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Transition from continental to oceanic basement in the Tasna nappe (Engadine window, Graubünden, Switzerland): evidence for Early Cretaceous opening of the Valais ocean

by *Duri Florineth*[1] and *Nikolaus Froitzheim*[2]

Abstract

The Cretaceous sedimentary cover of the Middle Penninic (Briançonnais) Tasna nappe, exposed in the Engadine window, rests on Tasna granite and associated gneisses to the South (continental basement) and on the Piz Nair serpentinite to the North (oceanic basement). Cataclasite at the top of the Tasna granite and ophicalcite at the top of the serpentinite were formed by brittle fracturing along a low-angle normal fault before deposition of the sedimentary cover, during Late Jurassic to Earliest Cretaceous rifting. Progressive normal fault displacement completely removed the hanging wall and exhumed the fault surface, on which then the Cretaceous postrift sediments came to lie. These start with the Lower Cretaceous Shale Formation ("Neokom"). The Piz Nair serpentinite is interpreted to represent subcontinental mantle peridotite, exhumed and serpentinized during rifting, and exposed at the floor of the Valais basin.

Keywords: rifting, ophicalcite, tectonic evolution, Valais ocean, Tasna nappe, Engadine window.

Introduction

The Penninic nappes of the Central Alps comprise basement units of both continental and oceanic provenance. The palinspastic restoration of the Penninic units for Late Jurassic and Early Cretaceous times results in the now widely accepted picture of two basins, either one of them or both floored by oceanic crust, divided by a continental swell. The southern basin, known as the South Penninic or Piemont-Liguria ocean, is characterized by the post-ophiolithic sedimentary sequence of Middle to Upper Jurassic radiolarite, uppermost Jurassic to Lower Cretaceous Aptychus Limestone (also known as Calpionella Limestone), Lower Cretaceous Palombini shale and limestone, and "middle" Cretaceous Lavagna Shale (Weissert and Bernoulli, 1985). These pelagic sediments rest on ultrabasic and basic rocks, mainly serpentinite, gabbro, and basalt, indicating that oceanic crust existed in this basin from the Middle to Late Jurassic onward. In Eastern Switzerland, remnants of the Piemont-Liguria ocean are found in the Arosa zone, the Platta nappe, the Malenco, Forno, and Lizun units, and in the Avers Bündnerschiefer. The continental swell separating the two basins, known as the Middle Penninic or Briançonnais swell, is represented, in Eastern Switzerland, by the basement-dominated Tambo and Suretta nappes and by the detached sediments of the Schams, Falknis and Sulzfluh nappes (Trümpy, 1980). The Tasna nappe, exposed in the Engadine window, is usually interpreted as an equivalent of the Falknis and Sulzfluh nappes (Trümpy, 1972). This unit and its relations to the northern basin, the North Penninic or Valais domain, are the subject of the present article.

As to the nature and age of the Valais basin, some problems are still unsolved. In eastern Switzerland, it is characterized by large volumes of Bündnerschiefer. These are low-grade metamorphic calcschists, occasionally associated with ophiolites, including metabasalts and rare serpentinites (Steinmann, 1994). It is not clear whether the North Penninic basin comprised

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oceanic crust (FRISCH, 1979; TRÜMPY, 1980) or was floored entirely by thinned continental crust (LAUBSCHER and BERNOULLI, 1982). Recently several authors have argued in favour of an oceanic nature, based on tectonic (SCHMID et al., 1990), geochemical (DÜRR et al., 1993; STEINMANN, 1994), and plate kinematic arguments (STAMPFLI, 1993). Accepting an oceanic nature of the Valais rises a second problem regarding the age of this ocean. FRISCH (1979) and STAMPFLI (1993) proposed that it opened later than the Piemont-Liguria ocean, in the Early Cretaceous, kinematically linked with the opening of the Gulf of Biscay and sinistral movement of Iberia relative to Europe, whereas SCHMID et al. (1990) assumed a Late Jurassic opening, because they found ophiolites with a – presumably – Jurassic cover in a "North Penninic" structural position (Martegnas ophiolite, Oberhalbstein area).

In the following we will present some new observations from the Tasna nappe in the Engadine window. We will show that Lower Cretaceous sediments were deposited on granitic-gneissic basement in the southern part of this nappe, and on serpentinitic basement in the northern part. We interpret the latter as a piece of subcontinental mantle material that became exhumed by normal faulting and exposed at the floor of the Valais basin. Far from completely solving the above-mentioned problems, these observations nevertheless represent an important piece of direct field evidence regarding the opening of the Valais ocean: Oceanic basement was formed by tectonic denudation of subcontinental mantle material during the Early Cretaceous. Furthermore, the Tasna nappe represents, in our view, a unique opportunity to study a former transition zone between oceanic and continental crust in the field.

Regional geology

The southwest-northeast-striking Engadine window, situated in Eastern Switzerland and Austria, exposes a stack of Penninic nappes, overlain and framed by Austroalpine nappes (Fig. 1). The latter comprise the Silvretta nappe to the North and West, the S-charl-Sesvenna nappe to the South and the Oetztal nappe to the East. The exposure of Penninic units in the window is not only due to erosion of the Austroalpine nappes by the river Inn, but also to the movement along the Engadine line, a fault of Tertiary age which runs along the southeastern border of the window. The Engadine line acted in this area as a southeast-dipping oblique normal fault, so that the Penninic units of the window were uplifted relative to the Austroalpine nappes in the southeastern block (SCHMID and FROITZHEIM, 1993). Additionally, the relative uplift of the window is accentuated by a southwest-northeast-striking anticline, of Tertiary age as well. The succession of Penninic nappes can be studied best along the northern and western border of the window. Along the southeastern border, the movement along the Engadine line has dismembered and telescoped the nappes.

The area described here is situated in the westernmost part of the window. The structurally highest Penninic unit, directly underlying the gneissic and amphibolitic basement of the Austroalpine Silvretta nappe, is the Arosa zone. This zone comprises a mélange of rock types of Piemont-Ligurian affinity, including ophicalcite, radiolarite and Aptychus Limestone, but also rocks of Austroalpine affinity, such as Triassic dolomites (GÜRLER, 1982). These rocks have been strongly deformed during the Eocene northward transport of the Austroalpine nappes over the Penninic units. The next deeper unit is the "Tasna flysch", an assemblage of flysch-type sedimentary rocks whose tectonic position is unclear. Originally, these flysches were interpreted as forming the youngest part of the sedimentary sequence of the underlying Tasna nappe (e.g., CADISCH et al., 1968). GÜRLER (1982) subdivided the flysches and attributed them partly to the Tasna nappe, partly to the Arosa zone. Whatever the exact tectonic position of the Tasna flysch may be, RUDOLPH's (1982) finding of Paleocene to Early Eocene foraminifera in a flysch sequence in the Fimber valley, north of the area described here, shows that the age of the flysch sediments reaches up into the Lower Tertiary and that the Silvretta nappe (probably together with its tectonic sole of Arosa zone) was emplaced on top of the Penninic units after the Early Eocene.

The Tasna flysch is underlain by the Mesozoic sediments of the Tasna nappe s.str. This unit comprises a gneissic and granitic basement and a sedimentary sequence of Triassic to Cretaceous age. The Tasna nappe, together with the Falknis and Sulzfluh nappes, was long regarded as a Lower Austroalpine unit, due to Austroalpine affinities of the basement and of the Triassic and Lower Jurassic sedimentary rocks (e.g., STAUB and CADISCH, 1921; GRUNER, 1981). Meanwhile most authors follow TRÜMPY (1960) in assigning the Tasna nappe to the Briançonnais, which is plausible in view of the facies of the Upper Jurassic and Cretaceous rocks. As a matter of fact, only rocks younger than Lower Jurassic should be used to decide from which side of the

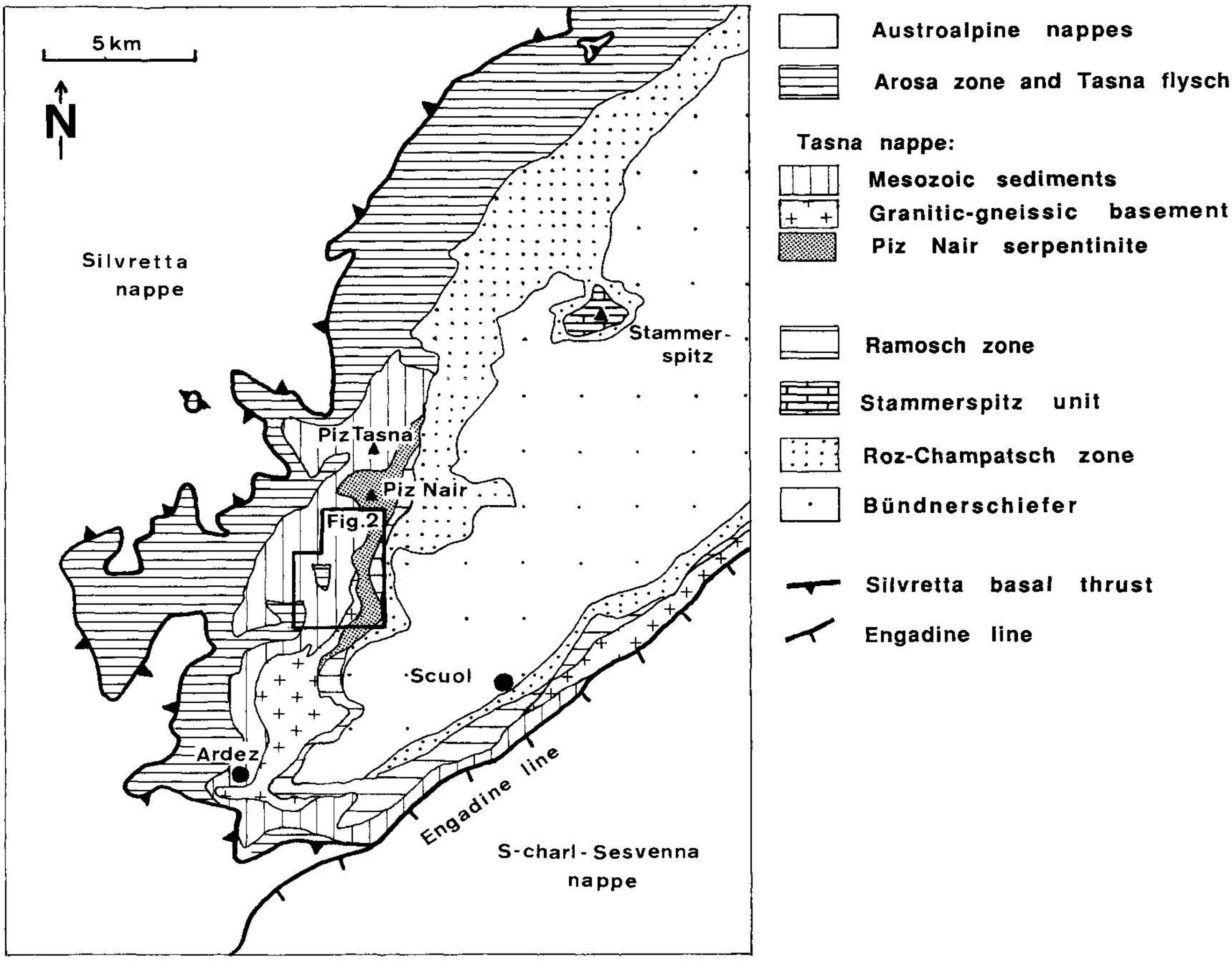

Fig. 1 Tectonic map of the southwestern part of the Engadine window. After TRÜMPY (1972), slightly modified.

Jurassic Piemont-Liguria ocean a particular unit is derived.

The Tasna nappe s.str. is underlain by ophiolites termed Ramosch Zone by TRÜMPY (1972). This unit comprises serpentinite, metabasalt, and metagabbro, as well as slivers of continental basement and Mesozoic sedimentary rocks. One of the larger serpentinite bodies directly underlies the Tasna nappe between Piz Minschun and Piz Tasna. In the following, it will be referred to as the Piz Nair serpentinite (Fig. 1). As we will show below, the contact between this serpentinite and the overlying Cretaceous sediments of the Tasna nappe is not an Alpine thrust fault. Instead, the serpentinite is part of the basement on which the sediments were deposited. Therefore, the Piz Nair serpentinite is part of the Tasna nappe, and the term "Ramosch zone", if it is meant to signify an Alpine tectonic unit, has to be restricted to a complex of mafic and ultramafic rocks, including pillowed basalts, which underlies the Piz Nair serpentinite along an Alpine thrust fault. Pillowed basalts of this lower complex are exposed, for example, at Mot da Ri (Fig. 2; VUAGNAT, 1965; VUICHARD, 1984). Serpentinite bodies along the southeastern margin of the window may be part of the Tasna basement as well (R. Trümpy, personal communication). At present, however, the position of these serpentinite bodies is yet unclear and we therefore include them in the Ramosch zone, following the traditional terminology (Fig. 1). The next deeper unit is the Roz-Champatsch zone, a mélange zone dominated by flysch-type sedimentary rocks, but including also some slivers of Triassic sedimentary rocks, continental basement, and serpentinite (TRÜMPY, 1972). TORRICELLI (1956) identified Maastrichtian foraminifera in a breccia layer of the Roz-Champatsch zone. The Stammerspitz unit, comprising Mesozoic sedimentary rocks of Austroalpine facies, was tectonically emplaced in the Roz-Champatsch zone (KLÄY, 1957). Underneath the

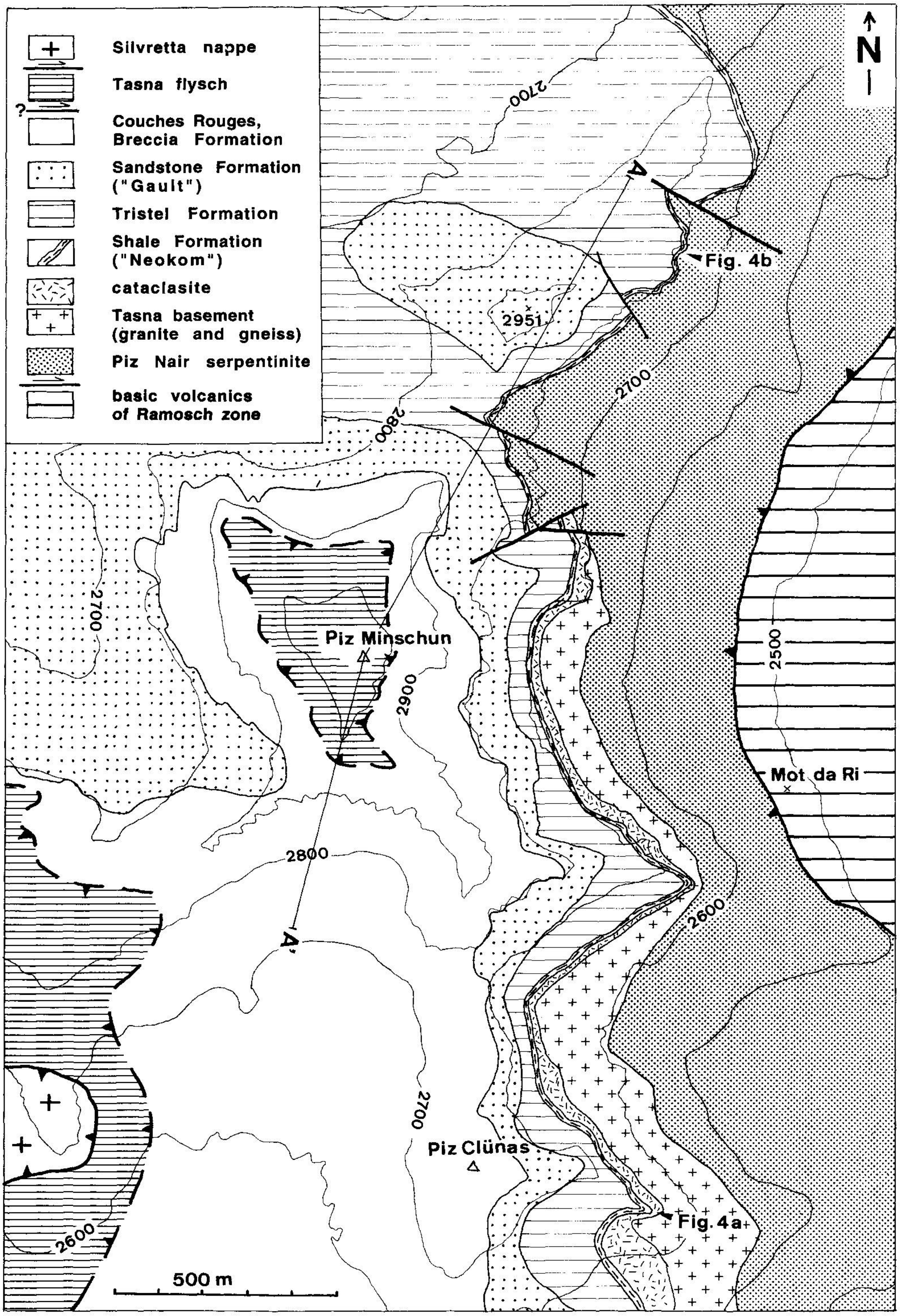

Fig. 2 Geologic map of the Piz Minschun area. After FLORINETH (1994).

Roz-Champatsch zone, and constituting the main part of the Engadine window, follow the several kilometers thick Bündnerschiefer, calcschists with some metabasalt bodies, representing the fill of the Valais basin (TRÜMPY, 1972).

Cretaceous sedimentary cover of the Tasna nappe

The Cretaceous sequence of the study area (Figs 2, 3) begins with dark grey to olive green shale and siltstone, often strongly bioturbated, in which some limestone layers are intercalated. These rocks, of Early Cretaceous age ("Neokom") according to KLÄY (1957) and CADISCH et al. (1968), have not yet been dated biostratigraphically and will therefore be informally referred to as "Shale Formation" in the following. We assume that the Lower Cretaceous age inferred by the above authors is correct, because we observed, particularly clearly on the southern slope of Piz Tasna (Fig. 1), a gradational upward transition of the Shale Formation into the Tristel Formation, dated as Late Barremian to Early Aptian (SCHWIZER, 1983). This interpretation is in contrast to GÜRLER (1982) who postulated a tectonic separation between the Shale Formation and the Tristel Formation. We found no evidence for such a tectonic contact, neither did SCHWIZER (1983) who studied the Tristel Formation of the Tasna nappe in great detail. Of special interest is the occurrence of manganese nodules in the Shale Formation in the vicinity of the underlying Piz Nair serpentinite (KLÄY, 1957).

The Barremian to Aptian Tristel Formation (SCHWIZER, 1983) is made up by calciturbidites. A breccia horizon with clasts of granite occurs locally at the base of the formation. The Cretaceous sequence is completed by Aptian to Cenomanian sandstone, greywacke and black shale ("Gault", HESSE, 1973), and Turonian to Senonian marly limestone (Couches Rouges). Compared to the respective formations in the Falknis nappe, the Tristel Formation, "Gault" and Couches Rouges of the Tasna nappe are rich in coarse-grained clastic, partly basement-derived material. This is particularly true for the Couches Rouges which locally are represented by polygenic breccias containing olistoliths of Tasna granite up to several tens of meters in diameter, with a matrix of typical Couches Rouges (Breccia Formation of GÜRLER, 1982; WAIBEL and FRISCH, 1989).

Basement-cover contacts in the Tasna nappe

In the following, we will describe two types of basement-cover contacts observed in the study

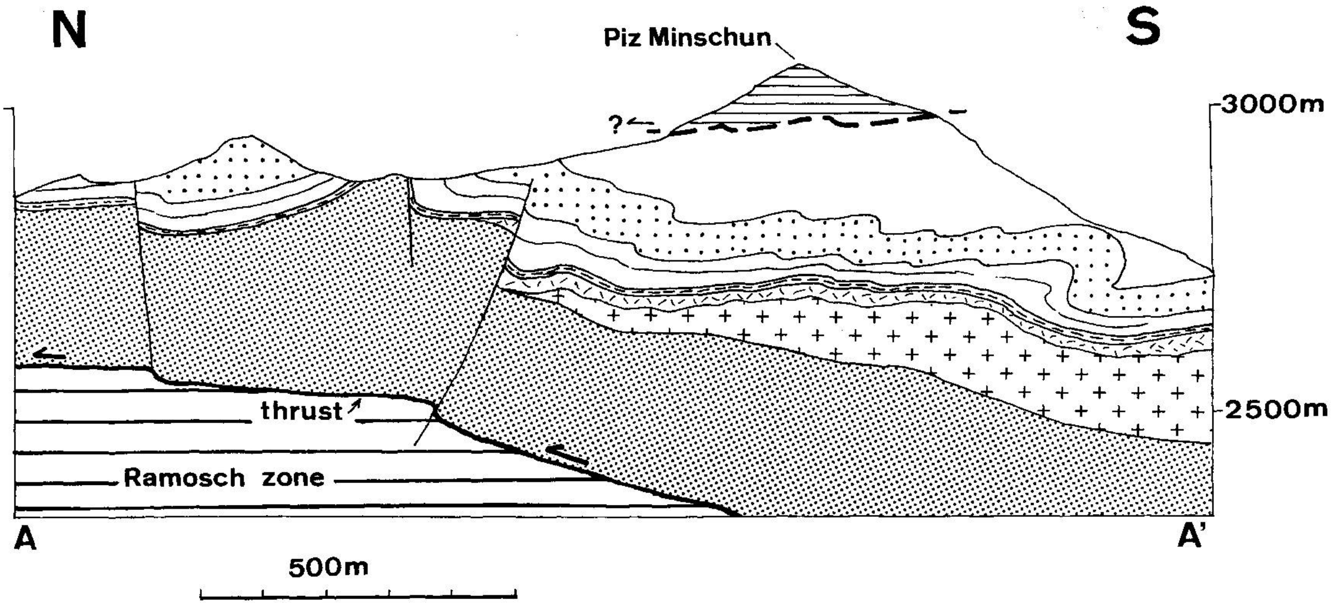

Fig. 3 Cross section of the study area. The Tasna nappe, including the Piz Nair serpentinite, overlies along an Alpine thrust fault pillowed basalts, gabbro and serpentinite of the Ramosch zone. The contact between Cretaceous sediments of the Tasna nappe and the Tasna flysch forming the summit of Piz Minschun is possibly a thrust as well (GÜRLER, 1982). Within the Tasna nappe, Alpine deformation is restricted to south-facing D2 folds of the Cretaceous sedimentary cover, visible in the cross section, abundant minor shear zones within the serpentinite (not shown), and late, steeply dipping faults. The general geometry of the Tasna nappe, characterized by a northward-tapering wedge of granitic-gneissic basement between Cretaceous sediments above and serpentinite below, is pre-Alpine and results from Late Jurassic to Early Cretaceous rifting.

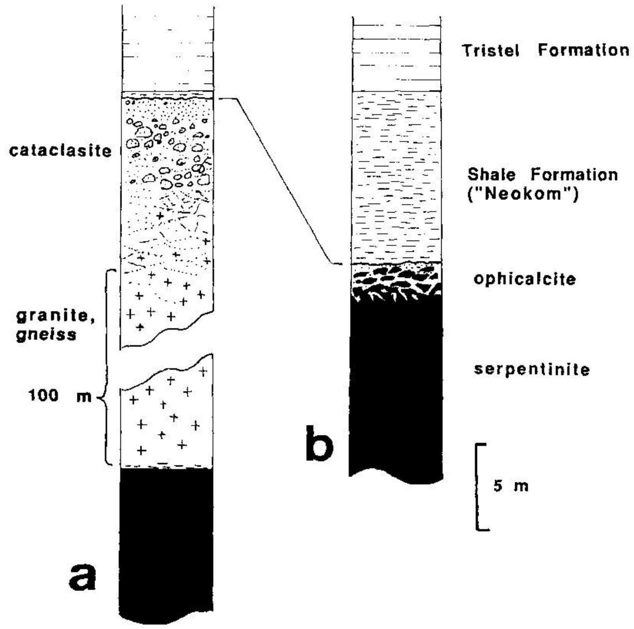

Fig. 4 Basement-cover contacts in the Tasna nappe. *a:* southeast of Piz Clünas, *b:* east of P. 2951 (see map, Fig. 2, for locations).

area. In the first type, the Cretaceous sedimentary sequence rests on granitic-gneissic Tasna basement. In the second type, the same sedimentary rocks rest on serpentinite.

East of Piz Clünas: Sediments on granitic/gneissic basement:

In this area (see Fig. 2 for location), the Cretaceous sediments rest on a layer of granitic and gneissic Tasna basement which is itself underlain by the Piz Nair serpentinite (Fig. 4a). The composition of the Tasna basement is rather heterogeneous; we distinguished Tasna granite (presumed to be of Late Variscan age), aplitic dykes, layered gneisses of acid to intermediate composition, and amphibolites. Towards the basement-cover contact, the Tasna basement is increasingly overprinted by brittle deformation and transformed into a tectonic breccia or cataclasite (Fig. 5) with a greenish, chlorite-rich matrix and angular to rounded basement fragments (chloritic breccia). In the uppermost few decimeters below the basement-cover contact, fine-grained cataclasite with a maximum clast size of about 2 centimeters develops. This is overlain by black to olive-green shale ("Neokom") with intercalated limestone layers. Here the shale is only several decimeters to about one meter thick. The contact between cataclasite and shale is clearly depositional: The top of the cataclasite is uneven, with a centimeter- to millimeter-scale relief that is filled up by the shale. There is no indication of a displacement between shale and cataclasite. Instead, cataclasite and sedimentary cover have been folded together around open, south-facing folds (D_2, FLORINETH, 1994). A cleavage observed in the shale is parallel to the axial planes of these folds and obliquely cuts the basement-cover contact. The shale is overlain by a polygenic sedimentary breccia representing the base of the Tristel Formation.

The contact between the granitic/gneissic Tasna basement and the underlying serpentinite is sharp. Strongly foliated amphibolite occurs locally immediately above the contact. The foliation is roughly parallel to the contact. Veins filled with light grey calcite are found in the uppermost few decimeters of the serpentinite. These are again subparallel to the contact with the overlying granitic-gneissic basement. However, steeply oriented calcite veins occur as well. We found such a calcite vein in the serpentinite at coordinates 814 600 / 189 650 (coordinate grid Schweiz. Landeskarte). It is about 10 centimeters thick, trends east-southeast (113°), and dips 75° toward south-southwest. It is filled with light grey calcite with layers of serpentinite fragments oriented parallel to the walls of the vein. These layers probably result from repeated sealing and re-opening of the vein. A similar calcite-filled pocket with layers of small granite fragments was found in the overlying Tasna granite, some tens of meters underneath the basement-cover contact (coordinates 814 400 / 189 500).

Formation of chloritic schist in the lowermost part of the gneissic-granitic basement and of talc schist, anastomosing shears, and abundant slickensides in the serpentinite, suggest that the contact between the serpentinite and the granitic-gneissic basement was affected by some shearing during the Alpine orogeny. The Alpine displacement across this contact, however, cannot be very substantial, because the contact is sealed by Cretaceous sediments (Fig. 2, see below).

Northeast of Piz Minschun: Sediments on serpentinite:

The granitic/gneissic Tasna basement becomes thinner towards the North and wedges out northeast of Piz Minschun (Fig. 2). From here on towards north, the serpentinite is directly overlain by the Shale Formation (Fig. 4b). The most beautiful outcrop of this type is found northeast of P. 2951 (Figs 6, 7; coord. 814 500 / 191 500). Visitors are friendly asked not to damage this outcrop by hammering.

The upper part of the serpentinite, several meters thick, is present in the form of an ophicalcite (Fig. 6). The serpentinite has been fractured

Fig. 5 Cataclastic fault breccia, derived from granitic/gneissic Tasna basement. Clasts of granite and gneiss, both angular and slightly rounded, "float" in a chlorite-rich, cataclastic matrix. This outcrop is about 15 meters below the basement-cover contact, southeast of Piz Clünas (coord. 814 500 / 189 200). Compare figure 4a. Diameter of coin is 2.7 cm.

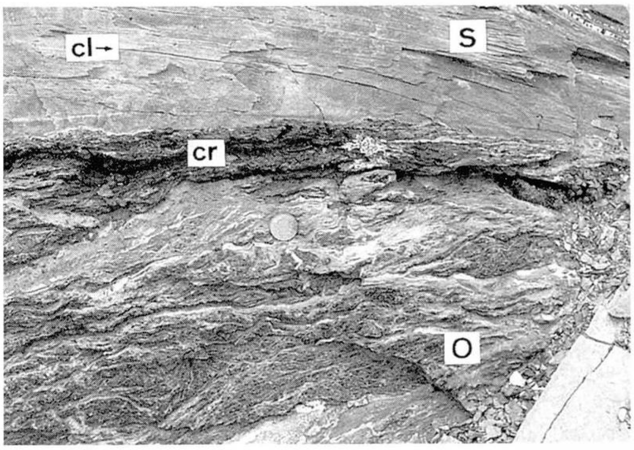

Fig. 6 Depositional contact of Shale Formation (S) on ophicalcite (O). Cleavage (cl) in shale is oblique with respect to shale/ophicalcite interface; note slight cleavage refraction towards interface. Uppermost part of ophicalcite is formed by erosion-resistant crust (cr). East of P. 2951 (coord. 814 500 / 191 500). Compare figure 4b. Diameter of coin is 2.3 cm, south is to the left.

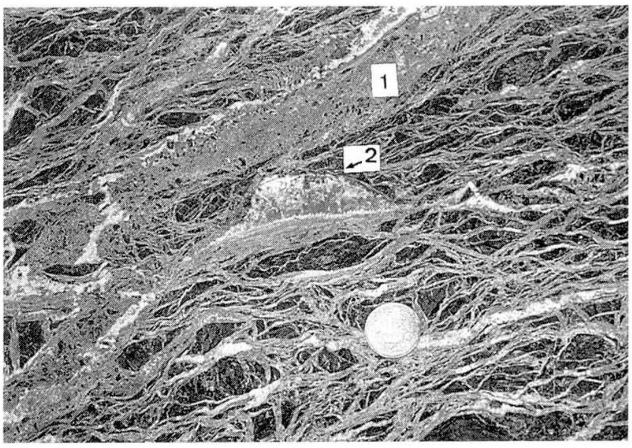

Fig. 7 Structure of ophicalcite about 40 centimeters below the base of the Shale Formation. Dark chips and lenses are serpentinite. Note regular arrangement of these lenses suggesting fracturing in a shear zone. Spaces between serpentinite lenses are filled with grey to reddish or orange calcite with serpentinite fragments (1) and reddish to white, drusy calcite cement (2). Same outcrop as figure 6. Diameter of coin is 2.3 cm, south is to the left.

and disintegrated into rhomboid lenses or chips. The intervening space is filled by two types of calcite: (1) Light grey to reddish or orange calcite with serpentinite fragments, and (2) reddish to white, drusy calcite cement with sparry crystals (Fig. 7). Overprinting relations between veins indicate that type 2 formed later than type 1. We did not find evidence for a sedimentary origin of calcite type 1, like layers of graded serpentinite sand as described by BERNOULLI and WEISSERT (1985) from Piemont-Ligurian ophicalcites.

The carbonate/serpentinite ratio increases upwards; locally the carbonate makes up more than half the volume of the rock. The uppermost ca 5 centimeters are more erosion-resistant than the underlying material and appear as a sort of crust (Fig. 6). Here, the carbonate is often dolomite instead of calcite. Detrital quartz and feldspar grains as well as small granite fragments (< 1 centimeter) are scattered over the top of this crust. The crust and the granitic debris are overlain by the Shale Formation ("Neokom") which seals the relief of the surface. Again the D_2 cleavage of the shale is oblique to the ophicalcite/shale interface (Fig. 6). In this area, the Shale Formation is several meters thick. It contains serpentinite-derived debris in the form of single spinel mineral grains or of up to 10 centimeters large serpentinite clasts, some of which are rounded. Granite and gneiss clasts also occur in the shale.

The shale is overlain by the basal, polygenic breccia horizon of the Tristel Formation.

Although the granitic/gneissic Tasna basement is generally no longer present in this area, remnants of it are locally found in the form of granite/gneiss cataclasites, similar to the ones from the Piz Clünas area (see above), intercalated as thin lenses between the ophicalcite and the overlying shale.

Interpretation of basement-cover contacts

The first type of basement-cover contact, where the Cretaceous sedimentary rocks rest on granitic/gneissic Tasna basement, is interpreted as an onlap onto an exhumed fault surface. The Tasna basement was transformed into a tectonic breccia through cataclastic deformation in a major brittle fault zone. The centre of this fault zone is presently located at the top of the basement, as indicated by the increasing grain-size reduction of the clasts in the breccia, reaching a minimum size at the top. At the initiation of faulting the hanging wall must have been made up of Tasna basement as well. However, this hanging wall was removed by progressive faulting which led to the complete tectonic exhumation of the footwall at the sea floor. Later, the shale formation was deposited onto the cataclastic fault rocks. This interpretation explains why the shale, in contrast to the underlying, intensely brecciated basement, shows no signs of deformation except for the Alpine D_2 cleavage. The fault surface on which the shale was deposited must have been subhorizontal. Otherwise, the sedimentary sequence would not begin everywhere with the thin Shale Formation, but different Cretaceous strata would onlap onto the fault.

The serpentinite-sediment contacts northeast of Piz Minschun are clearly depositional: the Shale Formation was deposited on top of the ophicalcite after the latter had formed. The disintegration of the serpentinite into chips and lenses results from brittle deformation in a fault zone. Therefore we assume that the serpentinite was, like the granitic/gneissic basement further south, tectonically brecciated along a fault. Most of the carbonate found in the ophicalcite probably formed hydrothermally during this stage, which implies a strong volume increase in the fault zone. During progressive fault displacement the hanging wall of this fault was finally removed and the fault rock, ophicalcite in this case, was exposed at the sea floor. The surface of the ophicalcite was altered and indurated by reactions with sea water, and the hard crust formed. Finally, the shale was deposited on top of the ophicalcite. When the shale was deposited, the surface of the ophicalcite must have been subhorizontal, because again, it is everywhere overlain by the thin Shale Formation. The granitic/gneissic and serpentinitic detritus found at the base of and within the Shale Formation must have been shed from local reliefs. We were, however, not able to identify such reliefs.

Discussion

An exhumed low-angle normal fault:

The ophicalcite forms a continuous blanket on top of the Piz Nair serpentinite. This blanket can be followed from the point where the granitic/gneissic Tasna basement wedges out, northeast of Piz Minschun, over about 3 km northward to the area of Piz Tasna. It is everywhere overlain by the Shale Formation, with lenses of granite/gneiss cataclasite occasionally found between the two. Everywhere, the ophicalcite grades down into carbonate-free serpentinite. We can only explain these relations by the assumption of an exhumed low-angle normal fault along the top of the Piz Nair serpentinite. A strike-slip fault would not have formed a subhorizontal surface, and a thrust fault would have progressively buried its fault rocks instead of exhuming them. The movement along the low-angle normal fault must have occurred before the deposition of the Shale Formation, i.e., in the latest Jurassic to Early Cretaceous.

This normal fault surface continues southward on top of the granitic/gneissic Tasna basement. The lenses of granite-gneiss cataclasite found on the ophicalcite were displaced or dragged along the fault surface from this southern area towards north. Therefore the displacement of the normal fault must have had a top-north directed component. In the absence of kinematic indicators, the exact movement direction cannot be determined and may have been between top-northwest and top-northeast in present-day coordinates. The granitic/gneissic basement has the shape of a wedge thickening southward and reaching its maximum thickness, several hundred meters, in the lower Val Tasna near Ardez (Fig. 1). There, the basement has a sedimentary cover of Triassic and Jurassic age, formations that are missing in our study area. This is in accordance with the assumption of a top-north normal fault: The Triassic and Jurassic formations are omitted along the fault, and the Lower Cretaceous, post-faulting formations onlap onto the fault surface.

The contact between the granitic/gneissic Tasna basement and the underlying serpentinite has, as already mentioned, been overprinted by some Alpine, probably Tertiary, shearing. Deformation, however, cannot have been of very large extent, because this contact reaches the basement-cover contact northeast of Piz Minschun, where the granitic/gneissic basement wedges out, without disrupting the sedimentary cover (Figs 2, 3). The geometry observed today, with a thin wedge of granitic/gneissic basement overlying serpentinite, must therefore already have formed in the Late Jurassic to Early Cretaceous.

Nature and emplacement of the Piz Nair serpentinite:

According to VUICHARD (1984), the Piz Nair serpentinite originated from lherzolithic mantle material. Some analyses of clinopyroxene and spinel composition carried out by one of us (FLORINETH, 1994) gave results typical for subcontinental mantle peridotite. The serpentinization of the mantle material occurred, at least in part, already before or during the exhumation, because ultramafic clasts in the Shale Formation are present as serpentinite.

VUICHARD (1984) suggested that the serpentinite was emplaced by diapiric protrusions along transform faults. This explanation has to be discarded because it cannot explain the observations along the serpentinite-sediment contact (see above). Alternatively, we suggest that the mantle material was exhumed from below the continental crust by tectonic denudation along low-angle normal faults (Fig. 8). Extensional exhumation of mantle material appears to be a common process in rifting, provided that the asthenosphere does not break through to the surface before the crust has been thinned out completely. Tectonically exhumed peridotite and serpentinite bodies have been detected near the continent/ocean transition of the Galicia passive margin (BOILLOT et al., 1987) and in the Red Sea rift (BONATTI et al., 1981). The same phenomenon has also been demonstrated for the Piemont-Liguria ocean (DECANDIA and ELTER, 1969; ELTER, 1972; LEMOINE et al., 1987; TROMMSDORFF et al., 1993).

What is the significance of the contact between serpentinite and granitic/gneissic basement? Clearly, this is not a paleo-Moho, because in this case the overlying, continental basement should be formed by lower-crustal rocks. The Tasna granite and associated gneiss, however, represent upper crust: Further south, near Ardez, granitic-gneissic Tasna basement is transgressively overlain by Triassic sediments (SPAENHAUER et al., 1940). On the other hand, the contact under discussion is not an Alpine thrust (see above). Therefore we assume that it represents another

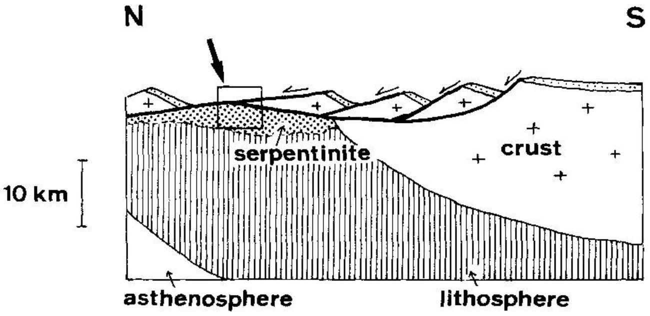

Fig. 8 Tentative reconstruction of continent-ocean transition between Briançonnais (right) and Valais (left). Arrow indicates position of the study area. "N" and "S" refer to present-day coordinates.

Late Jurassic-Early Cretaceous low-angle normal fault, responsible for the emplacement of upper crustal Tasna basement on mantle material, and the omission of lower-crustal levels (Fig. 8). The foliated amphibolite locally found along this fault may represent mylonite that formed during the rifting process. We have not yet studied, however, the continental Tasna basement in enough detail to decide whether the mylonitic amphibolites are related to rifting or, alternatively, to Variscan deformation.

Is exhumed and serpentinized mantle material oceanic crust?

There is a terminology problem regarding ultramafic bodies like the Piz Nair serpentinite that have been derived from subcontinental mantle and exhumed at the sea floor. Do these represent oceanic or continental lithosphere? Although the Piz Nair serpentinite, according to our hypothesis, formed from subcontinental mantle material, we tend to regard it as part of the oceanic crust. Considering its physical properties (density, seismic velocities), serpentinite is clearly a crustal rock. Exhumation of mantle material at the sea floor occurs not only at the edges of continental margins, but also along slow-spreading ridges like the Mid Atlantic ridge (LAGABRIELLE and CANNAT, 1990). In many cases it is impossible to decide whether a dislocated serpentinite body found in an orogen was originally formed at a slow-spreading ridge or by exhumation of subcontinental mantle (LAGABRIELLE and CANNAT, 1990). Therefore it appears reasonable that a serpentinite exhumed on the sea floor is generally called oceanic crust, and a terminologic distinction between oceanic crust and exhumed mantle material is of little use. Likewise, a subcontinental peridotite should be called oceanic mantle, if exhumed at the sea floor.

Paleogeographic implications:

We have shown above that the Piz Nair serpentinite is part of the Tasna nappe. The Tasna nappe is therefore no longer regarded as an exclusively continental unit, but a composite continental-oceanic one. Within this nappe, the transition between the Briançonnais microcontinent and oceanic crust is preserved. This oceanic crust must have been part of the Valais ocean, because the sedimentary cover of the serpentinite has a different age and facies than the one of the Piemont-Liguria ophiolites. Equivalents of Tristel Formation and "Gault" sandstones are missing in the Piemont-Ligurian ophiolites where the corresponding time interval is represented by Palombini and Lavagna shales. "Gault" sandstones are found in the Briançonnais and in the Helvetic realm, located on the other, northern, side of the Valais basin. The North Penninic (Valais) Bündnerschiefer of the Engadine window, although incompletely dated, include arenitic schist strikingly similar to "Gault" sandstone (CADISCH et al., 1968). Equivalents of the "Gault" sandstone are also found interfingering with the Aptian to Albian Nollaton Formation of the Tomül nappe, one of the Bündnerschiefer nappes in western Graubünden (STEINMANN, 1994). Tristel Formation and "Gault" occur also at the base of the Rhenodanubic flysch (HESSE, 1973) whose paleogeographic derivation is not completely clear (most authors assign it to the Valais basin). For these reasons, we assume that the Tasna nappe marks the transition between the Briançonnais swell and the Valais ocean. Oceanic crust of two oceans is thus preserved in the Engadine window: Piemont-Ligurian in the Arosa zone and Valais oceanic crust in the Tasna nappe and the Ramosch zone.

During the Alpine orogeny, the Tasna nappe, together with the Piz Nair serpentinite, was thrust over other ophiolitic units of the Ramosch zone, including the pillow basalts of Mot da Ri (Figs 2, 3). Stacking of tectonic units in the Engadine window presumably occurred in the Eocene and was top-north-directed (FROITZHEIM et al., 1994). The pillow basalts of the Ramosch zone therefore represent parts of the oceanic crust originally located to the north of the Tasna nappe, in a more central part of the Valais basin. The ophiolites of the Ramosch zone were in turn thrust over the Roz-Champatsch mélange zone and the Bündnerschiefer, derived from an even more northern part of the Valais basin.

The oceanic basin whose border is preserved in the Tasna nappe may have been several hundreds of kilometers wide, or alternatively, just a small pull-apart basin such as found in the Gulf of California (KELTS, 1981). The disintegrated outcrops of the Penninic zone in the Engadine window do not allow a decision of this question. The occurrence of a low-angle normal fault does not speak in favour of one or the other model, because such faults occur in the margins of large oceans (e.g., the Galicia margin of the Atlantic, BOILLOT et al., 1987) as well as along the extensional borders of pull-apart basins (e.g., Death Valley in California, WRIGHT and TROXEL, 1973).

Age of the Valais ocean:

The Shale Formation, the first sediment deposited on the serpentinitic basement, has not yet been dated. We can assume, however, that this very thin (0 to 30 m) formation, which grades upward into Upper Barremian to Lower Aptian (SCHWIZER, 1983) Tristel Formation, is part of the Lower Cretaceous succession. Consequently, the oceanic crust in the Tasna nappe must have formed during the latest Jurassic to Early Cretaceous. This is in line with the models of FRISCH (1979) and STAMPFLI (1993). Both authors proposed that the Valais ocean opened later than the Piemont-Liguria ocean, in relation with the opening of the Gulf of Biscay and with sinistral transtension in the Pyrenees.

Our observations do not imply that *all* oceanic crust in the Valais basin is of Cretaceous age. The Martegnas ophiolite (EIERMANN, 1988) in the Oberhalbstein area is probably Jurassic in age, since its pillow basalts are overlain by the succession radiolarite – Aptychus Limestone typical for Jurassic ophiolites in the Alps (WEISSERT and BERNOULLI, 1985). Still, this unit is in a "Valais" structural position (SCHMID et al., 1990). The occurrence of these Jurassic ophiolites in the structural position of the Valais units may be explained in – at least – two ways: Either, parts of the Valais ocean opened already in the Jurassic, as postulated by SCHMID et al. (1990) and STEINMANN (1994), or, Jurassic ophiolites of the Piemont-Liguria ocean were brought into a "Valais" position after their formation, by some subsequent tectonic displacement (e.g., strike-slip faulting). The first possibility makes the paleogeography more complicated, whereas the second necessitates additional tectonic complications. This problem remains unsolved.

Conclusions

The Cretaceous sedimentary sequence of the Tasna nappe lies with a depositional contact on granitic/gneissic basement in the southern part of the study area, and on serpentinitic basement in the northern part. Along both contacts, the top of the basement suffered intense brittle deformation, transforming it into granitic/gneissic cataclasite and ophicalcite, respectively. Cataclasite and ophicalcite were formed along the same low-angle normal fault. Progressive normal-fault displacement finally removed the hanging wall and exhumed the fault rocks, on which then the Cretaceous sediments, starting with Lower Cretaceous Shale Formation ("Neokom"), were deposited. The serpentinite is derived from subcontinental mantle material emplaced at the sea floor by extensional faulting.

The Tasna nappe thus includes the transition between continental basement of the Briançonnais microcontinent and oceanic crust of the Valais ocean. Our observations confirm that oceanic crust existed in the Valais basin and show that the formation of oceanic crust started, at least in this part of the Valais ocean, in the Early Cretaceous.

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