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, 1997

Lower Ordovician migmatisation in the Ötztal crystalline basement (Eastern Alps, Austria): linking U–Pb and Pb–Pb dating with zircon morphology

by *Eva Klötzli-Chowanetz*[1], *Urs Klötzli*[2] and *Friedrich Koller*[1]

Abstract

Partial anatexis of bio-plag-paragneisses is known from several sites within the Ötztal crystalline complex, a polymetamorphic basement unit of the Eastern Alps in Austria. One of these migmatite areas, the "Winnebach"-migmatite, has been investigated by single zircon Pb–Pb evaporation and conventional U–Pb zircon analysis in order to establish the time of the migmatisation. To be able to distinguish the anatectic event from other pre-Variscan metamorphic events, the zircon populations of the migmatite were compared to those of the adjacent paragneisses. Except for one zircon type, all populations exhibit polyphase crystal growth and do not show any specific mode of occurrence. Measured by single grain evaporation these zircon populations document three metamorphic events with mean $^{207}Pb/^{206}Pb$ ages of 484 ± 6 Ma, ~ 560 Ma, and ~ 635 Ma. However, since these ages are found both within the migmatite and the paragneiss, none of them can be directly assigned to the migmatisation.

One population of spheroidal, clear and colourless specimens is found to be characteristic for the migmatite only. These anatectically grown zircons yield a concordant U–Pb age of 490 ± 9 Ma, thus proving the Early Ordovician event to have caused the anatexis.

The minimum age of some of the inherited zircon cores can be established around 2440 Ma using both methods, thus providing evidence for the assimilation of zircons derived from earliest Proterozoic and/or Archaean sources.

Keywords: U–Pb dating, Pb–Pb evaporation, zircon typology, anatexis, Lower Ordovician, Ötztal crystalline complex, Austroalpine.

Introduction

Isotopic dating in polymetamorphic terranes is a challenge regarding the selection of the most appropriate geochronological method. Since conventional U–Pb zircon analysis has to deal with multistage Pb-loss and the complex zircon inheritance common in metasedimentary series, single zircon Pb–Pb evaporation dating is one of the most promising tools and an alternative to SIMS and laser ablation techniques to distinguish between different protoliths and steps of metamorphic evolution. In the case of small grain size (< 50 μm) and low U and Pb content in zircons the evaporation method has to be supplemented with conventional U–Pb analysis. In any case, a meticulous zircon typology study is required.

A combination of zircon typology, single zircon evaporation Pb–Pb and conventional U–Pb zircon study was used to establish age constraints for an anatectic event having occurred within an already metamorphosed basement prior to at least two further metamorphic overprints. At the same time, information was expected on the premigmatitic evolution of the paragneiss series and their different source materials.

Geological setting

The Ötztal crystalline complex (ÖCC) forms a polymetamorphic basement nappe of the Austroalpine (Fig. 1) in western Austria. The first absolute age determinations on rocks of the ÖCC

[1] Institut für Petrologie, Universität Wien, Althanstrasse 14, A-1090 Wien, Austria (corresponding author).
[2] Labor für Geochronologie, Universität Wien, Althanstrasse 14, A-1090 Wien, Austria.
E-Mail: urs.kloetzli@univie.ac.at.

were made by means of Rb–Sr whole rock and mica analyses, defining the age of the two youngest metamorphic episodes: The Alpine overprint increases from lowermost greenschist facies in the NW of the ÖCC to amphibolite facies in the SE, where it yields mica cooling ages between 90–70 Ma (SCHMIDT et al., 1967; THÖNI, 1981; HOINKES et al., 1991). The Variscan orogenic cycle (370–320 Ma, THÖNI, 1981) is thought to have reached medium to high grade conditions (about 650 °C in the sillimanite zone, HOINKES and THÖNI, 1993). In the central ÖCC a subduction event with eclogite formation at 27 kb and 730 °C has been established between 360 and 350 Ma by recent Sm–Nd data (MILLER and THÖNI, 1995). Ordovician magmatism in the central (SCHMIDT et al., 1967) and western ÖCC (BERNHARD et al., 1996) is dated between 480–490 Ma. No overall P-T estimates have been published. The eclogite precursors evolved in an oceanic rift between 530 to 520 Ma (MILLER and THÖNI, 1995).

In the central ÖCC a high-grade metamorphic event locally lead to in-situ anatexis within the biotite-plagioclase-paragneisses (HOINKES et al., 1972). The "Winnebach" migmatite is built up by granodioritic neosome (Q, Plag, Mu, Bio, minor amounts of Kfsp and Sill) and remnants of schollen. Anatectic temperature and pressure parameters were estimated between 660–685 °C at ≥ 4 kb by HOINKES (1973). Because of the uncertain field relations, the anatexis was first attributed to the Variscan cycle (HOINKES et al., 1972), but Rb–Sr white mica analysis from the central part of the migmatite gives a minimum cooling age of 461 ± 4 Ma (CHOWANETZ, 1991). As this central

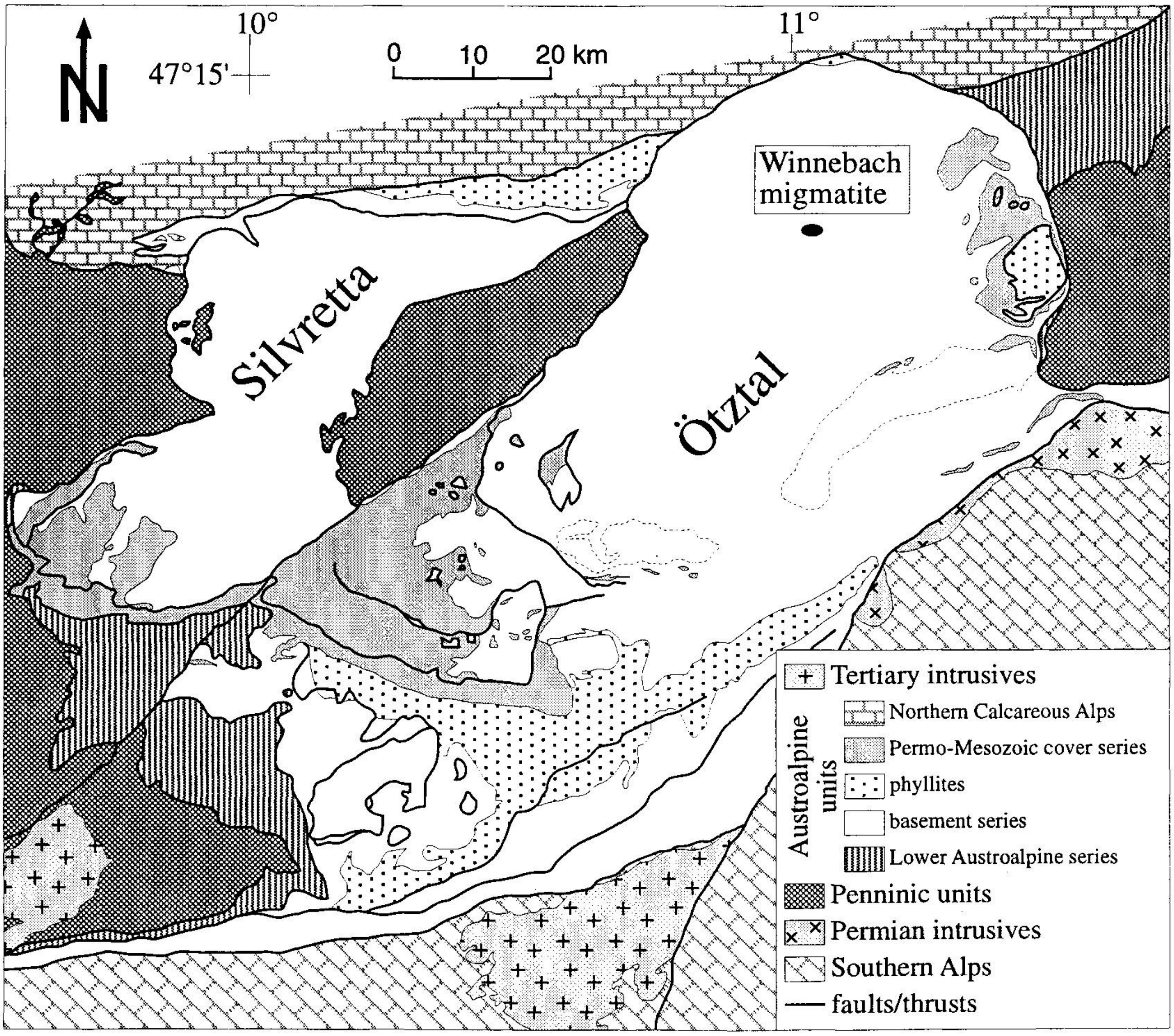
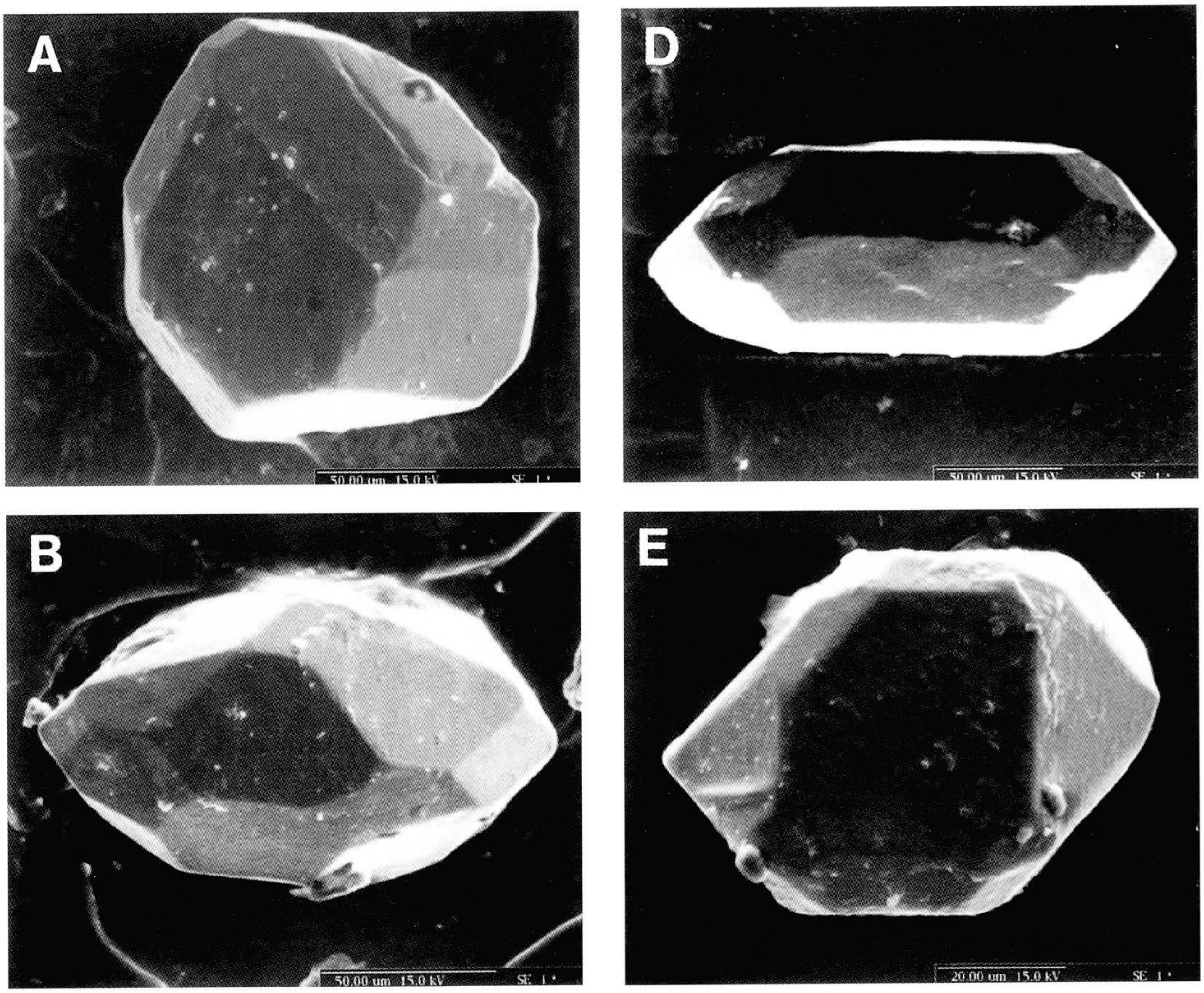


Fig. 1 Tectonic sketch map of the Austroalpine Ötztal crystalline basement, western Austria.

part does not show any post-anatectic structural overprint, this age is thought to represent cooling below ~ 450 °C (blocking conditions of white mica) directly after the migmatisation. SÖLLNER and HANSEN (1987) report conventional U–Pb zircon investigations pointing to a complex multi-stage Pb-loss with all data points plotting below a postulated "pan-African" discordia (lower intercept at 670 Ma and upper intercept at 2275 Ma). This assumed lower intercept age of 670 Ma is believed by SÖLLNER and HANSEN to represent the age of the anatexis. Thus, no unambiguous age



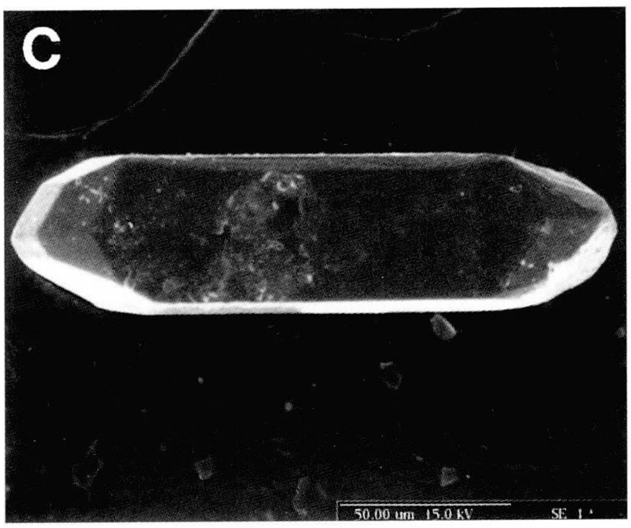


Fig. 2 SE images of zircons from the Winnebach migmatite. (A) Population A: clear, colourless, inclusion free, polyfaced zircons with spheroidal shape. This growth type is typical for highest metamorphic temperature conditions / anatectic melting and has only developed in the migmatite-neosome. (B) Population B: clear, colourless, very short prismatic, clustering around S 13. (C) Population C: clear, colourless to slightly pink, L 2. (D) Population D: clear, colourless to slightly pink, clustering around S 7. (E) Population E: clear to turbid, slightly pink to brownish, S 25.
The surrounding paragneisses contain the same zircon populations, except for the spheroidal population A.

Tab. 1 Single zircon evaporation Pb–Pb data, Winnebach migmatite (X_m) and adjacent paragneiss (X_p).

zircon type (*)	description		temp. steps	evaporation temp. range (± 10 °C)	^{207}Pb–^{206}Pb age Ma ± 2 σ (#)
C_{1m}	L 3	short prismatic, pink, inclusions	7	1370–1490	2443 ± 3 (1)
D_{1p}	S 7	short prismatic, pink	5	1370–1450	551 ± 4 (3)
D_{2p}	S 7	long prismatic, colourless	3	1380–1420	2434 ± 160 (1)
D_{3p}	S 7	short prismatic, pink	10	1375–1555	480 ± 6 (2) 561 ± 5 (1) 632 ± 4 (1) 2355 ± 85 (1)
D_{4p}	S 2	long prismatic, pink	8	1350–1490	484 ± 6 (8)
E_{1m}	S 25	short prismatic, colourless, inclusions	3	1450–1490	2409 ± 11 (3)
E_{2m}	S 25	long prismatic, slightly pink, some inclusions	4	1400–1470	635 ± 66 (4)

* X refers to the population, X_m are migmatite-, X_p paragneiss zircons,
# () number of temperature steps used for age calculation.

data for the migmatisation event in this part of the ÖCC has been obtained yet.

In the present study, two samples were investigated. We chose neosome from the migmatite-center as representing the highest degree of melting. However, even in the most homogeneous parts of this neosome, a restite component is nearly always present as cm^3 domains or in sub-millimetric layers. A mechanical separation of neosome and restite is therefore not possible. Consequently a paragneiss sample from the vicinity of the migmatite was taken as non-migmatitic reference material. A zircon typology study, comparing the zircon populations of the migmatite with those of the paragneiss, was expected to discriminate anatectical zircon growth from polyphase metamorphic growth.

Zircon typology

Zircon concentrates were gained using standard techniques and zircon characterisation was done using the classification scheme of PUPIN (1980). Four zircon populations can be distinguished in the migmatite as well as in the paragneisses (populations B, C, D, E in Fig. 2). In the migmatite only, a very distinct fifth population of polyfaced zircons is found (population A in Fig. 2).

Population A: spheroidal shape (not rounded, i.e. not detrital!), typical for zircons grown during highest metamorphic, granulite facies conditions (VAN BREEMEN et al., 1982; AFTALION et al., 1989; HANEL et al., 1993), clear, colourless and free of inclusions or cracks, cannot be classified by the scheme of PUPIN (1980), (Fig. 2A).

Population B: very short prismatic, clear, colourless, clustering around S 13, yielding few inclusions (Fig. 2B).

Population C: short to long prismatic, clear, colourless to slightly pink, L2-(L3), few inclusions, cores (Fig. 2C).

Population D: short to long prismatic, clear, colourless to slightly pink, clustering around S 7, some inclusions, cores (Fig. 2D).

Population E: short to long prismatic, clear to turbid, slightly pink to brownish, S 25, well visible cores (Fig. 2E).

Mention of inclusions or cores refers to observations from optical microscopy. For descriptions of the analysed single zircon grains, see table 1.

Analytical techniques

Single zircon evaporation Pb–Pb analysis and conventional U–Pb zircon dating were made on a Finnigan MAT 262 multicollector mass spectrometer equipped with an ion counter.

Single zircon evaporation dating followed modified procedures originally described by KOBER (1987). Full details of the technique applied are summarised in KLÖTZLI (1997). Evaporation temperatures were raised step by step until Pb evaporation from the zircon was complete. Ion beam intensities were measured in blocks of 10 scans with 4 seconds integration time and 2 seconds delay time each using dynamic ion counter acquisition procedures. The background was measured on half-masses every 5 blocks. The background correction was made on-line during data acquisition. $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios were corrected using correction factors derived from NBS SRM 982 standard measurements. Pb fractionation for the ion counter is typically in the range of 0.200 ± 0.001% per mass unit. Only high temperature steps (> 1300 °C) with $^{206}Pb/^{204}Pb$ > 5000 were used for age calculations. Therefore, no common Pb correction had to be applied. Data acquisition comprised 2 to 20 blocks. Reported ages and errors are propagated weighted mean values calculated from at least 20 measured $^{207}Pb/^{206}Pb$ ratios. All errors reported are 2 standard errors of the mean (approx. 95% confidence limit).

The U–Pb multi-grain analysis follows the procedures given by KROGH (1973), PARRISH et al. (1987) and KLÖTZLI (1997). U and Pb concentrations were determined using a mixed ^{205}Pb–^{233}U–^{235}U spike ($^{205}Pb/^{206}Pb$ = 26.38, $^{233}U/^{235}U$ = 1.0194, $^{205}Pb/^{235}U$ = 0.0091). Pb fractionation is corrected using NBS 981 and NBS 982 standard measurements (0.1070 ± 0.0001% per mass unit). The total procedural Pb blank is 8 pg.

Age calculation and error statistics of both methods were made using the "isoplot" software package of LUDWIG (1992).

Results

SINGLE ZIRCON EVAPORATION DATA

Data of single zircon evaporation analysis are summarised in table 1. X refers to the zircon pop-

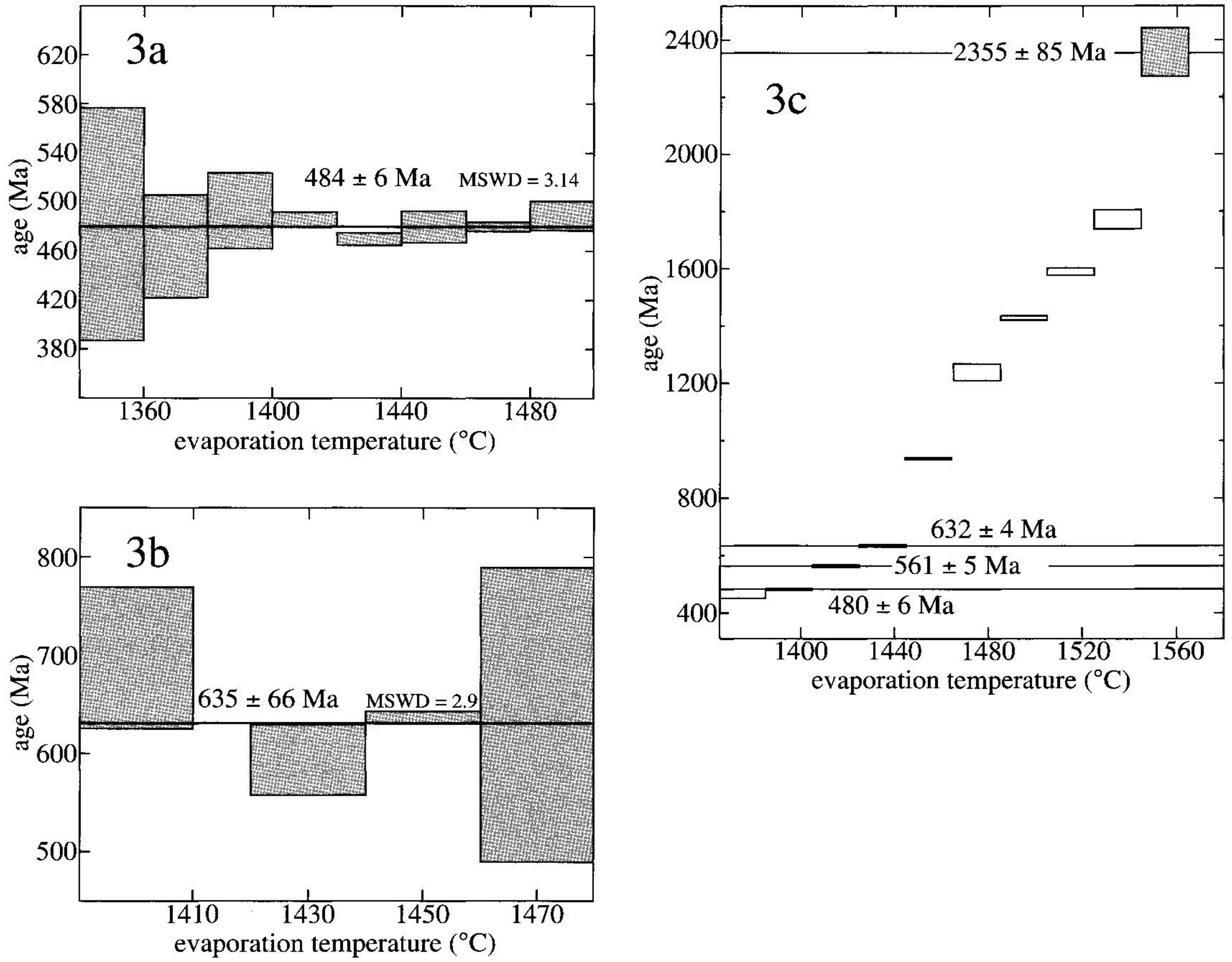


Fig. 3 Single zircon evaporation data in a plot showing evaporation temperature versus apparent $^{207}Pb/^{206}Pb$ ages (weighted mean values). Errors are 2 σ of the mean. Bars represent weighted mean values of runs from individual evaporation steps. (a) Zircon D_{4p} shows a plateau age of 484 ± 6 Ma. The ages between 480 and 490 Ma represent the youngest zircon forming event that can be documented in the ÖCC paragneisses by means of Pb–Pb and U–Pb dating. (b) Zircon E_{2m} shows an age of 635 ± 66 Ma. This is interpreted as being one of the thermal events having contributed to the multistage lead loss and which can therefore not be pinned down by conventional U–Pb dating alone. (c) Zircon D_{3p} has lasted for 10 temperature steps. The data of four steps are reproducible within error as plateau ages found in other zircons.

Tab. 2 Zircon U–Pb isotopic data, Winnebach migmatite.

Fraction name (population)	number of grains	Atomic ratios					Apparent Age (Ma)			corr. coeff.
		$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{232}Th/^{238}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	
A (A)	38	0.07874 ± 1.6%	0.6196 ± 1.6%	10 416	0.05672 ± .62%	0.441	489 ± 15	490 ± 13	494 ± 27	0.9260
B (B)	40	0.08187 ± .50%	0.6601 ± .63%	388	0.05828 ± .38%	0.422	507 ± 5	515 ± 5	548 ± 17	0.7941
B_a (B)	42	0.15240 ± .71%	2.3683 ± 1.7%	13 801	0.11192 ± 1.1%	1.389	933 ± 45	1244 ± 176	1831 + 342/–446	0.6673
C_a (C)	49	0.09062 ± .64%	0.8357 ± 3.8%	1 105	0.06708 ± 3.4%	0.351	559 ± 7	617 ± 35	834 +135/–148	0.6547
D_a (D)	58	0.12082 ± .78%	2.7813 ± 2.5%	1 746	0.16719 ± 2.1%	1.426	735 ± 11	1351 ± 37	2530 +68/–71	0.6339
M (C + D)	41	0.10169 ± .22%	0.9922 ± 1.3%	2 094	0.07076 ± 1.6%	0.951	624 ± 50	700 ± 225	951 + 644/–1114	0.7007

Errors are 1 std. error of mean in % except for apparent age errors which are 2 std. errors in Ma. U and Pb concentrations were not determined because sample weighing was not possible. Elemental ratios were determined using a ^{205}Pb–^{233}U–^{235}U spike.

ulation, X_p are paragneiss-, X_m are migmatite zircons. Most of the analysed zircons showed at the first (i.e. lowest) temperature steps $^{207}Pb/^{206}Pb$ ratios pointing to Ordovician ages, but ion beam intensities were almost always too low for measurement. Nevertheless, zircon D_{4p} exhibits a well defined plateau age of 484 ± 6 Ma over eight temperature steps (Fig. 3a). An age of 551 ± 4 Ma from grain D_{1p} is not very well constrained, consisting of a "plateau" age of only three temperature steps. Grain E_{2m} gives a plateau-age of 635 ± 66 Ma (Fig. 3b). These three ages are found to be in the same age range with data from single temperature steps of zircon D_{3p} (slightly metamict) giving 480 ± 6 Ma, 561 ± 5 Ma, and 632 ± 4 Ma, respectively (Fig. 3c). Zircons of different populations exhibit at the highest temperature steps ages of 2355 ± 85 (grain D_{3p}), 2409 ± 11 Ma (plateau age of grain E_{1m}), 2434 ± 160 Ma (grain D_{2p}), and 2443 ± 3 Ma (grain C_{1m}) respectively.

The roundish zircons were not measurable at all by means of the evaporation method (KLÖTZLI-CHOWANETZ et al., 1995). Since these crystals were of highest quality (very clear, no defects), we assume a missing silica gel effect, which means that Pb was evaporated, but no SiO_2 was emitted to retain it on the ionisation filament.

CONVENTIONAL U–Pb DATA

The data are listed in table 2 and plotted in a Concordia diagram (Fig. 4). All investigated fractions belong to the migmatite. The zircons were colourless and of good to very good quality. Subscript "a" indicates an abraded fraction (KROGH, 1982). Fraction A yields, within error, a concordant age of 490 ± 9 Ma (weighted mean from $^{206}Pb/^{238}U$ = 489 ± 15 Ma, $^{207}Pb/^{235}U$ = 490 ± 13 Ma and $^{207}Pb/^{206}Pb$ = 494 ± 27 Ma). The other fractions are more or less highly discordant. A three point discordia calculated through the fractions A (spheroidal), B and B_a (very short prismatic) yields a lower intercept at 495 ± 92 Ma and an upper intercept at 2379 ± 376 Ma. A two point discordia through A and B_a gives an upper intercept at 2365 ± 35 Ma and through A and D_a 3663 ± 53 Ma. A discordia calculated through the long prismatic fractions C_a and D_a results in intercepts at 548 ± 3 Ma and 4000 ± 49 Ma.

When using the STACEY-KRAMERS model for the common lead correction of fraction A, this becomes slightly inverse discordant. Thus, it seems that the common lead composition in this environment at about 480 Ma was slightly less radiogenic than proposed by the STACEY-KRAMERS (1975) or the CUMMINGS and RICHARDS (1975) model. We therefore used whole-rock Pb isotopic values of the paragneiss (Tab. 3) for the common lead correction which shifted the mean age from 488 ± 9 to 490 ± 9 Ma.

Discussion

SINGLE ZIRCON EVAPORATION DATA

The evaporation age of 484 ± 6 Ma from the paragneiss suite of the central ÖCC defines an important Ordovician thermal event resulting in complete isotopic resetting of some of the zircons. It is almost identical to the Pb–Pb zircon and Sm–Nd sphene magmatic formation ages of a Hedenbergite-Hornblende-gneiss of the western ÖCC (Kaunertal) of 484 ± 4 (mean of four zircon grains) and 487 ± 5 Ma respectively (BERNHARD et al., 1996). The slightly lower age of 480 ± 6 Ma of zircon D_{3p} could be due to a low but noticeable degree of metamictisation. These Ordovician ages are the youngest obtainable by Pb–Pb evaporation analysis. No Variscan overprint can be detected by this method.

The data of 551 ± 4 Ma and 561 ± 5 Ma can eventually be linked with the late Cadomian event which caused the intrusion of parts of the Older Orthogneisses in the Silvretta crystalline basement. Ages between 560–570 Ma are interpreted as remnants of Cadomian crust incorporated in the Variscan basement series (MÜLLER et al., 1995). In the western ÖCC a badly constrained Rb–Sr age of 583 ± 73 Ma from the Klopair tonalite intrusion is reported (SCHWEIGL, 1995).

A middle Cadomian magmatic/metamorphic event is documented between 630 and 640 Ma by population E zircons (635 ± 66 Ma in E_{2m}) and growth zones in population D (632 ± 4 Ma in D_{3p}).

Inherited cores of several zircon populations and zircons exhibiting magmatic typology (S 25) yield a minimum age range of 2355 ± 85 to 2443 ± 3 Ma. The age of 2355 ± 85 Ma is derived from the highest temperature step of the slightly metamict zircon D_{3p} (Fig. 3c) and is therefore considered to be too low. The age of 2409 ± 11 Ma (grain E_{1m}) is believed to be slightly too low because of low ion beam intensity during measurement, resulting in

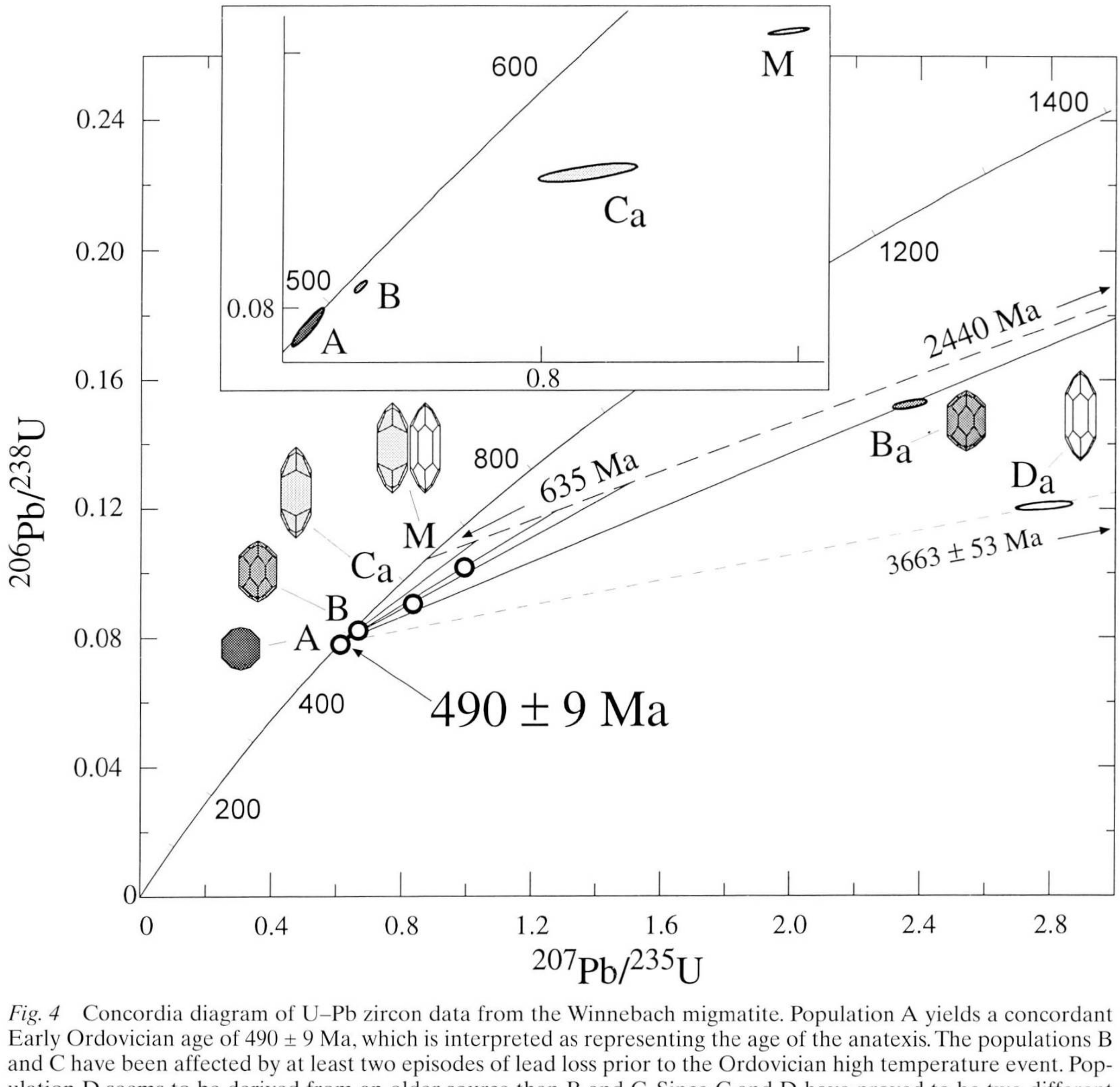


Fig. 4 Concordia diagram of U–Pb zircon data from the Winnebach migmatite. Population A yields a concordant Early Ordovician age of 490 ± 9 Ma, which is interpreted as representing the age of the anatexis. The populations B and C have been affected by at least two episodes of lead loss prior to the Ordovician high temperature event. Population D seems to be derived from an older source than B and C. Since C and D have proved to be two different populations, fraction M, consisting of a mixture of C and D, has to be regarded as meaningless. The notation X_a indicates the abraded fraction of a population. The discordia from 635 Ma to 2440 Ma has been drawn considering the single zircon evaporation results. For the common Pb correction whole-rock Pb isotopic values are used.

Tab. 3 U–Pb whole-rock isotopic data, Winnebach migmatite.

	U ppm	Pb ppm	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$ initial at 480 Ma	$^{206}Pb/^{204}Pb$ initial at 480 Ma
WR	1.2	11.5	38.34	15.29	18.52	15.26	17.93

deviating counting statistics (apparently counting to much ^{206}Pb). These "core"-ages represent a possible minimum mean value for a magmatic crystallisation age of one of the protoliths which contributed to the formation of the sedimentary paragneiss-precursor.

Actually, it is possible that some of the single zircon data from the time span between 1 and 2 Ga (Fig. 3c) record other geologically meaningful ages, but an interpretation is not possible at the moment. However, it should be remembered that Sr isotope systematics indicate a sedimentation age for the paragneiss-precursor of less than 850 Ma (CHOWANETZ, 1991).

CONVENTIONAL U–Pb DATA

Since at least two metamorphic events have taken place after the magmatic crystallisation of some of the zircon cores, we consider the interpretation of any discordia as questionable. However in a previous investigation SÖLLNER and HANSEN (1987) have reported U–Pb zircon dating using grain size fractions and dividing the zircons in long and short prismatic grains and disregarding atypical (e.g. roundish) grain morphologies. As their results from the migmatite zircon fractions showed no linear alignment, the authors proposed the existence of a Cadomian ("pan-African") high-T event causing the first disturbance of the U–Pb system and representing the time of migmatisation. A discordia from paragneiss zircons with a lower intercept of 490 ± 14 Ma and an upper intercept of 2208 ± 50 Ma was interpreted by these authors as being geologically meaningless. We agree that the interpretation of these discordia patterns is difficult, mainly because in this case zircon morphologies cannot be attributed to distinct thermal events.

Yet when classifying the zircons strictly by crystal habit, the above mentioned five populations are detected within the migmatite (cf. zircon typology, Fig. 2). Following PUPIN (1980), the populations B, C and D are typical for Al-rich anatectic melts. Since these populations are common to both the migmatite and the paragneiss, this classification is not helpful to pin down anatectic growth. In our opinion, these populations solely reflect high temperature metamorphic conditions, but not necessarely granulite facies/anatectic melting conditions. The way in which the fractions B, C_a, M and even B_a plot in the Concordia diagram (Fig. 4) clearly demonstrates at least two stages of lead loss. The first event at 635 Ma can only be traced by single zircon evaporation. The second event about 490 Ma leads to secondary lead loss resulting in a distinct offset of the data points from the first Cadomian discordia.

However, the population A zircons occur in the migmatite only and their polyfaced, spheroidal habit is known to reflect granulite facies conditions/anatectic melting. Thus this population A is expected to be a product of the anatexis. The zircons of population A (fraction A) give a concordant age of 490 ± 9 Ma (Tab. 2). We interpret this age as representing the time of anatexis within the paragneisses. As no unsupported Pb component has been detected within these zircons, they are either monophase or their cores have been totally reset during anatexis. Population B (fraction B and B_a) exhibits an outer morphology close to population A. The proximity of the paragneiss sample to the migmatite explains the outer growth shape of population B having reached high metamorphic temperatures but without melting! The non-abraded fraction B is nearly concordant and in line with the migmatitic event. The remaining discordance is conceivably due to an incomplete resetting/resorption of small amounts of pre-migmatitic cores and a Cadomian overgrowth/recrystallization zone. The presence of cores among these crystals is indicated by the least discordant abraded fraction B_a. The abrasion seems to have eliminated the anatectic overgrowth and most of the memory of the Cadomian metamorphism.

A discordia through A and B_a results in an upper intercept age of 2365 ± 35 Ma, approximately in the same range as the core ages found by single zircon evaporation. An incorporation of B and C_a in the discordia calculation would result in a slight shift of the lower intercept but still within error of the concordant fraction A.

Populations C and D (i.e. fractions C_a, D_a, M) include zircons with polyphase growth. They show high temperature, but not *anatectic* overgrowth. It seems reasonable therefore to assume that they belonged to the restite during anatexis, undergoing only lead loss at the time.

A discordia through C_a and D_a would give a lower intercept at 548 ± 3 Ma. Although this age figure fits the single zircon evaporation data, such an alternative interpretation is questionable because of an extremely high upper intercept of approximately 4000 Ma. Fraction D_a seems however to incorporate zircon components as old as 3663 ± 53 Ma (discordia through A and D_a). Since it is likely that population D, as well as population C, has suffered multiphase Pb loss, the 3663 Ma has to be regarded as maximum age. Postulating recent Pb loss (e.g. during the Alpine metamorphism) and with a discordia through D_a and origin, the minimum age for the upper intercept is 2530 Ma. However, we do not favor a model of recent Pb loss, mainly because of the following two reasons. If there was recent Pb loss, this should have occurred in all zircon populations. On the contrary, population A is concordant and fraction B is nearly concordant. Furthermore, when plotting the data in a Tera-Wasserburg diagram, no recent Pb loss can be detected.

Fraction M has not been divided in one prism- and two prisms-bearing zircons. Since the data of fraction C_a and D_a demonstrate clearly their belonging to two different populations, we reject fraction M for discordia calculation purposes.

The ages of 530–520 Ma reported for the gabbro intrusion in the central Ötztal (MILLER and THÖNI, 1995) and found as a probable relic in a hedenbergite-hornblende-gneiss (532 ± 1.2 Ma) in the Kaunertal area (BERNHARD et al., 1996) were not found in either the presently investigated paragneiss or the migmatite material, neither by single zircon evaporation nor by conventional U–Pb analysis.

Conclusions

We have demonstrated the existence of protoliths with ages of around 2400 Ma. Furthermore there is some evidence for the assimilation of zircon components derived from sources of possibly 3600 Ma, which have also contributed to the sedimentary precursor of the paragneisses of the Austroalpine Ötztal crystalline basement.

The first metamorphic event traceable by single zircon Pb–Pb evaporation, and which may be responsible for the primary stage of paragneiss formation, took place around 640–630 Ma. Pb–Pb evaporation data around 560 Ma possibly suggest another metamorphic event at about that time. Early Ordovician evaporation ages clearly prove an important thermal event between 480–490 Ma.

Since all evaporation ages are derived from zircons belonging to populations found in both the migmatite and the paragneiss, none of them can be assigned definitely to the anatexis.

Yet a meticulous zircon typology study revealed a spheroidal, clear, inclusion free population of zircons occurring only in the migmatite. U–Pb analysis of this population yielded an age of 490 ± 9 Ma. This gave the possibility of attributing the partial anatexis within the paragneisses to the Early Ordovician orogenic cycle; it is contemporary to an extended magmatism in the ÖCC, leading to the formation of rocks now found as acid orthogneisses from S- to A-type affinity (HOINKES et al., 1994; BERNHARD et al., 1996; SCHMIDT et al., 1967).

Variscan and Alpine metamorphic overprints have not been recorded in the zircon isotope data of the presently investigated rocks.

Acknowledgements

The project of which this study forms a part is supported by the "Jubiläumsfonds" (project n° 5203) of the Austrian National Bank. Many thanks to F. Bussy, G. Hoinkes and T. Skiöld for critical and improving comments, to T. Ntaflos for helping with the SE images and H. Rice for correcting the English.

References

AFTALION, M., BOWES, D.R. and VRANA, S. (1989): Early Carboniferous U–Pb zircon age for garnetiferous, perpotassic granulites, Blansky les massif, Czechoslovakia. N. Jahrb. Mineral. Mh., 1989/4, 145–152.

BERNHARD, F., KLÖTZLI, U., THÖNI, M. and HOINKES, G. (1996): Age, origin and geodynamic significance of a polymetamorphic felsic intrusion in the Ötztal crystalline basement, Tirol, Austria. Mineral. Petrol., 58, 171–196.

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

CHOWANETZ, E. (1994): The age of the Ötztal-migmatites – still a mater of debate. Mitt. Österr. Mineral. Ges., 139, 284–286.

CUMMINGS, G.L. and RICHARDS, J.R. (1975): Ore lead isotope ratios in a continuously changing earth. Earth Planet. Sc. Lett., 28, 155–171.

HANEL, M., LIPPOLT, H.J., KOBER, B. and WIMMENAUER, W. (1993): Lower Carboniferous Granulites in the Schwarzwald basement near Hohengeroldseck (SW-Germany). Naturwissenschaften, 80, 25–28.

HOINKES, G. (1973): Die Anatexis des Winnebachgranits (Ötztaler Alpen, Österreich) am Beispiel eines Aufschlusses. Tschermaks Mineral. Petrogr. Mitt., 20, 225–239.

HOINKES, G., KOSTNER, A. and THÖNI, M. (1991): Petrologic constraint for Eo-Alpine eclogite facies metamorphism in the Austroalpine Ötztal basement. Mineral. Petrol., 43, 237–254.

HOINKES, G., PURTSCHELLER, F. and SCHANTL, J. (1972): Zur Petrographie und Genese des Winnebachgranits (Ötztaler Alpen, Tirol). Tschermaks Mineral. Petrogr. Mitt., 18, 292–311.

HOINKES, G. and THÖNI, M. (1993): Evolution of the Ötztal-Stubai, Scarl-Campo and Ulten Basement Units. In: VON RAUMER, J.F. and NEUBAUER, F. (eds): Pre-Mesozoic Geology in the Alps, 485–494. Springer Verlag (Heidelberg).

HOINKES, G., THÖNI, M., BERNHARD, F., KAINDL, R., LICHEM, CH. and TROPPER, P. (1994): Prealpine magmatic and metamorphic evolution of the Austroalpine Ötztal basement in the Kaunertal Area. Mitt. Österr. Mineral. Ges., 139, 59–61.

KLÖTZLI, U. (1997): Single zircon evaporation TIMS. The Analyst, in press.

KLÖTZLI-CHOWANETZ, E., KLÖTZLI, U. and KOLLER, F. (1995): Prevariscan evolution of the Ötztal crystalline basement based on Pb-Pb-age-determination. Berichte Deutsch. Mineral. Ges., Beihefte zum European J. Mineral., 7/1, 132.

KROGH, T.E. (1973): A low contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations. Geochim. Cosmochim. Acta, 37, 485–494.

KROGH, T.E. (1982): Improved accuracy of U–Pb zircon ages by the creation of more concordant systems using air abrasion technique. Geochim. Cosmochim. Acta, 46, 637–649.

LUDWIG, K.R. (1992): Isoplot: a Plotting and Regression Program for Radiogenic-Isotope Data. US Geological Survey Open-File Report, 91–445, 40 pp.

MILLER, C. and THÖNI, M. (1995): Origin of eclogites from the Austroalpine Ötztal basement (Tirol, Austria): geochemistry and Sm–Nd vs Rb–Sr isotope systematics. Chem. Geol., 122, 199–225.

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

PARRISH, R.R., RODDICK, J.C., LOVERIDGE, W.D. and SULLIVAN, R.W. (1987): Uranium lead analytical techniques at the geochronology laboratory, Geological Survey of Canada. Geol. Surv. of Canada, Paper 87–2, 3–7.

PUPIN, J.P. (1980): Zircon and Granite Petrology. Contr. Mineral. Petrol., 73, 207–220.

SCHMIDT, K., JÄGER, E., GRÜNENFELDER, M. and GRÖGLER, N. (1967): Rb-Sr- und U-Pb-Altersbestimmungen an Proben des Ötztalkristallins und des Schneeberger Zuges. Eclogae geol. Helv., 60/2, 529–536.

SCHWEIGL, J. (1995): Neue geochronologische und isotopengeologische Daten zur voralpidischen Entwicklungsgeschichte im Ötztalkristallin (Ostalpen). Jb. Geol. B.A., 138/1, 131–149.

SÖLLNER, F. and HANSEN, B.T. (1987): "Pan-afrikanisches" und "kaledonisches" Ereignis im Ötztal-Kristallin der Ostalpen: Rb-Sr- und U-Pb-Altersbestimmungen an Migmatiten und Metamorphiten. Jb. Geol. B.A., 130/4, 529–569.

STACEY, J.S. and KRAMERS, J.D. (1975): Approximation of terrestrial lead isotope evolution by a two stage model. Earth Planet. Sc. Lett., 26, 207–221.

THÖNI, M. (1981): Degree and evolution of the Alpine metamorphism in the Austroalpine unit W of the Hohe Tauern in the light of K/Ar and Rb/Sr age determinations on micas. Jb. Geol. B.A., 124, 111–174.

VAN BREEMEN, O., AFTALION, M., BOWES, D.R., DUDEK, A., MÍSAR, Z., POVONDRA, P. and VRÁNA, S. (1982): Geochronological studies of the Bohemian massif, Czechoslovakia and their significance in the evolution of Central Europe. Transactions Royal Soc. Edinburgh: Earth Sc., 73, 89–108.

Manuscript received January 28, 1971; revised manuscript received July 31, 1997.