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THE GRAZ THRUST-COMPLEX (PALEOZOIC OF GRAZ)

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Introduction

The Upper Austroalpine Graz Thrust Complex (GTC), the so-called Paleozoic of Graz (Fig. 1), is a nappe pile which includes weakly grade metamorphosed metasediments and metavolcanic rocks of Silurian to Carboniferous age. The internal structure is dominated by several thrust sheets with distinct Paleozoic facies. The upper limit of the age of thrusting is given by a late Cretaceous overstep sequence, the Kainach Gosau. The physical margins of the GTC are the metamorphic Koralm complex to the west, the metamorphic Gleinalm complex to the north (both Middle Austroalpine), and the metamorphic Raabalpen complex to the east (Lower Austroalpine). The present contact to the surrounding metamorphic complexes is a tectonic one, no primary basement of the GTC is known. The southern termination is built by onlap of the Tertiary sediments of the Styrian basin (Friebe et al., this volume) which is western continuation of the Pannonian Basin.

History of research

Fundamental stratigraphic work was done in the early decades of this century, especially by Heritsch (1911, 1915, 1917). The development of conodont stratigraphy in the sixties gave raise to a second period of intense stratigraphic research and detailed mapping by the school of Flügel (Flügel, 1975; Flügel in Flügel and Neubauer, 1984 cum lit.). The tectonic concept of a fold-and-thrust belt originates from Clar (1935) and was later improved by Boigk (1951) and Flügel (1958).

Tectonostratigraphy

Three major nappe systems can be distinguished within the Graz Thrust Complex which differ in sedimentary facies, stratigraphic range of sedimentary sequences and metamorphic overprint. Polyphase stacking and folding caused internal imbrications, recumbent folds and structures commonly observed in a fold-and-thrust belt. Stacking of the nappes is proved by detailed mapping combined with stratigraphic and structural investigations. The nappe systems contains the following thrust sheets from bottom to the top (Fig. 1):

Lower nappe system

The Schöckl Nappe system at the base of the GTC comprises the sedimentary sequences of the Schöckl Group, Passail Group and Anger Crystalline Complex. Late Silurian to middle Devonian sedimentation is recorded from the Schöckl- and the Passail Groups. Metavolcanics and pelites dominate the Late Silurian to Early Devonian sequences, carbonates the Middle Devonian section (Ebner and Weber, 1978; Tschelaut, 1985; Weber, 1990; Fritz, 1991). The stratigraphic section is truncated by the higher nappe complexes, the structural base of the nappe complex is not exposed. Alpine greenschist facies metamorphism is common, locally amphibolite facies conditions are reached in the eastern part of the Graz Thrust Complex (Neubauer, 1981), the so-called Anger Crystalline Complex (Fig. 1).

Intermediate nappe system:

The Laufnitzdorf Nappe and Kalkschiefer Nappe are defined by the sedimentary sequences of the Laufnitzdorf Group respectively Kalkschiefer Group and occur either in basal parts of the GTC or, due to two-step stacking, in an intermediate structural level.

The Laufnitzdorf Group consists of pelagic limestones, shales and volcanic rocks of Early Silurian to Late Devonian age (Gollner et al., 1982). The metamorphic overprint was in the range of very low-grade to low-grade metamorphic conditions. Truncated teconic slices with variable stratigraphic range occur mostly along the western part of the Graz thrust complex (Fig. 1).

The Kalkschiefer Group is an uniformly developed sequence of carbonatic/siliciclastic rocks of Devonian age, the metamorphism is very low to low grade (Gollner and Zier, 1985; Tschelaut, 1984a). Slices occur in northern and western parts of the GTC (Fig 1).

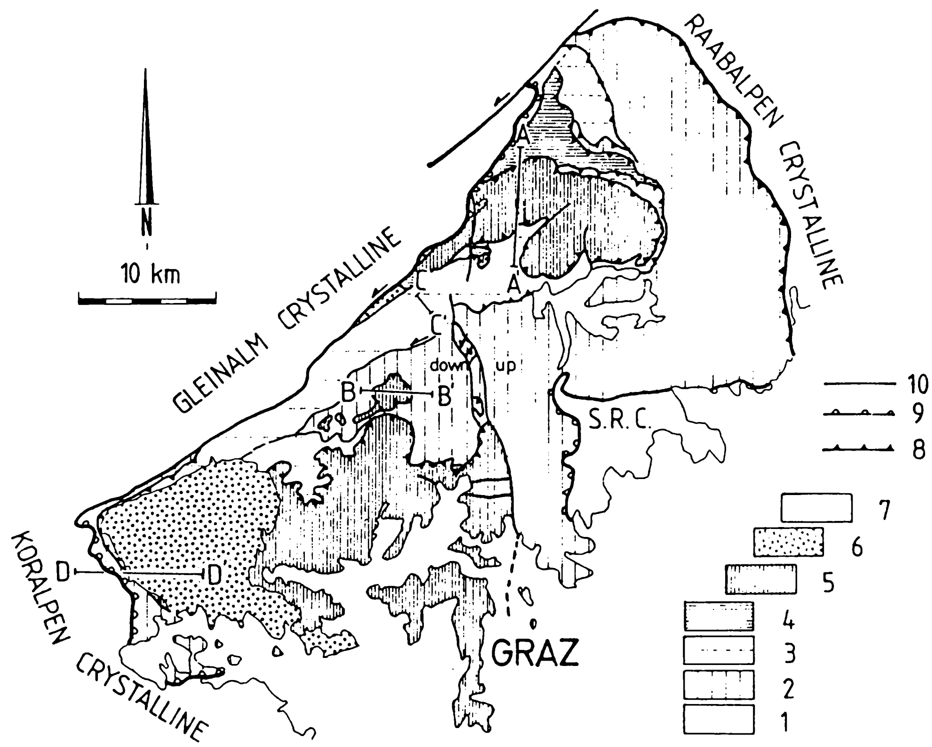

Fig. 1: Simplified tectonic map of the Graz Thrust Complex (after Fritz et al., 1991). Legend: 1 - Middle Austroalpine unit (S R C - St Radegund Crystalline); 2 - Lower nappe system; 3 - Kalkschiefer nappes and 4 - Laufnitzdorf nappe (both intermediate nappe system; 5 - Upper nappe system (Rannach nappe and Hochlantsch nappe; 6 - Kainach Gosau; 7 - Styrian/Pannonian basin (Neogene); 8 - thrust fault; 9 - ductile low angle normal fault; 10 - strike slip and high angle normal fault.

Upper nappe system:

The upper nappes, the Rannach and Hochlantsch Nappe, comprises the Rannach Group and Hochlantsch Group respectively, which are similar in stratigraphic range (Silurian to Carboniferous) and metamorphic overprint (very low-grade to low grade metamorphism, Hasenhüttl and Russegger, 1992). However, they differ in sedimentary/facial evolution. A very generalized section includes metavolcanic and clastic rocks from the Silurian to the Early Devonian and carbonates of platform and pelagic environments up to the Carboniferous (Fenninger and Holzer, 1978; Ebner et al., 1980; Poltnig, 1984; Gollner and Zier, 1985, Neubauer, 1989, 1991; Fritz, 1991; Hubmann, 1990). Rocks of the Rannach- and Hochlantsch Groups occur predominantly in western and northern parts of the GTC (Fig. 1).

Kainach Gosau basin (Late Cretaceous)

The internal nappe structure in the western part of the GTC is concealed by the Kainach Gosau sediments which unconformly overlie the nappe pile of Paleozoic rocks (Gräf, 1975). The sequence starts with conglomerates along the northern margin of the basin (Basiskonglomerat). Besides local detritus from the GTC, Mesozoic carbonates including few pebbles of probable Southalpine origin dominate the pebble spectrum (Gollner et al., 1987). The conglomerate is followed by limnic sediments (Bitumenmergel) and a thick turbiditic sequence, the so-called Hauptbeckenfolge.

Stratigraphy and Paleogeographic Evolution

A wide diversity of facies ranging from shallow marine to basinal pelagic environments is characteristic for the sedimentary evolution of the Graz Thrust Complex. The primary arrangement (Fig. 2) of the stratigraphic sequences, now dismembered by tectonic processes, is deduced from both structural and stratigraphic/facial investigations.

In spite of a facies differentiation the following general trends which are typical especially for the Schöckl Group, Kalkschiefer Group and the Rannach and Hochlantsch Groups can be observed. Numbers and formations in the description below refer to the stratigraphic/ sketch in Fig. 2.

-- The basal members of the stratigraphic sequences up to the late Silurian are dominated by alkaline mafic volcanoclastics which are interpreted as initial rift sequence (1: Lower Kher-Fm; Passail-Fm; Waldstein-Fm.) (Fritz and Neubauer, 1988; Loeschke, 1988).

-- An alternation of carbonates and fine grained siliciclastic sediments developed from the Late Silurian up to the Early Devonian. Characteristic is a progressive carbonate production and clastic input in subbasins of variable water depth (2: Upper Kher-Fm; 3: Parmasegg-Fm. [Crinoiden-Fm]; Arzberg-Fm.) (Ebner and Weber, 1978; Tschelaut, 1984b; Weber, 1990; Neubauer, 1991; Fritz, 1991).

-- Thick dolomites, coarse sandstones and partly fossil-rich limestones of a carbonate platform interfinger with lagoonal sandy coastal environments developed in lower to middle Devonian (4: Gschwendt-Fm; 5: Dolomit-Sandstein-Fm.; 6: Barrandei-Fm.; 7: Schöckl-Lmst.) (Fenninger and Holzer, 1978; Gollner and Zier, 1985; Hubmann, 1990).

-- A second climax of alkaline mafic volcanism occurd during the Givetian (8: Tyrnau-Fm.) (Gollner and Zier, 1985).

-- From Late Givetion to Early Frasnian the sedimentary environment changed from a platform setting (9: Kanzel-Lmst.; 10: Hochlantsch-Lmst.) to a conodont-rich, pelagic sequence including flaser limestones and cherts which continue locally to the Namurian A (11: Steinberg-Lmst.; 12: Sanzenkogel-Fm.) (Ebner, 1978, 1980, Ebner et al., 1980; Gollner and Zier, 1985).

-- In the Rannach and Hochlantsch Groups the stratigraphic sequence continues probably up to Westfalian/A. Significant stratigraphic gaps accompanied by erosion and karstification, characterized by mixed conodont faunas developed during Late Devonian and Early Carboniferous levels. A peculiarity of the Rannach Group are shales at the top of the sequence (13: Dult-shales) (Ebner, 1978, 1980; Ebner et al., 1980).

The Laufnitzdorf Group shows deviating characteristics with a continuous pelagic environment from the Early Silurian to Late Devonian (14: Hackensteiner-Fm; 15: Harrberger-Fm) probably interfingering with carbonatic/clastic shelf (16: Schattleiten-Fm;) and litoral environments (17: Dornerkogel-Fm) in the Devonian or probably Carboniferous times (Gollner et al., 1982; Gollner and Zier, 1985; Tschelaut, 1984a).

All these sequences reflect the evolution of a passive continental margin from the breakup of a Silurian continent with alkaline volcanism to the formation of shelf and platform sediments in the Devonian (Fritz and Neubauer, 1988; Loeschke, 1988). Facies heterogenities between the single

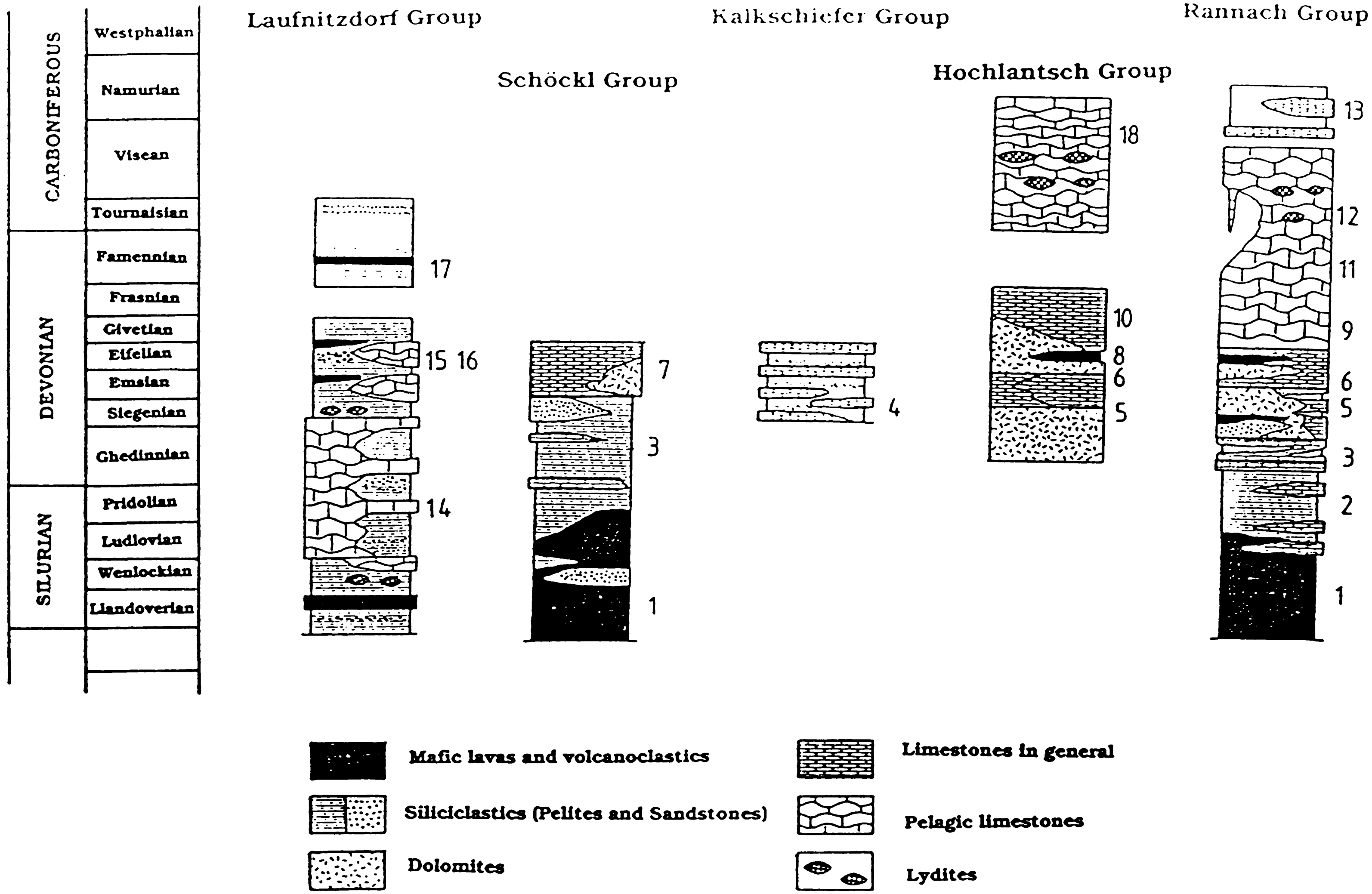

Fig. 2: Stratigraphic sketch of the Graz Thrust Complex: 1: Lower Kher Fm. (Rannach Group); Waldstein Fm. resp. Passail Fm. (Schöckl Group). 2: Upper Kher Fm.; 3: Parmasegg Fm. (Rannach Group); Arzberg Fm. (Schöckl Group). 4: Gschwendt Fm. 5: Dolomit-Sandstein Fm. 6 : Barandei Lmst. 7: Schöckl Lmst. 8: Tyrnau Fm. 9: Steinberg Lmst. 10: Hochlantsch Lmst. 11: Steinberg Lmst. 12: Sanzenkogel Lmst. 13: Dult Fm. 14: Hackenstein Fm. 15: Harrberger Fm. 16: Schattleitner Fm.17: Dornerkogel Fm. 18: Mixnitz "Carboniferous Lmst."

groups (Rannach-, Hochlantsch-, Schöckl-Group) indicating different bathymetric and hydrodynamic conditions reflect segmentation of the passive continental margin in subbasins and swells.

The sedimentary facies of the Devonian/Carboniferous carbonate shelf is controlled by eustatic sea level fluctuations and synsedimentary tectonics which caused stratigraphic gaps and the formation of conodont mixes faunas (Ebner, 1978).

However, the widely deviating sediments of the Laufnitzdorf Group do not fit into the concept of a single terrigenous hinterland. Recent investigations on detrital modes of Silurian/Devonian sandstones reveal clear differences between quartz arenites of the Rannach- Hochlantsch and Kalkschiefer Groups and the greywackes and arkoses of the Laufnitzdorf Group. The latter require a differnt source region which is incompatible with the former ones (Neubauer, in prep.).

Paleogeographic correlations to other extra- and intra-Alpine Paleozoic sequences are based on biogeography and stratigraphic/ facial comparisons. Algal floras suggest close relationships of the Graz Thrust Complex to the Rhenohercynien in the middle Devonian (Hubmann, 1990). In addition, the occurrence of widespread quartz arenites during the Early Devonian and red mature quartz arenites in the Middle Devonian Barrandei Limestone indicate possible relations to the Old Red-continent. A possible correlation to the Hungarian Uppony Mountains arises from strong similarities in the stratigraphic sequences and the fact that pelagic sedimentation continues up to the Westfalian and synorogenic flysch sedimentation is missing in both areas (Ebner et al., in prep.).

Structural Evolution

Structural association of the Graz Thrust Complex can be subdivided into structures which are related to Early Cretaceous crustal stacking, to Late Cretaceous extensional structures which are associated with the formation of the Gosau basin and to post-Gosauian faulting. Pre-Alpine structures are rarely preserved. However, there is some evidence for pre-Alpine static recrystallization under upper greenschist metamorphic conditions in the deeper nappes (Neubauer, 1981). All Alpine structures developed under decreasing temperature conditiones.

Early Cretaceous compressional structures

Shortening in the GTC resulted in structures which are known from fold-and-trust belts. Shortening directions are similar in all units, they reflect a two stage imbrication with approximately top-to-the WSW- (D1) to top-to-the NW (D2) directed thrusting (Fig. 3). Single displacement paths and structural associations, however, differ localy depending on rheological behaviour of minerals in different crustal levels and on the location within the thrust complex.

In the Schöckl nappe system deformation is concentrated in the Silurian to lower Devonian metapelites which include the most deformable rocks in this unit. These rocks formed the flats during nappe imbrication. Pressure solution and diffusional mass transfer are the dominant deformation mechanisms which developed during the first deformational event (D1). An intense stretching lineation is homogenousely east-west oriented. Rotational component of deformation is revealed by several shear sense indicators as asymmetrically pressure shadows around rigid objects, S-C surfaces, ecc-structures and structure in outcrop scale (thrust geometry) (Fritz, 1988, 1991; Fritz et al., 1991; Neubauer, 1989, 1991). The sense of shear is top-to-the W, the strain geometry is close to plane strain. This penetrative foliation was refolded in a second deformation increment (D2) (Neubauer, 1981; Agnoli, 1987; Fritz, 1988, 1991). Fold axes are parallel to stretching, strain geometry turns to flattening strain.

In the highest nappe, the Rannach nappe, the structures of the first deformation increment (D1) are very similar to those of the Schöckl nappe. Fabric asymmetries and large-scale sheath folds (Neubauer, 1991) again indicate shear towards top-to-the-W and top-to-the-WSW, respectively, as well as plane strain geometry. During the second increment of deformation (D2) the strain geometry persisted but the direction of stretching changed progressively towards NW. This is indicated by changing growth directions of synkinematic fibres behind rigid objects (Fritz, 1988). We interpret this feature as progressive change of nappe displacement from southwest towards northwest.

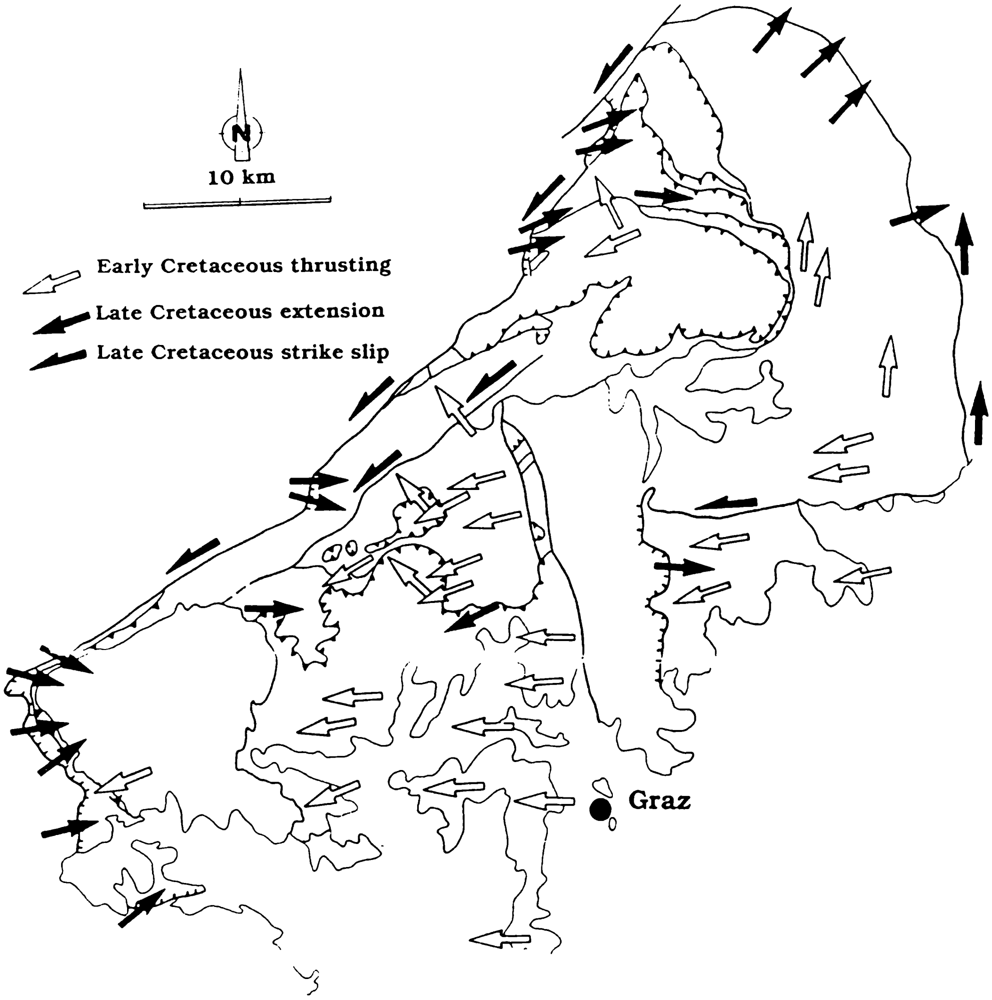

Fig. 3: Simplified structural map of the Graz Thrust-Complex.

Asymmetric fabrics in the Kalkschiefer Group indicate top-to-the-NW to top-to-the NE transport (D2) (Tschelaut, 1984b; Fritz et al., 1991). Decreasing temperatures caused progressive brittle behaviour and thrusting in a thin-skinned-tectonic manner (D2). Thrusts with ramps and flats developed in an outcrop scale, the direction of displacement persisted (top-to-the-W to top-to-the NE). NW-SE horizontal compression is supported by paleostress analyses (Fritz, et al. 1991).

On map-scale, arguments for a W-directed nappe stacking arise from the stratigraphic extend and spatial distribution of tectonostratigraphic units. Basal thrusts of the higher nappes are climbing towards higher stratigraphic levels during thrust-propagation. In western sections of the GTC the basal thrust planes cut the Devonian carbonates, whereas in eastern sections basal members of the stratigraphic column are preserved.

Macro-scale folding is best seen in the bedded limestones of the Kalkschiefer nappe. The relationships between bedding, axial plane foliation and minor second order folds point to NW-directed vergence (Tschelaut, 1984b). Large-scale recumbent folds developed mostly in the lowers nappe systems due to enhanced passive fold amplification (Clar, 1935; Neubauer, 1981).

An example for the two-phase stacking and the mode of thrust propagation is given from the northwestern parts of the GTC (Fritz, 1991). In a first step the Rannach nappe was thrusted onto the Schöckel nappe, later the whole nappe pile was involved into foreward propagation of thrusts (Fig. 4). Foreland dipping thrusts may be explained by duplex structures.

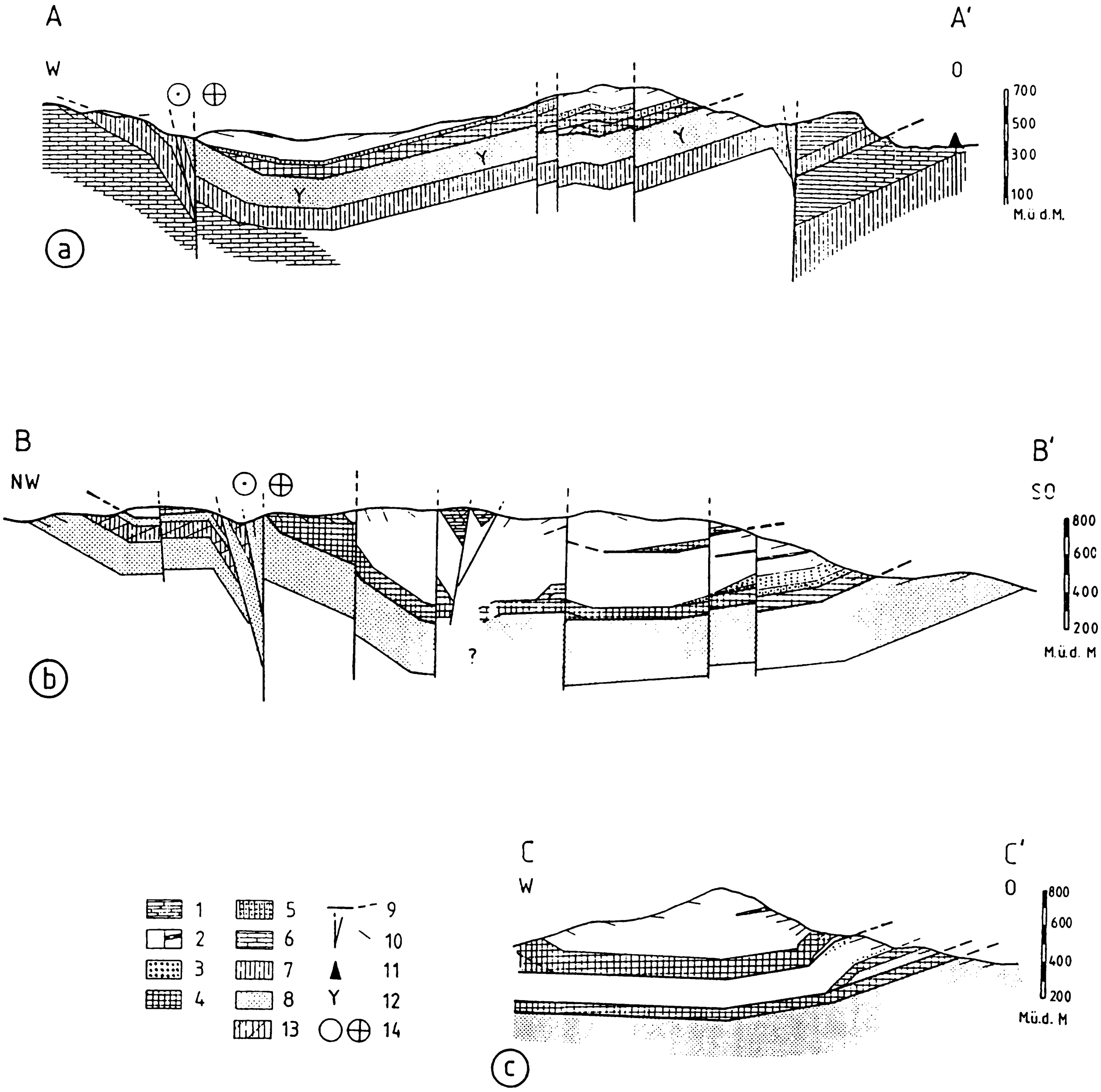

Fig. 4: Sections parallel to the direction of nappe emplacement in the northwestern part of the Graz Thrust Complex (after Fritz, 1991) shows mode of stacking. Fig. 4a is parallel to section B-B', Fig. 4b and 4c parallel to E-E' in Fig. 1. Legend: 1 - Barrandei-Fm; 2 and 3 - Dolomit-Sandstein-Fm; 4 and 5 - Parmasegg-Fm (all Rannach nappe); 6 - Schöckl-Lmst.; 7 - Arzberg-Fm; 8 - 13 Waldstein-Fm (all Schöckl nappe); 9 - thrust; 10 - strike slip fault and normal fault; 11 - well; 12 - inverted portions; 14 - sense of movement in strike slip zones.

Another example of two-phase stacking is seen along the northern margin of the GTC (Fig. 5). The section shows a double repetition of Early to Middle Devonian limestones of the Kalkschiefer nappe with Late Silurian and Devonian sediments of Laufnitzdorf nappe. This intermediate nappe pile is thrusted by Middle Devonian limestones of the Hochlantsch nappe. Again we interpret this special imbrication as a two-phase stacking with out-of-sequence thrusting. Thus, the Laufnitzdorf nappe was first thrusted onto the Kalkschiefer unit and stacking continued in further imbrication of both nappes and thrusting of the Hochlantsch nappe. The nappe transport inferred from stretching lineation and shear sense indicators is top-to-the-WSW to top-to-the-NW.

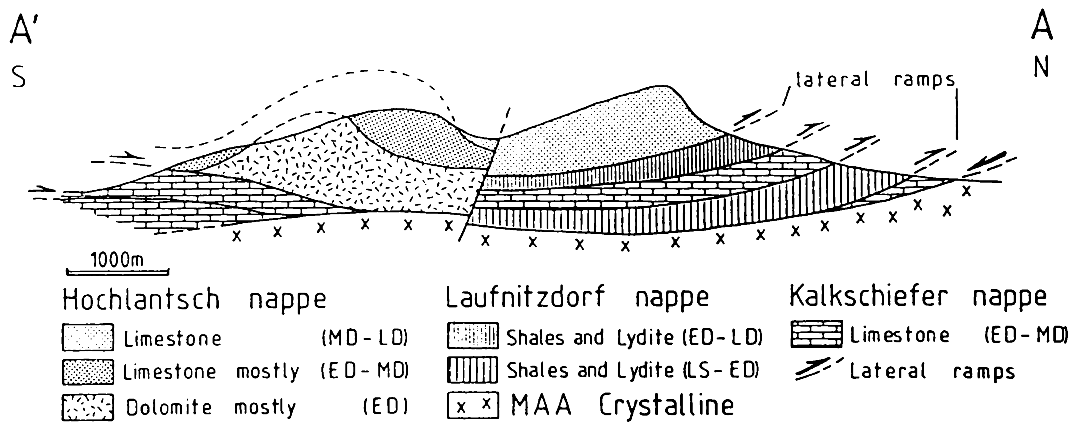

Fig. 5: Section parallel to A-A' in Fig. 1 modified after Gollner and Zier (1985) shows double stacking of nappes which is overprinted by extensional structures along the northern margin of the Graz Thrust complex.

Late Cretaceous extensional structures

Extensional structures are predominantly non-penetrative. Extension is accomplished by a system of NE-SW striking sinistral strike-slip faults and approximately N-S striking normal faults (Fig. 3). Examples for bulk extension arise from central parts of the Graz Thrust Complex and from the western margin (Neubauer, 1988; Fritz et al., 1991; Ratschbacher et al., 1991a) where extension resulted in the formation of the Gosau basin.

The western, northwestern and northern margins of the Graz Thrust Complex represent a system of NE-SW striking sinistral shear zones and East dipping decollements (Neubauer, 1988; Neubauer and Genser, 1990; Ratschbacher et al., 1991a). Arguments for extension on map-scale are the dramatically reduced lithotectonic profile, the oblique cut of nappes by the basal decollement zone, and the metamorphic break at the western and northern margin of the GTC. Confrontation of displacement directions, W-directed between internal nappes of the GTC and E-directed at the base to the Middle Austroalpine crystalline is interpreted in change of compression to extension (Fritz, et al. 1991). Extensional deformation continued in late Cretaceous time and affected also basal Gosau sediments which are incorporated in the sinistral shear zone along the northwestern margin of the GTC (Fig. 1).

Microfabrics indicating low temperature plasticity of quartz and calcite suggest that normal faults and sinistral shear zones were active under greenschist metamorphic conditions at the basal parts of the GTC . Textures indicate operation of sinistral strike slip displacement along NE-SW oriented faults together with E-dipping normal faults. Within the Gosau sediments respectively at the base of Gosau, paleostress analyses and the pattern of extension veins indicate E-W extension.

In the Schöckl nappe sinistral strike slip is achieved by semiductile steep shear zones. Widely spaced ecc surfaces cut the metamorphic layering which was created during previous deformations. In higher portions of the nappe pile discrete NE-SW striking faults are common.

Post-Gosauian faulting

Horst and graben structures north of Graz are bound to W-E striking faults. These faults are themselves cut by N-S striking normal faults with downward movement of the eastern blocks. The kinematic frame of these faults points to vertical shortening and E-W extension as commonly observed in Neogene faults of the Eastern Alps (Neubauer, 1988; Ratschbacher et al., 1991b). Continental scale extrusion of the consolidated Eastalpine block and formation of the Pannonian basin may be correlated with this system of faults commonly observed east of Tauern Window (Neubauer, 1988; Neubauer and Genser, 1990; Ratschbacher et al., 1991b).

Timing of the events

From the sedimentary record the upper limit of thrusting in the Graz Thrust-Complex is given by the overstep sequence of the Gosau with approximately 80 Ma. Although there is geochronological evidence for a pre-Alpine metamorphic event it is very likely that thrusting occurred during the Early Cretaceous (approximately 120 Ma) (Flügel et al. 1980; Fritz, 1991; Dallmeyer et al., in prep.). This is supported by geochronological data which point to Early Cretaceous compression in the Upper Austroalpine nappe pile (Kralik, et al., 1987; Frank et al., 1987, Ratschbacher et al., 1989).

Extensional regime is clearly connected with the formation of the Gosau basin. In addition, mineral ages of hornblende, biotite and white mica indicate rapid cooling of the metamorphic Gleinalm complex between 100 Ma to 80 Ma. This cooling is related to uplift in the metamorphic Gleinalm complex and relative down-dip movement of the Graz Thrust Complex during within a sinistral wrench corridor.

Discussion

Structural investigations indicates that the record of Variscan deformation in the Graz Thrust Complex was only minor. In addition, the continuous sedimentation up to the Westfalian in shallow marine facies suggests that this area had been in an external position relative to the main Variscan front.

Timing and evolution of Alpine structures is typically for the Upper Austroalpine nappe pile (e.g. Ratschbacher and Neubauer, 1989; Ratschbacher et al., 1989). Progressive change of extensional directions from approximately SW to NW is explained by transpressive collision between an Adriatic block and a segment of the Cimmerian terrane. The Graz Thrust Complex occupied an upper plate position during plate collision. Subsequent orogen-parallel extension and basin formation occured in two distinct periods and may be explained by lateral extrusion of crustal pieces in Late Cretaceous and Neogene times (e.g., Neubauer, 1988, Ratschbacher et al., 1989).

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