Geo.Alp, Vol. 9, S. 156–185, 2012

PROVENANCE SIGNATURES FROM WHOLE-ROCK GEOCHEMISTRY AND DETRITAL ZIRCON AGES OF METASEDIMENTS FROM THE AUSTROALPINE BASEMENT SOUTH OF THE TAUERN WINDOW (EASTERN TYROL, AUSTRIA)

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With 8 Figures and 1 Table

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Abstract

We present a study of the bulk-rock geochemistry including Nd and Pb isotopes of siliciclastic metasedimentary rocks of the Austroalpine basement south of the Tauern Window in combination with detrital zircon U-Pb-dating by LA-SF-ICP-MS.

Source-area composition signals show a strong contrast of the granitoid-detritus dominated older pre-Early-Ordovician metasediments against the younger Thurntaler Phyllite Group. The trace elements of the latter indicate various mafic and felsic, possibly volcanogenic admixtures to a very mature pelite background sedimentation that seems to be derived from an evolved source possibly with more mafic components than the former. A continental arc is clearly indicated by major and stable trace element characteristics for the tectonic setting of deposition of immature wacke-type metapsammites of the pre-Early-Ordovician units while the high maturity of the Thurntaler Group metapelites points to stable platform-type sedimentation

In most meta-arenites of the pre-Early-Ordovician units older well-recycled crustal components with high average crustal residence ages near 2 Ga and lowest $\varepsilon_{Nd(t)}$ (-10) are predominant, while metapelites and many metawackes contain variable proportions of more juvenile components with lower model ages, ranging from 2.0 to 1.5 Ga, and less negative $\varepsilon_{Nd(t)}$ up to -4 . The Thurntaler Phyllite Group pelites are special in showing a very narrow spread of model ages around 1.85 Ga and a systematic trend of $\varepsilon_{Nd(t)}$ increasing from -10 to -7 with the ^{147}Sm / ^{144}Nd ratio, probably due to more juvenile admixtures. The narrow range of lead isotope ratios ^{207}Pb / ^{204}Pb and ^{208}Pb / ^{204}Pb against ^{206}Pb / ^{204}Pb indicates old cratonic reservoirs as sources for all the studied metasediments. According to the youngest detrital zircons observed in this study, and considering the Ordovician zircon protolith-ages of intercalated orthogneisses established earlier, the age of sedimentation of the Defereggen Group and Gailtal Metamorphic basement paragneisses may be bracketed between Early Cambrian and pre-Early Ordovician. The age distribution in detrital zircons is dominated by populations of 600 - 700 Ma, probably delivered from the eroding Avalonian-Cadomian Belt and/or the Pan-African orogens. A very prominent „Grenvillian age" detrital zircon population (950 - 1050 Ma) is interpreted to have been supplied from Eastern Gondwanan source regions. The age gap between 1100 -1700 Ma indicates that Baltica can be almost ruled out as a source region. Following the conclusions from studies in other peri-Gondwanan units, the Saharan Metacraton/Trans-Saharan Basement and the West-African craton can be considered as the sources for Paleoproterozoic and Neoarchean sub-populations at 1700 - 2300 Ma, 2550 Ma and 2750 Ma in the Austroalpine metasediments.

Zusammenfassung

Wir untersuchten die Gesamtgesteinszusammensetzung inklusive der Nd- und Pb-Isotopie von siliziklastischen Metasedimenten des Austroalpinen Basements südlich des Tauernfensters in Kombination mit U-Pb-Datierungen detritischer Zirkone durch LA-SF-ICP-MS.

Indikatoren für die Zusammensetzung der Herkunftsareale zeigen einen starken Kontrast zwischen den von Granitoid-Detritus dominierten älteren prä-frühordovizischen Metasedimenten und der jüngeren Thurntaler Phyllit Gruppe. Spurenelemente der letzteren Gruppe weisen auf verschiedene mafische und felsische, vermutlich vulkanogene Einträge in eine mature pelitische Hintergrundsedimentation, die von einer ausdifferenzierten Quellregion mit eventuell mehr mafischen Komponenten als die erstere stammt. Die Charakteristiken der Haupt- und stabilen Spurenelemente der prae-frühordovizischen unreifen Wacke-Typ Metapsammite zeigt deutlich die Sedimentation im tektonischen Milieu eines Kontinentalbogens an. Dagegen weist die große Reife der Metapelite der Thurntaler Gruppe auf Sedimentation im Bereich einer stabilen Plattform hin.

In den meisten Meta-Areniten der prae-frühordovizischen Einheiten herrschen ältere rezyklierte Krustenkomponenten vor, mit Nd-Krustenresidenzaltern nahe 2 Ga und niedrigen negativen $\varepsilon_{Nd(t)}$ -Werten bis -10, während Metapelite und viele Meta-Wacken wechselnde Anteile von juvenileren Komponenten mit niedrigeren Modellaltern zwischen 2.0 und 1.5 Ga und weniger negativem $\varepsilon_{Nd(t)}$ bis -4 enthalten. Die Metapelite der Thurntaler Phyllit Gruppe zeigen eine geringe Streuung der Modellalter um etwa 1.85 Ga und einen systematischen Anstieg der $\varepsilon_{Nd(t)}$ -Werte von -10 bis -7 mit dem ^{147}Sm / ^{144}Nd -Verhältnis, wahrscheinlich auf Grund juvenilerer Beimischungen. Die geringe Bandbreite der Blei-Isotopenverhältnisse ^{207}Pb / ^{204}Pb und ^{208}Pb / ^{204}Pb versus ^{206}Pb / ^{204}Pb belegt alte kratonische Reservoire als Quelle für alle untersuchten Metasedimente.

Entsprechend den jüngsten hier beobachteten detritischen Zirkonen, und unter Einbeziehung der schon länger bekannten ordovizischen Eduktalter der eingeschalteten Orthogneise kann man das Sedimentationsalter der Paragneise der Defereggen Gruppe und des metamorphen Gailtal-Grundgebirges eingrenzen zwischen frühem Kambrium und vor dem frühen Ordovizium. Die Altersverteilungen der detritischen Zirkone werden dominiert von Populationen um 600 bis 700 Ma, die zumeist vom Avalonisch-Cadomischen Gürtel und/oder den Panafrikanischen Orogenen erodiert sein dürften. Eine sehr auffällige Population detritischer Zirkone mit „Grenvillian"-Alter (950 - 1050 Ma) wird als Indikator eines Ost-Gondwana-Liefergebietes interpretiert. Die durchgängige Lücke zwischen 1100 -1700 Ma zeigt, daß Baltica als Quelle fast auszuschließen ist. Wie in Studien anderer Peri-Gondwana-Einheiten werden für die palaeoproterozoischen und neoarchaischen Zirkon-Teilpopulationen der Austroalpinen Metapsammite (1700 - 2300 Ma, 2550 Ma und 2750 Ma) das Sahara-Metakraton/Trans-Sahara-Basement und der West-Afrikanische Kraton als Quellen für möglich gehalten.

1. Introduction

The Paleozoic and early Mesozoic geology of Central Europe results from the collisions of Africa, Baltica and the microplates which are situated in between. It is widely accepted that after the dispersal of the Neoproterozoic Rodinia Supercontinent many parts of the European basement belonged to the Gondwana continent assemblage. Successive openings of Neoproterozoic to Paleozoic oceanic basins (Iapetus, Tornquist, Rheic, Paleo-Tethys and the Galicia - Massif Central - Moldanubian oceans) led to a segmentation of the Gondwanan margin into numerous microcontinents and terranes. These dispersed continental fragments were amalgamated during the Variscan collision (Franke 2000; Linnemann et al. 2007; Nance et al. 2010; von Raumer et al. 2009; 2012). The Variscan collision is considered a polyphase process which involved the closure of several oceanic domains and led to a re-arrangement of continental fragments of which provenances are still ambiguous and highly debated. In each of these fragments, the Paleozoic and earlier plate tectonic history can be traced through whole-rock geochemical studies and protolith age dating of igneous and meta-igneous rocks. This turned out to be successful in the pre-Mesozoic basement of the Alps, which was additionally affected by the Cretaceous to Tertiary Alpine overprint (von Raumer & Neubauer 1993; von Raumer et al. 2012). Such studies led to the tracing of the oldest igneous rocks within each terrane, which are mostly around 600 Ma as in the case of the Alpine basement (Schulz 2008). In this frame, the U-Pb detrital zircon age dating in the metasedimentary host-rocks of meta-igneous rocks is an increasingly applied tool. It is further enhanced by whole rock geochemical and isotopic studies providing information on the sedimentary provenances and thus paleogeographic linkeages. This is a key to understand the relationships among older cratons and younger mobile belts, especially in the basement of the Alps which is often not considered in the geodynamic reconstructions of the European Paleozoic orogens (e.g. Nance et al. 2010).

Rocks of the Austroalpine basement are increasingly found to be important for the detailed reconstruction of the pre-Variscan evolution (Frisch et al. 1984; Frisch & Neubauer 1989; von Raumer & Neubauer 1993; Neubauer 2002; von Raumer et al. 2012). Geochemical and isotopic characteristics of pre-Carboniferous igneous rocks and their host-sediments can be recognized despite a considerable Variscan and Alpine overprint. The Austroalpine nappe and basement complex in the Eastern Alps has been assigned to an Intra-Alpine (Stampfli 1996) or Proto-Alpine terrane (Schätz et al. 2002). It was situated to the east of the Avalonia, Cadomia and Armorica terrane assemblages (Linnemann et al. 2007; von Raumer & Stampfli 2008; Stampfli et al. 2002; 2011). The role of of the Proto-Alps in the opening of the Rheic ocean is not yet fully understood. With the opening of the Paleo-Tethys, the Paleozoic Austroalpine was a part of a Gondwana-derived terrane, situated to the north of this ocean (von Raumer 1998; Stampfli 2000; von Raumer et al. 2002; 2012).

In the Eastern Alps to the south of the Tauern Window, typical lithostratigraphic units of the Austroalpine basement are exposed with only minor Alpine metamorphic overprint. After a detailed reconstruction of the Early-Paleozoic magmatic evolution, summarized in Schulz et al. (2004; 2008), here we present detrital zircon ages in combination with geochemical and isotopic data concerning the meta-psammopelitic host rocks of the meta-igneous suites.

2. Austroalpine basement units south of the Tauern Window

In the context of the Alpine architecture the Austroalpine basement belongs to the Upper Austroalpine Basement Nappes assemblage. More precisely, according to Schmid et al. (2004) the Northern Defereggen –Petzeck Group and other units north of the DAV are part of the Koralpe-Wölz nappe system. It is believed to form the footwall of the Drauzug-Gurktal nappe system which includes the lithotectonic groups situated between DAV and Periadriatic Line, e.g. the Defereggen and Thurntaler Phyllite Groups and the Gailtal metamorphic basement.

In terms of relative age and metamorphic grade the Austroalpine basement is composed of three principal units (Fig. 1.a, b). Unit (i) includes the weakly metamorphosed post-Early-Ordovician sedimentary and volcanic rocks of the Early Paleozoic parts in the Graywacke Zone, Gurktal Nappe Complex and the Carnic Alps. The higher metamorphic equivalents of these Paleozoic sequences occur as a unit (ii) in the phyllitic sequences, such as the Innsbrucker Quarzphyllite and the Thurntaler Phyllite Group. Common features of units (i) and (ii) are the occurrences of porphyroids and meta-porphyroids (rhyolites and rhyodacites) of Ordovician age. Unit (iii) summarizes several monotonous psammopelitic sequences of a pre-Early-Ordovician sedimentation age which are considered as the former basement of the units (i) and (ii). The Silvretta, Oetztal-Stubai, Campo and Ulten basements, and parts of the basement to the south of the Tauern Window belong to unit (iii). Ordovician granites with peraluminous and also metaluminous character, now outcropping as orthogneisses are widespread in this basement.

The sedimentation in units (i) and (ii) started earliest in the Lower Ordovician and lasted until the Upper Devonian (Schönlaub 1979, 1993; Heinisch et al. 1987; Loeschke 1989; Loeschke and Heinisch 1993; Neubauer and Sassi 1993). Sedimentation ages in the basement unit (iii) are yet poorly constrained. A Neoproterozoic minimum sedimentation age is indirectly provided by the yet oldest inherited magmatic rocks with U-Pb- and Pb-Pb zircon ages at around 600 Ma (Schaltegger et al. 1997; von Raumer et al. 2003; Schulz et al. 2004; 2008). However, these Cambrian to Neoproterozoic igneous rocks are not present in all the sequences and parts of unit (iii). Frisch and Neubauer (1989) proposed a subdivision of unit (iii) into a part with an Early-Paleozoic active margin magmatism (Celtic Terrane), and a unit with magmatism at a Paleozoic passive margin (Noric Terrane). This subdivision of the Unit (iii) was later confirmed by the magmatic protolith ages of Early Cambrian arc magmatic rocks in the Silvretta (Schaltegger et al. 1997) and in the basement to the south of the Tauern Window (Schulz and Bombach 2003). As a consequence the minimum (oldest) sedimentation ages in unit (iii) with Early Cambrian arc magmatic rocks should be Neoproterozoic, but older than ~600

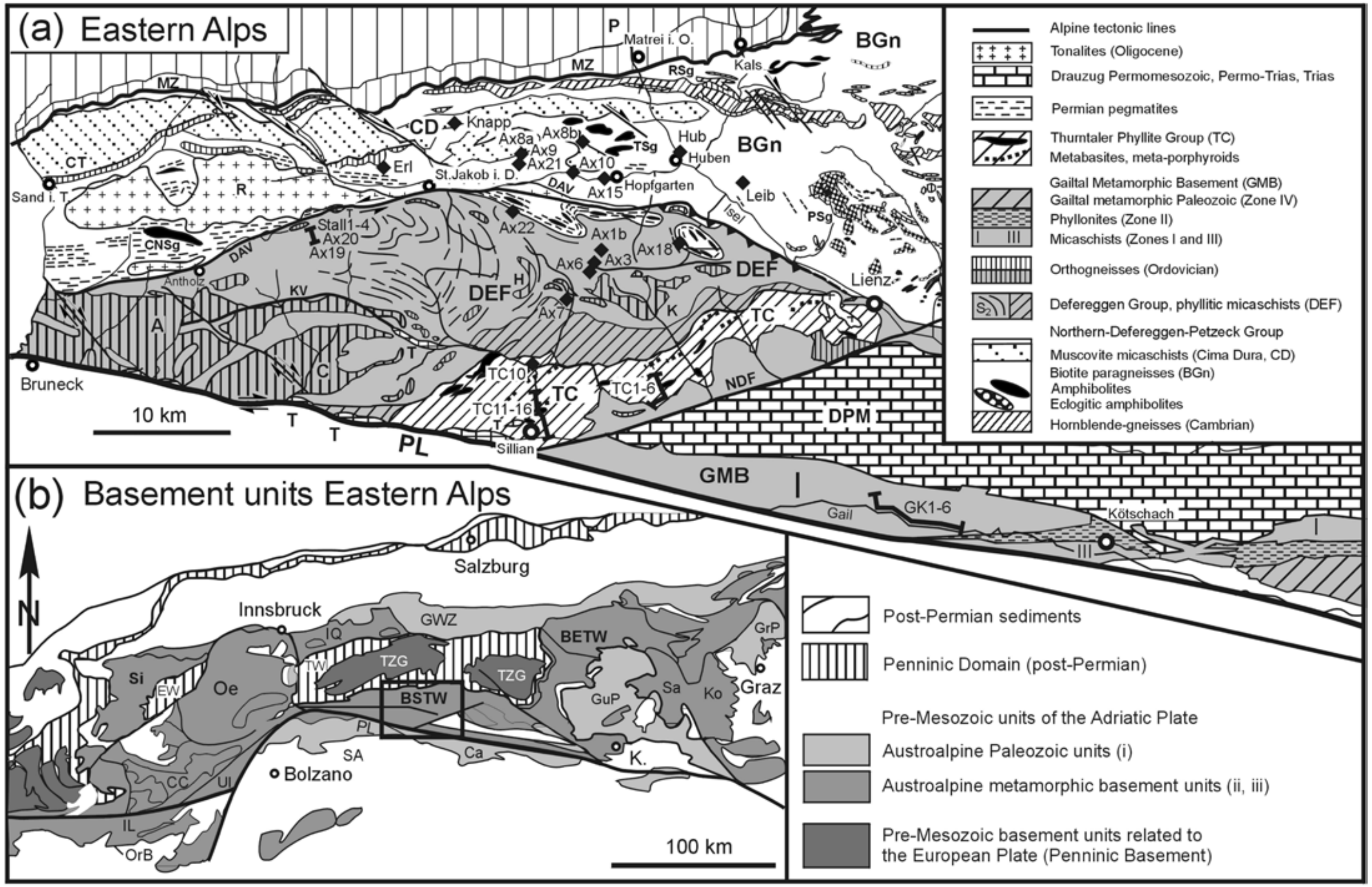

Fig. 1. (a) Major lithological units in the Austroalpine basement to the south of the central Tauern Window, Eastern Alps. Sampling locations are marked. Label of samples and map refer toTable 1.

A - Antholz/Anterselva muscovite orthogneiss (Ordovician); BQ - Brixen Quartzphyllite; C - Casies/Gsies biotite orthogneiss (Ordovician); CD - Cima-Dura muscovite schists in the Northern-Defereggen-Petzeck Group; CNSg - Croda Nera Subgroup (metabasites); CT - Campo Tures orthogneiss (Ordovician); DAV - Defereggen-Antholz-Vals line; DEF - Defereggen Group (monotonous metapsammopelites); GMB - Gailtal metamorphic basement with zones I - IV; DPM - Permo-Mesozoic of Drauzug; H - Hochgrabe biotite orthogneiss; K - Kristeinertal biotite orthogneiss (Ordovician); KV - Kalkstein-Vallarga line; MZ - Matreier Zone (Penninic); NDF - Northern Drauzug fault; BGn - biotite paragneisses of Northern-Defereggen-Petzeck Group; P - Penninic Upper Schieferhuelle; PL - Periadriatic Lineament, Pustertal line; PSg - Prijakt Subgroup (eclogitic amphibolites, 590 Ma, and hornblende-gneisses, Cambrian); R - Rieserferner tonalite (Oligocene); RSg - Rotenkogel Subgroup (hornblende-gneisses, Cambrian); SA - Southern Alps; T, Permo-Trias and Trias; TC - Thurntaler Phyllite Group; TSg - Torkogel Subgroup (amphibolites, 432 Ma).

(b) Pre-Mesozoic basement units in the Eastern Alps. The units are assigned to the Adriatic and European continental plates. BETW - Basement to the E of the Tauern Window; BSTW - Basement to the S of the Tauern Window; Ca - Carnic Alps; CC - Campo Crystalline; EW - Engadine Window (Penninic); GrP - Paleozoic of Graz; GuP - Paleozoic of Gurktal nappes; GWZ - Paleozoic of Greywacke Zones; IL - Insubric Line; Ko - Koralpe; Oe - Oetztal-Stubai Basement; OrB - Orobic Basement; PL - Periadriatic Lineament; SA - Southern Alps; Sa - Saualpe; Si - Silvretta; TW - Tauern Window (Penninic); TZG - Tauern Zentralgneise; Ul - Ultental.

Ma. In those parts of the basement unit (iii) without Early-Cambrian arc magmatites, the minimum sedimentation ages should be pre-Early-Ordovician, but could be younger than ~530 Ma. The pervasive Ordovician magmatism, represented either by the 'porphyroid' meta-volcanic rocks (Heinisch 1981; Söllner et al. 1991; 1997; Meli and Klötzli 2001) in units (i) and (ii) or the metagranitoids in unit (iii) (Peccerillo et al. 1979; Heinisch and Schmidt 1982; Sassi et al. 1985; Mazzoli and Sassi 1992) serve as lower bounds for the sedimentation ages in the Austroalpine Early-Paleozoic units.

In the Austroalpine basement to the south of the Tauern Window (Fig. 1.a), the post-Early-Ordovician units (i) and (ii) are represented by the Unit IV of the Gailtal metamorphic basement, labelled as GMB IV, (Sprenger & Heinisch 1992; Schulz et al. 1993) and the Thurntaler Phyllite Group (TC, Heinisch & Schmidt 1984; Schulz 1991; Kreutzer 1992; Schulz et al. 2004; 2008). In the present state of knowledge, the pre-Ordovician unit (iii) to the south of the Tauern Window is subdivided as discussed above. One can recognize a subgroup (iii-A) with Ordovician metagranitoids and lacking Early-Cambrian arc magmatites which is represented by the units I, II, III of the Gailtal metamorphic basement (GMB I - III) and the Defereggen Group (DEF). The other subdivision (iii-B) is the Northern Defereggen-Petzeck Group (Bgn), with Early-Cambrian arc magmatites as established by Schulz & Bombach (2003) and Schulz et al. (2004; 2008). Among the numerous Ordovician (480-440 Ma) granitoids (Borsi et al. 1973, 1978, 1980; Satir 1975, 1976; Brack 1977; Cliff 1980; Hammerschmidt 1981; Heinisch 1981; Heinisch & Schmidt 1982; Sassi et al. 1985; Klötzli 1995, 1999; Bücksteeg 1999; Schulz & Bombach 2003; Schulz et al. 2004, 2008; Siegesmund et al. 2007) a tendency of an older group of former I-type or continental-arc-granitoid-type rocks (CAG) and a younger group of former S-type or continental-collision granitoid-type (CCG) magmatites may be apparent.

According to whole-rock geochemistry and Pb-Pb zircon protolith ages four groups of metabasites can be distinguished within these Austroalpine basement units (Fig. 1). Amphibolites with a within-plate basalt (WPB)-type to mid ocean ridge (MORB)-type geochemical affinity appear as the youngest group (Pb-Pb zircon age of 432 Ma, Schulz and Bombach 2003). They occur mainly and widespread in the North Defereggen-Petzeck and Thurntaler Phyllite units (Kreutzer 1992; Steenken and Siegesmund 2000). Hornblende gneisses and amphibolites with volcanic arc basalt (VAB)-type geochemical characteristics occur only in the North Defereggen-Petzeck unit. The Pb-Pb zircon protolith ages of these metabasites with a subduction-related signature range from 550 to 533 Ma (Schulz and Bombach 2003; Schulz et al. 2004, 2008). The oldest group of metabasites south of the Tauern Window is also restricted to the North Defereggen-Petzeck unit. They are eclogitic amphibolites with a N-MORB-type geochemical signature and a Pb-Pb zircon protolith age of 590 Ma (Schulz 1995; Schulz and Bombach 2003; Schulz et al. 2004). The trace element signatures of these metabasites, especially the Tb/Ta and Th/Ta are interpreted to indicate a generation of the melts in a back arc setting. These Paleozoic acid and mafic magmatic rock suites were related to a Neoproterozoic to Ordovician active margin setting and a subsequent Paleo-Tethys passive margin setting along the north-Gondwanan periphery (Schulz et al. 2004; 2008).

A pre-Alpine (Carboniferous to Permian) amphibolite-facies metamorphic event with crystallization of garnet, staurolite and kyanite in metapelites, as well as garnet and omphacite in metabasites, can be recognized at least in some parts of the basement to the south of the Tauern Window (Schulz 1990; 1993; Schulz et al. 2008). A Permian low-pressure high-temperature metamorphic event has been found to be associated with the regional occurrences of Permian pegmatites (Schuster et al. 2001; Schulz et al. 2008; Krenn et al. 2012). Early- and Late-Alpine deformation and metamorphism overprinted the pre-Alpine structures and mineral assemblages to variable degrees (Hoinkes et al. 1999; Schulz et al. 2008; Krenn et al. 2012).

3. Samples and methods

The basement units to the south of the Tauern Window are composed of relatively monotonous metasedimentary sequences with predominantly metapsammopelitic rocks. Samples of representative lithologies were taken along profiles in field campaigns through several years. Therefore sample codes do not always coincide with the labels of the main lithotectonic units (Fig. 1.a, Table 1). The Gailtal Metamorphic Basement (GMB) is mainly represented by a sample suite GK1 to GK6 along the Gail valley in zone GMB I. Two sampling profiles through the Thurntaler Phyllite Group were taken around Anras (TC1 to TC6)

Metapelites

n =	GMB 4 AVG	S.D.	DEF 4 (2) AVG	S.D.	BGn 4 (2) AVG	S.D.	CD 4 (3) AVG	S.D.	TC 6 AVG	S.D.
SiO2	**60.73**	8.68	**66.16**	1.16	**64.73**	3.00	**63.79**	3.47	**58.30**	3.27
TiO2	**1.08**	0.24	**0.81**	0.03	**0.87**	0.06	**0.98**	0.04	**0.86**	0.26
Al2O3	**21.07**	5.20	**16.46**	0.62	**18.25**	1.58	**18.67**	2.10	**22.77**	2.64
Fe2O3-T	**7.58**	1.88	**6.09**	0.38	**7.37**	1.00	**7.45**	1.61	**8.37**	1.66
MnO	**0.11**	0.03	**0.09**	0.03	**0.13**	0.02	**0.12**	0.08	**0.24**	0.16
MgO	**2.24**	0.30	**2.79**	0.30	**2.40**	0.48	**2.48**	0.35	**2.67**	0.66
CaO	**1.21**	0.78	**1.64**	0.47	**1.29**	1.10	**1.15**	0.23	**1.00**	1.27
Na2O	**2.06**	0.62	**2.75**	0.93	**1.67**	1.25	**1.54**	0.79	**1.24**	0.43
K2O	**3.74**	1.34	**2.99**	1.18	**3.10**	0.63	**3.65**	0.97	**4.36**	0.62
P2O5	**0.19**	0.05	**0.22**	0.02	**0.18**	0.05	**0.17**	0.02	**0.17**	0.09
Rb	**128**	50	**136**	70	**120**	22	**125**	29	**181**	17
Cs	**3.7**	1.4	**5.3**	0.7	**3.8**	0.5	**9.7**	1.8	**8.9**	4.1
Ba	**788**	68	**670**	193	**530**	140	**695**	110	**589**	70
Sr	**200**	45	**254**	19	**169**	107	**222**	85	**144**	38
Th	**14.3**	5.4	**11.2**	1.8	**13.9**	1.2	**10.8**	0.9	**13.9**	4.0
Zr	**270**	78	**191**	33	**163**	56	**216**	66	**167**	43
Y	**39**	8	**29**	4	**28**	5	**32**	3	**39**	9
Nb	**16**	4	**13**	2	**15**	2	**16**	2	**13**	5
Ta	**1.4**	0.5	**0.9**	0.1	**1.2**	0.4	**0.9**	0.1	**1.3**	0.3
W	**1.6**	0.4	**0.91**	0.18	**1.5**	0.03	**1.7**	0.3	**2.3**	0.7
La	**36**	13	**35**	4	**44**	2	**42**	8	**26**	14
Ce	**79**	28	**69**	10	**88**	5	**77**	9	**59**	29
Sm	**7.2**	2.1	**6.4**	0.7	**7.2**	0.7	**7.1**	0.8	**5.6**	2.4
Eu	**1.4**	0.4	**1.4**	0.1	**1.5**	0.2	**1.5**	0.2	**1.0**	0.4
Tb	**0.93**	0.25	**0.92**	0.04	**0.93**	0.15	**0.91**	0.12	**0.78**	0.36
Yb	**3.3**	0.9	**2.8**	0.2	**2.7**	0.5	**2.5**	0.6	**2.7**	0.8
Lu	**0.49**	0.13	**0.39**	0.02	**0.40**	0.05	**0.37**	0.08	**0.39**	0.09
Sc	**16**	3	**17**	4	**20**	3	**20**	2	**15**	4
V	**116**	22	**102**	17	**110**	12	**124**	18	**125**	37
Cr	**105**	19	**80**	11	**86**	8	**84**	9	**99**	38
Co	**16**	4	**12**	0.5	**12**	7	**14**	3	**19**	5
Ni	**46**	9	**52**	11	**38**	13	**24**	11	**48**	17
SiO2/Al2O3	**3.1**	1.1	**4.0**	0.2	**3.6**	0.4	**3.5**	0.6	**2.6**	0.5
K2O/Na2O	**2.1**	1.2	**1.4**	1.1	**3.1**	2.6	**3.8**	3.8	**4.0**	1.6
CIA	**71**	6	**66**	2	**72**	10	**71**	4	**75**	6
K/Rb	**236**	15	**198**	60	**208**	19	**234**	23	**191**	25
Th/Sc	**0.88**	0.18	**0.94**	0.13	**0.77**	0.04	**0.78**	0.05	**1.00**	0.50
Zr/Sc	**17**	5	**12**	4	**8**	3	**11**	3	**12**	6
Co/Th	**1.2**	0.3	**1.1**	0.1	**0.9**	0.4	**1.3**	0.1	**1.5**	0.6
Cr/Th	**7.8**	2.0	**6.5**	1.2	**6.2**	0.5	**8.2**	1.3	**8.0**	3.9
Cr/V	**0.9**	0.1	**0.8**	0.1	**0.8**	0.1	**0.7**	0.1	**0.8**	0.2
Cr/Ni	**2.3**	0.1	**1.6**	0.3	**2.5**	0.9	**4.0**	1.3	**2.0**	0.3
Ni/La	**1.4**	0.7	**1.5**	0.4	**0.9**	0.3	**0.6**	0.3	**3.0**	3.0
Ti/(Lax20)	**9**	5	**7**	1	**6**	0.2	**7**	2	**16**	17
Ti/Zr	**24**	6	**26**	5	**34**	13	**29**	10	**32**	13
La/Sc	**2.3**	0.5	**2.1**	0.6	**2.2**	0.3	**2.1**	0.3	**1.8**	1.2
La/Th	**2.6**	0.7	**3.4**	0.3	**3.2**	0.2	**3.8**	0.6	**1.8**	0.7
ΣREE	**192**	63	**171**	22	**208**	16	**193**	23	**144**	67
Eu/Eu*	**0.62**	0.02	**0.68**	0.02	**0.68**	0.06	**0.67**	0.06	**0.60**	0.08
La_N/Sm_N	**3.2**	0.5	**3.4**	0.1	**3.8**	0.3	**3.7**	0.4	**2.8**	0.6
Gd_N/Yb_N	**1.6**	0.2	**1.7**	0.2	**1.8**	0.1	**2.1**	0.4	**1.4**	0.4
La_N/Yb_N	**7.5**	2.1	**8.5**	1.2	**11.0**	1.9	**11.3**	2.9	**6.3**	2.4

Metawackes

n =	GMB 1	DEF 7 (3) AVG	S.D.	BGn 6 (2) AVG	S.D.
SiO2	**70.43**	**71.48**	2.65	**71.20**	2.91
TiO2	**0.71**	**0.87**	0.30	**0.81**	0.15
Al2O3	**14.60**	**13.83**	1.36	**13.32**	1.26
Fe2O3-T	**5.01**	**4.84**	0.54	**5.17**	0.52
MnO	**0.07**	**0.09**	0.02	**0.09**	0.02
MgO	**2.33**	**1.86**	0.24	**2.09**	0.36
CaO	**1.29**	**1.67**	0.35	**2.34**	0.77
Na2O	**2.66**	**3.18**	0.73	**2.75**	0.54
K2O	**2.72**	**1.98**	0.49	**1.98**	0.54
P2O5	**0.19**	**0.19**	0.04	**0.26**	0.14
Rb	**96**	**77**	24	**73**	17
Cs	**2.9**	**3.2**	2.7	**4.4**	0.2
Ba	**589**	**482**	96	**501**	244
Sr	**201**	**257**	39	**197**	41
Th	**10.0**	**17.8**	12.4	**13.7**	1.9
Zr	**228**	**344**	221	**254**	67
Y	**30**	**32**	14	**28**	5
Nb	**14**	**13**	3	**13**	6
Ta	**1.0**	**0.9**	0.2	**1.1**	0.2
W	**1.39**	**0.58**	0.11	**3.2**	2.4
La	**34**	**44**	22	**37**	2
Ce	**71**	**86**	44	**72**	7
Sm	**6.7**	**7.7**	3.7	**6.4**	0.5
Eu	**1.1**	**1.5**	0.5	**1.3**	0.2
Tb	**0.89**	**1.05**	0.38	**0.92**	0.06
Yb	**2.8**	**3.0**	0.9	**2.8**	0.2
Lu	**0.41**	**0.45**	0.13	**0.40**	0.04
Sc	**11.1**	**13**	3	**14**	2
V	**81**	**77**	7	**90**	16
Cr	**81**	**72**	19	**81**	38
Co	**12**	**12**	2	**20**	0.04
Ni	**34**	**35**	7	**35**	5
SiO2/Al2O3	**4.8**	**5.2**	0.8	**5.4**	0.8
K2O/Na2O	**1.0**	**0.7**	0.3	**0.7**	0.2
CIA	**64**	**60**	4	**58**	2
K/Rb	**228**	**218**	39	**220**	35
Th/Sc	**0.89**	**1.25**	0.74	**0.77**	0.16
Zr/Sc	**20**	**26**	15	**19**	8
Co/Th	**1.2**	**0.9**	0.5	**1.5**	0.2
Cr/Th	**8.1**	**4.4**	2.1	**4.5**	0.05
Cr/V	**1.0**	**0.9**	0.2	**0.9**	0.4
Cr/Ni	**2.4**	**2.1**	0.4	**2.3**	0.8
Ni/La	**1.0**	**0.9**	0.4	**1.0**	0.1
Ti/(Lax20)	**6**	**6**	1	**7**	1
Ti/Zr	**18**	**17**	4	**19**	3
La/Sc	**3.0**	**3.3**	1.4	**2.6**	0.3
La/Th	**3.4**	**3.3**	0.4	**2.9**	0.5
ΣREE	**174**	**213**	104	**177**	13
Eu/Eu*	**0.54**	**0.66**	0.09	**0.67**	0.08
La_N/Sm_N	**3.2**	**3.6**	0.2	**3.6**	0.2
Gd_N/Yb_N	**1.9**	**1.8**	0.3	**1.7**	0.1
La_N/Yb_N	**8.2**	**9.6**	1.5	**8.9**	0.8

Metarenites

n =	GMB 3 AVG	S.D.	DEF 1	BGn 1	CD 2 AVG	S.D.	TC 1
SiO2	**84.43**	4.35	**94.02**	**94.03**	**86.33**	6.89	**83.35**
TiO2	**0.59**	0.08	**0.13**	**0.17**	**0.56**	0.20	**0.48**
Al2O3	**8.58**	2.61	**2.36**	**2.30**	**6.74**	3.37	**7.60**
Fe2O3-T	**2.94**	0.75	**1.04**	**0.95**	**2.99**	1.10	**2.05**
MnO	**0.04**	0.01	**0.05**	**0.04**	**0.06**	0.01	**0.05**
MgO	**0.90**	0.31	**0.33**	**0.21**	**0.73**	0.33	**0.63**
CaO	**0.25**	0.06	**0.40**	**0.31**	**0.33**	0.17	**0.73**
Na2O	**0.40**	0.03	**0.54**	**0.40**	**0.93**	0.24	**0.85**
K2O	**1.78**	0.65	**0.30**	**0.60**	**1.23**	0.79	**1.70**
P2O5	**0.09**	0.01	**0.11**	**0.03**	**0.09**	0.04	**0.06**
Rb	**61**	14	**10**	**22**	**47**	30	**61**
Cs	**1.6**	0.7	nd	nd	nd		**2.4**
Ba	**285**	107	**71**	**162**	**199**	133	**422**
Sr	**39**	3	**53**	**45**	**51**	33	**84**
Th	**12.6**	4.3	nd	nd	nd		**7.7**
Zr	**358**	144	**100**	**176**	**472**	31	**346**
Y	**26**	8	**<10**	**<10**	**11**	3	**19**
Nb	**14**	2	**<10**	**<10**	**17**	2	**13**
Ta	**0.4**	0.5	nd	nd	nd		**0.4**
W	**0.5**	0.7	nd	nd	nd		**0.71**
La	**31**	6	**5**	**9**	**22**	10	**21**
Ce	**64**	13	**8**	**16**	**35**	12	**44**
Sm	**5.3**	0.8	**1.3**	**1.3**	**3.3**	1.3	**3.7**
Eu	**1.0**	0.2	**0.3**	**0.3**	**0.6**	0.2	**0.7**
Tb	**0.71**	0.13	**0.20**	**0.17**	**0.43**	0.15	**0.48**
Yb	**2.4**	0.7	**0.6**	**0.6**	**1.4**	0.5	**1.5**
Lu	**0.35**	0.09	**0.09**	**0.09**	**0.21**	0.07	**0.22**
Sc	**7**	2	**1.5**	**3.0**	**5.2**	2.8	**4.8**
V	**41**	10	**14**	**10**	**43**	13	**43**
Cr	**43**	9	**41**	**42**	**89**	14	**35**
Co	**6**	1.97	nd	nd	nd		**4**
Ni	**17**	4	**20**	**19**	**40**	4	**10**
SiO2/Al2O3	**10.6**	4.0	**40**	**41**	**15**	9	**11**
K2O/Na2O	**4.5**	1.7	**0.6**	**1.5**	**1.2**	0.5	**2.0**
CIA	**77**	0	**62**	**64**	**70**	2	**70**
K/Rb	**231**	36	**249**	**226**	**212**	6	**231**
Th/Sc	**1.95**	1.17	nd	nd	nd		**1.61**
Zr/Sc	**56**	37	**67**	**59**	**109**	64	**73**
Co/Th	**0.6**	0.3	nd	nd	nd		**0.6**
Cr/Th	**3.7**	1.54	nd	nd	nd		**4.6**
Cr/V	**1.0**	0.1	**2.9**	**4.2**	**2.1**	0.3	**0.8**
Cr/Ni	**2.6**	0.3	**2.1**	**2.2**	**2.2**	0.2	**3.5**
Ni/La	**0.6**	0.2	**3.8**	**2.0**	**2.0**	0.7	**0.5**
Ti/(Lax20)	**6**	1	**7**	**5**	**8**	1	**7**
Ti/Zr	**10**	3	**8**	**6**	**7**	3	**8**
La/Sc	**4.6**	2.0	**3.5**	**3.1**	**4.4**	0.4	**4.3**
La/Th	**2.5**	0.4	nd	nd	nd		**2.7**
ΣREE	**153**	28	**27**	**40**	**92**	36	**105**
Eu/Eu*	**0.57**	0.08	**0.59**	**0.64**	**0.61**	0.01	**0.63**
La_N/Sm_N	**3.6**	0.2	**2.5**	**4.5**	**4.1**	0.3	**3.5**
Gd_N/Yb_N	**1.7**	0.3	**1.8**	**1.5**	**1.7**	0.02	**1.7**
La_N/Yb_N	**9.1**	2.4	**6.2**	**10.3**	**10.8**	1.0	**9.3**

Table 1. Chemical compositions of metasediments in Austroalpine basement units to the south of the Tauern Window. Labels DEF, BGn, CD and GMB refer to pre-Early-Ordovician units; Label TC refers to the post-Early-Ordovician Thurntaler Phyllite Group. AVG = average, SD = one standard deviation, n = number of analyses (number in brackets refer to Cs, Th, Ta, W, Co and related ratios if n of ICP-MS analyses is smaller), nd = no data; major elements in % wt., calculated volatile-free, total Fe reported as Fe_2O_3; trace elements reported as ppm; CIA = weathering index Nesbitt & Young (1982); REE_N normalised to C1 of Taylor & McLennan (1985); Eu/Eu* = $Eu_N/(Sm_N \times Gd_N)^{0.5}$.

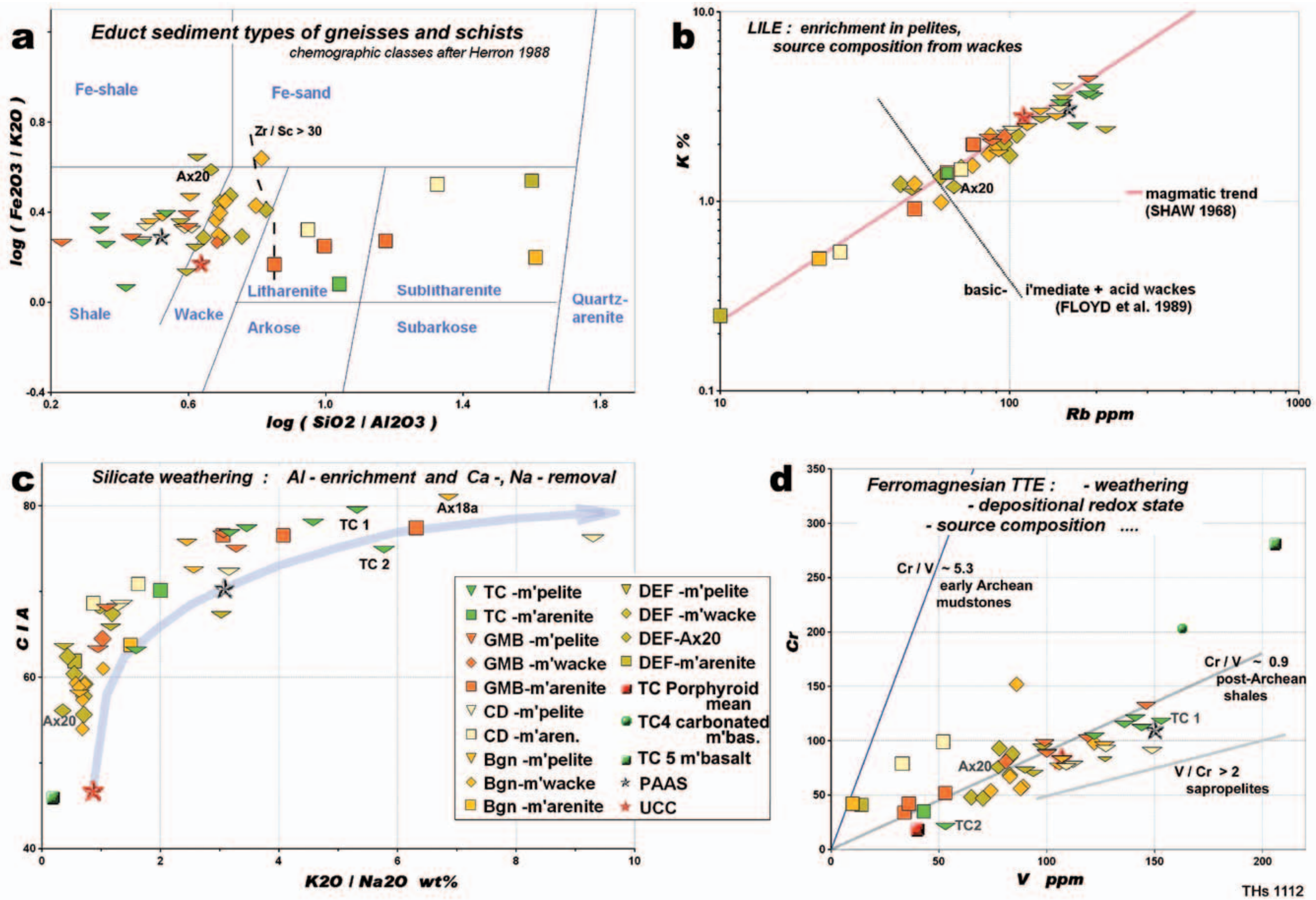

Fig. 2. (a) - (d) Whole-rock geochemistry of metasediments in the Austroalpine basement: Sediment types of paragneiss educts; weathering, sorting, redox state versus source composition. For labels of samples refer to text.

and along the Villgratenbach between Panzendorf and Ausservillgraten (TC10 to TC16). The Defereggen Group is characterised by several sample suites from locations widely apart, labelled DEF in Table 1 and Fiures 2 to 6. At the Staller Sattel region some metaquartzites were collected (Stall1 to Stall4, Ax19, Ax20). More metapelitic lithologies are encountered in samples from the eastern part of the Defereggen Group, e.g. the Winkeltal area (samples Ax1b, Ax3, Ax6, Ax7,). In the Northern Defereggen-Petzeck Group, two principal suites of clastic metasediments can be mapped. A suite of biotite paragneisses and biotite metaquartzites which are considered to be the host rocks of the Cambrian hornblende gneisses are labelled Bgn. Biotite paragneisses are represented by the samples Erl from Erlsbacher Alm, Hub from Huben and Leib from Leibnig, Ax10, Ax15 from Hopfgarten, Ax 21 from Fröz Alp, Ax 18 Stierbichl and Ax 22 from Stemmeringer Alp. The other suite comprises metapelites (garnet muscovite schists) and metaquartzites (metaquartzite sample Knapp from Knappengruben), belonging to the Cima-Dura-muscovite-schists, labelled as CD. Numerous samples labelled as Ax belong to either the CD or the BGn suites (Fig. 1a). The Cambrian hornblende gneisses do not appear in the belt of the Cima-Dura-muscovite-schists. This suggests that the CD and Bgn sequences may have different ages of sedimentation.

Whole-rock major and trace element geochemical analyses were performed on 44 paragneisses, metaquartzites, micaschists and phyllites (Table 1). Depending on grain size about 1 to 5 kg per sample were crushed. An aliquot was ground to <200 mesh. Major elements and Rb, Ba, Sr, Sc, Zr, Y, Nb, V, Cr, Ni were analysed by XRF from powder disks and the elements Cs, Ba, Sc, REE, Y, Nb, Ta, W, Co, Th, Pb by ICP-MS and ICP-AES from solution, checking results by internal and external standards.

Neodymium and Samarium whole-rock isotopic compositions were analysed by conventional isotope dilution technique. Before dissolution in a mixture of HF and HNO_3 with a Teflon PicoTrace digestion system, the samples were spiked with suitable amount of a ^{150}Nd-^{149}Sm spike solution to achieve optimal sample-spike homogenisation. The solutions were processed for purification of Nd and Sm fractions. The Nd and Sm were loaded on pre-conditioned Re filaments and analysed at isotopic ratios by a ThermoFinnigan Triton mass spectrometer in static mode (GZG Göttingen). Repeated measurement of the La Jolla Nd standard yielded a ^{143}Nd/^{144}Nd ratio of 0.511840+3 over the course of the study. The obtained Nd isotopic ratios of the samples were normalised to a ^{146}Nd/^{144}Nd ratio of 0.7219. The εNd_{CHUR} values have been calculated for 520 Ma (pre-Early-Ordovician units) and 480 Ma (Thurntaler Group) as approximate sedimentation ages.

For whole-rock lead isotope analysis the samples were pretreated with HBr, then dissolved by HF and HNO_3 with addition of HBO_3 as described by Conelly et al. (2006). After drying they were redissolved using HNO_3 . The samples were analysed in static multicollection mode using a VG Sector 54 IT mass spectrometer of the Institute of Geography and Geology, University of Copenhagen. Conventional anion exchange columns followed by 200-ml Teflon columns were used for chemical separation. Pb-fractionation was monitored by repeated analysis of the NBS 981 standard (Todt et al. 1996). It totaled 0.105 ± 0.008% per amu (n = 12, 2r). The Pb blanks all remained below 50 pg, which is a low figure that does not significantly affect the measured Pb-isotopic ratios of the samples.

Detrital zircons from three samples (Ax19, GK4, TC6) were analysed for U-Pb ages. The grains of the mineral separates are subrounded to rounded in all cases. The U–Pb age data, obtained at the Geological Survey of Denmark and Greenland in Copenhagen, were acquired by laser ablation - single collector - magnetic sectorfield - inductively coupled plasma - mass spectrometry (LA-SF-ICP-MS) employing a Thermo Finnigan Element2 mass spectrometer coupled to a NewWave UP213 laser ablation system. All age data presented here were obtained by single spot analyses with a spot diameter of 30 µm and a crater depth of approximately 15–20 µm. The methods employed for analysis and data processing are described in detail by Gerdes and Zeh (2006) and Frei and Gerdes (2009). For quality control, the Plešovice (Sláma et al. 2008) and M127 (Nasadala et al. 2008, Mattinson et al.2010) zircon reference materials were analyzed, and the results were consistently in excellent agreement with the published ID-TIMS ages. The calculation of concordia ages and plotting of concordia diagrams were performed using Isoplot/Ex 3.0 (Ludwig 2003). Results are presented in relative probability curves recalculated from the number of zircon analyses for each age class.

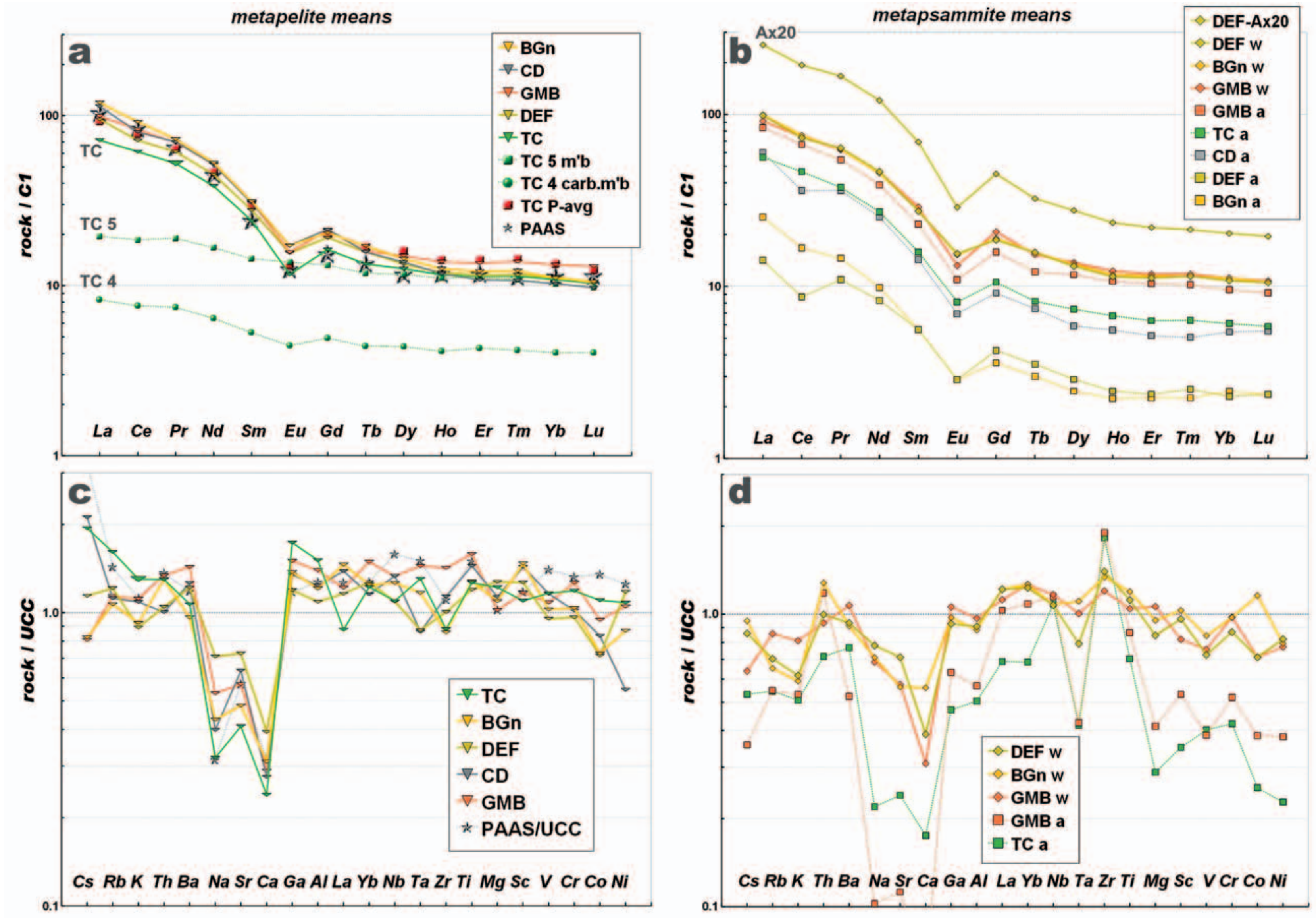

Fig. 3. (a) - (d) Whole-rock geochemistry of metasediments in the Austroalpine basement: Chondrite-normalized REE and Upper Continental Crust-normalized spider graphs. Sample sets correspond to table 1; see text.

4. Geochemistry of metasediments in the Austroalpine basement

To enable comparison REE were normalized to chondrite C1 of Taylor and McLennan (1985). A suite of major and trace elements was normalized to the average upper continental crust, UCC (McLennan 2001), and to the composite of post-Archean Australian shales, PAAS (Nance and Taylor 1976; Taylor and McLennan 1985). For the interpretation of weathering intensity we calculated the chemical index of alteration (CIA) defined by Nesbitt and Young (1982) as molar ratio $[Al_2O_3 / (Al_2O_3 + CaO^* + Na_2O + K_2O)]$ x100 where CaO* refers to the calcium in silicates, found by removing the small amounts of carbonate- and phosphate-bound calcium. The samples are very low in carbonate (CO_2 -mean 0.43, range 0.03 to 1.04% wt%) and calc-silicate rocks are excluded from the study. As shown by Fedo et al. (1995) the CIA is preferable over the CIW (Harnois 1988) as the latter suggests too high a weathering intensity for unweathered granitoid source rocks. A-CN-K coordinates (Nesbitt and Young 1984) were calculated to evaluate the type of weathering trend. For comparative interpretation of the Thurntaler Group metasediments we also used several new analyses of associated volcanogenic rocks: TC-P avg, a composite of 6 felsic tuffs („meta-porphyroids"); two mafic schists, e.g. TC4, a carbonatised basaltic tuff, and TC5, a metabasalt with MOR affinities transitional to WPB (La ca.10 x C1; Eu/Eu*=1.0, La_N/Yb_N=1.9, Zr/Y=5.0, Zr/TiO_2=87, V/Ti x 1000 = 27).

As our samples are taken from medium-grade metamorphic assemblages they lost most sedimentologic attributes by severe deformation and metamorphic crystallisation. However, chemical provenance signals are strongly dependent on detrital grain size and other petrographic properties related to sediment maturity (e.g. McLennan et al. 1989, 1990; Cullers 1993; 1995; 2000). We thus employed the chemographic schemes of Wimmenauer (1985) and Herron (1988) to assign the samples to three major sediment types, namely shales (pelites), wackes and arenites (Fig. 2.a). Both schemes use the major-element mass ratio SiO_2/Al_2O_3, set against Fe_2O_3/K_2O in Herron's (1988) scheme, versus Na_2O/K_2O in the Wimmenauer (1985) scheme. The assignments widely agree if the Wimmenauer (1985) shaly graywacke ($Na_2O/K_2O < 1.5$, $SiO_2/Al_2O_3 < 4.5$) is included in the shales group. Shale of the Herron (1988) scheme with $SiO_2/Al_2O_3 > 4.5$ is better grouped with wackes in accordance with Wimmenauer's scheme (e.g. sample Ax20 as discussed below). The wacke-arenite boundary is found roughly conforming to ratios of Zr/Sc around 30.

4.1 Effects of metamorphism, weathering of source, hydraulic separation, depositional redox-state

Chemical provenance analysis poses a many-sided problem. Ultimately we intend to retrieve information on the source area composition and on the tectonic setting of the depository. Such chemical signals are however blurred by a number of processes, e.g. weathering of the source rocks, mineral separation according to hydraulic properties, chemical alteration during transport and sedimentation, apart from mixing and reworking. Also potential element mobilisation by metamorphism has to be considered.

Mobilisation by metamorphism was studied by many authors with varied results. For siliciclastic rocks mobility of for example Tl, Li, Pb and certainly of the volatiles was established in a number of cases. However for most major and many trace elements there seems to be a general agreement on a largely isochemical metamorphism of siliciclastics at the dimension of a specimen, provided there is no indication of large water/rock ratios as for example in shear zones (Shaw 1956; Degens 1968; Ronov et al. 1977; Condie and Martell 1983; Haack et al.1984; Mingram 1995). With large water/rock ratios particularly the alkali elements, and to a lesser degree REE, may be mobilised. Mingram (1995) established a loss of B, Li, Bi and Zn with increasing metamorphism, but she stated that the mobility even of these elements is restricted to only some of the metamorphic units studied, so that element mobilisation should not be generalised. The trace elements used in the present study, the HFSE, like Y, Nb, Zr, Ti and the REE, are mostly contained in refractory minerals, e.g. phosphates or zircon, and the TTE, like Sc, V, Cr, Co, Ni are captured in chlorite-type clay minerals during weathering. Strong correlations (level of confidence >0.99) with Al, K, Fe, Ti, Mn and sometimes Mg show most TTE and some HFSE are now hosted by biotite, ilmenite and possibly garnet. While losses are possible particularly during metamorphic dehydration reactions, the trace elements used are generally considered to remain relatively immobile up to medium-grade metamorphism. We do not observe anomalous

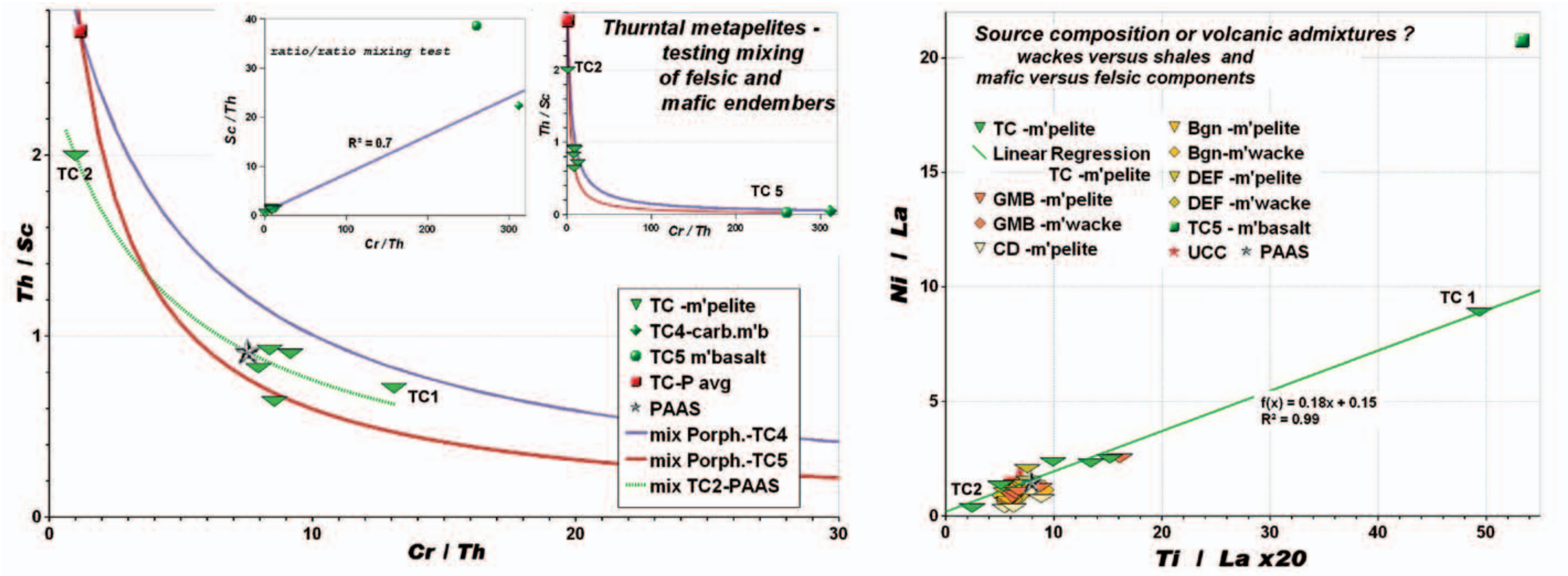

Fig. 4. Thurntaler Phyllite Group (TC) metapelites: Cr-Th-Sc and La-Ti-Ni ratios serve as mixing indicators. See text.

deviations of concentrations from reference compositions, e.g. UCC and PAAS (Fig. 3).

Even trace LILE, like Rb, Cs are present in our samples in concentrations and ratios close to unaltered rocks (Fig. 2.b). This may be due to the fact that they are captured in K-sites of micas as indicated by their strong correlation with K and Al in metapelites as well as in metapsammites (level of confidence > 0.99). Large alkali trace element ions are fixed in potassic clay minerals by ion exchange already during weathering (Nesbitt et al. 1980). This is inherited in the metapelites, as is shown here for K/Rb, but is also valid for K/Cs. The meta-wackes alkali element concentrations may reflect the source composition more closely as suggested by Floyd et al. (1989) while in the arenites their concentration is lowered by quartz dissolution. By contrast, the small alkali and alkaline earth elements Na, Sr, Ca are lost to solution during weathering, as is seen in the UCC-normalized spider diagrams of metapelites (Fig. 3.c). Metapsammites also show this effect, yet with lower intensity as the weathering signal is compounded by source composition signatures carried by the sand-sized detrital components, e.g. mainly plagioclase (Fig. 3.d).

The observed CIA values range from 56 to 81 over all types of sediments. Source rocks like basalts and granites would have CIA values between 45 and 60. A sample weathering trend from UCC (CIA 47), as a virtual source, to PAAS (CIA 70) and beyond shows the expected development of Al- concentration and loss of Na (Fig. 2.c). Most metawackes group with low CIA and low K_2O/Na_2O. CIA values of metarenites depend on the composition of their matrix. Values between 70 and 75 in shales indicate primary illite, smectite, muscovite derived from a moderately weathered source. The GMB metarenites, lithic arenites according to Herron's and quartzose arkoses in Wimmenauer's schemes, plot with evolved pelites, as would be expected for the kaolinite-rich matrix of an arkose. Only rare alumosilicate-staurolite schists (e.g. sample Ax18a of BGn set) with CIA > 80 indicate intense weathering forming Al-rich clays containing kaolinite, gibbsite. In A-CN-K compositional space (not shown) no indication for a steady-state weathering trend was found, in accordance with a lack of metapelites with CIA values larger than 80 (Table 1; Fig. 2c). This may suggest overall sedimentation in an active tectonic environment. Certainly it renders a stable platform situation unlikely, provided our rather small metapelite sample sets are representative. Yet the offset from low CIA values of the GMB- (64), DEF- (60 ± 4) and BGn-metawackes (58 ± 2) to the larger ones of the associated metapelites (71 ± 6, 66 ± 2, 72 ± 10; table 1) also indicates, at least for these subsets, absence of homogenization by intense recycling as would be expected for a stable platform.

Transition trace elements (TTE) like Sc, V, Cr, Co, Ni are fixed in chlorite-type clay minerals during weathering and so a source composition signal may be transferred to pelites. But variability of oxidation states leads to changing solubilities depending on the Redox conditions during sedimentation (Krejci-Graf 1966; Degens 1968; Breit and Wanty 1991). The Cr/V ratios of metapelites and metawackes observed (Fig. 2.d) are similar to the post-Archean shale average of Taylor and McLennan (1985), with only slight deviations due to larger V concentrations. The absolute concentrations are highest in metapelites and lowest in most metarenites. Note that the shale-type sample TC2 with abnormally low V and Cr concentrations shows admixtures from a felsic source as is detailed below. Its low Cr content resembles the one of the average metaporphyroid TC-P while the slightly higher level of V might reflect a low redox state in the sediment. Conversely, metapelite TC1 with the largest Cr and V concentrations carries more mafic admixtures than any of the remaining Thurntal metapelites, based on Cr-Th-Sc and Ti-Ni-La systematics (see below). Both samples have a comparable weathering status (Fig.2c). Thus the concentrations of Cr and V in the metapelites may reflect source composition modified by a weak signal from depositional redox state.

High Cr/V ratios at low concentration in some metarenites may result from heavy mineral sorting (Fig. 2d). Also strong heavy-mineral sorting is inferred in arenites, where unusual enrichments of Zr and of Th are observed (GMBa, TCa in Fig. 3.d). High REE, Zr and Th concentrations in a metawacke (Ax20, DEF set) are not easily attributed to sedimentary sorting, a wacke being an immature sediment by definition. Microscopic examination of this thick-bedded, fine-grained biotite plagioclase gneiss shows many well-rounded zircon grains in the coarse silt to fine-sand size range. While the sample is placed by Zr/Sc, Th/Sc, La/Sc, Ti/Zr systematics (Fig. 5.a, b) into the fields of heavily recycled sediments, the ferromagnesian element content and low K_2O/Na_2O put it close to the immature wackes (Fig. 5.d). It seems that there occurred a slight Na-metasomatism (low K_2O/Na_2O = 0.4), which may have taken place during metamorphism, or already in the granitoid source rocks where in outer zones of plutons high water/rock ratio en-

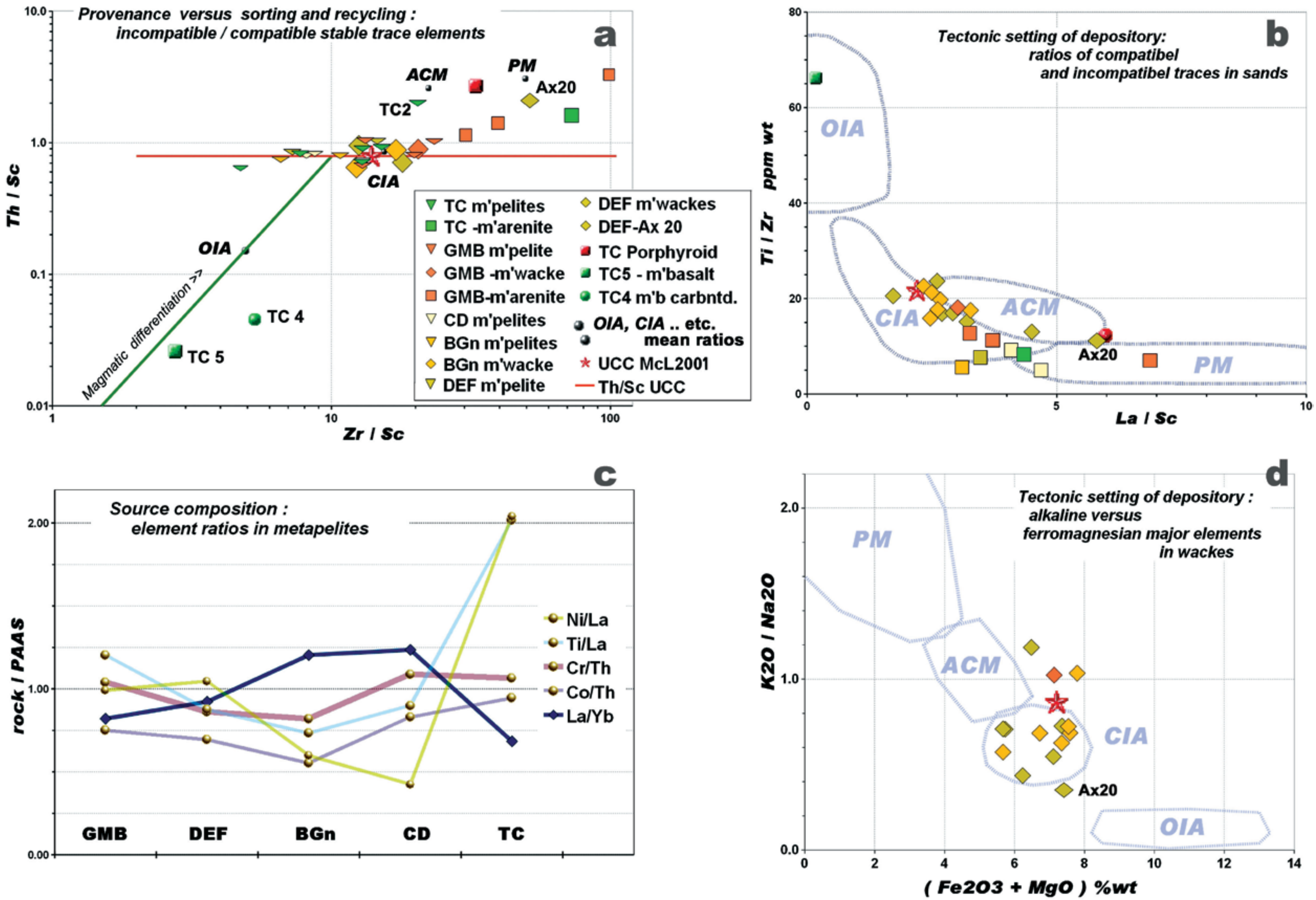

Fig. 5. (a) - (d). Whole-rock geochemistry of metasediments in the Austroalpine basement: Tectonic setting and source composition: discrimination from major and trace element ratios; OIA - oceanic island arc; CIA - continental island arc; ACM - active continental margin; PM - passive margin; mean ratios in (a) and discrimination fields in (b), (d) according to Bhatia (1983), Bhatia & Crook (1986).

vironments are common. Also, the high REE content coupled with an increase in LREE fractionation (La_N/Sm_N = 3.4, La_N/Yb_N = 12.4; Fig. 3b) over the remaining DEF wacke mean (La_N/Yb_N = 9.1 ± 0.9) may be attributed to a more differentiated granitoid source. However, in order to reconcile high Zr content and ferromagnesian element concentrations of this wacke one is forced to speculate on admixtures of mafic debris and pre-concentrations of zircons, either sedimentary or magmatic.

4.2 Source-area composition

The C1-normalized REE spectra of metapelites (Fig. 3a) show a very narrow spread of the BGn, DEF, CD and CMB data sets with an approximate 100-fold enrichment of La down to a 10-fold enrichment of the HREE's. The pattern is close to the one of the PAAS, except for a smaller La_N/Sm_N averaging 3.2 to 3.8, a similar Eu/Eu*, 0.62 to 0.68, and higher middle-REE concentrations. This points to a dominantly granitoid source, similar to, yet slightly less differentiated than the dominantly granitic source rocks indicated for the PAAS.

The average metapelite of the Thurntaler Phyllite Group differs from the aforementioned by a smaller La enrichment of ca 80-fold, an even smaller LREE fractionation, La_N/Sm_N averaging 2.8, a smaller Eu/Eu* of 0.60 versus 0.65 of PAAS, and a smaller total REE fractionation of La_N/Yb_N = 6 compared to 9 of the PAAS. This indicates a less differentiated or more mafic source than in the other metapelites. The admixtures may be assumed to be derived from erosion of a mafic terrain and/or from synsedimentary, predominantly mafic volcanic activity, of the types shown by the basaltic TC4, TC5 and the felsic TC-P REE-spectra (Fig. 3.a). This hypothesis is tested in Th, Sc, Cr and Ni, Ti, La coordinates of individual samples (fig. 4). The Sc/Th versus Cr/Th plot indicates a moderatly correlated spread of the TC metapelites but no match with the metabasalt TC5. However there is nearly a match with the carbonate-rich basaltic schist TC4, a suspected tuffite. In the Ni-Ti-La plot, the TC metapelites show a similar pattern while the other metapelites cluster close to the metawackes, as well as to the PAAS and UCC ratios. Obviously these metapelites are well homogenized while TC metapelites are not. Calculated bimodal mixing functions (Fig. 4) suggest that the Th-Sc-Cr system of most TC pelites can be explained by mixtures of various amounts of TC4-, TC5-type mafic endmembers with a pelite average close to PAAS. Corresponding mixing lines would be positioned between the hypothetic extremes of mixtures of the felsic TC-Pavg with the two mafic endmembers shown in the plots. However in order to arrive at the Th-Sc-Cr ratios of sample TC2 a felsic endmember with higher Th/Sc and lower Cr/Th than the average metaporphyroid TC-P would be required (Fig. 4, dashed mixing line).

The REE spectra of the metapsammites fall into two groups. Except for sample Ax20 with a total REE content twice as high as the averages, the very compact data set of the GMB, DEF, BGn metawackes has characteristics close to those of the metapelites with similar enrichments over C1, Eu anomalies and fractionation factors. They thus indicate the same source composition as the associated metapelites. Overall, the metarenites show lower REE concentrations, depending on the dilution by quartz, and they display somewhat more varied REE characteristics, which may reflect the variations in type and amount of matrix and accessories of the original psammites due to sorting.

Relative to Ti and Sc concentrations, the pelite spider-plot (Fig. 3.c) shows the lowest concentrations of the TTE V, Cr, Co, Ni in the CD samples while in the TC set the TTE remain constantly larger than in the UCC. In the remaining DEF, BGn, GMB sets concentrations are variable yet close to UCC values. This relation is similar to the observations gained from the PAAS-normalized ratio plot comparing the metapelites of the five geologic units (Fig. 5.c). Here the TC average pelite is indicated by the lowest La/Yb versus highest Ni/La, Ti/Lax20, Cr/Th, Co/Th ratios to be derived from the least evolved average crustal source. This remains correct even when culling the subset with the lowest Ni, Ti, Cr, Th, Co concentrations, e.g. 4 samples out of 6. According to La/Yb and the other ratios the CD, DEF, BGn unit pelites originate from more differentiated average sources, with the signal from GMB metapelites being intermediate.

4.3 Tectonic setting of depository

Not all the units are represented by wacke-type samples impeding a full comparison of source composition and tectonic setting. In the Th/Sc-Zr/Sc graph (Fig. 5.a) the DEF, BGn and one GMB wacke plot close to the continental island-arc mean of Bhatia and Crook (1986), which incidentially is close to the

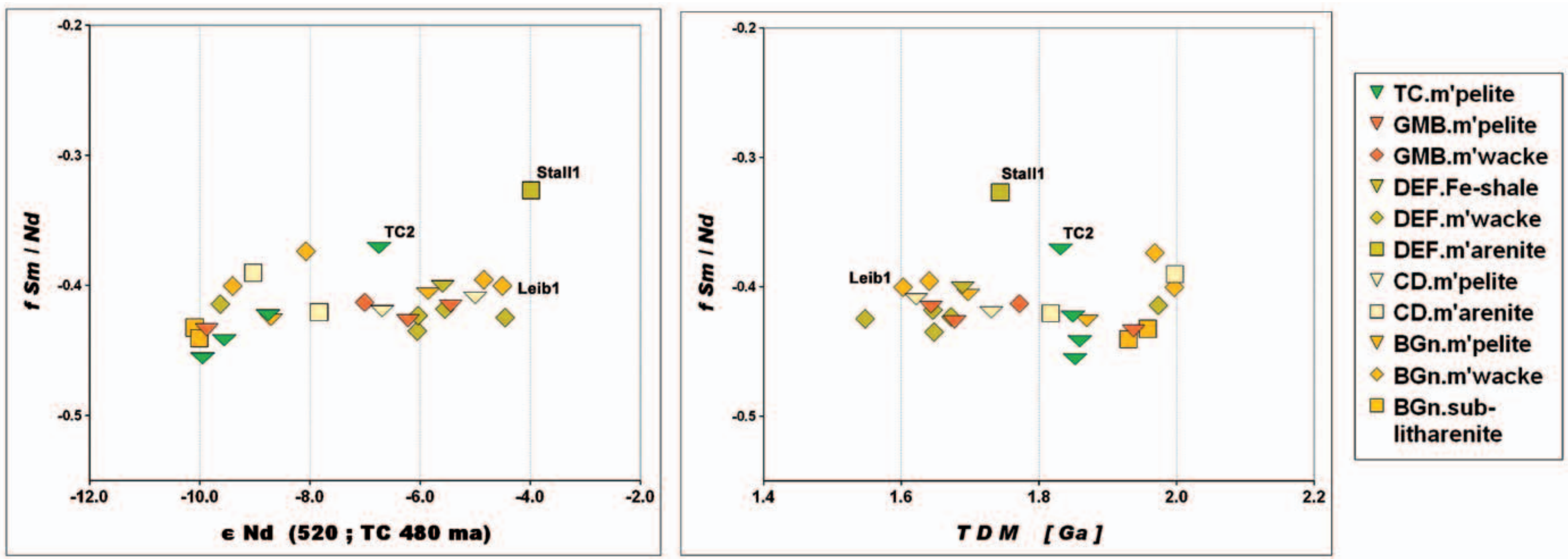

Fig. 6. (a) Epsilon Nd vs. f Sm/Nd in metasediments of the Austroalpine basement units to the south of the Tauern Window. Data from the Thurntaler Phyllite Group (TC) is calculated to 480 Ma; data from the other units to 520 Ma. (b) TDM mean crustal residence ages acc. to Goldstein model.

UCC. By comparison, the Th/Sc ratio of the metapelites is nearly identical to the metawackes while Zr/Sc seems to be reduced. The complementary increase of Zr and Th in arenites is generally interpreted as due to sorting and recycling so that it is not relevant for tectonic-setting analysis. Note however the high Th and Zr of metapelite TC2 which has been explained above by an admixture from felsic volcanic rocks.

The Ti/Zr-La/Sc and the K_2O/Na_2O-(Fe_2O_3 + MgO) plots (Fig. 5.b, d) similarly show the BGn and DEF metawackes and some of the lithic arenite-type rocks falling within or on the margin of the continental island-arc field according to Bhatia (1983) and Bhatia and Crook (1986). This finding is supported by several more of the discriminant element relations established by these authors for Paleozoic sandstones (graphs not shown). It may be added that characteristically low $K_2O/Na_2O < 1.0$ (DEF, BGn means ca 0.7, cf. Table 1) are also observed in recent deep-sea turbidite sands from continental arcs (Sumatra, Middle Americas: McLennan et al. 1990). The same field is covered by the DEF and BGn metawackes in a graph by the latter authors using the alkali-oxides ratio in conjunction with SiO_2/Al_2O_3.

Weathering trends recorded in sediments may indirectly reveal changes in tectonic setting and possibly plate drift (f.ex. Nesbitt and Young, 1982). Low-maturity pelitic deposits form in a cold, possibly glacial, climate and/or in a tectonically active environment, where they are associated with immature wackes, while high maturity in combination with a steady-state weathering trend would indicate a stable, platform-type environment and possibly weathering in a more temperate climate. A hypothetic trend of weathering intensity may be inferred from relatively immature DEF metapelites increasing to more mature CD garnet mica schists and to BGn alumosilicate-bearing schists, and possibly further to mature TC metapelites of a probable Early Ordovician depositional age (Fig. 2.c). However the stratigraphic and facies interrelations of these units remain unclear. More work is needed before such a hypothetic weathering trend can be established and a comparison with the development of late Neoproterozoic to Ordovician sediments in West-Gondwanan terrains (Bauluz et al. 2000; Mingram 1995) may eventually be possible.

5. Nd- and Pb-isotope geochemistry

Nd isotopes are of significance for sedimentary rocks in constraining a mean average crustal residence time of their source by the calculation of model ages (T_{DM}), which allows a characterisation of crustal domains of different age and geological history. Sediments derived from old continental crust have highly negative ε_{Nd} values, whereas juvenile, arc-derived detritus shows less negative or even positive ε_{Nd} data. The T_{DM} model ages were calculated based on the model of Goldstein et al. (1984) that assumes a linear mantle evolution of the Sm-Nd isotopic composition. The ε_{Nd} data of all analysed samples were back-calculated to 520 (pre-Early-Ordovician units) and 480 Ma (TC unit), which are the best estimates on the timing of their deposition (see detrital zircon ages below). All the samples have $^{147}Sm/^{144}Nd$ values ranging from 0.107 to 0.132. These values are low and consistent, and thus should yield meaningful model ages as indicated by the steep slopes of the sample isotopic evolution lines.

In this study four samples from the Thurntaler Phyllite Group (TC), four from the Gailtal Metamorphic Basement (GMB) and 20 samples from the other units (DEF, BGn) were analysed (Fig. 6). The four samples from the TC show homogeneous T_{DM} ages between 1.83 and 1.86 Ga and only slightly varying $\varepsilon_{Nd(480)}$ values of -6.7 to -9.9 with TC2 having the highest value (rest -8.8 to -9.9) due to the highest $^{147}Sm/^{144}Nd$ value (0.124) and the highest $^{143}Nd/^{144}Nd$ ratio (0.512063) of this unit. The $^{147}Sm/^{144}Nd$ values from the four samples of the GMB are similar to the TC (0.111 – 0.115) but the $^{143}Nd/^{144}Nd$ values of three samples are slightly higher, similar to TC2 (0.512002 – 0.512081) leading to T_{DM} model ages between 1.64 and 1.77 Ga and $\varepsilon_{Nd(520)}$ ratios of -5.4 to -7.0 with one exception (GK1) having a lower $^{143}Nd/^{144}Nd$ value of 0.511842 leading to a higher T_{DM} model age of 1.94 Ga and a more evolved $\varepsilon_{Nd(520)}$ ratio of -9.9. This sample has the lowest La_N/Yb_N ratio of 4.7 of this unit (rest 6.8 – 11.6), pointing to a loss of LREE that could have affected the Sm/Nd ratio. The Ax-samples show two groups of Nd data. One less evolved group with model ages between 1.55 and 1.73 Ga and $\varepsilon_{Nd(520)}$ data of -4.5 to -6.7 (Ax8a, Ax9b: CD unit; Ax3, Ax10, Ax22c: BGn unit) and another group

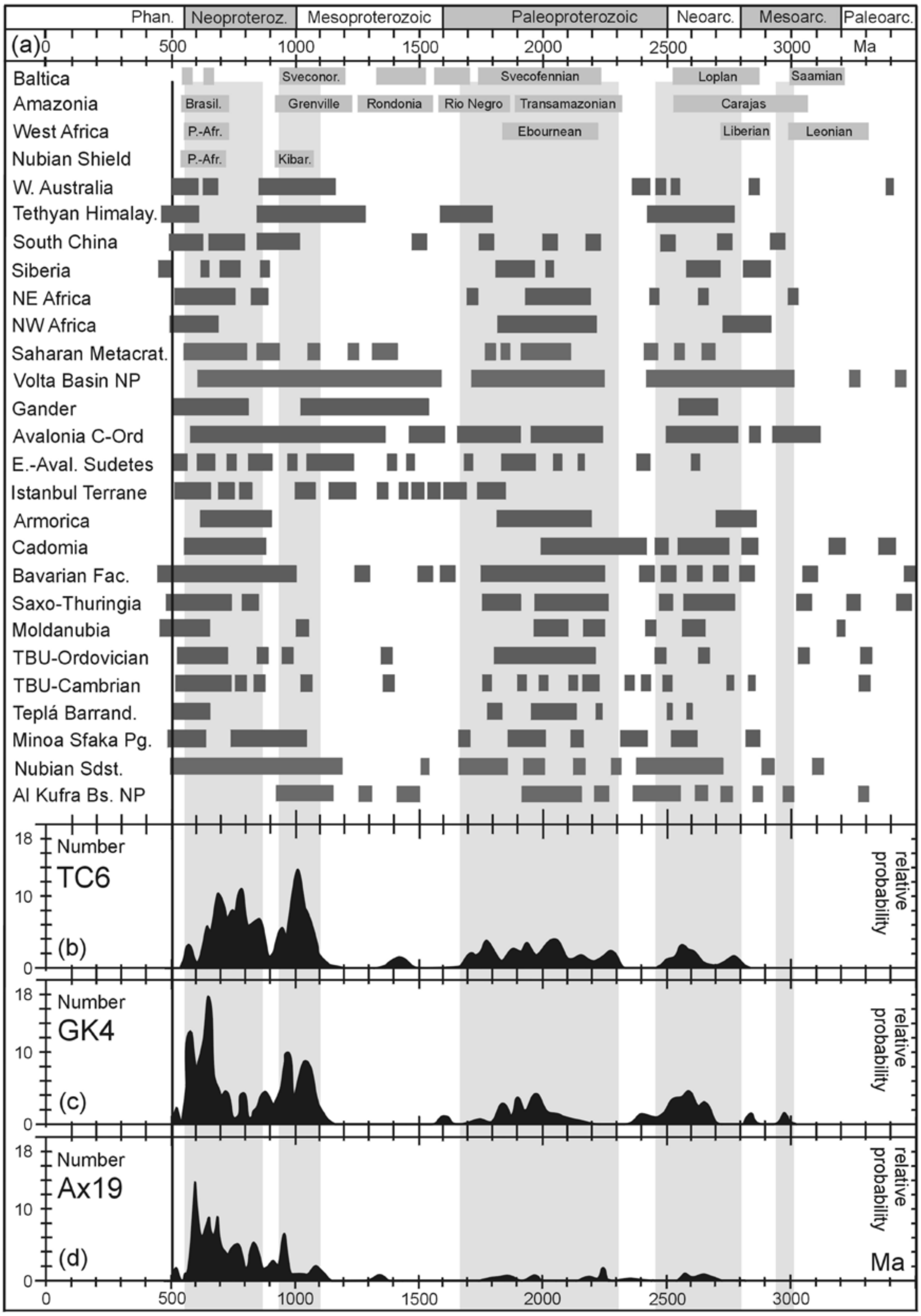

Fig. 7. Detrital zircon ages and comparison with potential sources: Relative probability plots of detrital zircon ages from the Early-Paleozoic sequences of the Austroalpine Basement to the South of the Tauern Window (b, c, d), zircon ages with < 10% discordance are considered. Data sources (a) for comparison are: Stern et al. (1994); Stern et al. (1994); Nance & Murphy (1996); Friedl et al. (2000; 2004); Avigad et al. (2003); Gehrels et al. (2003); Linnemann et al. (2004; 2007); Murphy et al. (2004); Kolodner et al. (2006); Zulauf et al. (2007); Bahlburg et al. (2010); Duan et al. (2010); Kuznetsov et al. (2010); Zeh & Gerdes (2010); Ustaömer et al. (2011); Drost et al. (2011).

with a more evolved Nd isotope composition and T_{DM} model ages between 1.87 and 1.97 and $\varepsilon_{Nd(t)}$ ratios of -8.1 and -9.6. Although the samples Ax6(DEF) and Ax8b(CD) have relatively high Eu/Eu* ratios of 0.77 and 0.73 they are in the group of the more evolved Nd data. The third sample from this group (Ax21:BGn) has significantly lower Eu/Eu* ratios of 0.55.

The five samples (Stall1, Stall2, Stall3b, Stall3c, Stall4a) from the Defereggen-Group (DEF; southern block) yielded very homogenous model ages between 1.65 and 1.74 Ga and $\varepsilon_{Nd(520)}$ data of -4.0 to -6.1. Six samples from the Northern Defereggen-Petzeck-Group belong to the Bgn (Hub1, Hub1a, Erl1, Leib1) and CD (Knapp1-2-3, Knapp4) units. The data of five of the six samples from these units are similar to the more evolved Ax and TC samples, giving T_{DM} model ages of 1.82 to 2.00 Ga and $\varepsilon_{Nd(t)}$ ratios between -7.8 and -10.1. Leib1 has a model age of 1.60 Ga and an $\varepsilon_{Nd(520)}$ value of -4.5. Elevated Ti and Cr concentrations and a high Fe_2O_3/K_2O ratio of this metawacke may hint at a mafic detrital component that could explain the less evolved isotopic composition.

The whole-rock Pb-isotope composition is rather uniform with one exception (TC2), as is seen from a $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ graph (not shown). The TC2 data show a high $^{208}Pb/^{204}Pb$ ratio at a low $^{206}Pb/^{204}Pb$ ratio which is explained by the high Th/U ratio of this sample compared to all other samples. The Pb evolution in a $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ graph (not shown) is not as linear as in the diagram before, but it is not possible to assign the samples to different domains. All samples plot into or even above the field for old cratons by Linnemann and Romer (2002). There are three samples with a tendency to lower $^{207}Pb/^{204}Pb$ ratios (GK3, GK7, Ax3), but they still fall in the old cratons field. No sample indicates tapping of a less-evolved crustal reservoir.

6. Detrital zircon ages

The 90 analysed zircon age spots from sample TC6 from the Thurntaler Phyllite Group display a broad maximum at around 600 - 850 Ma, followed by a minimum at ~900 Ma and a strongly developed single maximum at 1000 Ma (Fig. 7.b). The age period between 1100 and 1800 Ma is considered a gap, with only two zircons at 1400 Ma. Similar to sample GK4, about 30 % of all calculated ages are older than 1800 Ma. In contrast to sample GK4, the age distribution between 1800 and 3000 Ma does not define two maxima as seen before, but the data are scattered over several submaxima.

The age distribution from the 97 analysed zircon age data points from sample GK4 from the Gailtal metamorphic basement also has a maximum between 600 -700 Ma. This is followed by a minimum at around 750 - 900 Ma (Fig. 7.c). There is a considerable number of zircon ages of the time period 950 - 1050 Ma. The gap of zircon ages between 1100 and 1800 Ma is similar to the one observed in sample Ax19. In contrast to sample Ax19 where only around one sixth of the ages are older than 1800 Ma, around 30 % of the zircon ages in GK4 fall into the Paleoproterozoic and older periods. There are well developed maxima at around 1950 Ma and around 2550 Ma. Sample GK4 also contains the oldest zircon of nearly 3000 Ma of all the studied populations.

Ages of 67 zircons were calculated from sample Ax19 from the Defereggen Group. The data give $^{206}Pb/^{238}U$ ages between 507 and 2650 Ma, with a strong maximum around 600 – 700 Ma and a smaller number of ages from 700 to 850 Ma (Fig. 7.d). These maxima are followed by an almost complete gap until 1800 Ma. Only 10 out of 67 data are ages older than 1800 Ma.

To sum up, the samples Ax19 (DEF) and GK4 (GMB) have in common the 600 - 700 Ma detrital zircon age maximum and the 700 - 950 Ma relative minimum of Neoproterozoic age distribution. A relative probability minimum is also visible in sample TC6, but appears to be more focussed at ~900 Ma. All three samples show zircon ages in the time span 950 - 1100 Ma. But for this age period the samples GK4 and TC6 display similar high abundances, when compared to sample Ax19 with a considerable lower number. For the Paleoproterozoic and Neoarchean zircon ages, the samples TC6 and GK4 display similarities in relative abundances in the age periods 1800 - 2300 Ma and 2500 - 2800 Ma. These time periods are also observed in sample Ax19, but the absolute number of ages is considerably lower.

7. Discussion and interpretation of detrital zircon ages

A first point of the interpretation of the detrital zircon ages from metasediments is the constraint on the minimum age of sedimentary deposition. Both samples Ax19 and GK4 from the pre-Early-Ordovician sequences bear one zircon with an age of 520 Ma.

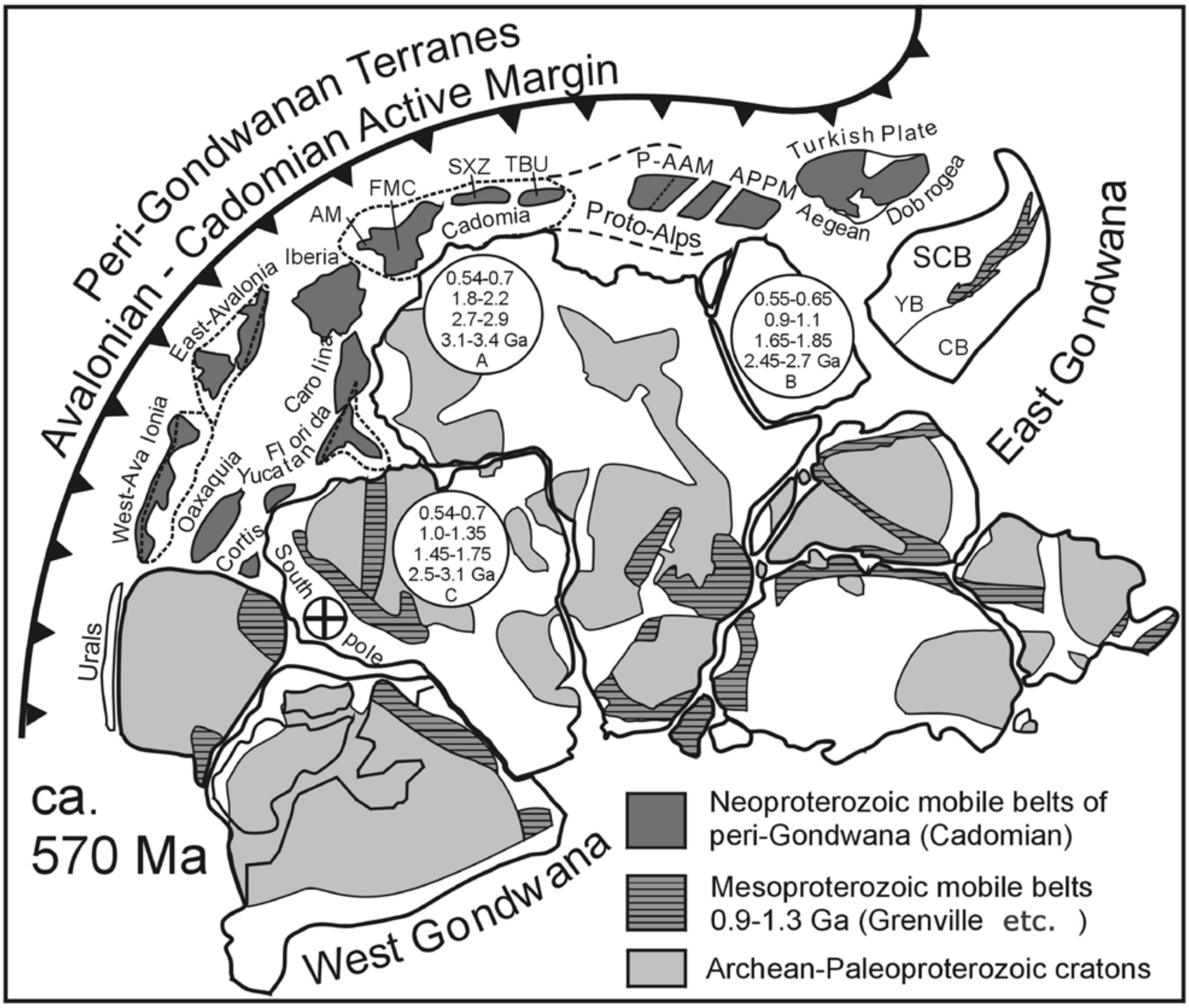

Fig. 8. Paleogeography. Early-Paleozoic paleogeography of the Cadomian-Avalonian active margin and related peri-Gondwanan terranes, at ~570 Ma; adopted from Linnemann et al. (2004; 2007). Paleogeography of the Gondwanan continental plates after Unrug (1996). Early-Paleozoic position of the South China Block (SCB) is added according to von Raumer & Stampfli (2008) and von Raumer et al. (2012). AM - Armorican Massif; APPM - Austroalpine Paleozoic Passive Margin; CB - Cathaysia Block; FMC - French Massif Central; P-AAM - Penninic-Austroalpine Active Margin; SCB - South China Block; SXZ - Saxo-Thuringian Zone (part of the Bohemian Massif); TBU- Teplá-Barrandium unit (part of the Bohemian Massif); YB - Yangtze Block. Numbers in circles: zircon ages from the cratons in Ga. A - compilation of Nance & Murphy (1994) and references therein); B - from Avigad et al. (2003); C - from Schneider-Santos et al. (2000); D - from the compilation of Zeh et al. (2001).

The two youngest detrital zircons in sample TC6 from the post-Lower-Ordovician sequences have ages at around 550 Ma. These youngest detrital zircon ages are older than the zircon magmatic protolith ages from acid orthogneisses and meta-porphyroids (~480 Ma) intercalated in both sequences. According to the established stratigraphy in the Austroalpine Phyllitic and Paleozoic Units (Loeschke & Heinisch 1993; Schönlaub 1993) the sedimentation ages of the TC samples should be < 530 Ma. Thus the detrital zircon ages are compatible with the previous conclusions on the ages of sedimentation. For the Defereggen Group, the detrital zircon ages from sample Ax19 indicate a maximal age of sedimentation ~520 Ma, which is younger than previously assumed. It also confirms that the Eo-Cambrian arc magmatites are not part of the Defereggen Group metasedimentary sequence. Zircon Pb-Pb protolith ages of 550 to 533 Ma were reported for these arc magmatites, e.g. hornblende gneisses from the North-Defereggen-Petzeck Group (Schulz et al. 2004) or from the Silvretta basement (Schaltegger et al. 1997).

It is widely accepted that the basement units of Western and Central Europe were located along the northern margin of Gondwana in Neoproterozoic to Early Cambrian times, as parts of a peri-Gondwanan Avalonian-Cadomian Belt (Murphy et al. 2006; Linnemann et al. 2007; von Raumer & Stampfli 2008; Nance et al. 2010). In the plate tectonic scenarios of the Early Paleozoic parts of the Alpine basement (Frisch & Neubauer 1989; Loeschke & Heinisch 1993; von Raumer & Stampfli 2008), two principal lines are followed by the reconstructions: The first line is a further refinement of the classical model of the Paleozoic paleogeography by Schönlaub (1979), with a pre-Early-Ordovician Penninic-Austroalpine active margin setting to the NW and a post-Early-Ordovician passive margin setting to the SE. The second principal line is the existence of an Early-Ordovician event of which nature and tectonic consequences are still in debate (von Raumer and Stampfli 2008; von Raumer et al. 2012). Under discussion are Early Ordovician active margin setting, continental collision, rifting and strike-slip amalgamation. Both lines of argument influence the interpretation of the detrital zircon ages in the Eastern Tyrolian Austroalpine basement. The Defereggen Group sample Ax19 which displays many similarities to sample GK4 with respect to the Neoproterozoic zircon age pattern is considered to represent a pre-Early-Ordovician sedimentary setting adjacent to a Cambrian magmatic arc. Sample TC6 represents the sedimentary and volcanic successions of the Thurntaler Phyllite Group and the other Palaeozoic units which can be related to a passive margin evolution since the Ordovician.

A major fraction of detrital zircons of the Austroalpine samples studied records magmatic or metamorphic events of the time span of 550 - 850 Ma (Fig. 7). This age group is also dominant in Neoproterozoic sediments in the Teplá-Barrandian unit of the Bohemian Massif (Drost et al. 2011), the Brotterode Group in the Saxothuringian Ruhla Crystalline Complex (Zeh & Gerdes 2010) and in the Urals (Kuznetsov et al. 2010). A detrital zircon age group 600 - 800 Ma is a common feature in the Avalonian-Cadomian Belt (Linnemann et al. 2007). The active magmatic arc of the Cadomian Belt (550 - 750 Ma) can be considered as an important source of these detrital zircons (Nance et al. 2002; Murphy et al. 2004; Linnemann et al. 2004; 2007). However, magmatic rocks of the age group 700 - 750 Ma are prominent in the post-Early-Ordovician sample TC6, while they are relatively rare in the Avalonian-Cadomian Belt (ACB). This is in contrast to the interpretation by Linnemann et al. (2007) who suggested that source rocks of such a remnant or older stage of the ACB were already eroded during the Neoproterozoic and thus do not appear as detrital zircons in younger sediments. An alternative source of the 550 - 850 Ma detrital zircons is the Arabian-Nubian shield with its various magmatites resulting from the Pan-African orogeny and subsequent rifting events, as reported by Avigad et al. (2003). The differences among the Neoproterozoic detrital zircon age populations between sample TC6 and Ax19/GK4 may be explained by the different positions of the sedimentary basins with reference to the two potential source regions, e.g. the Pan-African orogens and the Avalonian-Cadomian belt (Fig. 8).

As also observed from the other segments of the ACB (Gerdes & Zeh 2006; Linnemann et al. 2007; Drost et al. 2011), a considerable fraction of 950 - 1050 Ma detrital zircon occurs in the samples TC6 and GK4 (Fig. 7.b, c). In the Ax19 sample, the number of zircons in this age group is not so prominent, but a single peak at 950 Ma is also present in the age vs relative probability curve (Fig. 7.d). Zircons of this „Grenvillian-age" group were interpreted to have been eroded either from the Amazon craton (Friedl et al. 2000; Hegner & Kröner 2000; Fernández-Suarez et al. 2002) or from the Grenvillian Orogenic Belt (Nance & Murphy 1994; Keppie et al. 1998), which were parts of Western Gondwana and situated to the

W of the Proto-Alps (Fig. 8). However, compared to the Austroalpine basement and as it is outlined in Fig. 7.(a), the 950 - 1100 Ma zircon age population is neither very prominent in the Moldanubian, Teplá-Barrandian, Saxo-Thuringian, in Iberia with the Ossa-Morena Zone (Linnemann et al. 2008), nor in the Cadomian and Armorican units. As the latter units are situated in a more proximal position to the potential Western Gondwanan „Grenvillian-age" zircon source regions, one would expect a higher fraction of this age population compared to the Austroalpine basement, which would be more distal. Also, the „Grenvillian-age" zircon population has been described from the Lower Ordovician quartzite in the Istanbul Terrane (Ustaömer et al. 2011). These authors concluded that it could signalize a more proximal and thus comparably exotic position of the Istanbul Terrane near the West-Amazonian craton. However, according to the more recent reconstructions of the northern Gondwanan periphery, a position of the Istanbul Terrane to the E of the Proto-Alps has to be considered (Fig. 8). As a consequence of these observations it is proposed here that Western Gondwana with the Grenvillian Orogen, the West-Amazonian craton (Schneider Santos et al. 2000), and the Karelian-Uralian craton (Zeh et al. 2001) are not the source of the prominent „Grenvillian-age" zircon fraction, especially in the samples GK4 and TC6. If the Austroalpine basement represents an eastern part of the Avalonian-Cadomian Belt, the Arabian-Nubian Shield appears as a further potential source area. A significant amount of 0.9 - 1.1 Ga detrital zircons is reported in the Cambrian Nubian sandstone at Elat (Avigad et al. 2003). The authors discussed the occurrence of this detrital zircon age group as enigmatic, as igneous rocks of this age range are not yet known from the Arabian-Nubian shield. They proposed a far distance transport of boulders during Neoproterozoic glaciations. Paleozoic sedimentary basins of Eastern Gondwana, as in Western Australia, the Tethyan Himalaya or South China (Duan et al. 2010) also display very prominent 950 - 1100 Ma detrital zircon age populations (Fig. 7a). This suggests that there may have been a wide source region with plutonic rocks of corresponding ages in Eastern Gondwana, e.g. the Nubian shield or the above mentioned alternative sources (Figs. 7.a, 8). Recent paleogeographic and plate tectonic models (von Raumer et al. 2012) discuss and propose an Early-Paleozoic position of the Alpine basement units far to the east, facing the South China Block. In such a more easterly position, the Early-Paleozoic Alpine basement units would have been more proximal to the potential East Gondwanan 950 - 1100 Ma zircon source regions.

There is a marked age gap of 1100 - 1700 Ma in detrital zircons in the Austroalpine metasediments (Fig. 7.b to d). This time span represents the Sveco-Norvegian and Trans-Scandinavian orogen of Baltica (Fig. 7a). This age gap has also been observed by Zeh & Gerdes (2010) in their study of the metasediments in the Ruhla crystalline complex. Interestingly they found this „Baltica gap" only in a metapelite from the Neoproterozoic Brotterode Group of which other detrital zircons display the character of a Gondwanan source. In the Rögis Group of the Ruhla crystalline the Baltica-derived detrital zircons are abundant. It was concluded that both metasedimentary groups were attached to each other by the closure of the Rheic ocean which started from the Late Silurian onwards. As the „Baltica gap" is observed in both pre- and post-Early-Ordovician Austroalpine basement areas, this implies that both regions should have been situated far away from Baltica and furthermore at the southern margin of an Eastern Rheic ocean if it has ever existed in the eastern part of the Gondwanan periphery.

There is a considerable amount of Paleoproterozoic 1700 - 2300 Ma detrital zircon in the TC6 and GK4 samples (Fig. 7b - d). The age group is subdivided by several minor accumulations at around 1750 Ma, 1950 Ma, 2030 Ma and 2250 Ma in the sample TC6. In sample GK4 only the ~1950 Ma zircon group is obvious. This 1700 - 2300 Ma detrital zircons have been also described from Cambrian and Ordovician siliciclastics of the Teplá-Barrandian unit in the Bohemian Massif (Drost et al. 2011). In the Brotterode Formation of the Ruhla crystalline complex this age group is also present (Zeh & Gerdes 2010). By comparison, in the Montagne Noire and in the Ossa-Morena Zone this detrital zircon age group is much more prominent (Linnemann et al. 2008). The Saharan Metacraton/Trans-Saharan Basement and the West-African craton are considered as potential sedimentary source areas (Linnemann et al. 2008; Drost et al. 2011). The same source areas may also be taken into consideration for the Nubian sandstone. However, the prominent igneous zircon age group there is 1650 - 1850 Ma as discussed by Avigad et al. (2003) and therefore does not match the 1700 - 2300 Ma Austroalpine detrital zircons. According to Kuznetsov et al. (2010) and Drost et al. (2011), igneous zircon ages from the Baltic shield also cover the 1900 - 2300 Ma time span (Fig. 8). But the Baltic shield can be excluded as a provenance region due to the argument of the „Baltic gap" mentioned above. For the same reason an Eburnean (Ubendian) source in East Africa can be excluded because the regionally associated 1300 Ma Kibaran age group is missing. In line with the interpretation for other segments of the ACB, the Gondwanan and especially the West-African craton, and more likely the Sahara craton may have been the provenance areas for the post-Early-Ordovician sediments in the Austroalpine basement. Remarkably, the Paleoproterozoic zircon age group is present but only of minor importance in the pre-Early-Ordovician Defereggen Group sample Ax19. Only the age groups around 1950 Ma and 2250 Ma are present here as single zircons.

There are Neo-Archaean 2550 Ma and 2750 Ma detrital zircons in the Austroalpine pre- and post-Early-Ordovician metasediments. These distinct groups have also been described from the Saxothuringian, Teplá-Barrandian, Moldanubian domains and Mid-German Crystalline Rise (Linnemann et al. 2007; Zeh & Gerdes 2010; Drost et al. 2011). In the compilations of Zeh et al. (2001) and Linnemann et al. (2008) these zircon ages occur in the Amazonian craton. The updated compilation by Drost et al. (2011) takes also into account the Trans-Saharan Basement as a potential source region. Considering the Paloproterozoic and Neoarchean zircon distribution and age frequency in the Austroalpine basement, these similarities to other parts of the Avalonian-Cadomian Belt signal the Gondwanan Trans-Saharan Basement as a source region. Based on the „Grenvillian-age" zircon populations, apart from the Trans-Saharan belt also source regions of Eastern Gondwana should have contributed to the Early-Paleozoic Austroalpine detrital zircon populations.

8. Conclusions

The whole-rock geochemistry in combination with detrital zircon age-distributions shed light on the Early Paleozoic sedimentation history of partly highly metamorphic Austroalpine basement units south of the Tauern Window. In previous studies protolith zircon ages of mafic metavolcanics as well as of Ordovician orthogneisses and metaporphyroids served to distinguish lithotectonic units with pre-Early-Ordovician and post-Early-Ordovician ages of deposition. We found the youngest detrital zircon age group in a metarenite of the Thurntaler Group to be ca 550 Ma old whereas in the two studied metapsammites of the Gailtal Metamorphic Basement and of the Defereggen Group they are ca 520 Ma old. The sedimentation of the latter two units seems therefore to fall in a time window of Early to Late Cambrian or earliest Ordovician.

The bulk-rock composition of the pre-Early-Ordovician units shows granitoid-detritus dominated metapsammites. A continental arc is clearly indicated by major and stable trace element characteristics for the tectonic setting of deposition of these immature wackes. This suggests a sedimentation of the Defereggen, the Northern-Defereggen-Petzeck Groups and, with less confidence, of the Gailtal Metamorphic Basement paragneisses in the context of the Early-Paleozoic continental arc environment that was deduced earlier for eo-Cambrian calk-alkaline mafic educts of hornblende-plagioclase gneisses of the Rotenkogel and Prijakt units. The Nd isotopic composition shows further details and supports a younger input probably related to the arc environment. In most metarenites of the pre-Early-Ordovician units, older well-recycled crustal components with high average crustal residence ages near 2 Ga and lowest $\varepsilon_{Nd(t)}$ (-10) are predominant. For metapelites and many metawackes from these units mixing of variable proportions of old and more juvenile components are suggested by their model ages, ranging from 2.0 to 1.5 Ga, and by the wide range of $\varepsilon_{Nd(t)}$ from -10 to -4. Such large variations are considered compatible with an active tectonic environment. The narrow cluster of lead isotopes ^{207}Pb / ^{204}Pb and ^{208}Pb / ^{204}Pb against ^{206}Pb / ^{204}Pb confirm old cratonic reservoirs with near upper-crustal average Th/U ratios for the metasediments of all the units studied.

In the younger, post-Early-Ordovician, Thurntaler Phyllite Group the trace elements indicate various mafic and felsic admixtures to a very mature pelite background sedimentation that seems to be derived from a mixed source with more mafic components than in the pre-Early Ordovician sediment sources. The high maturity of the metapelites may be due to a stable, platform-type environment for the deposition of the Thurntaler Phyllite Group. The Thurntaler metapelites show a very narrow spread of Nd crustal residence ages around 1.85 Ga. A systematic trend of $\varepsilon_{Nd(t)}$ increasing from -10 to -7 correlates with an increase of the ^{147}Sm / ^{144}Nd ratio. This seems to support the concept of juvenile, probably volcanogenic mafic and felsic admixtures. The synsedimentary bimodal volcanism may point to an extensional setting.

In the three samples studied, e.g. from the Gailtal Metamorphic Basement, from the Defereggen Group and from the Thurntaler Phyllite Group, the detrital zircon age-spectra are dominated by the Neoproterozoic population of 550 to 950 Ma with a maximum around 600 to 700 Ma. The predominance of this age group indicates that a major share of the sediments was supplied from the eroding Avalonian/Cadomian Belt and/or the Panafrican Orogens. A distinct zircon population at 950 to 1050 Ma is most prominent in the Gailtal Metamorphic Basement and Thurntaler Group samples. Because of the easterly position of the proto-Alpine Terrane we dismiss a provenance of these zircons from the Amazon craton or the Grenvillian Orogenic Belt. Rather a supply of these „Grenvillian" zircons from East Gondwana sources is envisaged following records of such zircon populations in the Istanbul Terrane and in the Nubian Sandstone of Northwestern Arabia. Almost no zircons have been found in the time window from 1.1 to 1.7 Ga. This „Baltica Gap" precludes supply from Baltica. As suggested by other studies of peri-Gondwanan terranes the Paleoproterozoic and Neo-Archean populations in our zircon spectra of 1.7-2.3 Ga, 2.55 Ga and 2.75 Ga may be derived from the Saharan Metacraton/ Trans-Saharan Basement or even the West-African craton. The lack of 1.3 Ga Kibaran ages probably excludes the distant transport from East-African sources for these very old zircons in the Austroalpine paragneisses.

Acknowledgements

The authors enjoyed the great hospitality of S. Michelitsch (Erlsbach, St. Jakob in Defereggen) and other families in Eastern Tyrol during many years of long-term fieldwork and sampling. We also acknowledge the contributions and cooperation of numerous colleagues in the projects on the Austroalpine basement not to forget the support by the Geologische Bundesanstalt, Vienna. The German Science Foundation funded our studies in the Austroalpine basement for a long period and in numerous single projects.

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Manuscript submitted: 5.2.2013
Revised manuscript accepted: 4.3.2013