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Structure of Austroalpine and Penninic units in the Tilisuna area (Eastern Rätikon, Austria): Implications for the paleogeographic position of the Allgäu and Lechtal nappes

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Key words: Alps, Austroalpine nappes, Arosa zone, Northern Calcareous Alps, Lechtal nappe, Paleogeography.

ABSTRACT

This study presents new data related to the architecture and evolution of the Penninic-Austroalpine plate boundary in the vicinity of the Prättigau halfwindow (eastern Switzerland). The Tilisuna area in the northeastern corner of the Prättigau halfwindow provides a structural section from the Middle Penninic Sulzfluh nappe through various South Penninic and Lower Austroalpine units up to the Upper Austroalpine Phyllitgneis zone. The Tertiary age basal thrust of the units derived from the Apulian margin over the Penninic domain is located at the top of the lowermost subunit of the Arosa zone, which represents the remnants of the South Penninc ocean. The hanging wall of this basal thrust is formed by a nappe pile of higher South Penninic, Lower Austroalpine and Upper Austroalpine units that was already assembled in Late Cretaceous times. It is shown that the Cretaceous nappe stack beneath the Phyllitgneis zone in the study area is identical to that found below the Silvretta nappe southeast of the Prättigau halfwindow. In this scheme the Arosa Dolomites nappe represents the southern prolongation of the Allgäu nappe of the Northern Calcareous Alps. The results confirm earlier petrographic studies proposing that the Phyllitgneis zone and the Silvretta nappe are not separated by an important Alpine fault. Instead, the Phyllitgneis zone and the Silvretta nappe represent one and the same unit. Accordingly, the deposition area of the western Calcareous Alps (Lechtal- and Allgäu nappes) was located north of the Silvretta nappe.

Introduction

In eastern Switzerland and the adjacent areas in Austria and Italy the trace of the plate boundary between the Penninic and Austroalpine paleogeographic domains runs more or less N-S, perpendicular to the strike of the Alps. The Prättigau halfwindow represents an eastward embayment of this suture (Fig. 1). Around the halfwindow, slices of various and ambiguous paleogeographic origin including ophiolitic remnants of the South Penninic ocean are sandwiched between continental cover nappes below and vast Austroalpine basement nappes on top. This study reinvestigates the Tilisuna area which is located in the northeastern corner of the Prättigau halfwindow (Fig. 1). The objective is a new look at the ambiguous slices piled up between the Middle Penninic Sulzfluh nappe and the Upper Austroalpine Phyllitgneis zone. I will focus on the tectonic provenance and structural architecture of these slices and particularly discuss the location of the Austroalpine basal thrust. This first section provides a brief introduction into the geology of the region, followed by a more precise explanation of the problems and their significance.

The entire Penninic nappe complex represents a composite Mesozoic paleogeographic domain located between the European and the Apulian margins. It is commonly subdivided into Lower, Middle, and Upper Penninic nappes. Lower Penninic nappes are derived from the distal European margin and the adjacent Valais trough also called North Penninic ocean. Upper Penninic nappes record the South Penninic ocean, also called Piemont Liguria ocean, the main oceanic domain conserved in the Alps. West of the Engadine window Lower and Upper Penninic nappes are separated by continental basement- and/or cover nappes, which are referred to as Middle Penninic nappes. These originate from a ribbon continent, the so-called Briançonnais, an eastward promontory of the Iberian plate. It became isolated from Europe in Early Cretaceous times creating the Valais trough towards the north (Frisch

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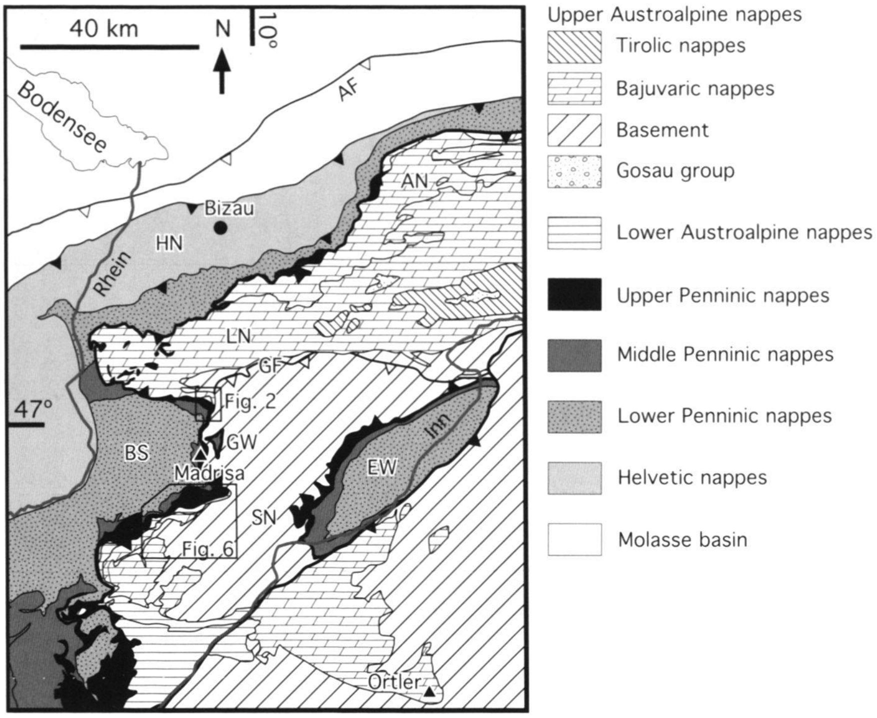

Fig. 1. Tectonic overview of the area around the Prättigau halfwindow in eastern Switzerland and Austria. The thrust north of the Silvretta nappe within Upper Austroalpine basement illustrates the location of the proposed boundary between Silvretta nappe sensu stricto and Phyllitgneis zone (GF).
AF, Alpine front; AN, Allgäu nappe; BS, Bündnerschiefer; EW, Engadine window; GW, Gargellen window; HN, Helvetic nappes; LN, Lechtal nappe; SN, Silvretta nappe. Triangles denote peaks.

1979; Stampfli 1993; Florineth & Froitzheim 1996; Stampfli et al. 2002). The Austroalpine nappe stack rests on top of the Penninic nappes and is derived from the Apulian margin. It is usually subdivided into Lower and Upper Austroalpine units, with the Lower Austroalpine nappes representing the more distal portion of the margin and the transition into the South Penninic ocean (Eberli 1985; Furrer 1985; Froitzheim & Eberli 1990). Some authors consider a large portion of the crystalline basement nappes in the central part of the Eastern Alps as an independent "Middle Austroalpine" complex (e.g. Tollmann 1963). I will follow the nomenclature of Janak et al. (2004) and call those units that have a structural position between the top of the Lower Austroalpine units below and the top of the Koralpe-Wölz high-pressure nappe system above (Schuster et al. 2001; Schmid et al. 2004) as Lower Central Austroalpine units (Janak et al. 2004). The Koralpe-Wölz nappe system represents an intra-Austroalpine unit that was affected by Late Cretaceous metamorphism under high-pressure conditions (Hoinkes et al. 1999; Schuster et al. 2001)

Two distinct orogenic events are recorded in the Penninic-Austroalpine nappe stack (e.g. Ratschbacher 1986; Froitzheim et al. 1994). The Austroalpine units were imbricated during a first orogeny in Cretaceous times, as is indicated by Late Cretaceous sediments of the Gosau group sealing internal nappe boundaries within the Austroalpine domain (Herm 1962; Ortner 1994; Willingshofer et al. 1999; Wagreich & Decker 2001). During the subsequent collision of Europe and Apulia in Eocene times the entire Austroalpine stack was thrust as a relatively coherent block, termed "traineau ecraseur" by Termier (1903), onto the deeper Penninic units (e.g. Laubscher 1989). This second collision and associated formation of the Penninic nappe pile followed the southward subduction of the South Penninic ocean. In contrast, the Cretaceous formation of the Austroalpine nappe pile was related to the Late Jurassic closure of the Meliata ocean (Froitzheim et al. 1996) located southeast of the Austroalpine domain (e.g. Mandl 2000). Cretaceous shortening and nappe stacking within the Austroalpine units were top-NW to top-W whereas Tertiary collision is N-S oriented (e.g. Ratschbacher 1986; Ratschbacher & Neubauer 1989; Ring et al. 1989; Froitzheim et al. 1994; Eisbacher & Brandner 1996).

The interior of the Prättigau halfwindow is formed by Lower Penninic nappes. These consist of clastic sediments of Cretaceous to Eocene age deposited in the Valais trough, the so-called Bündnerschiefer (Nänni 1948). The Middle Penninic domain is represented by two relatively thin cover nappes, the Falknis and the Sulzfluh nappe. The Austroalpine frame of the halfwindow is formed by a vast sheet of pre-Mesozoic basement. This basement sheet is called Silvretta nappe to the south and east and Phyllitgneis zone to the north. The Permo-Mesozoic sedimentary cover of the Silvretta nappe is preserved only in the so-called Landwasser zone, southeast of the halfwindow, while the Phyllitgneis zone is widely accepted to represent the original basement of the sediments exposed further north in the Lechtal nappe (Hammer 1918; Ampferer 1933). The Lechtal nappe represents the main unit of the Northern Calcareous Alps in western Austria. The relationship between the Silvretta nappe sensu stricto and the Phyllit-

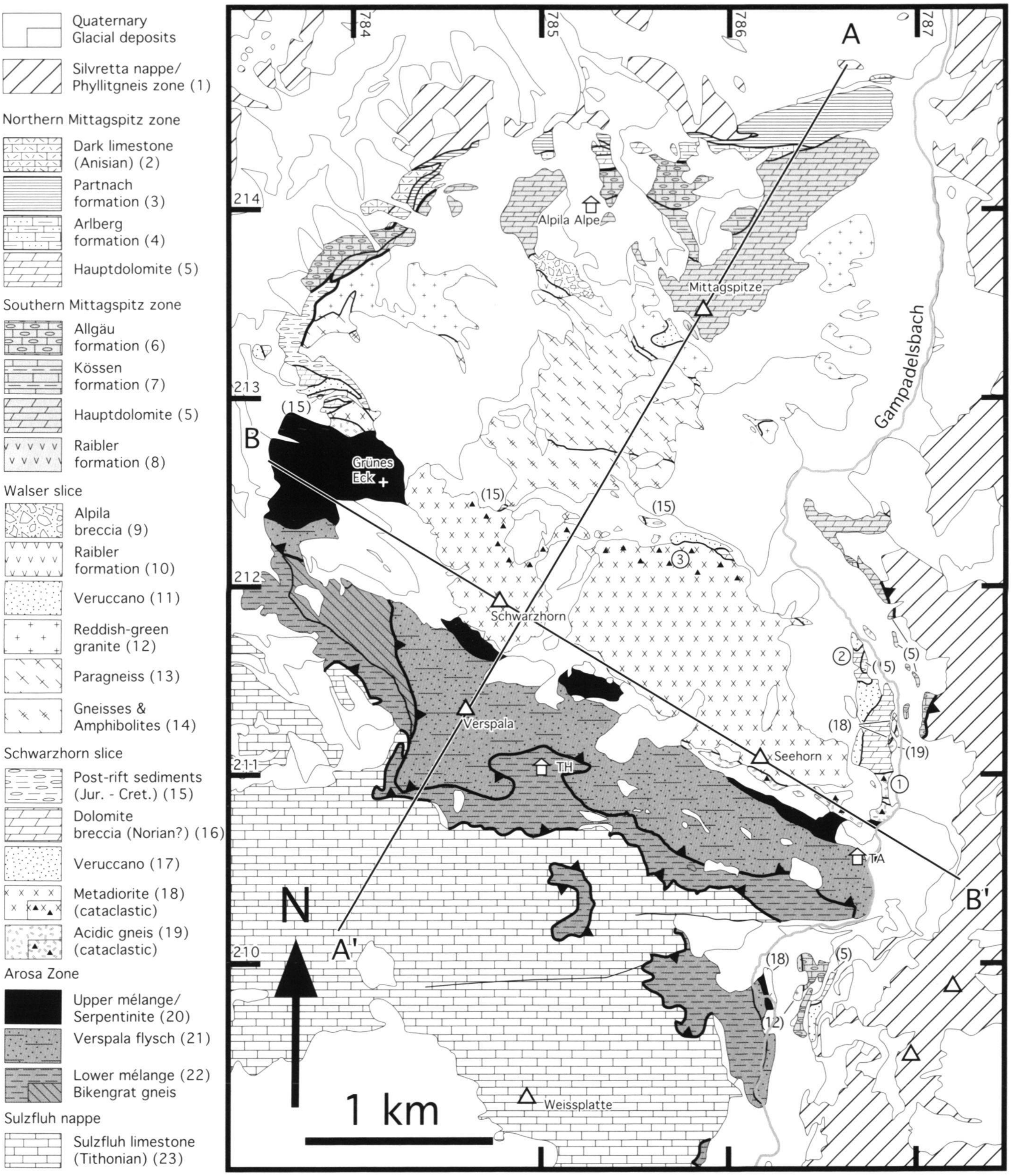

Fig. 2. Geological map of the Tilisuna area. Coordinates at the side are Swiss coordinates. A–A' and B–B' show location of cross sections shown in figure 3. Numbers in brackets refer to lithologies (see key). Labels 1–3 in circles refer to the geological reconstruction in figure 5.
TA, Tilisuna Alpe; TH, Tilisuna hut. Triangles denote peaks.

gneis zone has been a matter of discussion and is tightly connected to the classic controversy about the paleogeographic origin of the Northern Calcareous Alps. So far, there is no general agreement as to whether the extended allochtonous nappe complex of the Northern Calcareous Alps (Fig. 1) has a deposition area north or south of the Lower Central Austroalpine basement units (Tollmann 1959; 1963; Frank 1987; Eisbacher & Brandner 1996; Schuster & Frank 1999; Auer & Eisbacher 2003; Frisch & Gawlick 2003).

Around the Prättigau halfwindow, a pile of relatively thin nappes and slices derived from the South Penninic and Austroalpine domains is wedged between the Middle Penninic cover nappes and the large Austroalpine basement complex of the Phyllitgneis zone and the Silvretta nappe. Cadisch (1923) merged all slices into a single unit, the so-called "Arosa Schuppenzone". Nowadays, most authors associate the term "Arosa zone" exclusively with rocks derived from the South Penninic ocean (e.g.Trümpy 1980; Weissert & Bernoulli 1985; Winkler 1988). Lithology and position of the Arosa zone pose a paradox. In Graubünden the youngest dated sediments of the Arosa zone are of Turonian age (Oberhauser 1983; Lüdin 1987). Hence, this zone was probably accreted to the Austroalpine wedge during Cretaceous orogeny (Liniger & Nivergelt 1990). However, the Arosa zone as a whole also represents the Tertiary suture zone between the Penninic and Austroalpine domains and it discordantly cuts the base of the Austroalpine nappe pile (e.g. Blumenthal 1936; Oberhauser 1970). One objective of this study is to solve this paradox and to determine the precise location of the Tertiary basal thrust in the study area. The following section is a detailed description of the units found in the study area. Lithological composition will be used to attribute individual slices to established nappe complexes of Graubünden and western Austria in a new way.

The nappe stack in the Tilisuna area

The study area comprises the Penninic-Austroalpine nappe pile from the Middle Penninic Sulzfluh nappe up to the basement complex of the Phyllitgneis zone. Within most of the study area, tectonic boundaries strike northwest- southeast but abruptly change towards north-south in the easternmost part (Fig. 1, Fig. 2). Northwest-southeast striking nappe boundaries become progressively steeper towards north (Fig. 3a) and the base of the Phyllitgneis zone is already in a vertical to overturned, i.e. south-dipping orientation. Several monographs on the Tilisuna area have been published over the last century (e.g. von Seidlitz 1906; Leutenegger 1926; Blumenthal 1936; Burger 1978; Biehler 1990) and especially the map of Reithofer (in Heissel & Reithofer 1965) was an excellent basis for this work. In the following, I will portray the nappe pile south of and structurally below the Phyllitgneis zone starting with the lowest unit and progressing to the top. Each section contains a description of the rock assemblage and a discussion of the tectonic/paleogeographic derivation of that unit. While the Sulzfluh nappe can be clearly attributed to the Middle Penninic domain, the positions of the higher units are disputable. I will restrict the term "Arosa zone" to the ophiolite-bearing levels below the Schwarzhorn Slice (Ring et al. 1990). The units found between the Arosa zone and Phyllitgneis zone are attributed to the Austroalpine nappe pile by most authors. However, the degree of organization within this pile and the provenance of the individual slices is still unclear.

Sulzfluh Nappe

The Sulzfluh nappe is build by the sedimentary cover of the Middle Penninic microcontinent (e.g. Stampfli 1993). A few hundred meters of Tithonian platform carbonates (von Seidlitz 1906) form the backbone of the eastern Rätikon. This limestone is overlain by 20 meters of colored, Late Cretaceous to Early Tertiary pelagic marls, the so-called Couches Rouges (von Seidlitz 1906; Allemann 1952). A low angle unconformity and sinkholes of paleokarst are present at the top of the Tithonian limestone (Allemann 1987). Scarce remnants of a granitic basement of the Sulzfluh nappe are found outside the study area, directly below the Upper Jurassic limestone. As a result of internal stacking during late thrusting the Sulzfluh nappe has a total thickness of about a thousand meters (von Seidlitz 1906).

Arosa zone

I divide the Arosa zone in the study area into three subunits – (1) a lower mélange consisting of a clay matrix and various embedded blocks typical for the Upper Austroalpine and South Penninic domain, (2) a Cretaceous flysch (the so-called Verspala flysch), and (3) an upper mélange consisting of strongly deformed serpentinite, which contains tectonically emplaced slivers of Lower Austroalpine derivation.

The matrix of the lower mélange consists of a dark shale often containing crumbs of yellow dolomite or sandstone. No fossils have been found in this shale yet. Within this matrix blocks and slices of almost exclusively Upper Austroalpine or South Penninic origin are embedded. Most slices vary between tens and hundreds of meters. However, the 1 kilometer long Bilkengrat gneis southwest of peak Schwarzhorn (Fig. 2) is also considered as a component in this mélange. The most frequent lithology is dark, Anisian limestone, as found in the Northern Calcareous Alps (Reithofer & Schmidegg 1964) but also other Permo-Mesozoic sediments including radiolarite and more or less foliated acidic basement and ophicalcite occur. Among the less frequent blocks are a few slivers of grey marl identified as Couches Rouges. They represent the only component in the lower mélange, which is younger than Early Cretaceous (von Seidlitz 1906; Stahel 1926) and possibly derived from a structurally deeper unit (Middle Penninic Sulzfluh nappe?).

While some authors propose a tectonic origin of the lower mélange (e.g. Lüdin 1987), most geologists interpret it as a fine grained sediment with embedded olistolites (Haldiman 1975; Burger 1978; Biehler 1990). The material is obviously strongly

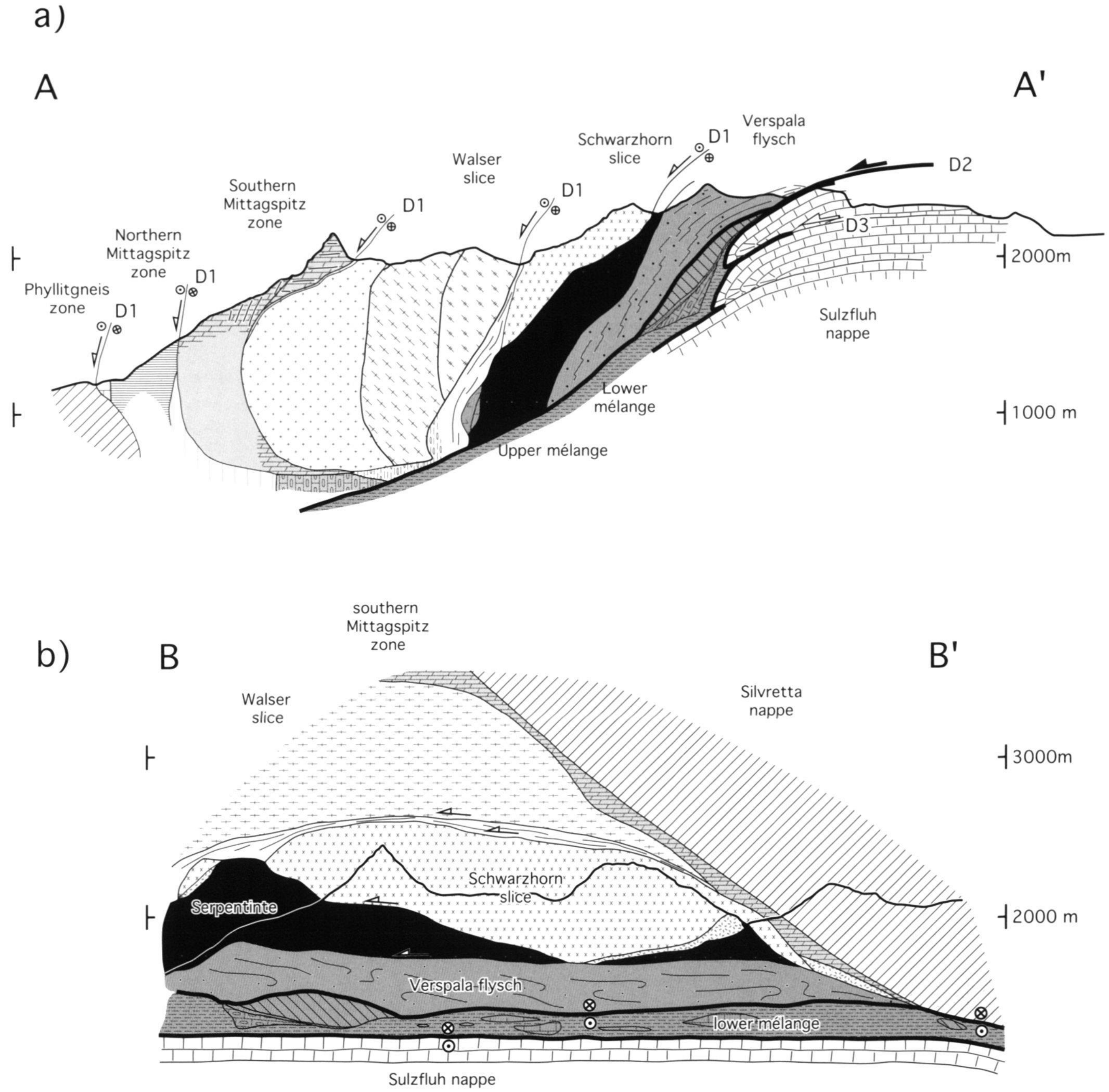

Fig. 3. Cross sections through the study area. Traces of cross sections are shown in figure 2. Three generations of thrusts are inferred (see section 3). D1, thin arrows with open arrow heads; D2, black arrows; D3, white arrows.

deformed (Ring et al. 1989; Biehler 1990). The shales are completely dismembered and I could not find unequivocal traces of sedimentary layering. However, the matrix is clearly of sedimentary origin and not a cataclasite derived from the components. Due to the lack of fossils, the age of the matrix has not been determined yet. Burger (1978) and Oberhauser (1983) proposed an Early Cretaceous age. Instead, Biehler (1990) argued for sedimentation in a Late Cretaceous accretionary wedge. If the shale would indeed be of Early Cretaceous age, the Couches Rouges slivers must have been incorporated tectonically.

The overlying Verspala flysch is a shaly-calcareous flysch. Its sedimentological aspects have been investigated in great detail by Burger (1978), Oberhauser (1983), and Lüdin (1987). It is Cenomanian-Turonian in age and thus represents the youngest dated flysch in the Arosa zone (Oberhauser 1983). Like many Cretaceous sandstones found in the Arosa zone, it contains abundant ultramafic detritus (Lüdin 1987). It is in-

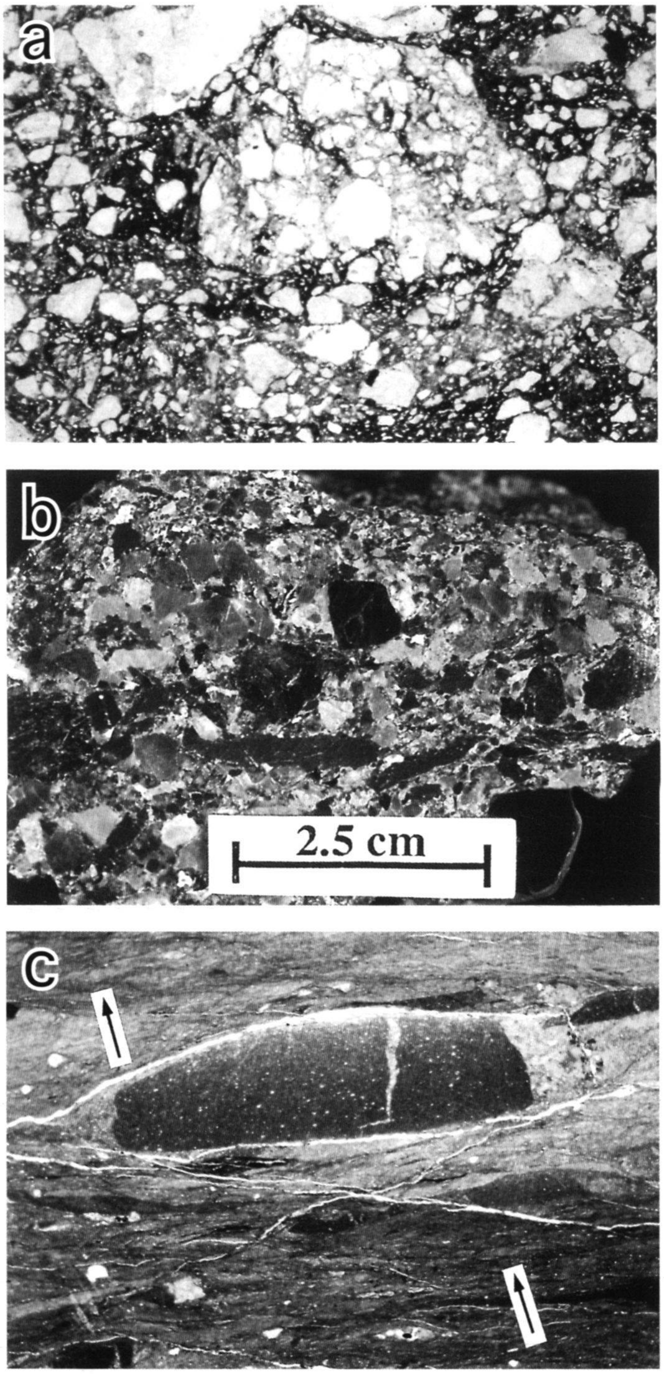

Fig. 4. Photographs of lithologies from the Schwarzhorn slice
4a: Photomicrograph of rift-related cataclasite in the Schwarzhorn slice. Vertical side of photo is approx. 2 mm long.
4b: Mixed, probably Liassic breccia in the sedimentary cover of the Schwarzhorn slice.
4c: Photomicrograph of pebbly mudstone in the sheared post-rift cover of the Schwarzhorn slice. The sample contains sc-microstructures (arrows) and asymmetric pressure shadows as shear sense indicators. Vertical side of photo is approx. 6 mm.

tensely deformed, but usually appears as a coherent pile of folded layers. The entire sequence becomes progressively younger towards north (Oberhauser 1983). Several geologists pointed to the good preservation of this flysch situated between two dismembered mélange units (e.g. Ampferer 1933; Lüdin 1987).

The upper mélange predominantly consists of highly deformed serpentinite. Within this matrix, slivers of sedimentary- and basement rocks are embedded. The frequency of slivers increases toward the contact to the next higher unit, the Schwarzhorn slice, and most non-ophiolitic components are derived from that unit. The dominant lithologies are Late Triassic dolomite breccias, dolomites, and acidic basement rocks with a cataclastic overprint. Less frequent are radiolarites, an alternation of pelagic limestones and shales of Cretaceous age (Palombini formation), fine grained breccias and shales of probably Middle Jurassic age and typical for the so-called Saluver formation, ophicalcite, and altered, albite-rich basalts. All these rocks are either derived from South Penninic or Lower Austroalpine units.

In summary, lower and upper mélange differ with respect to matrix and components. The most frequent component in the lower mélange (Anisian limestone) is not present in the upper mélange and vice versa the most frequent component of the upper mélange (Late Triassic dolomite breccia) is not found in the lower mélange. Sedimentary components of the lower mélange are typical for the Upper Austroalpine domain (i.e. they are rocks as found in the Lechtal nappe) whereas the Austroalpine components of the upper mélange are typical for the nearby Lower Austroalpine Schwarzhorn slice.

Schwarzhorn slice

The Schwarzhorn slice sensu stricto extends from the Gampadels valley in the east to the locality "Grünes Eck" in the Gauer valley (Fig. 2). It mainly consists of an amphibolite facies metadiorite to metaquartzdiorite, which builds the peaks Schwarzhorn and Seehorn. In the south and at the contact to the upper mélange, this basement also contains acidic rocks such as augengneis and garnet-bearing micaschist. The metadiorite displays distinct meso- and microstructures. More or less foliated amphibolites occur together with varieties preserving magmatic structures. All types of metadiorite contain plagioclase and green hornblende as major constituents. In samples with a magmatic structure, hornblende displays an isometric shape. Such hornblende usually contains inclusions of quartz and abundant submicroscopic rutile in the core leading to an almost opaque appearance. In foliated metadiorite, hornblende is progressively recrystallized to smaller, more acicular, clear and inclusion-free grains. Large magmatic plagioclase is only present in absolutely unstrained rocks. Even in weakly foliated samples it is completely recrystallized. The amphibolite facies event certainly occurred in pre-Mesozoic times, as is indicated by its Mesozoic cover which only underwent low grade metamorphic overprint (Ferreiro-Mählmann 1994).

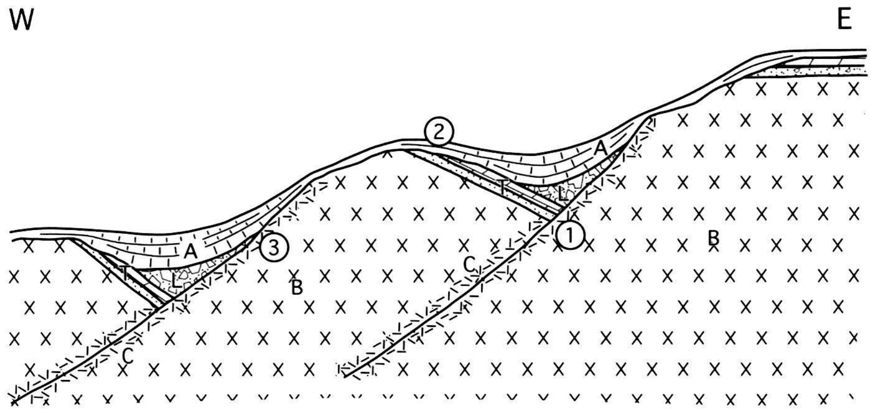

Fig. 5. Reconstruction of the tectonic architecture of the Schwarzhorn slice after rifting in Early Jurassic times. Labels 1–3 refer to specific situations preserved on the geological map at the same labels (Fig. 2). A, post-rift sediments; B, dioritic basement; C, rift related cataclasites; L, syn-rift sediments; T, pre-rift sediments.

Along two major fault zones the basement rocks of the Schwarzhorn slice display cataclastic overprint in various degrees (Fig. 2, Fig. 4). One zone follows the northern contact of the basement between the Gampadels valley and the pass north of the Schwarzhorn peak, the other is found in the southeast close to Alpe Tilisuna. Strongly deformed rocks have the appearance of a monomict, unbedded breccia. Occasionally, this breccia displays an eye-catching red matrix, and several workers considered it a sediment (Cornelius 1921; Blumenthal 1936; Biehler 1990). However, already Seidlitz (1906) proposed a tectonic origin and interpreted these rocks as generated by friction. In thin section it becomes evident, that the reddish color of the fine grained portions of the rock result from secondary pigment coating with hematite (Fig. 4a). Components in the breccia are unsorted, unrounded and show a self-similar grain size distribution. Many components consist themselves of the same breccia at a smaller scale. All these features are characteristic for cataclasites (Marone & Scholz 1989). Furthermore, continuous transitions from isolated faulting to complete cataclasis can be observed in the field (Nagel 1996).

At the eastern and northern side of the Schwarzhorn slice, a sedimentary cover with characteristics typical for the Lower Austroalpine nappes is preserved (Cornelius 1921; Cadisch 1921; Stahel 1926; Biehler 1990). In the Gampadels valley, an eastward dipping sequence of Skythian red clastics (quartzites and sandstones) and thick-bedded, yellowish dolomites, dolomite breccias and greenish-reddish claystones of probably Late Triassic age (compare Dietrich 1970) rest on unfaulted metadiorite. Towards south these strata are cut by one of the cataclastic fault zones. An array of strongly deformed and dismembered post-rift sediments discordantly overlies the Triassic sequence in the Gampadels valley as well as the cataclastic zone in the metadiorite northeast of the Schwarzhorn. In detail, these sediments are fine-grained, Middle Jurassic breccias (Saluver formation), radiolarites, Upper Jurassic to Lower Cretaceous pelagic limestones (Aptychus limestone), an Early Cretaceous alternation of dark limestone and shale (Palombini formation), and pebbly mudstone of probable Cretaceous age (von Seidlitz 1906; Finger 1978; Furrer 1985). Mixed into this deformed zone are large blocks of the Triassic cover. Sediments related to Early Jurassic rifting were only found in a small outcrop northeast of the Schwarzhorn. There, a well bedded breccia and coarse-grained sandstones rest on cataclastic basement rocks. The breccia contains clasts of red siltstone, white quartzite, various limestones and dolomites, and abundant greenish granite (Fig. 4b). The sequence is overlain by an assemblage of deformed post-rift sediments.

Cataclastic zones in the basement cut Triassic pre-rift sediments and are themselves sealed by Jurassic syn- and post-rift strata. Therefore, they were most likely formed during Early Jurassic rifting. Considering the northward inclination of the entire nappe stack in the study area, the rifting geometry in the Schwarzhorn slice can be best explained by originally west-dipping normal faults and associated east-tilting of pre-rift sediments (Fig. 2, Fig. 3 & Fig. 5). Basement-rich, Liassic breccias associated with west-dipping normal faults are characteristic for the Err nappe southeast of the Prättigau halfwindow, which is the deepest unit of the Lower Austroalpine nappe pile and derived from the distal continental margin (Furrer 1985; Eberli 1985).

Walser slice

The Walser slice is made up of continental basement with scarce sedimentary cover. In the south, the Walser slice consists of various amphibolite facies gneisses. These include staurolite-garnet-bearing micaschists and well-foliated amphibolites. The northern part is made up by a weakly deformed green or red colored granite. This granite is covered by two different sedimentary formations. In the northeast it is overlain by red clastic sediments of Permo-Skythian age (Verrucano formation). South of the Alpila Alpe, a firm, unbedded breccia directly rests on the granite. This breccia contains clasts of various sediments in a sandy to silty matrix. The main portion of clasts are dolomites and limestones. Also angular quartzites and red clastic sediments occur. In the lower part of the breccia, components of greenish basement rocks can be found. The breccia has not been dated. Blumenthal (1936) identified Upper Triassic limestones as components and suggested a Liassic age of the breccia. At its western edge poorly exposed dolomites and cargneules are located between breccia and granite. These rocks probably represent the relictic Triassic cover of the basement. Colored granitic basement and Liassic breccias point to a derivation of the Walser slice from the Lower Austroalpine domain. Particularly, basement poor breccias are typical for the Bernina nappe system (Furrer, 1985; Eberli 1985). According to this study, the Walser slice is not the basement of the Mittagspitz zone further north which is of Upper Austroalpine provenance (see below). Instead, it represents an independent Lower Austroalpine unit.

Mittagspitz zone and Phyllitgneis zone

The Mittagspitz zone is an assemblage of strongly faulted Permo-Skythian to Lower Jurassic sediments, sandwiched between the Walser slice in the south and the Phyllitgneis zone in the north. In the study area, the Mittagspitz zone is relative thin and outcrop conditions are poor. It is, however, better developed and well studied further west (e.g. Blumenthal 1936; Heissel et al. 1965; Kobel 1969). Descriptions of the architecture of the Mittagspitz zone are contrasting. Some authors interpret it as a regular synform (e.g. von Seidlitz 1906), while Laubscher (1989) calls it a "Carnian mélange". The interpretation as a mélange zone is inadequate. No matrix is present between coherent domains with sizes up to several kilometers, and the orientation of strata is consistently east-west striking. Tectonic provenance and structure of the Mittagspitz zone are still uncertain. All previous studies have regarded the Mittagspitz zone as a single unit. For reasons presented below, I propose a subdivision into an upright, i.e. northward younging, southern Mittagspitz zone, and an inverted, i.e. southward younging, northern Mittagspitz zone.

The southern Mittagspitz zone consists of three consecutive Upper Triassic to Lower Jurassic formations. The lowest unit is thick-bedded Norian dolomite (Hauptdolomit), which is cut at the bottom by a thin layer of cargneules marking the tectonic contact to the Walser slice. The preserved thickness of the Hauptdolomite is about 300 meters. Above rests an alternation of colored shales and fossiliferous limestones of Rhetian age (Kössen formation), and finally well bedded, dark blue limestones and marls of Early Jurassic age containing characteristic chert bands and chert nodules (Allgäu formation). Due to intense faulting and poor outcrop conditions the thicknesses of the two younger units can not be precisely deduced. Continuous outcrops in the Kössen formation do not cover more than a few tens of meters. In contrast, the Allgäu formation is well developed and certainly several hundred meters thick west of the study area (Heissel et al. 1965). There are no indications of a sedimentary contact between Walser slice and southern Mittagspitz zone. In contrast, the Liassic cover of the Walser slice (Alpila breccia) shows that the Triassic rocks of the Mittagspitz zones further north cannot belong to the Walser slice (see Ampferer 1933; Reithofer 1937; Tollmann 1976a).

The northern Mittagspitz zone comprises Permian to Upper Triassic sediments. It is even more intensely faulted than the southern Mittagspitz zone. However, there is an overall younging direction towards south. The oldest formation consists of continental red clastics of Permo-Skythian age (Verrucano formation). It is not preserved in the study area, but abundant in contact to the Phyllitgneis zone further west (Heissel et al. 1965). The next higher formation is dark limestone of Anisian age, equivalent to the slivers embedded in the lower mélange of the Arosa zone. The Ladinian is represented by grayish brown shales (Partnach shales) and subsequent thick bedded, partly dolomitic, partly sandy limestone interbedded with thin shales (Arlberg limestone). The Partnach shales are distinctive for the Northern Calcareous Alps (e.g. Kobel 1969). Scarce relicts of dolomites, cargneules, and clastic sediments of Carnian age (Raibl formation) and Hauptdolomite are the youngest formations. The sequence in the northern Mittagspitz zone and its continuation south-east of the study area, the so-called Madrisa zone, is identically found in the Lechtal nappe north of the Phyllitgneis zone and many authors interpret the entire Mittagspitz zone as a continuation of the Lechtal nappe (e.g. von Seidlitz 1906; Oberhauser 1970; Tollmann 1976a, 1976b).

The Phyllitgneis zone consists of well foliated micaschist, augengneis, and amphibolite. The basement shows widespread retrogressive overprint. However, pre-Mesozoic amphibolite facies conditions are indisputable, as indicated by the occurrence of staurolite and kyanite which cannot be of Alpine age (e.g. Reithofer 1937; Hoernes & Purtscheller 1970).

Several suggestions have been made for the structural architecture of Walser slice, Mittagspitz zone, and Phyllitgneis zone:

(1) Because of the opposed younging directions most early authors interpreted the entire Mittagspitz zone as a synform within Upper Austroalpine basement. According to this scheme the basement of the Walser slice represents the continuation of the Phyllitgneis zone (e.g. von Seidlitz 1906; Leutenegger 1928; Blumenthal 1936).

(2) In cross sections of Kobel (1969) and Oberhauser (1970) the Mittagspitz zone is also interpreted as the cover of the Phyllitgneis zone and the Walser basement. However, the sequence is considered as having been inverted before folding. Hence, the Mittagspitz zone would represent an antiformal syncline.

Both syncline models (1) and (2) are solely based on the opposed younging directions in the two Mittagspitz zones. However, basement and sediments are very different on both limbs of the inferred syncline. A closure of the basement beneath or above the sediments, as proposed by these two models is not indicated by any surface observations.

(3) Tollmann (1976a, 1976b) also interprets the entire Mittagspitz zone as the partly inverted Upper Austroalpine cover

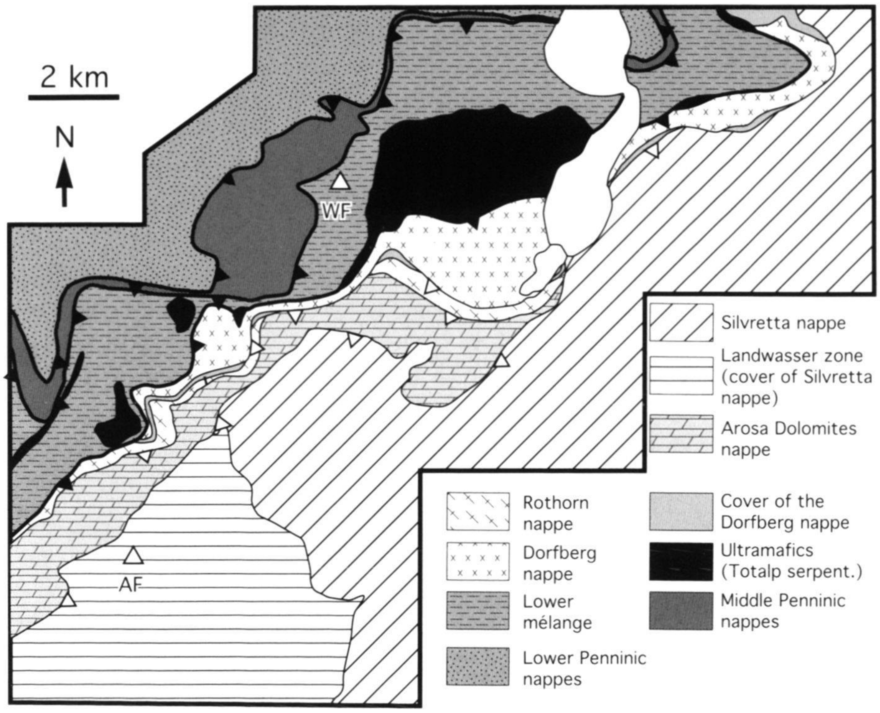

Fig. 6. Tectonic sketch of the area around Davos (after Streckeisen et al. 1966). Triangles denote peaks (AF, Amselfluh; WF, Weissfluh). Hypothesized D1 thrusts with thick lines and filled signature, D2 thrusts with thin lines and open signature.

of the Phyllitgneis zone. In contrast to Oberhauser (1970) he attributes the Walser slice to a deeper structural level (i.e. his Middle Austroalpine nappes) and rejects a sedimentary contact to the Mittagspitz zone.

(4) Reithofer & Schmidegg (1964) propose that the Mittagspitz zone neither represents the cover of the Walser basement nor that of the Phyllitgneis zone. In their interpretation the Walser slice and the entire Mittagspitz zone occupy a Lower Austroalpine position (see also Burger 1978). They reject a derivation of the Mittagspitz zones from the Lechtal nappe because of the specific facies of the Allgäu formation in the study area and further west. In the southern Lechtal nappe, the Allgäu formation is more marly and lacks abundant chert (Blumenthal 1936; Reithofer & Schmidegg 1964; Tollmann 1976b).

I propose yet another solution by dividing the Mittagspitz zone into two separate subunits. Only the northern Mittagspitz zone would represent the inverted Lechtal nappe at the base of the Phyllitgneis zone. The southern Mittagspitz zone, however, is regarded as an independent unit and has a structural position equivalent to the Allgäu nappe beneath the Lechtal nappe in the Northern Calcareous Alps. Only the northern Mittagspitz zone shows a strong lithological affinity to the Lechtal nappe and rests on the same basement, i.e. the Phyllitgneis zone (Haldiman 1975; Tollmann 1976b). In contrast, the southern Mittagspitz zone contains a younger sequence and remarkable differences to the Lechtal nappe with respect to the Lower Jurassic sequence. This sequence, however, is similar to the one in the Allgäu nappe which is characterized by Hauptdolomit, Kössen formation and up to 1200 m thick, cherty Allgäu formation (e.g. Jakobshagen 1965; Tollmann 1976c). The northern Mittagspitz zone is inverted, whereas the southern one is upright, and there is no indication that the two zones represent the two limbs of a syncline. This interpretation is further strengthened by comparing the study area with the situation found southeast of the Prättigau halfwindow as is discussed in the next section.

The nappe pile below the Silvretta nappe southeast of the Prättigau halfwindow

Figures 6 and 7 illustrate the striking similarities between the study area and the area around Davos, southeast of the Prättigau halfwindow and beneath the Silvretta nappe (Fig. 1). The inferred continuation of the northern Mittagspitz zone, the so-called Madrisa zone (Fig. 7), is not present in the area shown in figure 6, but appears only a few kilometers further north immediately beneath the Silvretta nappe. It has previously been interpreted as the inverted limb of the Lechtal nappe (e.g. Haldiman 1975; Tollmann 1976b; Burger 1978). Tectonic units in the Davos area are much better integrated into the overall picture of the Penninic-Austroalpine edifice in eastern Graubünden, and the Dorfberg nappe and the Rothorn nappe have been attributed to the lower Austroalpine nappe pile (e.g. Giger 1985; Froitzheim et al. 1994). Especially, detailed descriptions of the basement in the Dorfberg nappe by Streckeisen (1948) and Streckeisen et al. (1966) provide compelling evidence that it corresponds to the Schwarzhorn slice since it

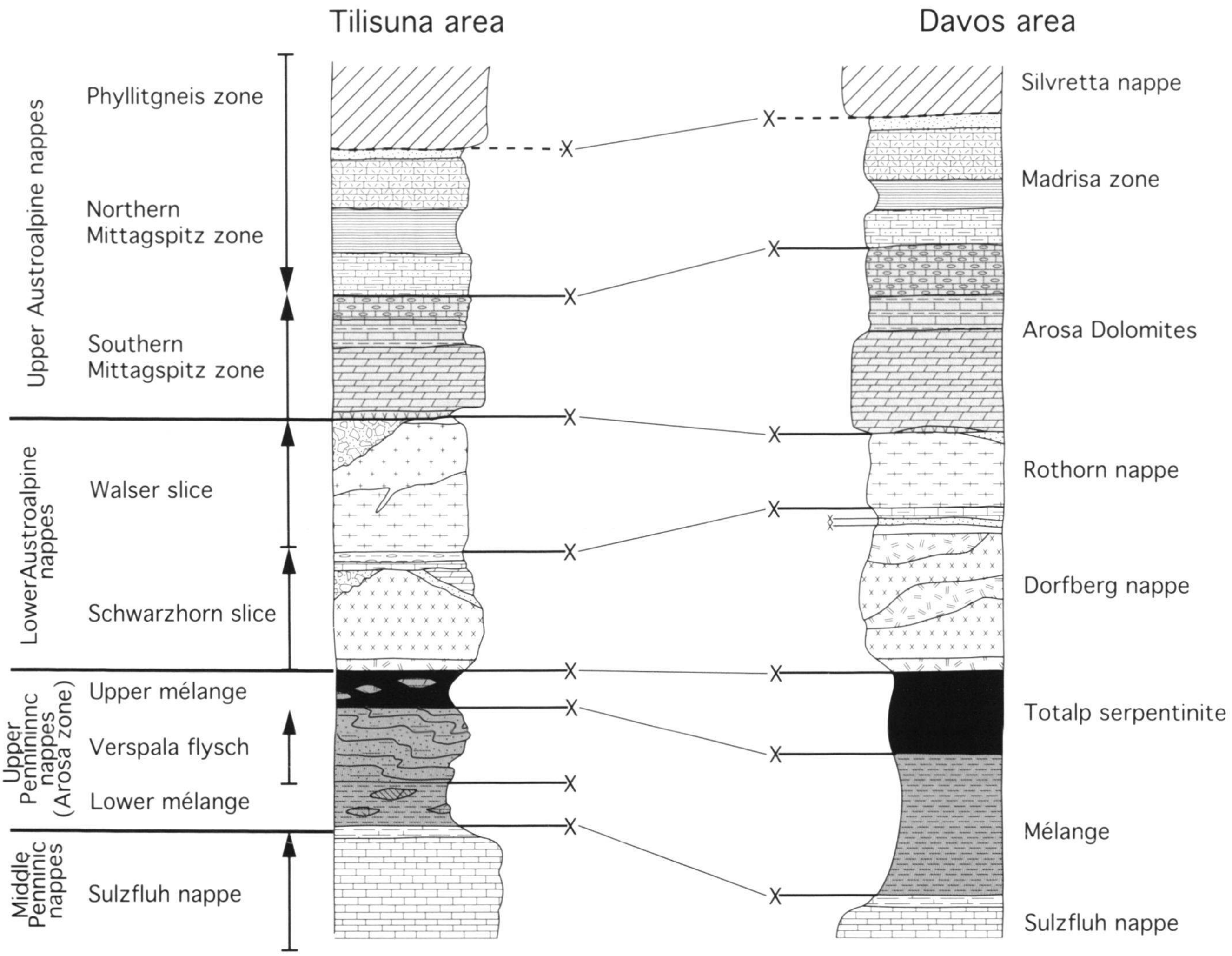

Fig. 7. Lithologic columns of the Tilisuna and Davos areas. Arrows indicate younging directions. Key is the same as in figure 2.

displays the very same peculiar lithological appearance. According to the correlation in figure 7 the Arosa Dolomites nappe represent the southward continuation of the southern Mittagspitz zone, and it is proposed that both correspond to the Allgäu nappe of the Northern Calcareous Alps. This interpretation is based on two arguments: Firstly, the southern Mittagspitz zone and the Arosa Dolomites nappe occupy a structural position between inverted slivers derived from the Lechtal nappe and units with typical Lower Austroalpine affinity. Secondly, all three units comprise the same Upper Triassic to Lower Jurassic assemblage of Hauptdolomit, Kössen formation, and a thick sequence of the Allgäu formation in the same cherty facies (Jakobshagen 1965; Haldiman 1975; Tollmann 1976; Furrer 1993). The close correspondence between the two areas allows a couple of conclusions. It strengthens the interpretation about the structural architecture of the Tilisuna area proposed in the previous section, including the subdivision of the Mittagspitz zone and the separation of the Walser slice from the southern Mittagspitz zone. A simple but far-reaching conclusion is that the Austroalpine units accreted beneath the Phyllitgneis zone and Silvretta nappe are identical. Hence, if the two basement units would be separated by an important tectonic boundary, it predates this accretion. In the following section I will try to unravel the deformation history and discuss when the Austroalpine nappe stack formed in this area.

3. Thrust generations

Due to low metamorphic conditions, fault rocks in the study area are commonly cataclasites. Only the contact between Schwarzhorn slice and Walser slice provided suitable shear sense indicators. However, thrust generations can be distinguished on the basis of overprinting relationships. Three compressive deformation phases D1 – D3 could be identified

(Fig. 3a). The oldest thrusts (D1) separate the Austroalpine units from each other. Also the two higher units of the Arosa zone, the upper mélange and the Verspala flysch, are constituents of the D1 nappe pile. North of the Schwarzhorn, in the shear zone separating the Schwarzhorn slice and the Walser slice, pebbly mudstones derived from the post-rift sequence of the Schwarzhorn slice display s-c and s-c' microstructures and asymmetric pressure shadows around limestone pebbles (Fig. 4c). All shear sense indicators denote a left-lateral shear sense with a slight normal fault component in the present geometric framework. Rotating the NNE-dipping shear zone around its strike into a horizontal orientation results in top-NW (i.e. 300°–310°) directed thrusting. This shear direction is typical for Cretaceous nappe stacking in the Austroalpine nappes (Ratschbacher & Neubauer 1989; Ring et al. 1989, 1990; Froitzheim et al. 1994; Eisbacher & Brandner 1996). I attribute D1-thrusts in the study area to Late Cretaceous, i.e. Turonian, deformation of the Austroalpine nappe stack in eastern Graubünden. No rocks younger than Turonian are present within the D1 nappe pile.

The top of the lower mélange crosscuts higher nappe boundaries and is therefore interpreted to be a younger thrust, formed during D2. The discordant relation to D1 thrusts is not evident in the study area, but can be observed further west in an area east of the Lünersee. There, the lower mélange shows a gentle dip towards north, truncating steeply oriented D1-thrusts as well as large scale folds in the Austroalpine units above (Blumenthal 1936; Oberhauser 1970). The same situation is found north and west of the Phyllitgneis zone in the Lechtal nappe. Huge folds with steep axial surfaces affecting intra-Austroalpine nappe contacts are cut by the gently dipping basal thrust of the Northern Calcareous Alps (Oberhauser 1970). A clayey mélange attributed to the Arosa zone surfaces below this thrust. Lithologically, this mélange corresponds to the lower mélange in the study area and both would represent the same high strain zone, that separates the Cretaceous South Penninic- Austroalpine nappe pile in the hanging wall from middle and Lower Penninc units in the footwall, where sedimentation continued until Eocene times (Oberhauser 1970; Weh & Froitzheim 2001). Around the Prättigau halfwindow the thickness of the entire Arosa zone varies between a few tens of meters and more than one kilometer. Where it is thin, it is characterized by rocks which represent the equivalent of the lower mélange (e.g. Lüdin 1987; Giger 1985, Haldiman 1975). Further rock types, if present, rest discordantly on top of this unit. Therefore, the lower mélange of the Arosa zone is interpreted to comprise the Tertiary basal thrust of the South Penninic-Austroalpine nappe pile. Convincing shear sense indicators associated with D2 were not found during this study. However, based on incremental strain analysis in the Arosa zone, Ring et al. (1989) and Biehler (1990) could infer a late top-north-directed event in the Tilisuna area and attributed it to Tertiary thrusting. In general, the main Tertiary thrusting event is considered to be top-north directed in eastern Graubünden (e.g. Ratschbacher 1986; Froitzheim et al. 1994).

A third generation of thrusts (D3) is associated with the formation of a south-over-north imbricated antiformal stack in the Sulzfluh nappe (von Seidlitz 1906; Fig. 3a). This phase clearly postdates D2 thrusting as is indicated by lower mélange of the Arosa zone present along D3 thrusts within the Sulzfluh nappe (Fig. 2). D3 thrusts allow estimating the contribution of late uplift and tilting in the Prättigau halfwindow to the steepening of the D1 thrusts in the north of the study area (compare Biehler 1990). Spectacularly exposed D3 thrusts within the Sulzfluh nappe show a dip of approximately 30° towards north.

In the study area, the base of the Silvretta nappe east of the Gampadels valley shows a relatively steep dip towards east and seems to cut the South Penninic-Austroalpine nappe pile further west (Fig. 2). This local situation might be best explained by a Late Cretaceous overprint by a normal fault with moderate offset (between D1 and D2 thrusting). This interpretation would concur with two observations. The lower mélange continues southeastward and is not affected by the dissection of the units above. Towards east the base of the Silvretta nappe must quickly turn into a more gentle dip as is indicated by the Gargellen window (Fig. 1). In conclusion, the results presented above indicate that a significant tectonic boundary of post-Turonian age does not exist between the two basement units.

Discussion

This study shows that the assemblage of small nappes and slices, sandwiched between Middle Penninic cover nappes and Upper Austroalpine basement nappes in the study area, is by no means a mélange but represents a regular nappe stack. The architecture of this stack accords with well established schemes of the Penninic-Austroalpine nappe edifice. The Tertiary basal thrust of the Austroalpine block crosscuts Turonian thrusts separating South Penninic, Lower and Upper Austroalpine units in the hangingwall, including the southward continuation of the Allgäu nappe and the inverted limb of the Lechtal nappe. Furthermore, the Cretaceous nappe pile above the Tertiary basal thrust can be traced all around the Prättigau halfwindow beneath the Phyllitgneis zone, as well as beneath the Silvretta nappe.

These results provide an important contribution to the discussion about the relationship between Northern Calcareous Alps and Lower Central Austroalpine nappes to which the Silvretta nappe belongs. Today, three different models are discussed. Some authors still favor a paleogeographic position of the entire Northern Calcareous Alps south of these nappes, a hypothesis first proposed by Tollmann (1959) and also known as "Fernschubhypothesis" (e.g. Tollmann 1959; Tollmann 1976b; Auer und Eisbacher 2003). However, many geologists believe that parts of the Lower Central Austroalpine basement nappes represent the substratum of the lowermost division of the Northern Calcareous Alps, the so-called Bajuvaric nappes, comprising the Lechtal and the Allgäu nappe (e.g. Schuster & Frank 1999; Frisch & Gawlick 2003). Recently, Schmid et al.

(2004) have even proposed that the entire Northern Calcareous Alps are derived from north of the suture that would exist on top of the Lower Central Austroalpine nappe complex, i.e. on top of the Koralpe-Wölz nappe system. This suture is marked by a unit which is characterized by Cretaceous metamorphism under eclogite facies conditions in its southeastern, structurally highest part (e.g. Hoinkes et al. 1999). The thick Triassic sediments of the Northern Calcareous Alps were deposited on the northwestern shelf of the Meliata ocean (Mandl 2000). Schmid et al. (2004) view the high pressure metamorphism in the topmost Lower Central Austroalpine nappes to be related to southeastward subduction of the Meliata ocean and the associated partly intracontinental suture to be found immediately above the Lower Central Austroalpine nappe complex. Alternatively, if only the Bajuvaric nappes would be derived from the Lower Central Austroalpine nappe complex this eclogite facies metamorphism would have to be related to an intra-continental suture zone paleogeographically located north of the Meliata suture (Janak et al. 2004).

This study provides a strong argument against the first mentioned theory, the Fernschubhypothesis. Since the Phyllitgneis zone is the original basement of the Lechtal nappe, the Lechtal nappe could only be rooted south of the Silvretta nappe, if Silvretta nappe and Phyllitgneis zone would be separated by an important tectonic boundary. The existence of such a boundary was indeed hypothesized by Tollmann (1976b) and the proposed trace of this fault is indicated with "GF" (Gampadels fault) in Figure 1. However, the existence of such a fault within the basement complex northeast of the Prättigau Halfwindow was never verified. All petrographic studies in this basement – before and after the Fernschubhypothesis came up – observed continuity between Phyllitgneis zone and Silvretta nappe (Hammer 1918; Reithofer 1935; Frank 1987; Rockenschaub 1990). However, outcrop conditions in the northern part of the Silvretta-nappe-Phyllitgneis-zone complex are generally poor and advocates of the Fernschubhypothesis still propose that an important fault exists between these two units (e.g. Auer & Eisbacher 2003). However, this work provides a new argument against the existence of a nappe-dividing Gampadels fault: there is no indication of older deformation that would predate D1 structures in the study area, and the Silvretta nappe experienced a Late Cretaceous history during D1 deformation which is identical to that of the Phyllitgneis zone. The Austroalpine units and the higher portions of the South Penninic Arosa zone around the Prättigau halfwindow represent an in-sequence nappe pile formed during D1. This implies that the Silvretta nappe and the Phyllitgneis zone were welded together before the onset of D1 deformation. In fact, there is no indication that they were separated at any time. The Phyllitgneis zone and the Silvretta nappe are one and the same basement and together they represent the stratigraphic substratum of the Lechtal nappe (Hammer 1918).

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