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Schists and Amphibolites of the Kleinelendtal (Ankogel-Hochalm-Gruppe/Hohe Tauern, Austria) / New Insights on the Variscan Basement in the eastern Tauern Window

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Abstract

In the Kleinelendtal/Ankogel-Hochalm-Group (eastern Tauern Window) pre-Mesozoic units are well preserved. These units comprise Variscan orthogneisses (the Zentralgneise) and their host rocks, the “Pre-Zentralgneis-Complexes” (formerly “Altes Dach”).

The “Pre-Zentralgneis-Complexes” comprise the “Zwischenelendschiefer” (biotite-schists, garnet-micaschists and sericite-schists) and amphibolites. Their contacts with the Zentralgneise are mostly concealed by debris- and rock flows or overprinted by shear zones and faults. Preserved primary contacts are rare. Characteristic of the biotite-schists are biotite-blasts of golden colour due to weathering. Besides this biotite, quartz, plagioclase, potassium feldspar, white mica, and chlorite also calcite, garnet, magnetite/ilmenite, titanite, and zircon are present.

Its whole rock analysis shows an intermediate chemism. The calculated initial $^{87}Sr/^{86}Sr_{(360\ Ma)}$-value of 0.70676 ± 0.000004 and an $\varepsilon Nd_{(360\ Ma,\ CHUR)}$ of -1.8 indicate that considerable amounts of juvenile crust/mantle material have been added to the sedimentary protolith.

Detrital zircons from the biotite-schists yield an U/Pb – LA-MC-ICP-MS maximum age of sedimentation of 360 ± 13 Ma for the host sediment, confirming that the “Zwischenelendschiefer” do not date back to pre-Variscan times or even earlier. This suggests a close relationship with the units of the central Tauern Window, i.e. the so-called Biotitporphyroblastenschiefer of the Granatspitz-Group.

Garnet-micaschists crop out adjacent to the biotite-schists. Major- and minor constituents are white mica, quartz, chlorite, and garnet; accessory minerals magnetite/ilmenite and titanite.

The appearance of sericite-schists is limited to a few outcrops. They are leucocratic crumbly rocks that are made up of sericite, quartz, and biotite.

The amphibolites show metamorphic banding and fine-grained mineral contents of hornblende, epidote-group minerals, and plagioclase, furthermore titanite, rutile, and magnetite/ilmenite. Main- and trace elements shows a basaltic chemism. The initial $^{87}Sr/^{86}Sr_{(360\ Ma)}$ -ratio is 0.70525 ± 0.000004 and the $\varepsilon Nd_{(360\ Ma,\ CHUR)}$ is +5.3. Thus the amphibolites are interpreted to be meta-magmatic. Furthermore also the amphibolites of the Kleinelendtal are geochemically similar to the Basisamphibolit of the central Tauern Window which again proposes a genetic relationship between these units.

All lithologies of the Pre-Zentralgneis-Complexes have been overprinted in multiple phases; the latest thermal event was a retrograde greenschist-facies metamorphism which is evident by new growth of chlorites, epidote-group minerals and albite.

Due to the Late Devonian maximum sedimentation age of the biotite-schists there is no evidence for the existence of pre-Variscan lithologic units within the Kleinelendtal, contrary to any former interpretations of the regional geology. Thus a position within the Variscan orogenic cycle is proposed for the genesis of some parts of the wall rocks of the Zentralgneise. This is in line with the dating-results of the Basisamphibolit and Biotitporphyroblastenschiefer in the central Tauern Window.

Im Kleinelendtal/Ankogel-Hochalm-Gruppe (östliches Tauernfenster) finden sich gut erhaltene prä-mesozoische Einheiten, welche variszische Orthogneise (die Zentralgneise) und ihre Nebengesteine, das so genannte „Alte Dach“, hier als „Prä-Zentralgneis-Komplex“ bezeichnet, umfassen.

Der teilweise migmatische Prä-Zentralgneis-Komplex beinhaltet die „Zwischenelendschiefer“ (Biotit-Schiefer, Granat-Glimmerschiefer und Serizit-Schiefer) und die Amphibolite. Ihre Kontakte zu den Zentralgneisen sind meist von Schuttströmen verdeckt und/oder durch Störungen und Scherzonen überprägt. Charakteristisch für den Biotit-Schiefer sind, aufgrund von Verwitterung, golden gefärbte Biotit-Blasten. Daneben sind Quarz, Plagioklas, Kalifeldspat, Hellglimmer und Chlorit, außerdem Kalzit, Granat, Magnetit/Ilmenit, Titanit und Zirkon im Dünnschliff zu beobachten.

Die Gesamtgesteinsanalyse zeigt einen intermediären Chemismus. Der berechnete $^{87}Sr/^{86}Sr_{(360\ Ma)}$ - Initialwert von 0.70676 ± 0.000004 und ein $\varepsilon Nd_{(360\ Ma,\ CHUR)}$ von -1.8 belegen eine Beimengung von beachtlichen Mengen juveniler Kruste bzw. Mantelmaterial zu seinem sedimentären Protolith.

Die Datierung detritärer Zirkone aus dem Biotit-Schiefer mittels LA-MC-ICP-MS liefert ein U/Pb - Maximalalter für die Ablagerung des Ausgangssediments von 360 ± 13 Ma, was bestätigt, dass die „Zwischenelendschiefer“ nicht bis in prä-variszische Zeiten zurückreichen. Dieses Ergebnis zeigt deutlich eine direkte Verwandtschaft mit Einheiten des zentralen Tauernfensters, genauer mit

den Biotitporphyroblastenschiefern der Granatspitz-Gruppe.

Granat-Glimmerschiefer sind direkt neben den Biotit-Schiefern aufgeschlossen. Ihre Haupt- und Nebenbestandteile sind Hellglimmer, Quarz, Chlorit und Granat. Als Akzessorien wurden Magnetit/Ilmenit und Titanit identifiziert.

Der meist sehr brüchige Serizit-Schiefer ist auf einige wenige Aufschlüsse begrenzt, zeichnet sich durch seine schimmernde Oberfläche aus und besteht hauptsächlich aus Serizit, Quarz und Biotit.

Die Amphibolite sind metamorph gebändert und weisen einen feinkörnigen Mineralbestand von Hornblende, Epidot-Gruppen-Mineralen und Plagioklas auf. Außerdem treten Titanit, Rutil und Magnetit/Ilmenit akzessorisch auf. Die Haupt- und Nebenelement-Analyse ergibt einen basaltischen Chemismus. Weiters charakterisieren das initiale $^{87}Sr/^{86}Sr_{(360\ Ma)}$ - Verhältnis von 0.70525 ± 0.000004 und das $\varepsilon Nd_{(360\ Ma,\ CHUR)}$ mit +5.3 die magmatischen Edukte des Amphibolits. Zudem ist der Amphibolit des Kleinelendtales in seiner Geochemie dem Basisamphibolit des zentralen Tauernfensters sehr ähnlich was als genetische Verwandtschaft dieser Einheiten interpretiert wird.

Alle Lithologien der Prä-Zentralgneis-Komplexe wurden in mehreren Phasen überprägt; zuletzt retrograd in einer grünschieferfaziellen Metamorphose, die durch das Auftreten von Chlorit, Epidot-Gruppen-Mineralen und Albit angezeigt wird.

Durch die Datierung eines maximalen Sedimentationsalters des Biotit-Schiefers ins späte Devon konnte im Kleinelendtal gezeigt werden, dass im Alten Dach der Zentralgneise nicht nur prä-variszische Gesteine vertreten sind. Somit kann für das Nebengestein der Zentralgneise bereichsweise eine Stellung innerhalb der variszischen Orogense angenommen werden, was auch im Einklang mit den Altersdatierungen des Basisamphibolits und der Biotitporphyroblastenschiefer im zentralen Tauernfenster ist.

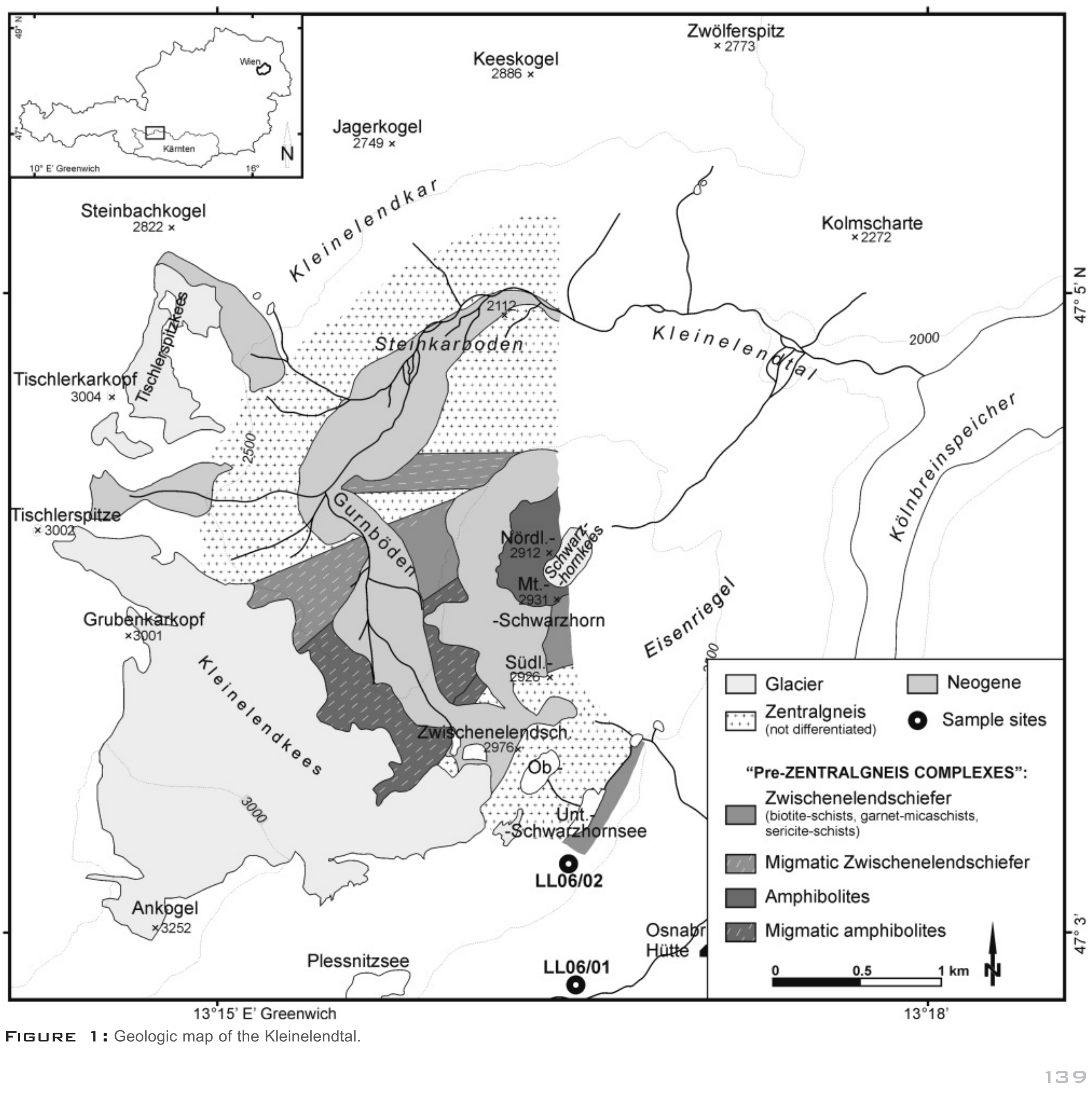

FIGURE 1: Geologic map of the Kleinelendtal.

1. Introduction

The Kleinelendtal is located in the backmost part of the Maltatal in the Ankogel-Hochalm-Gruppe in the north of Carinthia at the border to Salzburg (see section in Fig. 1).

Amongst those who did previous research in this area the work of Angel and Staber (1952) has to be mentioned particularly. To this date their map is still the only one giving an entire overview of the geology between Bad Gastein in the northwest, Mallnitz in the south and the upper Maltatal in the east. Holub and Marschallinger (1988) established a relative intrusive sequence within the different types of the Zentralgneise of the Großelend- and Maltatal and described them in detail.

The aim of this study was to map the distinct lithologic complexes and to provide new data on their age and genesis and to compare them with similar lithologic units ("Basisamphibolit" and "Biotitporphyroblastenschiefer") in the central Tauern Window. Thus the lithological units in the Kleinelendtal were mapped at a scale of 1:10,000 and were further characterized by thin section studies, geochemical analyses and in-situ U/Pb dating of detrital zircons.

2. Geologic overview

The working area is situated in the eastern part of the Tauern Window which, with its size of 160 km x 30 km, is the biggest one of the intra-Alpine tectonic windows. According to Schmid et al. (2004) it exposes sub-Penninic basement units (Venediger Nappe System; Frisch, 1976, 1977) overlain by the Penninic nappes (Glockner Nappe System, Staub, 1924; and the nappe system Matreier Zone-Nordrahmenzone, Schmidt, 1950, 1951, and 1952; Frisch et al., 1987; Pestal and Hejl, 2009). The frame of the window is formed by Lower Austroalpine thrust-sheets, which have been overridden by the main mass of the Upper Austroalpine nappes.

2.1 Venediger Nappe System

The Venediger Nappe System comprises basement units of the European crust pre-Variscan or Variscan in age which is overlain by Carboniferous to Cretaceous rock formations (?). The basement components are called "Altkristallin" ("Zwölferzug and Alte Gneise"), Stubach Group and Habach Formation in the central Tauern Window (= Storz Group in the eastern and Greiner Formation in the western Tauern Window), (e.g. Cornelius and Clar, 1939; Frasl, 1958; Frasl and Frank, 1966; Exner, 1971; Lammerer, 1986; Frisch and Neubauer, 1989), which represent the pre-Permian host rocks of Variscan granitoid intrusions (Zentralgneise).

2.1.1 Basement components of the Venediger Nappe System/Pre-Zentralgneis-Complexes

Habach Formation and Stubach Group:

According to Höck (1993) the Habach Formation (Frasl, 1958) is divided into the ophiolitic complex, the island arc sequence and the Eiser Sequence (see also Fig. 2; there the term "sequence" was changed into "formation" due to new terminology).

The ophiolites include the Lower Magmatic Sequence (Kraiger, 1987; 1989) and the "Basisamphibolit" (Cornelius and Clar, 1939; Frank, 1969; Frisch and Raab, 1987), the latter also being termed Stubach Group (Frisch and Raab, 1987; Frisch and Neubauer, 1989). It frames the Zentralgneis of the Granatspitz and includes layered coarse grained amphibolites (metagabbros) as well as layered ultrabasic rocks of the En-

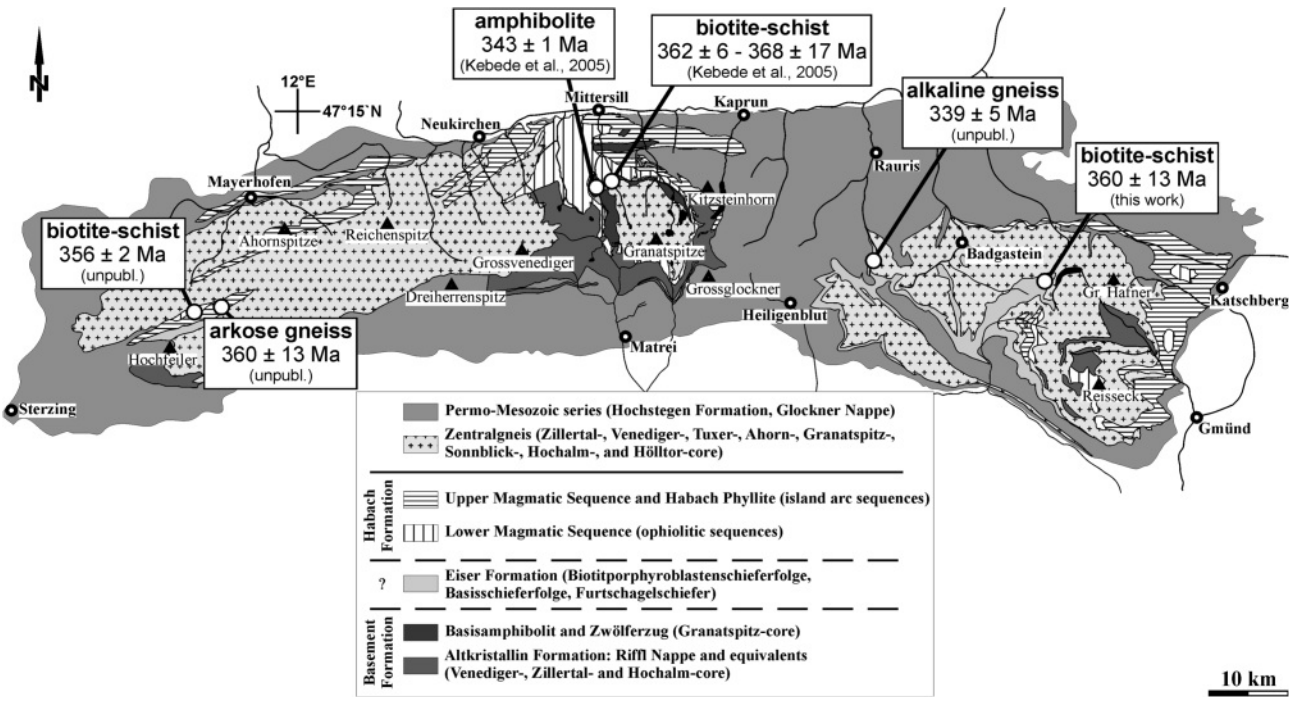

Figure 2: Modified after Höck (1993): Geologic overview of the Tauern Window with recent U/Pb-zircon geochronological data (unpubl. data by Kloetzli).

zinger Boden in the Stubach valley. Also the Zwölferzug, a sequence of garnet-bearing amphibolites and amphibole-bearing gneisses, strongly metamorphosed by a pre-Alpine metamorphism (the so called "Altkristallin"), (Frasl, 1958), is assigned to the ophiolites by Höck (1993) for simplicity.

The Greiner ultramafics (Lammerer, 1986) in the western part of the Hohe Tauern and small ultrabasic and gabbroic rocks of the Storz Formation in the easternmost sections (Exner, 1971; Stadlmann, 1990) between Hochalmspitze and Katschberg are also probably part of the ophiolitic complex.

The island arc sequence which equals the Upper Magmatic Sequence including the "Habachphyllites" (Kraiger, 1989) consists of a variety of metamorphosed intermediate to acidic lavas, sub-volcanic dikes, tuffs, and associated sediments. Again comparable rocks are widely distributed in the western and eastern parts of the Tauern Window.

The Eiser Sequence is identical with the so called Biotitporphyroblastenschiefer (Cornelius and Clar, 1939) or Basisschieferformation (Höll, 1975; Kupferschmied and Höll, 1994). It is unconformably overlying the Basisamphibolit at the ridge between Brentling and Kleinem Schankeck in the vicinity of the old Felbertal scheelite mine (Pestal, 1983). The Biotitporphyroblastenschiefer are considered to be an independent unit consisting of biotite-rich schists, former pelitic and psammitic sediments (although overprinted by multiphase tectono-metamorphic events, original sedimentary structures like graded bedding, is conserved), graphitic quartzites, garnet-bearing micaschists and acidic, basic and some intermediate volcanic intercalations. Apart from their distribution on top of the Basisamphibolit, these rocks appear in the Hüttwinkl valley (= southern part of the Rauris valley), (Exner, 1962) and at the rims of the "Göß-Zentralgneis" ("Draxel-Complex"; Exner, 1971, 1980; Pestal et al., 2006) in the Eastern Tauern Window. Equivalents in the western part of the Tauern Window are the Furtschagelschiefer (Christa, 1931) in the Greiner Formation (Vesela and Lammerer, 2008).

The Storz Group (Exner, 1971; 1980) in the eastern Tauern Window differs from the Habach Formation by virtue of its great proportion of paragneisses. It appears in structural synforms south of the large dome-shaped Zentralgneis body of the Hochalm-Göß area and in the Storz Nappe. Banded mesocratic to leucocratic biotite-plagioclase gneisses of detrital and in parts volcano-detrital origin constitute the major rock type. They are intercalated with basaltic amphibolites and acidic orthogneisses. Gabbroic amphibolites in the upper part of this group are associated with very small slices of ultramafic material.

U/Pb zircon data from Kebede et al. (2005) suggest that the magmatic protoliths of the Basisamphibolit were formed as pulses of different basic magmatism during Late Devonian to Early Carboniferous times (351-343 Ma). Thus magmatic protolith ages of the Basisamphibolit are coeval with the oldest lithologies of the Upper Magmatic Sequence of the Habach Formation. The volcanic island arc geochemical features of the Upper Magmatic Sequence compared to the MORB affinity of the Basisamphibolit (Höck, 1993) rules out any direct petrogenetic relationship (Kebede et al., 2005).

The Biotitporphyroblastenschiefer have been subordinated as a part of the "Habach Formation" by some authors (Söllner et al., 1991; Peindl and Höck, 1993; Eichhorn et al., 1995, 1999, 2000; Loth et al., 1997). But this rock formation overlying the Basisamphibolit as a layer of 500 m maximum thickness is not comparable to the true "Habachphyllites". Some typical examples of the lithologies of the Biotitporphyroblastenschiefer show affinities to Lower Carboniferous turbiditic sediments deposited during the Variscan orogeny (Frank, pers. com.; Pestal and Hejl, 2009). Their Variscan and pre-Variscan ages (concordant 351 to 360 Ma, 471 Ma, 613 Ma and 1795 Ma $^{207}Pb/^{206}Pb$ ages) obtained from detrital grains suggest a sedimentary provenance with a wide range of age distribution (Kebede et al., 2005).

The presence of abundant detrital zircons in the garnetiferous leucocratic gneiss of the Zwölferzug and its ages (maximum sedimentation age of 358 Ma) older than that of the garnet amphibolite (magmatic protolith age of 486 Ma; von Quadt, 1992) strongly suggest a sedimentary origin of the unit (Kebede et al., 2005). The garnet amphibolite of the Zwölferzug formed synchronously with the Lower Magmatic Suite of the Habach Formation at the margin of Gondwana, predating the opening of the Paleo-Tethys in the Early Silurian (Stampfli andBorel, 2002), constituting part of the "European Hun Terranes" and thus representing pre-Variscan basement rocks in the Tauern Window.

On the other hand, the Upper Magmatic Sequence with for-

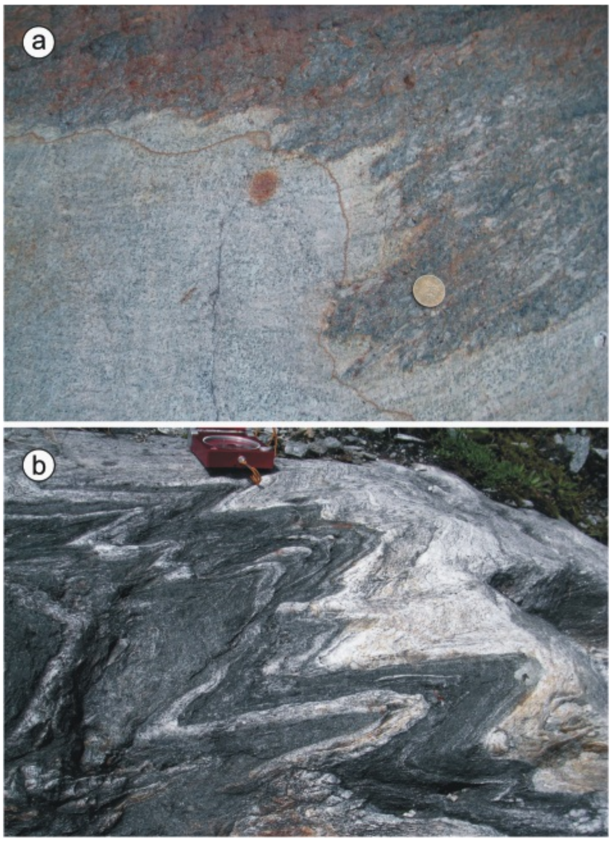

Figure 3: (a) Primary intrusive contact of the Kölnbreinleukogranit (left hand) and the garnet-micaschists. (b) Folded amphibolite with leucocratic layers of Zentralgneis.

mation ages generally ranging from the Lower Carboniferous to the Early Permian (355-380 Ma; Söllner et al., 1991; Vavra and Hansen, 1991; Peindl and Höck, 1993; Eichhorn et al., 1995, 1999, 2000; Loth et al., 1997) and the magmatic protoliths of the Basisamphibolit may have been formed during the Variscan orogeny (Kebede et al., 2005).

2.1.2 Zentralgneis (Complex)

The Zentralgneise are metamorphosed Variscan granitoids that have intruded the basement rocks during Permo-Carboniferous times (325-250 Ma after Cliff, 1981; Kebede et al., 2005) at the southern flank of the Variscan orogen. Paleogene metamorphism and deformation during the Alpine orogeny and exhumation strongly modified the shapes of the granitoid bodies to elongate gneiss cores (Lammerer and Weger, 1998).

In the eastern Tauern Window the Zentralgneise are exposed in the Sonnblick Massif (Exner, 1964) and the Badgastein-Hochalm Massif (or Hochalm-Ankogel Massif; Holub and Marschallinger, 1989).

3. Petrography

In the working area the host rocks of the Zentralgneise, i.e. the Zwischenelendschiefer and the amphibolites are united in the “Pre-Zentralgneis-Complexes”.

3.1 Zentralgneis (Complex)

The Zentralgneise of the Großelendtal were investigated in detail by Holub and Marschallinger (1988). The classification and intrusive sequence of the different types of Zentralgneise described by these authors can also be applied to the Variscan granitoids in the Kleinelendtal due to the visible cross-cutting-relationships and therefore will not be discussed in detail. These are the Großelendflasergranit (Holub, 1987), Maltatonalit (Marschallinger, 1987), Hochalmporphyrgranit (Exner, 1982), and Kölnbreinleukogranit (Holub, 1987).

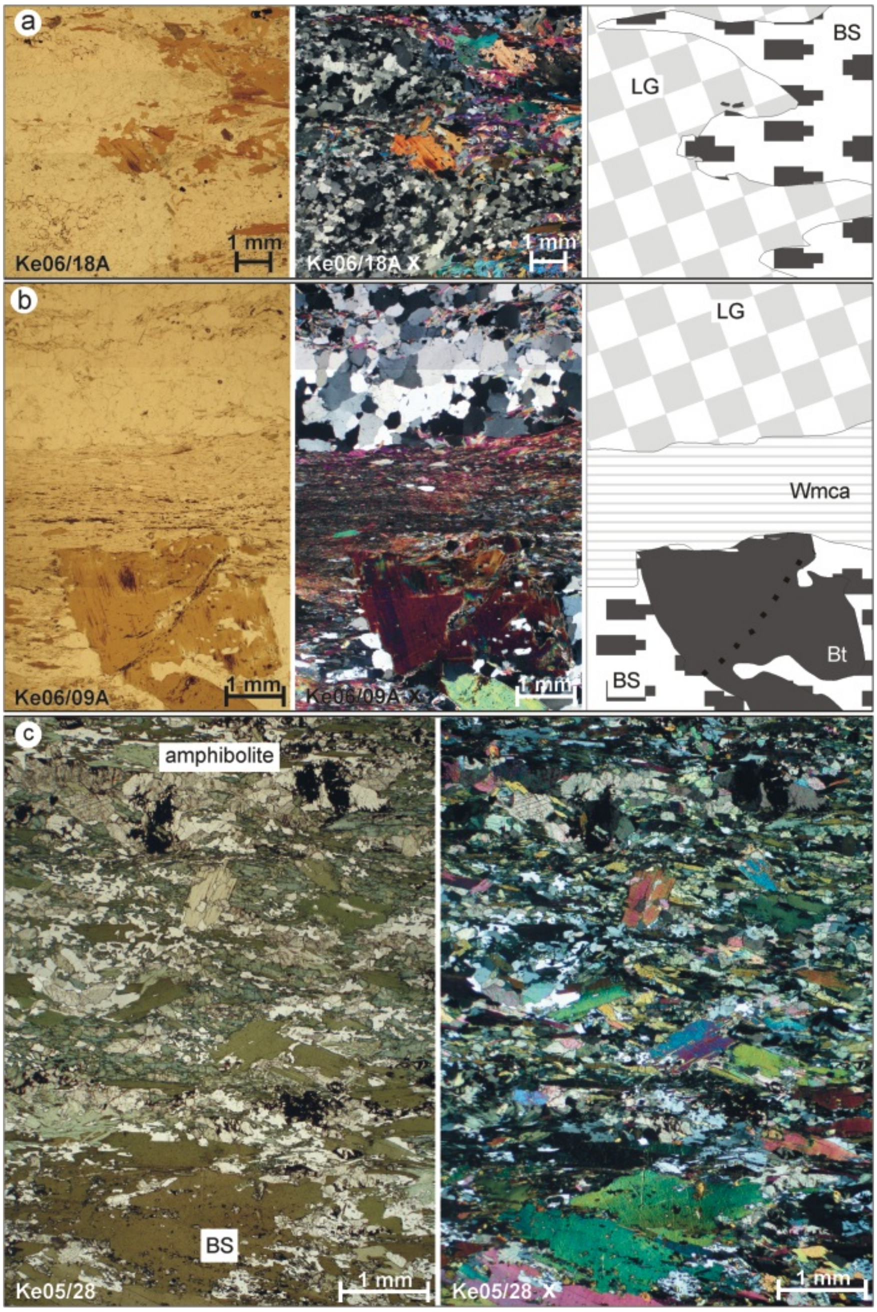

Figure 4: Primary (a) and overprinted (b) contact zone of the biotite-schists (BS) and the Kölnbreinleukogranit (LG) and contact zone between the amphibolites and biotite-schists (c).

3.2 “Zwischenelendschiefer” (nom. nov.)

The new term “Zwischenelendschiefer” (named after the area between the U. Schwarzhornsee and the Gurnböden, that is known as the “Zwischenelend” which marks the pass from the Kleinelendtal to the Großelendtal) has been introduced due to the local importance of these now well dated host rocks of the Zentralgneise. This rock complex comprises biotite-schists, garnet-micaschists, and sericite-schists.

3.2.1 Biotite-schists

These schists are predominantly characterised by their large biotite-porphyroblasts that have a unique golden colour most likely due to weathering. The type-locality is situated directly at the southern edge of the Unterer Schwarzhornsee where the biotite-schists crop out with a prominent striking foliation dipping 35-45° towards NW. At the contact zones with the Zentralgneise the biotite-schists are partly altered due to contact metamorphism (see also section “Schist-Zentralgneis – contacts”).

Thin section analyses show recrystallisation of the mineral assemblage, but due to the huge proportions of mica and accessory minerals grain enlargement by grain boundary migration has been inhibited.

Depending on the degree of deformation the biotite-blasts are rolled out and elongated or they are more or less undeformed and form augen within the matrix. These sometimes rotated augen are surrounded by white mica forming the schistosity whereas the resulting strain shadows are filled with quartz. Biotite is interpreted to be syntectonic and is chloritised. Additional alteration products of the biotite are clinozoisite, titanite, quartz, and white mica and it shows fractures normal to the schistosity. Quartz has recrystallised forming veins and ribbons with healed grains with even grain boundaries. Potassium feldspar is identified by its typical exsolution lamellae. Garnet shows at least a two-phase evolution with idiomorphic secondary rims. Within the matrix smaller garnets can be found that may be of the same origin as the rims. Garnet partly has decomposed to white mica, chlorite, and opaque mineral phases. Remarkably is the lack of graphite and any gradation.

3.2.2 Garnet-micaschists

The main differences between the biotite-schists and the garnet-micaschists are the higher proportions of white mica in the micaschists, which is also visible in hand specimen, and coarser grained garnets. The garnet-micaschists can be found at the south-eastern edge of the map (Fig. 1) near the Unterer Schwarzhornsee and throughout the highest parts of the Kleinelendtal. In zones affected by ductile shearing the partly crenulated schists also show the prominent NE-SW striking foliation dipping 35-45° towards NW.

The schists are composed of thin and platy white mica crystals that can be divided into two groups: an older one forming the schistosity that bends around the garnet and younger platy crystals within the garnet that probably have formed due to its decomposition. Biotite is orientated parallel to the schistosity, mostly transformed to chlorite, partly converted to titanite. A magnetite/ilmenite-fringe, whereas titanite itself has decomposed to ore minerals, might be present. Quartz occurs in two different generations: older, large, and strain free crystals which are elongated and show grain boundary migration and very young quartz that shows undulose extinction. Additionally, recrystallised quartz can be found in the strain shadows of rotated garnet. Potassium feldspar crystals are characterised by their cloudy appearance, exsolution lamellae and partly preserved twins. They are recrystallised and heterogeneously distributed, clustered in nests and layers. Like in the biotite-schists, garnet shows a two-phase evolution, observable along its rims. Larger ones show an internal schistosity rotated during subsequent simple shear. The cracks within the garnets are all oblique to the schistosity. Garnet has decomposed to chlorite, ore minerals, and epidote-group minerals.

Two populations of ore minerals (magnetite, ilmenite) must be distinguished: an older one with small, acicular columns that are orientated in the direction of the schistosity. These can be found as inclusions in garnet. The younger one forms larger crystals (100-150 µm) which have grown oblique to the schistosity. The ore minerals have formed at the expense of biotite and possibly hornblende. Like in the biotite-schists graphite and any gradation are missing.

From textures two distinct overprinting events can be identified: Firstly an event where static recrystallisation has occurred (healed quartz veins) and secondly a deformation event that has caused folding and the crenulation cleavage. Finally, the penetrative fabrics have been cross-cut by quartz veins.

3.2.3 Sericite-schists

This very fine grained rocks crop out only between the Südliches and the Mittleres Schwarzhorn. They consist mainly of lepidoblastic minerals like sericite and chlorite, secondary biotite and accessories like epidote-group minerals, zircon, apatite, titanite and magnetite/ilmenite.

Very fine grained white mica has developed a web that is dominating the whole rock and that has partly grown together with the biotite. Quartz forms large grains with straight boundaries and triple junctions.

Schist-Zentralgneis – contacts:

The contact of the Variscan intrusions to their respective wall are mostly tectonically overprinted, so only a few localities are found where primary intrusive contacts can be investigated (Fig. 3a, 4a). Primary contacts show the Kölnbreinleukogranit interfingering with the schists. No mentionable contamination of the Zentralgneis by biotite or other components can be observed (outcrop at the Gurnböden, Fig. 3a).

The leucocratic granite has intruded as discordant veins and can be found as schlieren. In those parts that have been deformed during late Variscan and Alpine orogeny, also the veins have undergone this overprint and now show a foliation parallel to that of the surrounding schists. Folding of these parts has resulted in a migmatite-like appearance of the rock: leucocratic schlieren resembling the neosome and the schists resembling the paleosome. In some parts the wall rocks have been heated up by the intrusions, such that recrystallisation of minerals is macroscopically visible (like blastesis of biotite and feldspar). Classic in-situ migmatites were not found in the Kleinelendtal. Sometimes a thick layer of white mica forms the transition of the biotite-schists and the Kölnbreinleukogranit which can be explained by deformation along the lithological boundary (Fig. 4b).

3.3 Amphibolites

The second type of wall rocks of the Zentralgneise are mostly banded amphibolites. Due to their dark colour the amphibolites can even be traced from the distance like those at the summit of the Nördliches Schwarzhorn.

3.3.1 Banded amphibolites

Banded amphibolites consist of pale and dark bands both of a thickness of some centimetres. This layering is primarily a metamorphic fabric and secondarily related to intrusion of the Zentralgneise. Due to overprinting deformation it gets challenging to differentiate between the primary layering and the dikes of Zentralgneis that cut through the amphibolite. The Zentralgneis can only be positively identified in thin sections where its characteristic mineral components (like the typical potassium feldspar-flasern and the rolled out biotite of the Großelendflasergranit (Holub, 1987), or the very rare amounts of biotite in the Kölnbreinleukogranit (Holub, 1987)) can be observed.

The major constituent apart from plagioclase and quartz is mainly green hornblende. These are either fine grained and hypidiomorphic or large crystals with idiomorphic head-sections. Decomposition to epidote-group minerals and biotite is common. They are orientated parallel to the main schistosity. The different sizes of hornblende crystals can be traced back to different deformation degrees in distinct shear zones.

Rounded plagioclase crystals may show the common inclusions of epidote-group minerals that are tracing the former zoning. Recrystallised quartz with inclusions such as zircon occurs in ribbons of fluctuating amounts. Biotites have consistently decomposed to chlorite. Secondary alteration products are also epidote, quartz, and calcite. Biotite has not just been generated by the alteration of hornblende, but has been also newly formed in fluid-affected zones within the amphibolite. Biotite-crystals are often kinked indicating subsequent deformation at low grade conditions.

Epidote-group minerals can be found throughout the lithology forming rounded, small crystals. There are at least two different generations: the younger one forming inclusions within the biotite and plagioclase and older epidote forming boudins (or pinch- and swell structures). Accessory minerals (rutile, titanite) are also products of the alteration of biotite. They are mainly found along the rims of the biotites.

Amphibolite-Zentralgneis – contact:

Like the primary contacts between the schists and Zentralgneise these are also overprinted and mostly folded, thus mimicking migmatites (Fig. 3b). The contacts are sharp with only little contamination of the Zentralgneis by hornblende and biotite i.e. without gradation from one lithology into the other.

Amphibolite-schist – contact:

The Zwischenelendschiefer and amphibolites are occurring in an alternating succes-sion. The contact zone of, for example the biotite-schists and the amphibolite, is just the transition of of the first lithology into the second. No sharp contact is visible (Fig. 4c). (For the interpretation see chapter 6.)

	LL06/01	LL06/02
SiO_2	63.38	49.28
TiO_2	0.74	1.13
Al_2O_3	16.26	15.26
Fe_2O_3	6.92	11.86
MnO	0.15	0.20
MgO	2.77	6.38
CaO	2.56	11.73
Na_2O	3.33	2.30
K_2O	2.09	0.39
P_2O_5	0.11	0.13
LOI	1.39	1.15
sum	99.70	99.81
Nb	14	8
Zr	196	83
Y	35	30
Sr	230	307
Rb	79	18
Pb	20	20
Ga	25	23
Zn	84	88
Cu	39	39
Ni	34	124
Co	19	47
Cr	84	354
Sc	21	39
V	116	307
Ce	49	12
Ba	573	72
La	22	11

Table 1: Whole rock main [in wt%] and trace [in ppm] element analyses of the biotite-schists (LL06/01) and the amphibolites (LL06/02).

3.3.2 Hornblende-cumulates/gabbros

In-situ parts of this lithology were mapped at only two locations. Within a debris flow fan at the northern flank of the Nördliches Schwarzhorn and south-western of the Unterer Schwarzhornsee.

These gabbroic and more or less monomineralic hornblendeaggregates look unndeformed due to their massy fabric. They thus might be regarded as a mafic member of the Variscan intrusions (i.e. cumulates and/or a gabbroic intrusion).

The large (up to one cm in diameter) hornblende crystals have decomposed to chlorite (+ epidote, quartz, calcite, and titanite at the rims) and show inclusions of magnetite/ilmenite and a marginal alteration to hematite.

Biotite in cracks also seems to have evolved from the amphibole. Plagioclase forms fine grained, recrystallised (?) crystals that are full of inclusions of epidote-group minerals and sericite. Rutile-crystals can be found in three different textural populations; first with (sub)idiomorphic crystals, a second with bigger, corroded crystals and thirdly as grids of sagenite that have developed due to decomposition of a Ti-rich biotite.

4. Geochemistry

4.1 Data acquisition

The whole rock main- and trace element concentrations of the biotite-schists (LL06/01) and the amphibolites (LL06/02) were determined by X-ray fluorescence analyses. Additionally, the Rb/Sr and Sm/Nd isotope systematics were measured (Tab. 1 and Tab. 2).

The isotope analytical work followed conventional procedures (Gallien et al., 2010).

A $^{87}Sr/^{86}Sr$ ratio of 0.710252 ± 0.000005 (n=8) was determined for the NBS987 (Sr) and a $^{143}Nd/^{144}Nd$ ratio of 0.511844 ± 0.000002 (n=8) for the LA JOLLA (Nd) international standard during the period of investigation. Within-run mass fractionation was corrected for $^{86}Sr/^{88}Sr$ = 0.1194 and for $^{146}Nd/^{144}Nd$ = 0.721903. Uncertainties on the isotope ratios are quoted as 2σm.

4.2 Interpretation

The analysed samples were plotted together with samples analyzed by Frisch and Raab

(1987), Gilg et al. (1988) and Eichhorn (1995) from the central Tauern Window to show their geochemical relations and to be able to classify the biotite-schists and amphibolites and put them into a regional context.

Volcanic rocks can be classified using the total alkalis versus silica diagram of Cox et al. (1979). In Fig. 5a this diagram shows that the amphibolites of the Kleinelendtal have a basaltic chemism and that they are comparable with the amphibolites of the Felbertal-tungsten-mine (metagabbroic rocks; Frisch and Raab, 1987). Further, the Basisamphibolit east of the Felbertal (Frisch and Raab, 1987) has a similar geochemical pattern. The basaltic chemism points to an ortho-amphibolite.

Another attempt to distinguish between ortho- and para-amphibolites was made by Leake (1964). He used the systematic variation between Ti and Cr, Ti and Ni and also Cr and Ni: basic igneous rocks show negative correlations between Ti and Ni, and also between Ti and Cr, whereas pelite-dolomite or pelite-limestone mixtures show a positive correlation between Ti and Ni, and between Ti and Cr. For a better illustration of these relationships the data points from the amphibolites (LL06/02) and biotite-schists (LL06/01) were again plotted together with reference samples (both of igneous and sedimentary origin).

It is obvious that the amphibolites are of an igneous origin and the biotite-schists are metasediments as they are plotting together with the reference samples (Fig. 5b + c).

The isotopic analyses support the above mentioned assumptions. A positive ε_tNd-value is indicative for mantle-affinity. Most non-enriched mantle reservoirs plot in the upper left "depleted" quadrant whereas most crustal rocks plot in the lower right "enriched" quadrant (DePaolo and Wasserburg, 1976), (Fig. 6).

The age corrected ε_tNd vs $^{87}Sr/^{86}Sr$ diagram for t = 360 Ma shows the mantle-derivation of the amphibolites (LL06/02) and two reference samples (amphibolites from the Basisamphibolit; Eichhorn, 1995). Considering the amphibolites (LL06/02) with

	LL06/01	LL06/02
Rb [ppm]	73.00	9.08
Sr [ppm]	227.00	321.00
$^{87}Rb/^{86}Sr$	0.930	0.082
$^{87}Sr/^{86}Sr$	0.711526	0.705673
$+/-2s_m$	0.000004	0.000004
$^{87}Sr/^{86}Sr_{360Ma}$	0.706760	0.705253
Sm [ppm]	5.29	2.89
Nd [ppm]	24.8 0	10.50
$^{147}Sm/^{144}Nd$	0.129	0.166
$^{143}Nd/^{144}Nd$	0.512385	0.512836
$+/-2s_m$	0.000002	0.000002
$^{143}Nd/^{144}Nd_{360Ma}$	0.512081	0.512445
e_tNd $_{(360Ma, CHUR)}$	-1.82	+5.28

Table 2: Whole rock Rb/Sr- and Sm/Nd-isotopic analyses and calculated initial $^{87}Sr/^{86}Sr$- and initial $^{143}Nd/^{144}Nd$-ratios and ε_tNd-values (initial t = 360 Ma) of the biotite-schists (LL06/01) and the amphibolites (LL06/02).

its ε_tNd-value of +5.3 as the upper endmember, the ε_tNd-value of -1.82 of the biotite-schists indicates that substantial amounts of juvenile crust have been added to the sediments.

5. Geochronology

5.1 Data acquisition

For geochronological dating using the U/Pb method in combination with in-situ LA-MC-ICP-MS (laser ablation – multi collector – inductively coupled plasma – mass spectrometry) single zircon grains were separated following conventional methods. From the biotite-schists (LL06/01) 255 zircons, classified by their translucence and grain size, were hand-picked and mounted. Cathodoluminescence (CL) pictures were taken of the grains to obtain information about internal structures of the zircons.

Zircon $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages were determined using

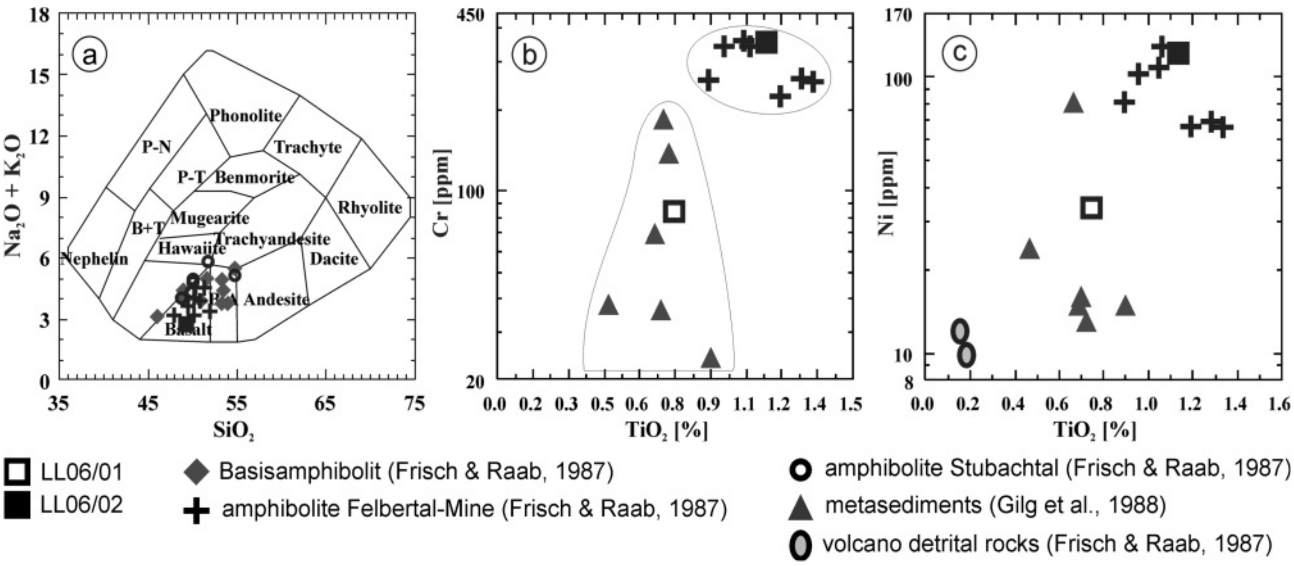

Figure 5: a: Chemical classification of the biotite-schists (LL06/01) and the amphibolites (LL06/02) with reference samples from the central Tauern Window. a: Alkali vs. SiO2 diagram after Cox et al. (1979); b + c: Trace element pattern sensu Leake (1964).

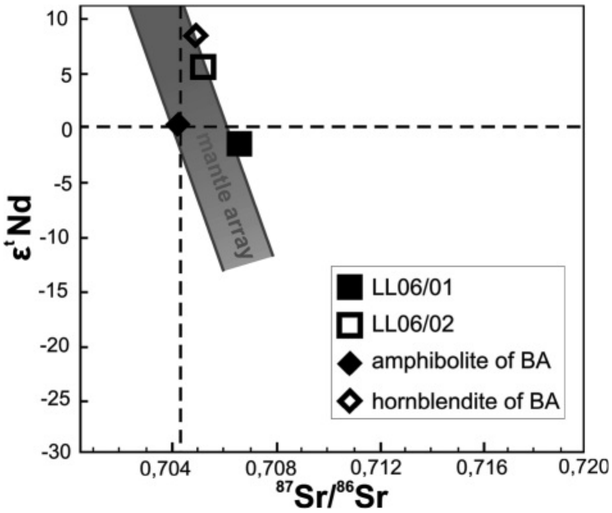

Figure 6: Age corrected ε_tNd vs. $^{87}Sr/^{86}Sr$ diagram for t = 360 Ma with reference data from Eichhorn (1995); (BA = Basisamphibolit).

a 193 nm solid state Nd-YAG (a neodymium-doped yttrium aluminum garnet is used as the laser medium) laser (NewWave UP193-SS) coupled with a multi-collector ICP-MS (Nu Instruments HR).

Ablation in a He atmosphere was raster-wise according to the CL zoning pattern of the zircons. Line widths for the raster were 10 – 15 µm with a raster speed of 5 µm/sec. Energy densities were 5 – 8 J/cm^2 with a repetition rate of 10 Hz. The He carrier gas was mixed with the Ar carrier gas flow prior to the plasma torch. Ablation duration was 60 to 120 s with a 30 s gas and Hg blank count rate measurement preceding ablation. Ablation count rates were corrected accordingly offline. Remaining counts on mass 204 were interpreted as representing ^{204}Pb.

Static mass spectrometer analysis was as follows: ^{238}U in a Faraday detector, ^{207}Pb, ^{206}Pb, and 204 (Pb + Hg) in ion counter detectors. ^{208}Pb was not analyzed. An integration time of 1 s was used for all measurements. The ion counter – Faraday and inter-ion counter gain factors were determined before the analytical session using standard zircons 91500 (Wiedenbeck et al., 1995) and Plesovice (Slama et al., 2008). Sensitivity for ^{206}Pb on standard zircon 91500 was ca. 30,000 cps per ppm Pb. For ^{238}U the corresponding value was ca. 35,000.

Mass and elemental bias and mass spectrometer drift of both U/Pb and Pb/Pb ratios respectively, were corrected using a multi-step approach: first-order mass bias was corrected using a dried ^{233}U-^{205}Tl-^{203}Tl spike solution which was aspirated continuously in Ar and mixed to the He carrier gas coming from the laser before entering the plasma. This corrects for bias effects stemming from the mass spectrometer. The strongly time-dependent elemental fractionation coming from the ablation process itself was then corrected using the "intercept method" of Sylvester and Ghaderi (1997). The calculated ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb intercept values were corrected for mass discrimination from analyses of standards 91500 and Plesovice measured during the analytical session using the standard bracketing method. The correction utilizes regression of standard measurements by a quadratic function.

A common Pb correction was applied to the final data using the apparent ^{207}Pb/^{206}Pb age and the Stacey-Kramers (Stacey and Kramers, 1975) Pb evolution model. Final age calculation was made with “Isoplot/Ex 3.00” (Ludwig, 2003).

Five age clusters, all giving concordant ages with an error of 2 SD (standard deviation), can be distinguished. This grouping is based on the characteristics and age of the single zircons.

- Group A (Fig. 7A; Fig. 8); (n = 8)
  The concordia age of group A is 355 ± 16 Ma. The grains all show the same oscillatory, magmatic zoning, and internal structure with many layers. The cores and pale parts of the grains (often alteration zones) do not seem to affect the results (Fig. 8).
- Group B (Fig. 7B); (n = 5)
  Zircons within this group yield a concordia age of 371 ± 23 Ma and are within errors of the same age as the ones of group A. Thus all data of these two groups can be summarised. Also the CL-images show that there is no evident difference between the two groups, thus they are combined in the final illustration (Fig. 9).
- Group C (Fig. 7C); (n = 2)
  Only two data points define a concordia age of 447 ± 25 Ma. The grains indicate no specific internal structure except for alteration zones.
- Group D (Fig. 7D); (n = 5)
  Group D zircons result in a concordia age of 505 ± 12 Ma. The zircons are cloudy and without a clear oscillatory zoning.
- Group E (Fig. 7E); (n = 3)
  These zircons yield a concordia age of 497 ± 13 Ma which is, within errors, the same as those in group D, thus they both can be regarded equally.
- Group F (Fig. 7F); (n = 8)
  These grains give an age of 581 ± 18 Ma. Although they show the oldest concordia age, they do not show any distinct internal features.

5.2 Interpretation

In a combined concordia plot (Fig. 9) all data points previously mentioned were plotted together. Zircons from group A + B and from D + E are summarised.

The 360 ± 13 Ma – age (group A + B) is interpreted to date a magmatic event with zircon growth. As these zircons are now present in a metasediment this age is interpreted as the maximum sedimentation age of the biotite-schists. The quantity of data points showing this age (Fig. 10) strengthens the fact that this is a valid interpretation whereas the other maxima are taken as inheritance of other events.

This result fits perfectly well to the published data from the central Tauern Window (Kebede et al., 2005) but is surprising too, as the host rocks of the Zentralgneise in the Kleinelendtal formerly were considered to be of pre-Variscan age (e.g. Holub and Marschallinger, 1989).

The Late Cambrian age of 496 ± 15 Ma could be interpreted as detrital zircons from the Panafrican orogeny that can be found throughout the Alps. Also, in the central Tauern Window

	BLANK CORRECTED INTENSITIES (V)				STANDARD CORRECTED RATIOS								
group	204	206Pb	207Pb	238U	207Pb/235U	1SE	206Pb/238U	1SE	Rho	207Pb/206Pb	1SE	Concordia age ± 2 SD[Ma]	
A	5.91E-06	2.35E-03	1.62E-04	2.84E-02	0.3631	0.0349	0.0509	0.0040	0.41	0.0519	0.0018	355 ± 16	360 ± 13
	7.05E-06	7.81E-04	5.14E-05	8.36E-03	0.3841	0.0368	0.0569	0.0021	0.19	0.0502	0.0033		
	3.75E-06	1.45E-04	1.31E-05	2.11E-03	0.4033	0.1199	0.0554	0.0100	0.30	0.0549	0.0072		
	9.57E-06	2.30E-04	2.03E-05	2.14E-03	0.4102	0.1635	0.0538	0.0066	0.15	0.0562	0.0164		
	1.56E-06	1.67E-03	1.02E-04	1.61E-02	0.4139	0.1295	0.0588	0.0081	0.22	0.0511	0.0091		
	5.64E-06	9.99E-04	6.93E-05	1.12E-02	0.4160	0.0413	0.0545	0.0054	0.50	0.0562	0.0033		
	1.30E-06	7.01E-04	4.99E-05	7.30E-03	0.4401	0.0757	0.0595	0.0093	0.46	0.0550	0.0052		
	3.19E-06	7.77E-04	4.64E-05	6.46E-03	0.4493	0.0424	0.0624	0.0030	0.25	0.0532	0.0041		
B	3.89E-06	2.75E-04	1.87E-05	2.55E-03	0.5039	0.0879	0.0564	0.0037	0.19	0.0628	0.0091	371 ± 23	
	2.65E-06	1.53E-04	1.17E-05	1.41E-03	0.5061	0.0966	0.0572	0.0027	0.12	0.0665	0.0099		
	3.70E-06	4.13E-04	2.70E-05	3.90E-03	0.5066	0.0912	0.0606	0.0061	0.28	0.0606	0.0082		
	4.85E-06	8.10E-04	5.13E-05	5.83E-03	0.5160	0.0639	0.0721	0.0085	0.48	0.0523	0.0023		
	2.62E-06	8.73E-04	5.50E-05	7.50E-03	0.5372	0.1028	0.0747	0.0137	0.48	0.0506	0.0027		
C	6.00E-06	2.64E-04	2.00E-05	2.42E-03	0.5685	0.0581	0.0707	0.0030	0.21	0.0598	0.0055	447 ± 25	
	6.40E-06	9.70E-04	7.17E-05	8.83E-03	0.5724	0.0374	0.0718	0.0032	0.34	0.0590	0.0037		
D	1.62E-05	3.93E-04	3.45E-05	2.75E-03	0.6088	0.0795	0.0736	0.0086	0.45	0.0612	0.0035	505 ± 12	508.1 ± 8.6
	5.93E-06	5.04E-03	3.28E-04	3.46E-02	0.6124	0.0466	0.0835	0.0056	0.44	0.0533	0.0014		
	9.09E-06	1.01E-03	7.88E-05	8.14E-03	0.6155	0.0942	0.0782	0.0047	0.20	0.0580	0.0100		
	2.05E-06	3.95E-04	2.77E-05	2.59E-03	0.6271	0.0577	0.0782	0.0035	0.24	0.0574	0.0046		
	6.20E-06	8.24E-04	6.21E-05	6.58E-03	0.6362	0.0887	0.0754	0.0086	0.41	0.0615	0.0085		
E	1.16E-05	7.25E-04	5.32E-05	3.73E-03	0.6559	0.0394	0.0775	0.0038	0.41	0.0591	0.0034	497 ± 13	
	4.68E-06	6.82E-04	5.02E-05	5.17E-03	0.6587	0.0586	0.0788	0.0025	0.18	0.0602	0.0048		
	7.79E-06	2.56E-03	1.85E-04	1.30E-02	0.6778	0.0366	0.0831	0.0033	0.36	0.0578	0.0020		
F	2.35E-06	2.75E-04	2.36E-05	2.34E-03	0.7252	0.0944	0.0997	0.0085	0.33	0.0543	0.0052	581 ± 18	
	2.39E-05	1.33E-03	1.22E-04	8.19E-03	0.7479	0.0430	0.0837	0.0038	0.40	0.0651	0.0017		
	9.91E-06	1.61E-03	1.29E-04	1.20E-02	0.7757	0.0346	0.0906	0.0040	0.49	0.0618	0.0014		
	4.32E-06	8.08E-04	6.06E-05	5.15E-03	0.7787	0.1802	0.0852	0.0087	0.22	0.0667	0.0145		
	6.01E-06	8.92E-04	6.64E-05	5.77E-03	0.7924	0.0492	0.1007	0.0037	0.30	0.0586	0.0026		
	3.44E-06	2.75E-04	1.98E-05	1.42E-03	0.7949	0.1250	0.1065	0.0048	0.14	0.0562	0.0073		
	6.47E-06	4.95E-04	5.14E-05	2.76E-03	0.8194	0.2179	0.0740	0.0149	0.38	0.0802	0.0107		
	7.74E-06	1.30E-03	1.03E-04	5.82E-03	0.8645	0.1251	0.0936	0.0038	0.14	0.0652	0.0090		

Table 3: Corrected geochronological data from LA-MC-ICP-MS measurements (grouping and analytical details – see text). SE = internal precision on Pb isotope ratios; SD = standard deviation; Rho = correlation coefficient of $^{207}Pb/^{206}Pb$ errors.

such ages were obtained by von Quadt (1992) for rocks of the Lower Magmatic Sequence.

The age of 581 ± 18 Ma may result from metamorphic overprinted zircons which still contain information from the Cadomian orogeny that can again be seen within the Lower Magmatic Sequence of the central Tauern Window (Eichhorn et al.,1999).

6. Discussion

Our new geochemical and geochronological data from the biotite-schists (Zwischenelendschiefer) and amphibolites help to compare them with the Biotitporphyroblastenschiefer and the Basisamphibolit of the central Tauern Window. These rock complexes can be put in context and a similar Late Paleozoic, i.e. Variscan, evolutionary history for the two areas can be suggested.

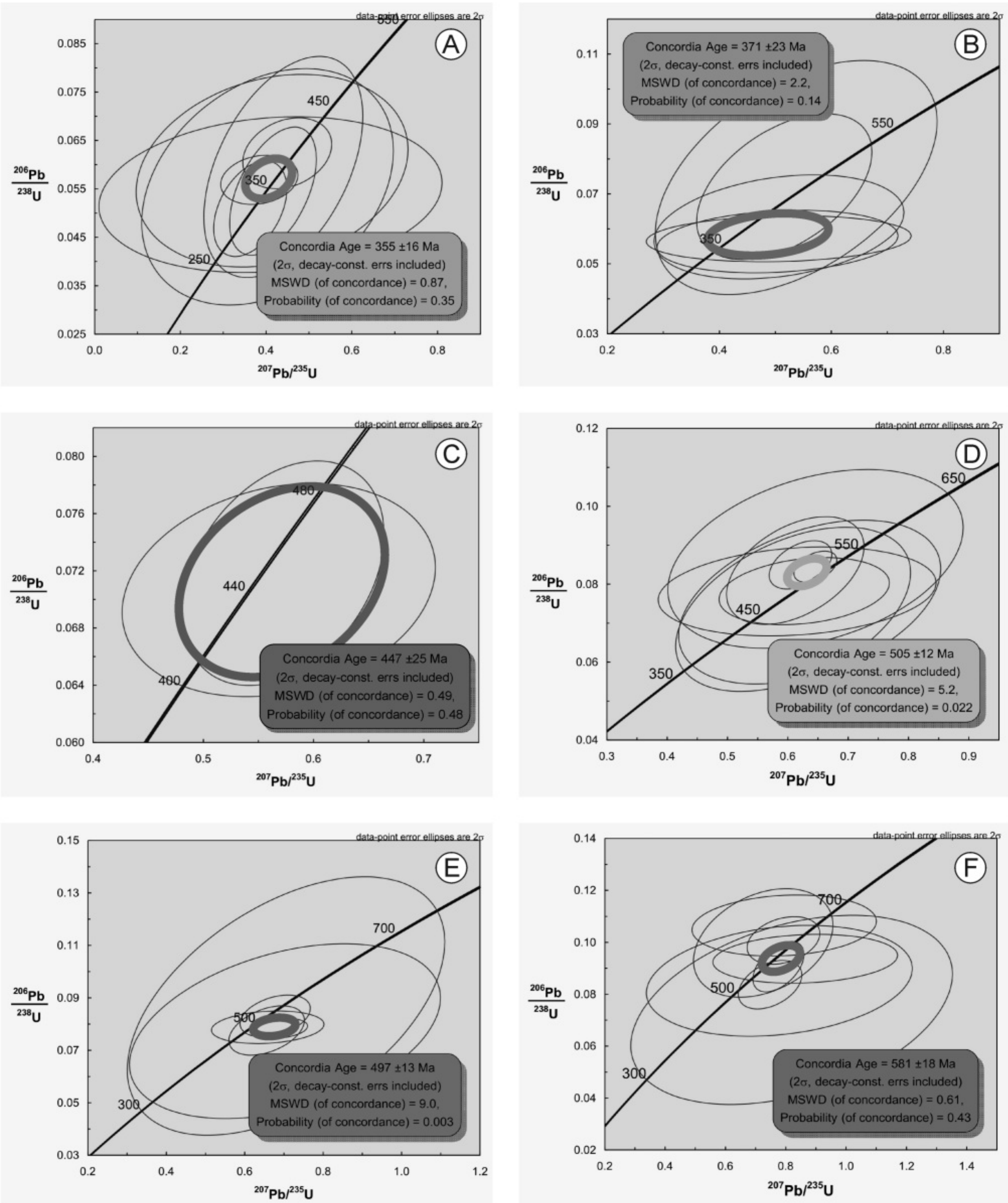

Figure 7: Concordia plots of age groups A-F (biotite-schists; LL06/01). MSWD = mean square weighted deviation.

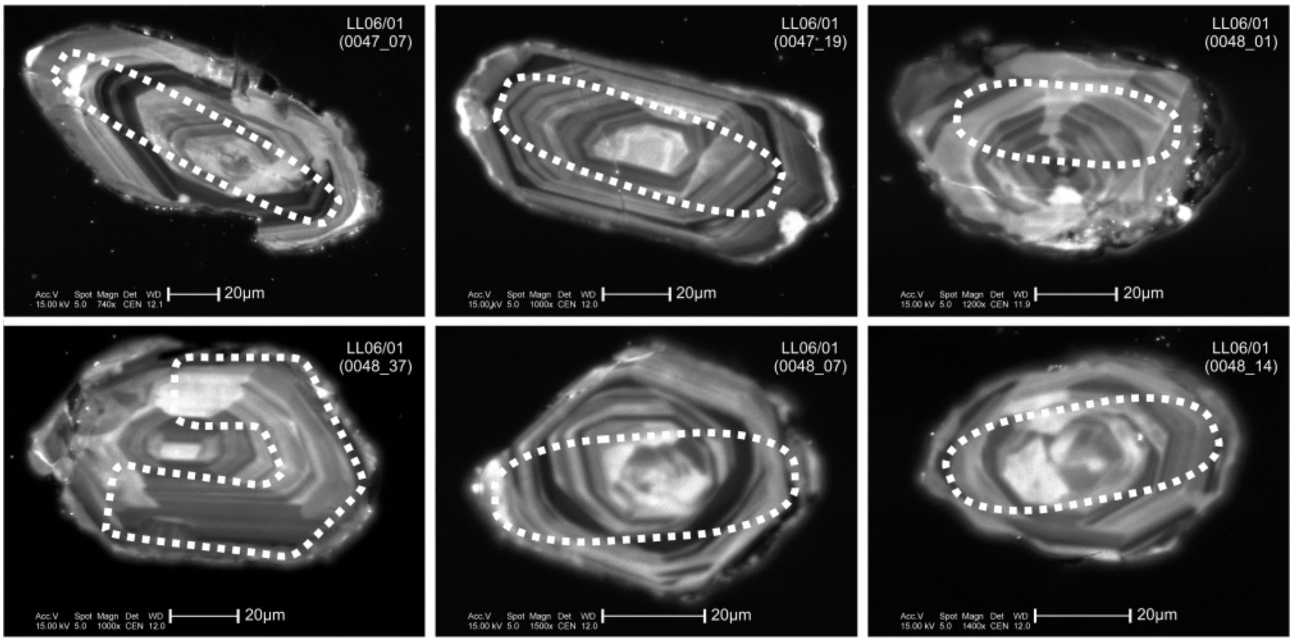

Figure 8: CL-pictures of group A - zircons (see text) with marked ablation-paths.

In the Kleinelendtal and around the Schwarzhornseen the amphibolites and Zwischenelendschiefer occur in an alternating succession. Even in thin section it is obvious that one lithology passes into the other without any clear contact. This may be explained by a small time gap between the sedimentation of the protoliths of the biotite-schists and the extrusion of basalts, i.e. the protoliths of the later amphibolites. Thus the original geologic setting of these rocks could have been a basin where all the future schists have been deposited with a nearby volcano which has provided the basalts.

7. Conclusions

- Mapping of the lithologies in the Kleinelendtal has revealed the occurrences of different types of wall rocks of the Zentralgneise that now are termed “Pre-Zentralgneis-Complexes” and confirmed the studies on the Zentralgneise by Holub and Marschallinger (1988). This new nomenclature concludes with the term “Zwischenelendschiefer” for the schists to emphasise their local importance.
- In contrast to previous descriptions (Angel and Staber, 1952; Krainer, 2003, who displayed a certain unit of migmatites in his map of the Kleinelendtal) no true migmatites, i.e. partially molten rocks, were found, whereas some marginal heating or at least warming of the wall rocks is visible by the blastesis of biotite and plagioclase. It is the particular form of the intrusion of leucocratic Zentralgneis melts in fissures and pathways within the schists and amphibolites and a secondary folding of these units that have made them look like migmatites with paleoseome and neosome.
- For all lithologies an at least two-phase metamorphic evolution can be established, where in all cases the Paleogene metamorphism has been the dominating one. Partly a pre-Zentralgneis-deformation is still visible. A high grade overprint has resulted in the recrystallisation of the mineral assemblage and it has been retrogradely overprinted at

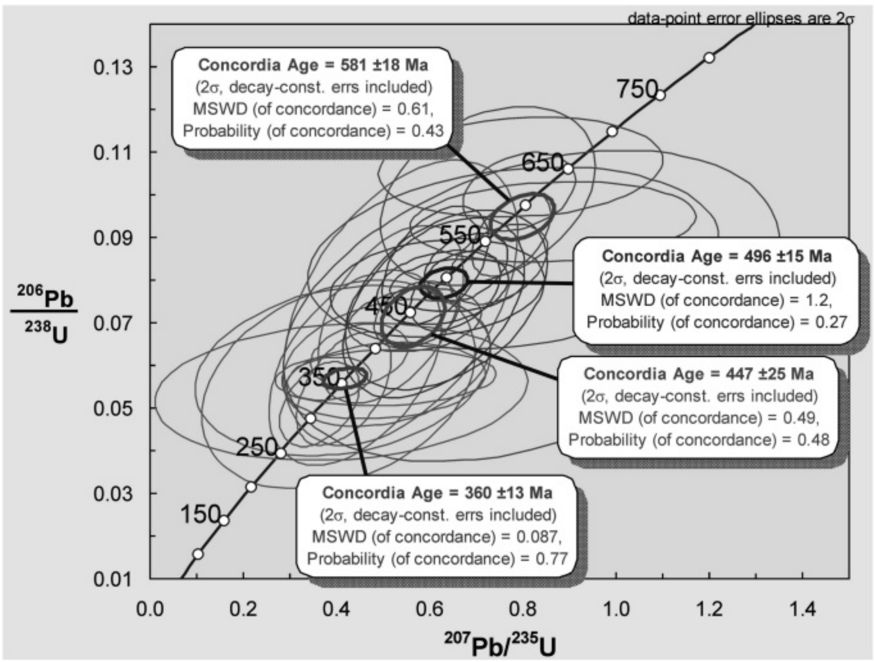

Figure 9: Concordia plot showing four generations of detrital zircons for the biotite-schists (LL06/01). MSWD = mean square weighted deviation.

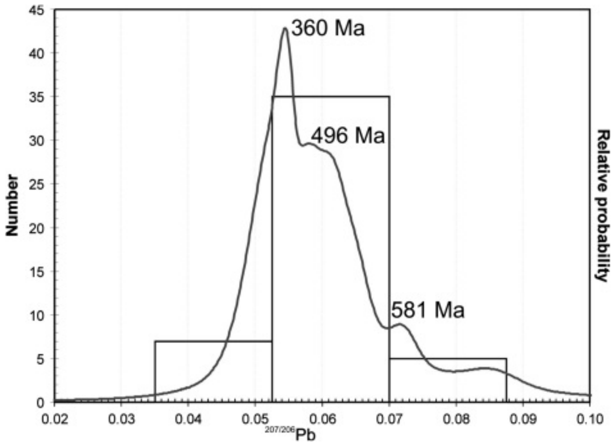

Figure 10: Probability plot showing the quantitative distributions of the obtained ages (i.e. the $^{207/206}$Pb-ratios) of the biotite schists (LL06/01).

greenschist-facies metamorphic conditions. Different generations of mica attest various stages of deformation, most of them in localised shear zones. Brittle structures visible in broken garnet, together with some fluid activity resulting in discordant, more or less unstressed quartz veins, mark the youngest activities.

- The amphibolites are interpreted to be of igneous origin, forming either submarine (?) lava flows or tuffs. This is shown by the geochemical and isotopic analyses, producing an $\varepsilon Nd_{(360\ Ma,\ CHUR)}$ of +5.3, which also show similar patterns like the Basisamphibolit in the Felbertal (central Tauern Window).
- Geochemical analyses of the "Zwischenelendschiefer" (the biotite-schists, respectively) confirm their sedimentary origin and an $\varepsilon Nd_{(360\ Ma,\ CHUR)}$ of -1.8 proposes the participation of quite substantial amounts of juvenile mantle melts.
- In situ U/Pb - dating of detrital zircons from the biotite-schists yields a maximum sedimentation age of 360 Ma. This result disproves the assumption that the "Altes Dach" in the eastern Tauern Window is of Cambrian age or even older. The sedimentation of the Zwischenelendschiefer has to be placed into the Variscan orogenic cycle instead.
  Thus a line can be drawn to the Biotitporphyroblastenschiefer in the central Tauern Window suggesting a similar evolutionary history for these two units.

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