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The evolution of the southern continental margin of the Jurassic Tethys Ocean as recorded in the Allgäu Formation of the Austroalpine Nappes of Graubünden (Switzerland)

By GREGOR P. EBERLI[1])

ABSTRACT

The Jurassic sediments of the Austroalpine nappes of southeastern Switzerland (Graubünden) were deposited on the passive, southern continental margin of the future Jurassic Tethys Ocean. A combination of sedimentological analysis and lithostratigraphical and scarce biostratigraphical correlations of the basinal sediments – the Allgäu Formation – are used to reconstruct the evolution and the paleogeography of the margin in the highly tectonized cross-section of the western part of the Eastern Alps.

A characteristic sedimentary prism displaying a thinning- and fining-upward megacycle accumulated after each rifting event. The base of the prism is formed by unsorted breccias, followed by an association of thin-bedded limestones and calciturbidites with intercalated megabreccias. This association is overlain by thick-bedded and, further up-section, thin-bedded calciturbidites with increasingly abundant background sediments. Bioturbated marls and limestones finally document the decline of the rifting-related sedimentation. In the study area the components of the redeposited beds consist exclusively of carbonates indicating that the basement was not exposed along the fault scarps.

The rifting occurred in two major phases. The first one began in the early Hettangian in the southermost tectonic unit (Ortler unit) and culminated in the Sinemurian. After an anoxic event in the early Toarcian documented by the deposition of ferro-manganese shales, a second major phase of rifting is recorded in the northwestern Austroalpine units (Ela and Bernina nappe). Many of the basinal sediments of these units might therefore be not of Early Jurassic, as hitherto supposed but of Middle Jurassic age.

The paleotectonic reconstruction of the Central Austroalpine complex shows a progressive fragmentation of the margin from east to west by a sequence of faults that today trend approximately N–S. The exposed faults as well as the asymmetric sedimentary prisms indicate that the faults dip towards the continent. In the Ela nappe, there is evidence for a second E–W striking system. The progressive fragmentation towards the future ocean and the dipping of the faults towards the continent do not fit a symmetrical passive margin geometry. The shift of the spreading center, or more likely the development of a detachment fault in the lower crust and the mantle lithosphere, are possible explanations for the unusual evolution and asymmetrical geometry of the continental margin in the Austroalpine cross-section.

ZUSAMMENFASSUNG

Die jurassischen Sedimente der ostalpinen Decken Graubündens werden als Ablagerungen des passiven, südlichen Kontinentalrandes der mesozoischen Tethys angesehen. Dieser entstand, als infolge von Extensionsbewegungen die während der Trias aufgebaute Karbonatplattform in ein kompliziertes Muster von submarinen Hochzonen und Becken zerbrach. Sedimentologische, lithostratigraphische und, sofern die seltene Fauna es erlaubte, biostratigraphische Untersuchungen der Beckensedimente der Allgäu-Formation bilden in dieser Arbeit

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die Grundlage für die Analyse der Entwicklung des Kontinentalrandes im zentralostalpinen Querschnitt. Bei der paläogeographischen Rekonstruktion wurde ferner die alpine regionale Tektonik mitberücksichtigt.

Jeweils im Anschluss an eine Rifting-Phase wurde ein charakteristisches Sedimentprisma abgelagert, das allgemein einen «thinning-and-fining-upward»-Trend zeigt. Die Basis des Prismas bilden unsortierte Breccien, überlagert von dünnbankigen Kalken und Calciturbiditen mit zwischengelagerten, bis zu 50 m mächtigen Megabreccien. Darüber folgen zuerst dickbankige, dann vermehrt dünnbankige Calciturbidite, denen gegen oben immer mehr Normalsedimente, bestehend aus bioturbierten Mergeln und Kalken, zwischengelagert sind. Resedimentfreie Serien belegen schliesslich das Ausklingen der riftbedingten Sedimentation. Im Untersuchungsgebiet bestehen die Komponenten der Resedimente ausschliesslich aus Biodetritus und den Erosionsprodukten der obertriadischen Kössen- und Hauptdolomit-Formation sowie der Allgäu-Formation selber. Es scheint, dass die jurassischen Brüche in diesem Abschnitt keine älteren Formationen oder das Grundgebirge freigelegt haben.

Die Extension des Kontinentalrandes lief in zwei Phasen ab. Eine erste Phase setzte im frühen Hettangian in der südöstlichen Einheit, dem Ortler-Element, ein. Während der Hauptphase dieses Rift-Ereignisses im Sinemurian wurde auch die Ela-Decke erfasst. Gegen das Ende des Pliensbachian war das Relief in den Becken wieder ausgeglichen, und bioturbierte Mergelkalke dominieren die Profilabschnitte. Darüber abgelagerte, schwarze Schiefer mit rostrot verwitternden Calciturbiditen werden mit lithologisch ähnlichen Ablagerungen in den Nördlichen Kalkalpen und Südalpen verglichen, wo sie als frühes Toarcian datiert sind. Unmittelbar nachher setzte eine zweite Rifting-Phase ein. Die damit verbundenen Bruchstufen und Resedimente sind vor allem in den nordwestlichen Einheiten (Ela- und Bernina-Decke) zu beobachten. Viele in diesen Decken, besonders in der Bernina-Decke, erhaltenen jurassischen Beckensedimente dürften deshalb eher ein mitteljurassisches und nicht ein liasisches Alter haben.

Die paläogeographische Rekonstruktion dokumentiert eine von Osten nach Westen fortschreitende Fragmentierung des Kontinentalrandes. Dabei entstand als dominantes Bruchsystem eine Schar von heute ungefähr N–S verlaufenden Brüchen. Die Brüche und die asymmetrische Verteilung der angrenzenden Beckensedimente belegen gegen den Kontinent einfallende Brüche. Ein Hinweis für ein zweites, E–W verlaufendes Bruchsystem ist in der Ela-Decke gegeben. Das progressive Zerbrechen vom Kontinent gegen den zukünftigen Ozean sowie die Orientierung der Brüche gegen den Kontinent hin stehen im Gegensatz zum Modell eines symmetrischen, passiven Kontinentalrandes. Die Verschiebung des Spreading-Zentrums oder eine grosse Abscherungsfläche (detachment fault) im tiefen Krustenbereich und oberen Mantel sind mögliche Ursachen für die asymmetrische Entwicklung des Kontinentalrandes im Ostalpen-Querschnitt.

Introduction

The present-day Eastern Alps of Switzerland are a complex edifice of nappes. Paleogeographically they belong, like the Southern Alps, to the Apulian plate and were part of the southern continental margin of the Jurassic Tethys Ocean. Although the exposures are good, Alpine tectonism complicates palinspastic reconstruction. Therefore, a combination of sedimentological features, litho- and biostratigraphical correlations and structural analysis was used to reconstruct the paleogeography and the evolution of the continental margin in this highly tectonized area. The area lies paloegeographically at the corner of the Apulian plate facing the Piemont–Ligurian Ocean to the west and to the north the trough connecting the Piemont-Ligurian Ocean with the Vardar trough (Trümpy 1975; Laubscher & Bernoulli 1977; Biju-Duval et al. 1977).

The Piemont-Ligurian Ocean is one of the basins, which opened as Pangea split with eastward movement of Africa resulting in sinistral transform movements between the southern and northern continents. At this time, a series of rhomb-shaped basins connected by troughs dominated by transform faults formed. In many of these Tethyan basins probalby no complete ophiolithic sequence developed. This complicated segmentation pattern with a variety of small basins differs widely from the linear, large-scale Atlantic-type rifting geometry. However, the cross-section of the Southern Alps is often taken as an example of an ancient continental margin and compared with modern analogues, such as the Bay of Biscay (BALLY et al. 1981; WINTERER & BOSELLINI 1981; BERNOULLI 1981, BERNOULLI & LEMOINE 1980; HSÜ 1983).

North of the Southern Alps, separated by a deep Tertiary fault, the Insubric Line, lay the Eastern Alps of Switzerland. The purpose of this paper is to document the evolution of the continental margin in this cross-section, where a higher degree of segmentation due to increased transform movements is expected. The basinal sediments, stratigraphically known as Allgäu Formation (GÜMBEL 1856, JAKOBSHAGEN 1965, DÖSSEGGER et al. 1982), contain the best record of the rifting history. In particular, the distribution of the redeposited sediments can be taken as indicator for rifting events and basin geometry.

Regional Setting

The Eastern Alps of Switzerland are composed of numerous thrust sheets with north- or west-directed thrusting and with a present-day generally east-dipping exposure. They are formed by two main tectonic realms, the Penninic realm which to the east is overlain by the Austroalpine units (Fig. 1). The highest nappes of the Penninic realm, the Platta-Arosa-Zone and the equivalent series in the Lower Engadine window, are ophiolite-bearing and interpreted as relics of the Piemont–Ligurian Ocean. The overlying Lower Austroalpine units consist of a Pre-Permian crystalline basement covered by Mesozoic sediments and are characterized by thin Triassic sequences (TRÜMPY 1980; NAEF 1987). In their Middle Jurassic sequences components of crystalline basement in conglomerates and turbidites document partial erosion of the basement in the Middle Jurassic (FINGER 1978). To the east, the nappes of the Central Austroalpine complex overlie the Lower Austroalpine units. The complex is composed of five major basement nappes and their Mesozic cover plus two nappes consisting only of Mesozoic sediments. The Engadine Line, a late-Alpine, sinistral wrench fault, cuts through this edifice and complicates the correlation of the nappes on both sides of the line (TRÜMPY 1977; 1980). North of the Engadine line, the two lowest units of the Central Austroalpine complex, the Ela nappe and the Arosa Dolomites, are nappes containing only sediments and both have a similar tectonic position below the large Silvretta nappe (Fig. 1; EICHENBERGER 1986). South of the Engadine line, the lowest tectonic unit of the complex is the Languard nappe. It is overlain by the Campo nappe, a large crystalline basement nappe, which is partially in normal stratigraphic contact with the sediments of the Ortler unit, the western- and southernmost unit of the Engadine Dolomites.

The studies concentrated on the sediments of the Central Austroalpine complex and of the Bernina nappe in the Mezzaun half-window of the underlying Lower Austroalpine unit. In addition, comparative studies were made in the western Lechtal nappe of the Northern Calcareous Alps (EBERLI 1985a).

The pre-Jurassic evolution of the Eastern Alps

During the latest Paleozoic and especially during the earliest Triassic, the V-shaped embayment of Panthalassa, the Paleo-Tethys, transgressed from the east into the modern Alpine-Mediterranean realm and a large marginal carbonate platform was established (TRÜMPY 1960; LAUBSCHER & BERNOULLI 1977). In mid-Triassic time, the platform was

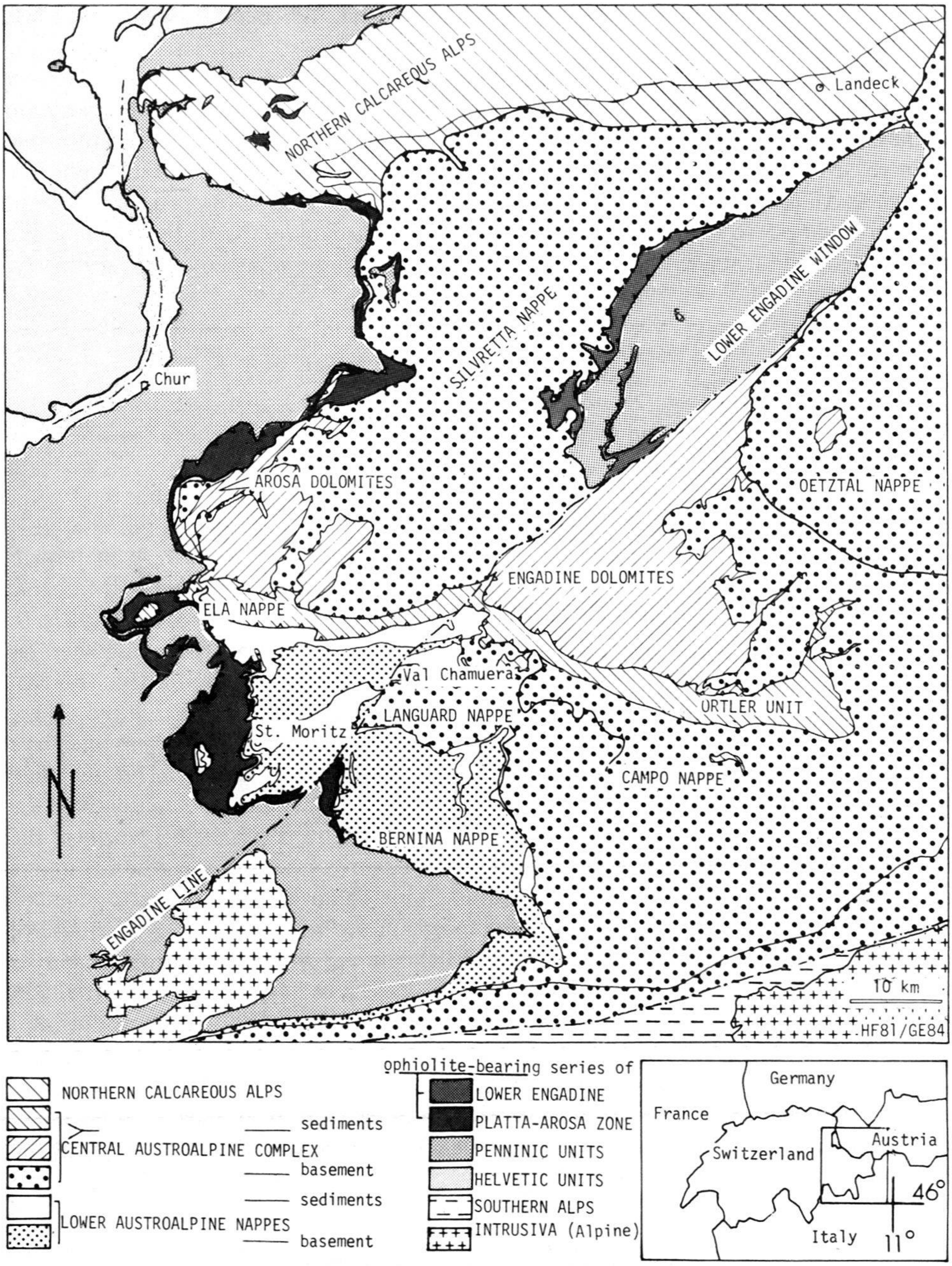


Fig. 1. Tectonic map of Graubünden, Switzerland, simplified after SPICHER (1972). The nappes east and south of the dark-shaded, ophiolite-bearing Platta–Arosa-Zone were part of the southern continental margin of the Jurassic Tethys Ocean. From EBERLI (1987).

segmented and deeper basins formed, comprising submarine basalts, pelagic limestones and redeposited sediments. The event was accompanied by volcanism, but no ophiolithic crust developed in the basins. Because the morphology of these basins is related to tensional faulting, the segmentation is thought to be the result of an aborted rifting phase (BECHSTÄDT et al. 1976, 1978). Towards the end of the Triassic the relief was equalized over most of the Alpine-Mediterranean realm and shallow-water carbonates are characteristic of the Norian.

In the Eastern Alps, the Norian Hauptdolomit Formation is up to 1500 m thick and consists of dolomites, poor in fossils, deposited on a broad platform with wide tidal flat areas and closed internal lagoons (FURRER 1981). The overlying Plattenkalk Formation comprises well-bedded limestones, which are partially oolitic or bear coquina beds, silicified fossils and siliceous concretions. During the Rhaetian, the sedimentation started to change as fine-grained siliciclastic material was deposited. In addition, the depositional area started to differentiate and a patchwork of lagoons, coral reefs and sandbars evolved. Within the 200 to 300 m thick Kössen Formation, several shallowing-upward cycles are interpreted as the result of short subsidence steps and might be the first indications of the breakup of the Triassic carbonate platform (FURRER 1981).

The Jurassic sediments

General remarks

During the rifting in early Jurassic time, the Upper Triassic carbonate platform was fragmented by intense block faulting, which created a complex pattern of submarine highs and basins (SCHÜPBACH 1974; FINGER 1978; FURRER 1981; EBERLI 1985a). As a consequence, the Lower and Middle Jurassic sediments of the Eastern Alps are characterized by numerous facies changes from condensed submarine high deposits to basinal sediments. In many places, tilting of the fault blocks and subsequent erosion produced an unconformity between the Triassic and the Jurassic deposits. Along the fault scarps high-angle unconformities can be observed, e.g. at Monte Motto (Ortler unit), at Piz Toissa (Ela nappe) and at Piz Mezzaun (Bernina nappe). In the basinal areas the hemipelagic sediments of the Allgäu Formation conformably overlie the Kössen Formation.

On the submarine highs of the Central Austroalpine complex, sedimentation was reduced and often interrupted. Micritic and crinoidal limestones, hardgrounds associated with ferro-manganese crusts, nodular limestones, neptunian dykes and redeposited beds characterize the deposits on these drowned submarine highs (for description of the different lithostratigraphic units see: FURRER 1981, 1985; EBERLI 1985a). However, slow and interrupted sedimentation provides an incomplete record of the evolution of the continental margin. The basinal sediments, on the contrary, have a much faster and more continuous sedimentary record. They are used here to investigate the evolution of the southern continental margin of the Jurassic Tethys Ocean in the western part of the Eastern Alpine cross-section.

The Allgäu Formation

The Allgäu Formation represents the sedimentary prisms, which accumulated in the basins formed during the Jurassic rifting phase of the Tethys Ocean. Lithologically, the Allgäu Formation consists of bioturbated – often regularly alternating – marls and limestones interbedded with different types of redeposited carbonates, such as breccias, conglomerates and calciturbidites (JAKOBSHAGEN 1965). Trace fossils (especially *Chondrites*) are abundant, whereas bivalves, belemnites and ammonites are seldom found, except in the lowest members (DÖSSEGGER et al. 1982). In the investigated area, the lithoclasts are exclusively carbonates and were eroded from the Upper Triassic Hauptdolomit and Kössen Formations, from the Jurassic submarine high deposits and to a smaller extent from the basinal sediments themselves. Within the 200 to 500 m thick formation, the amount of redeposited beds varies, allowing the distinction of different members (see Appendix and Fig. 2).

The Allgäu Formation was deposited during the Early and Middle Jurassic as determined by ammonite stratigraphy (JAKOBSHAGEN 1965; FURRER 1981). In the Central Austroalpine complex, biostratigraphic control is limited to the Early Jurassic. The base is heterochronous, ranging from early Hettangian to early Toarcian (Fig. 2; FURRER 1981, 1985; EBERLI 1985a). As no Middle Jurassic fossils were recognized, it is assumed that manganese-bearing shales overlying a series of redeposited beds of a first megacycle (Trupchun Beds) are coeval with similar deposits in the Northern Calcareous and the Southern Alps where they were dated as early Toarcian and interpreted as the record of an anoxic event (JAKOBSHAGEN 1965; JENKYNS et al. 1985; JENKYNS & CLAYTON 1986). Using the Manganese Shales as a correlation horizon, it is suggested that the second megacycle, the Mezzaun Beds, was deposited mainly during the Middle Jurassic. The upper boundary of the Allgäu Formation is taken at the base of the first overlying

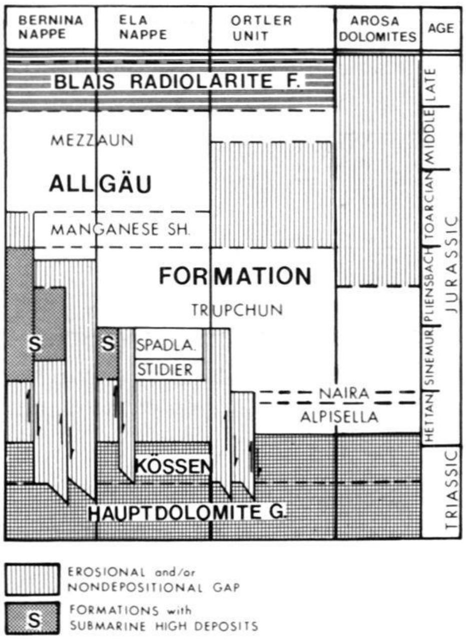


Fig. 2. The Allgäu Formation and its lithostratigraphic subdivisions in the Central Austroalpine complex. The definition of the different members is given in the Appendix. Modified after EBERLI (1987).

radiolarite bed. As in the entire Piemont–Ligurian Ocean, radiolarite sedimentation might have started in the latest Middle Jurassic (BAUMGARTNER 1985).

Sedimentology

Lithofacies

The up to 500 m thick Allgäu Formation comprises bioturbated marls and limestones with interbedded carbonate turbidites. The redeposited beds can be grouped in eight lithofacies types ranging from slump units and megabreccias to fine laminites (EBERLI 1987).

At the base of many sections or intercalated in the basal thin-bedded Jurassic sediments, one or several spectacular, up to 50 m thick, megabreccias are found. The mostly angular components consist of dolomites and limestones of the Upper Triassic Hauptdolomit and Kössen Formations. Matrix is scarce and consists of marls and finer-grained clasts of a similar composition as the larger components. The non-channelized beds are interpreted as thick debris sheets generated by the catastrophic collapse of the newly formed fault escarpments.

The most abundant redeposits within the basinal sediments are bio- and lithoclastic grainstones and packstones. Their sedimentary structures indicate a variety of transport

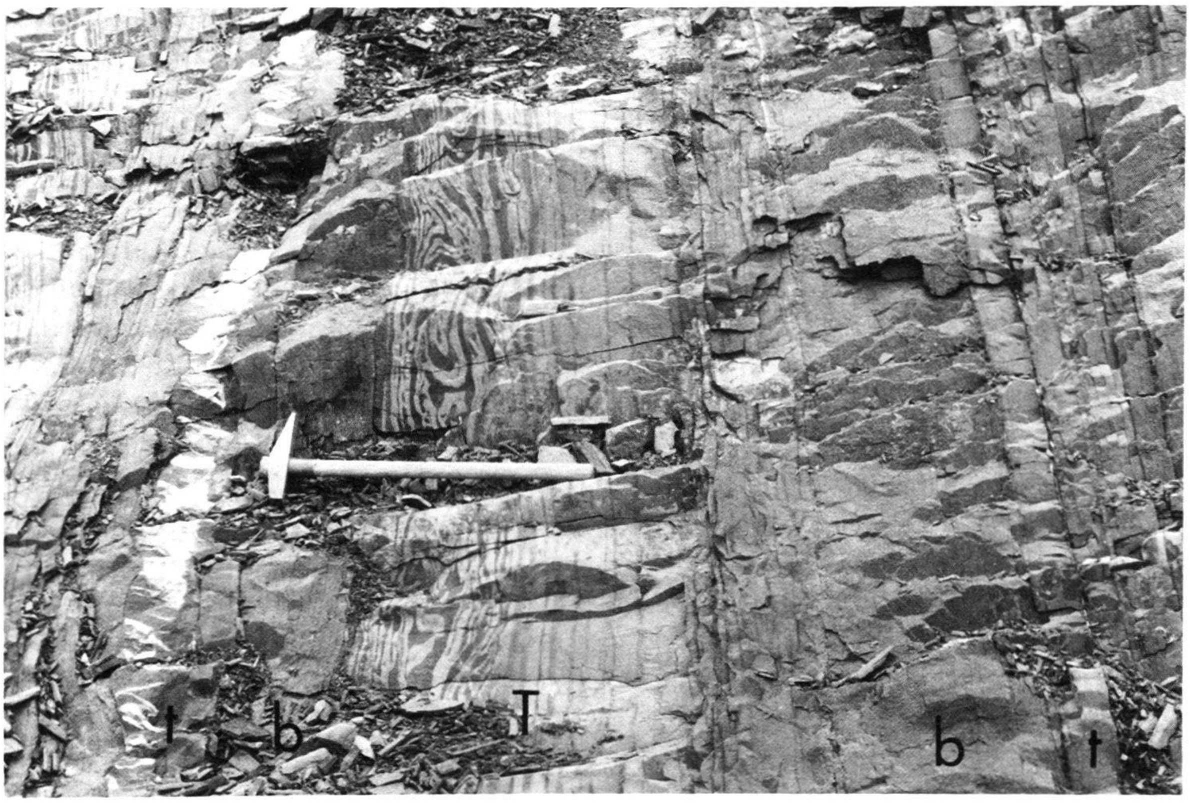


Fig. 3. Calciturbidites with secondary silicification are the most abundant redeposited beds of the Allgäu Formation. They are identified, as are their siliciclastic counterparts, by the occurrence of the Bouma sequence or parts of it. T = $T_{(b)c}$-turbidite; t = marly T_e-turbidite; b = marly background sediment. Up section is to the right. Hammer is 0.6 m long. Foura da l'Üertsch, Ela nappe. From EBERLI (1987).

mechanisms ranging from grain flow to high- and low-density turbidity currents (EBERLI 1987). The sedimentary column is in many sections dominated by calciturbidites which show, compared to their siliciclastic counterparts, some characteristic features. In the calciturbidites, cross and convolute bedding as well as bottom marks are rare. The beds often have a bimodal distribution of the components with lithoclasts preferentially occurring at the bottom part and lighter bioclasts in the top part of the bed. Most of the beds display secondary silicification, appearing on the weathered surface as yellowish-grey layers or nodules. Other sedimentary structures, such as base-cut-off features, which are commonly thought to be produced by lateral segregation due to flow mechanism, are not significantly influenced by the carbonate composition (EBERLI 1985a, 1987). It is therefore assumed that bed-thickness and the development of the Bouma sequence therein can be used as indications of the transport distance, as it is done in siliciclastic turbidite sequences (WALKER 1967, 1975, 1978; MUTTI & RICCI LUCCHI 1975, 1978).

Basin analysis

The sedimentary investigations revealed that in the rift basins a distinct prism accumulated after each rifting event. The prism display a characteristic thinning- and fining-upward megacycle. Within a complete megacycle, six facies associations can be distinguished (Fig. 4; EBERLI 1987). The base of the megacycle consists of breccias with angular clasts and with no internal structure. This base-of-fault scarp association is found either as a breccia bed draping unconformities (e.g. Chaschaunacrest, Fig. 5) or as a massive body along the escarpment (e.g. Piz Alv). The overlying association is characterized by the intercalation of megabreccias, conglomerates with finer-grained calciturbidites and bioturbated marls and limestones. The megabreccia association is best developed along the escarpments and has a restricted lateral extent. A thick-bedded turbidite association with minor background sediments covers these associations or forms farther basinward the base of the redeposited sequence. As the cyclicity diminishes towards the top of the association a rather monotonous sequence of thin, fine-grained calciturbidites is found. This thin-bedded turbidite association develops upsection into bioturbated marls and limestones with intercalated, mostly base-cut-off calciturbidites. Within this basin plain association, occasional pebbly mudstones indicate that the relief was not completely buried and debris flows were still being shed into the basin. On the gentle slopes opposite to the fault escarpment, marl/limestone alternations and weakly nodular limestones dominate the sequence. Marl/limestone alternations may also form the top of the megacycle in the center of the basin.

A complete thinning- and fining-upward megacycle as described above is only developed in the vicinity of the faults; with increasing distance from the faults the megacycle becomes incomplete. In a similar way as in a single turbidite bed the basal Bouma sequences are missing with increased distance, the carbonate turbidite megacycle looses its basal associations basinwards. In some cases a roll-over structure and antithetic faults might have enhanced the asymmetry (GIBBS 1984). However, no matter how many of the basal associations of the megacycle are cut off, the remaining intervals display a thinning- and fining-upward trend. This succession from associations with thick-bedded, coarse redeposited bed to those with relatively finer grained and thinner beds upsection is

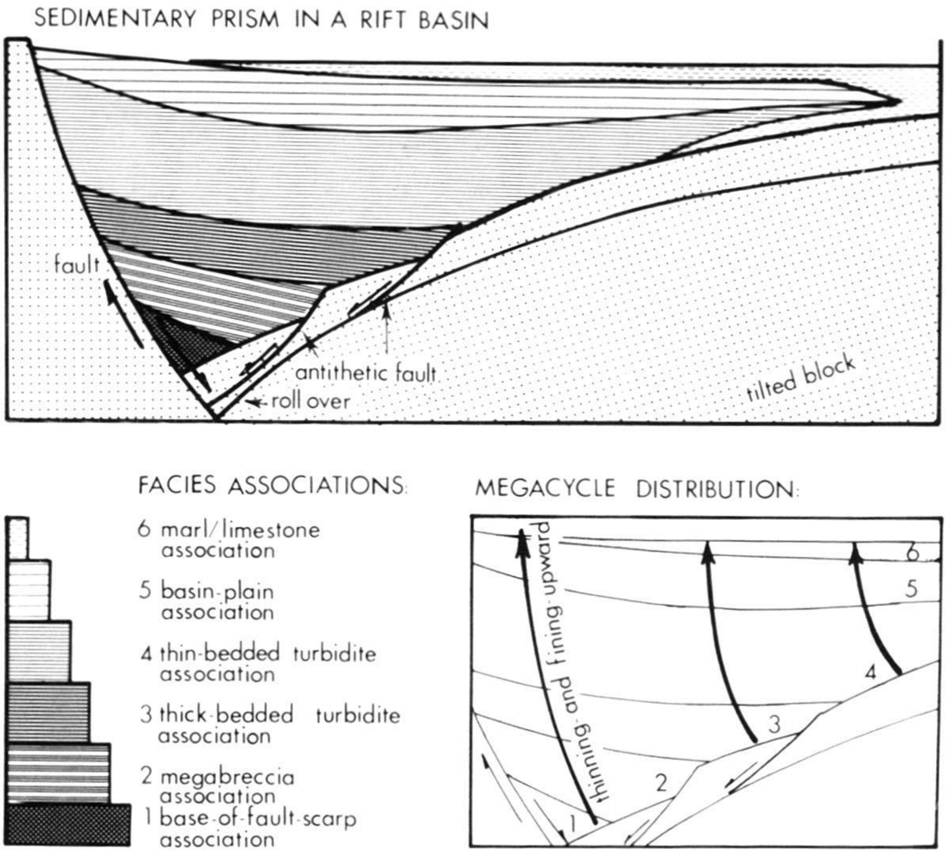


Fig. 4. Schematic distribution of the sedimentary prism in a rift basin formed by tilting of a fault-block and modified by a roll-over structure. In the asymmetric basin a thinning- and fining-upward megacycle composed of six facies associations accumulated. The depocenter of the coarse-grained, basal breccias and turbidites is parallel to the fault. With increasing distance from the fault the basal associations are cut-out owing to the basin asymmetry and diminishing sediment supply. At the distal edge of the tilted fault block resediment-free series are deposited and form the tip and, after filling, the top of the wedge-shaped prism. For the lithological description of the six facies associations see text.

contrast to the succession found in prograding turbidite systems (Walker, 1975, 1978; Mutti & Ricci Lucchi 1978). The thinning- and fining-upward trend is thought to be one of the most characteristic features of turbidite sequences in rift basins (Surlyk 1978; Eberli 1987).

The wedge-shaped sedimentary prism as seen in Figure 4 containing all six facies associations represents an idealized, elementary unit of a rift basin fill. The study of numerous sections in each tectonic unit showed that the cycle can be repeated. These repetitions and variations of the megacycle record the successive evolution of the breakup of the continental margin as rifting proceeded. The distribution of the redeposited sediments as well as their age can be used for a comparative basin analysis between the tectonic units. For example, if two sedimentary prisms do not display the same distribution in time and space, they were most probably not deposited in the same basin. These comparative basin analyses, together with structural information, are the basis for the paleogeographic reconstruction.

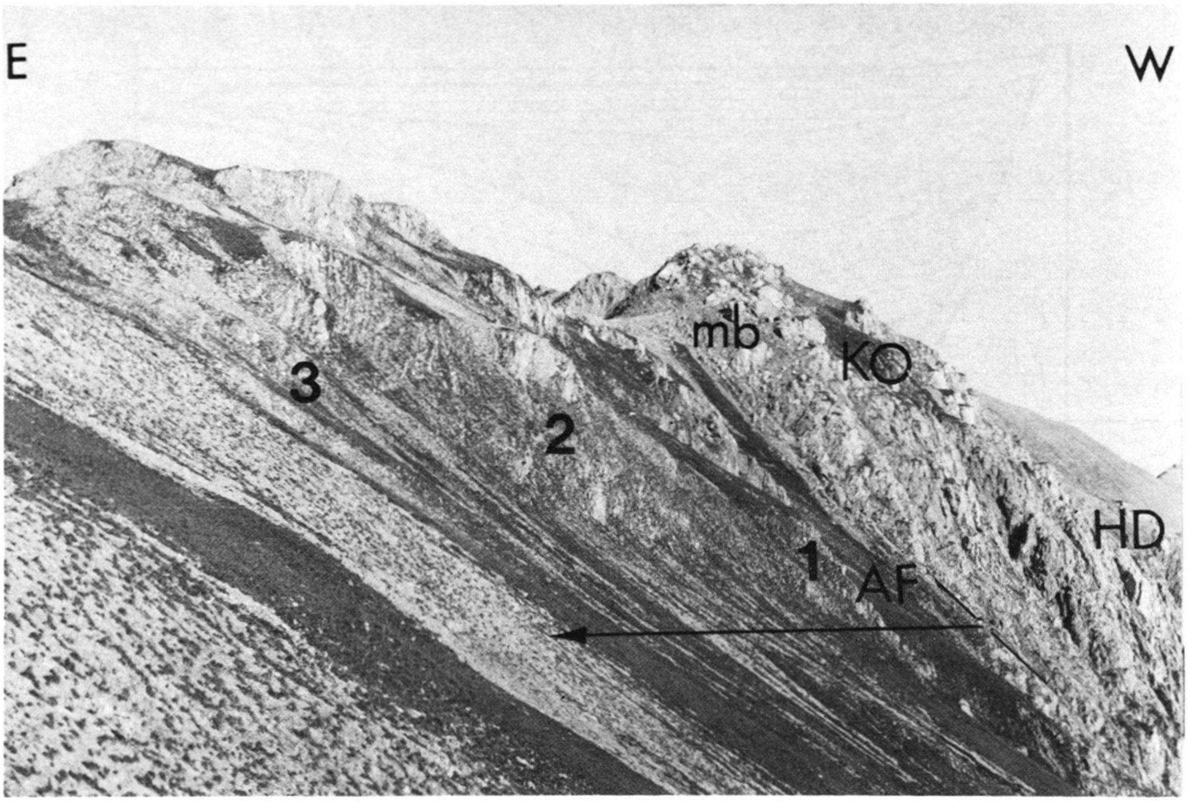


Fig. 5. The base of the megacycle at Spi da Chaschauna. A megabreccia (mb) approximately 30-m thick overlying a nearly completely eroded sequence of the Rhaetian Kössen Formation (KO). Up-section (to the left) the transition from the megabreccia-association into the thick- and thin-bedded turbidite associations is exposed. Three pulses (1, 2, 3) of coarse-grained breccias and turbidites, each displaying a fining-upward cycle, are recognized. The last grades into regularly bedded turbidites of the thin-bedded turbidite association. Spi da Chaschauna, Ortler unit. HD = Hauptdolomit Formation, AF = Allgäu Formation. Exposed section is approximately 150 m thick.

Distribution of the Allgäu Formation in the different tectonic units

In the following chapters the Jurassic sedimentary prisms of the investigated nappes are described and their rifting history is reconstructed. In addition, a short tectonic overview and the interpretation followed is given for each tectonic unit.

Ela nappe

Tectonic overview

The Ela nappe is a decollement sheet of Upper Triassic, Jurassic and locally Cretaceous sediments. In the eastern part, it overlies Lower Austroalpine units, in the western Penninic units (Ott 1925; Furrer 1974; Trümpy 1980, Frank 1981). The Ela nappe itself is overthrust by the Silvretta nappe (Eugster 1924; Heierli 1955; Eichenberger 1986). The internal structure of the nappe is characterized by approximately E–W trending folds and post-nappe synforms and antiforms. The main body of the nappe overlies three lower digitations (Crap Ses synform, Bergüner Stein, Gualdauna slice) (see

Fig. 9; EBERLI 1985a). In these digitations, condensed sequences of micritic limestones and abundant synsedimentary dykes are found in the Lower Jurassic section whereas the main body of the nappe is dominated by carbonate turbidite sequences.

The Lower Jurassic sediments of the Ela nappe (main nappe)

The Lower Jurassic sediments of the Ela nappe were deposited on partially incomplete Upper Triassic sections (Fig. 6). At the eastern end of the nappe (Piz Üertsch), marly limestones drape a truncated surface of the Hauptdolomit Formation. 12 km westard, north of Piz Mitgel at Fil da Stidier, the Liassic sediments overlie conformably the entire Kössen Formation (Fig. 7). At the western end of the nappe (Piz Toissa), again a large portion of the Upper Triassic Formations is removed and a breccia unconformably covers the Triassic series. The different preservation of the Triassic section gives a first indication of the initial basin geometry formed by the Jurassic rifting. The truncation surface at Piz Üertsch could have been formed at the edge of a tilted fault block. At the west, the high-angle discordance provide evidence for a fault escarpment at or near Piz Toissa.

The facies distribution of the Lower Jurassic sediments is consistent with this inferred basin geometry. At the western end of the Ela nappe at Piz Toissa, the basal series are

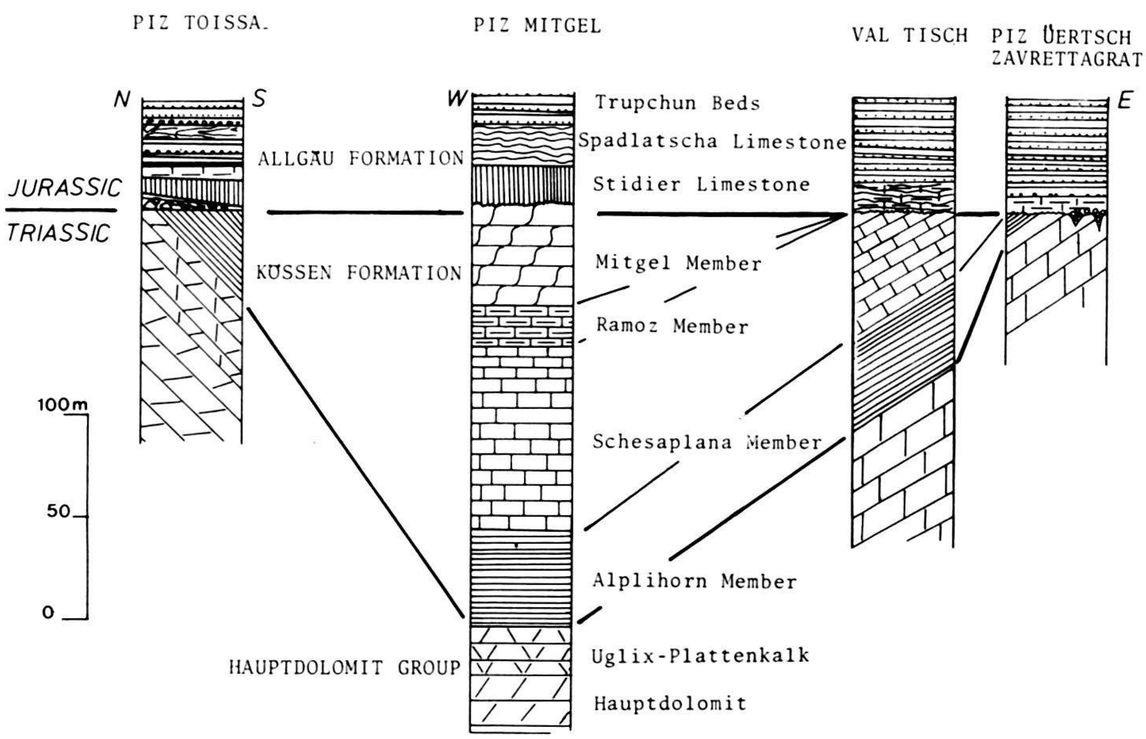


Fig. 6. The preservation of the Upper Triassic Formations underlying the Allgäu Formation in the Ela nappe in a east-west cross-section. At Piz Toissa, a Jurassic megabreccia overlies the Triassic formations with a high-angle discordance which is interpreted as a fault contact. At Piz Mitgel the entire Triassic section is preserved and the subsequent concordant boundary is thought to be formed in a basinal setting with no erosion. At Val Tisch and at the Zavrettagrat a low-angle unconformity is found and at Piz Üertsch fissures cut into the eroded Hauptdolomit Formation. This truncation surface might have formed at the edge of a tilted fault block. Triassic sections after FURRER (1981). For location see Figure 10.

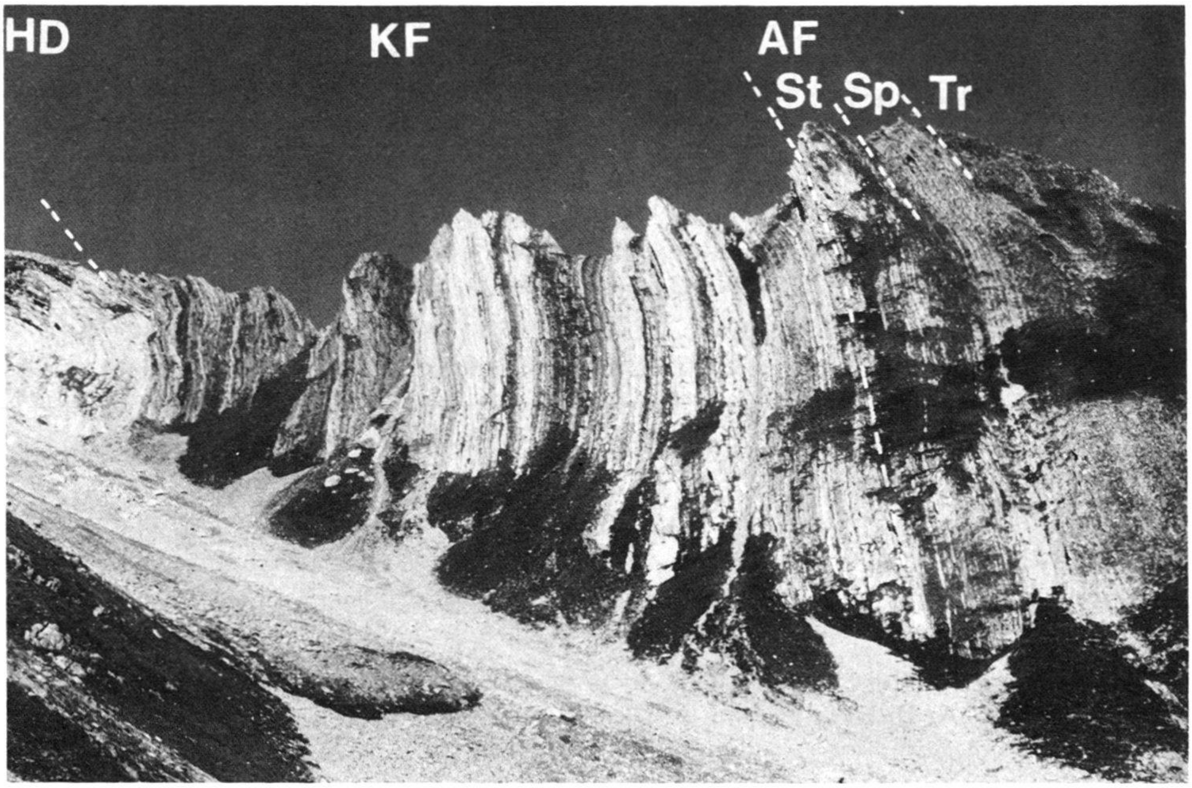


Fig. 7. The Triassic/Jurassic boundary at Fil da Stidier (eastside). The entire, Upper Triassic Kössen Formation (KF) is preserved and overlain almost concordantly by the Jurassic Allgäu Formation (AF). A thin hardground at the boundary suggests a hiatus probably representing most of the Hettangian. HD = Hauptdolomit Group, St = Stidier Limestone, Sp = Spadlatscha Limestone, Tr = Trupchun Beds. Photograph courtesy of H. Furrer.

dominated by breccias and thick-bedded turbidites of the megabreccia and the thick-bedded turbidite association. The base is formed by a nearly 30 m thick megabed consisting of a graded breccia overlain by 13 m of cherty limestone and 10 m of marly limestone (Eberli 1985a). The following thick-bedded turbidites are preferentially arranged in thinning- and fining-upward cycles (20 to 30 m). The age of the basal series is probably younger than late Sinemurian, as indicated by large belemnites in the basal breccia (Furrer 1981).

Approximately 7 km to the east (Piz Mitgel), the basal turbidites overlie a couplet of cherty limestone (Stidier Limestone) and a marl/limestone alternation (Spadlatscha Limestone). At the bottom of the Stidier Limestone, overlying a thin hardground, 1–3 m of grey crinoidal limestones of late early Sinemurian age are found (Furrer 1981). Microscopical investigations of the overlying cherty limestone (Stidier Limestone) give evidence for an originally bioclastic sand mainly composed of sponge spicules.

The Spadlatscha Limestone above is a regular alternation of grey marls and limestones representing a typical marl/limestone association. The up-to-30 m thick series has a slightly nodular appearance, abundant trace fossils and a fair amount of other fossils but no redeposited beds. Ammonites, *Echioceras* sp. and *Paltechioceras* sp. document the *raricostatum* zone of the late Sinemurian. Both, the Stidier Limestone and the Spadlatscha Limestone are thought to have been deposited on the gentle counterslope or

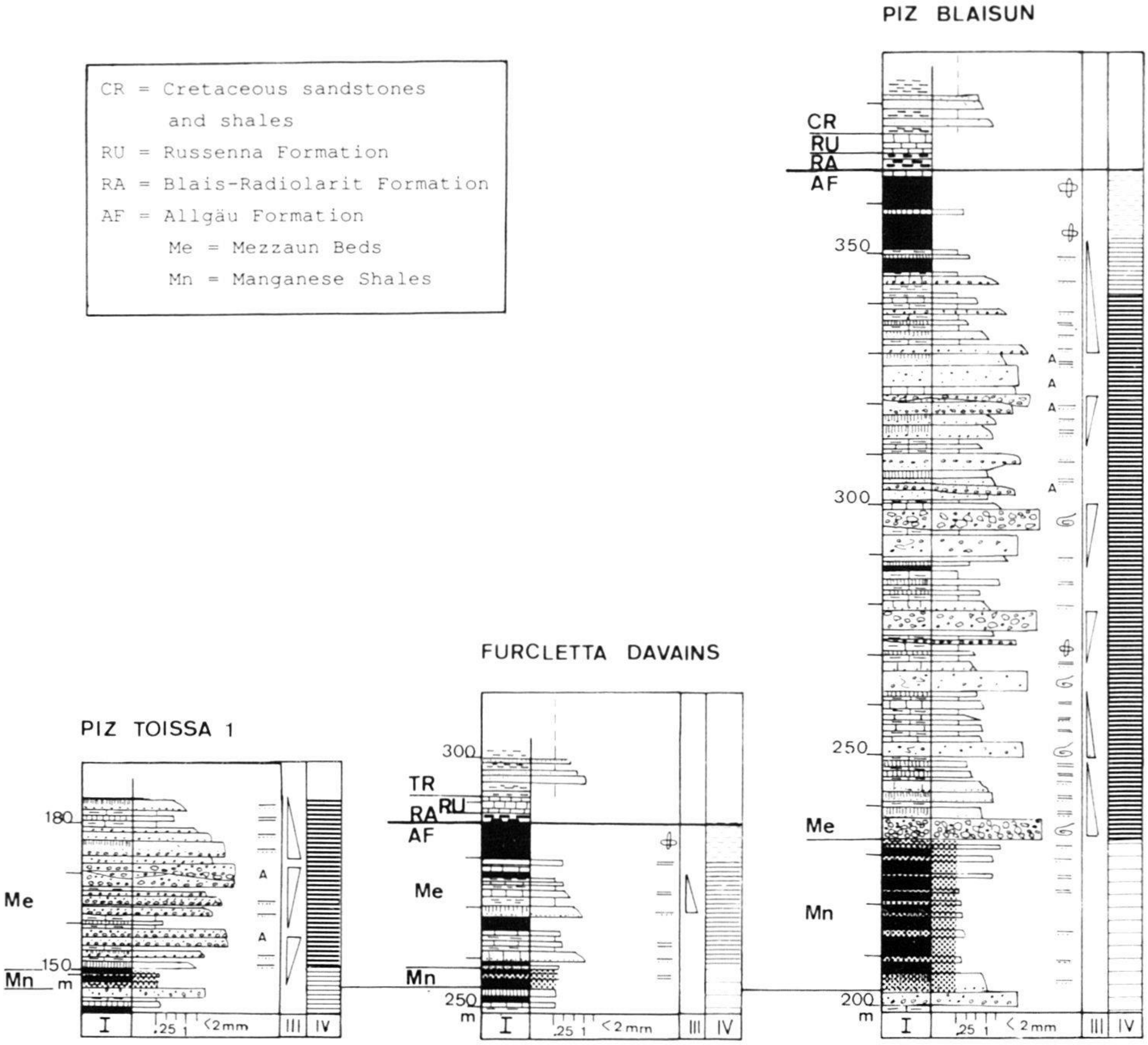


Fig. 8. Three profiles of the inferred Middle Jurassic section of the Allgäu Formation in the Ela nappe. At Piz Blaisun the whole section is preserved, whereas the top is eroded at Piz Toissa. At Furcletta Davains it may not have been deposited or is tectonically removed. Assuming that the Manganese Shales are of Toarcian and the overlying radiolarites of latest Middle Jurassic age these sequences were deposited mainly in the Middle Jurassic. Column I = lithology, II = grain-size + sedimentary structures, III = cycles, IV = facies associations (shades as in Fig. 9).

the hanging wall of a tilted block (Gibbs 1984). A sharp boundary then marks the base of the first calciturbidites. Compared to the basal turbidites at Piz Toissa, the beds are generally thinner and only a few conglomerates are interbedded. After about 50 m a monotonous thin-bedded turbidite association forms the following 250 m of the section (Fig. 9).

In the eastern part of the Ela nappe (Piz Üertsch), the Hauptdolomit is dissected by numerous fissures and brecciated at its top. 1–3 m of marly limestones drape the breccia and are followed by highly silicified calciturbidites. Although the individual beds are rather thick (1–7 m), they are fine-grained with dolomitic lithoclasts of 1–2 mm at the base of some beds. After about 60 m the bed thickness decreases and a 20 m thick thinning-upward cycle leads into a series of thin-bedded calciturbidites with more than

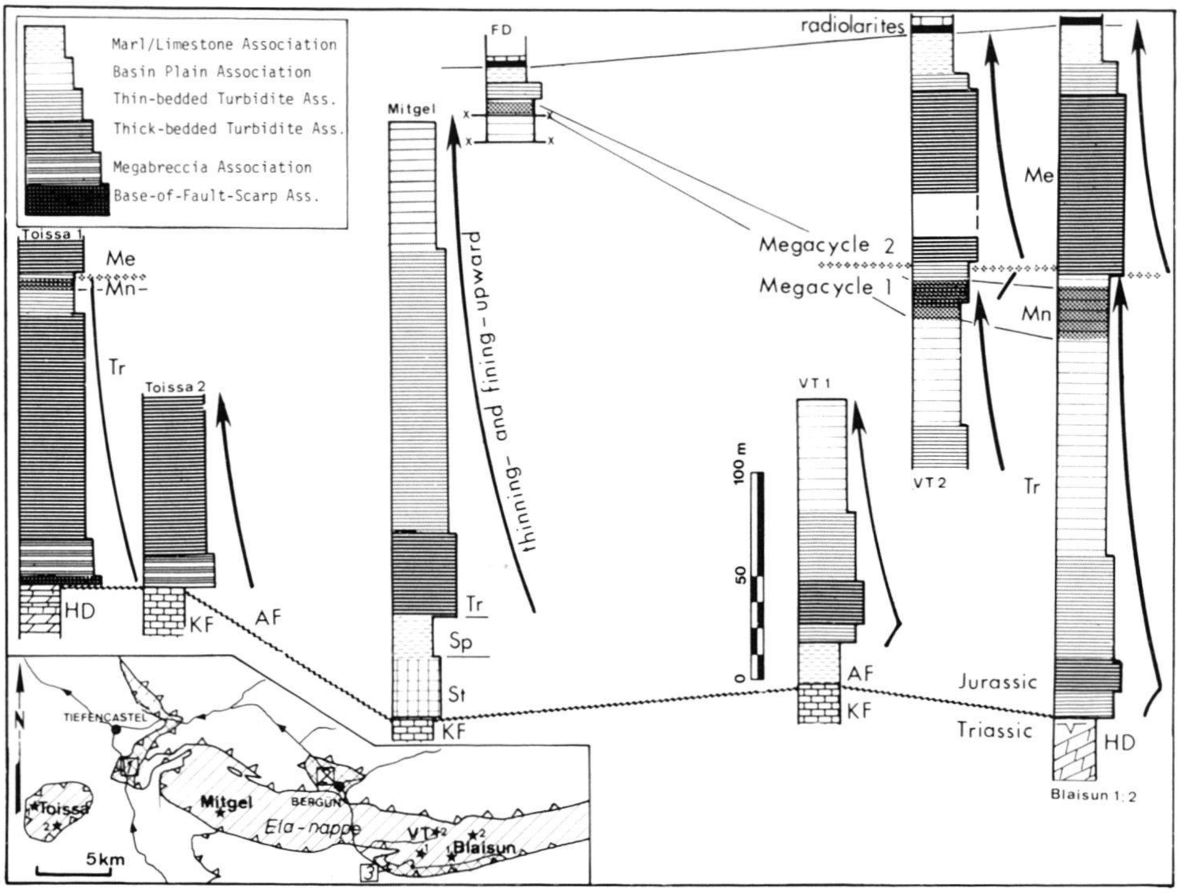


Fig. 9. Schematic sections of the basinal sediments in the main body of the Ela nappe. Note the overall thinning- and fining-upward trend and the development of the second megacycle. (1, 2, 3, in the location map indicate the three lower digitations of the Ela nappe.) (Base of Blaisun 1 is equal to Piz Üertsch section of Fig. 6.) Modified after EBERLI (1987).

30% of background sedimentation. Besides turbidites, several pebbly mudstones mainly consisting of components of the basinal sediments themselves, are observed in this 120 m of typical basin-plain association (EBERLI 1987). The base of the section is not dated; however, 50 m upsection large belemnites indicate a late Sinemurian or younger age.

Using ammonites and the size of the belemnites as a rough estimate for an age assignment, it seems that the onlap of the basal carbonate turbidites become younger from west to east, at least between Piz Toissa and the Bergüner Stöcke, indicating the progressive onlap up the counterslope of the inferred, tilted fault block.

In the Ela nappe, no biostratigraphic control for the Jurassic sediments younger than early Pliensbachian is provided. However, a series of dark, manganese-bearing shales intercalated with rusty weathering limestones can be used as a correlation horizon. The lithological characteristics of the horizon are comparable to the "Manganschiefer" in the Northern Calcareous Alps, which were dated by JAKOBSHAGEN (1965) as early Toarician. JENKYNS et al. (1985) and JENKYNS & CLAYTON (1986) interpreted similar deposits in the Southern Alps as the record of an anoxic event. In the Ela nappe, the Manganese Shales are correlated with these occurrences and taken as the Toarcian time line. At Piz Toissa and the Bergüner Stöcke, they are observed within the thin-bedded turbidite association, and, in the east at Piz Blaisun, within the basin-plain association suggesting a nearly smooth, wide basin in the early Toarcian (Fig. 8 and 9).

The Middle Jurassic sediments of the Ela nappe (main nappe)

The Manganese Shales do not only indicate a possible anoxic event but also precede a turning point in the basin evolution. In many sections just above the dark horizon, the renewed onset of coarse grained conglomerates and turbidites is observed. This second megacycle is best exposed and preserved at Piz Blaisun (Fig. 8 and 9). There, the 80 m thick-bedded turbidite association displays an overall thickening- and coarsening-upward trend until finally amalgamation of coarse (2 m thick) beds occurs (Fig. 8). This part of the section displays characteristics of a prograding turbidite system (WALKER 1975, 1978). Afterwards, the sequence shows a rapid decrease in bed thickness and 20 m upsection marls and limestones dominate. Finally radiolarites (4 m) and pelagic limestones (4 m) separate the Allgäu Formation from turbidites with abundant siliciclastic components (Fig. 8). These turbidites contain foraminifers typical of the Late Albian and Cenomanian (PÖTSCHKE 1982).

In the Bergüner Stöcke, the second megacycle seems not be developed but it could be buried by a structural feature. A series of quartz-bearing turbidites thought to represent the top of the Jurassic section ("sandige Turbiditfolge"; FURRER 1974, ROHRBACH 1977, BOLLIGER 1981) are correlated with the siliclastic turbidites of Cretaceous age from the Val Tisch–Piz Blaisun area, because an outcrop with radiolarites and pelagic limestones was found between the two turbidite sequences at Furcletta Davains (768.925/166.550).

The Jurassic sediments of the lower digitations

The syn- and antiforms of the main body of the Ela nappe partially cover three smaller tectonic slices. In all these digitations of the Ela nappe (Crap-Ses synform, Bergünerstein, Gualdauna), the top of the Triassic and the basal units of the Jurassic sediments are dominated by micritic limestones and multicolored dolomitic breccias, which are reminiscent to the Alv breccia of the Lower Austroalpine units. These basal series are then followed by calciturbidites, which might be correlated with the second megacycle of the main body of the nappe (OTT 1925, FRANK 1981, BOLLIGER 1982).

In the half-window of the Bergünerstein, small belemnites, *Nannobelus* sp. suggest a Sinemurian age for the basal laminated limestone. Within the Gualdauna slice, a multicolored breccia (Alv breccia of HEIERLI 1955) drapes the Hauptdolomit Formation and fills its cracks and fissures. The matrix-poor breccia consists at the base mainly of dolomitic components whereas upsection more and more limestones are incorporated into the component assemblage. In some places, the breccia represents the filling of neptunian dykes, in others, like at the Gualdauna itself it may be formed by a submarine rockfall (EBERLI 1985a, b). Large belemnites in the matrix suggest a late Sinemurian or younger age for this breccia. The breccia is followed by a thick-bedded turbidite association, in which after about 45 m two boulder beds are recognized.

Basin evolution and paleogeography of the Ela nappe

The distribution of the Jurassic sediments suggests that in the Ela nappe two paleotectonic units are represented: The tilted fault block of the main body with a N–S trending high in the east and a fault in the west as well a submarine high north of the tilted block.

The preservation of the underlying Triassic sections as well as the basal Jurassic sequences suggest that in the Ela nappe between Piz Üertsch and Piz Mitgel a westward-tilted fault block with its deepest part between the Piz Toissa and the Bergüner Stöcke is presented. After a long hiatus during the Hettangian and the early Sinemurian, crinoidal and spiculitic limestones were deposited in the basin. In the late Sinemurian, the earliest redeposited beds document the main phase of the first rifting event. Probably at the same time, about 8 km to the east at Fil da Stidier, the marl/limestone alternation of the Spadlatscha Limestone was deposited on the gentle counterslope or the nearly flatlying hanging-wall block not yet reached by the turbidites. However, if the Spadlatscha Limestone is not time-equivalent but older than the basal turbidites at Piz Toissa, the Spadlatscha Limestone could alternatively be interpreted as a deposit in a starved basin. As the filling of the basin proceeded, the turbidite sequences overlapped the limestone,

Fig. 10. The Jurassic fault at Monte Motto (Ortler unit). The Upper Triassic Hauptdolomit Formation (HD) terminates against the Allgäu Formation (AF) in a steep gully, which is thought to represent the fault plane. Several beds of very coarse-grained megabreccias can be recognized in the the basal part of the Allgäu Formation. The host formation consists of thin-bedded calciturbidites and bioturbated marls and limestones. The stars indicate locations of biostratigraphic control: 1 = Late Hettangian; 2 = Early Sinemurian; 3 = Latest Sinemurian–Early Pliensbachian. Note that the series are folded from approximately 150 m above the base. View to the northwest.

progressed to the east and finally covered, probably at the beginning of the Pliensbachian, the edge of the fault block at Piz Üertsch. With ongoing filling, bed thickness and frequency of the turbidites decreased indicating the decline of the first rifting phase.

Shortly after the anoxic event of the early Toarcian, thick-bedded turbidite sequences document the onset of a second rifting phase. During this phase the basin was further fragmented, probably as a result of the development of a second half-graben within the tilted block or alternatively by the development of a new fault further to the east (EBERLI 1985a). The rift-basin evolution ended with the onset of pelagic deposits of radiolarites and limestones, probably in the latest Middle Jurassic (BAUMGARTNER 1985).

In the three lower digitations of the Ela nappe the basal series of Jurassic represent deposits of a highly fragmented submarine high. From the late Sinemurian onward, these highs were also covered by carbonate turbidite sequences. Structural indications suggest that the main body of the Ela nappe was principally transported in a S–N direction over the lower digitations, which extend over approximately 25 km from the Gualdauna in the east to the Grap Ses in the west. The submarine high of the lower digitations was therefore most probably north of the Ela nappe main body. This suggests the existence of E–W trending fault system separating this high from the tilted block of the main body.

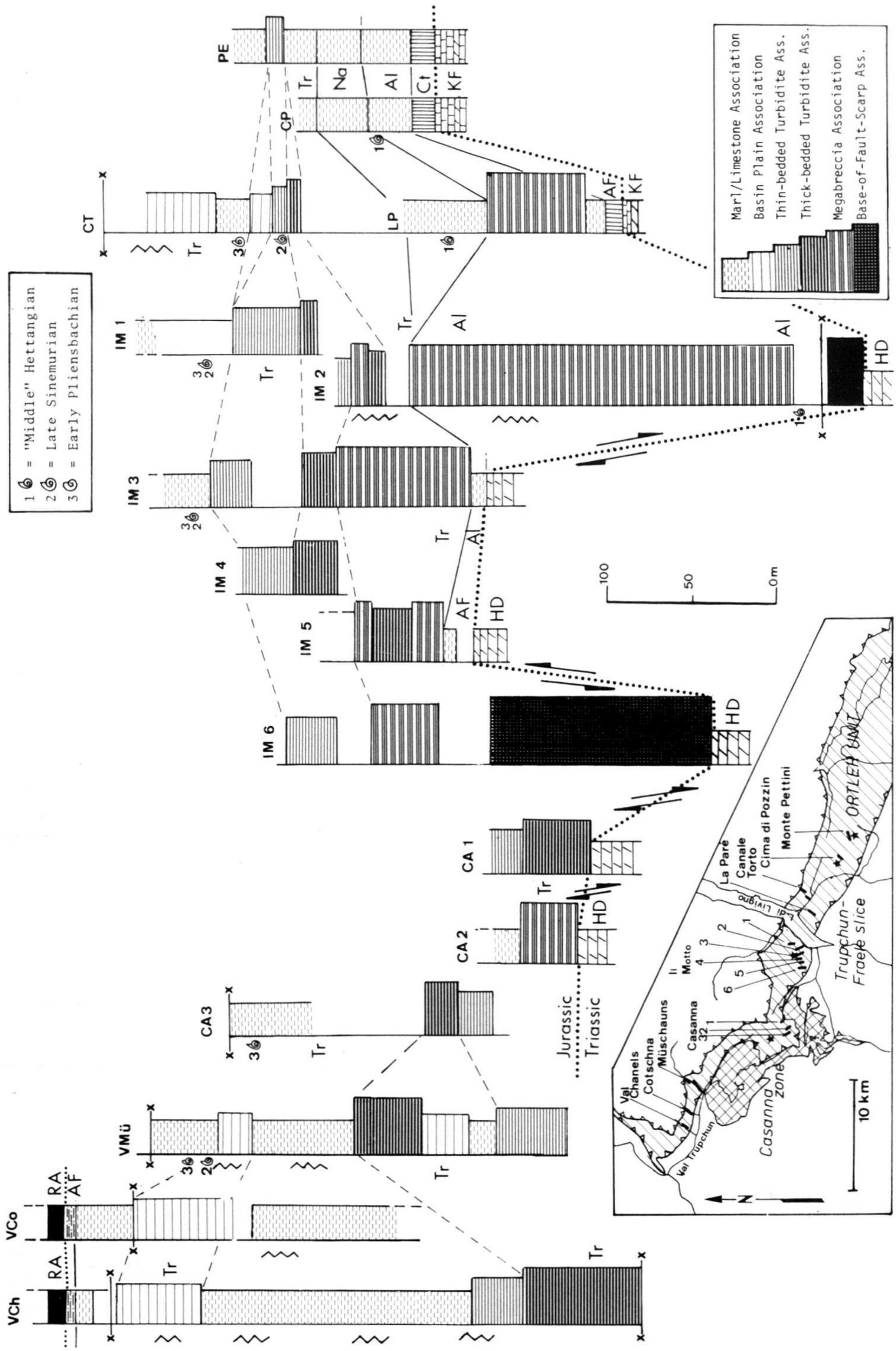
Ortler unit

Tectonic overview

The Ortler unit of the Engadine Dolomites consists of a section ranging from the crystalline basement of the Campo nappe to the Cretaceous Chanels Formation (STAUB 1937, DÖSSEGGER et al. 1982, CARON et al. 1982); the contact between basement and cover rocks is generally tectonic, but locally complete. Along the Braulio–Trupchun line the Ortler unit is overthrust by higher units of the Engadine Dolomites (SCHMID 1973). Jurassic sediments are only preserved from Lago di San Giacomo di Fraele to the west in the so-called "Fraele Zone" (HESS 1953, SOMM 1965). In contrast to most authors, STAUB (1964, p. 82) divided the "Fraele Zone" into two tectonic units. Our own investigations support Staub's division. Ammonite stratigraphy and the distribution of the facies associations suggest a tectonic repetition of the Jurassic series in the Val Trupchun. In addition, there is a significant difference in the structural style of the two sides of the valley (EBERLI 1985a, b). Therefore, the series of the Chaschaunacrest with the crystalline and Triassic slices and the overlying Jurassic Allgäu Formation are considered as a separate tectonic unit (Casanna zone), underlying the larger Trupchun–Fraele slice (see Fig. 11).

The Jurassic sediments of the Trupchun–Fraele slice

In the Ortler unit, different preservation of the underlying Triassic carbonates are found east and west of the Livigno valley. East of Livigno, the entire Kössen Formation and the lowermost Jurassic sequences are preserved (FURRER 1981). West of it, the Triassic platform carbonates are fragmented by early Jurassic tectonism and the subse-


1 = "Middle" Hettangian
2 = Late Sinemurian
3 = Early Pliensbachian
Marl/Limestone Association
Basin Plain Association
Thin-bedded Turbidite Ass.
Thick-bedded Turbidite Ass.
Megabreccia Association
Base-of-Fault-Scarp Ass.
PE
CP
CT
LP
IM 1
IM 2
IM 3
IM 4
IM 5
IM 6
CA 1
CA 2
CA3
VMü
VCo
VCh
Tr
Na
Al
Ct
KF
AF
HD
RA
Jurassic
Triassic
100
50
0m
Val Chanels
Cotschna
Müschauns
Casanna
Il Motto
La Paré
Canale Torto
Cima di Pozzin
Monte Pettini
ORTLER UNIT
Trupchun-Fraele Slice
Casanna Zone
Val Trupchun
Livigno
10 km
N

quent erosion removed in many places the entire Kössen and part of the Hauptdolomit Formation.

Along the southern side of Monte Motto, an early Jurassic fault separating a western horst from a eastern basin is exposed (Fig. 10, FURRER & EBERLI 1985). Adjacent to the fault a monomictic dolomite breccia of Alv type is followed by the Alpisella Beds; an association consisting of dark, fossil-rich partially spiculitic limestones and marls, fine-grained calciturbidites and seven megabreccia beds. The huge boulders and clasts of the up-to-30 m thick, matrix-poor megabreccias are mainly derived from the Kössen and Hauptdolomit Formations (FURRER 1981; DÖSSEGGER et al. 1982). In their prolongation to the east the Alpisella Beds document the lateral evolution of the megabreccia association displaying a decrease of redeposited beds to the east (EBERLI 1987).

In the eastern part of the Trupchun–Fraele slice, the basal series of the Allgäu Formation can be subdivided into three members (Fig. 11; FURRER 1981). The Triassic/Jurassic boundary is marked by a 10 m thick, micritic limestone bed (Culmet Limestone). The following Alpisella Beds are overlain by the fossil-poor limestones of the Naira Limestone (10–50 m). These evenly thin-bedded limestones are best developed in the east (Monte Pettini) and represent the marl/limestone facies association of the counterslope. The Alpisella Beds and the Naira Limestone are dated as "Middle" Hettangian (*Waehneroceras* sp.) and document a coeval deposition of huge catastrophic debris sheets at Monte Motto as well as debris-free sequences only 10 km to the east. Because debris flows and turbidites would easily flow this distance (LÜTHI 1978, CREVELLO & SCHLAGER 1980), it is thought that a narrow depression parallel to the fault existed and that the Monte Pettini area represents part of a hanging-wall block with a roll-over structure along the fault.

At Monte Motto, the Alpisella Beds are followed by calciturbidite sequences of the Trupchun Beds, developing from the megabreccia association. In the highly folded series, some thinning- and fining-upward cycles are recognized. After about 50 m, few calciturbidites occur, and in the series of marly limestones ammonites of late Sinemurian and earliest Pliensbachian age are found. 2 km eastward, at Canale Torto, the basal turbidites overlie the Naira Limestone. From the folded and tectonically truncated section, consisting of thin-bedded turbidites, a fairly rich ammonite fauna covering most of the Sinemurian stage is known (POZZI 1959, 1960; SCHLATTER et al., in prep.).

From Monte Motto westward, several megabreccias of younger age are found in the Allgäu Formation documenting a progressive fragmentation from the Motto to the west. At Monte Motto, west of the Liassic fault, the truncated Hauptdolomit Formation is directly overlain by a megabreccia association of early Sinemurian age (Fig. 10). On its westside, along a 200 m high fault monomictic dolomite breccias and megabreccias were deposited. Going farther westard up to the Punta Casanna, unconformities between the Hauptdolomit and the overlying megabreccia association can be observed in several

Fig. 11. Schematic sections of the Allgäu Formation in the Trupchun–Fraele slice of the Ortler unit. Note that lithostratigraphic units do not coincide with the facies associations. For example, the Alpisella Beds (Al) contain both the megabreccia (Motto) and the marl/limestone association (Pettini). HD = Hauptdolomit Group; KF = Kössen Formation; AF = Allgäu Formation; Ct = Culmet Limestone; Al = Alpisella Beds; Na = Naira Limestone; Tr = Trupchun Beds; RA = Blais-Radiolarit Formation.

outcrops. The megabreccia association is usually thinner than at Monte Motto and interfingers with the thick-bedded turbidite association. After 60 m, it is followed by thin-bedded turbidites and finally a marl/limestone alternation of early Pliensbachian age (*Uptonia* sp.). (The dolomitic cap of the Punta Casanna is a klippe of a higher tectonic unit.)

Four kilometers westward, in the Val Trupchun and the Val Müschauns, the elsewhere tectonically cut out upper boundary of the Allgäu Formation is preserved. In the Val Müschauns, the formations starts with thin-bedded silicified turbidites followed by bioturbated marls and limestones. The overlying approximately 50 m thick package of thick-bedded turbidites in a dark marly background sediment has a characteristic flysch-like appearence and can be correlated with a waterfall-forming step in the Val Cotschna. The rest of the section is dominated by bioturbated marl/limestone alternations. In the upper part of the section, above a zone where thin-bedded turbidites are more frequent, ammonites of the late Sinemurian and early Pliensbachian are found.

The transition into the radiolarite beds can best be studied in the Val Cotschna (Fig. 12). There, the last 30 m of the Allgäu Formation consist of bioturbated marls and marly limestones but 4 m underneath the radiolarites, greenish and reddish silty and sandy beds occur. The beds comprise of 10 (silty) to 50% (sandy beds) of detrital quartz, 2–5% of mica, redeposited ooids and 20–40% of biodetritus, especially calcified sponge spicules and pseudoplanctonic bivalves (*Bositra*?) (Fig. 12b). This lithological composition, especially the detrital quartz and the redeposited ooids, is exceptional in the basinal sediments of the Central Austroalpine complex but is common for late Liassic–Middle Jurassic rocks in other areas of the Alpine realm (WINTERER & BOSELLINI 1982; FELDER 1984). The siliciclastic material might be shed from the Lower Austroalpine realm, where erosion of the crystalline basement occurred probably in the Middle Jurassic (STÖCKLIN 1949, TRÜMPY 1975b, FINGER 1978). The Manganese Shales (of presumably early Toarcian age) are not found in the Ortler unit but biodetrital and siliciclastic components at the top part of the section suggest a Middle Jurassic age, which would imply a reduced sedimentation in this time interval.

The Jurassic sediments of the Casanna zone

FURRER (1981) investigated the basal units of the Chaschaunacrest and documented several small faults and accompanying breccia beds. Small belemnites near the base of the Jurassic section (beneath Pt. 2677 m) suggest an early Sinemurian age. Upsection, i.e. towards the Val Trupchun a complete thinning- and fining-upward megacycle is developed ending with bioturbated marls and limestones of Pliensbachian age (EBERLI 1987). Within the components of the thickest and youngest (Pliensbachian) megabreccia (50 m) a reworked early Jurassic hardground gives indication of the erosion of a former submarine high.

Noteworthy is the basal contact of the Allgäu Formation with the underlying units. At the Chaschaunacrest the Jurassic sediments overlie unconformably the Upper Triassic sections in which small, near-vertical faults can be observed, but southward the Allgäu Formation terminates against the whole Triassic and Permian series and the crystalline basement along a flat-lying plane (STEIGER 1962, VROLIJK, unpubl. data). It is speculated that this basal contact represents the deeper portion of a Jurassic fault.

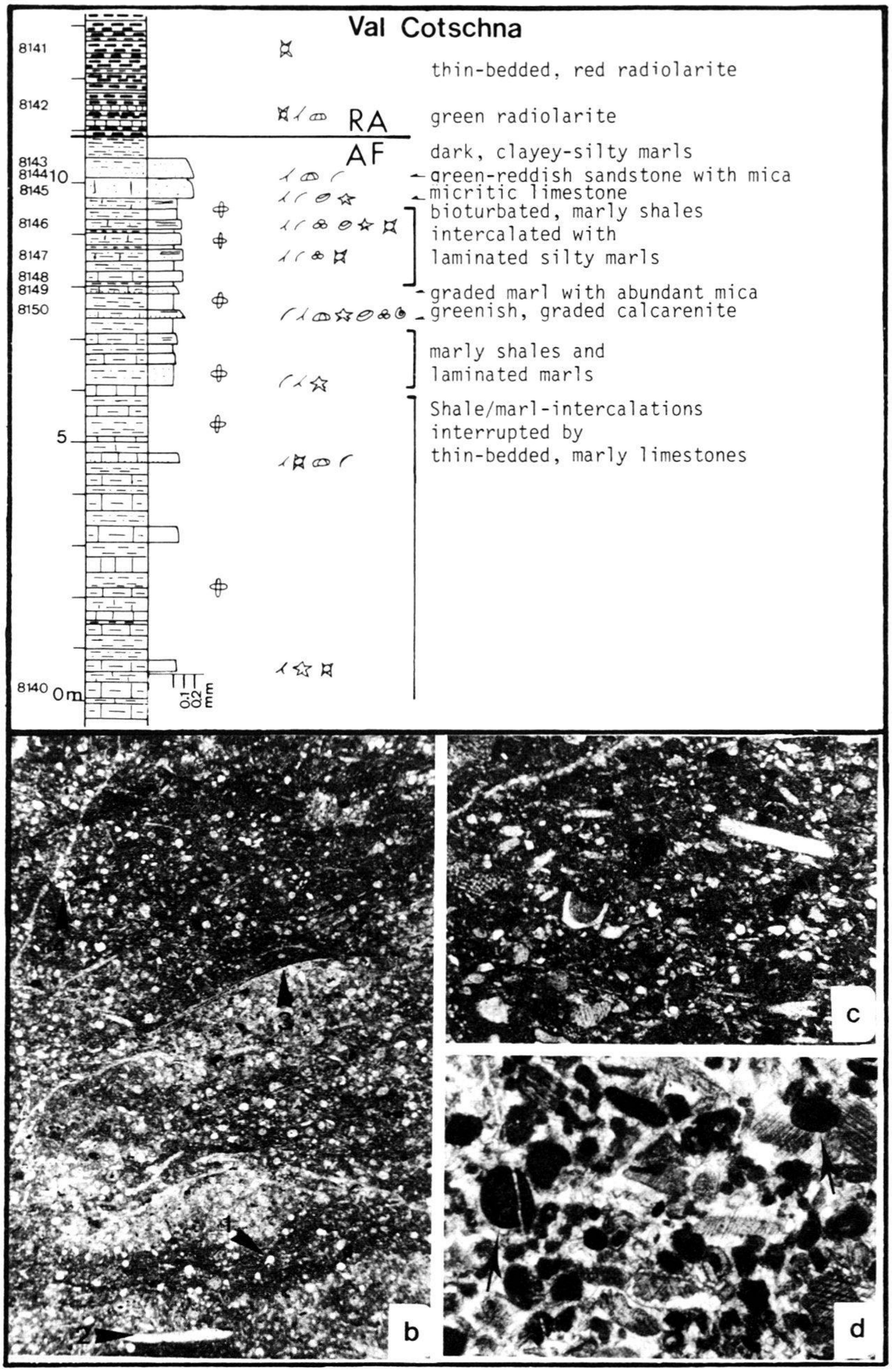


Fig. 12. The upper boundary of the Allgäu Formation in the Ortler unit. a: Lithological description. The fossils are microscopically determined. RA = Blais-Radiolarit Formation; AF = Allgäu Formation. (Numbers to the left are sample numbers.) b: Thin section of sample 8146: Biomicritic limestone with pseudoplanktonic bivalves (*Bositra* sp.?). 1 = radiolaria, 2 = sponge spicule, 3 = pseudoplanktonic bivalve, 4 = detrital quartz (5%). c and d: Thin sections of graded, biodetrital limestone (sample 8150); c = laminated top with abundant echinoderm skeletal debris, sponge spicules, benthic foraminifers, radiolarians and a pyritized, embryonic ammonite chamber. d = graded bottom part with echinoderm skeletal debris and ooids.

Basin evolution and paleogeography

The most characteristic feature of the rift basin in the Ortler unit is the progressive fragmentation from Monte Motte towards the west, resulting in the development of a series of relatively small faults. The fault movements start in the Hettangian at Monte Motto. The fault as well as the distribution of the basal Jurassic sediments indicate the downthrow of the eastern part and the evolution of an asymmetric approximately N–S trending basin. As indicated by the repetition of megabreccias, during the Sinemurian the fragmentation proceeded stepwise to the west, creating new faults and a wider basin as the older relief, such as the horst of Monte Motto, was buried. Towards the end of the Sinemurian rifting declined and in most sections bioturbated marls and limestones are found. Only in the tectonic unit of the Chaschaunacrest does a megabreccia give a record of faulting in the Pliensbachian. The westward-younging fault system of the Ortler unit shows many characteristics described for a listric fan (GIBBS 1984). Listric fans develop over a relatively flat sole fault as extension proceeds. If the flat-lying basal contact of the Allgäu Formation along the Chaschaunacrest is the expression of a Jurassic fault, it could be the corresponding sole fault to the smaller normal faults at the Chaschaunacrest.

The lack of biostratigraphic data does not allow definitive conclusions about the Middle Jurassic history of the basin, but there is evidence that in the Middle Jurassic the whole Ortler unit was an area of slow sedimentation similar to deeper parts of the Generoso and the Monto Nudo basin in the Southern Alps (BERNOULLI 1964, KÄLIN & TRÜMPY 1977).

Arosa Dolomites

Tectonic overview

The Arosa Dolomites are a cover nappe of Upper Triassic and Lower Jurassic sediments. It is overthrust by the Silvretta nappe and, at its western end, is in a similar tectonic position as the Ela nappe. However, facies differences in the Upper Triassic and in the Jurassic sediments give evidence for a different paleogeographic origin of the two nappes (BRAUCHLI 1924; BAUMGARTNER 1974; FURRER 1981). The internal tectonic style is characterized by the superposition of different slices (CADISCH et al., 1919; BAUMGARTNER 1974). However, the Jurassic sediments, when preserved, display a very uniform development, suggesting that all the imbricates can be considered as derived from one paleogeographic unit.

The Jurassic sediments

The Jurassic sediments of the Arosa Dolomites overlie conformably the Kössen Formation and are characterized by the lack of an any redeposited sequences related to the Jurassic rifting.

The Ramoz Member of the Kössen Formation is overlain by the Schattwald Beds, a 6–10 m thick series of brown siliciclastic siltstones and olive marls interpreted as shallow

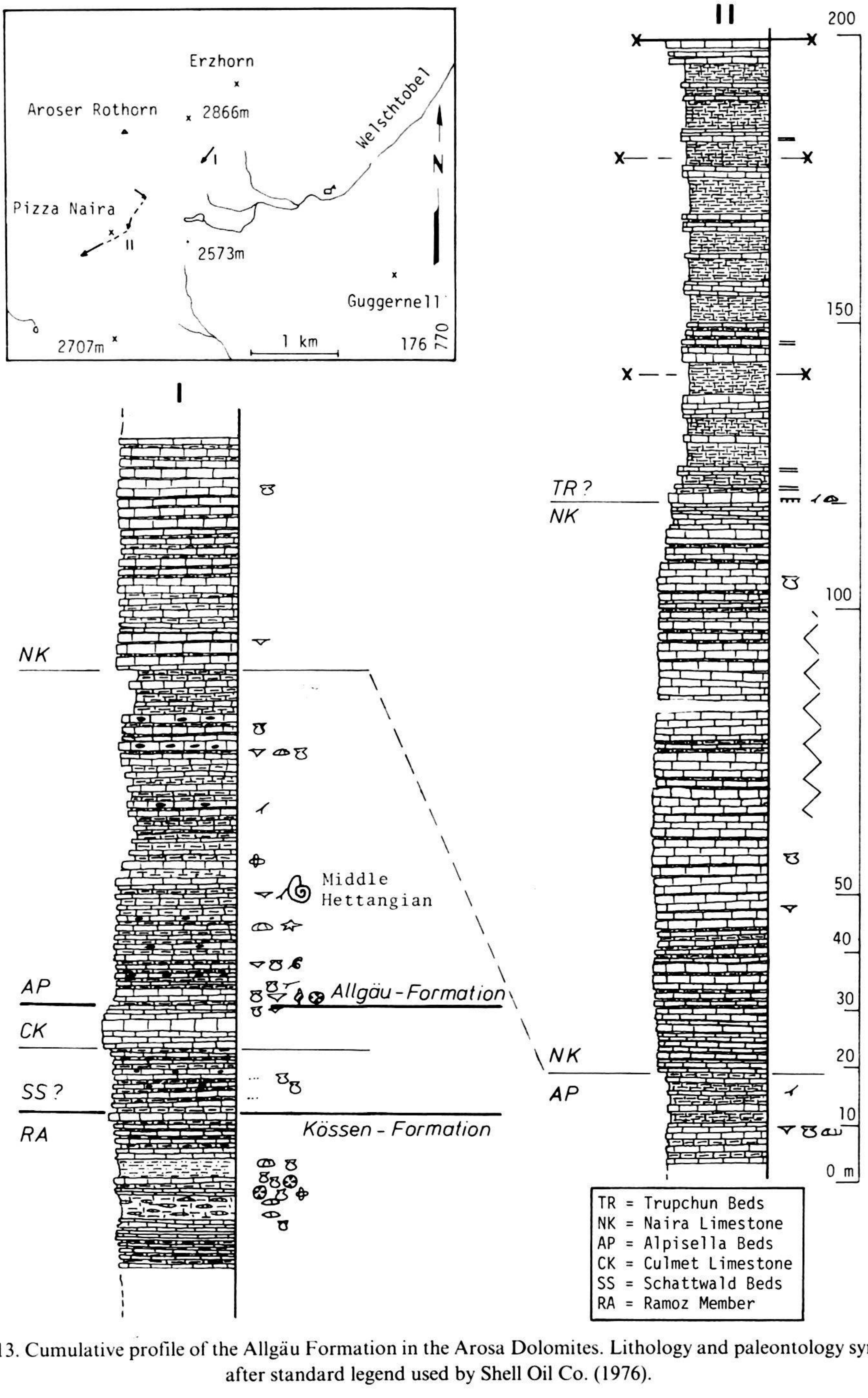


Fig. 13. Cumulative profile of the Allgäu Formation in the Arosa Dolomites. Lithology and paleontology symbols after standard legend used by Shell Oil Co. (1976).

marine deposits (Furrer 1981). Above the Schattwald Beds, the section is similar to that found at the eastern end of the Ortler unit. Approximately 7 m of Culmet Limestone form a distinct marker bed at the base of the Alpisella Beds (Fig. 13). In the latter, atypical, reddish brown marls are intercalated in the usually dark, fossil-rich marls and limestones. The age of the about 60 m thick sequence is, similar as in the Ortler unit, "Middle" Hettangian as determined by ammonites. Upsection follow the thin-bedded limestones of the Naira Limestone. At the Piz Naira, the regularly bedded and folded series is at least 100 m thick. Above a sharp boundary, marls and shales set in, which are reminiscent to the dark marly background sediments within the Trupchun Beds of the Ortler unit. At the base of the marls one graded bed of 0.3 m thickness and another one 20 m higher are found (Baumgartner 1974). Otherwise the highly tectonized marls are only interrupted by some thin-bedded micritic limestones. The undated series is tectonically truncated at the top.

Basin evolution and paleogeography

At the Rhaetian/Liassic boundary, the Schattwald Beds were deposited in a shallow marine environment. The Culmet Limestone marks the change to a deeper-water environment suggesting subsidence below the high-energy level in the early Hettangian(?). The increased fossil content within the Alpisella Beds documents favorable conditions in the "Middle" Hettangian. The marl/limestone alternation of the Naira Limestone with the rare turbidite intercalations were deposited in an area not influenced by mass gravity flows. A flat submarine high or a sheltered basin could provide such an environment. Within the overlying brown marls the lack of fossils and bioturbation indicate oxygen-poor conditions as expected in a basin with stagnant water masses.

The similar evolution of the basal Jurassic sediments suggests a close spatial relationship between the Arosa Dolomites and the eastern part of the Ortler unit (Furrer 1981).

The Bernina nappe in the Val Chamuera

Tectonic overview

In the Val Chamuera, sediments and relics of crystalline basement of the Bernina nappe are exposed in a half-window below the Languard nappe (Roesli 1927). Schüpbach (1976) distinguished 8 thrust slices within the window. Furger (1985) has revised this complicated internal structure. Schüpbach divided the Middle Mezzaun Element (Roesli 1927) into the Stevel and Medras slice based on the occurrence of Sinemurian ammonites above large (Pliensbachian or younger) belemnites suggesting a tectonic repetition. My own investigations strongly suggest that a separation between the two slices does not exist, but that the ammonites are reworked and that consequently a continuous section from the Hauptdolomit at Stevel to the Cretaceous marls at the Mezzaun crest is preserved (Eberli 1985a).

The Jurassic sediments in the Val Chamuera

The Jurassic sediments in the Val Chamuera are developed in various facies. At the entrance of the valley (Lower Mezzaun Element) in dispersed outcrops, three facies types

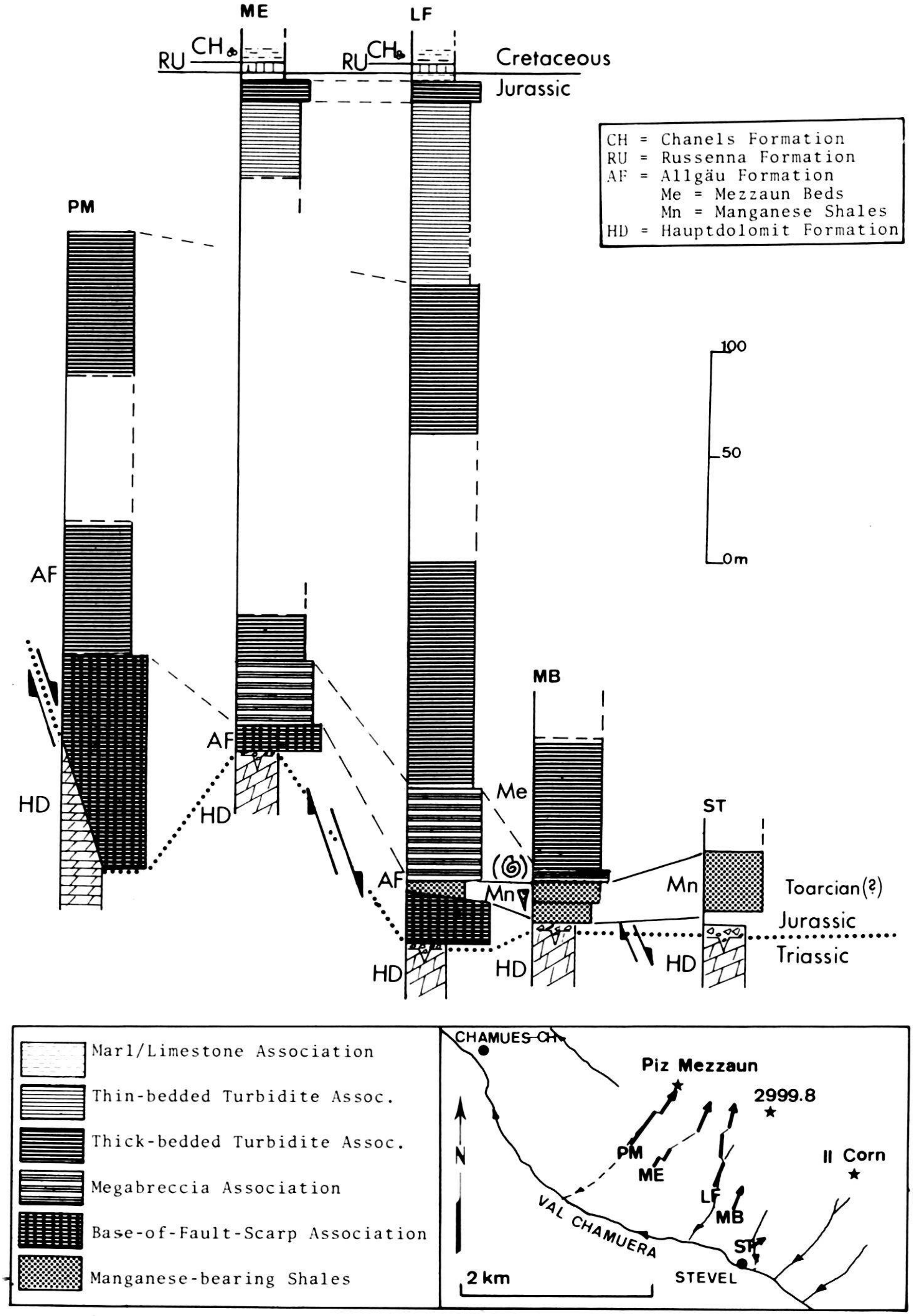


Fig. 14. Schematic sections of the Allgäu Formation at Piz Mezzaun (Bernina nappe). The Mezzaun Beds overlying the Manganese Shales of Toarcian(?) age were deposited mainly during the Middle Jurassic.

are found. 1. a series of multicolored breccias, partially of Alv type, interbedded with micritic and crinoidal limestones, 2. a reddish, crinoidal limestone of Hierlatz type and 3. a nodular limestone of Adnet type. Large belemnites and poorly preserved ammonites indicate that the nodular limestones are probably not older than Pliensbachian.

In many sections (Medras, Val Lavirun, overturned series of Upper Mezzaun Element), a breccia of Alv type consisting of angular mostly dolomitic clasts in a yellow to red matrix drapes the truncated Hauptdolomit Formation and fills fissures within the dolomite. The breccia and both the crinoidal and the nodular limestones are interpreted as submarine high deposits.

In the Middle Mezzaun Element (ROESLI 1927), a Jurassic fault escarpment and the adjacent basinal sediments are preserved (Fig. 14). The escarpment cuts approximately N–S through the Piz Mezzaun and consists of a series of three parallel faults. Along the faults, the Hauptdolomit Formation is disintegrated and brecciated as documented by a grey, 100 m thick momomictic breccia in the upper Seguond Laviner (Fig. 15a).

At Stevel da la Bes-cha, the basinal sequences start with a series of dark shales with interbedded rusty weathering turbidites and conglomerates (Manganese Shales), in which large belemnites suggest a late Sinemurian or younger age. Above follow the calciturbidites of the Mezzaun Beds (Fig. 14). Within the basal conglomerate of the turbidite sequence, several ammonites (*Paracoroniceras* sp. and *Arietites* sp.) and nautilids were found.

In the Laviner da Fontaina Naira, the Manganese Shales pinch out between two megabreccias (Fig. 15b). The overlying megabreccia consists of large components of the Hauptdolomit and partially huge intact packages of the Kössen Formation. ROESLI (1927) and STAUB (1946) considered the latter as in place. The megabreccia is overlain by thick-bedded turbidites. Multigradation and dispersed larger lithoclasts within the beds with abundant echinoderm skeletal debris indicate amalgamation of high-density turbidity currents and grain flow deposits in the vicinity of the fault. Gradually, the turbidites become finer-grained and the beds are separated by bioturbated marls. Locally well-preserved burrows of *Zoophycus* are found in the latter. Towards Pt. 2963 m the turbidite sequence displays as thinning- and fining-upward trend. But near the very top, two conglomerates and four thick-bedded turbidites in between occur (Doggerbreccien of ROESLI 1927). The second conglomerate is overlain by a 3 m of marls and limestones and followed by 2 m of micritic, light grey limestone (Aptychus Limestone). Radiolarite seems not to have been deposited, but chert nodules rich in radiolarians occur in silty marls above the Aptychus Limestone. These marls are dated by foraminifers as Early Cretaceous to earliest Turonian (SCHINDLER 1987).

Basin evolution and paleogeography

The evaluation of the basin evolution of the Bernina nappe in the Val Chamuera is largely dependent on the interpretation of the ammonite occurrence at the base of the Mezzaun Beds. Here, the ammonites in the basal conglomerate are considered as reworked and an essentially Middle Jurassic age is proposed for the turbidite series. The following consideration supports this interpretation. If the Mezzaun Beds within an

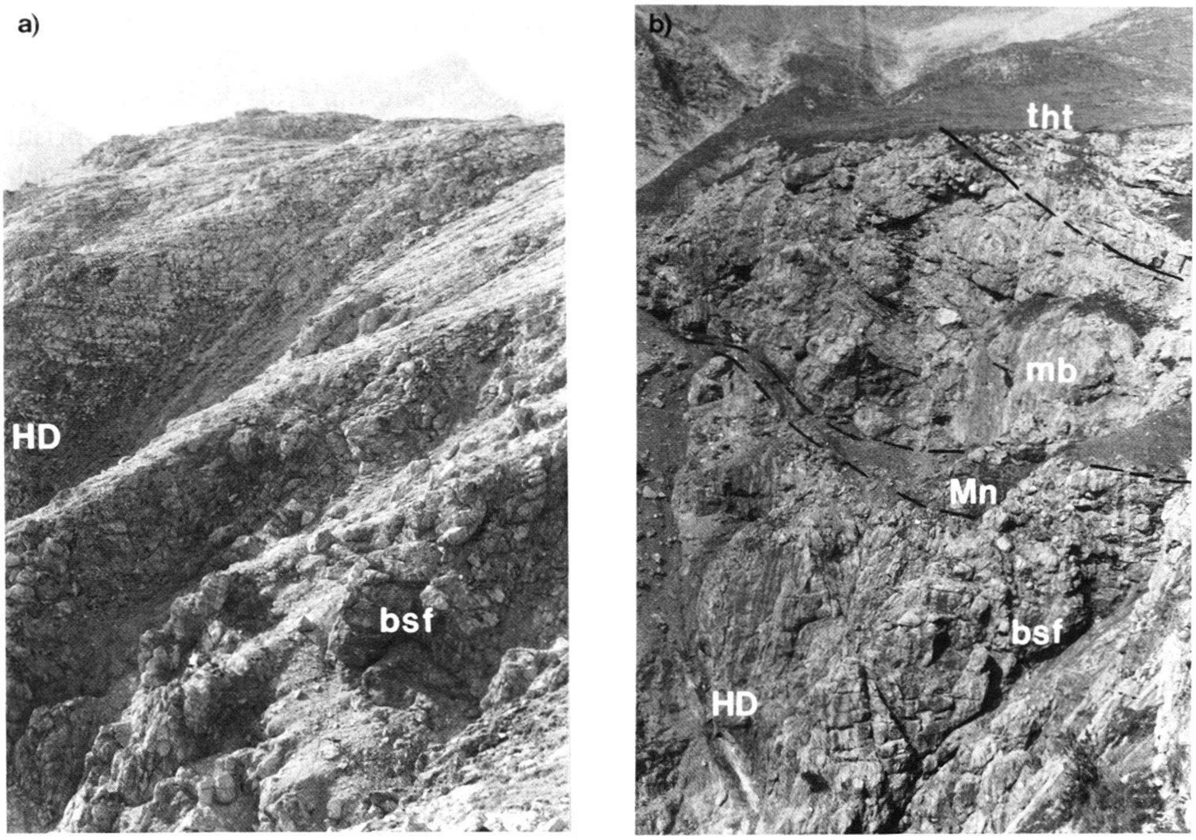


Fig. 15. a) The contact between horizontally bedded shallow-water carbonates of the Hauptdolomit Formation (HD) and the chaotic monomictic dolomite breccia (bsf) of the base-of-fault-scarp association. The fault runs through the steep gully (Section PM). b) The base of the Jurassic section in Laviner de la Fontaina Naira (LF Fig. 14). Note how the Manganese Shales (Mn) pinch out between the base-of-fault-scarp breccia (bsf) and the basal megabreccia (ca. 40 m thick) of the carbonate turbidite sequence. tht = thick-bedded turbidite association. In both pictures the view is to the NNE. Val Chamuera, Bernina nappe.

independent Medras slice (Schüpbach 1976) would represent a complete section of the early Sinemurian to the latest Jurassic, the Manganese Shales of presumably early Toarcian age, which are well developed in the underlying Stevel slice (Schüpbach 1976), should also be found in the upper turbidite section (Medras slice). A less likely alternative would be that two basins, one affected by an anoxic event and the other not, would have existed in the Bernina nappe.

Assuming a Middle Jurassic age for the Mezzaun Beds, the following basin evolution is reconstructed. During the early Jurassic, a first differentiation of the area into a highly fragmented submarine high occurred. During the early Toarcian, when anoxic conditions prevailed, turbidites heralded the rifting event. Immediately after this anoxic event major fault movements created an approximately N–S trending basin. The basin became filled by as complete thinning- and fining-upward megacycle. Coarser beds near the top indicate late tectonic movements and another phase of redeposition late in the Middle Jurassic.

Paleogeography of the study area

The analysis of the Jurassic sediments in four tectonic units of the Eastern Alps revealed that despite Alpine tectonism enough elements of the Jurassic sedimentary prism are preserved to allow a basin analysis and paleogeographic reconstruction for each tectonic unit. More difficult is the reconstruction of the relative position of each unit on the Jurassic continental margin. Two lines of evidence, the comparison of the basin evolution and the regional tectonic position were used for this.

Comparative basin analysis and rifting history

The comparison of the basin evolution shows that each tectonic unit has its own history. A similar development of the Jurassic sequences exists only in the Arosa Dolomites and the eastern end of the Ortler unit (FURRER 1981). The differences in the basin evolution of the other units are documented by the diachronous onset of the redeposition cycles (Fig. 16). In addition, these cycles are taken as indicators for different rifting events and reflect a sort of a rifting timetable in the Austroalpine units. The Jurassic rifting took place in two major phases, a first one in the Early Jurassic and a second one at the beginning of the Middle Jurassic.

The oldest Jurassic basinal sediments, dated as Hettangian, are found at Monte Motto in the Ortler unit. Several megabreccias farther westward indicate the ongoing fragmentation of the Ortler unit during the Sinemurian. Series free of redeposited intervals document the decline of this rifting phase in the latest Sinemurian and the early Pliensbachian. At the same time rifting related sedimentation started in the Ela nappe producing a first megacycle of redeposited beds (Fig. 16). Resedimentation declined towards the Toarcian, but after an anoxic event in the early Toarcian, the onset of a second megacycle indicates a second rifting phase. This second rifting phase seems not to be recorded in the Ortler unit. It is, however, coeval with the carbonate turbidite sequences in the Lower Austroalpine Bernina nappe in the Val Chamuera, if we accept the above-mentioned dating of the latter. Similar age assignments were also given for the turbidite sequences in the Lower Austroalpine units of the Zone of Samedan (FINGER 1978). The Jurassic sediments of the Ela nappe are therefore not correlated with those of the Ortler unit, but their characteristic two megacycles recording both rifting phases suggest a paleogeographic position of the Ela nappe in the vicinity of the Lower Austroalpine (Bernina nappe), as northernmost respectively westernmost Central Austroalpine unit.

Tectonic indications

Information about relative movements of the nappes from their original location is provided by the internal structure of the tectonic units and their position in the nappe edifice. It is a general consensus that the Lower Austroalpine units represent the distal part of the continental margin. The Ela nappe is today the westernmost Central Austroalpine unit north of the Engadine line and, in a first assumption, a candidate for a paleogeographic neighbour to the Lower Austroalpine. The folds in the Ela nappe indicate a northward transport during the Alpine deformation and a location probably south or southeast of the Bernina nappe (HEIERLI 1955). The question is, which crystalline complex formed the basement of the sedimentary Ela nappe? One possibility is the Languard nappe, the westernmost unit of the Central Austroalpine complex south of the Engadine Line, which is connected with the Bernina nappe (Stretta digitation) in the syncline of the Sassalbo (ZEHNDER 1974). The evolution of the Jurassic sediments does at least not exclude this possibility. In the Ortler unit the structures suggest one or more phases of thrusting of the nappe towards the west (SOMM 1965; SCHMID 1973). Therefore, assuming the Ela nappe as derived from the Languard unit, the Ortler unit would have lain east of it.

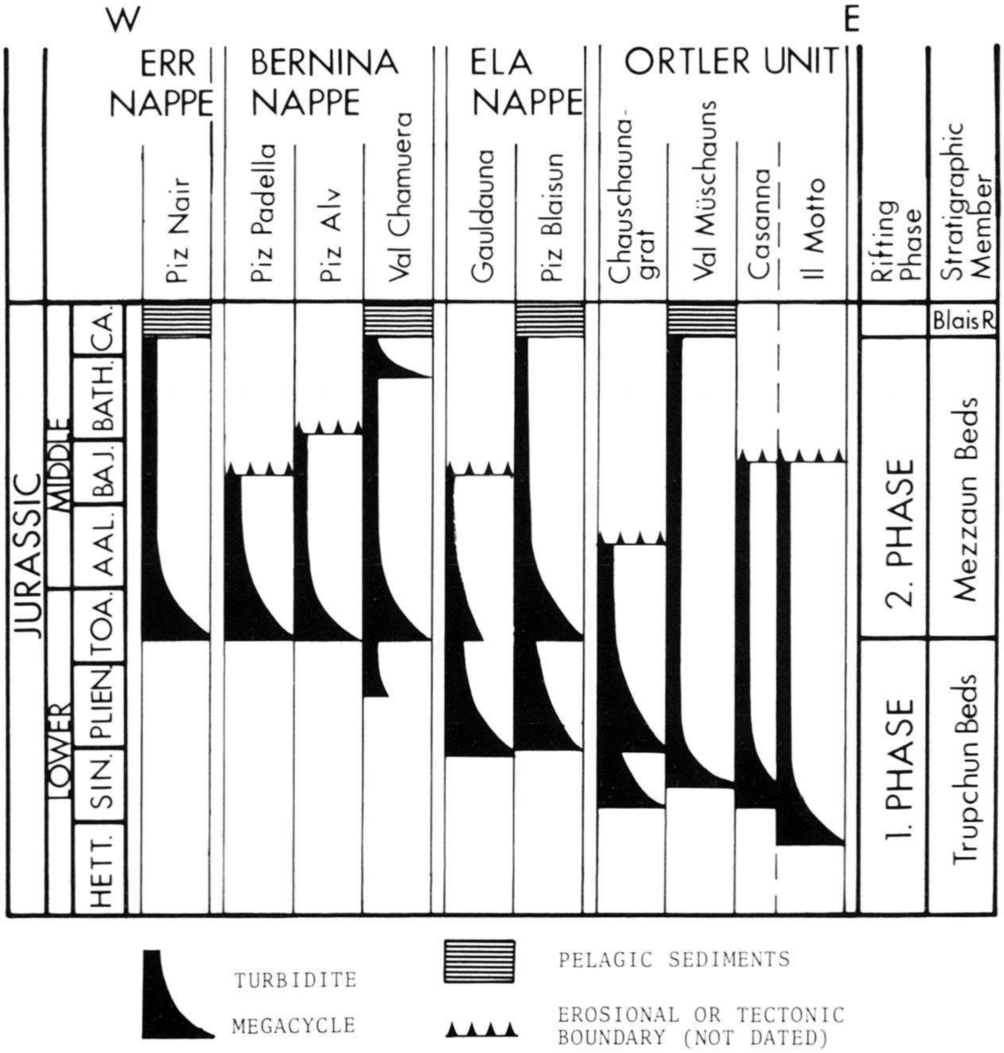


Fig. 16. The onset of the turbidite sedimentation in the Austroalpine units indicates two distinct rifting phases. The first started in the Hettangian in the Ortler unit and continued progressively from east to west until the Pliensbachian. The second phase started in the late Toarcian but the lack of biostratigraphic control in the Middle Jurassic inhibits the recognition of a possible diachronous succession. Data for Err nappe after FINGER (1978).

The interpreted paleogeography

The envisaged Jurassic paleogeography is given in Figure 17. A generally E–W arrangement of the depositional areas of the Ortler–Ela (Languard)–Bernina nappe seems tectonically possible and also fits the distribution of the Jurassic sediments. An original position of the Arosa Dolomites north of the eastern end of the Ortler unit is based on the similarities of the Upper Triassic and the Jurassic sediments.

The interpreted paleogeography implies three approximately N–S trending basins in the study area. Faults are recognized along the western side of the basins, dipping towards the east i.e. towards the continent. The distribution of the basin fills suggests asymmetric basins with their deepest depression to the west close to the faults, a geometry indicative for tilting of the fault blocks. Between the Ela nappe and its lower digitations an east/west trending fault is inferred. The paleogeographic reconstruction places the oldest faults in the more proximal part of the continental margin (Ortler unit) and the youngest in the more external part (Bernina nappe).

Comparisons

In a palinspastic cross-section through the Eastern Alps of Switzerland, the more distal part of the continental margin would be formed by the Julier–Bernina nappe s.l. and the Err nappe (Fig. 18). FINGER (1978) studied the Jurassic sediments and reconstructed the paleogeography of these two units in the Zone of Samedan. The Jurassic sections of the tectonic slices considered as parts of the Julier–Bernina nappe s.l. are characterized by a basal breccia (Alv breccia) overlain by carbonate turbidite sequences and intercalated megabreccias. At Piz Padella, these sequences display a 100 m thick megabreccia association. Their exclusive carbonate clasts suggest a lithostratigraphic correlation of the "Padella Serie" with the Mezzaun Beds. This clast composition also implies that in the eastern part of the Julier–Bernina nappe, the Jurassic fault displacements did not, similarly to the study area, expose the basement.

The Err and the western Bernina nappe, paleogeographically farther oceanward, however, bear components of crystalline basement rocks in the Jurassic redeposited beds. It seems, that all conglomerates and breccias comprising components of eroded crystalline basement are of Middle Jurassic age (STÖCKLIN 1949, TRÜMPY 1975b, FINGER 1978). In the Zone of Samedan two troughs (Saluver and Bardella) are distinguished. In both, bottom marks indicate transport of the sediments mainly from east and south and the thickest sediment accumulation at the eastern side of the basins (FINGER 1978). This basin geometry is contrary to that found in the nappes of the Central Austroalpine complex where thickest sediment accumulation occurred at the western side of the basins. This suggests that in the present-day western Bernina nappe and the Err nappe the main faults were dipping oceanward (Fig. 18). Biostratigraphic control indicates that these faults formed during the second phase of rifting during the Middle Jurassic. A Middle Jurassic age is also suggested for most of the breccia and turbidite sequences in the outermost part of the continental margin, the present-day Carungas nappe (STÖCKLIN 1949, EBERLI 1980).

The transition from the Ortler unit eastward i.e. away from the future ocean is more equivocal, because of scarce preservation of the Jurassic sediments and tectonic uncer-

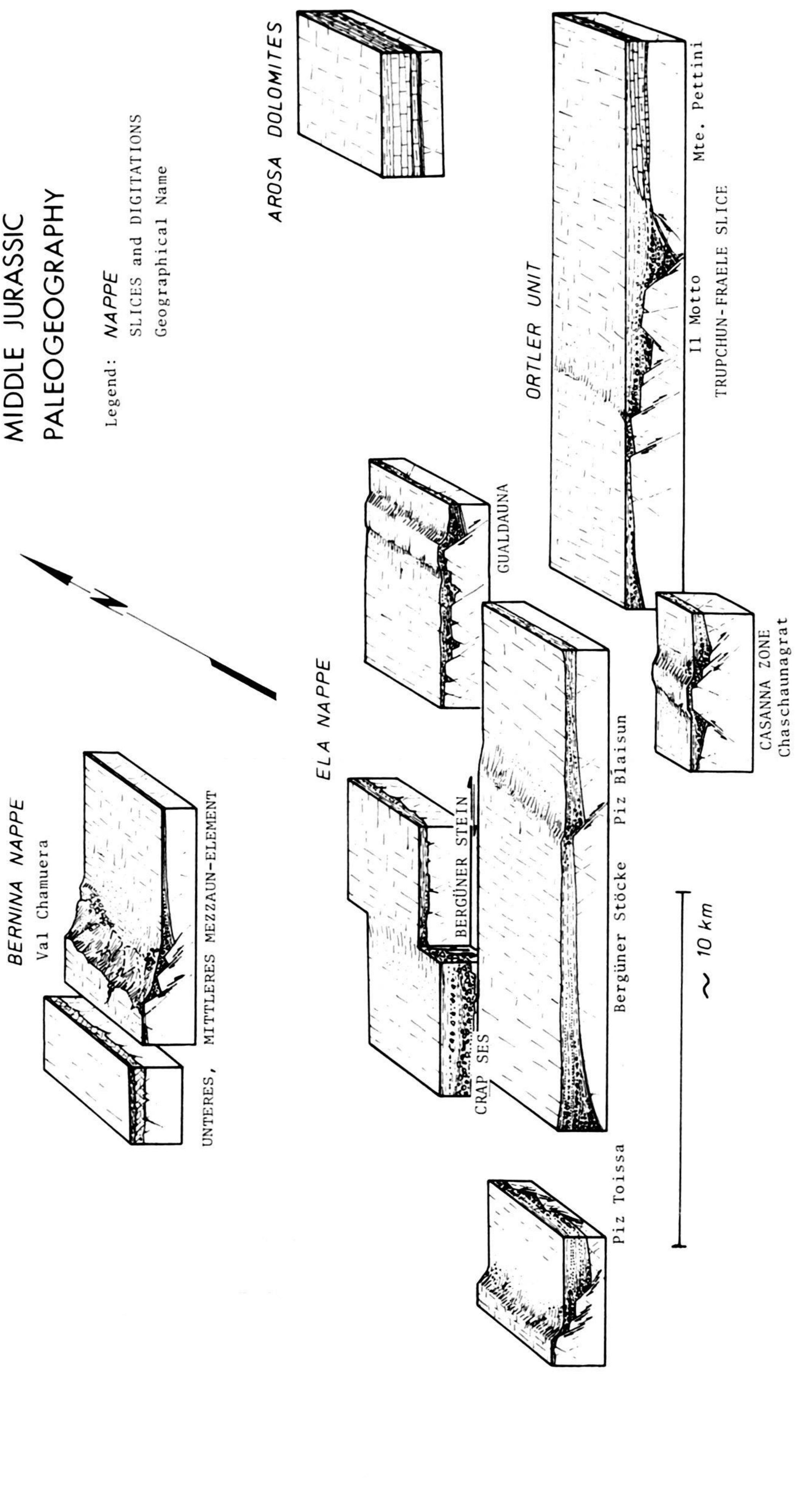


Fig. 17. Middle Jurassic paleogeographic positions of the investigated tectonic units in the Austroalpine units of Graubünden. Note that in the eastern units the Lower Jurassic relief is already buried.

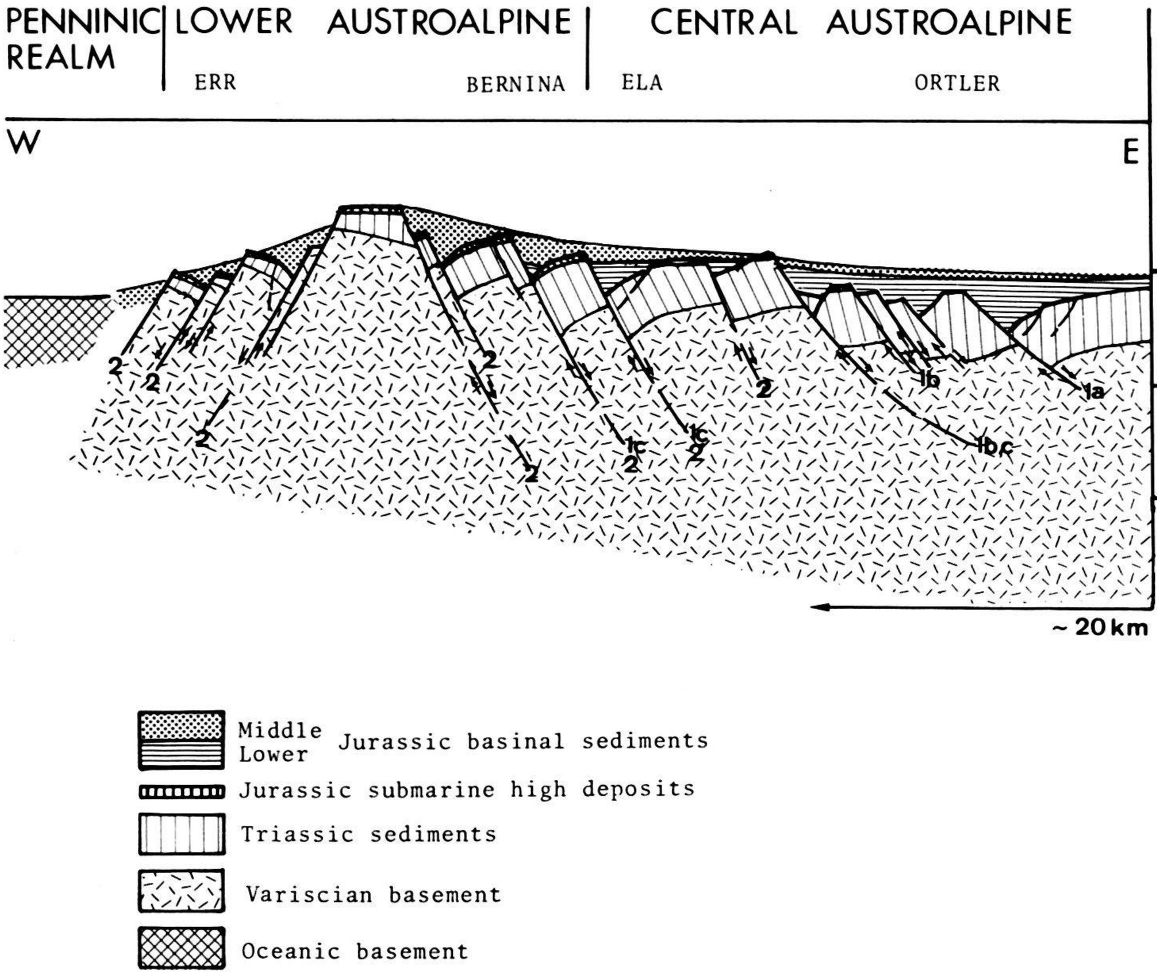


Fig. 18. The Austroalpine cross section of the southern continental margin of the Jurassic Tethys Ocean. Note the dip of the faults towards the continent (in the Central Austroalpine units and the Bernina nappe of the Lower Austroalpine) and the progressive fragmentation oceanwards. Inferred fault movements: 1a = Hettangian, 1b = Sinemurian, 1c = Early Pliensbachian, 2 = Post early Toarcian.

tainties. East of the Ortler unit in the Engadine Dolomites, Jurassic sediments are preserved only in the S-charl unit between Piz Lischana and the Schlinig thrust. They overlie unconformably the Hauptdolomit Formation and are dominated by two generations of breccias indicating again two distinct phases of rifting (Bally et al. 1981; Stutz & Walter 1983; Mader 1987). Crystalline components document the erosion of basement, but fault direction and the paleogeographical position with respect to my study area are uncertain.

The Northern Calcareous Alps might have originated somewhere east of the study area and probably represent a more proximal part of the continental margin. The Jurassic sediments of its westernmost unit, the western Lechtal nappe differ significantly from those of the Central Austroalpine complex (Jakobshagen 1965; Eberli 1985). There, shallow-water conditions persisted locally into the Hettangian. The following basinal sediments comprise much less calciturbidites than the Allgäu Formation in the Central Austroalpine. In the Toarcian the area of the western Lechtal nappe is characterized by reduced sedimentation with accompanying deposition of nodular limestones indicating the evolution into a submarine high or the beginning starvation of the basin. However, the first tectonic disintegration and subsidence into deep water occurred, similar to the areas of the Ela and Ortler nappe, in the Sinemurian and Pliensbachian (FURRER 1981; EBERLI 1985a).

In the Allgäu, the type area of the formation, the Jurassic sediments consist of a thick (1500 m) sequence of mainly bioturbated marls and limestones. In this basinal sequence a series of dark, Manganese-bearing shales (Manganschiefer) of early Toarcian age separate a lower calcerous member from an upper calcerous member (JAKOBSHAGEN 1965), indicating a similar basin evolution as in parts of the Central Austroalpine complex, especially the Ela nappe, where dark shales separate the calciturbidites of the Trupchun Beds from those of the Mezzaun Beds.

Discussion and conclusions

Sedimentological investigation of the Allgäu Formation revealed that these basinal sediments are arranged in thinning- and fining-upward megacycles. It is assumed that each megacycle represents the sedimentary prism which accumulated after a distinct rifting event. The lithostratigraphic and scarce biostratigraphic correlations of the megacycles in the different tectonic units can be used to reconstruct the evolution of the southern continental margin in the Austroalpine cross-section.

Two major phases of rifting are recognized. The first began in the early Hettangian in the southernmost unit, the Ortler unit, and culminated in the Sinemurian. No Middle Jurassic fossils were found, but it is assumed that the Manganese Shales overlying the sedimentary prisms created by the first rifting phase are coeval with similar deposits in the Northern Calcareous Alps where they were dated as early Toarcian (JAKOBSHAGEN 1965; JENKYNS et al. 1985) and interpreted as deposits during an anoxic event (JENKYNS & CLAYTON 1986). After this anoxic event, a second major phase of rifting occurred in the northwestern Austroalpine units, i.e. the more distal part of the continental margin. Radiolarites overlie finally the Allgäu Formation and document pelagic conditions over the entire margin, probably from the latest Middle Jurassic onwards (BAUMGARTNER 1985).

The paleogeographic reconstruction shows a progressive fragmentation of the margin from east to west, i.e. from the proximal to the distal part of the continental margin. A series of basins (trending approximately N–S today) were formed (Fig. 17, 18). Faults at the western side of these basins and the asymmetric distribution of the sedimentary fill indicate half-grabens and tilted fault blocks. In the Ela nappe, evidence for an E–W trending fault is given by the occurrence of condensed submarine high deposits north of basinal sediments.

The evolution of the continental margin in the Austroalpine cross-section displays three features which differ from structures expected from symmetric extension models (MCKENZIE 1978, SCLATER & CHRISTIE 1980). The first is the preferential dip of the faults towards the "continent"; the second is the progressive fragmentation oceanwards; the third is that the location of the final breakup does not coincide with the oldest rift basins but occurred in the oceanward basement blocks of the Lower Austroalpine units. One possible explanation is that the rift system shifted to the west due to a movement of the subcrustal convection cell. This interpretation could be supported by the fact that two rifting phases occurred between which the shift might have taken place. In the younger, mid-Jurassic rift system the faults do indeed dip towards the ocean (FINGER 1978) and are in agreement with the symmetric model. However, recent studies of passive continental margins reveal that symmetrical rift structures are the exception rather than the rule (BALLY 1981, 1982; GIBBS 1984). Major detachment faults cutting through the crust and mantle are thought to be responsible for an inherent asymmetry of extensional structures and subsidence patterns (WERNICKE 1985). LISTER et al. (1986) suggest that the asymmetry of a margin is determined by whether the underlying master detachment fault originally dipped toward the ocean or away from it. Furthermore, they propose two classes of passive margins, upper-plate margins comprising rocks originally above the detachment fault and lower-plate margins, which comprise the deeper crystalline rocks of the lower plate overlain by highly faulted remnants of the upper plate. A lower-plate passive margin with two detachment faults could explain the three "aberrant" features of the Austroalpine cross-section. In this model, rift basins defined by half-grabens would lie inboard of an external basement high and the faults would be expected to dip towards the continent. Furthermore, subsidence would be greatest in areas where the rift basins formed and not outside the lower plate culmination, where the breakup occurs. All these characteristic are in agreement with the observed cross-section in the Eastern Alps. The final breakup took place within the Lower Austroalpine, which displays slower subsidence than the continentward Central Austroalpine complex (HSÜ 1982).

A comparison with the Southern Alps shows that there the final breakup also occurred west of the main rift basins and many of the major faults e.g. the Lugano fault and the Lago Maggiore fault also dip to the east (BERNOULLI 1964, WINTERER & BOSELLINI 1981; BALLY et al. 1981). However, stretching parameters in the two cross-sections vary with a higher degree of stretching in the Southern Alps (LEMOINE & TRÜMPY 1987). This indicates that the two cross-sections belong to two different segments on the southern continental margin of the Jurassic Tethys Ocean. GIBBS (1984) proposes that two segments of a passive margin are separated by a transfer fault, which performs a function similar to that of an oceanic transform fault. The position of this transfer fault separating the Southern Alpine from the Austroalpine cross-section is unknown.

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APPENDIX

The Allgäu Formation and its subdivision in the central Austroalpine area

GÜMBEL (1856) first referred to the Jurassic basinal, calcareous sediments of the Northern Calcareous Alps as "Allgäu-Schiefer" and JAKOBSHAGEN (1965) was the last to redefine the formation at its type area. In the Austroalpine units of Graubünden several synonyms were used to describe the Jurassic basinal sediments: Allgäu-Schiefer (THEOBALD 1864), Lias-Schiefer (SPITZ & DYHRENFURTH 1913), Formazione del Mte. Motto (POZZI 1959), Calcare di Valle del Monte (GELATI in BONSIGNORE et al. 1969). FURRER (1981) and DÖSSEGGER et al. (1982) redefined the Allgäu Formation in the Austroalpine units of Graubünden. Their definition is used here, with, however, their informal subdivisions partially revised and completed. In addition, the Jurassic (pre-radiolarite), calcareous, basinal sediments of the Lower Austroalpine Bernina nappe are included in the Allgäu Formation. As a consequence, the formations described by SCHÜPBACH (1974) and the Padella Serie defined by FINGER (1978) become members of the Allgäu Formation.

The Allgäu Formation

Lithology

The Allgäu Formation consists of bioturbated – often regularly alternating – marls and limestones interbedded with different types of redeposited carbonates, such as breccias, conglomerates and calcarenites (FURRER 1981). Trace fossils (esp. *Chondrites*) are abundant, whereas belemnites, ammonites and bivalves are rarely found. Siliceous concretions in bioturbated beds and secondary silicification in redeposited beds are characteristic. The components of the redeposited beds consist mainly of carbonates and biodetrital material such as sponge spicules and echinoderm skeletal debris. Within the 200 to 500 m thick formation the amount of redeposited beds varies, resulting in the separation of different members.

Boundaries

The lower boundary is taken at the change in lithology from platform carbonates to redeposited series comprising breccias, conglomerates and/or calciturbidites or at the base of a monotonous alternation of marls and limestones with abundant trace fossils and siliceous concretions. The underlying shallow-water carbonates are either Triassic platform deposits (Kössen Formation and Hauptdolomit Group) or platform and submarine high deposits of the Lower Jurassic (Adnet Limestone, Hierlatz Limestone, Schattwald Beds). The upper boundary is drawn at the base of the first radiolarian chert bed of the Blais-Radiolarit Formation or at the base of the micritic limestone of the Russenna Aptychus Limestone.

Age

The Allgäu Formation was deposited during the Early and Middle Jurassic. The lower boundary is diachronous. In the Ortler unit and in the Arosa Dolomites the formation starts in the early Hettangian. In the Ela nappe and in the western Lechtal nappe the basal sequences are dated as late early Sinemurian. In the Bernina nappe of the Val Chamuera and at Piz Padella the first redeposited beds were not deposited before the early Toarcian; in the Piz Alv area, however, thin-bedded cherty limestone were deposited in the Sinemurian (SCHÜPBACH 1974). The upper boundary is not dated in the Austroalpine units of Graubünden. The overlying cherts are lithologically correlated with the radiolarites deposited in the latest Middle Jurassic over the entire Piemont–Ligurian Ocean and part of its margin (BAUMGARTNER 1985).

Members of the Allgäu Formation

FURRER (1981) divided the basal series of the Allgäu Formation into several informal members. The following of his members are retained:

Alpisella Beds

The Alpisella Beds consist of an alternation of dark-gray to black, cherty limestones and marls with occasional black chert nodules. The beds are rich in fossils. In the Ortler unit, breccia beds are locally intercalated. In the Ortler unit and the Arosa Dolomites the Alpisella Beds form the base of the Allgäu Formation. They do not occur in the other nappes. Age: Early to late Hettangian.

Naira Limestone

The Naira Limestone consists of a monotonous, fossil-poor sequences of thin-bedded gray limestones, which are seldom interrupted by thin marls (FURRER 1981). The 10 to 50 m thick Naira Limestone represents a limestone-rich variation of a marl/limestone association described in the preceding pages and occurs only above the Alpisella Beds. Age: Late Hettangian to early Sinemurian. (Only in the Ortler unit with biostratigraphic control.)

Stidier Limestone

The Stidier Limestone is composed of 10 to 20 m thick middle- to thick-bedded cherty limestones to cherts overlying a 0.5–3 m thick limestone rich in echinoderm skeletal debris. Occurrence: Ela nappe. Age of the Base: Late early Sinemurian.

Spadlatscha Limestone

The Spadlatscha Limestone consists of a regularly alternation of bioturbated marls and limestones. The slightly nodular limestones are rich in cephalopods. The 30 m thick Spadlatscha Limestone overlies the Stidier Limestone and is, like the latter, restricted to the Bergüner Stöcke of the Ela nappe. Age: Late Sinemurian.

The different megabreccias and the conglomerates (FURRER 1981) and the Chaschauna Breccia (DÖSSEGGER et al. 1982) are not considered as separate members, because of their repeated occurrence in different members of the Allgäu Formation. The "Allgäu-Schichten s. str." (FURRER 1981) are replaced by three new members.

Trupchun Beds (new, informal)

Lithology: The Trupchun Beds represent the first megacycle of redeposited beds within the Allgäu Formation and consist of a thinning- and fining-upward carbonate turbidite sequence in which the bed thickness as well as the frequency of the redeposited beds decreases from the base to the top. The member is dominated by calciturbidites with abundant secondary silicification, preferentially occurring in the laminated part and along the base of the beds. Upwards, the amount of bioturbated marls and limestones forming the background sediments increases until they dominate the section. Trace fossils of *Chondrites* type are abundant and pyrite occurs in the bioturbated beds. The thickness varies between 100 and 300 m.

Boundaries: The lower boundary is positioned at the base of the first redeposited bed, usually a calciturbidite, overlying the Triassic Kössen Formation or Hauptdolomit Group, the Lower Jurassic Hierlatz or Adnet Limestone or the following members of the Allgäu Formation: Alpisella Beds, Naira Limestone and Spadlatscha Limestone. The upper boundary is drawn at the base of the overlying manganese-bearing shales (Ela nappe) or greenish, mica and quartz-bearing shales (Ortler unit). The thick, turbidite-dominated Trupchun Beds are easily differentiated from the Kössen Formation and the other basal members of the Allgäu Formation but a differentiation from the lithologically similar Mezzaun Beds might be more difficult (see below).

Age: The Trupchun beds are biostratigraphically not well dated. The lower boundary is diachronous. In the Ortler unit the member probably starts in the early Sinemurian. In the Ela nappe, the Spadlatscha Limestone underlying the Trupchun Beds bear ammonites of the late Sinemurian and the early Pliensbachian. Assuming that the overlying Manganese Shales are coeval with similar deposits in the Northern Calcareous where they are dated as early Toarcian (JAKOBSHAGEN 1965), the Trupchun Beds were deposited mainly in the Sinemurian and Pliensbachian.

Profiles: Lower boundary; Fil da Stidier (771.950/165.800 to 771.950/165.900). Upper boundary; Fuora da l'Üertsch (785.050/163.500 to 785.050/163.850).

Manganese Shales (name adopted from the Northern Calcareous Alps)

Lithology: A interval of black shales with reddish and brownish weathering redeposited beds is called Manganese Shales. The name is adopted from a lithologically comparable but thicker interval in the Allgäu Formation of the Northern Calcareous Alps (JAKOBSHAGEN 1965). The shales are clayey to marly, usually black with an occasional dark-blue overprint due to manganese. The thickness of the Manganese Shales varies between 0.5 to 35 m.

Boundaries: The lower boundary is positioned at the base of the first black shale horizon or the first reddish weathering limestone. The upper boundary is drawn below the first bioturbated marls or redeposited beds of the overlying carbonate turbidite sequence.

Age: The abscence of ammonites does not allow a exact dating in the Central Austroalpine area. Large belemnites of the genus *Passaloteuthis* within the redeposited beds indicate that the Manganese Shales are of Middle Liassic or younger age (SCHÜPBACH 1974). In the Northern Calcareous Alps, the "Manganschiefer" are dated as Toarcian (JAKOBSHAGEN 1965).

Mezzaun Beds (new, informal)

The Mezzaun Beds are equivalent to the Mezzaun Formation defined by SCHÜPBACH (1974). The Mezzaun Formation is lithologically comparable to parts of the Allgäu Formation and occurs also below the radiolarites. Therefore it is incorporated as a member into the Allgäu Formation.

Lithology: The Mezzaun Beds consist mainly of carbonate turbidite sequences. The base is locally formed by carbonate breccias. The turbidites with secondary silicification are arranged in cycles. In the Bernina nappe they form a thick thinning- and fining-upward megacycle; in the Ela nappe smaller thickening- and coarsening-upward cycles occur. Towards the top of the sections bioturbated marls and limestones are interbedded. Trace fossils, especially *Chondrites* and *Zoophycus* are abundant.

The Mezzaun Beds are lithologically similar to parts of the Trupchun Beds. However, trace fossils of *Zoophycus* were never recognized in the Trupchun Beds. In addition, the stratigraphic position above the Manganese Shales differentiates the Mezzaun Beds from the Trupchun Beds.

Boundaries: The lower boundary is at the top of the Manganese Shales. The upper boundary is drawn below the first radiolarian chert of the Blais-Radiolarit Formation or the first micritic limestone of the Russenna Aptychus Limestone and is equivalent to the upper boundary of the Allgäu Formation.

Age: There is no biostratigraphic control. Assuming a Toarcian age for the underlying Manganese Shales (JACOBSHAGEN 1965) and a late Middle Jurassic age for the radiolarites (BAUMGARTNER 1985), the Mezzaun Beds were deposited in the latest Early and early Middle Jurassic.

Profiles: Piz Mezzaun (794.300/195.650 to 794.550/160.450); Piz Blaisun (785.550/166.000 to 785.550/166.300).

Calcareous Jurassic sediments of the Bernina nappe s.l.

SCHÜPBACH (1974) and FINGER (1978) divided the calcareous, Jurassic sediments of the Bernina nappe s.l. into different formations and informal members. Lithologically and stratigraphically these sediments are comparable to the Allgäu Formation or parts of it. It is therefore suggested that the Allgäu Formation is expanded to include all Early and Middle Jurassic formations and members of the Lower Austroalpine units, which are lithologically characterized by bioturbated marls and limestones with interbedded redeposited carbonates (FURRER 1985).

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