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THE GURKTAL NAPPE COMPLEX

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Introduction

The Gurktal Nappe Complex (GNC), part of the Upper Austro-Alpine thrust sheet, mainly contains weakly metamorphic Ordovician to Early Carboniferous basement sequences and Late Carboniferous to Triassic cover sequences (Fig. 1). It is thrusted onto the Middle Austro-Alpine Nappe Complex from which Permo-Mesozoic sediments are preserved below the northern and western margin of the GNC (Fig. 1). The GNC extends from the Nockberge area to the foreland of the Karawanken and may be traced along the southern Saualpe and Koralpe to the Pohorje Mts. in Slovenia (Hinterlechner and Moine, 1977) (Fig. 1).

The existence of the thrust sheet and the scale of displacement played an important role for the interpretation of internal tectonics of the Austro-Alpine Nappe Complex (Clar, 1965; Frank 1987; Neubauer, 1987; Tollmann, 1959, 1977; von Gosen, 1982, 1989).

Internal stratigraphy

The Gurktal Nappe Complex is internally subdivided into two major nappes, both composed of Early Paleozoic rocks, which are distinguished by lithology and degree of metamorphic overprint. The lower Murau Nappe is composed of lithologies mainly in upper greenschist facies, the upper Stolzalpe nappe in lower greenschist facies (Becker et al., 1987). The Pfannock gneiss and accompanying cover sequences, probably a part of the Stolzalpe Nappe, occurs along the western margin. The Ackerl gneiss and micaschist complexes together with Permotriassic cover sequences form another local klippe, the Ackerl Nappe as apparently highest tectonic unit in northwestern Gurktal thrust complex (Fig. 1). The Paleozoic nappes, the Stolzalpe and Murau Nappes, contain a similar trend in stratigraphic evolution but striking differences in detail. The stratigraphy is largely based on rare conodont findings which are derived from minor dolomite lenses within metapelitic and metavolcanic sequences (for reviews, see Schönlaub, 1979; Neubauer and Pistotnik, 1984; Neubauer and Sassi, in press).

Stratigraphy

The stratigraphy of the Murau Nappe is uncertain because of the lack of continuous, fossil-bearing sections, and strong, partly unresolved deformation structures which include large-scale isoclinal folding, internal imbrication and transposition by large-scale shearing. As a rule, the stratigraphy follows that of the Schöckl Unit within the Paleozoic of Graz (see Fritz et al., this volume). Prasinites and greenschists derived from lava flows, sills and tuffs occur at the supposed stratigraphic base within a phyllite matrix (Fig. 2) (Neubauer, 1980a). Most of these greenschists show transitional to mildly alkaline basaltic chemical characteristics (unpublished data). A phyllite-rich unit overlay the greenstones. Carbonatic phyllites, black phyllites, and quartzites with minor greenstones and orthoquartzites build up the next higher stratigraphic unit. Along the southern margin of the Gurktal nappe, widespread acidic volcanics occur (Loeschke, 1989b). The stratigraphic higher level is made up by carbonates which exhibit lateral facies differentiation. Dolomites at the base of the

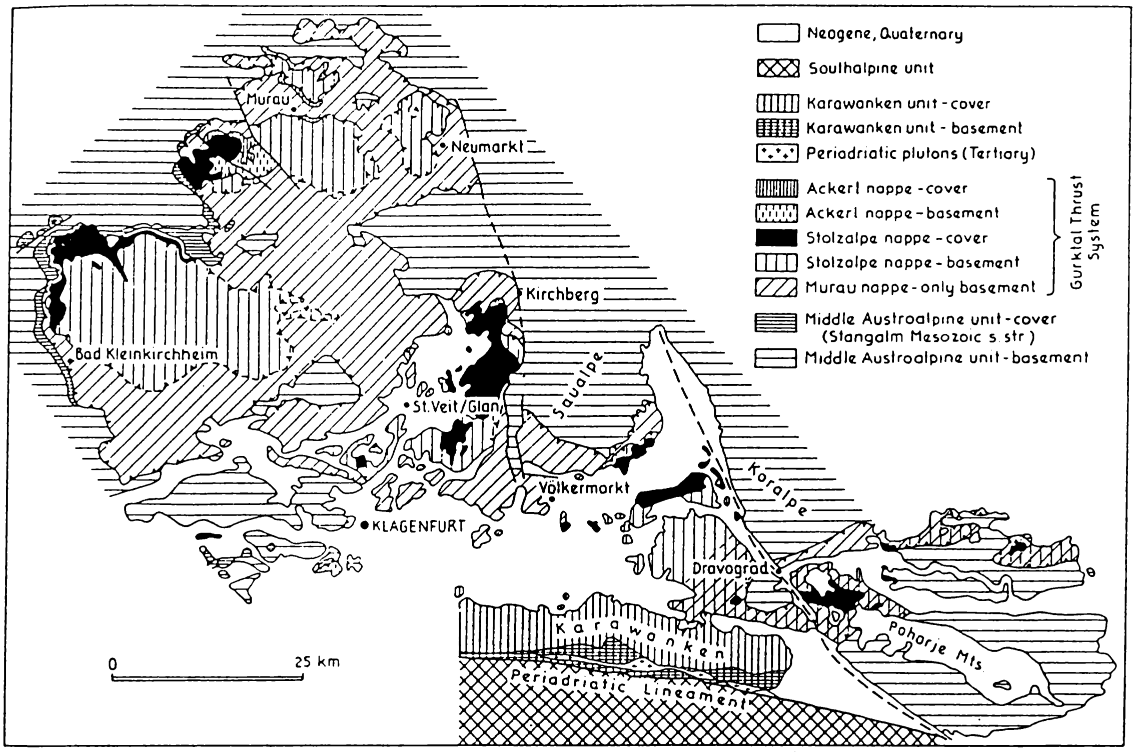


Fig. 1: Simplified map of the Gurktal thrust complex (from Neubauer, 1987).

carbonates in the more northern region yielded a Late Silurian to Early Devonian, respectively a Pragian to Zlichovian conodont fauna (Buchroithner, 1979; Neubauer, 1980a, b; Niederl, 1980; Schönlaub, 1979). Calcite marbles are widespread. A singular finding of a brachiopod support the late Silurian and/or early Devonian age of the carbonates in the southern Saualpe (Neugebauer, 1970). The marbles sometimes bear coarse-grained mafic dykes of transitional basalt affinity (Neubauer, 1989).

The Stolzalpe Nappe also exhibits an internal imbrication, and is composed probably of slices which differ in Late Silurian to Early Devonian facies. The separation from the Murau Nappe is uncertain in the interior of the GNC because of missing Permo-Mesozoic rocks along thrust surfaces and comparable lithologies, mainly quartzphyllites, in both units (e.g., von Gosen, 1982, 1989).

The differentiation of various stratigraphic levels within the Stolzalpe Nappe is well-constrained by stratigraphic valuable fossils. As a rule, thick mafic volcanic sequences occur at the stratigraphic base (Fig. 2). They are overlain by pelitic-psammitic dominated sequences, whereas pelagic limestones occur at the top. In detail, mafic dominated volcanics at the base are subdivided in two subunits: A late Middle Ordovician and Late Ordovician age, respectively, is proved for the Magdalensberg Fm. at the Magdalensberg by brachiopods (Havlicek et al., 1987) and conodonts (Riehl-Herwirsch, 1970). The Nock Series (Giese, 1988) occur in the late Ordovician (Neubauer and Pistotnik, 1984). The Kaserer Fm. is a further probably Ordovician volcanic unit with major basaltic sills and stocks. A pre-Silurian age is supposed for the Kaserer Fm. because of its superposition by the Silurian Eisenhut Fm. The earlier one is interpreted as a basaltic-keratophyric marine island volcanoe (Riehl-Herwirsch, 1970) with alkaline geochemical characteristics (Loeschke, 1989a, b). The Nock Series exhibit calc-alkaline affinities (Giese, 1988; Loeschke, 1989b).

These units are contrasted by Early to Mid Silurian volcanics, the Eisenhut Fm. at the northwestern edge of the GNC (Höll, 1970; Neubauer and Pistotnik, 1984), the Metadiabase Formation at the northern edge of the GNC (Schnepf, 1989), and the younger portion of the Magdalensberg Formation (West to the Saualm: Neubauer and Pistotnik, 1984). All these Silurian volcanic units have a coherent mildly alkaline geochemical characteristics (Giese, 1988; Schnepf, 1989; Antonitsch and Neubauer, 1992). However, Ordovician and Early Silurian volcanics are probably separated by a Late Ordovician unit of slates, quartzphyllites and sandstones which contain also lydites and thin carbonate layers (Neubauer, 1980a; Neubauer and Pistotnik, 1984).

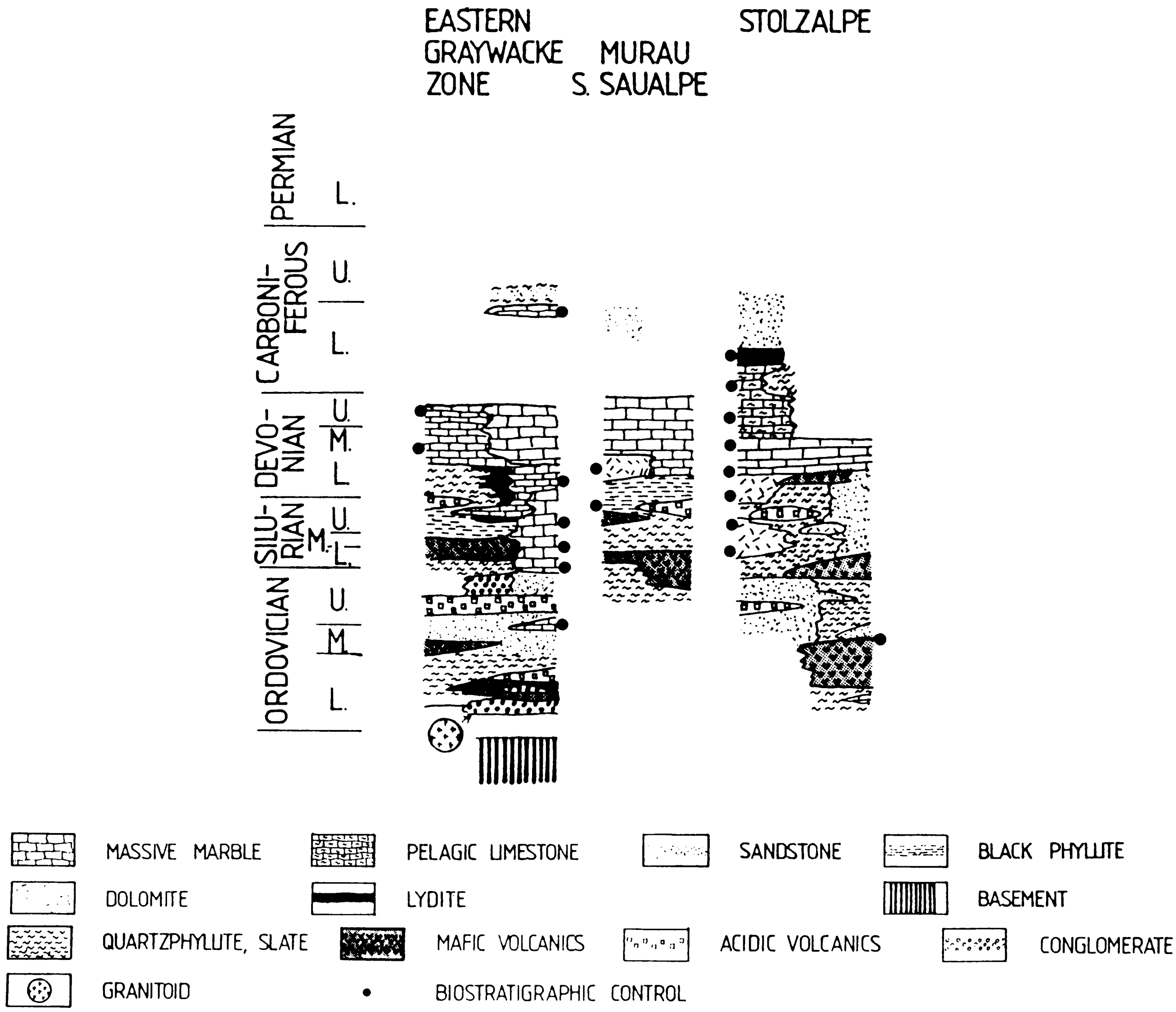


Fig. 2: Stratigraphic sections of the Murau and Stolzalpe Nappes (modified from Neubauer and Sassi, in press).

A slaty facies with cherts and allodapic limestones persists through the Wenlockian to the boundary of Lochkovian/Pragian (Magdalensberg facies; Fig. 2). On the other hand, thick sandstones, quartz wackes and quartz arenites (Fig. 3), occur locally covering the same time span. The composition of these Late Ordovician to Early Devonian sandstones varies from quartz arenites to quartz wackes and subarkoses. A preliminary 40Ar/39Ar age of a detrital muscovite yielded a fairly good plateau at ca. 560 Ma with minor later, probably combined Variscan/Alpine overprint (Dallmeyer et al., this volume). The siliciclastic sediments are contrasted by thin Late Wenlockian to Pragian dolomites, and pelagic limestones. At latest at the boundary Pragian/Zlichovian, comparable pelagic limestones occur in all units differentiated before. The Zlichovian to Pragian carbonate includes mafic volcanics (Neubauer, 1980b). These carbonates locally persist up to the Early Carboniferous and are overlain by cherts and graywackes. The cherts yielded conodont faunas from the Tournaisean/Visean boundary (Neubauer and Herzog, 1985). Rare diabase dykes and detrital modes of graywackes suggest felsic and mafic intrabasinal volcanoes (Neubauer and Herzog, 1988). Recent investigations show evidence for the presence of late Visean corals in carbonates within cover rocks on the stratigraphic top of quartzphyllites (Schlöser and others, 1990). Therefore, deformation and metamorphism occurred within a short intra-Visean time.

The Ackerl Nappe consists of a lower Ackerl micaschist unit with mainly micaschist and the upper Ackerl gneiss unit, a two-mica plagioclase paragneiss with minor aplite, pegmatite, amphibolite and orthogneiss (Neubauer, 1980c). The age of metamorphism of both complexes is pre-Alpine with an eo-Alpine, Cretaceous metamorphism in lower greenschist facies. 40Ar/39Ar muscovite plateau ages yielded ca. 310 Ma which is interpreted as the age of postmetamorphic cooling through the approriate closing temperature of ca. 350 - $400^{o}C$ (see Dallmeyer et al., this volume).

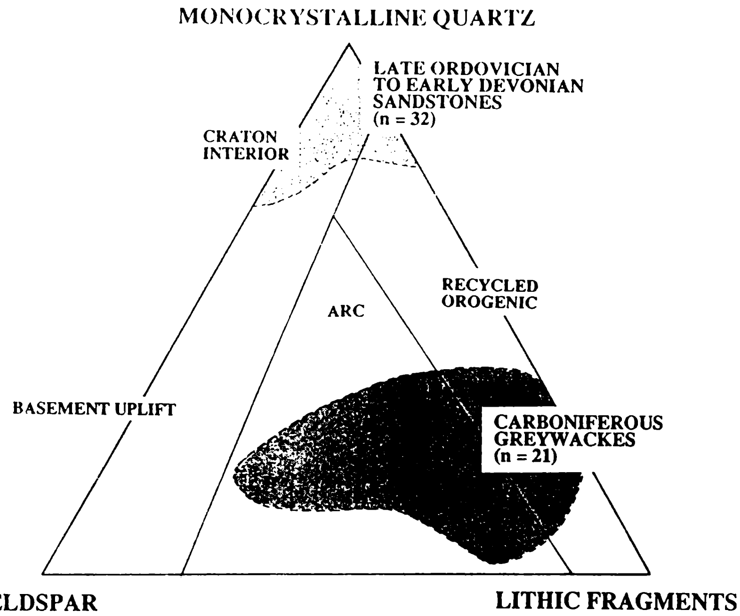


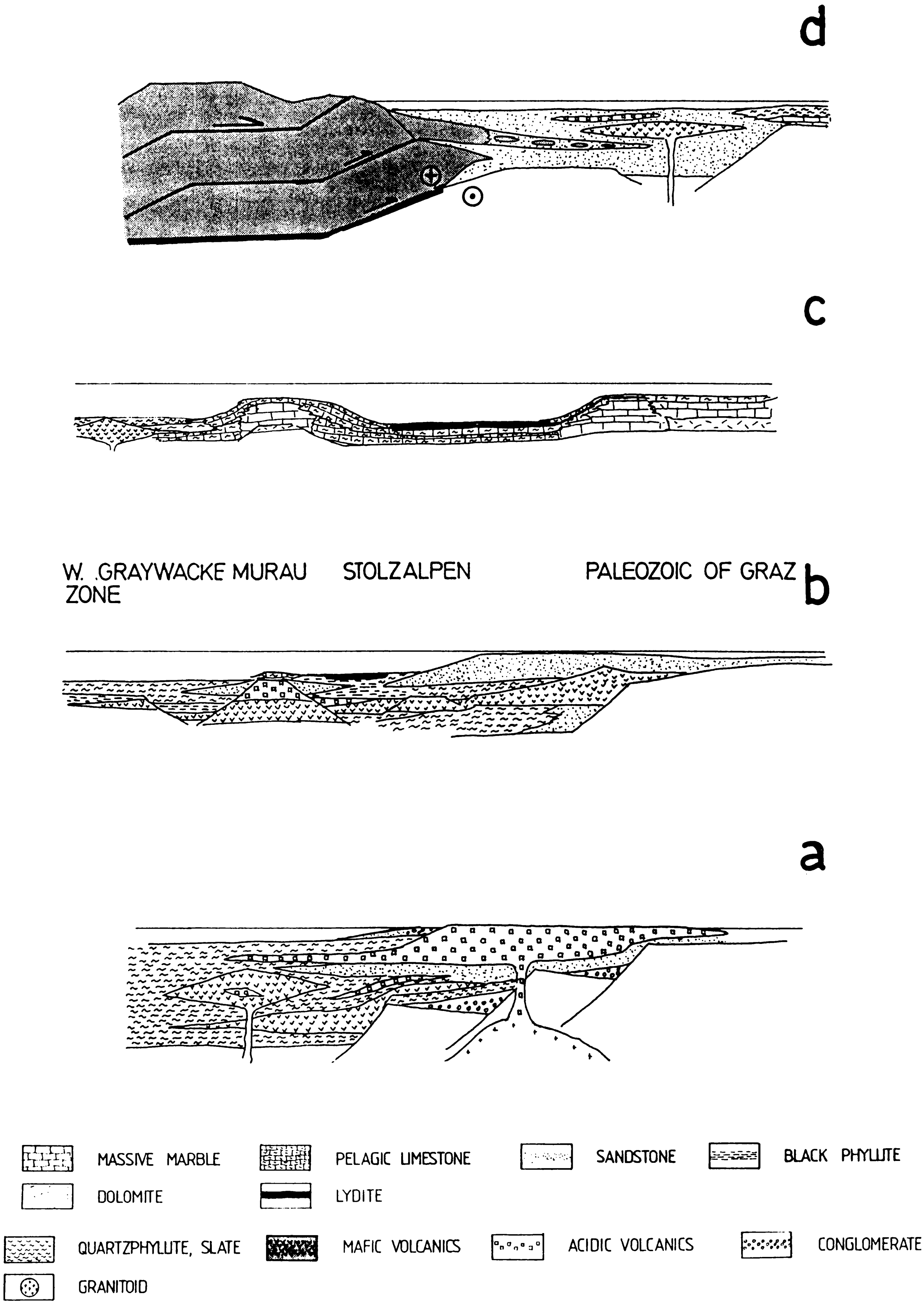
Fig. 3: Detrital modes of Late Ordovician and Early Carboniferous sandstones of the Stolzalpe Nappe.

Paleozoic geodynamic setting

The Early Paleozoic geodynamic evolution is a matter of controversies (Giese, 1988; Loeschke, 1989b; Neubauer and Frisch, 1988, Neubauer and Sassi, in press). Both, the sequences of the Murau and Stolzalpe Nappes, although distinct in sequence, are part of the same depositional system. It may regarded as an example for the evolution of the entire Upper Austro-Alpine Paleozoic sequences (see Fig. 4, from Neubauer and Sassi, in press).

A basement on which these were deposited is missing most probably due to detachment of the entire content. The Middle Ordovician to Silurian sequences are rich in volcanics which monitors a distinct evolution with early calc-alkaline mafic rocks (Kaserer and Nock series) and later mainly alkaline volcanism. The entire controlling factor is the evolution of a back-arc basin system. The accompanying sedimentation of siliciclastic sediments is controlled by low water energy, and variable

Fig. 4: Evolution of Upper Austro-Alpine quartzphyllite sequences (from Neubauer and Sassi, in press) as models for the sedimentary and orogenic evolution of the Gurktal Nappe Complex. Assumed orientation of sections is ca. NW to SE in relation to the present-day geographic coordinates. Facies differentiation is shown for restricted stages. ***a****: The Ordovician evolution is interpreted as time of the back-arc basin formation. The basin is formed on top of a Cadomian crust which has been consolidated during the Late Proterozoic and/or Cambrian. The basin is filled up with clastics and bimodal volcanic piles.* ***b****: The Silurian and basal Early Devonian is the time of renewed rifting, block faulting, alkalic mafic and acidic volcanism and SEDEX-type mineralization (e.g. Murau Nappe). Afterwards, the basin is filled up with clastic sediments derived from southeastern areas.* ***c****: During late stages of the Early Devonian until Early Carboniferous the siliciclastic input looses importance except in western areas. Near-shore carbonates, lagoonal dolomites and reefs dominate the southeastern margin (Paleozoic of Graz), and probably an intra-basinal high (Murau Nappe). The deeper part of the basin is filled up with pelagic limestones and cherts. Volcanism occurred along the northwestern margins.* ***d****: Contraction and basin closure by thrusting started during Mid-Visean times. Subsidence of the flysch basin may be explained by loading of incoming thrust sheets. The basin is filled up with partly volcanogenic graywackes which are derived mafic and acidic volcanics.*


d
c
W. .GRAYWACKE ZONE
MURAU
STOLZALPEN
PALEOZOIC OF GRAZ
b
a
MASSIVE MARBLE
PELAGIC LIMESTONE
SANDSTONE
BLACK PHYLLITE
DOLOMITE
LYDITE
QUARTZPHYLLITE, SLATE
MAFIC VOLCANICS
ACIDIC VOLCANICS
CONGLOMERATE
GRANITOID

influence of terrigenous clastics (quartz-, feldspar-, and white mica-rich sandstones). The Late Silurian to Devonian evolution displays a gradual shift to the formation of a carbonate platform with more shallow water deposits in the Murau Nappe, and pelagic sediments in the Stolzalpe Nappe. During the Famennian, the entire carbonate platform subsided to pelagic levels. During Visean time, flysch-like greywackes followed, most probably accompanied by deformation. The exact timing of the Variscan deformation is uncertain, but must predate Westfalian B/C.

Cover sequences

The basement is overlain by Late Carboniferous to Triassic cover sequences which are preserved along the northwestern margin of the Gurktal thrust complex, and in the Eberstein and Griffen areas (Krainer 1984, 1987, 1989; Pistotnik, 1975; Sylvester, 1987).

Terrestrial Late Carboniferous to Permian sequences form some tectonically independent thrust slices of the Stolzalpe Nappe (Krainer, 1987, 1989; for detailed information, see Krainer, this volume). The Stangnock Formation is an about 400 metres thick intramontaneous coal-bearing molasse formation of Late Westfalian to Stefanian age (Krainer, 1989). It has been deposited by an approximately west to east fluent river system under humid climate conditions. The clasts are derived from gneisses which have apparent similar Rb-Sr model ages and isotopic signatures like the Bundschuh orthogneisses of the immediate tectonic footwall (Frimmel, 1986a, b; 1988). A single occurrence of Early Carboniferous limestone of uncertain origin, redeposited clast or conformable lense, is reported from one locality below the Stangnock Formation (Schlöser et al., 1990).

The Werchzirm Formation (Permian) with redbeds monitors the gradual transition to semi-arid climatic conditions. Basal portions contain acidic tuffs which are used for large-scale correlation with Early Permian formations in the Southalpine unit.

The depositional age of the Pfannock sequence, mostly interpreted as detached portion of the Stolzalpe Nappe, is a partly overturned sequence along the western edge of the Gurktal Nappe Complex (Tollmann, 1975) which range from Late Permian to Late Triassic (Norian). The similarity of the Anisian sandy/carbonatic alternations of the Pfannock sequence with such of the underlying Middle Austro-Alpine Stangalm unit is called for local derivation of the Gurktal Nappe System (Frank, 1987; Krainer, 1984).

The Ackerl nappe as well as the cover sequences along the thrust surface between the Murau and the Stolzalpe Nappe contain local redbeds (mostly purple-coloured silt- and sandstones), Semmering-Quartzite-type quartzarenites (or Gröden Fm.; late Permian to Scythian age ?), rauhwacke and minor dolomites (Anisian ?) (Neubauer, 1980c).

Both the Eberstein and Griffen Permo-Triassic sequence commence with terrestrial deposits of Permian age (Werchzirm Fm.) grading into quartzarenites (Gröden Fm.) of Late Permian to Scythian age. The transition to carbonate deposition is given by Anisian rauhwackes. The further sequence is apparently incomplete and tectonically disturbed. It contains Middle Triassic basinal limestones sequences, tectonically thickened Carnian siliciclastic Raibl beds and mainly Norian Haupt Dolomite (for details, see Appold, 1989; Lein, 1989).

Successor basins

Following a period of deformation and erosion, both Eberstein and Griffen Trias are overlain by Late Cretaceous basinal sequences of the Krappfeld and St. Paul Gosau basins. The sequence of the Krappfeld Gosau is more complete (van Hinte, 1963; Neumann, 1989) and ranges with an approximate thickness of 1,500 metres (Neumann, 1989) from Late Santonian (Herrmann and Wascher, 1972) to lower Late Maastrichtian (Thiedig and Wiedmann, 1976). The Krappfeld Gosau occurs in the Krappfeld graben, a Miocene structure. Basal conglomerates and dolomite arenites onlap the Triassic Haupt Dolomite (Neumann, 1989). Locally, a detrital reef limestone with rudists occurs (Fig. 5). The main sequence shows a turbiditic facies which is subdivided into several formations by lithology and the occurrence of olistolithic marker beds (Neumann, 1989). This lithofacies is composed of basinal pelagic marls and limestones with planctic foraminifera, inoceramens and ammonoideas. The pelagic sediments contain olistolitic beds with thicknesses ranging from metre to more than 30 metres which are essentially composed of shallow water rudist reef limestone clasts, which locally reach the size of several meters.

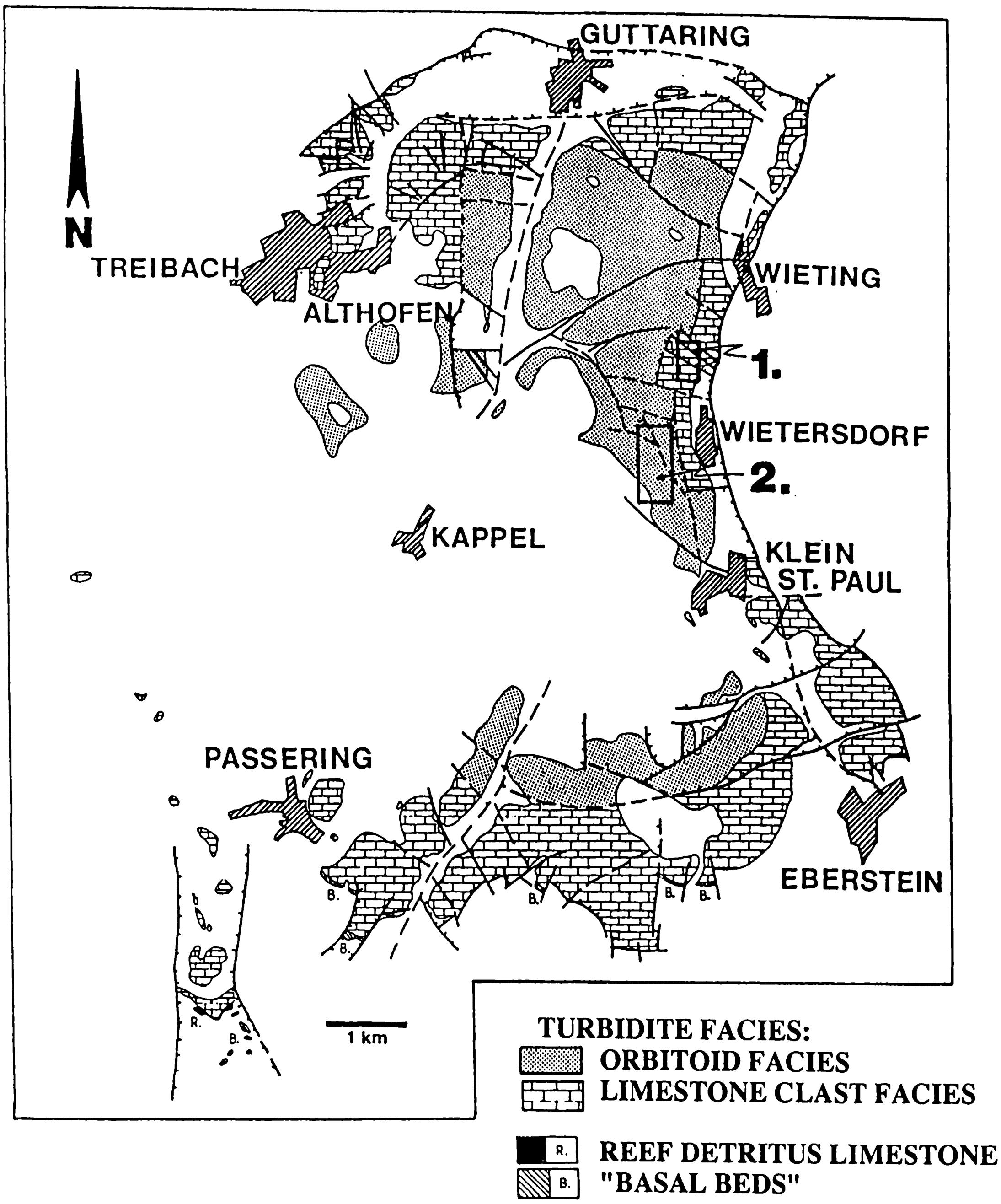


Fig. 5: Map of the Krappfeld Gosau basin (from Neumann, 1989).

The facies patterns of the Krappfeld Gosau basin monitors three major steps of evolution (Neumann, 1989):

After the Late Santonian transgression a carbonate platform developed in front of a terrestrial environment. After a period of lithification of platform sediments, rapid subsidence resulted in a turbidite facies with local debris flow sediments which contain mainly clasts derived of the earlier platform. This is interpreted as a dramatic collapse event in the platform area (Neumann, 1989; Thiedig, 1975). Thiedig (1975) suggested a source to the east on top of the metamorphic Saualpe region which cooled and uplifted during the Late Cretaceous.

A last phase resulted in the diminishing occurrence of limestone clasts, decreasing grain sizes and transition to more orbitoid-rich clasts of a submarine fan. For the first time clasts of basement rocks of the highest structural levels (Stolzalpe Nappe) occur.

Paleogene of the Krappfeld area

The Gosau beds are locally overlain by Paleogene sequences with an erosional unconformity. The sequences range from uppermost Paleocene to middle Eocene with a stratigraphic thickness of more than 1,000 metres (Wilkens, 1989). At the base red beds occur above an erosional relief with red clay, quartz gravels, local coal seams and rare horizons of black, marine detrital limestones (Fig. 6). It is suceeded by nummulite marls with only minor terrigenous clasts. A second formation with coal seams, and abundant siliciclastic sediments monitors enhanced terregenous input. Limestone-marl alternations are followed by nummulite limestones with decreasing content of siciliclastic material.

It should be noted that Paleogene clasts are abundant in Miocene gravels in the surroundings of the Krappfeld graben (Wilkens, 1989). Therefore, Paleogene sediments were most probably also present outside of the Krappfeld graben.

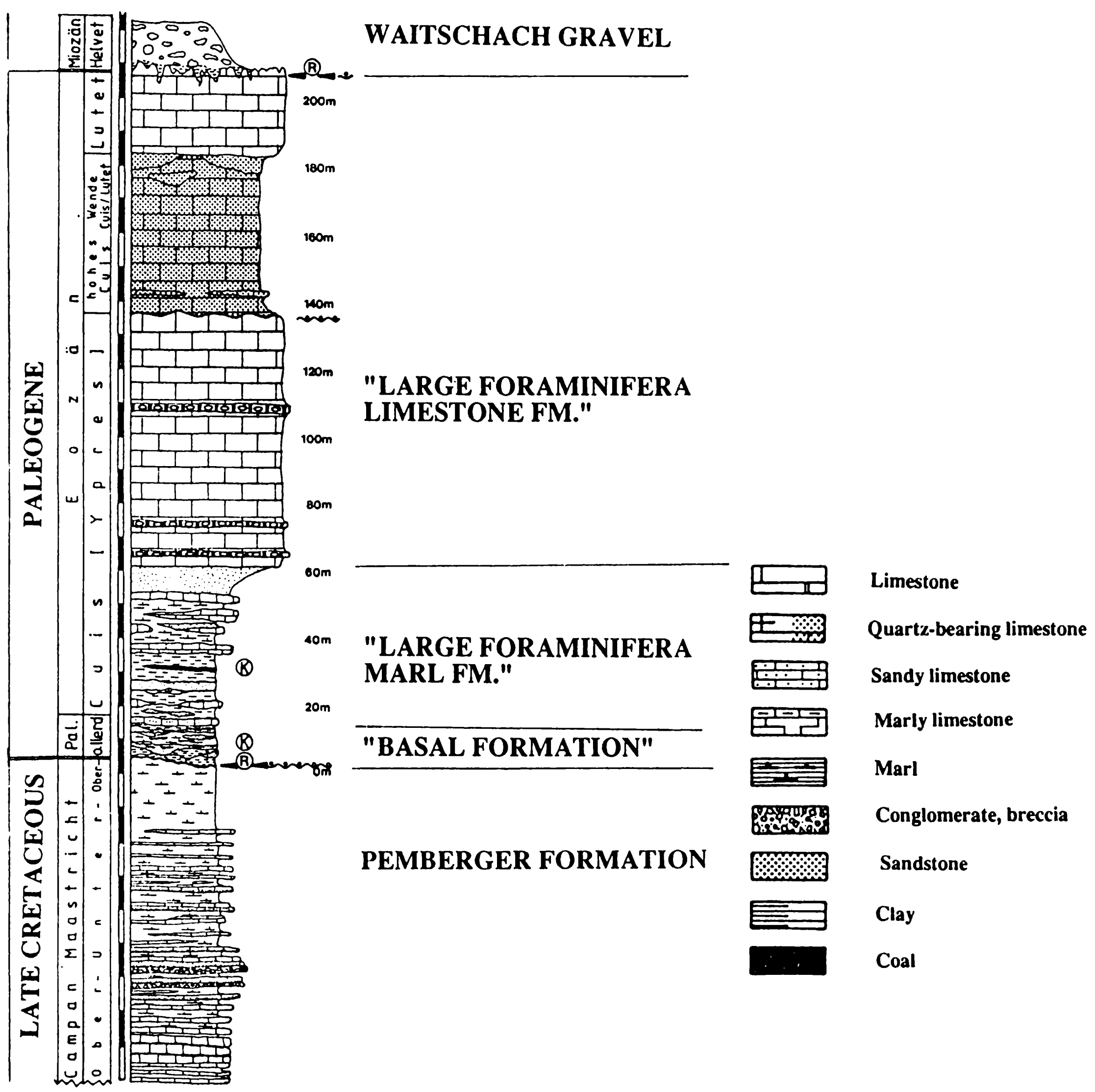
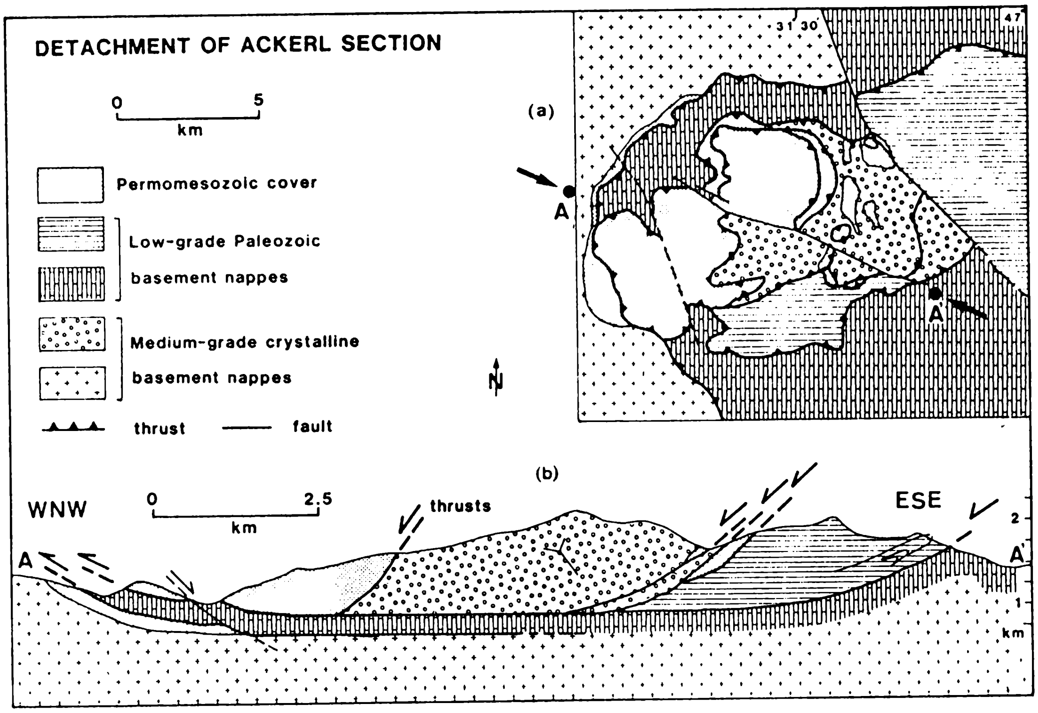


Fig. 6: Paleogene section of the Krappfeld (from Wilkens, 1989).



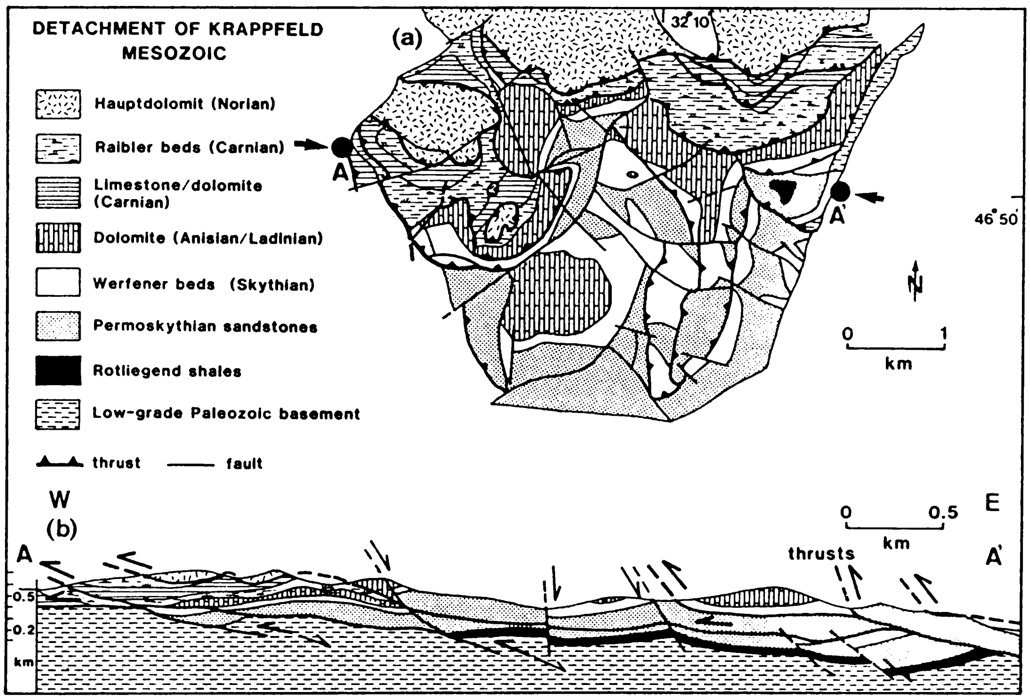
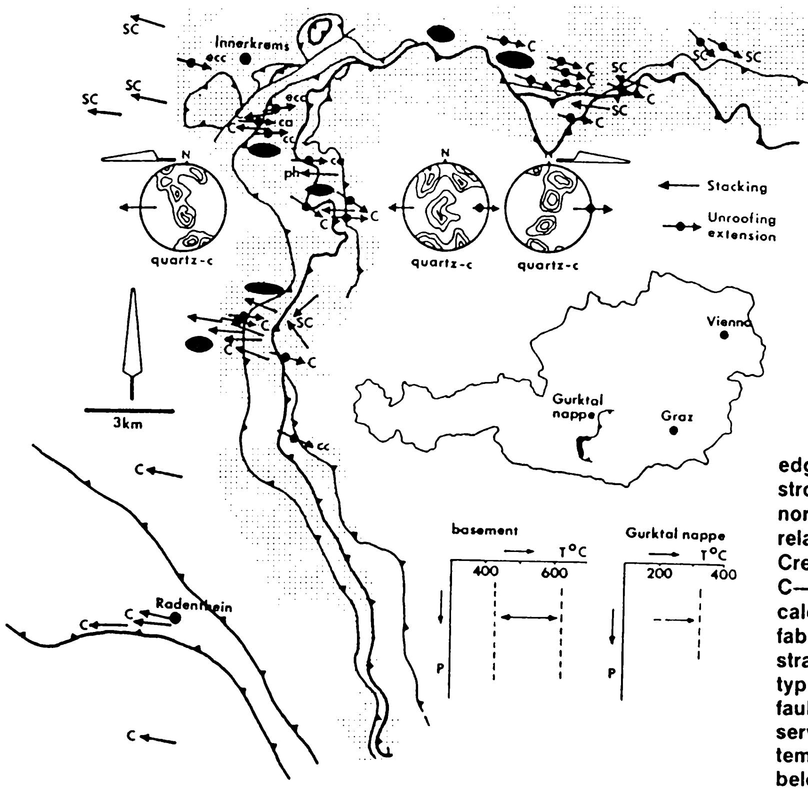


Fig. 7: Some structures related to nappe imbrication (from Ratschbacher and Neubauer, 1989).

The deposition of Paleogene sediments was followed by a period of erosion, karst formation and deposition of terrestrial red clays. During Middle Miocene, the thick gravels (e.g., Waitschach gravels) were deposited both west of the Saualpe region and along the southern edge of the GNC. These deposits resulted from a new period of faulting,especially along the Görtschitztal and Lavanttal fault zones. These basins includes both half grabens (Zollfeld graben) and pull apart basins, e.g., along the Lavanttal fault zone.

Deformation and metamorphism

The Late Carboniferous angular unconformity at the base of the Stolzalpe Nappe clearly separates Variscan and Alpine deformational and metamorphic events. Variscan metamorphism of the Stolzalpe Nappe apparently reached low grade metamorphic conditions largely overprinted by Alpine effects. All detailed pre-Alpine deformation structures are uncertain. The Alpine deformation of the GNC occurred under very low to low grade metamorphic conditions. Alpine metamorphic conditions regularly increase from hangingwall tectonic units the footwall. Only a few geochronological data are reported (Frank et al., 1987). The geochronological ages cluster around 120 Ma.



Simplified structural map, western edge of Gurktal nappe. Stippled area: zone of strong, Late Cretaceous, unroofing-related normal faulting. Arrows indicate displacement related to Early Cretaceous stacking and Late Cretaceous normal faulting. Kinematic criteria: C—quartz c-axis; cc—calcite c-axis; ca—calcite a-axis; ph—mica textures; SC—S-C fabrics; ecc—shear bands; ellipses—finite strain in foliation plate. Quartz c-axis textures: typical end-member (stacking and normal-faulting related) and superposition fabrics observed in east-west sections. Pressure (*P*)-temperature (*T*) diagrams record *T* fields below (left) and above (right) zone of normal faulting, based on geothermometry, phase equilibria, and illite crystallinity (e.g., Schimana, 1986).

Fig. 8: Late Cretaceous extensional structures along the western margin of the Gurktal Nappe Complex (from Ratschbacher et al., 1990).

A sequence of Alpine deformation events is reported from several areas. Interpreting all structures, the deformational sequence started at about peak temperature conditions with top to the west shearing and stacking of large nappes, such as the transport of the Stolzalpe Nappe onto the Murau Nappe (Fig. 1, 7), overriding Permotriassic sequences at the northern and northwestern margin of the GNC (von Gosen, 1989; Neubauer, 1987; Ratschbacher and Neubauer, 1989). The next deformation event was a NNE-SSW contraction by folding with about NNW-SSE fold axes. Ductile shear fabrics are largely overprinted by low-temperature mylonites and shear fabris which are due to top to the E and ESE, respectively, shearing and low-angle normal faulting (Neubauer, 1980b; Ratschbacher et al., 1989, 1990, Stock, 1989). This event reactivated the previous ductile thrust faults at the structural base and especially in the hangingwall of the Murau Nappe resulting in a break of the Alpine metamorphic section (amphibolite and lower greenschist facies conditions in the Middle Austro-Alpine unit vs. very low grade conditions in the higher Gurktal Nappe Complex; compare Gosen et al., 1987). Therefore, the present structure is a ductile low angle normal fault (Fig. 8). An age of about 80 Ma in the Middle Austro-Alpine units is called for starting of post-metamorphic cooling. The subsidence of the Krappfeld Gosau basins is approximately coeval with cooling and uplift of footwall units resulting in a dramatic collapse event in the Gosau beds. Direction of sediment transport as well as 80 Ma old Pb-Pb ages on galena within the Görtschitztal line favours first activity on this line during the Late Cretaceous. The significance of the Paleogene sediments are not well understood although the more than 1,000 m thick sequences call for activity of a major normal fault system.

The Miocene fault system is both related to large sinstral, E-W trending faults and NNW-SSE trending, sigmoidal dextral faults which are related to the Escape of Central Alps to the East.

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