}Pb/^{238}U and the ^{207}Pb/^{235}U ratios was carried out after LUDWIG (1980, 1991), considering the errors of measured isotopic ratios, the uncertainties of the U/Pb ratio in the mixed spike, the error propagation due to the spike/sample ratio, and errors



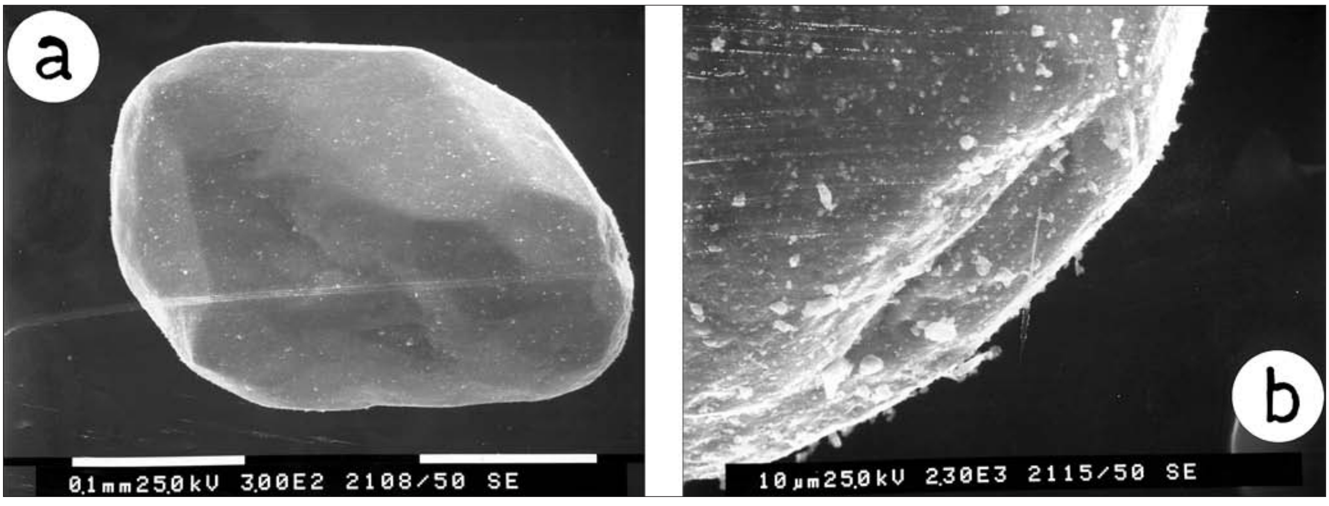
Text-Fig. 3.
Typical textures of the paragneiss and the plagioclase amphibolite.
a) Migmatitic structures of hornblendefels (H) and trondhjemite (T) within plagioclase amphibolite (A).
b) Two generations of leucosome in migmatitic paragneiss. Penetratively foliated leucosome (L1) from anatexis 1 with foliation (F) postdating anatexis 1 are discordantly cut by leucosome 2 (L2).

arising from uncertainties of Pb blank and common Pb correction (MATTINSON, 1987). The error assigned to the ^{207}Pb/^{204}Pb and ^{206}Pb/^{204}Pb initial and blank Pb isotopic composition is less than 1 percent. The error ellipses on the concordia diagrams were drawn for a 95 % confidence level. The discordias were calculated according to the least squares method (YORK, 1969), with individual errors and correlation factors of the ^{206}Pb/^{238}U and ^{207}Pb/^{235}U isotopic ratios. Correlation with the geological time scale is based on calibrations of HARLAND et al. (1989), GRADSTEIN & OGG (1995) and REMANE (2000).

4. Geochronologic Results

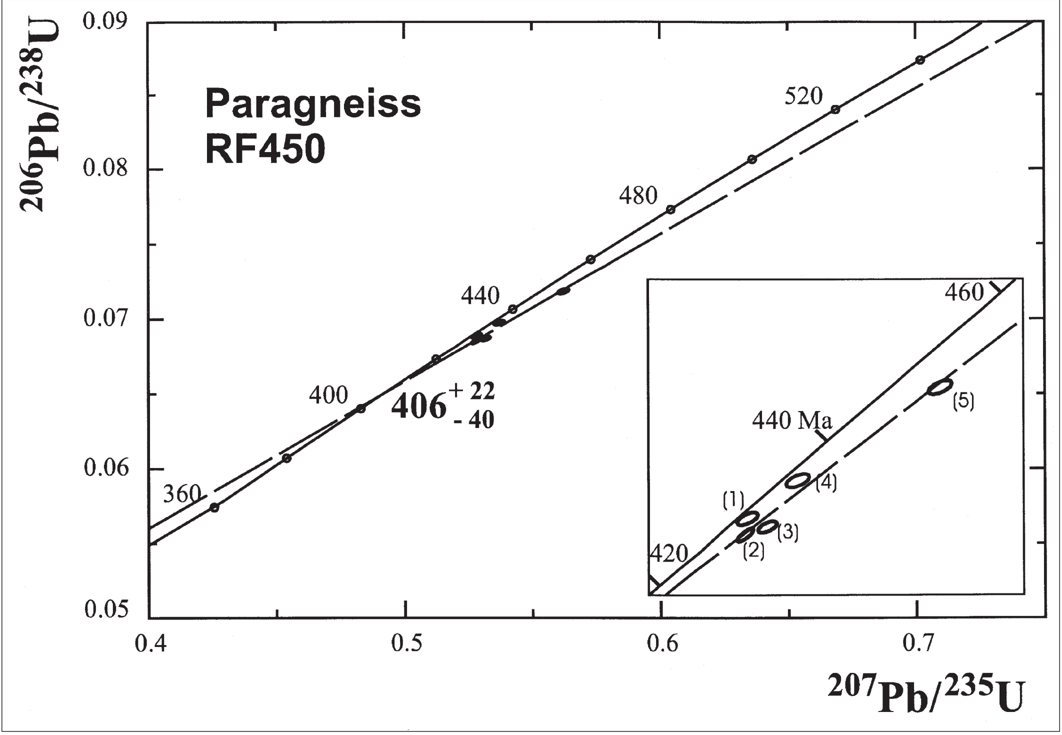
4.1. Paragneiss

The investigated paragneiss (RF450) is represented by a strongly foliated, quartz-rich biotite gneiss without leucosomes. All zircons are well-rounded due to their detrital origin (Text-Fig. 4). Three types of zircons were distinguished according to their colour: (1) Red (or pink) zircons dominate. They show smooth surfaces, although sometimes richly facetted crystals are found (Text-Fig. 4a). Some crystals show grooves (Text-Fig. 4b). (2) Colourless zircons are distinguished from the pink ones only by their colour. There are all transitions to the pink zircons. (3) Intensely brown-



Text-Fig. 4.
Paragneiss zircons (sample RF450).
a) Multifacetted crystal with rounded edges.
b) Surface of the crystal with grooves.

Text-Fig. 5.
Concordia diagram with paragneiss zircon data (sample RF450).
Note that regression may have no significance.



coloured zircons are only present in coarse fractions. They often exhibit a "pitted" surface with small angular grooves and casts.

Five fractions of the red zircons were studied. Their U contents range from 222 to 282 ppm (Table 1) which is unusually low in comparison to other detrital zircons from Austroalpine paragneisses (GRAUERT & ARNOLD, 1968; SÖLLNER & HANSEN, 1987).

The paragneiss zircons are close to the concordia in the concordia diagram with apparent $^{207}Pb/^{206}Pb$ ages of 437 to 483 Ma (Text-Fig. 5). They do not define a discordia. The data rather resemble a magmatic origin than to a clastic rock with mixed, old sources. These data appear to be only compatible with a magmatic zircon source not older than Late Proterozoic.

4.2. Garnet Amphibolite

In contrast to the enclosing plagioclase amphibolites, the rare garnet amphibolite lenses (location of sample RF112G; Text-Fig. 2) show high zirconium contents (ca. 1200 ppm) contained in numerous zircon crystals. The garnet amphibolite show the chemical, especially trace characteristics of an alkaline basaltic rock (NEUBAUER [1988] and further own unpublished data). The zircon crystals (Text-Fig. 6a, b) are clear, translucent, colourless or sometimes slightly pink. They are elongated, have rounded surfaces, and never show clearly developed crystal faces probably due to anatectic overprint. Irregular, contorted shapes and mutual intergrowths are abundant.

The U contents of the zircons are low and range from 42.8 to 64.4 ppm without systematic relationship to grain size (Table 1). The $^{206}Pb/^{204}Pb$ ratios range from 76 to 3,148. Because of the low $^{206}Pb/^{204}Pb$ ratios of two fractions (Table 1), the analytical uncertainty is high and respective discordias are not well defined. However, the data constrain a thermal disturbance of the Pb isotopic system younger than ca. 450 Ma (Text-Fig. 7).

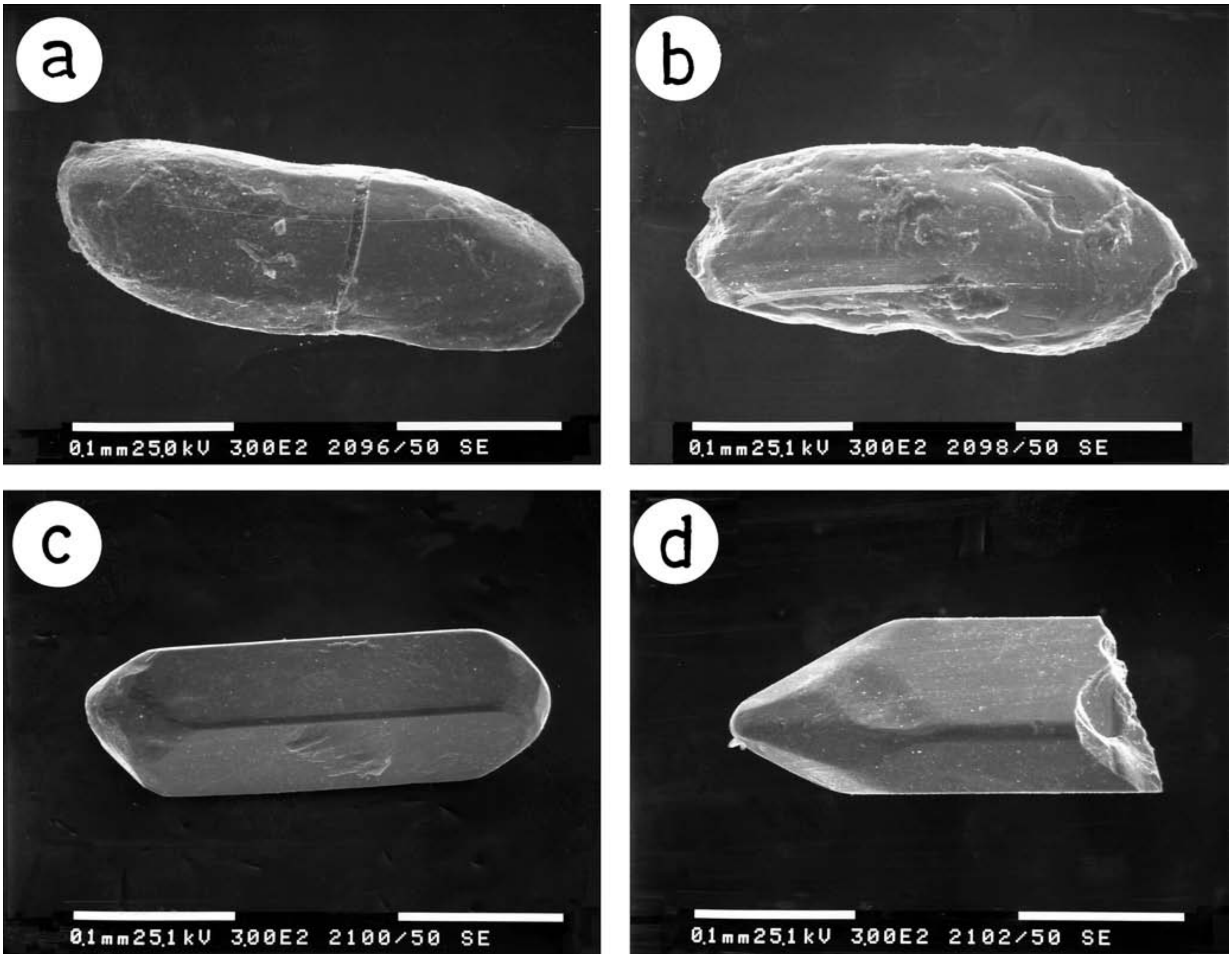
4.3. Metatonalite

The metatonalite (sample RF118G) has Zr contents around 400 ppm (NEUBAUER, 1988) and contains numerous zircon crystals. The zircons are coloured and show rounded edges and surfaces or even embayments and grooves, which is interpreted as dissolution effects (Text-Fig. 8a, b). In rare cases there are rounded cores visible in the microscope. Some zircons are overgrown on one side by homoaxial rims which results in club-shaped crystals. NEUBAUER (1988) showed that zircon crystals, which are included in biotite, amphibole, and plagioclase, are significantly smaller than intergranular crystals, indicating that they were enclosed in an early stage of their growth. In contrast, some of the big zircon crystals may have been added by assimilation of country rock during magma uprise, and were subsequently overgrown by magmatic rims.

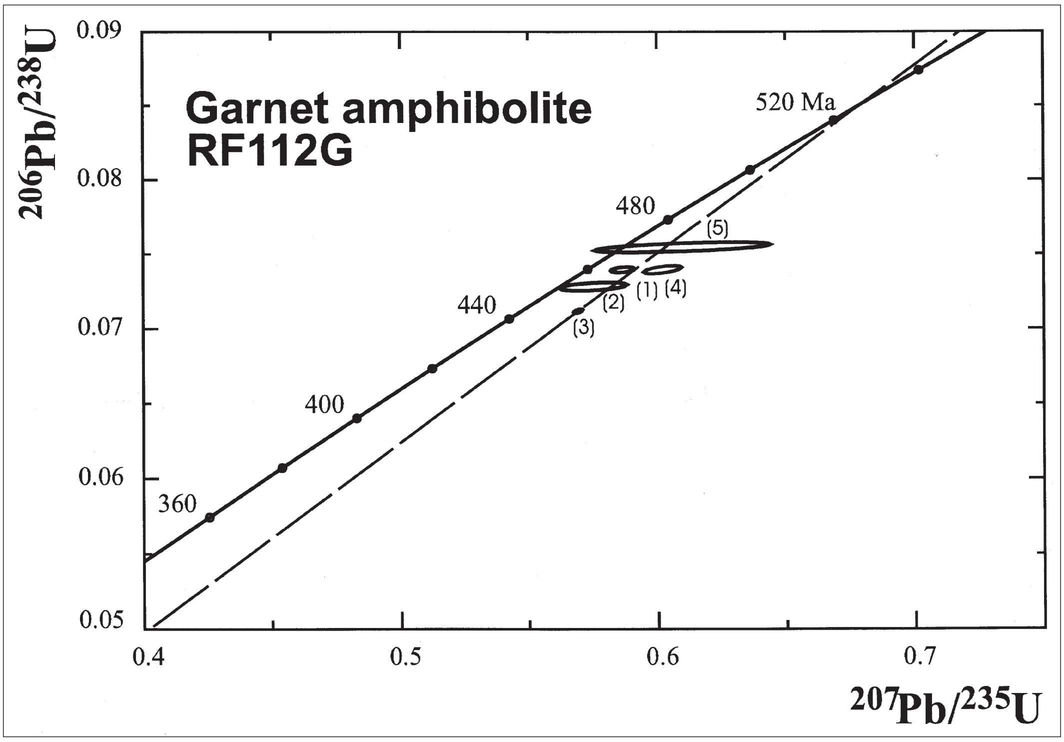
Grains with optically discernible cores or overgrowth rims were excluded from analysis. Seven grain size fractions were analysed (Table 1). The U contents of the zircons do not exhibit a systematic clustering (Tab. 1). The U contents of the fractions 40–63 μm and 100–125 μm are between 539 and 588 ppm, of the fraction >160 μm 397 ppm, and of the fraction 125–160 μm 304 ppm. The five fractions between 40 and 125 μm define a discordia with a lower intercept at 353 +7/–10 Ma and an upper intercept near 3,000 Ma (2,975 ± 206 Ma: Text-Fig. 9a). The two coarsest fractions (125–160 μm, >160 μm) define a nearly parallel discordia with a lower intercept at 367 ± 3 Ma and an upper intercept at ca. 3,200 Ma.

The lower intercept age could be explained as mixing between inherited and newly grown magmatic zicons which have been affected by secondary solution, likely during a late stage of crystallization due to autothermal effects. Consequently, due to missing euhedral zircons, which we could expect in a plutonic rock, and solution effects, the lower intercepts of the metatonalite are interpreted to be related to a thermal event rather than to zircon crystallization in the magma. However, these events are related to each other. We therefore assume, that the age of zircon crystallization is close to the lower intercept ages, and the most likely crystallization age of the Rennfeld metatonalite is between 367 and 353 Ma.

The upper intercepts indicate the presence of an Archaean component contained in the crystal cores. The zircon cores are interpreted to be inherited from an Archean source region of the tonalitic magma.



Text-Fig. 6.
Zircons from the garnet amphibolite (a, b = sample RF112G) and trondhjemite (c, d = sample RF107G).



Text-Fig. 7.
Concordia diagram with garnet amphibolite zircon data. Note that regression may have no significance.

4.4. Augengneiss

The augengneiss forms lenses (c. 10 metres thick) within metatonalite. There are transitions between both rock types suggesting a cogenetic origin or gradual assimilation of an older porphyric granite into the tonalite magma.

The augengneiss (sample RF460) contains elongated zircon crystals with rounded edges and faces (Text-Fig. 8c, d). The crystal habit is only recognizable in some cases: there is an equivalent development of the (100) and (110) prisms and a predominance of the (211) over the (101) pyramid. The crystals are affected by anatectic solution which formed concave grooves (Text-Fig. 8c).

Four zircon fractions were analysed. The U contents are 512 to 652 ppm (Table 1). The isotopic data however, plot completely differently in the concordia diagram (Text-Fig. 9b). Although there is no systematic variation of the U contents with the grain size, the ^{207}Pb/^{206}Pb apparent ages increase with increasing grain size (Text-Fig. 9b). The four fractions define a discordia with a lower intercept at ca. 433 (+9/–19) Ma and an upper intercept at ca. 2,252 Ma (Text-Fig. 9b). Since the data plot near the lower intercept, this intercept can be interpreted either as intrusion or as metamorphism age. Solution effects of the zircons of both the metatonalite and the augengneiss may be indicative for a high-grade metamorphic overprint. The upper intercept of the augengneiss is interpreted to reflect the presence of old cores in the zircon cores inherited from Precambrian crust.

The lower intercepts of both augengneiss and metatonalite reflect two different metamorphic events rather than zircon growth in protolith magmas.

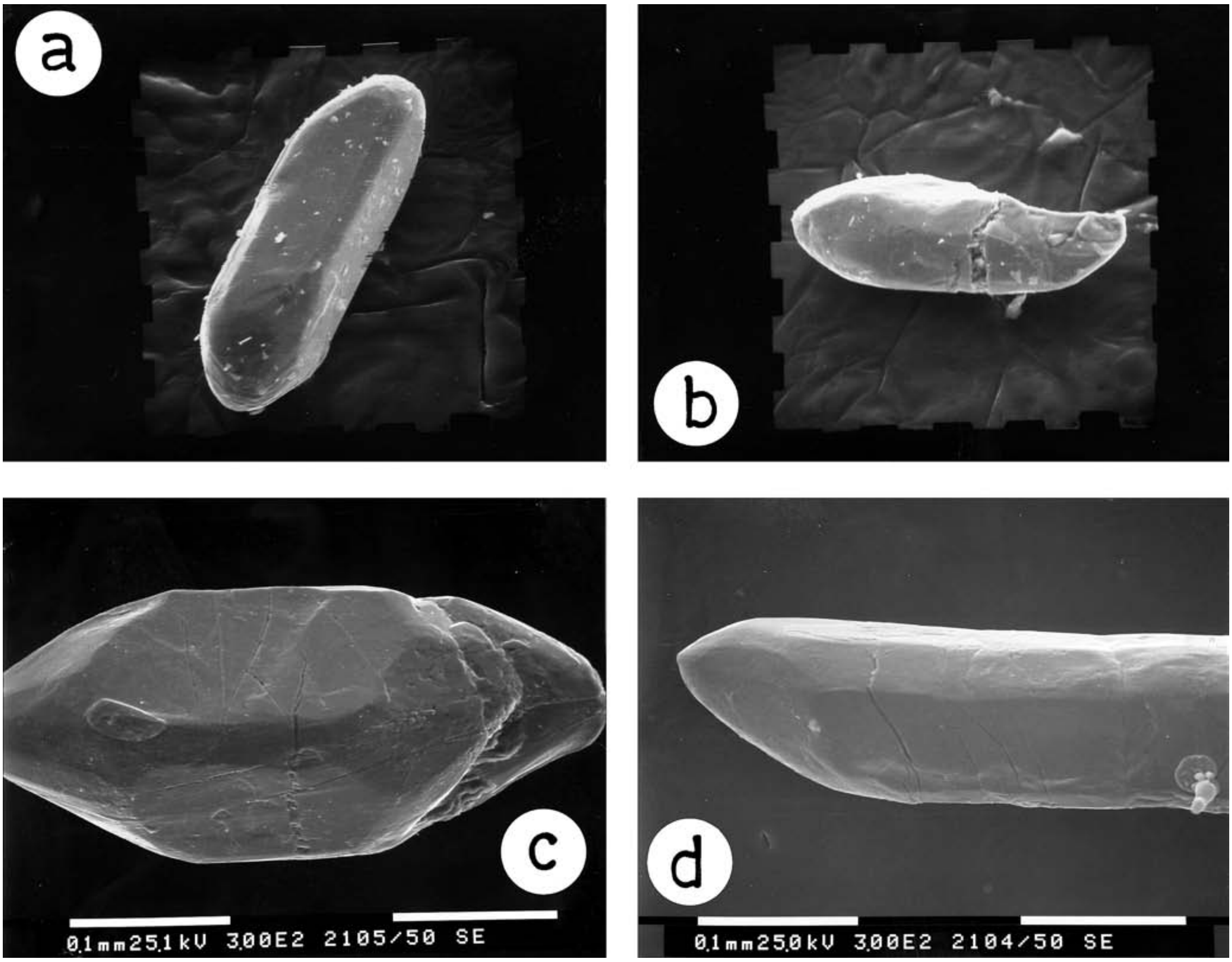
4.5. Trondhjemite Gneiss

The trondhjemite gneiss (sample RF107G) is characterized by exclusively euhedral zircon crystals (Text-Fig. 6c,d), which are only contained in the fractions >80 μm, most crystals being larger than 125 μm. It is the only sample in the present study that contains euhedral zircons. The (100) prism predominates over the (110) prism, and the (211) pyramid over the (101) pyramid (Text-Fig. 10). Some zircons show oscillatory zoning or bubbles elongated parallel to the crystallographic c-axis. A few zircons include metamict cores; these were excluded from U-Pb analysis.

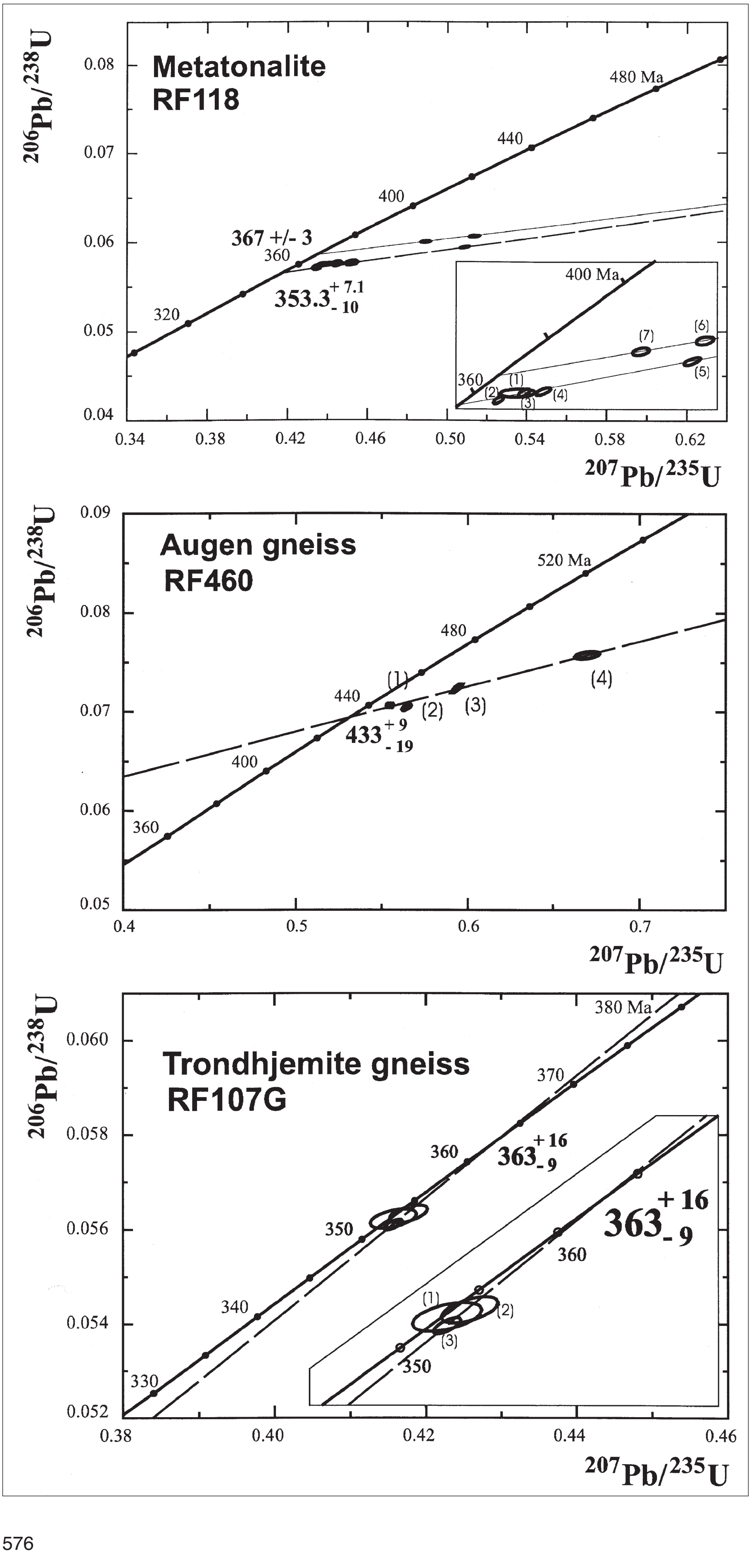
Three fractions were analysed. The U contents range from 136.6 to 180 ppm. The fraction 100–125 μm within the analytical error at 353 ± 2 Ma on the concordia (Text-Fig. 9c), the other two near the concordia. Calculating a discordia, the upper intercept of these three fractions is at 363 (–9/+16) Ma, the lower intercept at 106 Ma. The upper intercept age is interpreted to date the crystallization of the trondhjemite magma. The lower intercept corresponds to a low-grade Cretaceous metamorphic overprint as also constrained by ^{40}Ar/^{39}Ar and Rb-Sr isotopic systems.

5. Discussion

The U-Pb data of zircon populations from selected rocks of the Rennfeld area reflect a complex history of the Austroalpine crystalline basement. Three of four studied samples of magmatic origin yielded zircons with rounded surfaces and grooves but no crystal faces. Such features are known from migmatites and granulites (e.g., HOPPE, 1966; PIN & LANCELOT, 1982; GUPTA & JOHANNES, 1985; PEUCAT,



Text-Fig. 8.
Zircons from rocks of the Rennfeld metatonalite suite: a, b = Rennfeld metatonalite; c, d = granitic augengneiss.

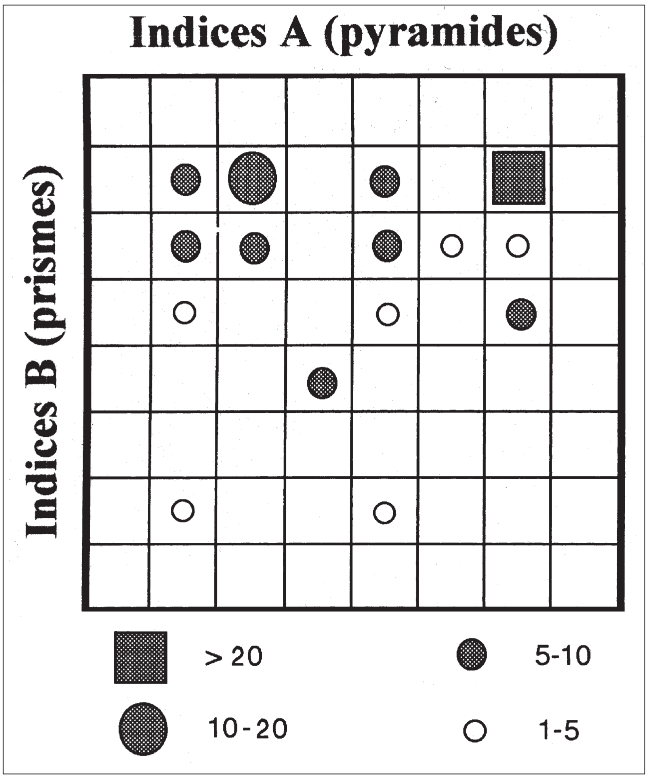


Text-Fig. 9.
Concordia diagram with U-Pb zircon data from the Rennfeld metatonalite suite.
a) Rennfeld metatonalite.
b) Granitic augengneiss from the Rennfeld tonalite suite.
c) Trondhjemite from the base of the plagioclase amphibolite.

1986). In contrast, the trondhjemite gneiss contains euhedral zircon crystals. We conclude that the rounded, partly dissolved zircons also grew as euhedral crystals in the protolith magma but attained their rounded shape during high-grade metamorphism (anatexis). This anatectic event is obviously the same that produced the trondhjemite magma by partial melting of amphibolite (NEUBAUER, 1988).

Zircons with a polystage thermal evolution are difficult to assess (for recent reviews, see LEE et al., 1997; MEZGER & KROGSTADT, 1997). Zircons with a low uranium content are affected only by a low degree of diffusion although diffusion depends, beside temperature, from many factors like duration of the heating event. The uranium contents of zircons from paragneiss and garnet amphibolite are low compared with similar rock types. Consequently, we assume that these rocks are not drastically reset by thermal events subsequent to the first stage of metamorphism.

This interpretation favours the view of a multistage evolution of the zircons of all studied rocks with the exception of the trondhjemite gneiss. The zircon populations of these samples are positioned near the concordia in the U-Pb evolution diagram. This means that the thermal event which resulted in lead loss could not be much older than the ^{207}Pb/^{206}Pb apparent ages. On the other hand, the nearly concordant zircons from the paragneiss show that the protoliths of the host rocks in which the magmatic rocks intruded cannot be older than ca. 700 Ma. The near-concordancy of the paragneiss zircons, their unusual low U contents, and their young age relative to their sedimentation age exclude a continental source



Text-Fig. 10.
Pupin diagram of trondhjemite gneiss zircons.
Indices A and B according to Pupin (1980). Note two groups of crystal habits.

region and strongly suggest a juvenile subduction-related magmatic source.

Zircons with a polystage thermal evolution are difficult to assess (for recent reviews, see Lee et al., 1997; Mezger & Krogstadt, 1997). Zircons with a low uranium content are affected only by a low degree of diffusion although diffusion depends, beside temperature, from many factors like duration of the heating event. The uranium contents of zircons from paragneiss and garnet amphibolite are low compared with similar rock types. Consequently, we assume that these rocks are not drastically reset by thermal events subsequent to the first stage of metamorphism.

The concordant age of the trondhjemite is, within the analytical error, the same as the lower intercept age of the Rennfeld metatonalite. This matches the field evidence with the presence of a contact aureole within which feldspar metablastesis in paragneiss and anatexis of amphibolite and paragneiss occurred. As no further geochronological evidence exists (beside of an inconclusive Rb-Sr errorchrone), we do not entirely exclude the possibility of a slightly earlier age of intrusion as shown by lower intercept of coarse-graned zircon fractions.

The lower intercept of the metatonalite discordia gives a younger age (353 Ma) than the lower intercept of the granitic augengneiss (433 Ma). The dated augengneiss is part of a number of lenses which represent inclusions within the metatonalite. The augengneiss inclusions have similar petrographic, chemical, and Sr isotope signatures over distances of more than 20 km (Neubauer, 1992). These data preclude differentiation of the granitic augengneisses from the tonalitic magma. Field observations, chemical and geochronologic data clearly indicate that the metatonalite intruded into a porphyric granite after the peak of the first and before the second anatectic event. Both events show characteristics of a high-grade metamorphic overprint and anatexis. We suggest that the intrusion of the tonalite magma provided heat to trigger anatexis during the second migmatitic event. This is corroborated by the restriction of migmatite formation, feldspar blastesis and general coarsening of grain size to a zone in the order of 1 kilometre width from the Rennfeld metatonalite contact.

We propose the following two alternative models for the evolution of the Rennfeld block which appears to be characteristic for an important part of Austroalpine basement:

1) The magmatic protoliths of the garnet amphibolite and the augengneiss intruded volcanogenic sediments in Late Proterozoic or Early Paleozoic times. These rocks together suffered high-grade metamorphism in the time span between 450 and 425 Ma. The zircons were in part reset during this thermal event.
2) Alternatively, the augengneiss protolith intruded within the 450–425 Ma interval.

The intrusion of the Rennfeld tonalite followed at ca. 367–353 Ma. It is related to the second anatectic event between 360 and 350 Ma, which resulted from heat transfer during the tonalite intrusion.

The metatonalite reveals a pronounced Precambrian lead component, which is in contrast to the mantle origin of the magma as suggested from its chemical composition. We explain the Precambrian component by the presence of Archean rocks in the continental crust through which the magma ascended. The augengneiss and the garnet amphibolite contain Proterozoic memories. The memory of the augengneiss (2,275 Ma) is within the range of the upper intercepts of paragneiss zircons reported from elsewhere in the Austroalpine realm (Grauert et al., 1973, 1974; Söllner & Hansen, 1987).

The new radiometric data of the Rennfeld region show that the Austroalpine basement experienced accretion of important volumes of juvenile, subduction-related magmatic rocks and their detrital derivates in late Proterozoic and early Paleozoic times (Haiss, 1990; Maggetti & Flisch, 1993; Müller et al., 1995; Thöni, 1999; Neubauer et al., 2002) and contains memory of older, partly Archean crust in zircon cores. Similar patterns have been found in the Penninic and Helvetic basements of the Swiss Alps (Gebauer et al., 1988, 1989; Gebauer, 1993; Köppel, 1993, Neubauer, 2002 for reviews). Archean and Proterozoic components are also found in the extra-Alpine Variscides (e.g., Kröner et al., 1988; Liew & Hofmann, 1988; Teufel, 1988; Gebauer et al., 1988, 1989). Recycling processes by metamorphism and anatexis destroyed much of the Precambrian lithologies during the Paleozoic orogenies.

The U-Pb zircon data confirm the two-stage magmatic/metamorphic evolution of the Rennfeld block which already becomes obvious by the field relations. The strong tectonothermal event in Ordovician to Early Silurian times is interpreted as the expression of an important orogeny (e.g., Frisch et al., 1984). Ages between 470 and 420 Ma, mainly for magma intrusions, are widespread in the Austroalpine basement (Cliff, 1980; Scharbert, 1981; Scharbert & Schönlaub, 1980; Neubauer & Frisch, 1993). In the Western Alps (Helvetic and Penninic basement units) similar ages were found as an expression of a high-pressure metamorphic event and of magma formation (e.g., Gebauer, 1993, for review; Paquette et al., 1998).

The magmatic episode at ca. 367–353 Ma is obviously much more important as suggested in previous models in the Alps (for review of older literature, see Bonin et al., 1993; Finger et al., 1997; Schermaier et al., 1997) and extra-Alpine Variscides (e.g., Pin & Paquette, 1997). Scharbert (1981) reported a similar Rb-Sr whole rock age from the Zinken granite in the Seckauer Tauern, a western lateral extension of the Rennfeld block, Peindl (1990) from the easternmost Austroalpine units. We interpret the calc-alkaline Rennfeld layered metatonalite suite to result from subduction-related magmatism around the Devonian/Carboniferous boundary and to indicate an early stage of Variscan plate convergence. This event predates continental plate collision recorded by early Visean onset of flysch deposition on top of the Devonian to Tournaisian carbonate platform sediments of the later Southalpine and Austroalpine units (e.g., Schönlaub & Histon, 2000), representing the lower plate at that time.

Final collision occurred in the late Early Carboniferous and led to consolidation of the Austroalpine basement complex. Intrusion of the Gleinalm granite (ca. 330 Ma; later transformed to augengneiss; Frank et al., 1983) along the southeastern margin of the Gleinalm postdated the subduction-related, calcalkaline magmatism in the Rennfeld block.

The Paleozoic evolution of the Rennfeld region is in line with other Austroalpine and extra-Alpine Variscan basement complexes that record polyphase tectonothermal evolution with Ordovician/Silurian orogenic events overprinted by early Carboniferous magmatic and metamorphic paroxysm. An important new finding is the evidence for age of subduction magmatism at the Devonian/Carboniferous boundary.

The U-Pb zircon data from the Rennfeld basement complex record only a weak Alpine metamorphic overprint (e.g. in the trondhjemite gneiss) which is in accordance with ^{40}Ar/^{39}Ar mineral data from the overlying cover rocks and the Gleinalm basement (Neubauer et al., 1995; Dallmeyer et al., 1996, 1998). This is in line with well-preserved pre-Alpine structures and metamorphic mineral assemblages, which are overprinted by Cretaceous greenschist grade metamorphism only along distinct shear zones active in the Cretaceous under the influence of fluid infiltration (Neubauer et al., 1995). On the other hand, it is in contrast to other Austroalpine basement units (e.g., in the northern vicinity of the Rennfeld block; Neubauer et al., 1987, 2002), which experienced more penetrative Cretaceous low-grade metamorphic overprint. There, this overprint is recorded in the U-Pb zircon isotopic system.

6. Conclusions

From conventional U-Pb zircon analysis in the Rennfeld region of the Austroalpine basement we draw the following conclusions:

❶ Metamorphosed Paleozoic magmatic rocks reveal early Precambrian lead zircon components (up to 3 Ga in age).

❷ Metaclastic rocks contain seemingly juvenile zircons of possible late Proterozoic/early Phanerozoic age that may be derived from a magmatic source.

❸ There was formation of alkaline basaltic rocks and granitoids in early Paleozoic times.

❹ Two episodes of metamorphic/magmatic overprint, likely between 470–420 Ma and well-proofed by concordant data close to 353 Ma, are indicated by the U-Pb zircon data.

❺ The Rennfeld metatonalite suite and trondhjemite intruded at the Devonian/Carboniferous boundary and represents an important episode of calcalkaline magmatism.

❻ Only a minor Alpine metamorphic overprint was detected by means of the U-Pb zircon method in the Rennfeld block.

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