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Single Zircon Pb-Pb Geochronology of the Early-Palaeozoic Magmatic Evolution in the Austroalpine Basement to the South of the Tauern Window

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11 Text-Figures, 3 Tables

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Osttirol
Defereggen Alpen
Schobergruppe
Ostalpines Grundgebirge
Jungproterozoikum
Altpaläozoikum
Metabasit
Geochemie
Geochronologie

Inhalt

Pb-Pb-Einzelzirkon-Geochronologie prä-variskischer Magmatite im ostalpinen Kristallin südlich des Tauernfensters

Zusammenfassung

Das variskisch und teilweise alpidisch metamorphe ostalpine Kristallin südlich des zentralen Tauernfensters ist in vier lithologische Einheiten gegliedert:

1) Nord-Defereggen/Petzeck-Gruppe mit den metabasischen Rotenkogel-, Torkogel-, Michelbach- und Prijakt-Subgruppen.
2) Durreck-(Cima Dura-)Muscovitschiefer-Gruppe
3) Defereggen-Gruppe.
4) Paläozoische Thurntaler Phyllit-Gruppe.

Anhand der Gesamtgesteins-Geochemie lassen sich mehrere Suiten von Metamagmatiten unterscheiden. Einige Protolith-Alter von Gesteinen aus diesen Suiten wurden mit der Pb-Pb-Einzelzirkon-Evaporations-Methode bestimmt. Die eklogitischen Amphibolite aus der Prijakt-Subgruppe zeigen N-MORB-typische Elementkonzentrationen, wobei magmatische Anreicherung von LIL und LREE sowie $(Th/Ta)_N$ von 1,38–2,5 Hinweise auf einen Backarc-Magmatismus ergeben. Ein aus 10 Zirkonen gemitteltes gewichtetes Protolith-Alter ist 590±4 Ma. Hornblende-Plagioklas-Gneise der Rotenkogel- and Prijakt-Subgruppen haben basische bis intermediäre Zusammensetzungen. Ihre Ti/Zr-, Ti/V- und Cr/Y-Werte sind typisch für kalk-alkalische Arc-Magmatite. Ihre Protolith-Alter liegen zwischen 550±5,9 und 533±3,8 Ma. Orthogneise metaluminöser dioritischer bis peraluminöser granitischer Zusammensetzung sind mit diesen Arc-Magmatiten vergesellschaftet, kommen aber auch in der Defereggen-Gruppe weit verbreitet vor. Die Protolithe von Orthogneisen im Diskriminationsfeld der Continental-Arc-Granite sind mit 471 bis 461 Ma etwas älter als von Orthogneisen im Feld der Continental-Collision-Granite mit Altern zwischen 457 und 448 Ma. In den Meta-Porphyroiden der Thurntaler Phyllit-Gruppe und in den Orthogneisen

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treten sehr ähnliche geochemische Signaturen und REE-Verteilungsmuster auf. Protolith-Alter der Meta-Porphyroide liegen bei 473±6,7 und 469±6,2 Ma. Beim Vergleich der gesammelten einzelnen Zirkonalter erscheint der Porphyroid-Vulkanismus etwas älter als der Granitoid-Plutonismus. Beide saure Gesteinsgruppen führen sehr viele ererbte Zirkone mit Altern bis 1930 Ma. Amphibolite in der Nord-Defereggen/Petzeck-Gruppe zeigen die Zr-, Ti- und Y-Gehalte von MORB-Tholeiiten bis hin zu Intraplatten-Alkalibasalten. Ein Spätdifferentiat aus der alkalibasaltischen Suite in der Torkogel-Subgruppe ergab ein Pb-Pb-Einzelzirkon-Evaporations-Alter von 430±1,6 Ma. Das ostalpine Kristallin gehörte zu einem aktiven Kontinentalrand nördlich Gondwanas. Es kam zu neoproterozoischem dehnungsgebundenem Magmatismus mit Backarc-Signatur und danach zur Bildung eines frühkambrischen magmatischen Arcs. Den ordovizischen sauren Magmatismus kann man als ein reifes Stadium dieser subduktionsgebundenen Entwicklung sehen. Der frühsilurische alkalibasaltische Magmatismus zeigt dann schließlich eine teilweise gleichzeitig einsetzende passive Kontinentalrand-Entwicklung an, die wahrscheinlich mit der Öffnung der Paläo-Tethys zusammenhing.

Abstract

The Variscan and partly Alpine metamorphic Austroalpine basement to the south of the central Tauern Window is subdivided into four lithological units:

1) Northern Defereggen/Petzeck Group with the metabasic Rotenkogel, Torkogel, Michelbach and Prijakt Subgroups.
2) Durreck (Cima Dura) Muscoviteschist Group.
3) Defereggen Group.
4) Palaeozoic Thurntaler Phyllite Group.

Several suites of meta-magmatic rocks can be characterized by whole-rock geochemistry. Protolith ages of defined members in these suites were dated by the Pb-Pb single zircon evaporation method. Eclogitic amphibolites of the Prijakt Subgroup in the Schobergruppe have element abundances typical of N-MORB. Their magmatic LIL and LREE enrichment and $(Th/Ta)_N$ of 1.38–2.5 can be interpreted as a sign of backarc magmatism. The protolith age is 590±4 Ma (weighted average from 10 zircons). Hornblende-plagioclase-gneisses of the Rotenkogel and Prijakt Subgroups have basic to intermediate compositions. They display Ti/Zr, Ti/V and Cr/Y ratios typical of calc-alkaline volcanic arc magmatites. Their protolith ages range between 550±5.9 and 533±3.8 Ma. Orthogneisses with compositions ranging from metaluminous dioritic to peraluminous granitic are closely associated with the arc magmatic suite, but occur as well widespread in the Defereggen Group. Protoliths of orthogneisses with compositions matching the continental arc granites discriminant field appear as slightly older (471 to 461 Ma) than those of orthogneisses ranging in the continental collision field (457 to 448 Ma). Geochemical signatures and REE patterns of these orthogneisses and the meta-porphyroids in the Thurntaler Phyllite Group are very similar. The meta-porphyroid protolith ages are 473±6.7 and 469±6.2 Ma. However, when corresponding single zircon ages are compared, the porphyroid volcanism appears slightly older than the granitoid plutonism. Both acid rock groups bear many inherited zircons with ages up to 1930 Ma. Amphibolites in the Northern Defereggen/Petzeck and in the Thurntaler Phyllite Groups have Zr-Ti-Y contents ranging from MORB tholeiites to within-plate alkalibasalts. A highly differentiated sample from the alkalibasalt-like suite in the Torkogel Subgroup yielded a 430±1.6 Ma Pb-Pb zircon age. The Austroalpine basement was part of an active continental margin to the north of Gondwana. Active margin development involved a Neoproterozoic extensional magmatism with backarc signature and culminated in the formation of an Early-Cambrian magmatic arc. The Ordovician acid volcanism and plutonism appears as a mature stage of this subduction-controlled evolution. An Early-Silurian alkalibasaltic magmatism then signalizes a subsequent and partly simultaneously starting passive margin evolution, which was probably related to the opening of the Palaeo-Tethys.

1. Introduction

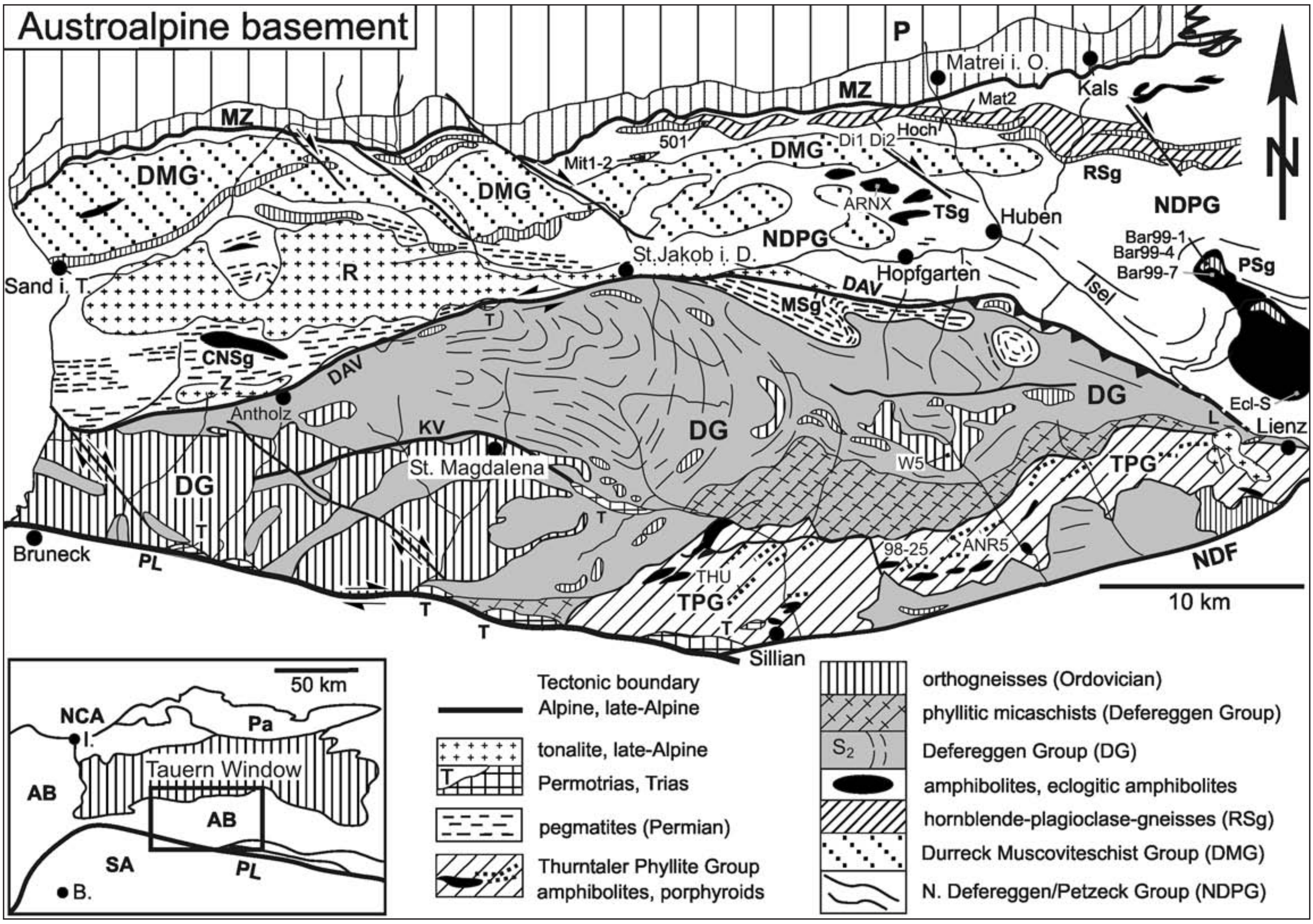
The pre-Mesozoic basement areas in the Alps play an increasingly important role in the reconstruction of the peri-Gondwanan Neoproterozoic to Early-Palaeozoic history of Central Europe. Especially, the weakly metamorphosed sedimentary and volcanic rocks of the Early-Palaeozoic units of the Eastern Alps provided evidence of a Silurian to Devonian passive margin evolution (LOESCHKE, 1989; SÖLLNER et al., 1991; LOESCHKE & HEINISCH, 1993; SCHÖNLAUB, 1993; NEUBAUER & SASSI, 1993). Suites of alkaline basic volcanic rocks give evidence of such a rifting stage of the Palaeotethys. Acid volcanics and metavolcanics ("porphyroids") in the Greywacke Zone and phyllitic units, as well as metagranitoids in the pre-Upper-Ordovician basement are widespread in the Austroalpine domain. These rocks have been interpreted to give evidence of an active margin setting, presumably involving Early-Ordovician crustal collision or amalgamation (see compilation by VON RAUMER et al., 2002). From the Austroalpine Silvretta nappe (MAGGETTI et al., 1990; MÜLLER et al., 1995, 1996; POLLER et al., 1997; SCHALTEGGER et al., 1997) and the Gleinalpe (FRANK et al., 1976; THÖNI, 1999), and from the Penninic Basement units (VON QUADT, 1992; FRISCH et al., 1993; EICHHORN et al., 1995; VON QUADT et al., 1997) there are as well reports of pre-Ordovician magmatic rocks which belonged to an active margin setting. According to FRISCH et al. (1984), the gneiss-amphibolite association within the Austroalpine basement complex should have been generated in a Late-Precambrian to Early-Palaeozoic island-arc or active continental margin system. Furthermore, hints to a Neoproterozoic ("Cadomian") event have been detected in detrital zircon of Austroalpine Ordovician sedimentary successions (NEUBAUER et al., 2001).

Protolith age data of pre-Variscan magmatites from the Eastern Alps is scarce (SÖLLNER & HANSEN, 1987; THÖNI, 1999). Apart from ages of Ordovician metagranitoids by whole-rock Rb/Sr-dating (BORSI et al., 1973, 1978, 1980; SATIR, 1975, 1976; BRACK, 1977; HAMMERSCHMIDT, 1981, SASSI et al., 1985), and some U-Pb and Pb-Pb zircon data (CLIFF, 1980; KLÖTZLI, 1995, 1999a; BÜCKSTEEG, 1999), no radiochronological data on protoliths are yet available from the pre-Variscan magmatic suites in the Austroalpine basement to the south of the Tauern Window.

Here we present Pb-Pb single zircon evaporation data on the protolith ages of some rock suites. This is based on a whole-rock geochemical discrimination of the meta-magmatites and on a revised lithotectonic subdivision of the basement. Apart from precision and confirmation of already presumed Ordovician protolith ages of meta-porphyroids in the Thurntaler Phyllite Group, we find Silurian meta-alkalibasalts, further Ordovician metagranitoids, Early-Cambrian arc magmatism and Neoproterozoic (590 Ma) meta-tholeiites in this part of the Austroalpine crystalline complex.

2. Lithological Subdivision of the Austroalpine Basement

The crystalline basement between the southern rim of the Central Tauern Window and the non-metamorphic autochthonous Permo-Mesozoic Drauzug is subdivided into several lithological groups (Fig. 1). To the south of the late-Alpine Defereggen-Antholz-Vals-Line (DAV), the Thurntaler Phyllite Group (TPG) overlies the monotonous metapsammopelitic Defereggen Group (SCHÖNLAUB, 1979; SCHULZ et al., 1993, 2001). To the north and to the east of the DAV, and in a structural position beneath the Defereggen Group (DG), the basement is composed of the biotite paragneisses and micaschists of the Northern Defereggen/Petzeck Group (NDPG). This series has been



Text-Fig. 1.
Lithological units in the Austroalpine basement to the south of the central Tauern Window, Eastern Alps. Sampling locations for zircon dating are marked.
AB = Austroalpine basement; CNSg = Croda Nera Subgroup (metabasites); DAV = Defereggen-Antholz-Vals line; DG = Defereggen Group (monotonous metapsammopelites); DMG = Durreck Muscoviteschist Group; NDF = Northern Drauzug fault; KV = Kalkstein-Vallarga line; L = tonalite of Lienz; MSg = Michelbach Subgroup (amphibolites); MZ = Matreier Zone; NDPG = Northern Defereggen/Petzeck Group; NCA = Northern Calcareous Alps; P = Penninic unit; Pa = Palaeozoic of Greywacke Zone; PL = Periadriatic Lineament; PSg = Prijakt Subgroup (eclogitic amphibolites and hornblende-plagioclase-gneisses); R = Rieserferner tonalite; RSg = Rotenkogel Subgroup (hornblende-plagioclase-gneisses); SA = Southern Alps; T = Permo-Trias and Trias; TPG = Thurntaler Phyllite Group; TSg = Torkogel Subgroup (amphibolites); Z = Zinsnock tonalite.

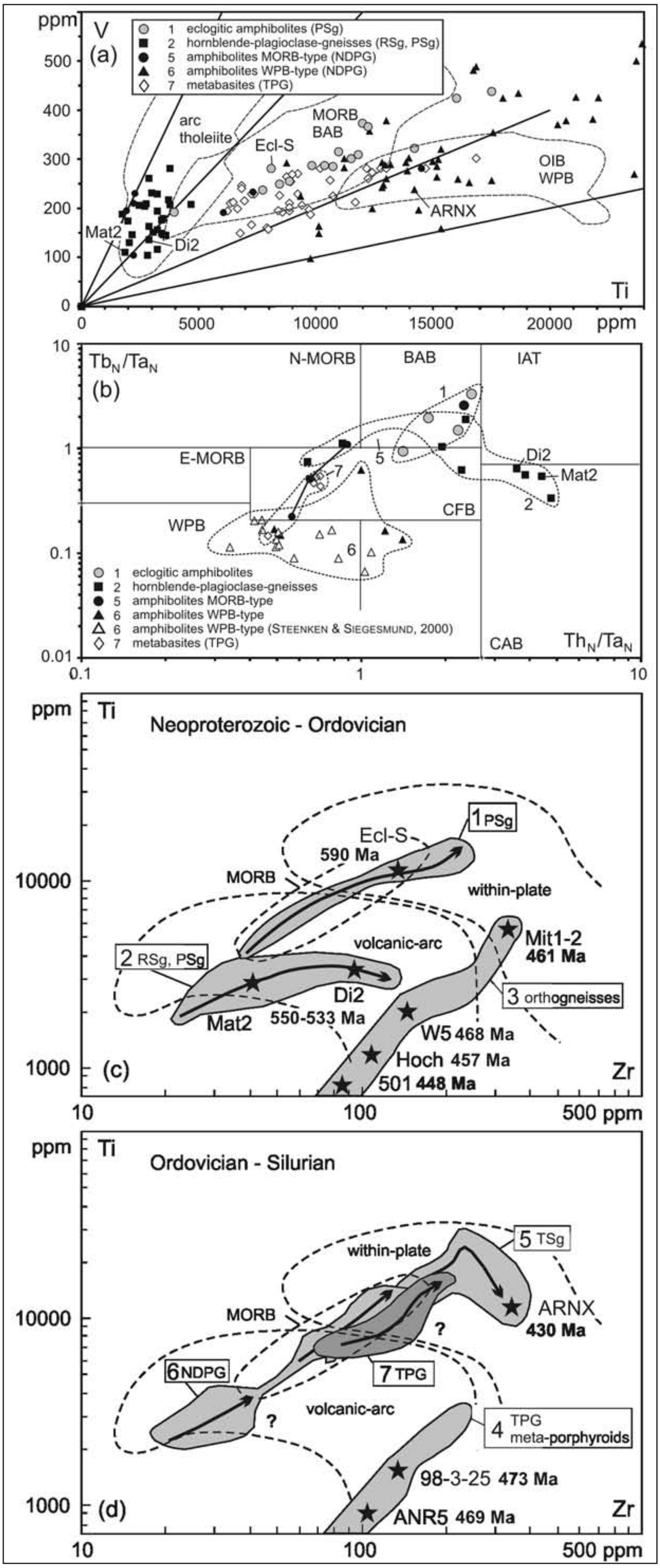
previously referred to as the AMU metapsammopelite-amphibolite-marble-unit (SCHULZ et al., 1993; SCHULZ, 1997). To the west of the Isel valley this unit can be subdivided into a lower and upper part by the Durreck (Cima Dura) Muscoviteschist Group (DMG). The latter unit corresponds to the Cima Dura Series which can be traced beyond the Tauferer Valley toward the west.

An important lithological characteristic in this northern basement domain of the Northern Defereggen/Petzeck Group (NDPG) is the occurrence of metabasite formations (Fig. 1). The Rotenkogel Subgroup (RSg) with hornblende-plagioclase-gneisses crops out along the southern rim of the Tauern Window. It can be traced through the Schobergruppe toward the west up to the Lasörling. Hornblende-plagioclase gneisses occur as well in the Prijakt Subgroup (PSg) in assembly with eclogitic amphibolites (TROLL & HÖLZL, 1974; BEHRMANN, 1990; BÜCKSTEEG, 1999). Acid orthogneisses with geochemical characteristics matching the dated Ordovician granitoids (BORSI et al., 1973; PECCERILLO et al., 1979; CLIFF, 1980; HAMMERSCHMIDT, 1981; KLÖTZLI, 1995) are associated with the hornblende-plagioclase-gneisses of both Rotenkogel and Prijakt Subgroups (TROLL et al., 1976; BÜCKSTEEG, 1999; SCHÖNHOFER, 1999). Apart from hornblende-plagioclase-gneisses and acid orthogneisses, the eclogitic amphibolites are characteristic of the Prijakt Subgroup. Amphibolites and garnet-amphibolites of the Torkogel Subgroup (TSg) in the hangingwall of the Durreck Muscoviteschist Group are associated with marbles. This similarly can be observed in the Michelbach Subgroup (MSg) (SENARCLENS-GRANCY, 1964). Due to this lithological similarities, the Michelbach Subgroup is considered to be part of the Northern Defereggen/Petzeck Group despite its outcrop to the south of the DAV. A pre-Alpine foliation-parallel lithological contact between Defereggen Group and Michelbach Subgroup can be traced in an antiform partly eroded by the Michelbach and Grünalmbachtal valleys. This structural situation has been explained by a late-Alpine km-scale folding and associated thrusting of the southern block towards the NE along the DAV (SENARCLENS-GRANCY, 1964; SCHULZ, 1989). Pegmatites of Permian age (SCHUSTER et al., 2001) are abundant in the Michelbach Subgroup. Some of these pegmatites occur as well in the lowermost part of the Defereggen Group, and to the north of the DAV.

The Defereggen Group is a several kilometres thick monotonous metapsammopelitic sequence of banded quartzitic gneisses, paragneisses and micaschists (SCHMIDEGG, 1936; SENARCLENS-GRANCY, 1964; SCHULZ et al., 2001). Interlayered rare and thin amphibolites show no textural evidence of former eclogitic assemblages. Thin layers of marbles, graphitic gneisses and quartz-feldspar gneisses are rarely found. Micaschists with smaller grain sizes, a shearband foliation and containing garnet but no staurolite outcrop along the northern border of the Thurntaler Phyllite Group. These rocks have been labelled as phyllitic micaschists within the Defereggen Group. The monotonous metapelitic sequence is concordantly interlayered by several km-scale orthogneiss bodies which differ in grain size, mode and fabric (BORSI et al., 1973, 1978; SCHULZ et al., 2001).

The Thurntaler Phyllite Group overlies the Defereggen Group along a pre-Alpine foliation-parallel contact (HEINISCH & SCHMIDT, 1984; SCHULZ, 1991; KREUTZER, 1992). However, the contact has been overturned and obscured in many profiles. Quartzphyllites and phyllitic micaschists are interlayered by amphibolites, epidote-amphibolites, chlorite schists, quartzites, graphite phyllites and rare marbles. Horizons of porphyroid schists and gneisses were interpreted as metatuffites (HEINISCH & SCHMIDT, 1976, 1984; SCHÖNLAUB, 1979).

The metamorphism of this basement was polyphase, Variscan and Alpine. One observes Variscan amphibolite-facies metamorphism to the west of the Isel river. Here in metapelites, assemblages with garnet, staurolite and kyanite were followed by andalusite and sillimanite bearing assemblages of presumably Permian age (SCHULZ et al., 2001; SCHUSTER et al., 2001). A 204±3 Ma biotite Rb-Sr age and a 193±2 Ma muscovite Ar-Ar age (SCHUSTER et al., 2001) in this part of the basement confirm an incomplete Alpine overprinting and a pre-Alpine age of the principal foliation. In the phyllitic micaschists and in the adjacent Thurntaler



Text-Fig. 2.
Magmatic evolution trends in meta-magmatites of the Austroalpine basement to the south of the Tauern Window. Some dated samples are marked.

a) Ti-V discrimination diagram after SHERVAIS (1982).
b) Discrimination $(Th/Ta)_N$ – $(Tb/Ta)_N$ after THIÉBLEMONT et al. (1994).
c,d) Discrimination Zr-Ti after PEARCE (1982).

Meta-magmatic suites are labelled by numbers and protolith ages of some samples are indicated: 1 = N-MORB-type eclogitic amphibolites of the Prijakt Subgroup (SCHULZ, 1995); 2 = VAB-type hornblende-plagioclase-gneisses of Rotenkogel and Prijakt Subgroups; 3 = Granitoid orthogneisses; 4 = Meta-porphyroids of the Thurntaler Phyllite Group; 5 = WPB-type amphibolites of the Northern Defereggen/Petzeck Group (Torkogel Subgroup [DINKELMEYER, 1998]); 6 = MORB-type amphibolites of questionable age in the Northern Defereggen/Petzeck Group (GODIZART, 1989; SCHÖNHOFER, 1999; SCHULZ, unpublished data). 7 = MORB and WPB-type metabasites of the Thurntaler Phyllite Group (SCHULZ, unpublished data).

Abbreviations of Austroalpine lithological units: DG = Defereggen Group; MSg = Michelbach Subgroup; NDPG = Northern Defereggen/Petzeck Group; PSg = Prijakt Subgroup; RSg = Rotenkogel Subgroup; TPG = Thurntaler Phyllite Group; TSg = Torkogel Subgroup.

Phyllite Group, the staurolite is lacking. However, amphibolites bearing tschermakite and oligoclase signalize that the Thurntaler Phyllite Group underwent at least epidote-amphibolite-facies metamorphism (SCHULZ, 1991; SCHULZ et al., 2001). Carboniferous mica cooling ages give evidence of a pre-Alpine and Variscan metamorphism to the south of the DAV and in the Defereggen Group (BORSI et al., 1978). The Alpine metamorphism did hardly exceed 300°C to the south of the DAV, as is demonstrated in the Triassic carbonate rocks of Kalkstein and Staller Alm along the late-Alpine faults (GUHL & TROLL, 1987; SCHULZ, 1991).

The pre-Alpine metamorphic rocks were overprinted by a greenschist-facies Alpine metamorphism with increasing degree from the DAV towards the north. To the west of the Isel river, in a profile between St. Jakob i. Def. and the southern rim of the Tauern Window, the pre-Alpine metapelite garnets display no distinct Alpine overgrowths (SCHÖNHOFER, 1999), as it has been observed in the southern Oetztal basement (PURTSCHELLER et al., 1987). To the east of the Isel valley, assemblages with garnet, staurolite and kyanite prevail in the metapelites and garnet occurs with clinopyroxene (Jd 35–42) in the Prijakt Subgroup eclogitic amphibolites (SCHULZ, 1993). An Alpine overprinting of these presumably pre-Alpine assemblages is obvious from Eo-Alpine mica cooling ages (TROLL, 1978).

3. Geochemistry of Meta-Magmatites

Whole-rock geochemistry allowed a further discrimination of the metabasites within the various subgroups of the Northern Defereggen/Petzeck Group (Fig. 2, 3). It has been demonstrated in detail (GODIZART, 1989; SCHULZ, 1995; DINKELMEYER, 1998; SCHÖNHOFER, 1999) that element abundances (especially for HFSE) and element ratios in selected suites of samples have not been affected by metamorphic processes and represent preserved signatures of magmatic fractionation. In the Ti-Zr coordinates (PEARCE, 1982) and similarly in the Cr-Y and Ti-V diagrams of PEARCE (1982) and SHERVAIS (1982) one can distinguish among several fractionation lines which define the following suites in the Austroalpine basement (Fig. 2a–d):

a) N-MORB-type signatures have been found in the eclogitic amphibolites of the Schleinitz and Prijakt areas of the Prijakt Subgroup (SCHULZ, 1995; BÜCKSTEEG, 1999), but occur as well in amphibolites of the Rotenkogel Subgroup. Compositions are tholeiitic with 46–49 wt % SiO_2 and Zr/Y ratios of 2.1–4.1. In Al_2O_3-TiO_2 (PEARCE, 1983) and FeO_{tot}/MgO-TiO_2 (PFEIFER et al., 1989) coordinates for discrimination of basalts and gabbros, the rocks mostly plot in the field of basaltic liquids. The LIL elements and Ce are slightly enriched compared to MORB (Fig. 3a). REE patterns are slightly enriched in LREE with $(La/Yb)_N$ ranging from 0.68 to 1.85 at 10–50 times chondrite abundances (Fig. 3b). The $(Tb/Ta)_N$ 0.93–3.31 and $(Th/Ta)_N$ (THIEBLÉMONT et al., 1994) between 1.38 and 2.50 (Fig. 2b) can be considered as a sign of back-arc basin magmatism. Whole-rock $\delta^{18}O_{SMOW}$ values are 4.2–8.0 ‰.

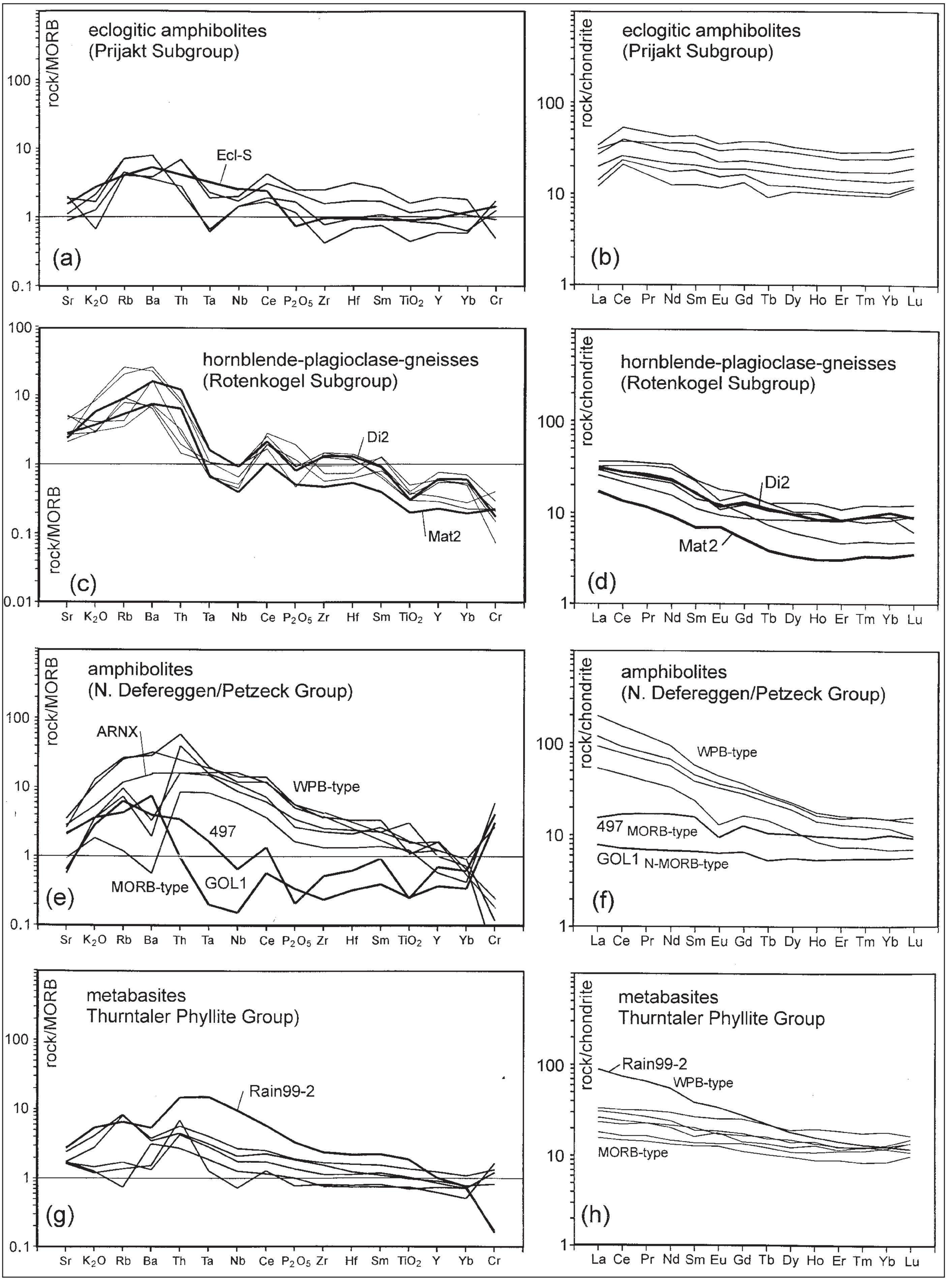
b) MORB-type signatures are typical of numerous isolated and m-scale occurrences of amphibolites within the metasediments and metabasic subgroups of the Northern Defereggen/Petzeck Group and its continuation toward the west (GODIZART, 1989; SCHULZ et al., 1993; SCHÖNHOFER, 1999). The compositions range from 45.5–52.2 wt. % SiO_2 along a tholeiitic trend and Zr/Y ratios are 0.8–3.4 (Fig. 2a, d). The MORB-normalized variation diagrams display 2–10 times enrichment of LIL elements (Fig. 3e). REE patterns are LREE depleted to flat with $(La/Yb)_N$ = 0.5–1.1 with a marked negative Eu-anomaly and contrast the N-MORB-type eclogitic amphibolites and metabasites (Fig. 3b, f).

c) WPB-type signatures are widespread in numerous isolated and m-scale amphibolites and in the metabasic subgroups within the Northern Defereggen/Petzeck Group (GODIZART, 1989; SCHULZ et al., 1993), and in the distinct metabasic subgroups of the Torkogel (DINKELMEYER, 1998; STEENKEN & SIEGESMUND, 2000) and the Croda Nera (STEENKEN & SIEGESMUND, 2000). These rocks have tholeiitic, transitional and alkaline compositions and Zr/Y are highly variable from 4.7 to 13.0 (Fig. 2a, d). The compositions match the basaltic liquid fields in the diagrams Al_2O_3-TiO_2 (PEARCE, 1983) and FeO_{tot}/MgO-TiO_2 (PFEIFER et al., 1989). There is significant enrichment in LIL and HFS elements (Fig. 3e). Also the LREE and HREE display 10–200 times enrichment (Fig. 3f) with $(La/Yb)_N$ = 14.6–19.6. Whole-rock rock $\delta^{18}O_{SMOW}$ values are 9.3–10.6 ‰.

d) VAB-type or island arc tholeiite geochemical signatures are found in the hornblende-plagioclase-gneisses in the Rotenkogel and Prijakt Subgroups (Fig. 2a, c). The compositions range from basaltic andesites to andesites with SiO_2 contents between 52–63 wt. %. They follow a calc-alkaline fractionation trend. Zr/Y ratios range from 1.3 to 13.1 (Fig. 2c). When plotted into the diagrams Al_2O_3-TiO_2 (PEARCE 1983) and FeO_{tot}/MgO-TiO_2 (PFEIFER et al., 1989) for discrimination of basalts and gabbros, the hornblende-plagioclase-gneisses are situated in the field of Cpx-gabbros. This geochemical hint to a plutonic origin is supported by the occurrence of the hornblendites, interpreted as former autoliths. Multi-element, MORB-normalized plots (PEARCE, 1982) show enrichment of LILE relative to MORB and negative HFSE anomalies, characteristic for melts formed in island arc and active continental margin settings (Fig. 3b). Variations of incompatible elements in the hornblende-plagioclase-gneisses are similar to data from lower continental crust as listed in ROLLINSON (1993). In detail, these rocks show enrichment of Sr, K_2O, Rb, Ba, Th and Ce. The elements Nb, Zr, Hf, Sm, Ti, Y, Yb, Cr appear depleted when compared to MORB. However, Ta, Nb and TiO_2 display marked negative anomalies, which points to a contribution of upper crustal material during magma formation (Fig. 3c). Negative Eu and Sr anomalies could be attributed to a similar fractionation of these elements due to Ca-substitution in plagioclase. In the chondrite-normalized REE variation diagram (Fig. 3d), subparallel patterns with systematically stronger enrichment of LREE (10–30 times) compared to HREE are observed, the $(La/Yb)_N$ ranging from 2.6–8.1. The hornblende-plagioclase-gneisses as well differ by their whole-rock $\delta^{18}O_{SMOW}$ values of 6.9–8.2 ‰ from the acid orthogneisses and the other metabasites.

e) Transitional MORB-type and WPB-type tholeiitic to alkaline compositions with 42–51 wt. % SiO_2 are observed in the metabasites of the Thurntaler Phyllite Group (KREUTZER, 1992; SCHULZ, unpublished data) and Zr/Y ratios range from 2.3 to 10.4 (Fig. 2a, d). Slight enrichment of LILE occurs in MORB-normalised variation diagrams (Fig. 3g). In most of the studied samples, the REE patterns show very slight enrichment of LREE with $(La/Yb)_N$ ranging between 1.5 and 2.3. One alkaline-type sample displays stronger LREE enrichment with $(La/Yb)_N$ of 7.0 (Fig. 3h). Whole-rock $\delta^{18}O_{SMOW}$ values are 11.2–11.9 ‰.

f) The orthogneisses can be subdivided into several macrochemical groups:
   1) The orthogneiss of Gsies/Casies has a tonalitic to granodioritic, rarely dioritic character and bears biotite and amphibole.


eclogitic amphibolites
(Prijakt Subgroup)
rock/MORB
Ecl-S
(a)
Sr K2O Rb Ba Th Ta Nb Ce P2O5 Zr Hf Sm TiO2 Y Yb Cr
eclogitic amphibolites
(Prijakt Subgroup)
rock/chondrite
(b)
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
hornblende-plagioclase-gneisses
(Rotenkogel Subgroup)
rock/MORB
Di2
Mat2
(c)
hornblende-plagioclase-gneisses
(Rotenkogel Subgroup)
rock/chondrite
Di2
Mat2
(d)
amphibolites
(N. Defereggen/Petzeck Group)
rock/MORB
ARNX
WPB-type
497
MORB-type
GOL1
(e)
amphibolites
(N. Defereggen/Petzeck Group)
rock/chondrite
WPB-type
497 MORB-type
GOL1 N-MORB-type
(f)
metabasites
Thurntaler Phyllite Group)
rock/MORB
Rain99-2
(g)
metabasites
Thurntaler Phyllite Group
rock/chondrite
Rain99-2
WPB-type
MORB-type
(h)

Text-Fig. 3. ◄ ◁ ◄
MORB-normalized variation diagram (PEARCE, 1982) and chondrite-normalised REE pattern (BOYNTON, 1984) of metabasites in the Austroalpine basement to the south of the Tauern Window.
Note WPB-type and MORB-type amphibolites in (e) and (f).

2) Fine grained and strongly foliated biotite orthogneisses of 0.1 to 1 km thickness bearing up to 20 % epidote-group minerals and sometimes garnet occur in the southern and eastern parts of the Defereggen Group at Blankenstein, Hochgrabe, Sauspitze and in the Kristeinertal.
3) The orthogneiss of Antholz/Anterselva bears muscovite and is a former alkalifeldspar granite. This leucocratic orthogneiss further occurs in numerous bodies of <100–200 m thickness within the Defereggen Group (Kalkstein, Grumauer Berg, Staller Sattel) and in the Northern Defereggen/Petzeck Group. The orthogneisses rarely show metaluminous and mostly peraluminous character (Fig. 4a). The Gsies/Casies-type and the fine-grained biotite orthogneisses plot in the CAG continental arc granites field (Fig. 4a), the Antholz/Anterselva and the other orthogneisses cover the CCG continental collision granites field in the diagram of MANIAR & PICCOLI (1989). In the R1–R2 diagram (not shown) of BATCHELOR & BOWDEN (1985) and DE LA ROCHE et al. (1980) the orthogneisses follow an equivalent magmatic trend which starts in the pre-plate-collision field (orthogneisses of Casies/Gsies) and ends in the field of syncollisional granites (SCHÖNHOFER, 1999; BÜCKSTEEG, 1999; SCHULZ et al., 2001). S-type affinity results from A/CNK-values between 1.05 and 1.35 (CHAPPEL & WHITE, 1974). The [Na/K] of 1.02–1.35 indicating participation of mantle-derived melts in some samples should be considered with caution due to the possible mobility of Na and K during metamorphism and deformation. However, the selected data provided that these elements were not mobile. The LREE are fractionated and the HREE are poorly fractionated in the Gsies/Casies orthogneiss (PECCERILLO et al., 1979; MAZZOLI & SASSI, 1992). More acidic samples show higher HREE fractionation. A negative Eu anomaly occurs (Fig. 4b). The whole-rock $\delta^{18}O_{SMOW}$ values are 10.3–9.2 ‰, dependent on the increasing SiO_2 contents which range from 63–75 wt. %.

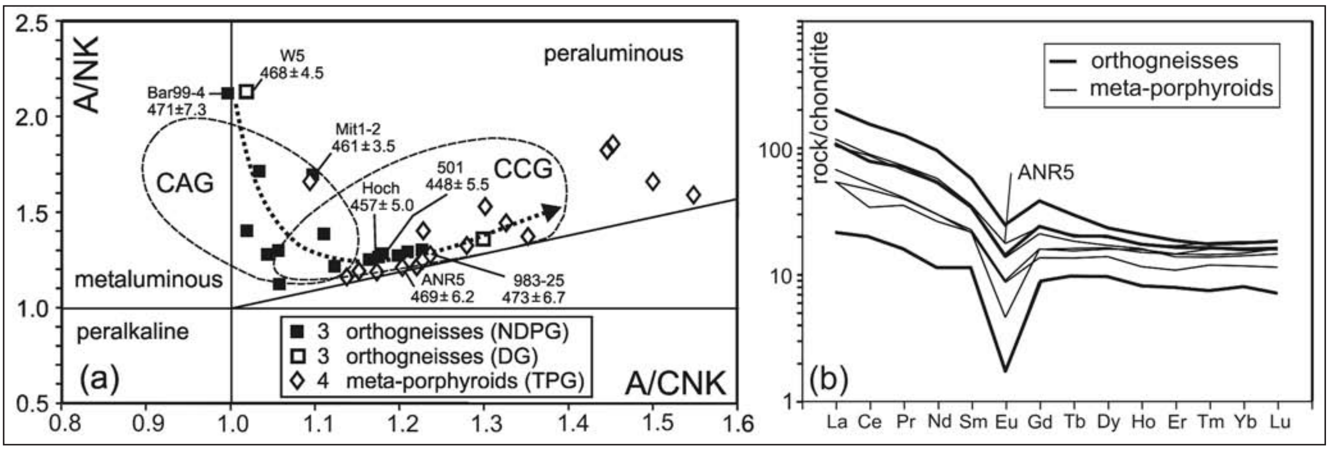
g) Compositions of meta-porphyroids in the Thurntaler Phyllite Group range from 67 to 79 wt. % SiO_2. They plot only into the CCG field (Fig. 4a) in the A/CNK-A/NK diagram of MANIAR & PICCOLI (1989). In the R1-R2 diagram (not shown), the meta-porphyroids follow a trend in the late-orogenic and syncollisional fields, slightly different from the orthogneisses. However, the REE patterns perfectly match the data from the orthogneisses (Fig. 4b) and demonstrate the geochemical similarity of both rock groups, as has already been stated by HEINISCH (1981) and HEINISCH & SCHMIDT (1982). The whole-rock $\delta^{18}O_{SMOW}$ values of 12.7–13.3 ‰ in samples with 75–78 % SiO_2 slightly exceed the data obtained from the orthogneisses. This is attributed to the higher SiO_2 contents.

It has been demonstrated that each of these meta-magmatic suites covers a considerable range of compositions (PECCERILLO et al., 1979; HEINISCH, 1981; GODIZART, 1989; SCHULZ et al., 1993; 2001; SCHULZ, 1995; SCHÖNHOFER, 1999; STEENKEN & SIEGESMUND, 2000). The intra-suite geochemical variations are mainly attributed to magmatic fractionation processes.

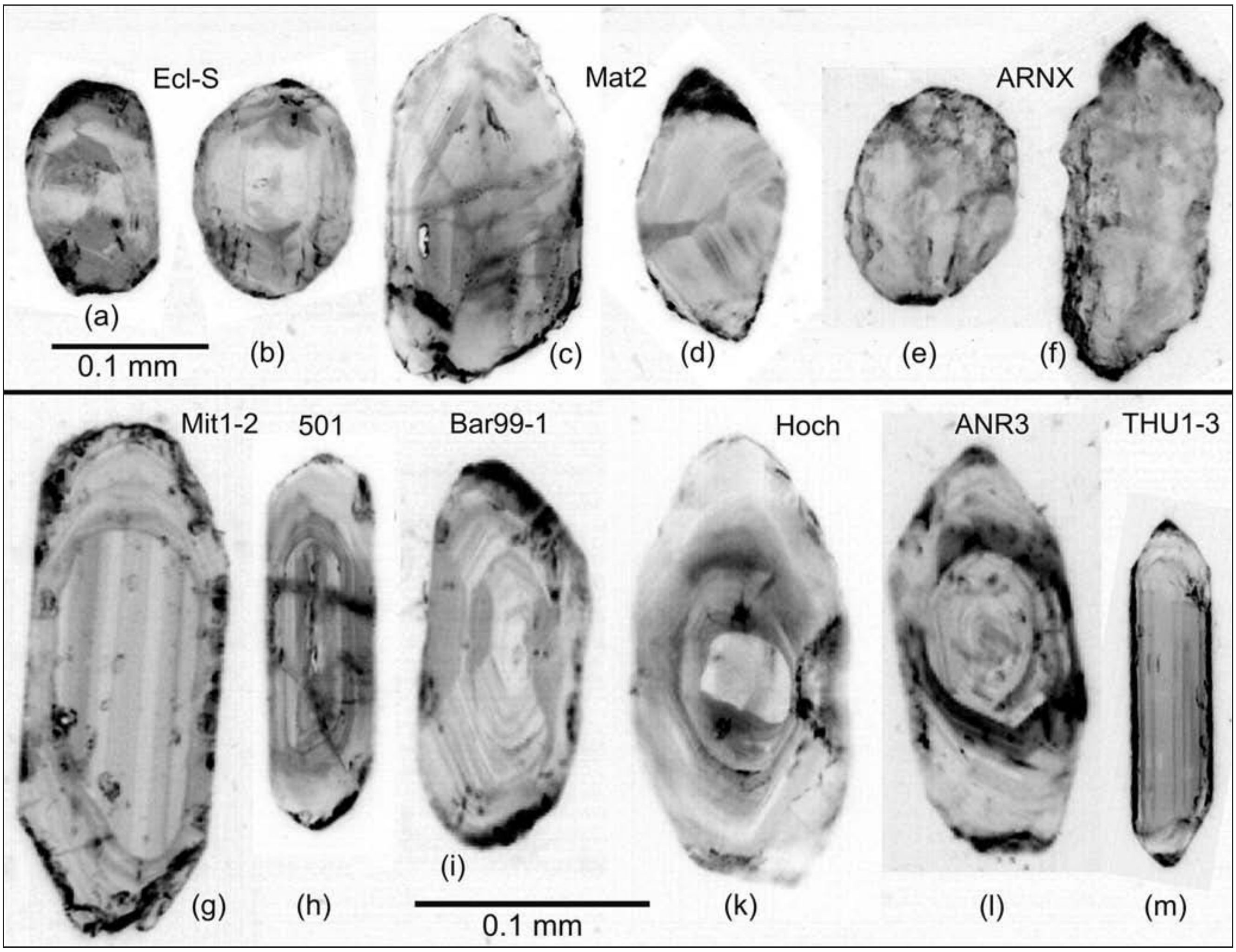
When geochemical whole-rock data from widely scattered and small metabasite outcrops are compiled, there remains uncertainty whether fractionates belonging to a single and progressive magmatic process are regarded. Detailed study of larger metabasite outcrops as in the Torkogel (DINKELMEYER, 1998), the Rotenkogel (SCHÖNHOFER, 1999) and the Prijakt Subgroups (SCHULZ, 1995) revealed broad compositional ranges which can be understood by single magmatic fractionation processes, sometimes in a discontinuous and cyclic way. Therefore the dating of selected and geochemically defined samples out of these meta-magmatic suites will give important insight to the geodynamic evolution of the Austroalpine basement.

However, when dating the protolith ages, the question arises if there are some genetic links among the different metabasite suites. When regarding the magmatic fractionation trends, the N-MORB- and MORB-type metabasite suites could have been differentiated during a single magmatic event. In contrast, the WPB-type suite should belong to an other magmatic event, even when some overlapping of the compositional fields occurs (Fig. 2a–d). Metabasites of the Thurntaler Phyllite Group enclose both WPB- and MORB-type compositions.

According to the fractionation trends, these rocks belong to a single magmatic event. When the WPB-type metabasites of the Northern Defereggen/Petzeck Group and of the Thurntaler Phyllite Group are compared, strong compositional similarities exist, which favour a common magmatic event.



Text-Fig. 4.
Geochemistry of acid magmatites in the Austroalpine basement.
a) Discrimination diagram after MANIAR & PICCOLI (1989), the stippled arrow marks chemical and chronological evolution trend in the orthogneisses.
b) Chondrite-normalised REE pattern, using the reference data of BOYNTON (1984).



Text-Fig. 5.
Cathodoluminescence of zircons in various meta-magmatites of the Austroalpine basement. Irradiation with a hot cathode, conversion of the color images by inversion (parts with yellow CL appear dark, parts with intense blue CL are light grey), and greyscaling.
a, b) Eclogitic amphibolite.
c, d) Hornblende-plagioclase-gneisses; magmatic oscillatory CL-zonation does not match crystal faces in zircon (d).
e, f) WPB-type amphibolite; corrosion pits are visible in zircon (f).
g–k) Orthogneisses; distinct inherited cores are visible in zircons (g) and (k).
l, m) Meta-porphyroids; distinct inherited core is obvious in zircon (l); dating of long prismatic zircons as (m) yielded Ordovician Pb-Pb ages (see text).

4. Geochronology

4.1. Pb-Pb Single Zircon Evaporation Methodology

It has been proposed by KOBER (1986, 1987) to analyse lead isotopes in zircons by the evaporation of single grains in a the two-filament arrangement of a TIMS. This method has been further developed and successfully applied in many magmatic, metamorphic and sedimentary terrains (e. g. KRÖNER et al., 1995; KARABINOS, 1997; KLÖTZLI, 1997, 1999b; TICHOMIROWA et al., 2001). The method requires a careful selection of zircons on the basis of morphology (PUPIN, 1980) in optical and RE microscopy, and by cathodoluminescence (CL) under a hot cathode (GÖTZE, 2000). Modifying the analytical procedure outlined by KOBER (1986; 1987) and further detailed in KLÖTZLI (1997), a single zircon grain of 125–250 μm size mounted on Rhenium filaments has been "cleaned" for 10 minutes by heating at 1450°C. This should remove possibly present common lead from cracks and discordant parts of the zircon. Then the zircon grain was evaporated and the Pb transferred to the second filament during a single cycle at 1600°C. Pb was then ionized at temperatures between 1190 and 1220°C, and the ^{207}Pb, ^{206}Pb and ^{204}Pb isotopes were analysed in a FINNIGAN MAT 262 using dynamic SEM ion counter. Ion beam intensities have been measured in 10 blocks of 9 scans. The ^{207}Pb/^{206}Pb ratios were

1) corrected by contents of common lead derived from the ^{204}Pb/^{206}Pb ratios, following the two-stage Pb isotope evolution model of STACEY & KRAMERS (1975) and
2) by further correction of 0.0036 per amu involving fractionation and mass-bias of the spectrometer, determined through repeated analyses of zircon standards (BOMBACH, unpublished data). The obtained values were checked by repeated analysis of the zircon standards 91500 (WIEDENBECK et al., 1995) and S-2-87 (Geological Survey of United States). After evaluation of outliers and the corrections mentioned above, a mean ratio of ^{207}Pb/^{206}Pb$_{cor}$ has been gained from the single scans (Tables 1, 2, 3).

Apparent zircon ages were produced by iteration of the two equation system of the decay chains ^{238}U – ^{206}Pb and ^{235}U – ^{207}Pb; the error on the single zircon ages was calculated as 2 standard errors of the mean (2σmean), using the mean ratio of ^{207}Pb/^{206}Pb$_{cor}$ and the error of the measured ratios (BOMBACH, unpublished calculation program Isotopengeochemisches Labor der TU Bergakademie Freiberg/Sachsen). For the age estimation it is important to

Table 1.
$^{207}Pb/^{206}Pb$, $^{204}Pb/^{206}Pb$ and corrected $^{207}Pb/^{206}Pb$ data from evaporation of single zircons from Austroalpine metabasites. Sample Ecl-S is a N-MORB-type eclogitic amphibolite; ARNX is a WPB-type amphibolite; Di1, Di2, Mat 2 and Bar99–7 are VAB-type hornblende-plagioclase-gneisses.

zircon	$^{204}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb_{cor}$ 2σmean	age [Ma] 2σmean	scans
EclS-ZA	0.0001860	0.06177	0.0593100 ± 7	578.4 ± 2.6	90
EclS-Z41	0.0000507	0.05984	0.0593270 ± 12	579.1 ± 4.3	90
EclS-Z3	0.0000339	0.05966	0.0593880 ± 6	581.3 ± 2.1	90
EclS-ZH	0.0009480	0.07287	0.0594750 ± 8	584.5 ± 3.0	90
EclS-Z31	0.0000631	0.06021	0.0595200 ± 5	586.1 ± 1.9	90
EclS-Z4	0.0000909	0.06066	0.0595670 ± 34	587.8 ± 12.3	33
EclS-Z1	0.0000150	0.05963	0.0596260 ± 4	590.0 ± 1.3	90
EclS-Z7	0.0000307	0.05992	0.0596940 ± 5	592.4 ± 2.0	90
EclS-Z11	0.0000939	0.06084	0.0597020 ± 4	592.8 ± 1.7	90
EclS-Z5	0.0000209	0.05986	0.0597770 ± 3	595.5 ± 1.1	90
ARNX-Z2	0.0000750	0.05611	0.0552210 ± 24	421.1 ± 9.9	51
ARNX-ZD	0.0005700	0.06333	0.0553010 ± 15	424.4 ± 6.2	80
ARNX-Z4	0.0001230	0.05692	0.0553400 ± 8	425.9 ± 3.3	90
ARNX-ZB	0.0007520	0.06604	0.0553740 ± 35	427.3 ± 14.3	90
ARNX-ZC	0.0000673	0.05616	0.0553890 ± 11	427.9 ± 4.4	90
ARNX-ZD1	0.0001250	0.05704	0.0554330 ± 3	429.7 ± 1.4	79
ARNX-Z3	0.0000623	0.05619	0.0554920 ± 3	432.0 ± 1.1	80
Di1-Z3	0.0000493	0.05870	0.0581990 ± 9	537.2 ± 3.3	90
Di1-Z4	0.0002750	0.06209	0.0583460 ± 7	542.7 ± 2.8	88
Di1-ZD	0.0002080	0.06122	0.0584320 ± 19	546.0 ± 7.1	63
Di1-ZB	0.0000618	0.05913	0.0584520 ± 5	546.7 ± 1.7	90
Di1-Z1-2	0.0001440	0.06046	0.0585900 ± 5	551.9 ± 1.9	36
Di1-Z1-1	0.0001860	0.06113	0.0586630 ± 3	554.6 ± 1.1	88
Di2-Z4	0.0000568	0.05881	0.0582060 ± 16	537.5 ± 6.1	90
Di2-ZC	0.0001170	0.05977	0.0582980 ± 7	540.8 ± 2.5	90
Di2-Z1	0.0001820	0.06072	0.0583180 ± 9	541.7 ± 3.4	90
Di2-Z6	0.0000278	0.05856	0.0583330 ± 9	542.3 ± 3.3	90
Di2-ZStan	0.0000031	0.05819	0.0583590 ± 4	543.2 ± 14	61
Di2-Z7	0.0000291	0.05857	0.0583630 ± 8	543.3 ± 2.9	90
Di2-ZB	0.0002810	0.06220	0.0583700 ± 12	543.6 ± 4.8	90
Di2-Z2A	0.0000486	0.05887	0.0583760 ± 3	543.9 ± 1.3	81
Bar99-7-Z1	0.0001770	0.06022	0.0578810 ± 17	525.2 ± 6.6	90
Bar99-7-ZG	0.0000708	0.05881	0.0580010 ± 4	529.8 ± 1.4	84
Bar99-7-Z5	0.0001630	0.06017	0.0580290 ± 4	530.8 ± 1.7	89
Bar99-7-Z4	0.0001190	0.05959	0.0580770 ± 4	532.6 ± 1.7	80
Bar99-7-Z6	0.0001020	0.05942	0.0581680 ± 3	536.0 ± 1.1	86
Mat2-Z3	0.0000598	0.05897	0.0583180 ± 10	541.7 ± 3.7	90
Mat2-Z7	0.0000619	0.05905	0.0583680 ± 9	543.5 ± 3.4	90
Mat2-Z2	0.0001840	0.06081	0.0583680 ± 7	543.6 ± 2.6	90
Mat2-Z5	0.0002120	0.06123	0.0583900 ± 4	544.4 ± 1.6	90
Mat2-Z1	0.0000271	0.05864	0.0584600 ± 3	547.0 ± 1.3	90
Mat2-ZN	0.0000677	0.05928	0.0585160 ± 4	549.1 ± 1.3	90
Mat2-ZB1	0.0000434	0.05896	0.0585510 ± 3	550.4 ± 1.2	90
Mat2-Z2F	0.0000244	0.05877	0.0586270 ± 3	553.2 ± 1.2	90
Mat2-Z6	0.0000498	0.05914	0.0586360 ± 4	553.6 ± 1.4	90
Mat2-Z4	0.0002420	0.06193	0.0586550 ± 3	554.3 ± 1.1	90

obtain reproducible ages by analysis of several zircons from the same sample, because the calculated $^{207}Pb/^{206}Pb$ ages are model ages with no information about concordance or the degree of discordance. They are of necessity minimum ages. In view of the fact that these ages resulted from high-temperature evaporation with no significant changes in the $^{207}Pb/^{206}Pb$ ratios, we are confident that the data points are concordant or nearby so. In addition we argue on a statistical basis: when 5–7 zircon ages from one sample fall within a similar range, this has been considered to date a zircon magmatic crystallization event. The single zircon isotopic data has been evaluated by two methods:

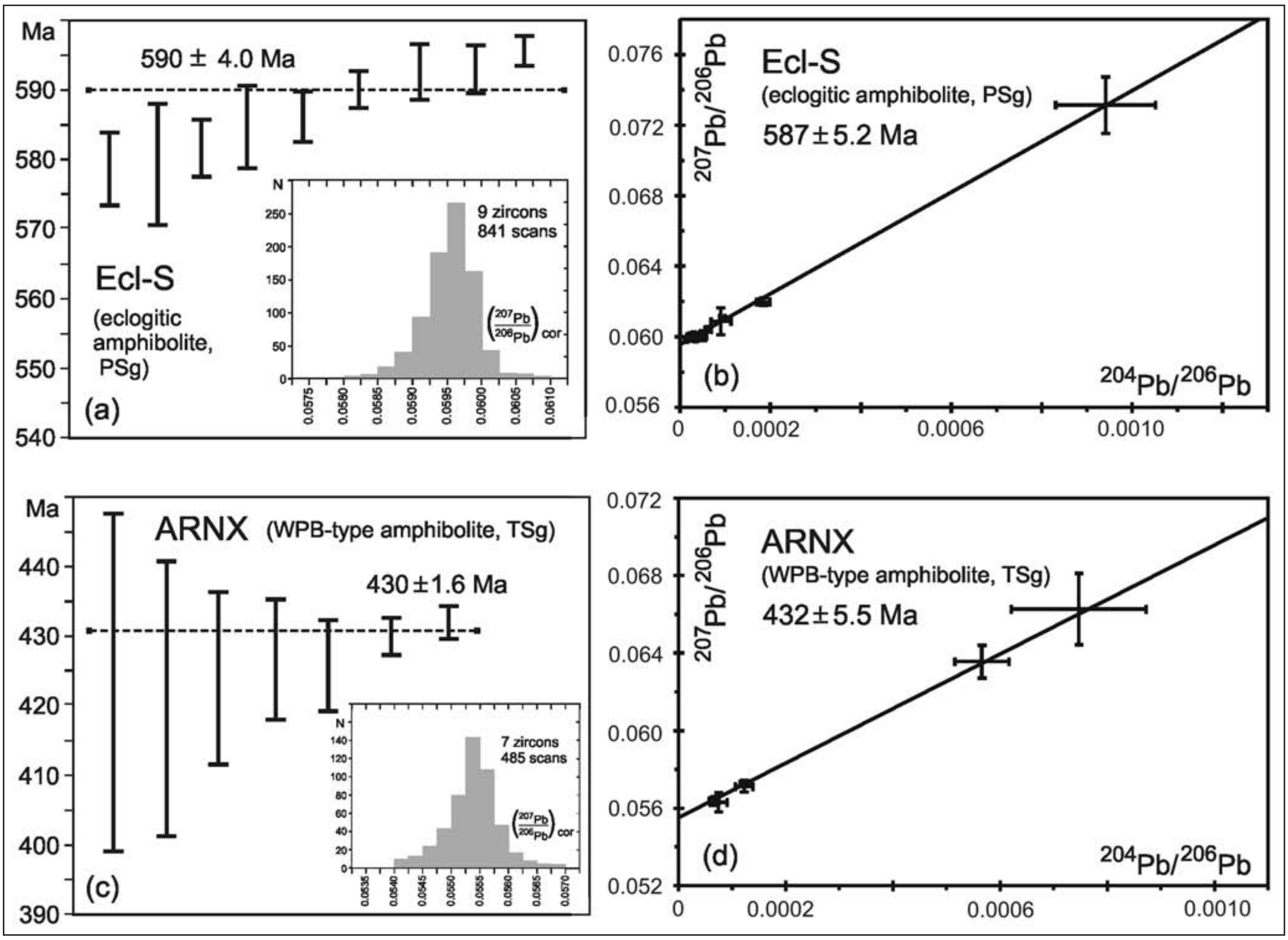
1) Weighted mean ages: Age data and corresponding error from a zircon population has been plotted in a single variable diagram. A weighted mean age was calculated (LUDWIG, 2001) from this population. These ages are quoted for the discussion.
2) Isochron ages: When the $^{204}Pb/^{206}Pb$ values from a zircon population of equivalent ages show a spread, this allows to plot the data in $^{204}Pb/^{206}Pb$ vs $^{207}Pb/206Pb$ coordinates and to calculate a regression line (LUDWIG, 2001). The intersection of this regression line at $^{204}Pb/^{206}Pb = 0$ gives an optimally corrected $^{207}Pb/^{206}Pb$ value, which can be used to calculate a corresponding "isochron" age. However, in many cases only very small and thus welcome values between 0.00001 and 0.0003 of common lead $^{204}Pb/^{206}Pb$ have been analysed from the zircons. This small spread of the data prevented a small error in the isochron age calculations. The lower, and welcome for the weighted mean age determination the common lead contents are, the higher the resulting error upon such an isochron age could be.

4.2. Eclogitic Amphibolites

Eclogitic amphibolites with the N-MORB-type compositional signature (Fig. 2a–c, 3a,b) and bearing garnet, clinopyroxene, amphibole, plagioclase, epidote, quartz, rutile (SCHULZ 1995) were sampled at Barrenle-See (near Prijakt) in the northern part (samples Pri, Bar99-2), and at 1500 m along the road from Oberdorf to Zettersfeld in the southern part of the Prijakt Subgroup (sample Ecl-S). Zircons in the Pri and Bar99-2 samples are whitish clear and prismatic with etched crystal faces. Length to width ratios range between 1 and 2. The CL images signal defect crystal structures by predominant yellow colours and deeply corroded crystals. Accordingly, weak signals and elevated $^{204}Pb/^{206}Pb$ were analysed. The zircon ages display a large scatter from 411.7±6.6 to 338.4±12.7 Ma and are considered to have been arbitrarily reset during Variscan and Alpine metamorphism. In contrast, whitish clear short prismatic to round zircons of sample Ecl-S display intense blue CL colours of an intact crystal lattice. They display internal oscillatory zonation and sector zoning (Fig. 5a, b). This is generally attributed to growth in a melt (HANCHAR & MILLER, 1993; VAVRA, 1994; CONELLY, 2000). In many of these zircons, the symmetry of the internal oscillatory and sector zoning is not related to the symmetry of the crystal faces. The $^{207}Pb/^{206}Pb$ zircon ages range from 578 to 595 Ma and represent a homogeneous population. A weighted mean age from 10 zircons is 590.0±4 Ma (Fig. 6a). Even when hampered by the welcome generally low $^{204}Pb/^{206}Pb$ values, one zircon with elevated $^{204}Pb/^{206}Pb$ of 0.0009 allowed a reliable estimate by the isochron method (587.5±5.2 Ma), which supports the weighted mean age (Fig. 6b). The age is interpreted to date the magmatic protolith crystallization of the eclogitic amphibolite.

4.3. Hornblende-Plagioclase-Gneisses

The hornblende-plagioclase-gneisses with the VAB-type geochemical signature (Fig. 2a–c, 3c,d) occur in dm- to m-thick foliated layers with variable modes of amphibole. Amphibole is found in patchy lens-like aggregates with sizes up to 0.5 cm and is surrounded by a foliated and lay-



Text-Fig. 6.
a, c) Corrected $^{207}Pb/^{206}Pb$ data from evaporated zircon single grains in Austroalpine eclogitic amphibolites and WPB-type amphibolites (see Table 1). Calculation of weighted mean ages and isochron ages in (b), (d) by using the program of LUDWIG (2001).

ered matrix composed of plagioclase, epidote and quartz, resulting in a flaser structure. A retrogressive replacement of the amphiboles by chlorite is frequently observed. The gneisses were sampled to the NW of Arnitzalm along a forest road at 1420 m, from layers several meters distant (samples Di1 and Di2). Another location is situated to the south of Matrei along a forest road to Außer Klaunzer Berg, at 1200 m (sample Mat2); both locations concern the Rotenkogel Subgroup. One sample (Bar99-7) comes from the Barrenle-See continuous outcrop of the Prijakt Subgroup with the eclogitic amphibolites (Fig. 1).

In the hornblende-plagioclase-gneiss samples several slightly differing morphological subpopulations of zircons are found. The typical length to width ratios are between 2 and 3. Edges of zircons have a medium degree of rounding and traces of corrosion and pitting occur. In most cases (70 %) only one prism is well developed with (100) > (110). Pyramids (211) are predominant and the pyramids (101) are poorly developed. When the morphological criteria of PUPIN (1980) are applied, most zircons fall into the S16, S17, S21 and S22 groups. Optical control by CL revealed fine-banded oscillatory growth zoning in combination with sector zoning (Fig. 5c, d). In most zircons, the symmetry of the internal oszillatory and sector zoning is not related to the symmetry of the crystal faces. Distinct cores have not been detected in the zircons, but some central parts display more intense dark blue luminescence colours. From each of the four samples, between 5–10 clear and inclusion-free zircon grains without cracks have been dated.

In sample Bar99-7 from the Prijakt Subgroup, the ages from a homogeneous zircon population range between 525 and 536 Ma, with the exception of a 603.0±3.1 old zircon which is considered inherited. A weighted mean age from the population is 532.9±3.8 Ma (Fig. 7a). This age is matched by the 531±12 Ma estimated by the isochron method (Fig. 7b). In the other three samples, no inherited old zircons have been found. Sample Di2 provided a more homogeneous group of 8 zircons ranging between 537 and 543 Ma, with a weighted mean age of 542.9±1.9 Ma (Fig. 7c). Even when the $^{204}Pb/^{206}Pb$ values are low, the data fit an equivalent isochron age of 544.2±3.9 Ma (Fig. 7d). In sample Di1 situated nearby, the 6 zircons yielded ages between 537 and 554 Ma with a weighted mean of 550.6±5.9 Ma (Fig. 7e). The corresponding isochron age (543±17 Ma) is afflicted by a considerable error due to low $^{204}Pb/^{206}Pb$ values. From the weighted mean ages which differ about 8 Ma in samples Di1 and Di2, just beyond the 2σmean error, the question arises if possibly two distinct zircon crystallization events have been recorded. This question can be similarly addressed in sample Mat2. In this sample the 10 single zircon ages range between 541 and 554 Ma, enclosing the zircon ages found in Di1 and Di2. When the data from Mat2 are treated as a single homogeneous population, one arrives at a weighted mean age of 548.0±3.7 Ma (Fig. 7f).

However, by exploring the data in the single variable plot, one can figure out two distinct groups, each of 4 zircons, connected by two zircons with intermediate ages. The group of the younger zircons gives a weighted mean age of 543.3±2.4 Ma; the older group is 552.9±2.3 Ma (Fig. 7f). This matches the data from the D1 and D2 samples. When the frequency of single scans from all zircons in the

Table 2
$^{207}Pb/^{206}Pb$, $^{204}Pb/^{206}Pb$ and corrected $^{207}Pb/^{206}Pb$ data from evaporation of single zircons from Austroalpine acid orthogneisses.

zircon	$^{204}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb_{cor}$ 2σmean	age [Ma] 2σmean	scans
W5-ZF	0.0001490	0.05819	0.05624 ± 7	461.7 ± 2.7	90
W5-ZC	0.0001660	0.05846	0.05627 ± 33	462.9 ± 13.2	45
W5-ZB	0.0000515	0.05681	0.05627 ± 5	463.0 ± 2.1	90
W5-Z1	0.0002750	0.06010	0.05633 ± 14	465.4 ± 5.5	90
W5-ZA	0.0001700	0.05866	0.05642 ± 11	468.7 ± 4.4	90
W5-ZE	0.0000648	0.05718	0.05645 ± 4	470.1 ± 1.7	90
W5-ZC	0.0001230	0.05807	0.05650 ± 36	472.1 ± 14.2	63
W5-ZB1A	0.0002670	0.06023	0.05659 ± 7	475.4 ± 2.7	90
Bar99-4-Z5	0.0001230	0.05801	0.05644 ± 5	469.5 ± 1.8	90
Bar99-4-ZE	0.0000881	0.05760	0.05653 ± 5	473.1 ± 1.8	90
Bar99-4-ZH	0.0008310	0.06859	0.05683 ± 5	484.7 ± 1.8	90
Bar99-4-ZG	0.0019500	0.08492	0.05699 ± 6	491.0 ± 2.4	80
Bar991-ZB	0.0000565	0.05676	0.05615 ± 4	458.2 ± 1.6	89
Bar99-1-Z1	0.0001420	0.05811	0.05657 ± 4	462.8 ± 1.7	90
Bar99-1-Z1A	0.0000755	0.05718	0.05629 ± 3	463.8 ± 1.5	90
Bar99-1-Z3	0.0000748	0.05734	0.05646 ± 4	470.5 ± 1.7	90
Mit1-2-ZF1	0.0000885	0.05705	0.05598 ± 16	451.3 ± 6.6	18
Mit1-2-ZF	0.0000869	0.05710	0.05605 ± 14	454.3 ± 5.8	80
Mit1-2-Z1	0.0000348	0.05644	0.05614 ± 8	457.7 ± 3.0	90
Mit1-2-ZE	0.0000489	0.05666	0.05616 ± 5	458.4 ± 1.8	61
Mit1-2-ZE2	0.0000347	0.05657	0.05627 ± 4	463.0 ± 1.6	90
Mit1-2-ZD	0.0001330	0.05802	0.05631 ± 10	464.6 ± 4.2	88
Mit1-2-Z8	0.0001760	0.05870	0.05637 ± 8	466.8 ± 3.1	90
Hoch-Z4	0.0000930	0.05711	0.05597 ± 4	450.9 ± 1.5	90
Hoch-ZG	0.0001210	0.05759	0.05604 ± 4	454.0 ± 1.6	90
Hoch-Z5	0.0000421	0.05650	0.05609 ± 8	456.0 ± 3.3	90
Hoch-ZG	0.0000715	0.05693	0.05611 ± 7	456.5 ± 2.8	90
Hoch-Z7	0.0000854	0.05725	0.05622 ± 3	460.8 ± 1.0	90
Hoch-ZA	0.0018000	0.81991	0.05630 ± 7	464.1 ± 2.8	66
Hoch-Z1	0.0004590	0.06296	0.05655 ± 42	474.0 ± 16.8	55
Hoch-ZF	0.0000126	0.05655	0.05657 ± 23	474.7 ± 9.3	40
501-Z4	0.0001150	0.05727	0.05580 ± 5	444.5 ± 2.1	62
501-ZF	0.0001510	0.05788	0.05590 ± 6	448.3 ± 2.5	90
501-ZH	0.0001450	0.05789	0.05600 ± 18	452.3 ± 7.4	50
501-ZA1	0.0000436	0.05652	0.05609 ± 13	455.9 ± 5.1	90
501-Z1	0.0001030	0.05743	0.05614 ± 18	457.9 ± 7.3	90
501-ZF1	0.0001800	0.05881	0.05642 ± 3	468.7 ± 1.1	90

hornblende-plagioclase-gneisses is considered, one can figure out three distinct cumulative groups around 532, 542 and 552 Ma, which match the weighted mean ages from the individual samples. There is no correlation of these age groups to zircon morphology. The time span covered by the data from the hornblende-plagioclase-gneisses could reflect a longer-lasting magmatic crystallization process along several stages.

4.4. Amphibolite from the Torkogel Subgroup

The amphibolites and garnet-amphibolites of the Torkogel Subgroup display the signatures of an alkaline WPB-type suite (Fig. 2a,b,d, 3e,f). Zircons can be expected to crystallize in Zr-rich late differentiates of the corresponding magmas. The metabasite suite sampled at Moldaber and Arnitzalm (DINKELMEYER, 1998) shows a considerable spread in Zr contents, attributed to magmatic fractionation. From the location Arnitzalm, a garnet gneiss with hornblende garben (ARNX) and comparably high Zr contents of 350 ppm is a late fractionate of this magmatic suite. The sample contains 125 μm long whitish clear zircons with length to width ratios between 1 and 2. The crystal faces show signs of a suturation by dissolution. From the CL study, the zircons appear as internally homogeneous with only weakly developed oscillatory zonations. Several zircons show yellow CL colours as a sign of postcrystalline crystal defects (Fig. 5e, f). Accordingly, some single zircons yielded comparably high $^{204}Pb/^{206}Pb$ and provided low signals during short periods of ionisation. These zircons, with ages between 394 and 410 Ma are therefore considered as arbitrarily reset during metamorphism. The majority of the analysed zircons provided high and constant signals with low $^{204}Pb/^{206}Pb$ and ages from 421–431 Ma. A weighted mean age of 430.5±1.6 Ma from 7 zircons matches well the corresponding isochron age of 432.6±5.5 Ma and is considered to date zircon formation during crystallization of the basic protolith magma (Fig. 6c, d).

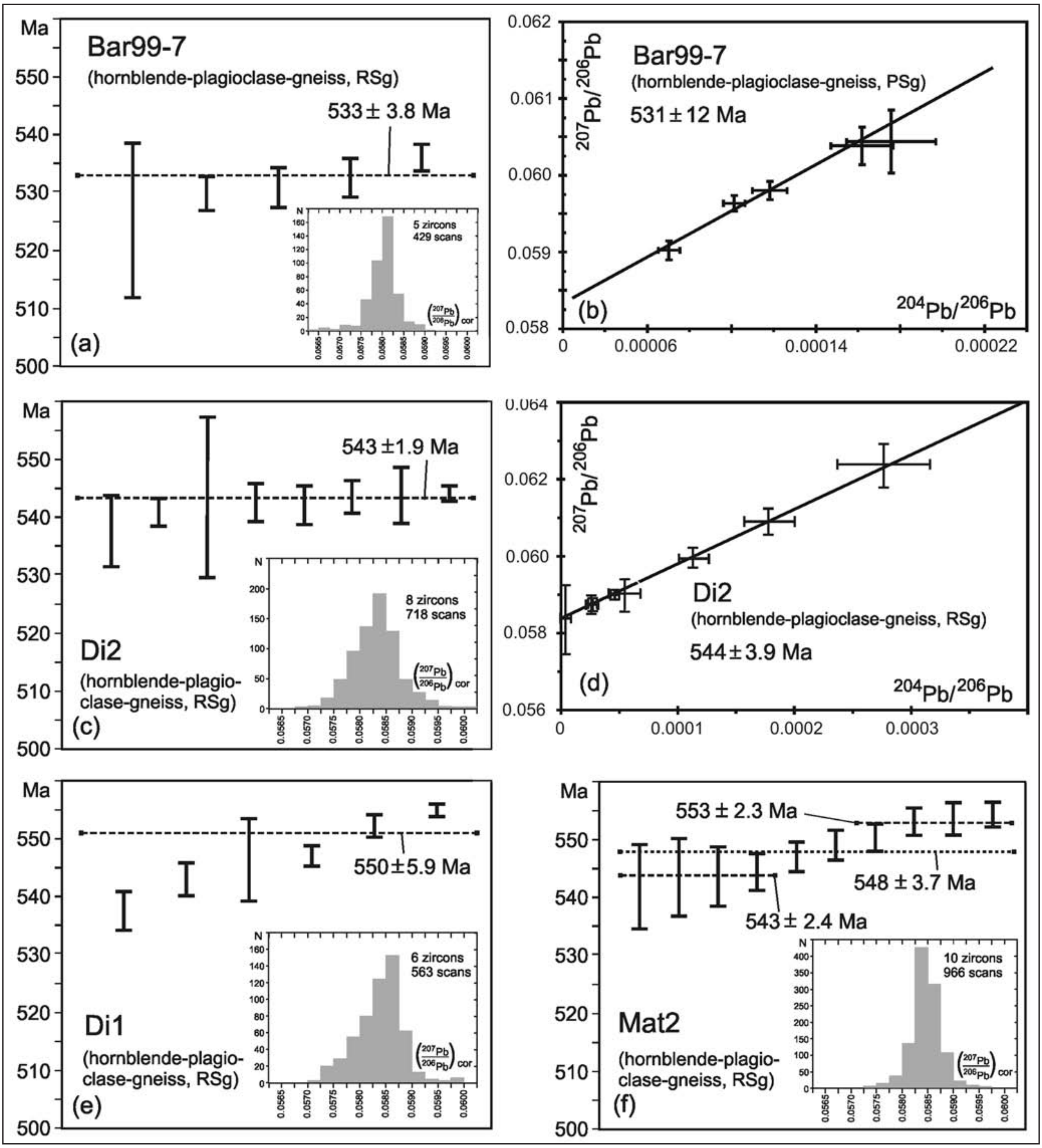
4.5. Orthogneisses

Kristeinertal (sample W5)

A fine-grained biotite orthogneiss bearing epidote/clinozoisite and sometimes amphibole and garnet is found only in the Defereggen Group. With 65 wt. % SiO_2 it belongs to the tonalitic and granodioritic Gsies/Casies- and Hochgrabe-type group of orthogneisses in the CAG discriminant field (Fig. 2c, 4a). It has been sampled in the Kristeinertal along the forest road to the Gölbnerblick-Hütte (W5). Several morphological subpopulations of zircons with the characteristics of types S21, S22, S19, S17 and

Table 3.
$^{207}Pb/^{206}Pb$, $^{204}Pb/^{206}Pb$ and corrected $^{207}Pb/^{206}Pb$ data from evaporation of single zircons from meta-porphyroids of the Thurntaler Phyllite Group.

zircon	$^{204}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb_{cor}$ 2σmean	age [Ma] 2σmean	scans
ANR5-Z2	0.0002920	0.05996	0.05595 ± 14	450.1 ± 5.6	90
ANR5-Z1	0.0005200	0.63504	0.05621 ± 9	460.7 ± 3.7	90
ANR5-Z3	0.0002500	0.05974	0.05634 ± 4	465.6 ± 1.6	90
ANR5-Z3	0.0003990	0.06196	0.05641 ± 5	468.5 ± 1.9	90
ANR5-Z6	0.0001160	0.05802	0.05656 ± 4	474.2 ± 1.7	144
ANR5-Z5	0.0003510	0.06148	0.05662 ± 9	476.8 ± 3.4	72
ANR4-ZF	0.0003730	0.06131	0.05610 ± 7	456.1 ± 2.9	90
ANR3-Z1	0.0001220	0.05791	0.05635 ± 13	466.2 ± 5.4	90
ANR3-ZN7	0.0002280	0.05969	0.05662 ± 21	476.7 ± 8.4	63
983-25-ZD	0.0000557	0.05693	0.05632 ± 20	465.1 ± 7.8	72
983-25-ZD1	0.0000627	0.05706	0.05636 ± 7	466.6 ± 2.6	90
983-25-ZA	0.0004580	0.06285	0.05645 ± 8	470.0 ± 3.0	90
983-25-ZC	0.0000594	0.05724	0.05659 ± 5	475.5 ± 2.0	90
983-25-Z5	0.0000629	0.05738	0.05668 ± 6	479.0 ± 2.2	78
THU1-1-ZB	0.0001460	0.05882	0.05692 ± 12	488.4 ± 4.9	90
THU99-1-Z4	0.0001490	0.05769	0.05574 ± 15	441.8 ± 6.1	90
THU99-1-Z2	0.0001480	0.05814	0.05620 ± 6	460.3 ± 2.1	90
THU99-1-ZC	0.0001600	0.05836	0.05626 ± 4	462.7 ± 1.7	90
THU99-1-Z1	0.0000947	0.05771	0.05655 ± 8	473.9 ± 3.0	27
THU99-1-Z3	0.0003080	0.06122	0.05698 ± 13	490.8 ± 5.0	80

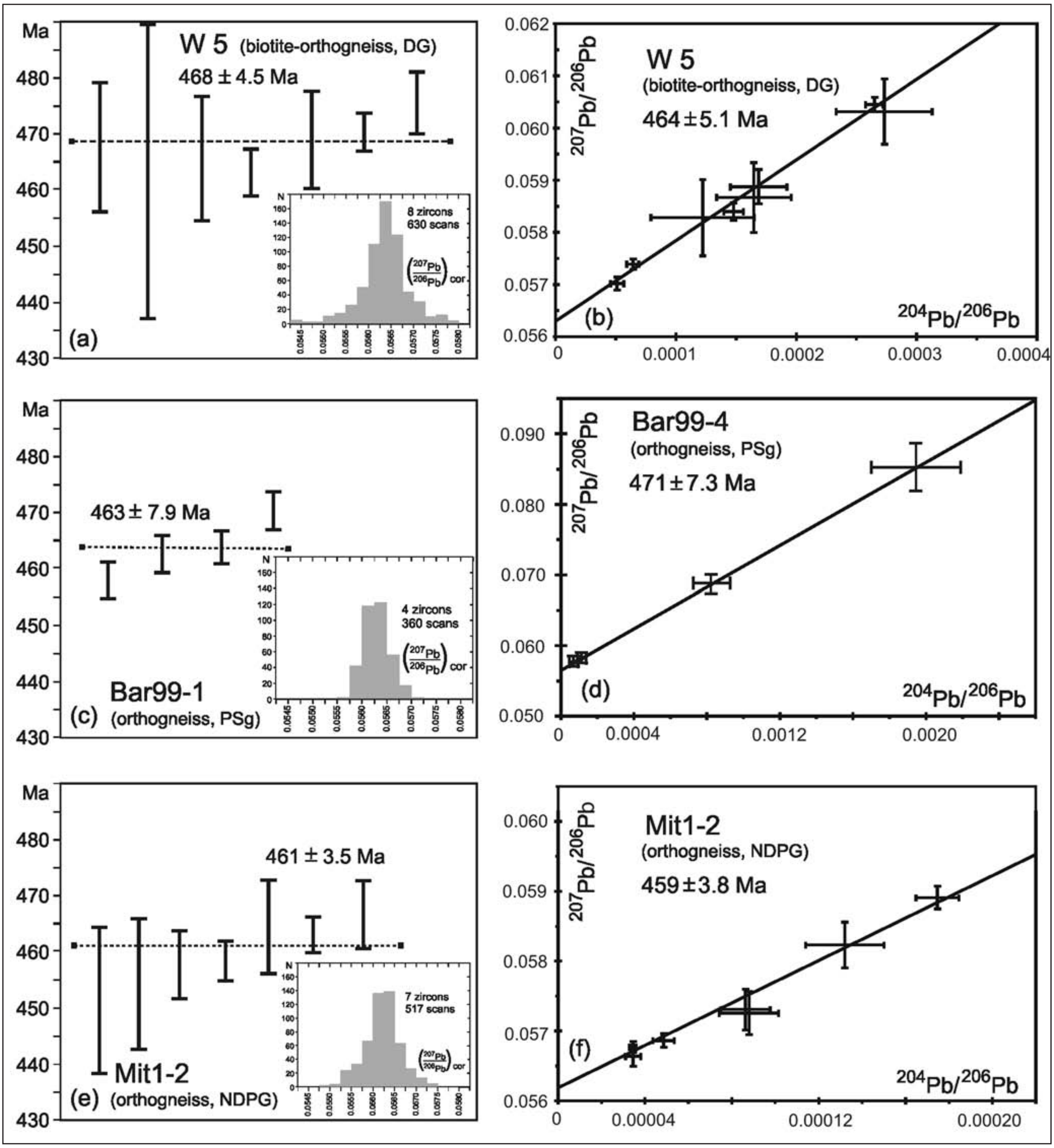


Text-Fig. 7.
a, c, e, f) Corrected $^{207}Pb/^{206}Pb$ data from evaporated zircon single grains in Austroalpine hornblende-plagioclase-gneisses (see Table 1).
Calculation of weighted mean ages and isochron ages in b and d by using the program of LUDWIG (2001).
f = Interpretation of a two-step crystallization in sample Mat2.

S11 (PUPIN, 1980) are found. The typical length to width ratios are between 3 and 4. Optical control by CL revealed

a) fine-banded oscillatory growth zoning,
b) internally homogeneous crystals and
c) zircons with distinct cores.

Especially dark ruby large zircons (250 μm) of the morphological group S11 with equivalently developed prisms (100) and (110) yielded $^{207}Pb/^{206}Pb$ ages older than 475 Ma and ranging from 490–810 Ma. They are considered to represent inherited zircons and/or zircons with inherited old cores, resulting in mixed ages. No zircons younger as 461 Ma have been analysed from this sample. The other ages range between 461 and 475 Ma and were analysed from long prismatic zircons mostly of group S21 with prisms (100) >> (110) and pyramids (101) << (211). A weighted mean age from 8 zircons of this group is 468.6±4.5 Ma and matches an isochron age of 464±5.1 Ma (Fig. 8a, b). This age of the Kristeinertal orthogneiss does not exactly coincide with the multigrain U-Pb (427 Ma, 443 Ma) and single-grain Pb-Pb data previously reported by CLIFF (1980) and KLÖTZLI (1995), but is equivalent to a single zircon age of 466±10 Ma gained from the Gsies/Casies orthogneiss



Text-Fig. 8.
a, c, e) Corrected $^{207}Pb/^{206}Pb$ data from evaporated zircon single grains in Austroalpine orthogneisses (see Table 2).
Calculation of weighted mean ages and isochron ages in b, d, f by using the program of LUDWIG (2001).

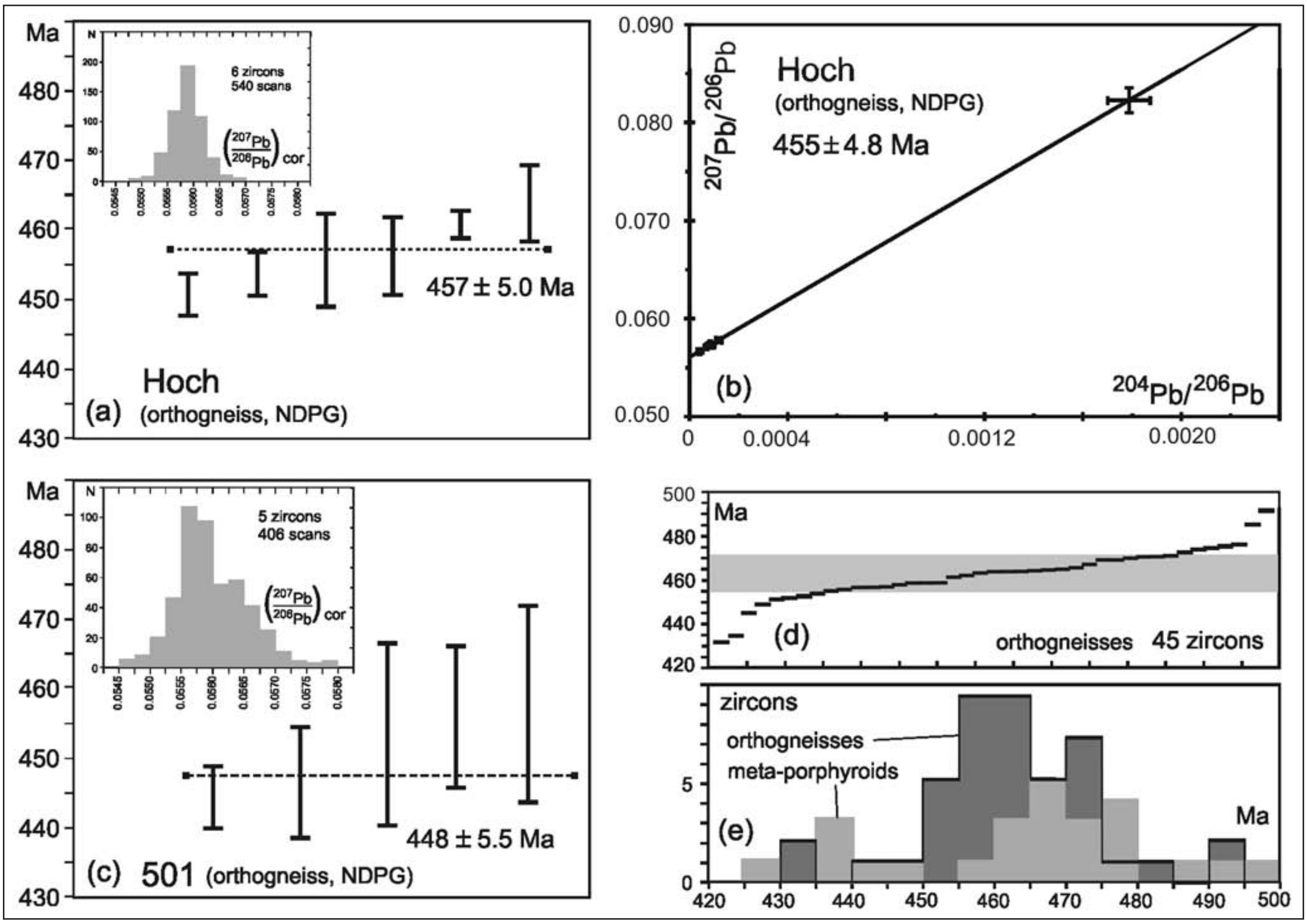
(KLÖTZLI, 1995). It is concluded that KLÖTZLI (1995) and CLIFF (1980) obtained data from Kristeinertal orthogneiss zircons which had been slightly reset during Variscan metamorphism.

Sample Bar99-4

from the Barrenlesee location in the Prijakt Subgroup is a biotite orthogneiss with extremely flattened lens-like feldspar grains and a CAG-type composition (Fig. 4a). It yielded a 471±7.3 Ma isochron age (Fig. 8d). In this specific case, the weighted mean age of 478±15 Ma is less well defined than the isochron age due to elevated common lead contents in the zircons.

Plagioclase-orthogneiss (sample Mit1-2)

To the NW of the Prägrater Törl in the Northern Defereggen/Petzeck Group occur orthogneisses with plagioclase augen in a foliated matrix of biotite and muscovite with quartz. This rock type belongs to the CAG-type granitoids and can be distinguished from the CCG-type muscovite-orthogneisses in the Rotenkogel and Prijakt Subgroups. It contains only 62 % SiO_2 and shows the highest Ti and Zr concentrations among all studied orthogneisses. There is a considerable range of zircon populations with different morphologies (Q5, Q3, S16) enclosing the length to width ratios of 1 to 3. Cores with resorbed crystal faces and oscillatory zonations discordant to the rim zonations



Text-Fig. 9.
a, c) Corrected $^{207}Pb/^{206}Pb$ data from evaporated zircon single grains in Austroalpine orthogneisses (see Table 2).
Calculation of weighted mean ages and isochron ages in b by using the program of LUDWIG (2001).
d) In a single variable plot the majority of orthogneiss zircon ages falls within the 450–470 Ma age range.
e) Histogram of single zircon ages in orthogneisses and meta-porphyroids. Each rock group displays a distribution with two peaks. The age frequency peaks in the meta-porphyroids appear as 10 million years older than in the orthogneisses.

are abundant in CL microscopy (Fig. 5g). The $^{207}Pb/^{206}Pb$ ages enclose 430–560 Ma as well as 1734 Ma, apparently irrespective of the morphological group of zircons. However, it turned out that long prismatic S1 type crystals from the 125 μm size fraction provided a restricted range of ages between 451 and 466 Ma, giving a weighted mean age of 461.0±3.5 and a fairly well defined isochron age of 459.8±3.8 Ma (Fig. 8e,f). These zircons are interpreted to date the protolith crystallization.

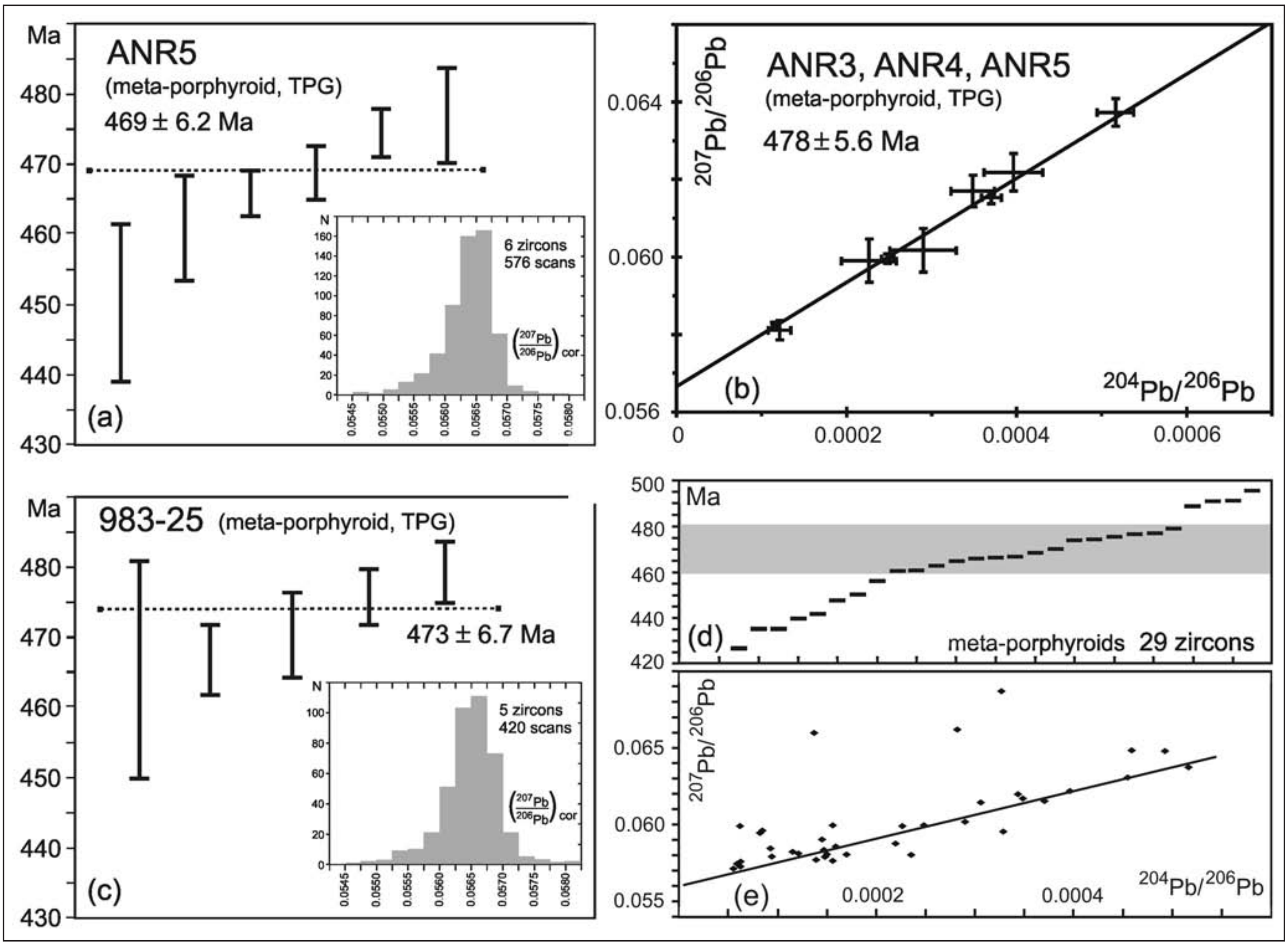
Muscovite-orthogneisses (samples 501, Hoch, Bar99-1)

Apart from the large orthogneiss bodies of Antholz/Anterselva, the muscovite-orthogneisses with cm-sized Kfeldspar augen are abundant in the Rotenkogel and Prijakt Subgroups where they form 10–50 m thick layers. They were sampled to the NE of Saiche immediately in the hanging wall of the Matreier Zone (sample 501), at the Hochstein quarry to the south of Matrei (sample Hoch) and around the Barrenle-See in the Prijakt region (sample Bar99-1). The SiO_2 contents of 73 wt. % in these samples considerably exceeds those in the tonalitic/granodioritic CAG-type orthogneiss samples W5, Mit1-2 and Bar99-4. As in the orthogneisses with lower SiO_2 contents, a considerable range of zircon morphologies and internal structures is observed. The length to width ratios range from 1 to 3 and inherited cores surrounded by rims with oscillatory zonations are abundant (Fig. 5k). Ages from various zircons in sample 501 range from 330 to 996 Ma. However, most zircons out of a distinct population of 125 μm sized long prismatic crystals (Fig. 5h) fall in the time span of 444–468 Ma (sample 501) or 450–474 Ma (sample Hoch). The weighted mean ages are 447.6±5.5 Ma in sample 501 and 457.0±5.0 Ma (an isochron age from 6 zircons is 455.4±4.8 Ma) for sample Hoch (Fig. 9a–c). The Bar99-1 sample yielded 463.7±7.9 Ma (Fig. 8c).

4.6. Meta-Porphyroids of the Thurntaler Phyllite Group

Meta-porphyroids with variable acid composition have been sampled at 1480 m along a small forest road to the NW of Anras (samples ANR3, ANR4, ANR5, ANR6, situated along a continuous outcrop); along the forest road from Strassen to Bichl and Ragglerboden at 1850 m (sample 983-25) and from various outcrops mainly around the Thurntaler summit (samples THU).

There occurs a considerable range of zircon morphological populations. As similarly has been observed from the orthogneisses, most of the zircons display inherited cores (Fig. 5l). A possible discrimination among meta-porphyroids and orthogneisses based on zircon typology has been demonstrated by MAGER (1981) and KREUTZER (1992), but is strongly hampered by the predominant occurrence of the inherited crystals. Large and short prismatic 250 μm sized zircons with length to width ratios of 1–3 (Fig. 5m), mostly with equally developed prisms (100) and (110), always yielded pre-Ordovician ages ranging

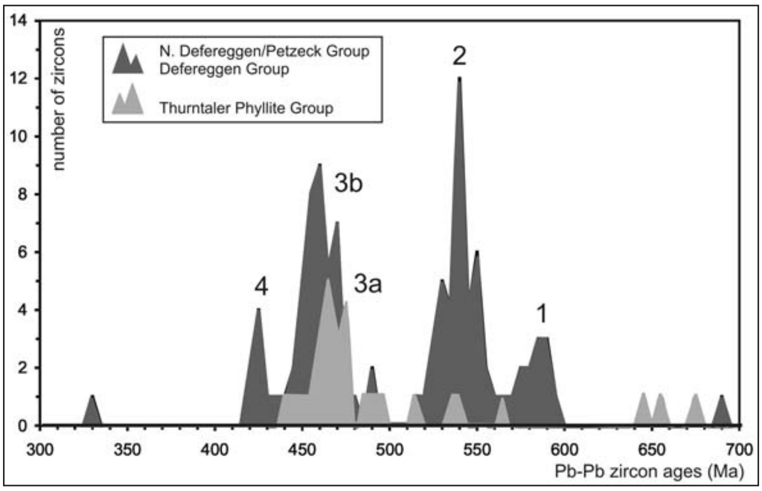


Text-Fig. 10.
a, b) Corrected $^{207}Pb/^{206}Pb$ data from evaporated zircon single grains in meta-porphyroids in the Thurntaler Phyllite Group (see Table 3).
Calculation of weighted mean ages and isochron ages in (b) by using the program of LUDWIG (2001).
d) In a single variable plot the majority of meta-porphyroid zircon ages falls within the 460–480 Ma age range.
e) Meta-porphyroid zircon data in $^{204}Pb/^{206}Pb$ – $^{207}Pb/^{206}Pb$ coordinates allows visualization of a "minimum" isochron, indicating the most suitable age of the magmatic crystallization period. Data from inherited zircons plots above the "minimum" isochron, data from zircons with resetted ages plots below.

between 515 and 1938 Ma. Such zircons are considered inherited. The evaporation dating method has been successfully applied to long prismatic zircons of the 125 μm size fraction (aspect ratio is 3–5) with predominantly developed (211) pyramids and a typology around subtype S1 (Fig. 5m). They provided younger ages ranging from 395–495 Ma, with most single zircon ages falling in the range of 460–480 Ma (Fig. 10d). The ages of <440 Ma are considered to be reset during Variscan epidote-amphibolite facies metamorphism. In detail, a weighted mean age (6 zircons) from sample ANR5 is 469±6.2 Ma (Fig. 10a). When zircon data from samples ANR3 and ANR4 nearby are additionally considered, one obtains a weighted mean age (9 zircons) of 467.7±5.1 Ma. Calculation of a corresponding isochron age yielded around 478±6 Ma and is characterized by single zircon data with elevated $^{204}Pb/^{206}Pb$ values of >0.0003 (Fig. 10b). From the 983-25 sample, a meta-porphyroid with feldspar blasts, a weighted mean age from 5 zircons is 473±6,7 Ma (Fig. 10c). Needle-like zircons with aspect ratios of >7 as described by MELI & KLÖTZLI (2001) and HUBICH & LOESCHKE (1993) from the South Alpine Comelico porphyroids have not been found in the Thurntaler meta-porphyroid heavy mineral separates, possibly due to damage during the sample preparation. However, the typology of the population 37A described and analysed by MELI & KLÖTZLI (2001) is most similar to the Ordovician zircons dated here. Concordant U-Pb ages 479±8 and 485±8 from this Comelico zircon population (MELI & KLÖTZLI, 2001) are quite similar to the data obtained from the Thurntaler meta-porphyroids.

These Ordovician single zircon evaporation ages from the meta-porphyroids do not confirm KLÖTZLI (1997) and RIZZO et al. (1998) who supposed a pre-Ordovician maximum sedimentation age of the Thurntaler Phyllite Group from single zircon data ranging around 514 and 598 Ma. The discrepancy is easily explained by single zircon age bulk statistics. More than 80 % of the zircons extracted from the meta-porphyroids yielded signatures of inherited old cores or are even homogeneous inherited zircons. Therefore, meta-porphyroid magmatic protolith crystallization ages can be only obtained by frequent analysis of single zircons within selected morphological populations.

However, the selection of zircons to estimate weighted mean and isochron ages from the orthogneiss and meta-porphyroid samples with heterogeneous morphological populations of zircons which give a wide range of ages, appears subjective. Therefore a semiquantitative and bulk statistical treatment of the data has been performed: When the zircon data from all meta-porphyroid samples are plotted in $^{204}Pb/^{206}Pb$ vs. $^{207}Pb/^{206}Pb$ coordinates, one can estimate an overall "minimum" isochron which matches the data from single samples reported above (Fig. 10e). In a single-variable plot it can be easily recognized that the majority of single zircon ages from the orthogneisses and meta-porphyroids ranges in 450–470 Ma (Fig. 9d) and in the 460–480 Ma time spans (Fig. 10d) respectively. In



Text-Fig. 11.
Landmarks of the pre-Variscan magmatic evolution in the Austroalpine basement to the south of the Tauern Window.
Number of zircons reflects the probability of ages of the magmatic crystallization events.
1 = Neoproterozoic N-MORB-type eclogitic amphibolites, extension in a backarc. 2 = Early-Cambrian arc magmatism. 3a = Ordovician calcalkaline acid volcanism in the Thurntaler Phyllite Group. 3b = Ordovician calcalkaline acid plutonism in the pre-Ordovician basement; culmination of the active margin magmatic setting. 4 = Alkaline basic magmatism in the pre-Ordovician basement and presumably in the Thurntaler Phyllite Group; passive margin magmatic setting.

detail, the orthogneiss zircons have an age distribution with two peaks at 455–460 Ma and at 470 Ma, whereas the two peaks of the meta-porphyroid zircons bulk age distribution are situated at 465 and 475 Ma (Fig. 9e). Thus it appears that the meta-porphyroid magmatism was slightly older than the orthogneiss protoliths. In both rock groups there are some zircon ages around 430 and 435 Ma. As is demonstrated for the meta-porphyroids, these analyses plot as outliers below the overall „minimum" isochron in Fig. 10e. These ages apparently have been reset during Variscan metamorphism and are not considered to date magmatic crystallization.

5. Neoproterozoic to Early-Palaeozoic Magmatic Evolution

The single zircon Pb-Pb dating of meta-magmatic rock suites in the Austroalpine basement revealed several landmarks of a pre-Variscan geodynamic evolution (Fig. 11). A pre-Neoproterozoic history is documented by inherited zircons in some hornblende-plagioclase-gneisses, orthogneisses and meta-porphyroids with ages up to 1938 Ma. Some of these ages could be mixtures of zircons with Proterozoic cores and Palaeozoic rims. However, there is observation from two orthogneisses which bear three apparently homogeneous zircons with ages ranging between 800 and 810 Ma. This points to a distinct magmatic crystallization event. The data from the inherited zircons at least indicate the participation and assimilation of Proterozoic crust during the Palaeozoic magmatism.

The formation of N-MOR-type basalts, now eclogitic amphibolites in the Prijakt Subgroup, at 590±4 Ma is yet the oldest magmatic event found in the basement. It demonstrates a pre-Neoproterozoic minimum age of the psammopelitic host rocks. From the field relations and geochemical data it is clear that no ultrabasic members are related to the N-MOR basalts. Therefore it appears likely that the rocks apparently represent no ophiolitic or ocean-floor suite, but minor and sill-like intrusions into the crust. Some geochemical signatures (Fig. 2b, 3a,b) signalize that this magmatism could be related to a backarc (SCHULZ, 1995).

The hornblende-plagioclase-gneisses within the Rotenkogel and Prijakt Subgroups show geochemical signatures of basic to intermediate volcanic arc rocks and can be clearly distinguished from the other MORB-type, N-MORB-type and WPB-type metabasite suites in the Northern Defereggen/Petzeck Group (Fig. 2a–c, 3c,d). Element concentrations and normalised variation patterns of the gneisses are typical of a magmatism in an active continental margin and driven by a subduction. Protolith ages of the presumably former gabbros and diorites have been derived from single zircon $^{207}Pb/^{206}Pb$ evaporation data and range between 533±3.8 and 550±5.9 or 553±2.3 Ma respectively. This gives evidence that the Austroalpine basement was part of an active continental margin setting during the Neoproterozoic and the Early Cambrian. A similar suite of rocks ("older orthogneisses") with slightly younger Cambrian protolith ages has been described from the Austroalpine Silvretta basement (MÜLLER et al., 1995; 1996; SCHALTEGGER et al., 1997). Both findings support the early interpretation of FRISCH et al. (1984) who considered the Austroalpine gneiss-amphibolite association as an active margin sequence. The rocks of the Neoproterozoic to Early-Cambrian arc magmatism belong to the northern parts of the Austroalpine basement and yet have not been found in the southern parts or in the phyllitic and non-metamorphic Palaeozoic sequences. In sight of the palaeogeographic models of the Early-Palaeozoic evolution in the Alps outlined in FRISCH et al. (1984), STAMPFLI (1996), VON RAUMER (1998) and VON RAUMER et al. (2002), the former subduction zone should have been situated to the north or northwest of the Austroalpine peri-Gondwanan terrane assemblage.

The next major step of magmatism was the Ordovician intrusion of granitoids into the pre-Neoproterozoic basement and the deposition of acid volcanoclastics (the later meta-porphyroids) in the Thurntaler Phyllite Group. From the Pb-Pb single zircon ages it can be concluded that the Ordovician acid magmatic event was almost contemporaneous in Early-Palaeozoic sequences and the older parts of the basement, as it has been presumed previously from lithological and geochemical similarities (SCHÖNLAUB, 1979; HEINISCH & SCHMIDT, 1982). The age data from the meta-porphyroids further indicate that speculations about a pre-Ordovician maximum possible sedimentation age in the Thurntaler Phyllite Group (RIZZO et al., 1998) should have been drawn from the dating of inherited zircons. Even when the 465–475 Ma old meta-porphyroids turned out to be slightly older than Caradoc and Ashgill, the previously presumed Ordovician maximum sedimentation age in the Thurntaler Phyllite Group (SCHÖNLAUB, 1979) and in the non-metamorphic Palaeozoic sequences is still justified.

The geochemical signatures of the Ordovician granitoids could be interpreted to indicate an evolution from continental arc granitic magma (CAG), crystallized in the Gsies/Casies-type tonalitic/granodioritic granitoids to entirely anatectic continental collision granitic magmas, crystallized in the Antholz/Anterselva-type granitoids. Both granite types can be expected in mature arcs and/or in continental collision zones. An Ordovician anatectic event at 484±6 Ma has been directly dated in the Austroalpine Ötztal basement (CHOWANETZ, 1991; KLÖTZLI-CHOWANETZ et al., 1997). Therefore the question arises, if the melting event and related acid magmatism could be the consequence of an Early-Ordovician crustal collision or amalgamation, as discussed in the compilation by VON RAUMER et al. (2002). Until now, no petrological, radiochronological and structural data from the Austroalpine basement to the south of the Tauern Window could support such a hypothesis. However, Cambrian arc magmatites are restricted to the Northern Defereggen/Petzeck Group, whereas the Ordovician acid magmatites are widespread in all lithotectonic groups. This regional distribution pattern may give an argument for an Early-Ordovician amalgamation of rock suites from different palaeogeographic or geotectonic positions.

THÖNI (1999) mentioned that a striking difference between the western Ötztal-Silvretta and the southeastern (Saualpe/Koralpe) parts of the Austroalpine basement is the abundant occurrence of Early-Palaeozoic metaigneous rocks to the west, whereas in the southeastern parts such rocks are yet unknown. When the Cambrian arc magmatism and the Ordovician acid plutonism are taken into account, the similarity of the Austroalpine basement parts to the south and to the west of the Tauern Window is strongly supported by the single zircon evaporation chronological data reported here.

The WPB-type alkaline basic magmatism is widespread in the Austroalpine basement, enclosing the Thurntaler Phyllite Group. In the less metamorphic Palaeozoic sequences of the Greywacke Zone this magmatism has been found to cover a considerable time span from the Upper Ordovician to the Silurian/Devonian (LOESCHKE & HEINISCH, 1993). The opening of the Palaeo-Tethys and a related passive continental margin evolution have been discussed as a corresponding geodynamic scenario. However, due to lacking radiochronological data, it has not yet been clear, if the widespread alkaline basic rocks in some of the pre-Ordovician parts of the Austroalpine basement were related to this passive margin Palaeozoic alkaline basic magmatism in the Greywacke Zone. The 430±1.6 Ma zircon evaporation age from a highly evolved member of the Torkogel alkaline basic suite in the Northern Defereggen/Petzeck Group confirms that these metabasites belong to this Upper Ordovician to Silurian/Devonian magmatism.

As long as the protolith ages have not been precised, the apparently coeval calcalkaline acid magmatism and the alkaline magmatism ("bimodal" magmatism) in the Austroalpine during the Palaeozoic posed problems for its geodynamic interpretation. In the light of the whole-rock geochemical and single zircon age data presented, a modified geodynamic interpretation of the magmatic evolution appears possible: Chronological and geochemical data from the hornblende-plagioclase-gneisses give witness of an Early-Cambrian magmatic arc and of an active margin magmatism in the Austroalpine basement to the south of the Tauern Window. When data from the Silvretta basement (SCHALTEGGER et al., 1997) are considered, this magmatism could have lasted throughout the Cambrian. Thus one can understand the Ordovician acid magmatism as a final stage of a precedent long lasting active margin evolution. The Ordovician „bimodal" magmatism then signals a change from the active margin to a subsequent passive margin evolution. The alkaline magmatites are related to the onset of crustal extension during initial stages of Palaeotethys rifting.

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References

BATCHELOR, R. & BOWDEN, P., 1985: Petrogenetic interpretation of granitoid rock series using multicationic parameters. – Chem. Geol., **48**, 43–55.

BEHRMANN, J.H., 1990: Zur Kinematik der Kontinentkollision in den Ostalpen. – Geotektonische Forschungen, **76**, 1–180.

BORSI, S., DEL MORO, A., SASSI, F.P., VISONA, D. & ZIRPOLI, G., 1980: On the existence of Hercynian aplites and pegmatites in the lower Aurina Valley (Ahrntal, Austrides, Eastern Alps). – N. Jb. Miner. Mh., **1980**, 501–514.

BORSI, S., DEL MORO, A., SASSI, F.P. & ZIRPOLI, G., 1973: Metamorphic evolution of the Austridic rocks to the south of the Tauern Window (Eastern Alps): radiometric and geopetrologic data. – Mem. Soc. Geol. Ital., **12**, 549–571.

BORSI, S., DEL MORO, A., SASSI, F.P., ZANFERRARI, A. & ZIRPOLI, G., 1978: New geopetrologic and radiometric data on the Alpine history of the Austridic continental margin south of the Tauern Window. – Mem. Ist. Geol. Min. Univ. Padova, **32**, 1–17.

BOYNTON, W.V., 1984: Geochemistry of the rare earth elements: meteorite studies. – In: HENDERSON, P. (ed.): Rare earth element geochemistry, 63–114, Amsterdam (Elsevier).

BRACK, W., 1977: Geochronologische Untersuchungen an Gesteinen des Altkristallins in der Schobergruppe, Österreich. – Dissertation Ludwig-Maximilians-Universität München, (unpubl.).

BÜCKSTEEG, A., 1999: Zur Geologie des Kristallins der Schobergruppe (Osttirol/Österreich). – Aachener Geowiss. Beitr., **33**, 206 pp.

CHAPPELL, B.W. & WHITE, A.J.R., 1974: Two contrasting granite types. – Pacific Geol., **8**, 173–174, Tokyo.

CHOWANETZ, E., 1991: Strukturelle und geochronologische Argumente für eine altpaläozoische Anatexis im Winnebachmigmatit (Ötztal/Tirol, Österreich). – Mitt. Ges. Geol. Bergbaustud. Österr., **37**, 15–35.

CLIFF, R.A., 1980: U-Pb isotopic evidence from zircons for lower Palaeozoic tectonic activity in the Austroalpine nappe of the Eastern Alps. – Contrib. Mineral. Petrol., **71**, 283–288.

CONELLY, J.N., 2000: Degree of preservation of igneous zonation in zircon as a signpost for concordancy in U/Pb geochronolgy. – Chem. Geol., **172**, 25–39.

DE LA ROCHE, H., LETERRIER, J., GRAND, C.P. & MARCHAL, M., 1980: A classification of volcanic and plutonic rocks using R1-R2-diagrams and major element analyses - Its relationships with current nomenclature. – Chem. Geol., **29**, 183–210.

DINKELMEYER, R., 1998: Petrographische und strukturgeologische Untersuchungen, sowie Geochemie einiger Amphibolite am Südrand des Tauernfensters bei Matrei (Osttirol, Österreich). – Diplomarbeit Institut für Geologie und Mineralogie der Universität Erlangen-Nürnberg, 119 pp, Erlangen (unpubl.).

EICHHORN, R., SCHÄRER, U. & HÖLL, R., 1995: Age and evolution of the scheelite-hosting rocks in the Felbertal deposit (Eastern Alps): U-Pb geochronology of zircon and titanite. – Contrib. Mineral. Petrol., **119**, 377–386.

FRANK, W., KLEIN, W., NOWY, W. & SCHARBERT, S., 1976: Die Datierung geologischer Ereignisse im Altkristallin der Gleinalpe (Steiermark) mit der Rb/Sr-Methode. – Tschermaks Mineral. Petrogr. Mitt., **23**, 191–203.

FRISCH, W., NEUBAUER, F. & SATIR, M., 1984: Concepts of the evolution of the Austroalpine basement complex (Eastern Alps) during the Caledonian-Variscan cycle. – Geol. Rundsch., **73**, 47–68.

FRISCH, W., VAVRA, G. & WINKLER, M., 1993: Evolution of the Pennic Basement of the Eastern Alps. – In: VON RAUMER, J.F. & NEUBAUER, F. (eds.): The pre-Mesozoic Geology of the Alps, 349–360, Heidelberg (Springer Verlag).

GODIZART, G., 1989: Gefüge, retrograde Metamorphose und Geochemie der Amphibolite im ostalpinen Altkristallin südlich des westlichen Tauernfensters (Südtirol, Italien). – Dissertation Universität Erlangen-Nürnberg, 156 pp, Erlangen. (unpubl.)

GÖTZE, J., 2000: Cathodoluminescence microscopy and spectroscopy in applied mineralogy. – Freiberger Forschungshefte, C485, 128pp.

GUHL, M. & TROLL, G., 1987: Die Permotrias von Kalkstein im Altkristallin der südlichen Deferegger Alpen (Österreich). – Jb. Geol. B.-A., **130**, 37–60.

HAMMERSCHMIDT, K., 1981: Isotopengeologische Untersuchungen am Augengneis vom Typ Campo Tures bei Rain in Taufers, Südtirol. – Mem. Ist. Geol. Min. Univ. Padova, **34**, 273–300.

HANCHAR, J.M. & MILLER, C.F., 1993: Zircon zonation patterns as revealed by cathodoluminescence and backscattered electron images: implications for interpretation of complex crustal histories. – Chem. Geol., **110**, 1–13.

HEINISCH, H., 1981: Zum ordovizischen „Porphyroid"-Vulkanismus der Ost- und Südalpen. – Jahrb. Geol. Bundesanst., **124**, 1–109.

HEINISCH, H. & SCHMIDT, K., 1976: Zur kaledonischen Orogenese in den Ostalpen. – Geol. Rdsch., **65**, 459–482.

HEINISCH, H. & SCHMIDT, K., 1982: Zur Genese der Augengneise im Altkristallin der Ostalpen. – N. Jb. Geol. Paläont. Mh., **1982**, 211–239.

HEINISCH, H. & SCHMIDT, K., 1984: Zur Geologie des Thurntaler Quarzphyllits und des Altkristallins südlich des Tauernfensters (Ostalpen, Südtirol). – Geol. Rdsch. **73**, 113–129.

HUBICH, D. & LOESCHKE, J., 1993: Der Comelico-Porphyroid der westlichen Karnischen Alpen (Österreich/Italien): Stratigraphie, Petrographie, Geochemie und Zirkonmorphologie. – Jb. Geol. B.-A., **136**, 351–374.

KARABINOS, P., 1997: An evaluation of the single-grain zircon evaporation method in highly discordant samples. – Geochim. Cosmochim. Acta, **61**, 2467–2474.

KLÖTZLI, U.S., 1995: Geochronologische Untersuchungen an Metagranitoiden im ostalpinen Altkristallin W und S des Tauernfensters. – Kurzfassungen Arbeitstagung Lienz der Österreichischen Geologischen Bundesanstalt, 95–97.

KLÖTZLI, U.S., 1997: Zircon evaporation TIMS: Method and procedures. – Analyst, **122**, 1239–1248.

KLÖTZLI, U.S., 1999a: Resolving complex geological histories by zircon dating: a discussion of case studies from the Bohemian Massif and the Eastern Alps. – Mitt. Österr. Geol. Ges., **90**, 31–41.

KLÖTZLI, U.S., 1999b: Th/U zonation in zircon derived from evaporation analysis: a model and its implications. – Chem. Geol., **158**, 325–333.

KLÖTZLI-CHOWANETZ, E., KLÖTZLI, U.S. & KOLLER, F., 1997: Lower Ordovician migmatisation in the Ötztal crystalline basement (Eastern Alps, Austria): linking U-Pb and Pb-Pb dating with zircon morphology. – Schweiz. Mineral. Petrogr. Mitt., **77**, 315–324.

KOBER, B., 1986: Whole-grain evaporation for $^{207}Pb/^{206}Pb$ age investigations on single zircons using a double-filament thermal ion source. – Contrib. Mineral. Petrol., **93**, 482–490.

KOBER, B., 1987: Single-zircon evaporation combined with Pb^{+} emitter bedding for $^{207}Pb/^{206}Pb$-age investigations using thermal ion mass spectrometry, and implications to zirconology. – Contrib. Mineral. Petrol., **96**, 63–71.

KREUTZER, S., 1992: Zur Geologie des östlichen Thurntaler Quarzphyllitkomplexes und seiner tektonischen Einbindung in das Ostalpin der südöstlichen Deferegger Alpen, Osttirol. – Dissertation Rheinisch-Westfälische Technische Hochschule Aachen, 166 pp., Aachen.

KRÖNER, A., WILLNER, A., HEGNER, E., FRISCHBUTTER, A., HOFMANN, J. & BERGNER, R., 1995: Latest Precambrian (Cadomian) zircon ages, Nd isotopic systematics and P-T evolution of granitoid orthogneisses of the Erzgebirge, Saxony and Czech Republic. – Geol. Rundsch., **84**, 437–456.

LOESCHKE, J., 1989: Lower Palaeozoic volcanism of the Eastern Alps and its geodynamic implications. – Geol. Rundsch., **78**, 566–616.

LOESCHKE, J. & HEINISCH, H., 1993: Palaeozoic volcanism of the Eastern Alps and its palaeotectonic significance. – In: VON RAUMER, J. F. & NEUBAUER, F. (eds.): The pre-Mesozoic Geology of the Alps, 441–455, Heidelberg (Springer Verlag).

LUDWIG, K.R., 2001: Users manual for Isoplot/Ex rev. 2.49. A geochronological toolkit for Microsoft Excel. – Berkeley Geochronology Center Spec. Publ., 1a, 55 pp.

MAGER, D., 1981: Vergleichende morphologische Untersuchungen an Zirkonen des altkristallinen Augengneises von Sand in Taufers (Südtirol) und einiger benachbarter Gesteine. – N. Jb. Miner. Mh., **1981**/9, 385–397.

MAGGETTI, M., GALETTI, G. & STOSCH, H.G., 1990: Geochemische Argumente zur Genese der "Älteren Orthogneise" der Silvretta. – Schweiz. Mineral. Petrogr. Mitt., **70**, 103–107.

MANIAR, P.D. & PICCOLI, P.M., 1989: Tectonic discrimination of granitoids. – Geol. Soc. Amer. Bull., **101**, 635–643.

MAZZOLI, C. & SASSI, F.P., 1992: New chemical data on the Upper Ordovician acidic plutonism in the Austrides of the Eastern Alps. – In: CARMIGNANI, L. & SASSI, F.P. (ed.). Contributions to the geology of Italy with special regard to the Palaeozoic basements. IGCP No. 276, Newsletter Vol. **5,** 263–277 (Siena).

MELI, S. & KLÖTZLI, U.S., 2001: Evidence for Lower Palaeozoic magmatism in the Eastern Southalpine basement: zircon geochronology from Comelico porphyroids. – Schweiz. Mineral. Petrogr. Mitt., **81**, 147–157.

MÜLLER, B., KLÖTZLI, U.S. & FLISCH, M., 1995: U-Pb and Pb-Pb dating of the older orthogneiss suite in the Silvretta nappe, eastern Alps: Cadomian magmatism in the upper Austro-Alpine realm. – Geol. Rundsch., **84**, 457–465.

MÜLLER, B., KLÖTZLI, U.S., SCHALTEGGER, U. & FLISCH, M., 1996: Early Cambrian oceanic plagiogranite in the Silvretta Nappe, eastern Alps: geochemical, zircon U-Pb and Rb-Sr data from garnet-hornblende-plagioclase gneisses. – Geol. Rundsch., **85**, 822–831.

NEUBAUER, F., KLÖTZLI, U.S. & POSCHESCHNIK, P., 2001: Cadomian magmatism in the Alps recorded in Late Ordovician sandstones of the Carnic Alps: preliminary results from zircon Pb/Pb evaporation dating. – Schweiz. Mineral. Petrogr. Mitt., **81**, 175–179.

NEUBAUER, F. & SASSI, F.P., 1993: The Austroalpine quartzphyllites and related Palaeozoic Formations. – In: VON RAUMER, J.F. & NEUBAUER, F. (eds.): The pre-Mesozoic Geology of the Alps, 423–439, Heidelberg (Springer Verlag).

PEARCE, J.A., 1982: Trace element caracteristics of lavas from destructive plate boundaries. – In: THORPE, R.S. (ed.): Andesites, 525–548, Wiley (Chichester).

PEARCE, J.A., 1983: Role of the sub-continental lithosphere in magma genesis at aktive continental margins. – In: HAWKESWORTH, C.J. & NORRY, M.J. (eds.): Continental basalts and mantel xenoliths, 230-249, Nantwich (Shiva).

PEARCE, J.A. & NORRY, M.J., 1979: Petrogenetic implications of Ti, Zr, Y and Nb variations in volcanic rocks. – Contrib. Mineral. Petrol., **69**, 33–47.

PECCERILLO, A., POLI, G., SASSI, F.P., ZIRPOLI, G. & MEZZASCA, G., 1979: New data on the Upper Ordovician acid plutonism in the Eastern Alps. – N. Jb. Mineral. Abh., **137**, 162–183.

PFEIFER, H.-R., COLOMBI, A. & GANGUIN, J., 1989: Zermatt-Saas and Antrona zone: A petrographic and geochemical comparison of polymetamorphic ophiolithes of the West-Central Alps. – Schweiz. Mineral. Petrogr. Mitt., **69**, 217–236.

POLLER, U., NÄGLER, Th., LIEBETRAU, V. & GALETTI, G., 1997: Geochemical and Sm-Nd characteristics of a polymetamorphic S-type granitoid: The Mönchalpgneiss – Silvretta nappe/Switzerland. – Eur. J. Min., **9**, 411–422.

PUPIN, J.P., 1980: Zircon and granite petrology. – Contrib. Mineral. Petrol., **73**, 207–220.

PURTSCHELLER, F., HAAS, R., HOINKES, G., MOGESSIE, A., TESSADRI, R. & VELTMANN, C., 1987: Eoalpine metamorphism in the crystalline basement. – In: FLÜGEL, H.W. & FAUPL, P. (eds.): Geodynamics of the Eastern Alps, 185–190, Wien (Franz Deuticke Verlag).

RIZZO, G., KLÖTZLI, U.S. & SPIESS, R., 1998: Single zircon Pb/Pb age constraints on maximum sedimentation ages for quarzphyllite complexes from the Eastern and Southern Alps. – Mitt. Österr. Miner. Ges., 143, 372–373.

ROLLINSON, H.H., 1993: Using Geochemical Data: Evaluation, Presentation, Interpretation. – 378 pp, London (Longman Scientific and Technical).

SASSI, F.P., CAVAZZINI, G., VISONA, D. & DEL MORO, A., 1985: Radiometric geochronology in the Eastern Alps: results and problems. – Rend. Soc. Ital. Min. Petr., **40**, 187–224.

SATIR, M., 1975: Die Entwicklungsgeschichte der westlichen Hohen Tauern und der südlichen Ötztalmasse auf Grund radiometrischer Altersbestimmungen. – Mem. Ist. Geol. Mineral. Univ. Padova, **30**, 1–84.

SATIR, M., 1976: Rb-Sr- und K-Ar-Altersbestimmungen an Gesteinen und Mineralien des südlichen Ötztalkristallins und der westlichen Hohen Tauern. – Geol. Rundsch., **65**, 394–410.

SCHALTEGGER, U., NÄGLER, Th.F., CORFU, F., MAGGETTI, M., GALETTI, G. & STOSCH, H.G., 1997: A Cambrian island arc in the Silvretta nappe: constraints from geochemistry and geochronology study. – Schweiz. Mineral. Petrogr. Mitt., **77**, 337–350.

SCHMIDEGG, O., 1936: Steilachsige Tektonik und Schlingenbau auf der Südseite der Tiroler Zentralalpen. – Jb. Geol. B.-A., **86**, 115–149.

SCHÖNHOFER, R., 1999: Das ostalpine Altkristallin der westlichen Lasörlinggruppe (Osttirol, Österreich): Kartierung, Stoffbestand und tektonometamorphe Entwicklung. – Erlanger geol. Abh., **130**, 128 pp.

SCHÖNLAUB, H.P., 1979: Das Paläozoikum in Österreich. – Abh. Geol. B.-A., **33**, 1–124.

SCHÖNLAUB, H.P., 1993: Stratigraphy, biogeography and climatic relationships of the Alpine Palaeozoic. – In: VON RAUMER, J.F. & NEUBAUER, F. (eds.).: Pre-Mesozoic Geology in the Alps, 65–92, Heidelberg (Springer-Verlag).

SCHULZ, B., 1989: Jungalpidische Gefügeentwicklung entlang der Defereggen-Antholz-Vals-Linie, Osttirol, Österreich. – Jb. Geol. B.-A., **132**, 775–789.

SCHULZ, B., 1991: Deformation und Metamorphose im Thurntaler Komplex (Ostalpen). – Jb. Geol. B.-A., **134**, 369–391.

SCHULZ, B., 1993: Mineral chemistry, geothermobarometry and pre-Alpine high-pressure metamorphism of eclogitic amphibolites and mica schists from the Schobergruppe, Austroalpine basement, Eastern Alps. – Mineralogical Magazine, **57**, 189–202.

SCHULZ, B., 1995: Geochemistry and REE magmatic fractionation patterns in the Prijakt amphibolitized eclogites of the Schobergruppe, Austroalpine basement (Eastern Alps). – Schweiz. Mineral. Petrogr. Mitt., **75**, 225–239.

SCHULZ, B., 1997: Pre-Alpine tectonometamorphic evolution in the Austroalpine basement to the south of the central Tauern Window. – Schweiz. Mineral. Petrogr. Mitt., **77**, 281–297.

SCHULZ, B., SIEGESMUND, S., STEENKEN, A., SCHÖNHOFER, R. & HEINRICHS, T., 2001: Geologie des ostalpinen Kristallins südlich des Tauernfensters zwischen Virgental und Pustertal. – Z. dt. geol. Ges., **152**, 261–307.

SCHULZ, B., NOLLAU, G., HEINISCH, H. & GODIZART, G., 1993: Austro-Alpine basement complex to the south of the Tauern Window. – In: VON RAUMER, J.F. & NEUBAUER, F. (eds.). Pre-Mesozoic Geology in the Alps, 493–512, Heidelberg (Springer-Verlag).

SCHUSTER, R., SCHARBERT, S., ABART, R. & FRANK, W., 2001: Permo-Triassic extension and related HT/LP metamorphism in the Austroalpine-Southalpine realm. – Mitt. Ges. Geol. Bergbaustud. Österr., **45**, 111–141.

SENARCLENS-GRANCY, W., 1964: Zur Grundgebirgs- und Quartärgeologie der Deferegger Alpen und ihrer Umgebung. – Z. dt. geol. Ges., **116**, 502–511.

SHERVAIS, J.W., 1982: Ti-V plots and the petrogenesis of modern and ophiolitic lavas. – Earth Planet. Sci. Lett., **59**, 101–118.

SÖLLNER, F. & HANSEN, B., 1987: „Panafrikanisches“ und „kaledonisches“ Ereignis im Ötztal-Kristallin der Ostalpen: Rb-Sr- und U-Pb-Altersbestimmungen an Migmatiten und Metamorphiten. – Jb. Geol. B.-A., **130**, 529–569.

SÖLLNER, F., HÖLL, R. & MILLER, H., 1991: U-Pb-Systematik der Zirkone in Meta-Vulkaniten („Porphyroiden“) aus der Nördlichen Grauwackenzone und dem Tauernfenster (Ostalpen, Österreich). – Z. dt. geol. Ges., **142**, 285–299.

STACEY, J.S. & KRAMERS, J.D., 1975: Approximation of terrestrial lead isotope evolution by a two-stage model. – Earth. Planet. Sci. Letters, **26**, 207–221.

STAMPFLI, G., 1996: The intra-Alpine terrain: a palaeotethyan remnant in the Alpine Variscides. – Eclogae geol. Helv., **89**, 12–42.

STEENKEN, A. & SIEGESMUND, S., 2000: Evidence for an Alkaline Basaltic Volcanism at the Northern Margin of Gondwana within the Austroalpine Basement Complex of the Eastern Alps (Austrian/Italian Border). – Jb. Geol. B.-A., **142**, 235–247.

THIÉBLEMONT, D., CHÉVREMENT, P., CASTAING, C., TRIBOULET, C. & FEYBESSE, J.-L., 1994: La discrimination géotectonique des roches magmatiques basiques par les éléments traces. Réévaluation d´après une base de données et application à la chaîne panafricaine du Togo. – Geodinamica Acta, **7**/3, 139–157.

THÖNI, M., 1999: A review of geochronological data from the Eastern Alps. – Schweiz. Mineral. Petrogr. Mitt., **79**, 209–230.

TICHOMIROWA, M., BERGER, H.-J., KOCH, E.A., BELYATSKI, B.V., GÖTZE, J., KEMPE, U., NASDALA, L. & SCHALTEGGER, U., 2001: Zircon ages of high-grade gneisses in the Eastern Erzgebirge (Central European Variscides) – constraints on origin of the rocks and Precambrian to Ordovician magmatic events in the Variscan foldbelt. – Lithos, **56**, 303–332.

TROLL, G., 1978: The „Altkristallin“ of Eastern Tyrol between Tauern Window and Periadriatic Lineament. – In: CLOSS, H., ROEDER, D. & SCHMIDT, K. (eds.): Alps, Apennines, Hellenides. Inter-Union Commission on Geodynamics Scientific Report No. **38**, 149–154, Stuttgart (Schweizerbart).

TROLL, G., FORST, R., SÖLLNER, F., BRACK, W., KOHLER, H. & MÜLLER-SOHNIUS, D., 1976: Über Bau, Alter und Metamorphose des Altkristallins der Schobergruppe, Osttirol. – Geol. Rundsch., **65**, 483–511.

TROLL, G. & HÖLZL, E., 1974: Zum Gesteinsaufbau des Altkristallins der zentralen Schobergruppe, Osttirol. – Jb. Geol. B.-A., **117**, 1–16.

VAVRA, G., 1994: Systematics of internal zircon morphology in major Variscan granitoid types. – Contrib. Mineral. Petrol., **117**, 331–344.

VON QUADT, A., 1992: U-Pb zircon and Sm-Nd geochronology of mafic and ultramafic rocks from the Central part of the Tauern Window (eastern Alps). – Contrib. Mineral. Petrol., **110**, 57–67.

VON QUADT, A., GÜNTHER, D., FRISCHKNECHT, R., ZIMMERMANN, R. & FRANZ, G., 1997: The evolution of pre-Variscan eclogites of the Tauern Window (Eastern Alps): A Sm/Nd-, conventional and Laser ICP-MS zircon U-Pb study. – Schweiz. Mineral. Petrogr. Mitt., **77**, 265–279.

VON RAUMER, J.F., 1998: The Palaeozoic evolution in the Alps: from Gondwana to Pangea. – Geol. Rundsch., **87**, 407–435.

VON RAUMER, J.F., STAMPFLI, G.M., BOREL, G. & BUSSY, F., 2002: Organization of pre-Variscan basement areas at the north-Gondwanan margin. – Geol. Rundsch., **91**, 35–52.

WIEDENBECK, M., ALLE, P., CORFU, F., GRIFFIN, W.L., MEIER, M., OBERLI, F., VON QUADT, A. & SPIEGEL, W., 1995: Three natural standards for U-Th-Pb, Lu-Hf, trace element and REE analysis. – Geostand. Newsl., **19**, 1–23.

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