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## Post-Hercynian formations of the western Tauern window: sedimentological features, depositional environment, and age

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With 3 Figures

### Summary

The post-Hercynian formations of the western Tauern window are briefly described, and their sedimentology, depositional environment, and age are discussed. The most important results are:

(1) New fossil findings from Middle Triassic carbonates and the Hochstegen marble confirm the suggested ages.

(2) The Keuper formation is present at the base of the Glockner nappe in several places of the western Tauern window.

(3) The Bündner Schiefer of the Glockner nappe are at least in part flysch deposits resembling distal turbidites. Despite metamorphism, rhythmic layering and sometimes grading of the grain species are discernible. Carbonate concentrates at the bottom of the layers which usually comprise a lime-free upper horizon. A continuous profile through the sequence is presented, and the term "Bündner Schiefer and Tauernflysch formation" is proposed.

(4) The Kaserer formation also shows grading in places and is characterized by partly coarser clastic material (arkoses). A depositional environment in a slope basin on the southern continental margin of the Middle Penninic zone is suggested.

### Zusammenfassung

Es werden die postvariszischen Formationen des westlichen Tauernfensters vorgestellt, wobei vor allem auf ihre sedimentologischen Merkmale, ihr Ablagerungsmilieu und die Alterseinstufung eingegangen wird. Als wichtigste neue Resultate sind zu nennen:

(1) Neue Fossilfunde aus Mitteltriaskarbonaten und Hochstegenmarmor bestätigen die bisherigen Einstufungen.

(2) Die Keuperformation ist im westlichen Tauernfenster an mehreren Stellen an der Basis der Glocknerdecke anzutreffen.

(3) Die Bündner Schiefer der Glocknerdecke stellen zumindest zu einem Teil Flyschbildungen dar, die im Erscheinungsbild distalen Turbiditen entsprechen. Rhythmischer Sedimentationswechsel, wobei fast stets eine kalkfreie Lage beteiligt ist, ist trotz der Rekristallisation vielerorts zu erkennen, manchmal auch

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Gradierungen der Kornart, wobei Karbonat an der Basis der Turbiditlagen angereichert ist. Ein vollständiges Profil durch die Gesteinsabfolge wird kurz vorgestellt und die Bezeichnung „Bündner Schiefer- und Tauernflysch-Formation“ vorgeschlagen.

(4) Die Kaserer Formation zeigt ebenfalls Gradierungen und ist durch teilweise gröberklastisches Material (Arkosen) ausgezeichnet. Für sie wird ein Ablagerungsmilieu in einem Hangbecken am südlichen Kontinentalrand der Mittelpenninischen Zone angenommen.

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## Introduction

The Mesozoic formations of the (western) Tauern window belong to two different facies regions characteristic for two tectonic units. The Bündner Schiefer (Schistes lustrés) and Tauernflysch formation predominates in the (1) South Penninic oceanic basin from which the tectonically higher Glockner nappe derives; the (2) Middle Penninic zone which is represented by the Venediger nappe, is made up of a mighty Hercynian basement and thin Mesozoic cover with the Hochstegen formation as the characteristic member.

Hitherto, especially since FRASL's "Seriengliederung" (1958), it was customary to term the rock sequences of the Tauern window "series"; with regard to the new rules of nomenclature (HEDBERG, 1976), the author avoids this term and uses "formation" for the metamorphic lithostratigraphic units of the window which are, throughout, not well defined by age.

For additional information on the post-Hercynian formations, the reader is referred to EXNER (1957, 1964), FRASL (1958) and TOLLMANN (1965), among others.

## The Wustkogel formation

This formation has been defined "Wustkogelserie" by FRASL (1958). The post-Hercynian transgressive sequence is found in a strongly tectonized zone at the base of the Glockner nappe. In the western Tauern window, the formation is best developed in the Tuxer Tal and the Gerlostal. Moreover, young members of the formation sporadically occur in the Venediger nappe: e.g., in the westernmost tip of the Wolfendorn nappe south of the Brenner pass, and in the Greiner synclorium.

In local basins the lower member of the Wustkogel formation attains several hundred metres in thickness. It is an immature clastic sediment, often coarse-grained, and rich in granitic and rhyolitic material. Carboniferous and Permian granites, and probably Permian rhyolites are both found in the basement of the Venediger nappe.

The upper member of the Wustkogel formation consists of mature and pure quartzites which may be conglomeratic (quartzite pebbles) in places. It is up to several tens of metres thick. The entire formation is characterized by its light green colour due to phengite.

**Depositional environment:** The lower member of the formation is considered a terrestrial sediment deposited as fanglomerate in flat pans of the peneplained Hercynian basement. Variations in thickness, in the distribution of fine and coarse clastic material, and in the roundness of the clasts, are characteristic.

By onlap, the hanging quartzite spreads farther (e.g., parts of the Wolfendorn nappe) than the lower member. Maturity and monotony of this sediment reflect a remote hinterland. The quartzite can well be compared with the Buntsandstein in the Northern Calcareous Alps and the Germanic realm; for this latter formation BACKHAUS (1974) brought evidence of predominantly terrestrial (fluvial to limnic) sedimentation in a semiarid climate. Although marine sedimentation was put forward by some authors (e.g., EISBACHER (1963) for the Buntsandstein of the Northern Calcareous Alps) there is no proof for this, and it seems more probable to the author that the terrestrial environment of the lower Wustkogel formation continues through the upper part, with the difference that peneplainization was a far-reaching one.

**Age:** FRASL (1958) attributed Permian age to the Wustkogel formation which is generally accepted, and compared the lower member with the Grödnertal formation, the upper one with the Buntsandstein. The lower limit of the formation is unknown, and the author suggests that sedimentation began some time after the radiometric event at about 240 m.y. Thus, the lower member will probably be of Upper Permian, the upper member of Scythian age; the author, however, consciously avoids to assume exact coincidence of the border between coarser-clastic, mainly "Upper Permian" portion and mainly "Scythian" quartzite with the Permian/Scythian boundary as it was accomplished by TOLLMANN (e.g., 1965) although this will be roughly valid.

TOLLMANN (1965) reports Röt schists from the central Tauern window which conclude the clastic sequence.

### **The Middle Triassic carbonate formation**

There are local names for this formation in the central Tauern window, e.g., Seidlwinkltrias (CORNELIUS & CLAR, 1939), Hochtortrias (PREY, 1939).

The Middle Triassic carbonate formation begins with a thin, sometimes thickening horizon of cargneules. The typically fine-porous, quartz-bearing cargneules are rich in small fragments of phyllite which originally will have formed continuous layers but became boudinaged and contorted by tectonics.

The carbonates are predominantly white and grey, well-bedded fine-grained dolomite marbles. At the base there is limestone marble which may also appear within the sequence. The thickness of the formation varies from a few tens to several hundreds of metres.

**Depositional environment:** The sequence is deposited in very shallow water, initially in an evaporitic environment (cargneules). Finely banded dolomites from several localities show different pigmentation; possibly the laminæ reflect the pattern of algal mats.

**Age:** Fossils are reported from the dolomites in several places of the western Tauern window. They are diplopores and, more frequently, crinoids yielding Middle Triassic ages. KRISTAN-TOLLMANN determined crinoids from a new finding at the Kalkwandstange south of the Brenner pass: Middle Triassic, very probably Anisian (FRISCH, 1975). The cargneules, comparable to the Reichenhaller Rauhwacke of the Northern Calcareous Alps, are generally suggested to mark the beginning of the Anisian.

### The Keuper formation

The Keuper formation has been recognized by HOTTINGER (1931) in the central Tauern window but has not yet been described from its western part\*. FRANK (unpubl.), however, has distinguished this formation in several places: at the new road west of Gerlos pass; at the Kalkwandstange (see FRISCH, 1975); and in the Pfitschtal (quarry of Stein).

At the Kalkwandstange, there are coarse-cellular cargneules at the base of the Keuper formation, connected by transition with the Middle Triassic dolomites. Above, there are alternating chloritoid schists and quartzites. The formation possesses a thickness of several tens of metres in this locality. A similar sequence is found in the quarry of Stein, except the cargneules.

Moreover, a part of the "Mittlere Bündner Schiefer" of MILLER (1978) is, after the author's opinion, attributable to the Keuper formation: chloritoid and quartzite schists, as well as gypsum are found in the area north of Vorderlanersbach in the Tuxer Tal. MILLER also attributes other members to the Upper Triassic.

All the mentioned occurrences of Keuper strata are part of the tectonically contorted and sliced Permotriassic rocks at the base of the Glockner nappe.

**Depositional environment:** Like in the Germanic Keuper, a depositional environment near the terrestrial-marine boundary is suggested. Above the basal cargneules deposition presumably occurred in a predominantly terrestrial environment.

**Age:** The age is supposed to be Upper Triassic. With the cargneules (probably Carnian) the sequence joins the Middle Triassic carbonates.

\* The occurrence described by HOCK (1969) on top of the Hochstegen marble south of the Tuxer Joch is part of the Cretaceous Kaserer formation (see below) and does not belong to the Keuper formation; the attribution to the Keuper followed from the assumption of Triassic age for the underlying Hochstegen marble. The lithology of the strata in question does not, moreover, really correlate with the other Keuper occurrences.

## The Bündner Schiefer and Tauernflysch (BS-TF) formation

Except of its tectonically contorted basal zone of Permotriassic rocks, the Glockner nappe is entirely made up of a sequence termed here "Bündner Schiefer and Tauernflysch formation". Flysch in the Tauern window had already been described by BLESER (1934) and HOTTINGER (1934, 1935). Recently, PREY (1975, 1977) described flysch from near the northern margin of the eastern Tauern window (Rauristal), and the author (FRISCH, 1978b, c) from the western end of the window (Valser and Schmirntal) where rhythmic layering of turbidite cycles is excellently developed in several places (Fig. 1). Recent investigations of the author brought strong evidence that the Bündner Schiefer, at least for a great part if not entirely, are of turbiditic origin and display flysch character although often obscured by metamorphic recrystallization. The orogenic position in a rather narrow, at last subducting oceanic basin (FRISCH, 1977) is predestinate for the formation of flysch deposits. According to the present state of knowledge, i.e. that undoubtedly an important part of the Bündner Schiefer (Schistes lustrés) is in fact flysch, the denomination "Bündner Schiefer and Tauernflysch formation" was chosen; the term "Tauernflysch" was introduced by PREY (1975).

In the western Tauern window the BS-TF formation attains an apparent thickness of up to several kilometres, the true thickness is certainly less. The formation can be subdivided into several members. In the northwestern corner of the window, a boudinaged horizon of Triassic strata: quartzite, cargneules, dolomites, and (post-Triassic?) dolomite breccias divides the BS-TF formation and, consequently, the Glockner nappe into two sub-units. Corresponding relations are found in the South Tyrolian portion of the window (LAMMERER, pers. commun.) and are known to the author from the southern Granatspitz mountains (see also FRISCH, this vol.).

The profile Tuxer Joch-Reckner in the northwestern corner of the window is one of the best profiles through the BS-TF formation and can be taken as a standard profile for this region. It shows the following sequence (Fig. 2):

The lowermost, first member is characterized by paucity in lime and predominance of lime-free phyllites (blackschists). For the most part there is distinct alternation of layers in millimetre to decimetre scale: calcareous phyllites alternate with lime-free ones; in a bed of a few tens of metres in thickness, there are lime-free blackschists containing fine quartzite layers; in a quartzitic bed, quartzite layers predominate over the intercalated schistose layers.

In other places there is a characteristic white marble horizon of a few metres at most within the lowermost member. In the southern part of the western Tauern window there are thick sequences of prasinites, sporadically accompanied by serpentinites, the BS-TF formation begins with.

The thinly bedded schistose chlorite sericite quartzites from the Tuxer Joch described by HÖCK (1969) as metamorphic radiolarites, meanwhile clearly proved as part of the Wustkogel formation at the base of the Glockner nappe.

The second member in the profile Tuxer Joch-Reckner consists of calcpyllites (calcmicaschists) and impure calcschists which also display a sort of

1a



1b



1c



Fig. 1: Different types of rhythmical layered beds of the Bündner Schiefer and Tauern-flysch formation. a, b: Deposits of typical flysch appearance with carbonate-quartz layers and lime-free phyllitic layers; third and fourth member, resp., Schmirn valley. c: Calcphyllite with thin, rhythmically intercalated lime-free blackschieists layers; fifth member, ridge between Schmirn and Naviser valley. For further explanation, see text.

rhythmic layering: very fine layers of lime-free blackschieists (rarely up to a few centimetres thick) are intercalated in the calcschieists at intervals of several centimetres. The quartz content of the rock occasionally increases considerably.

The third member is made up of similar rock types as the second one but contains abundant carbonate quartzite or quartz marble which occurs in a

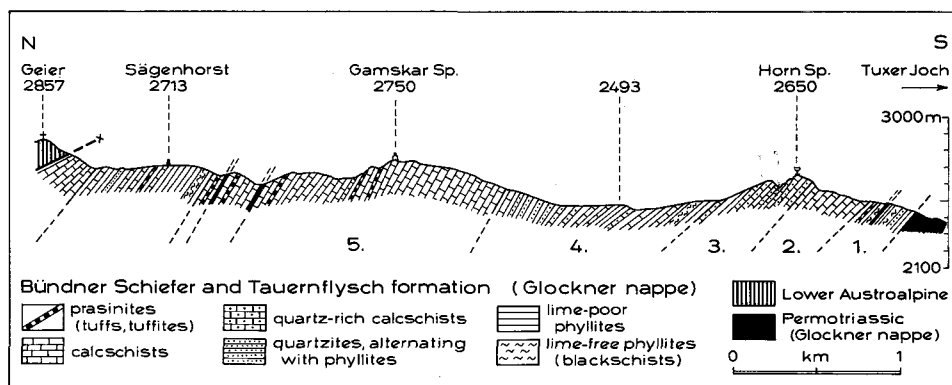


Fig. 2: Profile through the Bündner Schiefer und Tauernflysch formation from the Tuxer Joch to the Geier in the Reckner massif. For further explanation, see text (1.—5. correspond to the five members of the lower unit described in the text).

number of horizons up to tens of metres in thickness. Here also the thin lime-free intercalations are present if not obscured by metamorphic recrystallization; in places they attain dm-thickness between the quartzitic layers.

The fourth member, like the first, is poor in lime and rich in black-schists. A prominent blackschist bed is again characterized by alternations of the predominating lime-free phyllites with very thin (sometimes weakly carbonatic) quartzite layers. The main part of the member is made up of calcareous phyllites alternating with lime-free phyllites.

The uppermost, fifth member is again predominantly rich in lime. Thin rhythmic blackschist layers are present and often even more accentuated than in the second and third members. Few prasinites are present.

In the profile Tuxer Joch—Reckner the upper boundary of the sequence cannot be clearly drawn, because there are two horizons of Triassic rocks separating against the higher sub-unit. These Triassic rocks belong to the “Schuppenpaket des Sägenhorstes” of BLESER (1934) who attributed them to the Matreier zone.

This higher sub-unit (Fig. 2) has lesser thickness than the lower one but contains equivalent rock types although the sequence is not the same. At the bottom there is a lime-rich member with few prasinites (corresponding to the fifth member of the lower sub-unit?); a member poor in lime with abundant blackschists follows; on top there is again a lime-rich member. The rhythmic layering between calcareous resp. quartzitic layers and lime-free blackschists is again the dominating feature. It was BLESER (1934) who already mapped this part of the BS-TF formation as flysch. Sedimentologically there is, however, no difference to the rocks below.

**Depositional environment:** Although there are no complete ophiolite sequences in the Glockner nappe, it can be concluded that the Bündner Schiefer and Tauernflysch formation, at least for the most (central) part, has been

deposited on oceanic crust (FRISCH, 1974; TOLLMANN, 1975) by the following reasons: serpentinites occur in connection with tholeiitic (ocean floor) basalts (BICKLE & PEARCE, 1975), and there are more complete ophiolite sequences in the same position in the Western Alps. A crystalline basement is missing; the tectonically contorted zone with continental and shallow-marine Permotriassic sediments at the base of the Glockner nappe is not considered to be the substratum of the BS-TF formation except in a marginal position (FRISCH, 1978a).

All members of the BS-TF formation bear a common feature: the rhythmic layering (Fig. 1) which appears in a more or less clear manner even though metamorphism has obscured many of the primary structures and textures. Throughout, lime-free (or nearly lime-free) phyllitic material forms one part of the cycles. This is also valid for the lime-rich members (Fig. 1c). Despite metamorphism, the carbonatic or quartzitic layers often reveal graded bedding (see below).

Hence it may be suggested that the entire sequence of the BS-TF formation, or at least the great part of it, has been deposited as turbidity currents. This, the generally accepted deep-water environment of deposition, and at last the orogenic position of the South Penninic basin in the Cretaceous, justify the specification as "fl y s c h".

It is questionable if the lime-free, originally pelitic layers represent the hemipelagic sedimentation or are part of the turbidites or both; further investigation is necessary. The possibility: the carbonatic layers represent the pelagic sediment, and the pelites are very distal turbiditic inputs, is rejected because there is a sort of graded bedding in the carbonatic layers recognizable in several places (see below). It is quite conceivable though not implicitly pleaded for here, that the sequence subsided below the (local) calcite compensation depth in a very early stage: the opening of the South Penninic ocean in the Jurassic will have enabled cold, deep-situated currents to circulate and thus caused a sudden raising of the CCD. For the Northern Calcareous Alps, GARRISON & FISCHER (1969) postulate a shallow CCD in the early Jurassic which gradually lowers subsequently.

The South Penninic or Piedmont basin in which the BS-TF formation is deposited, represents an oblong basin of oceanic crust, the width of which did not exceed several hundreds of kilometers (FRISCH, 1977, 1979). In such a basin, throughout turbiditic sedimentation is quite possible, in a similar way as it was the case in the (younger) North Penninic (Valais) basin.

In narrow basins like the South Penninic one, longitudinal currents generally prevail and warrant a certain continuity of the strata. This explains the predominance of layers resembling distal turbidites in the BS-TF formation so far this can be established despite metamorphism. Coarse clastic material indicating proximal positions is found in the "Sandstein-Brekziendecke" in the eastern Tauern window (BRAUMÜLLER, 1939). There, PREY (1977) brings evidence for meridional transport and suggests a lateral feeder channel.

The relation of the Penninic breccias of the western Tauern window (e.g., Penkenbrekzie, Richbergkogel formation) to the BS-TF formation are still insufficiently elucidated.

The investigated turbidite cycles of the BS-TF formation display the following sedimentological features: carbonate and quartz are the main constituents of the coarser, turbiditic portions (sand fraction); quartz and mica (originally silt and clay) accompanied by abundant carbonaceous (graphitic) matter represent the pelitic portion. The difficulty with the interpretation of the pelitic portion: uppermost part of the turbiditic layers or hemipelagic sediment, has been already pointed out above, and both may be realized in one, i.e. that the lower part of the pelitic layer belongs to the turbidite and that the upper part represents the normal sedimentation.

In the turbiditic layers, frequently a vertical shift in the carbonate/quartz ratio is to be discerned; from nearly pure marble to carbonate-free quartzite all ratios are realized. Owing to metamorphic recrystallization, there is generally no grading of the grain size (grading proper) but only of the grain species. Carbonate concentrates at the bottom of the layers and decreases upward while quartz increases correspondingly. Besides calcite, ankerite (or ankeritic carbonate – determination with the aid of staining with Alizarin S) and/or dolomite participate with the grading and may, in cases, predominate over calcite.

In some thin sections, dolomite occurs as scattered euhedral crystals which contain a number of minute inclusions and are, in turn, surrounded by anhedral ankeritic or dolomitic carbonate. The appearance of the dolomite rhombohedrons resembles that known from diagenetically formed dolomite crystals. As dolomite remains rather inactive at low-grade metamorphic conditions, it is considered possible that it has still preserved its diagenetic forms whereas the recrystallized carbonates are anhedral and bare of such minute inclusions.

Of interest are the Ca/Sr ratios of the carbonatic rocks of the BS-TF formation and their comparison with those of other carbonates of the Tauern window. First results indicate formation of the carbonatic material in rather shallow water and thus support the interpretation of turbiditic deposition. The analyses are in train, and no definite results can yet be presented.

**Age:** It will require thorough investigation to decide whether the members of the BS-TF formation represents continuous stratigraphic sequences or if there are repetitions by megafolds or slices which may well be the case if we have to deal with an accreting wedge above a subduction zone as suggested by HAWKESWORTH et al. (1975) and FRISCH (1977, 1978a).

With regard to the general paleogeographic situation and comparisons with the Western Alps, the beginning of sedimentation of the BS-TF formation is considered to coincide with the early Jurassic (lower lime-poor member) but was restricted to the then still very narrow basin. The prominent calcphyllites and calcmicaschists are suggested to represent, for a good part, the Upper Jurassic and early Cretaceous (FRISCH, 1976). The renewed intensification of lime-free sedimentation may indicate the approach of a trench related to a subduction zone during Lower (to Middle) Cretaceous; this is also suggested for the "Nordrahmenzone" in the eastern Tauern window. Provided a continuous sequence, the termination with a lime-rich member may indicate filling-up of the trench in a late stage before the continent-continent collision (FRISCH, 1978a, 1979) in about early Upper Cretaceous time.

Tectonic emplacement in an accreting wedge would imply that sedimentation ceased earlier in higher slices than in lower ones. Accordingly, the shift from internal to external parts also applied to the changes in the sediment compositions.

### The Hochstegen formation

The Jurassic formations of the Tauern window are differentiated into the Bündner Schiefer and Tauernflysch formation (in part) of the oceanic South Penninic basin, and the Hochstegen formation deposited on continental basement and belonging to the Middle Penninic Venediger nappe. Over great distances, the Hochstegen formation transgresses directly upon Hercynian basement, in place thin Triassic strata are intercalated.

Usually there is a member of quartzite, sometimes accompanied by phyllites, at the base of the formation. Quartz-bearing limestone marbles follow, and by decrease of the detritic quartz content, they pass into the common Hochstegen marble. Dolomite marbles are found in the lower part of the marble sequence in the paleogeographically northernmost position (upon the Ahorn Zentralgneiss Kern). There are also flint-bearing marbles.

The primary thickness of the Hochstegen formation does hardly exceed 100 m near the Brenner, and decreases towards the east (Gerlostal – upper Salzachtal and Ahrntal). The formation seems to be primarily missing around the Granatspitz gneiss core. The latter area is considered to be largely bare of Mesozoic cover: it is part of the Briançonian cordillera continuing from the Western Alps where a high relief in the Jurassic is a characteristic feature of this zone.

**Depositional environment:** The basal quartzite reveals proximity of a land area. The mature and pure quartzite contains a certain percentage of clastic feldspar in its paleogeographically northern part indicating the direction of material supply.

The carbonates are considered to be those of a subsiding shelf in a pelagic environment: this is supported by pelagic fossils (see below) and the constantly high Ca/Sr ratios which are in strong contrast to those of the Triassic carbonates (results in preparation). A certain H<sub>2</sub>S content (distinct in lower parts of the marbles, esp. in the northern area) indicates an oxygen-poor environment.

**Age:** The finding of an impression of *Perisphinctes* sp. in fine-grained dolomite marble near the type locality, proves Upper Jurassic, probably Oxfordian age (KLEBELSBERG, 1940; MUTSCHLECHNER, 1956). At least a part of the carbonates is hence Upper Jurassic, and possibly the sequence enters the early Cretaceous. The carbonates of the Hochstegen formation are therefore considered being about contemporaneously deposited with the main part of the lime-rich Bündner Schiefer in the adjacent basin. New fossil findings from the same locality (a belemnite, radiolarians, sponge spicules; SCHÖNLAUB et al., 1975) supplement the old one.

The basal quartzite and quartz-bearing marbles are attributed to the Jurassic not younger than Oxfordian and probably represent Lias and Dogger.

FRISCH (1975b) compared the Hochstegen formation with the Jurassic sequence of the Ultrahelvetic Grestener zone and concluded that during this

period (not later!) both were part of one continuous facies region, still not separated by the North Penninic basin. Although the sequence of the Grestener zone is somewhat more differentiated (e.g., local coarse clastic sediments), there is, in opposition to TOLLMANN (e.g., 1977), no reason not to parallel these well-matching formations.

### The Kaserer formation

In parts of the western Tauern window, the Hochstegen formation passes into the Kaserer formation (Kaserer Serie, THIELE, 1970). Hitherto, the Kaserer formation is only known from the Wolfendorn nappe and the autochthonous cover of the Zillertaler Zentralgneiss Kern, and unknown also from the eastern Tauern window. The sedimentologically similar Brennkogel formation in the central Tauern window is most probably older than the Kaserer formation because of its sedimentary superposition on Triassic sequences (FRASL, 1958; FRASL & FRANK, 1966).

The Kaserer formation attains a thickness of more than 200 m near the Brenner pass and is characterized by frequent composition changes in vertical direction. In the Gerlostal (north) and the Ahrntal (south), the formation becomes monotonous (blackschists, micaschists) and disappears towards the east, probably due to non-deposition (cp. Hochstegen formation!).

In the area Brenner–Tuxer Joch the Kaserer formation can be subdivided into three members (Fig. 3). The lower member is about 100 m thick and consists of lime-poor to lime-free phyllites (blackschists), arkoses and quartzites. The phyllites are characterized by a steady alternation of quartzitic or quartz-rich and schistose layers, or of phyllitic layers of different carbonate (sometimes lime-rich) content. Pure and very fine-grained dolomite layers are also met with in the phyllites, at the base of the first arkose bed, and sometimes in quartzites. Mostly they are a few millimetres thick but there is also the one or other thick layer attaining several metres in boudins. The arkoses generally contain rounded alkali feldspars (rarely plagioclases) of 2–3 mm diameter; in some horizons, well-rounded, up to fist-sized pebbles of leucogranitic material are present. Phyllites near the base of the lower member are partly rich in chlorite and epidote and are considered to contain basic tuffaceous material.

The middle member is only about 20 m thick and characterized by calc-phyllites which alternate with other phyllites.

The upper member has again a thickness of about 100 m or less. It is comparable to the lower member, and the same is valid what has been said above about the different rock types. There are, however, even less calcareous and only exceptionally dolomitic layers. Lime-free phyllites alternate with quartzites and arkoses, lime-poor phyllites are rare. Thin dolomitic layers have been found in places above the lower arkose. In this arkose bed, well-rounded leucogranitic cobbles and boulders attain up to half a metre in diameter at the Flatschspitze (Fig. 3). Within the phyllites there is a prasinite horizon a few metres thick, which represents a basaltic lava flow; the compact magmatic fabric is still well-preserved. The thickness increases towards the northeast (Tuxer Joch), towards the southeast it seems to diminish to zero.

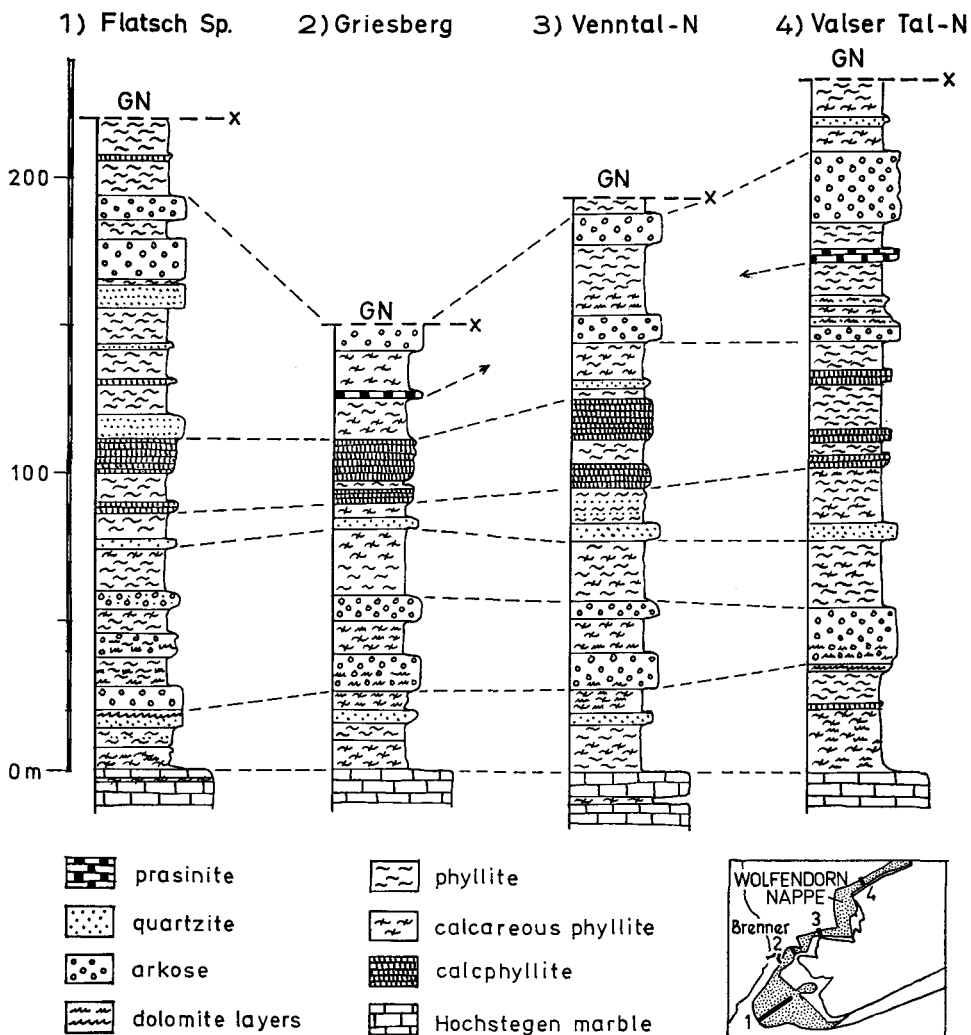


Fig. 3: Profiles through the Kaserer formation of the Wolfendorn nappe at the western end of the Tauern window. GN: Glockner nappe. For further explanation, see text.

The arkoses and carbonatic quartzites of the Kaserer formation sometimes exhibit graded bedding: in some arkose layers, clastic feldspar and carbonate are accumulated at the base and gradually disappear towards the top, the feldspars diminishing in size; in quartzitic layers, again, like in the BS-TF formation (see there), the carbonate-rich part is considered to mark the bottom – by isoclinal folding the layers are sometimes reversed.

**Depositional environment:** The question after the depositional environment of the Kaserer formation raises certain problems. Parts of the formation are deposited as turbidites or fluxites; this, however, could have happened in different environments.

A certain key position is carried by the dolomite layers which are frequent in horizons of the lower member: they can be considered as primary sediment formed in a sabkha environment as it was pointed out by P. FAUPL on the occasion of a common field excursion; another possibility is clastic sedimentation in deep water. Considering the second interpretation, the purity of the dolomite layers is perhaps surprising. The author, however, regards the following possibility: a submarine fan of fine dolomite sand, derived from a land area where exclusively Triassic dolomites erode, periodically alternates with one or several other fans supplying quartz, clay, calcite, and feldspar. The graded carbonate quartzites show that at least a part of the carbonate is of clastic origin.

On the other hand, origin of the dolomite layers in a sabkha environment should be also seriously considered. The hitherto only sporadically recognized turbiditic layers within the arkoses are partly considered as fluxoturbidites as they can be formed by subaerial debris flows. The following arguments may, however, be decisive against this interpretation: analogous dolomite layers are known to the author from several places within the Bündner Schiefer and Tauernflysch formation; and the phyllitic rock types of the Kaserer formation are exactly the same as found in the BS-TF formation which is a deep-water sediment; moreover, graded carbonate quartzites are of the same appearance in both formations. Last not least the deposition upon the pelagic Hochstegen marble favours the interpretation of formation in deeper water.

For these reasons, the author considers the depositional environment of the Kaserer formation a limited slope basin at the southern (southeastern) margin of the Briançonnian continent. The morphology of the basin was traced out by the Hercynian Zentralgneiss cupolas: the Kaserer formation, for its great part, was deposited upon the schistose rocks of the Greiner synclinorium forming a morphological depression between the Zentralgneisses, but also overlapped upon the Zillertaler Zentralgneiss Kern to the south, i.e. in direction to the South Penninic basin. On the Zillertaler Kern which probably formed a smooth swell, the Kaserer formation changes its composition: on the southern flank of the Zillertaler Kern there are monotonous micaschists with some intercalated quartzites in the equivalent position, as was recently confirmed by MESSNER (1978).

The coarse clastic material of the arkoses presumably derived from a granitic landmass in the northwest or west. Towards the east, the arkoses decrease in thickness, and the coarse components diminish in size until they disappear; the biggest components are known from the westernmost outcrop. A southerly direction of sediment supply can be excluded for paleogeographical reasons. Transport from a westerly to northwesterly direction will thus be most probable.

**Age:** The key for the age determination of the Kaserer formation is found in the fact that the formation is primarily connected with the underlying Hochstegen formation (THIELE, 1970; Fig. 3). The Hochstegen formation possibly includes lowermost Cretaceous, lower Upper Jurassic is proven (see above). For the Kaserer formation, therefore, essentially Lower Cretaceous age is suggested although the upper limit is unknown and early Upper Cretaceous may as well be included. Younger portions are not to be expected considering the mid-Cretaceous

nappe thrustings which will have been terminated before the 80 m.y. radiometric cooling phase (FRANK, this vol., FRISCH, this vol.) and prevented further sedimentation by overthrusting of the units exposed in the Tauern window.

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