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Late Paleozoic of the Carnic Alps
(Austria/ Italy)

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GUIDEBOOK

Field-trip of the SCCS Task Group to establish GSSP's close to
the Moscovian/Kasimovian and Kasimovian/Gzhelian boundaries
31. July - 01. August 2006

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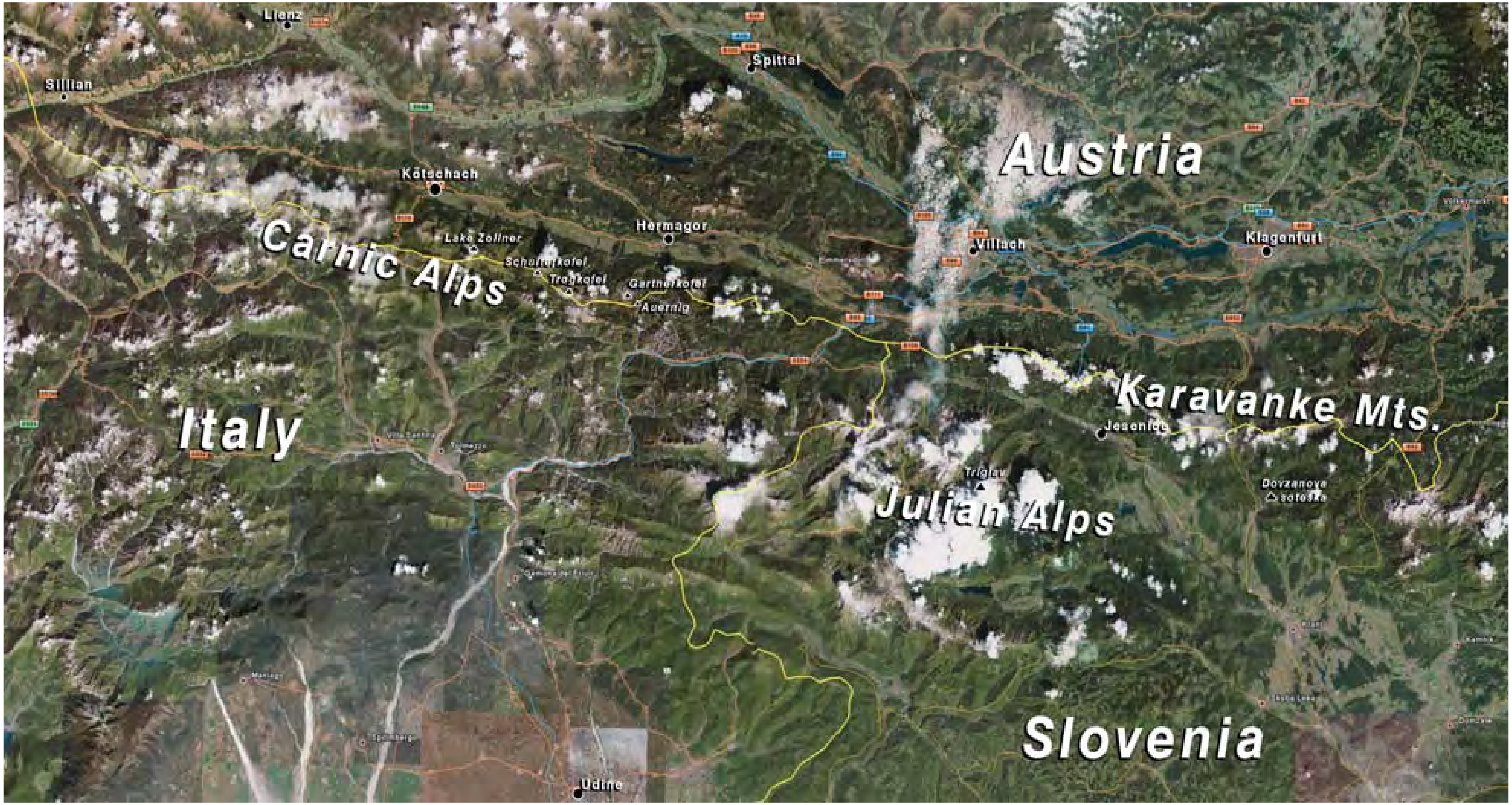

Satellite image of the Southern Alps region from Sillian in the West to Klagenfurt in the East.

FIELD TRIP SCHEDULE

31. July 2006 (Monday)

08:00 Leaving Ljubljana to the Carnic Alps by car (Group 1) and by train (Group 2)

10:00 Meeting of Group 2 with Prof. Schönlaub in Villach (Railway station). The trip will continue by car to the Carnic Alps.

11:00 Meeting of all participants in the Carnic Alps.

12:00 Stops in the western part of the Nassfeld area at Lake Zollner with lower-middle Kasimovian sections, resting with an angular unconformity on pre-Variscan basement.
Lunch: Picnic, or lunch in the surroundings of Lake Zollner

13:00 Walk will be continued to the stops around the Waidegger Alm and Straniger Alm, Kasimovian fauna along the Waschbühel ridge and Cima Val di Puartis.

18:00 Leaving the Lake Zollner area in eastward direction to the Nassfeldpass (Passo di Pramollo).

19:00 Arrival at Berghotel Krieber (Nassfeldpass)

20:00 Dinner at the Hotel, or another restaurant nearby (not included in the price for accomodation).

01. August 2006 (Tuesday)

08:00 Breakfast at Berghotel Krieber.

09:00 Leaving the Hotel in southward direction to the Italian side.

09:30 Stops at the Auernig Alm and surroundings (Hochwipfel Formation, Auernig Limestone Breccia, lower part of Auernig Formation).

11:00 Driving by car to the Gartnerkofel Saddle,
Lunch: Picnic in the surroundings of the Gartnerkofel Saddle.
Off-road walking tour along the Gugga and Mount Auernig (late Gzhelian), including the famous “bed s” with silicified fauna.

18:30 Return to Ljubljana by car. (Group 2 will possibly take again the train from Villach to Ljubljana).

21:30 Arrival at Ljubljana.

GUIDEBOOK

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Field-trip of the SCCS Task Group to establish GSSP's close to the Moscovian/Kasimovian and Kasimovian/Gzhelian boundaries

31. July – 01. August 2006

Contents

Part I Introduction to the Geology of the Late Paleozoic of the Carnic Alps: State of the Art

Aim of the Excursion

The Carnic Alps are one of the few areas in Western Europe, where Late Paleozoic deposits are almost completely developed in marine facies. The excursion will primarily concentrate on the Upper Carboniferous (Kasimovian/Gzhelian) deposits (Auernig Formation) of the Nassfeld (Pramollo) area between Collendiaul/ Lake Zollner in the West and the Auernig in the East. It also summarizes former data and recent advances in the understanding of the onset of post-Variscan sedimentation and the lithologic/biostratigraphic subdivision of the Auernig Formation in the Carnic Alps.

The Paleozoic in Austria – an Overview

During the Variscan and Alpine orogenesis several remnants of Paleozoic age were dismembered and are now incorporated into the complicated Alpine nappe system. To date, their original geographic positions and mutual biogeographic relations remain poorly understood. A possible arrangement of Paleozoic areas south of the Alpine front, including high-grade metamorphosed crystalline complexes of Paleozoic age, is shown on the sketch-map (fig.1).

Fig. 1: Variscan regions in Europe. Geographic positions of Palaeozoic areas of the Eastern and Southern Alps (15-27) are reconstructed after palinspastic subtraction of alpidic tectonic movements. Redrawn and modified after Faupl (2000) and Ratschbacher & Frisch (1993). (1) Brabant Massif, (2) Ardennes, (3) Rhenish Slate Mountains, (4) Spessart, Odenwald, (5) Harz, (6) Thüringerwald, Frankenwald, (7) Erzgebirge, (8) Sudetes, (9) Barrandian, (10) Bohemian Massif, (11) Polnische Mittelgebirge, (12) French Central Massif, (13) Vogeses, (14) Schwarzwald, (15) Err-Bernina, (16) Hohe Tauern, (17) Sivretta, (18) Ötztal, (19) Cristalline south of the Hohe Tauern, (20) Quartzphyllites of Innbruck, Radstadt, Ennstal, (21) Wechsel, (22) Seckau and Wölzer Alps, (23) Koralpe, Saualpe, (24) Greywacke Zone, (25) Graz Palaeozoic, (26) Gurktal Nappe System, (27) Carnic Alps, Karavanke Mountains.

On the territory of Austria, anchizonal to lower greenschist metamorphosed Paleozoic successions are irregularly distributed (fig. 2). Two major regions occupied by Paleozoic strata are distinguished being separated by one of the most prominent Alpine fault system, i. e. the Periadriatic Line (P. L.). Variscan sequences to the north of the P. L. form part of the so-called "Upper Austroalpine Nappe System" whereas sequences to the south belong to the "Southalpine System".

Fig. 2. Main regions of "classical", i. e., fossil bearing Paleozoic strata in Austria. Note the Periadriatic Line (P. L.) separating the Carnic Alps and Karavanke Mountains (Southern Alps) from other Alpine Paleozoic remnants belonging to the Eastern Alps.

Austroalpine Paleozoic regions are the Greywacke Zone of Lower Austria, Styria, Salzburg and Tyrol, the Nötsch Carboniferous and the Gurktal Nappe System in Carinthia, the Graz Paleozoic and some small isolated outcrops in southern Styria and Burgenland.

Within the borders of Austria, Paleozoic sequences of the Southalpine System are developed in the Carnic Alps and the Karavanke Mountains of southern Carinthia.
The main lithological and paleontological differences between the Austroalpine and the Southalpine depocenters are the result of independent histories attributed to different paleogeographical settings, subsidence rates, amount of volcanic activities and climatic impacts (Schönlaub, 1992, 1993; Schönlaub & Heinisch, 1993).

Review of the Variscan Orogeny in the Eastern Alps

In modern literature the Variscan Orogeny is interpreted as a long lasting collision and subduction related process which affected several microcontinents in a time frame between 400 and some 300 Million years. During this orogenic event significant parts of the central European crust were formed, although it includes also remnants of older tectonometamorphic and magmatic fragments. In particular in the Alps, the latter reflect a complex polymetamorphic history characterized by almost identical structural and metamorphic conditions. This is the reason why a detailed reconstruction of the geodynamic history during the early Phanerozoic is extremely difficult, although in the Alps there are clear evidences of Cadomic to Variscan events.

The geodynamic evolution of the Alps during the Lower Paleozoic has been subject of detailed studies by several authors in recent years (e.g. Franke, 1989, v. Raumer et al., 2002, 2003; Stampfli & Borel, 2002, and Stampfli et al., 2002). According to these authors during the closure of the Rheic Ocean those microcontinents accreted successively with Baltica and Laurentia, which split off from the northern margin of Gondwana during the Lower Ordovician to drift in northward direction. In the scientific literature these microcontinents are either named the "Hun-Superterrane" (Stampfli & Borel, 2002 and Stampfli et al., 2002) or the "Armorica-Terrane-Assemblage" (Tait et al, 1997). Finally, also Gondwana collided with Laurasia to assemble in the supercontinent Pangaea. Due to an oblique approach between Gondwana and Laurasia the continent-continent collision caused an anticlockwise rotation with significant dextral movements.

Generally, the Alpine structural development is subdivided into a pre-Alpine and an Alpine evolutionary history.

The Variscan Orogeny is characterized by widespread nappe tectonics, polyphase deformation, high-grade metamorphism and an intense magmatism. In addition, during the Carboniferous in the bordering zones synorogenic flysch-type sediments were deposited (Matte, 1986; Frank et al., 1987; Flügel, 1990).

Depending on the metamorphic facies and the age of metamorphism the Variscan tectono-metamorphic event affected the so-called Penninic and Eastalpine Nappes of the Eastern Alps in different degrees than the Southalpine units.

The oldest Variscan radiometric data of the Eastalpine Nappe System plot around 375 Ma [Kaintaleck-Vöstenhof Crystalline Complex, Troiseck Complex]. At around 350 Ma in some Eastalpine regions like the Silvretta and Ötztal Complexes and the Ulten Zone eclogites were formed reflecting the deepest burial during the low-temperature/high-pressure Variscan metamorphism. The culmination of the thermal overprint occurred under intermediate pressure conditions during the Lower Carboniferous, or more precisely during the Visean Stage at around 340 Ma. Typical Variscan cooling ages plot around 310 Ma and thus correspond approximately with the beginning of the transgression of the post-Variscan Upper Carboniferous Molasse-type deposits of the Carnic Alps (Miller & Thöni, 1995; Neubauer et al., 1999; Thöni, 1999). This excellent temporal relationship between the rising and eroding metamorphic hinterland and transport of clastic sediments into the deepening and widening Tethys shelf sea suggests a close proximity between the central part of the Eastern and the Southern Alps in late Carboniferous time.

In the Hohen Tauern region the Sub-Penninic Basement is overprinted by a Variscan high-temperature amphibolite-grade metamorphism, which was accompanied by the intrusion of granites. An older Silurian event is indicated by some eclogites.

The Eastalpine basement varies with respect to the grade and timing of metamorphism ranging from greenschist-facies to granulites. In the eastern part of the Southern Alps the Variscan metamorphism reached greenschist-grade conditions.

During the Permian the Southern and Eastern Alps were affected by extensional tectonics giving rise to ascending basaltic magmas from the lithospheric mantle into the lower crust followed by plutonic and volcanic activities and accompanied by high-temperature/low-pressure metamorphism (Schuster et al., 2001).

In the Eastern Alps the Alpine metamorphic evolution is subdivided into two events each being based on a specific geodynamic situation (Froitzheim et al., 1996; Schmid et al., 2004).

(1) The so-called "Eo-Alpine Event" is attributed to the Cretaceous. It is hold responsible for the huge pile of nappes forming the Eastalpine system which originated from the closure and collision of the Tethys Ocean in the Upper Jurassic and the Cretaceous. The thermal climax affecting both the Variscan and the Permo-Triassic metamorphic and sedimentary rocks has recently been dated at 90 Ma (Thöni, 1999). The youngest cooling ages cluster around 65 Ma.

At the northern margin of the Eastalpine unit the grade of metamorphism did not exceed the greenschist-facies. However, in the southern Koralpe-Wölz-Nappe-System, locally the eclogite-grade was reached.

(2) As a result of the opening of the Atlantic Ocean the Penninic Ocean opened to the northwest of the Eastalpine Zone („Alpine Tethys") in Jurassic and Cretaceous time. The latter ocean is subdivided into the Brianconnais and the Valais Trough. According to Wagreich (2001) the transformation of the passive continental margin between the Penninic and the Eastalpine to an active plate margin occurred 120 Ma ago. It caused the subduction of oceanic lithosphere and parts of the northern Eastalpine margin ("Lower Eastalpine") in a southern direction below the the Eastalpine Nappe System. In the Eocene (approx. 40 Ma) the Penninic Ocean was completely subducted und the former southern margin of stable Europe had collided with the Eastalpine tectonic unit.

The metamorphism during the Tertiary reached in parts of the Penninic Windows and in the Lower Eastalpine Nappe System blueschist-grade conditions. In a narrow belt at the southern margin of the Hohe Tauern region even eclogite-grade metamorphism occurred during this event.

Following the thermal climax some 30 Ma ago exhumation and cooling started in the Penninic and Sub-Penninic nappes. K-Ar and Ar-Ar ages of white mica and fission dating of zircons and apatite prove an age for this event at 20 to 21 Ma before present.

Summary Remarks to the Paleozoic History of the Southern Alps

For this summary the available faunal, floral and sedimentological data are derived from a continuous record of Middle to Upper Ordovician through end-Permian fossiliferous strata exposed in both the Carnic Alps and its eastward continuation in the Karavanke Mountains. These data, supplemented by paleomagnetic measurements, suggest a constant movement from more temperate regions of some 50° southern latitude in the late Ordovician to the equatorial belt during he Permian. Although direct evidence is missing it may be concluded that the Southern Alps, like other regions in Southern and Western Europe, belonged to the northern margin of the African part of eastern Gondwana during the Cambrian. Initiation of rifting indicated by basic volcanism in certain regions of the Central Alps, may have occurred during the Lower Ordovician leading to fragmentation and northward drifting of several smaller and larger microplates. In fact, during the late Ordovician the supposed former close spatial relationship to northern Africa decreased.

Instead, the faunistic and lithic pattern suggests a warm water influx from Baltica and even Siberia. The biota, in particular bivalves, nautiloids, trilobites and corals from the Silurian and Devonian show close affinities to coeval faunas and floras from southern, central and south-western Europe. However, the relationships to the Atlantic bordering continents and microplates in low latitude position such as Baltica, Avalonia and also Siberia were also remarkably close suggesting a setting of about 35°S for the Silurian and within the tropical belt of some 30° or less for the Devonian when huge masses of carbonates including reefal deposits accumulated in the Southern Alps. Whether or not Sardinia, the Montagne Noire, Iberia and the Amorican Massif occupied a similar paleo-latitudinal position or even were attached to northern Africa is a matter of ongoing discussion. Recently, however, strong arguments favour a close link with parts of Africa. In any case, exchange of faunas between these regions and the Southern Alps seems well founded and may have been aided through currents.

During the Visean Stage of the Lower Carboniferous the Lower Paleozoic sequence of the Southern Alps collided with the Central Alps and migration paths developed across the accreted Alpine terranes. Both, Lower and Upper Carboniferous faunas and floras appear of limited biogeographic significance as they exhibit either cosmopolitans, or represent a general humid equatorial setting. Nevertheless, they provide key elements for correlating continental deposits and shallow marine sequences.

Progressive northward drifting during the Upper Carboniferous and the Permian resulted in sem-arid and arid conditions, which started in the Central Alps in the Lower and in the Southern Alps during the Middle Permian indicating that the forerunner of the Alps may have crossed the equator at slightly different times during Upper Paleozoic.

In the Southern Alps the spatial distribution of the different Lower Paleozoic to Lower Carboniferous litho- and biofacies indicates a SW – NE directed polarity from shallow water environments to an open-marine and deep-sea setting. The latter must be assumed further north of the present Carnic Alps and Karavanke Mountains which, however, are fault-bounded. A least during the Lower Carboniferous this northern counterpart comprised an extensive shallow water carbonate platform of which, however, only small remnants and exotic limestone clasts have been preserved embedded mainly in the Southalpine flysch-like Hochwipfel Formation. Therefore, any conclusion about the width of this presumed intervening area and the nature of the rocks separating different Alpine terranes, remains a matter of speculation.

On a larger scale, these Alpine blocks represent peri-Gondwanide terranes and arcs similar to Avalonia, Armorica-Iberia, Perunica, Mixteca, Zapoteca, Famatima and others which originally formed the northern and western margin of Gondwana. According to more recent reconstructions they belonged to the Hun-Superterrane with a complex geodynamic history. Some of these may have been permanently or loosely attached to Africa, while others including the Southern Alps slit off in the early Ordovician to drift northward more or less rapidly until they successively collided and accreted with Laurentia and Baltica, respectively, during the Devonian and Carboniferous.

Introduction to the Carnic Alps

The Carnic Alps of Southern Austria and Northern Italy represent one of the very few places in the world in which an almost continuous fossiliferous sequence of Paleozoic age has been preserved. They extend in a W – E direction over 140 km from Sillian in Tyrol to Arnoldstein in central Carinthia. Continuing into the Western Karavanke Mountains the Variscan sequence is almost completely covered by rocks of Triassic age. Further in the east, however, Lower Paleozoic rocks are excellently exposed in the Seeberg area of the Eastern Karavanke Mountains crossing the Austrian-Slovenian border. Differing from the Carnic Alps, in this region Lower Paleozoic strata are distributed on either side of the Periadriatic Line (Gailtal Fault) which separates the Southern and the Central (or Northern) Alps. These rocks have been subdivided into a northern and southern domain, respectively, with the latter extending beyond the state border to northern Slovenia. In both the Carnic and Karavanke Mountains systematic research started soon after foundation of the Geological Survey of Austria in the middle of the 19th century. Interestingly, the equivalents of the Lower Paleozoic were first found in the Karavanke Mountains and not in the more fossiliferous Carnic Alps (Suess, 1868, Tietze, 1870). In this latter area main emphasis was drawn on marine Upper Carboniferous and Permian rocks.

At the end of the 19th century this initial phase was followed by the second mapping campaign carried out mainly by Georg Geyer from the Geological Survey of Austria and detailed studies by Fritz Frech from the University of Breslau. During the first half of the last century Franz Heritsch and his research group from Graz University revised the stratigraphy on the Austrian side, while Michele Gortani from Bologna University and others worked on the Italian part of the mountain range. One of the outstanding contributions of that time focusing on the Lower Paleozoic was provided by H. R. von Gaertner, 1931.

The detailed knowledge of Upper Carboniferous and Permian rocks mainly resulted from studies by Franz Kahler beginning in the early 1930s. Since that time many students of geology and paleontology started to visit both regions. During this third campaign study of various microfossil groups began and newly introduced techniques were applied. This research culminated in the publication of detailed maps, a new stratigraphic framework, and revisions of old and discoveries of new faunas and floras (see e. g., Schönlaub, 1971, 1980, 1985, 1997, Schönlaub & Kreutzer, 1994, Hubmann et al. 2003, Schönlaub & Forke, 2005).

Geodynamic evolution during the Variscan Orogeny

Introduction

In the Carnic Alps Fritz Frech (1894) first provided the evidence for both Variscan and Alpine tectonics that affected the Carnic Alps. His arguments were on one hand the transgressive relationship of late Carboniferous and Permian sediments upon older basement rocks and on the other hand the involvement of late Carboniferous and Permian deposits into the Alpine tectonics. Although in the following years many arguments were put forward in support of this hypothesis (cf. v. Gaertner, 1931; Heritsch, 1936; Selli, 1963; Kahler, 1971), some authors still raised doubts about this general concept. For example, Argyriadis (1970) and Mariotti (1972) argued that the contact between the late Carboniferous and the underlying strata is not a sedimentary relationship, but actually represents a tectonic contact. Furthermore, they noted that in the Carnic Alps two different cover sequences are developed. The first one represents an autochthonous sequence characterized by the Permian Gröden Fm. disconformably overlying late Carboniferous clastics and volcanites while the second one is an allochthonous Upper Carboniferous to Permian sequence.

Mariotti (1972) confirmed the angular unconformity between the Variscan basement and its cover at locality Collendiaul southwest of Lake Zollner well known since the detailed description by Heritsch (1936), which will be visited during the excursion. In this area he postulated three instead of two paleogeographically different facies developments, which were thrusted into the present position due to the Alpine tectonics. In conclusion, he added the “Stranig Series” to the „Auernig” and “Dimon Series” already known by Argyriadis (1970) and defined the first paleogeographical unit as the Upper Carboniferous cover sequence transgressively overlying the Variscan basement strata. According to Mariotti (1972), this sequence ranges into the Middle Permian Gröden Fm., which, however, is separated from the Upper Carboniferous by a gap comprising the equivalents of the Lower Permian.

This misleading concept in which any Variscan tectonics was denied was strongly refused by Fenninger et al. (1974) who presented several arguments which clearly demonstrated that the Carnic Alps are a mountain range affected by both Variscan and Alpine deformation (Heritsch, 1936).

Timing of the Variscan Deformation in the Carnic Alps

In the Carnic Alps the timing of the main deformation of the Ordovician to Late Paleozoic sedimentary sequences has long been a matter of debate (for the onset of post-Variscan sedimentation in the Carnic Alps see also the chapter about the biostratigraphy of the Auernig Formation) (Fig. 3).

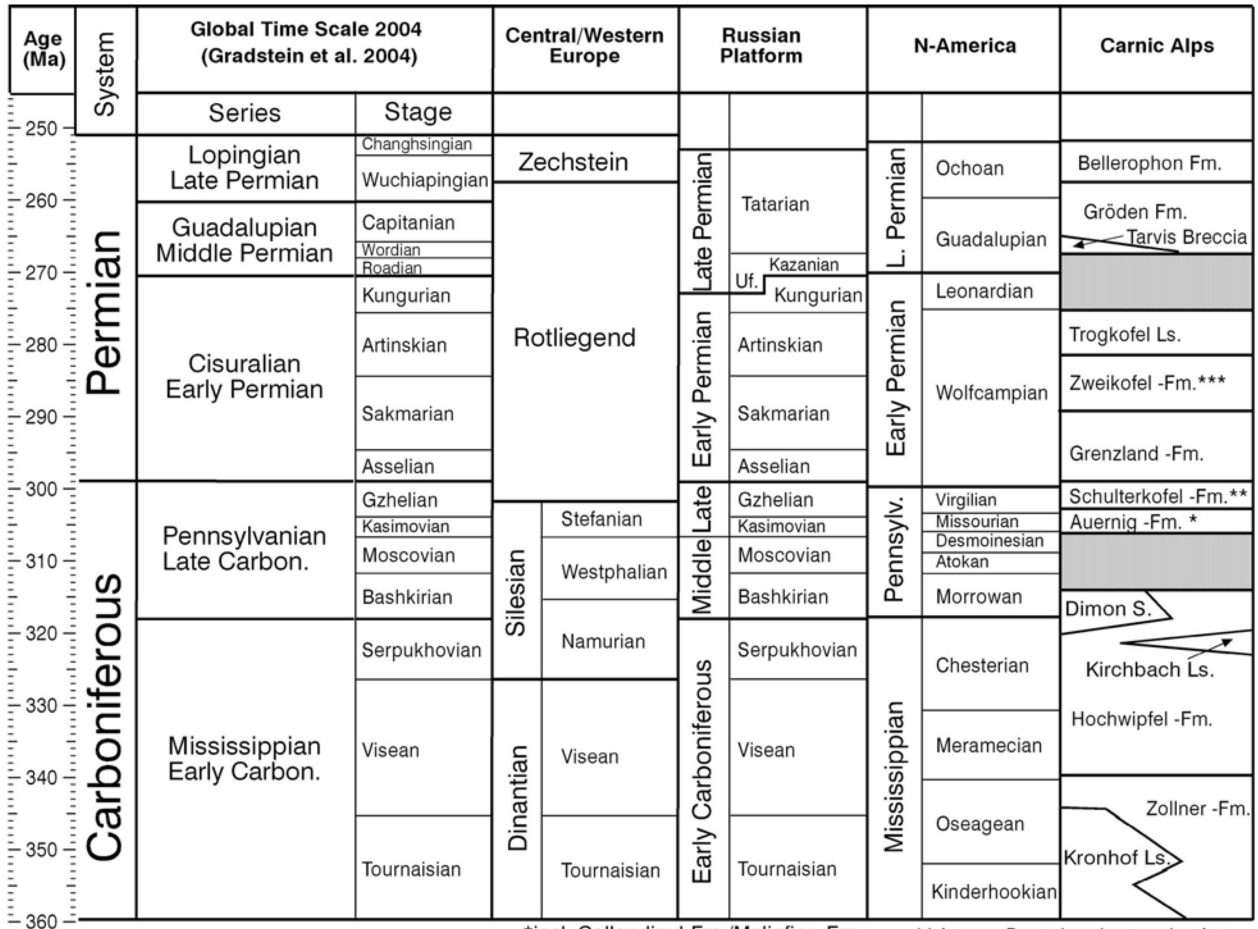
Based on the available stratigraphic data the main deformation must have occurred in a time span between the deposition of the youngest basement rocks assigned to the Hochwipfel Fm. and the oldest part of the cover sequence. According to plant fossils such as *Archaeocalamites scrobiculatus*, which first were identified by Frech (1894) and later on were confirmed from several localities, the clastic flysch-type Hochwipfel Fm. is evidently Culmian in age. However, this species ranges into the Namurian. Although this age was generally confirmed by Francavilla (1966) from spore data, he finally concluded for the Hochwipfel Fm. an age ranging from the Namurian B to the Westfalian C.

According to Kahler (1971) the Variscan sequence of the Carnic Alps as well as the Greywacke Zone underlying the Northern Limestone Alps generally ends in the Westfalian B. For the Westfalian C he concluded a stratigraphic gap followed by renewed sedimentation during the Myachkovian which was correlated with the Westfalian D. Kahler argued that the corresponding gap may have lasted some 10 Ma, which seemed “long enough” for the Variscan Orogeny.

In addition, during the last 20 years additional fossils were obtained from the underlying Variscan basement rocks such as plants, conodonts, foraminifera, algae, corals and crinoids, which mainly occur in the Kirchbach Limestone stratigraphically intercalated in the Hochwipfel Fm.. These fossils suggest an age within the lower Namurian or in the upper part of the Serpukhovian, respectively.

In summary, the new data reflect the following scenario for the Variscan Orogeny at the border zone of the Southern and Eastern Alps (fig. 4):

- In the Lower Carboniferous and more precisely at the beginning of the Visean Stage the sedimentary basin of the Carnic Alps was dramatically reorganized: The former extensional regime and a passive margin was



*incl. Collendiaul-Fm./Malinfier -Fm.

** Lower *Pseudoschwagerina* Ls.

***Upper *Pseudoschwagerina* Ls.

Fig. 3: Correlation of the Global Time Scale (Gradstein et al., 2004) with selected Regional Stratigraphic Scales of the Carboniferous and Permian.

transformed into an active margin setting of a collisional zone.

- In the course of the beginning compressional tectonics some areas were uplifted above sea-level and karstification started while others subsided to become a deep-water trough (Schönlaub, 1990; Schönlaub et al., 1991; Läufer et al., 1993; Schönlaub & Histon, 1999).
- The transformation also affected the extensive shelf platform covered with fossiliferous peritital carbonates surrounding the northern microcontinental margin which was incorporated into an accretionary wedge and was completely destroyed and reworked (Flügel & Schönlaub, 1990).
- Starting in the Middle Visean to the south of the collision zone a deep-water trough developed which was supplied from a northern source area with more than 1500 m thick flysch-type sediments of the Hochwipfel Fm.. These siliciclastic deposits comprise varying lithologies including bedded sandstones, shales, chert-bearing conglomerates to pebbly siltstones, bedded greywackes and locally basic volcanics. During phases of decreased clastic sedimentation the deep-water Kirchbach Limestone was formed.
- To date no detailed age data about the youngest sediments of the Hochwipfel Fm. are available. Most probably, however, sedimentation ceased during the middle or upper Bashkirian.
- Due to ongoing collision and subduction the Carnic basin completely closed during the Upper Bashkirian or Lower Moscovian. This event was succeeded by uplifting.
- For the main deformation of the pre-Variscan basement sequences a rather short duration is envisaged which may correspond to less than the duration of the Bashkirian and Moscovian. Depending on the timescale this means less than 11 and 15 Ma, respectively.
- The outcrops east of the Auernig Alm on the southern side of Nassfeld suggest that the actual sedimentary and time gap between the pre-Variscan Hochwipfel Fm. and the post-Variscan Auernig Fm. was rather short.
- In conclusion, the Variscan Orogeny was a long-lasting process that started at the beginning of the Visean and reached its climax during the late Bashkirian or early Moscovian. At this time in the Carnic Alps the main deformation may have taken place.

Review of Tectonics

The post-Variscan cover sequence is characterized by fairly thick and more rigid platform carbonates of Permian and Triassic age which are broken into single huge slabs

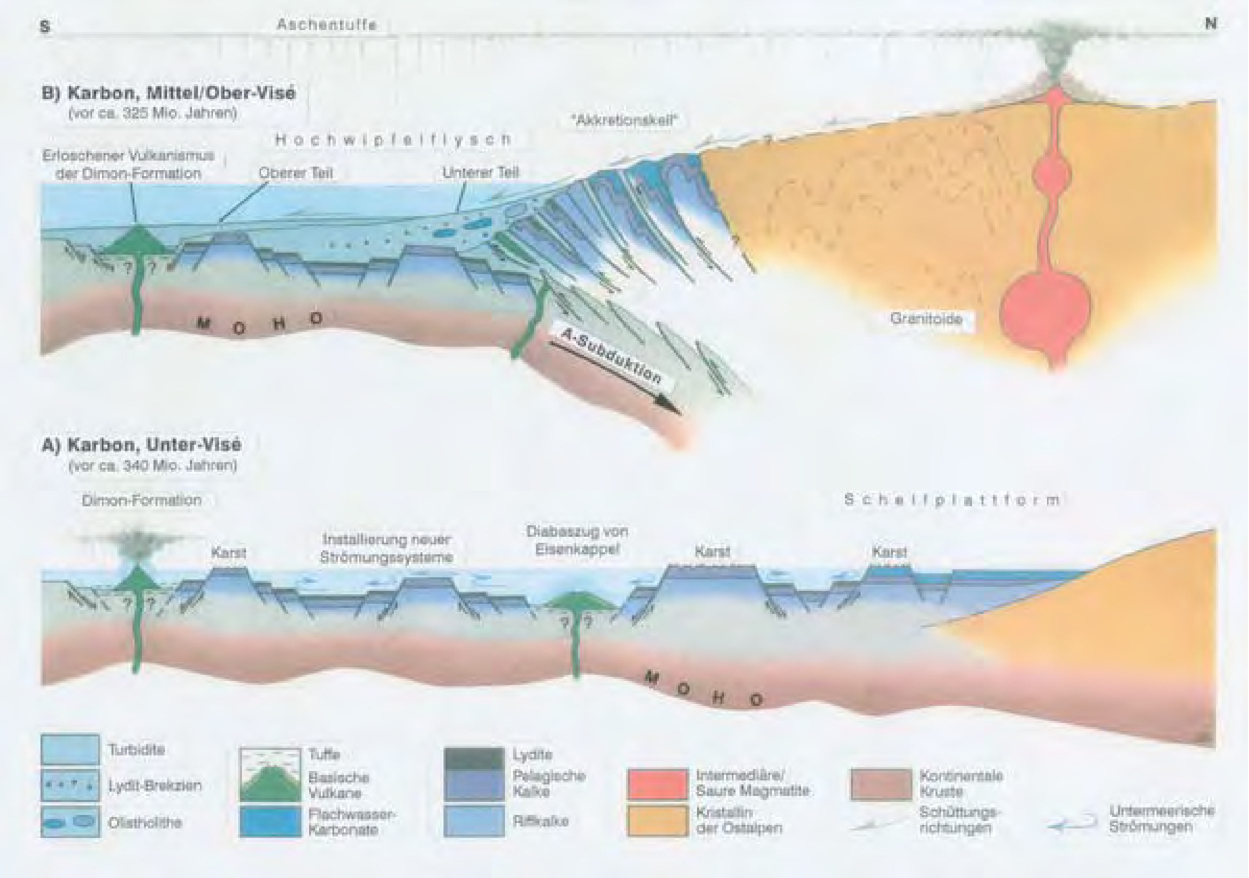


Fig. 4: Geodynamic model of the tectonic and sedimentary evolution in the Southern and Eastern Alps during the Lower Carboniferous assuming the transformation from a passive to an active plate margin (after Läufer et al., 1993, modified by Schönlaub & Histon, 1999).

and slightly tilted. In contrast the more incompetent shaly interbeds are more or less intensively folded. Nevertheless, the stratigraphic order has mostly been preserved during the Alpine tectonics except very few places were an inverse sequence can be found.

Within the area of the post-Variscan cover two units are distinguished:

1. The autochthonous Stranig Unit is characterized by the Gröden and Bellerophon Fm. overlying deposits of the Auernig Fm. with the latter resting unconformably on different pre-Variscan basement strata. The sedimentary gap between the Auernig Fm. and the Gröden Fm. comprises roughly the equivalents of the Lower Permian.
2. The allochthonous Gartnerkofel Nappe represents a thrust sheet which was transported over a distance of at least 3 km. In this unit the post-Variscan sequence is well preserved and comprises an uninterrupted sediment pile ranging from the Upper Carboniferous (Auernig Fm.) to the Middle Triassic Ladinian Stage (Schlern Dolomite). The thrust plane is only preserved in the region of Lanzenboden south of the Austrian/Italian border were the sediments of the Auernig Fm. tectonically overly the equivalents of the Bellerophon Fm., or more common the Gröden Fm. belonging to the Stranig Unit.

According to new field data obtained by one of the authors (H. P. S.) thrusting of the Gartnerkofel Nappe took place in northward or North-northwestern direction. This orientation seems to have been caused by the superposition of an Alpine N-S-compression and the dextral movement along the Periadriatic Line occuring in the early Neogene.

Following the formation of an extensive shear system ("Schwarzwipfel-Fault", "Hochwipfel-Fault") the NW-SE directed compression continued resulting in south-east-verging en échelon folds and minor thrusting. This event was associated with vertical displacements along the shear system. For example, along the Hochwipfel-Fault separating the mountains Hochwipfel and Schulterkofel displacements of several hundred meters must be assumed.

The allochthonous nature of the Gartnerkofel mountain as eastern continuation of the Alpine nappe pile in the region of Lanzenboden – Trogkofel is based on newly established field data and geological reasoning. The direct connection, however, is due to Quaternary cover deposits, mass movements and erosion not exposed.

Historic overview and nomenclatoric notes to the lithostratigraphic units of the Late Paleozoic succession in the Carnic Alps (Fig. 5)

Auernig Formation

The name “Auernigschichten” was first introduced by Frech (1894) for the conspicious Upper Carboniferous clastic-carbonate succession cropping out in the western part of the Nassfeld area from Madritschen to Krone.

Heritsch et al. (1934) lithologically defined and subdivided the Auernig Formation according to the predominance of limestone horizons into five members (“untere kalkarme, untere kalkreiche, mittlere kalkarme, obere kalkreiche, obere kalkarme Schichtgruppe”). As type section for the lower two members they choose the “Waschbühel” ridge in the vicinity of the Waidegger Alm. Due to their biostratigraphic data, they supposed an inversion of this section with the oldest sediments lying in the north (fig. 25). The upper part of the second member (untere kalkreiche Schichtgruppe) was defined as “Watschiger Schichten” with the type locality above the Watschiger Alm. The upper three members have their type section along the mountain ridge from Gugga to Garnitzen (fig. 31).

Selli (1963) introduced in his description of the five members of the Auernig Formation the terms Meledis, Pizzul, Corona, Auernig, and Carnizza, which are regarded as equivalents to those of Heritsch et al. (1934).

Fenninger et al. (1971) reinvestigated the type section of the lower two members along the “Waschbühel” ridge. They rejected an inversion of the section, because of sedimentary structures and geopetal fabrics within the fossils. Furthermore, the superposition of the “untere kalkreiche Schichtgruppe” above the “untere kalkarme Schichtgruppe” was refuted. They suggested a tripartite division of the section with partly sedimentary and partly tectonic contacts. The Nölbling Member is equivalent to the “untere kalkreiche Schichtgruppe” but in a reverse sense. The base of the sequence is not clearly defined, because of assumed faults in the south. The “untere kalkarme Schichtgruppe” is divided into two groups. The northern (“lower”) part is called Waidegger Member and represents the oldest sediments of the Auernig Formation. The southern (“upper”) part (Waschbühel Member) is set apart by a striking fault bundle from the Waidegger Member and probably also from the Nölbling Member (fig. 25).

During mapping of the area around Lake Zollner, Leditzky (1974) sampled the limestones SW of the Lake Zollner (fig. 21), which were regarded as Lower “*Pseudoschwagerina*” Limestone (Uppermost Gzhelian) by Heritsch et al. (1934). A Kasimovian age was later recognized by Kahler (1983).

Fenninger et al. (1976) described in detail several localities, where the contact between folded pre-Variscan basement and post-Variscan cover rocks is exposed with a clear angular unconformity. The basal sediments (lydite breccias, or limestone conglomerates) resting on the

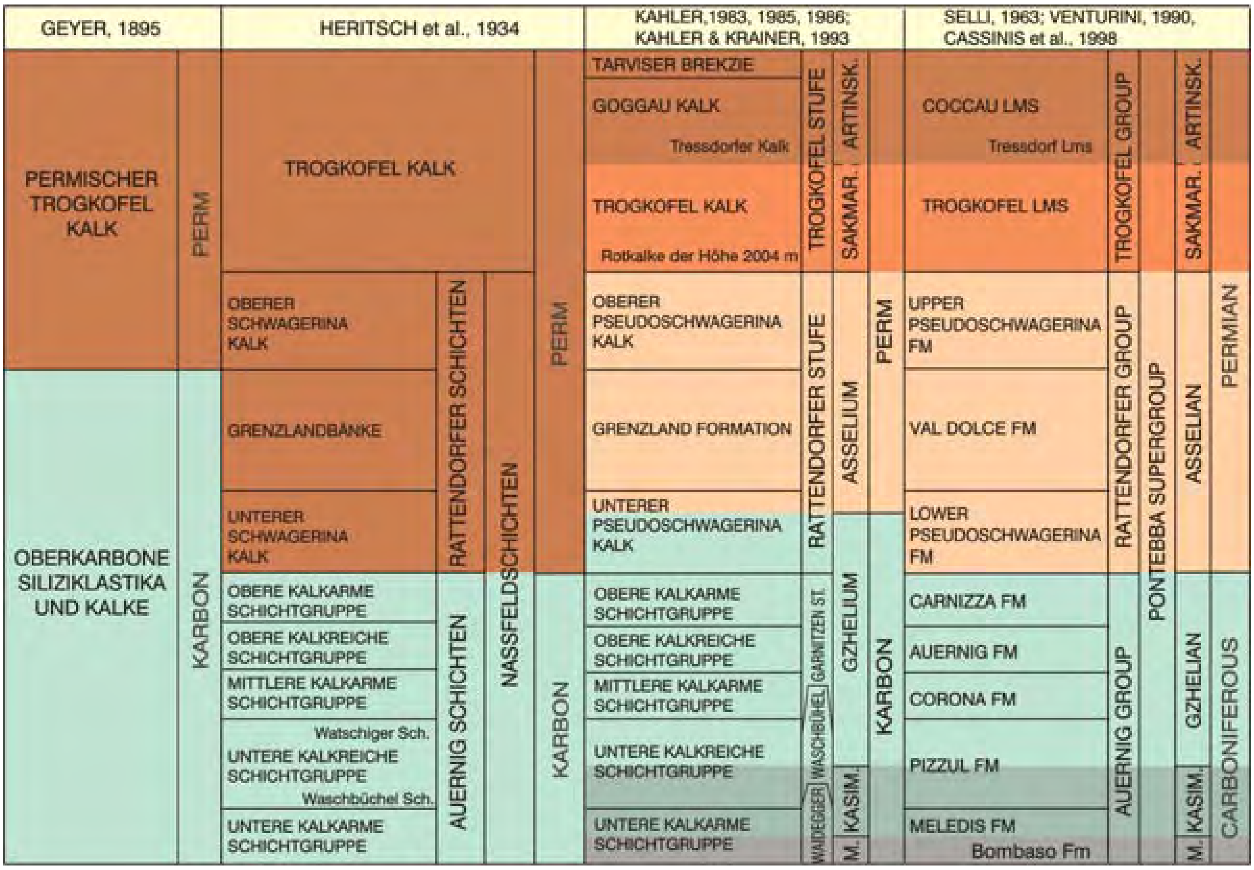


Fig. 5: Historic development of the lithostratigraphic subdivision of the Upper Carboniferous/Lower Permian succession in the Carnic Alps.

folded Variscan basement in several places, were placed outside the Auernig Formation by Venturini (1989, 1990) and named Bombaso Fm. However, the term Bombaso Fm., including the Pramollo Member, for the basal breccias and conglomerates was abandoned recently (Schönlaub & Forke, 2005), because of the inappropriate definition of the type section, which in fact represents sediments of the Hochwipfel Formation. Instead, the term Collendiaul Fm. was introduced with the type section at the right bank along the outflow of the Lake Zollner (figs.11, 12).

Upper Carboniferous, clastic-carbonate beds, on top of the Devonian reef limestones at the summit of M. Cavallo (Rosskofel) have already been mentioned by Geyer 1896, and were later correlated with the Pizzul Member by Selli (1952). Felser (1975) studied corals from several scattered outcrops in the M. Cavallo (Rosskofel) massif, and supposed a younger, Lower Permian age. He suggested correlating the sediments with the "clastic" Trogkofel beds, a clastic-carbonate sequence so far described only from Slovenia (Ramovš & Kochansky-Devidé, 1965). A Sakmarian age was also supposed by Argnani & Cavazza (1984).

Fenninger et al. (1976) described a limestone sequence, forming the peak of M. Cavallo (Rosskofel). Unlike the other sediments (sandstones, or fine conglomerates) in this area, the sequence rests with limestone to limestone contact on the folded Variscan basement (fig. 15). The correlation with the "clastic" Trogkofel beds of Slovenia was put into question, but the limestones were compared with the Schulterkofel Fm. (Lower *Pseudoschwagerina* Limestone), on the basis of lithologic similarities. The fusulinoidean fauna was studied later by Kahler (1983, 1985) and regarded as late Kasimovian-early Gzhelian. A late Kasimovian-early Gzhelian age of the limestones on top of the M. Cavallo (Rosskofel) was confirmed by Luppold (1994), who encountered a few conodonts from a single sample. Forke (1994) discovered Upper Carboniferous deposits, forming the foothill of the M. Cavallo (Rosskofel) massif, which are lithologically similar to the limestones described from the summit of M. Cavallo (Rosskofel) and Creta di Rio Secco (Trögl). The fusulinoidean and conodont fauna of several sections in the Creta di Rio Secco (Trögl) – M. Cavallo (Rosskofel) massif were studied (Forke, 2001 unpubl.) and a preliminary correlation of the limestone sequence ("Rosskofel Limestone") with the upper Kasimovian cyclothems of the Moscow Basin, Donets Basin, and Midcontinent North America were mentioned in Forke & Samankassou (2000) and Heckel et al. (2005).

The upper part of the Auernig Formation were already investigated in detail by Frech (1894), Schellwien (1892) and Geyer (1896), who introduced the letters a-t (numbers 1-31 respectively) for individual limestone, conglomerate and sandstone beds (fig. 31).

Further studies addressed the sedimentology (Fenninger, 1971; Krainer, 1992), cyclicity (Boeckelmann, 1985; Krainer, 1991; Massari et al., 1991; Samankassou, 2002), and fauna (Kodsi, 1967; Fohrer, 1991; Leppig et al., 2005; Forke, 2006) of the succession.

Venturini (1990) and Vai &Venturini (1997) proposed a revised stratigraphic subdivision of the Upper Carboniferous clastic carbonate succession with the Auernig "Group", consisting of five formations and excluded the basal breccias and conglomerates as Bombaso Formation (now Collendiaul Fm.). This scheme was adopted by most following authors (Krainer, 1990, 1991, 1992, 1995a, Krainer & Davydov, 1998, Davydov & Krainer, 1999).

However, due to the strong faulting and complex tectonics in the areas where the Collendiaul Fm. and lower part of the Auernig Formation are exposed, it is often difficult to find complete sections, allowing a definition of the base and top of stratigraphic units. Up to know, it is not possible to reconstruct the Upper Carboniferous succession with composite sections, which are needed to define base and top of individual sections lithologically and faunistically for correlation. A definition of stratigraphic units after the "recommendations (guidelines) of the usage of stratigraphic nomenclature" (Steiniger & Piller, 1999) has never been undertaken.

Furthermore, the proposed stratigraphic subdivision of the "Auernig Group" into formations would require distinguishing the formations as mappable units in the field. However, the formations are neither traceable for longer distances, nor reproducable in geological maps.

There are several reasons to keep the Upper Carboniferous succession as Auernig Formation and to give informal names for the different investigated sections.

1. The "untere kalkreiche Schichtgruppe", (or the equivalent "Pizzul Formation") consists of two parts (Waschbühel section and Watschiger Schichten), which have never been successfully correlated. Moreover, the base of the formation has never been defined after the revision of Fenninger et al. (1971). The alternatively proposed type section (after the locality Monte Pizzul) is neither lithologically, nor biostrati-graphically sufficiently investigated for correlation.
2. The "untere kalkarme Schichtgruppe" (or the equivalent "Meledis Formation") in its original type section (Waschbühel ridge) is composed of two units bounded by tectonic contacts. Biostratigraphic data are available only from the northern ("lower") part (so-called "Waidegger fauna" of Heritsch et al., 1934; Gauri, 1965). In the alternatively proposed type section (section Rio Cordin east of the Casera Meledis) the base of the formation is not exposed and the succession is overlain directly by the Middle Permian Gröden Formation. Moreover, Krainer & Davydov (1998) described an "early Gzhelian" (more probably late Kasimovian) fauna from this section, although the overlying? Pizzul Formation is partly older (middle-late Kasimovian fauna of the Waschbühel ridge).

Rattendorf Group

In the dawn of geological investigations in the Carnic Alps, only a simple stratigraphic subdivision into the clastic dominated Upper Carboniferous and overlying "Permocarboniferous" Trogkofel Limestone existed (fig. 5). Kahler (in Heritsch et al., 1934) first recognized the Permian age of parts of the clastic succession, which led to the revised stratigraphic scheme. They introduced the Rattendorf Group between the Auernig Formation and Trogkofel Limestone, which was subdivided into three formations: the Lower *Schwagerina* Limestone, the predominantly siliciclastic Grenzland Beds, and the Upper *Schwagerina* Limestone. Later, the Lower/Upper *Schwagerina* Limestone was renamed into Lower/Upper *Pseudoschwagerina* Limestone, because of changes in the fusulinoidean systematics (Kahler, 1947). However, according to the recent fusulinoidean systematics there is neither a *Pseudoschwagerina* in the lower, nor in the upper limestone succession.

Krainer (1995) has therefore proposed to substitute the fossil-related names according to the stratigraphic guidelines for topographic names (Schulterkofel Formation, Zweikofel Formation).

Trogkofel "Group"

Regarded as Triassic by Frech (1894), Geyer (1895) correctly recognized the Trogkofel massif as Lower Permian in age. Lithologically, the light-colored (sometimes reddish), massive, and often dolomitized reef limestones are easily recognizable in the field. The transition from the underlying, dark-grey, well-bedded limestones of the Zweikofel Formation is generally distinct. However, discrepancies existed about the biostratigraphic correlation of the reef limestones with other sections. Due to the poor fauna of the Trogkofel Limestone itself, other faunas from lithologically similar deposits (mostly reddish limestones) were used as representatives for the biostratigraphic correlation (reddish "Trogkofel Limestones" of Altitude 2004m, "Trogkofel Limestone" from the Dovžanova Soteska in Slovenia, Trogkofel Limestone of Forni Avoltri in Italy) (Heritsch, 1938; Ramovš, 1963, 1968; Kahler & Kahler, 1980). Geologic mapping and comparison of fusulinoidean and conodont faunas have revealed that the aforementioned limestones belong to different lithostratigraphic units and are older than the Trogkofel Limestone itself (Forke, 1995b, 2002; Buser & Forke, 1996). In the Nassfeld area, only the Tressdorf Limestone (a polymict limestone breccia, Homann, 1969) may represent a stratigraphic equivalent of the Trogkofel Limestone.

Towards the SE (in the Austrian, Italian, and Slovenian border triangle), the Goggau Limestone seems to represent a lateral facies development of the Trogkofel reef limestones with a diverse fusulinid fauna (Kahler & Kahler, 1980).

Biostratigraphy and correlation of Late Paleozoic deposits of the Carnic Alps (Fig. 6)

The biostratigraphy and correlation of the Upper Carboniferous/Lower Permian succession with other standard subdivisions is predominantly based on the fusulinids (Kahler & Kahler, 1937, 1982; Kahler, 1939, 1962, 1983a, 1985, 1986a, b, 1992; Pasini, 1963; Forke et al., 1998; Krainer & Davydov, 1998; Davydov & Krainer, 1999), partly in combination with conodonts (Forke 1995a, 2002, Forke & Samankassou, 2000). Brachiopods, arthropods and ostracodes are further used for biostratigraphic purposes (Gauri, 1965; Hahn & Hahn, 1987, Fohrer 1991, 1997). Additionally, other marine fossil groups (smaller foraminfera, bryozoans, bivalves, corals, sponges, and algae) have been used for characterization of the depositional environment (Homann, 1970, 1972; Flügel, 1971, Flügel & Flügel-Kahler, 1980; Vachard & Krainer, 2001a, b). Floral remains provide an important contribution for correlation with coeval Western and East European deposits (Fritz & Boersma, 1986a, b, 1990).

Auernig Formation

In the Carnic Alps the question of the main deformational phase of Ordovician to Carboniferous sedimentary rocks and the onset of the post-Variscan sedimentation is discussed controversially. Because of the brachiopods found in the basal Auernig Formation close to the Waidegger Alm, Heritsch (1934) assumed a late Moscovian (Myachkovian) age for the first transgressions. The same locality, however, was regarded as Kasimovian by Gauri (1965), who studied trilobites and brachiopods.

A correlation with the Myachkovian was confirmed later by Kahler (1983, 1986b, 1992) and Davydov & Krainer (1999), who studied fusulinoideans from the basal part of the Auernig Formation in the area around Lake Zollner.

However, Forke & Samankassou (2000) doubted the correlations after a comprehensive study of several sections across the entire Nassfeld area. Based on the combined use of conodont and fusulinoidean faunas and the comparison of faunas from the Cantabrian Mts., Moscow and Donets Basins during the SCCS Task Group meetings, they concluded that the oldest fossiliferous beds of the Auernig Formation correlate biostratigraphically with the lower Kasimovian (Krevyakinian). They further could show that the onset of sedimentation on the pre-Variscan basement is not time-equivalent in all areas (fig. 7). It ranges from early Kasimovian in the area around Lake Zollner and Auernig, to middle Kasimovian (Khamovnikian) at Cima Val di Puartis, and late Kasimovian (Dorogomilovian) at the Creta di Rio Secco (Trögl)-Monte Cavallo (Rosskofel) massif.

Early Gzhelian faunas in the Carnic Alps are mentioned in the literature, but most occurrences seem to represent late Kasimovian (Rosskofel massif after Kahler, 1985; section Rio Cordin after Davydov & Krainer, 1998).

The upper part of the Auernig Formation ("Watschiger" Mb., Corona Mb., "Auernig" Mb., Carnizza Mb.) in its type section represents a continuous succession of approximately 400 m thickness. It starts probably during the Gzhelian D (*Jigulites jigulensis* Zone) and ranges throughout the Gzhelian E (*Daixina sokensis* Zone) (Davydov & Krainer, 1998; Forke, 2006).

Schulterkofel Formation

The biostratigraphy of the Schulterkofel Formation is intimately connected with the controversial discussion about the C/P boundary in the Carnic Alps. Since the

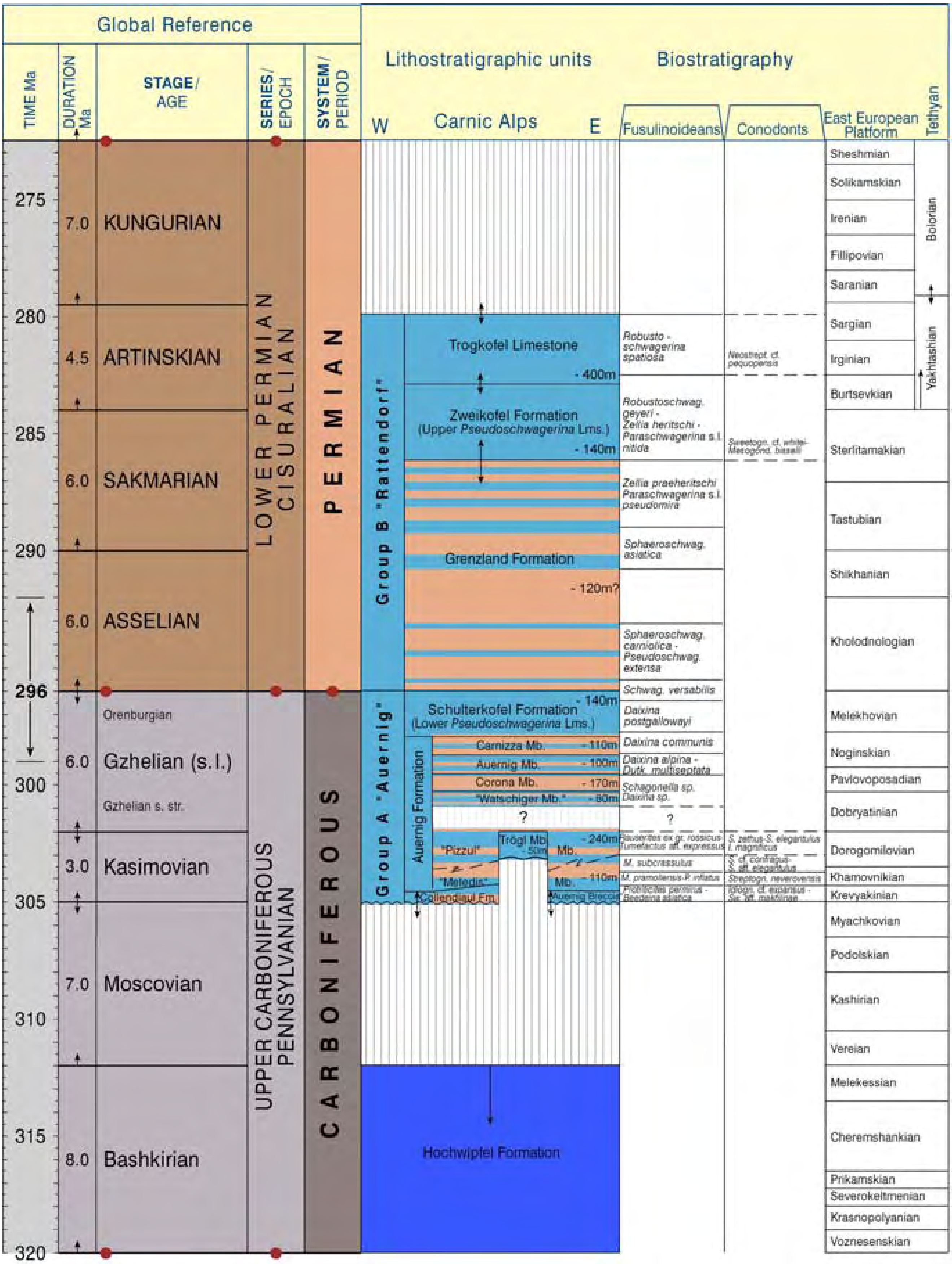


Fig. 6: Lithostratigraphic units and biostratigraphy of the Upper Carboniferous/Lower Permian succession in the Carnic Alps.

revised lithostratigraphic scheme of Heritsch et al. (1934), the boundary between the Carboniferous and Permian Systems has long been drawn at the base of the Schulterkofel Formation. Further studies from the type section demonstrated that the index fossil (“*Occidentoschwagerina alpina*” sensu Kahler) has its first appearance in the upper part (~ SK 107 of the described section) and a new proposal has been made for the C/P boundary (Kahler, 1983b; Kahler & Krainer, 1993). This coincided approximately with the C/P boundary (as it was usually drawn by many authors at that time) in the type regions of the Southern Urals (Kireeva et al. 1971; Pnev et al. 1975) and Middle Asia (Bensh 1972).

New investigations in the type area of the Southern Urals (Chuvashov et al., 1986; Davydov et al., 1994) led to a refined fusulinoidean zonation (establishing of the new *Daixina bosbytauensis-robusta* Zone) and a reinterpretation of the base of the Permian System (Davydov et al., 1998).

Three fusulinoidean assemblages can be distinguished in the Schulterkofel Fm.(fig. 8) The lowermost part yields species of *Ruzhenzevites, Dutkevitchia* (known also from the underlying Auernig Group), and the *Schwageriniformis perstabilis* group. Species of the *Rugosofusulina stabilis* group and of *Rugosochusenella* have their first appearance in the middle and upper part of the section, which is primarily characterized by the occurrence of highly inflated species of the genus *Daixina* (subgenus *Bosbytauella*). In the uppermost part *Daixina* (*Bosbytauella*) became extinct and species of *Schwagerina* and *Dutkevitchites* occur in the topmost layers.

The lowermost assemblage of the Schulterkofel Formation may still belong to the *Daixina sokensis* Zone, whereas the main part of the sequence can certainly be correlated with the *Daixina* (*B.*) *bosbytauensis-Daixina robusta* Zone. The base of the following *Sphaeroschwagerina vulgaris-S. fusiformis* Zone cannot be precisely correlated, as a fusulinoidean assemblage with intermediate characteristics occurs in the topmost layers of the Schulterkofel Formation. Therefore, the boundary between the Carboniferous and Permian Systems, defined by the First Appearance Datum of *Streptognathodus isolatus* (approximately coinciding with the base of the *Sphaeroschwagerina vulgaris-S. fusiformis* Zone) is slightly imprecise in the Carnic Alps, and spans an inferred interval from the topmost layers of the Schulterkofel Formation to the basal limestone beds of the Grenzland Formation.

Grenzland Formation

Limestone beds with fusulinoideans are present only in the lower and uppermost parts of the predominantly siliciclastic Grenzland Formation. Originally correlated with the middle Asselian, the Grenzland Fm. seems to represent the entire Asselian plus basal Sakmarian (Forke, 2002).

Longer intervals of non-deposition and erosion may have occurred, but have not been demonstrated sedimentologically in the succession.

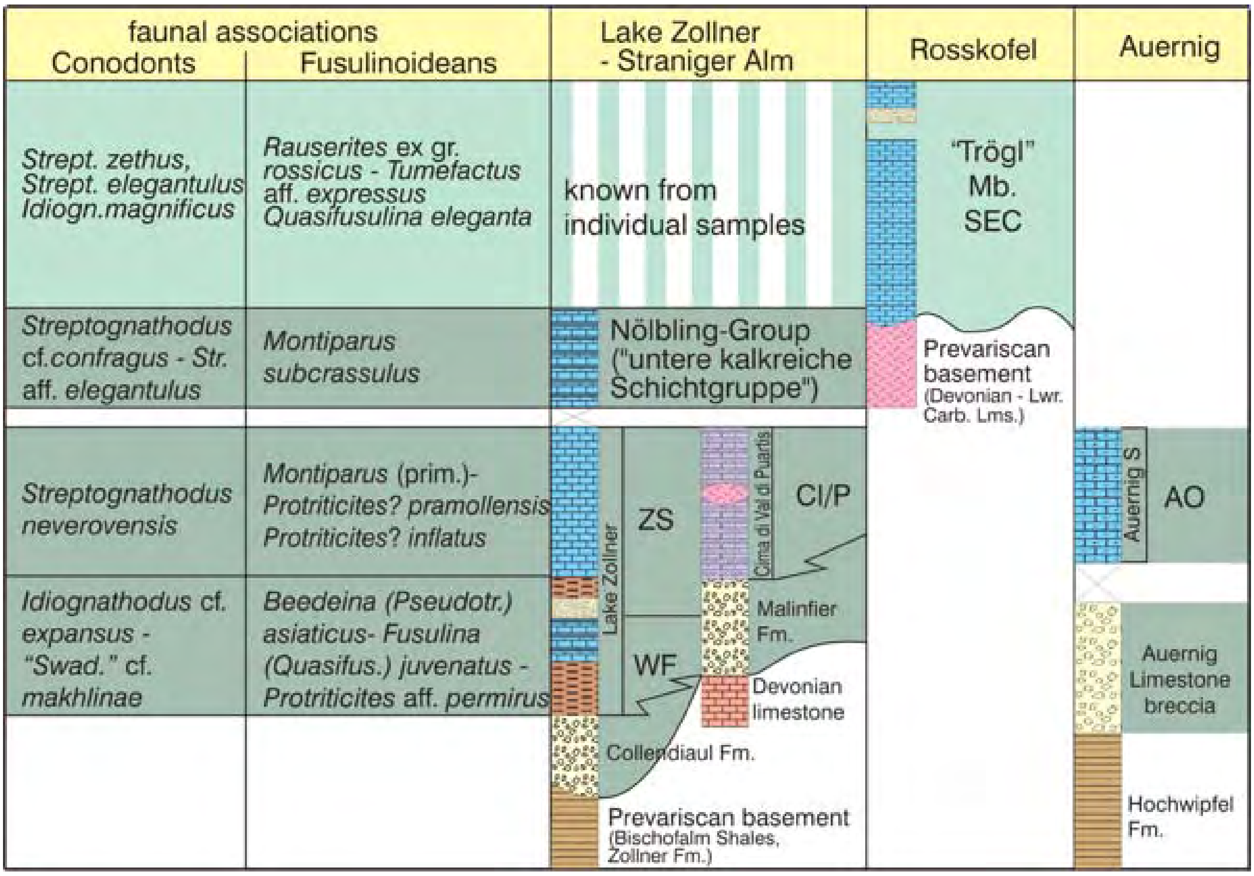


Fig. 7: Litho- and biostratigraphic framework of the lower part of Auernig Formation in the western, central, and eastern part of the Nassfeld area (modified from Forke & Samankassou, 2000).

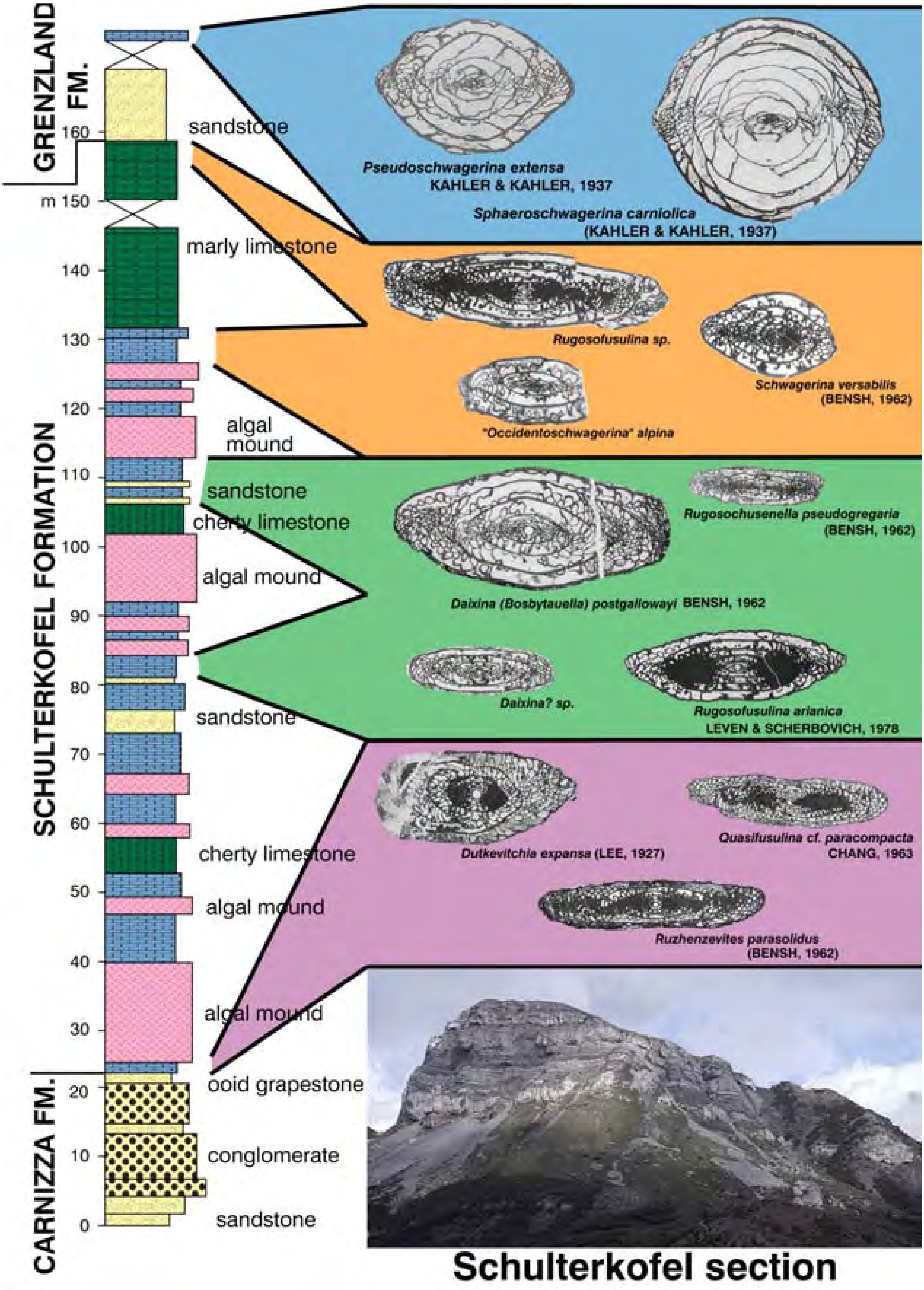


Fig. 8: Lithology and fusulinoidean fauna of the Schulterkofel Formation and basal Grenzland Formation at the Schulterkofel peak (2091 m) (after Forke, 2000).

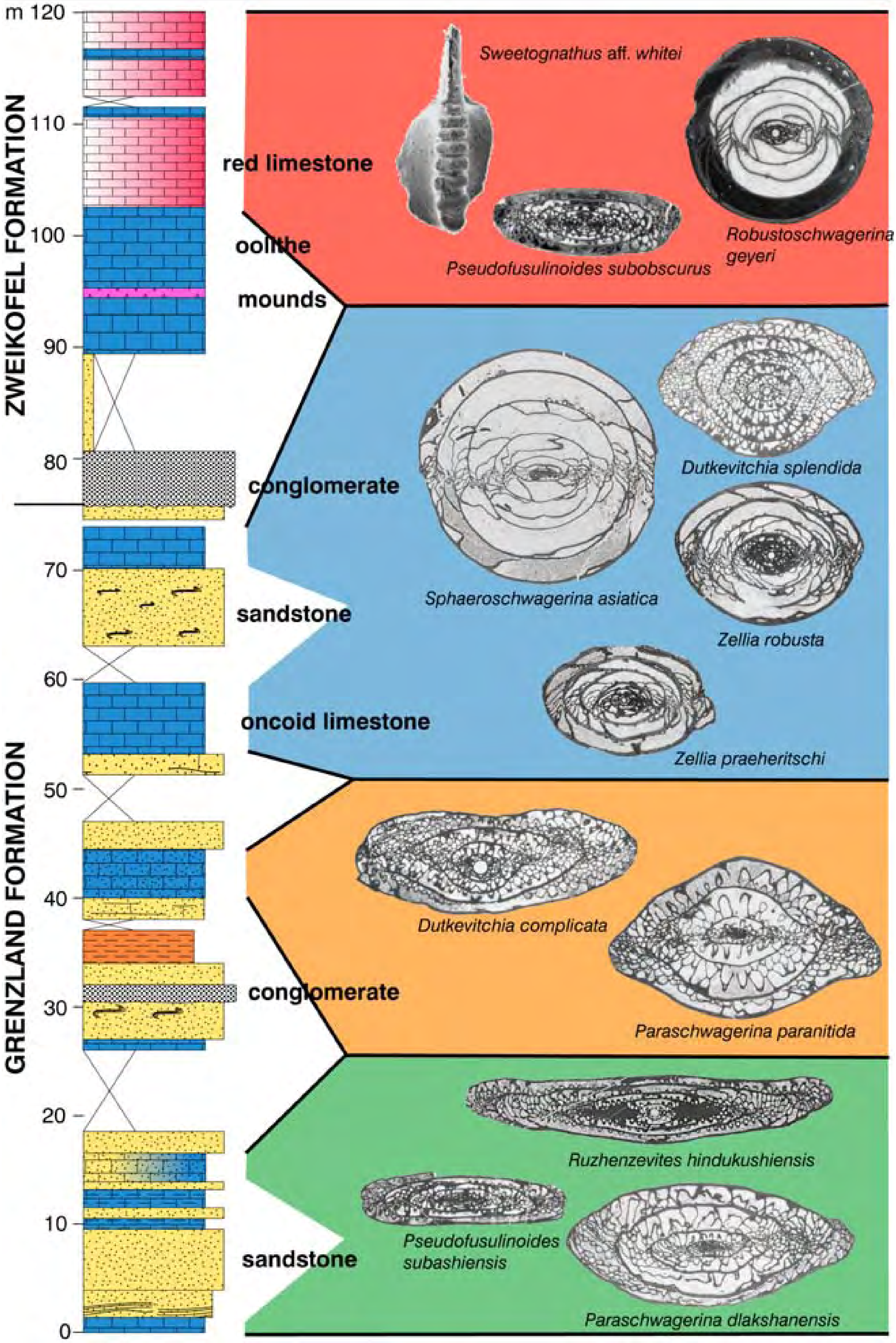


Fig. 9: Lithology and fusulinoidean fauna of the upper part of the Grenzland Formation and basal Zweikofel Formation (Rudnigalm-Trogkar area).

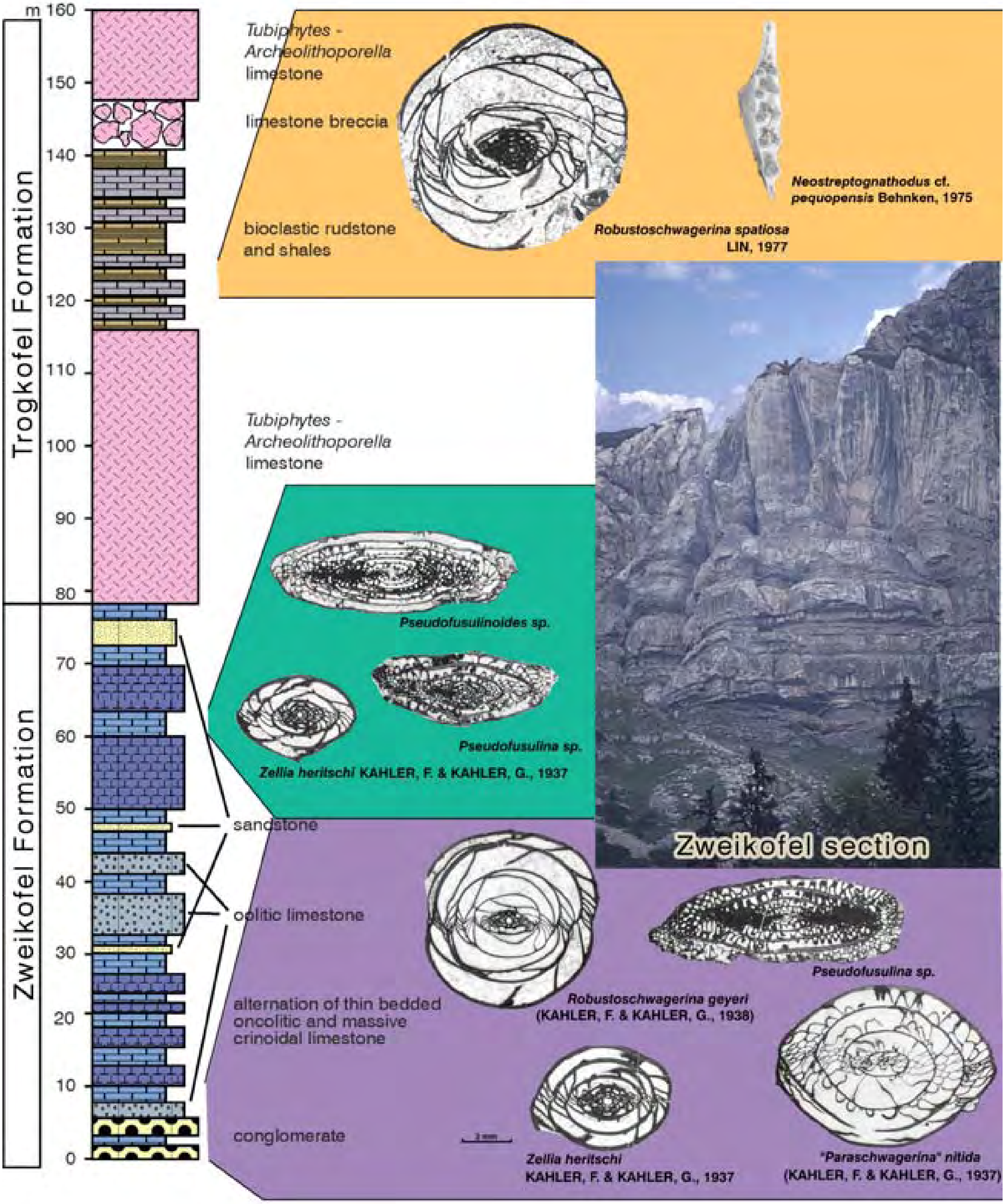


Fig. 10: Lithology and fusulinoidean/conodont fauna of the Zweikofel Formation at the Zweikofel peak (2059 m) (after Forke, 2000).

The faunal assemblages of the lower part indicate a lower? to middle Asselian, according to the presence of *Sphaeroschwagerina carniolica* and *Pseudoschwagerina extensa* (fig. 8). The upper part yields *Sphaeroschwagerina asiatica*, species of the *Paraschwagerina nitida* group, and first primitive *Zellia* and *Robustoschwagerina* (fig. 9).

Zweikofel Formation

Due to the three-fold subdivision of the Asselian (lower-middle-upper) and the disappearance of "inflated schwagerinids" at the beginning of Sakmarian in the Urals, the Zweikofel Formation has been correlated with the upper Asselian by Kahler (1986).

More recent publications have however shown that geographic barriers and/or changes in the oceanographic circulation pattern are responsible for the impoverished fusulinoidean faunas of the Urals. The presence of "inflated schwagerinids" with Sakmarian/Artinskian conodonts has demonstrated that these groups have much longer stratigraphic ranges in the Tethyan faunal realm. The Zweikofel Formation has been therefore correlated with the late Sakmarian-early Artinskian.

The Zweikofel Formation yields very rich fusulinoidean assemblages with abundant *Zellia*, *Robustoschwagerina*, *Paraschwagerina*, "*Pseudofusulina*", *Pseudochusenella*, a.o. Conodonts (*Sweetognathus* aff. *whitei*, *Diplognathodus*, *Mesogondolella bisselli*) are present in the lower part (figs. 9, 10).

Trogkofel Formation

The Trogkofel reef limestone is rather poor in fusulinoideans and the species diversity is low. The *Shamovella-Archaeolithoporella* cement boundstone obviously prevented fusulinoideans to thrive in this evironment. Rare occurrences in bioclastic interstices show a low diversity fauna. Schubertellids (*Schubertella*, *Biwaella*) are the most common constituents, together with representatives of certain "*Pseudofusulina*" ("*Leeina*" *fusiformis* group). The rare occurrences of *Robustoschwagerina spatiosa* together with a single conodont (*Neostrepto-gnathodus* cf. *pequopensis*) indicate late Artinskian for the Trogkofel Limestone (fig. 10).

Cyclic sedimentation and carbonate mounds

Late Paleozoic stratigraphic successions around the world are known for their strong cyclic character (Veevers and Powell 1987; Ross and Ross 1988, 1995). Most authors have attributed the synchronous and worldwide occurring cyclic sedimentation as well as the high frequency of sea-level fluctuations to glacial eustasy (associated with waxing and waning of the Gondwanan ice sheet; see Wanless and Shepard 1936; Crowell 1978; Heckel 1986, 1994; Veevers and Powell 1987). The Pennsylvanian and Permian succession of the Carnic Alps, thus, is an interesting candidate for the study of cyclic sedimentation processes. Furthermore, cyclothems in the Carnic Alps include numerous carbonate mounds, as do their counterparts in coeval basin (see Wahlman, 2000), providing the opportunity to explore these features at the same time.

Auernig Formation

The existence of Late Paleozoic depositional cycles has been recognized in the 19th century by Frech (1894) and Geyer (1896) studying the section of the Late Carboniferous Auernig Formation in the Nassfeld area. Here, repetitive alternations of marine carbonates (with fusulinids, algae, ostracodes, bryozoans, and brachiopods) and siliciclastics with fossil megaplants are exposed. Heritsch et al. (1934) gave a more detailed description of the alternating sedimentary rock record. The transgressive-regressive pattern has been termed "Auernig rhythm" by Kahler (1955).

Buttersack and Boeckelmann (1984) explained the cyclic patterns by changes in subsidence: Marine sediments were deposited during phases of low subsidence and low siliciclastic input whereas siliciclastics were shed to the basin during phases of high subsidence. Recent publications (Massari and Venturini 1990; Massari et al. 1991; Venturini 1990a, b, 1991; Krainer 1991, 1992; and Samankassou 1997), however, favor a cyclothem model and glacio-eustasy as the main controlling factor, similar to the interpretation drawn from cyclothems elsewhere (e.g., North American Midcontinent; Heckel 1986).

Cyclothems in the Auernig Formation are 10-30 m thick. Different types occur. The lithologies show rapid changes and the sequences exhibit clear transgressive (fining-upward) and regressive (coarsening-upward) tendencies.

The duration of one cyclothem is estimated to be ca. 40 k.y. (Massari and Venturini 1990). Krainer (1992) proposed 100 k.y. per cyclothem. As no continuous section of the entire Auernig Formation is exposed and the biostratigraphic resolution by fusulinids is well above the cyclothem duration, uncertainties remain as to the duration (similar to other cyclothems, e.g., that of the North American Midcontinent; see Heckel 1986, Klein 1990, and Yang and Kominz 1999).

The Auernig Formation records a wide spectrum of buildups (fig. 11):

(1) Auloporid corals and the alga *Rectangulina* were the dominant mound builders during the Kasimovian. These two types of buildups are limited to the lower part of the Auernig Formation and to the Carnic Alps generally.

(2) Algae were the dominant mound builders during Gzhelian. Mounds generally exhibit a higher diversity than those from the Kasimovian do. Except for phylloid algal mounds, all buildups comprise two or more fossil groups. Commonly, *Archaeolithophyllum*-bryozoan-brachiopods mounds are smaller (centimeter-scale) than mounds dominated by *Anthracoporella-Archaeolithophyllum* (meter-scale).

(3) The depositional environment was carbonate-siliciclastic dominated, under moderate water depth close to or just below wave base. Cooler-water fossil asso-

ciations consisting of bryozoans, brachiopods, and crinoids occur in rocks just above the mounds. Thus, the input of cool water is assumed to be a limiting factor of mound growth. Biodiversity is high despite limiting factors such as siliciclastic input and cooler temperatures (Samankassou 2002).

Schulterkofel Formation

Homann (1969) described four depositional cycles within the Schulterkofel Formation. The cycles are traceable basinwide, using mounds and cherty limestones as markers (Homann 1969) as well as similarities in microfacies and biotic association (Flügel 1974). Each cycle starts with siliciclastics, grading upward into bedded and massive algal limestones. Homann (1969) further documented the high-frequent sea-level fluctuations. Samankassou (1997) confirmed the 4 cycles - termed cyclothems because of the transgressive-regressive patterns of Homann (1969). The author assigned the incompleteness of cyclothems at some positions to local relief built by algal mounds and explained the high frequency and high amplitudes of sea-level changes, reflected in the rapid facies changes, by glacio-eustasy. As the cyclothems are fully subtidal, they can not be traced by subaerial exposure surfaces. The Schulterkofel Formation, representing about one fusulinid zone (*Daixina* (*B.*) *bosbytauensis-Daixina robusta* Zone), is composed of four cyclothems (Homann 1969; Samankassou 1997). The mean duration of one fusulinid zone is 1.3 to 1.6 Ma (Ross and Ross 1995), implying a mean duration of 0.3 to 0.4 Ma for each single cyclothem. This value is not overestimated, considering the inferred duration of 0.235 to 0.400 Ma for North American Midcontinent major cyclothems (Heckel 1986, 1994; cf. also Klein 1994 for discussion). The duration is too short for any event other than those driven by glacio-eustasy (Soreghan 1994; Dickinson et al. 1994; Heckel 1994). Furthermore, the repeated (cyclic) patterns are inconsistent with a tectonic cause as a major controlling factor.

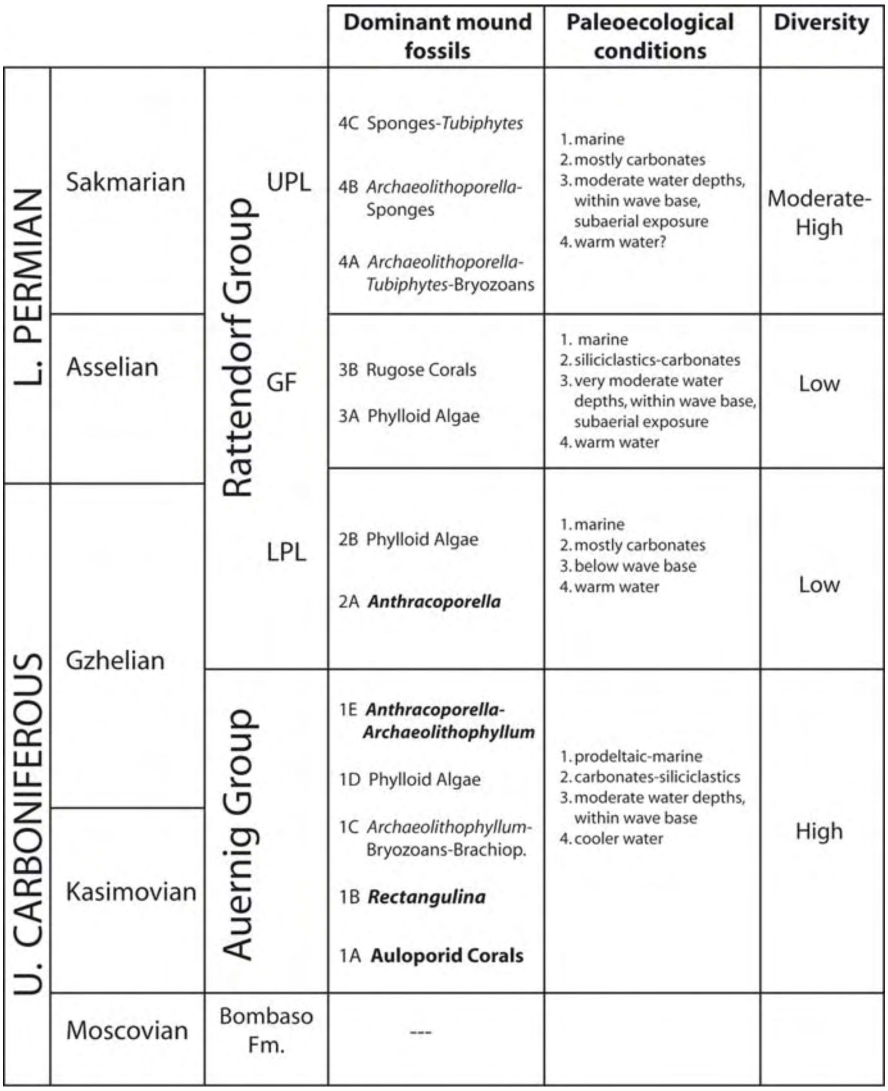
Both types distinguished in the Schulterkofel Formation, *Anthracoporella* and phylloid algal mounds, are nearly monospecific. The thickest mounds of the entire interval analyzed occur in the Schulterkofel Formation. The depositional environment was typically carbonate dominated, and water depths were deeper than that of the mounds in the Auernig Formation. Warm-water conditions are inferred for the Schulterkofel Formation based on the abundance of ooids and aggregates (Samankassou, 2003).

Mounds occur in the transgressive phase of the Schulterkofel Formation cyclothems (Samankassou 1997). Thick mounds, resulting from increased accommodation space, indicate that mounds kept pace with sea level. Mound growth was terminated by drowning through sea-level rise ("Shroud Facies" draping *Anthracoporella* mounds; Samankassou 1999).

Grenzland Formation

The predominantly siliciclastic Grenzland Formation is characterized by shallowing-upward sequences of up to 10 m thickness. Paleosols, fracture fillings and collapse breccia occur within sections exposed at the Zweikofel, proving intervals of subaerial exposures (Venturini 1990a, b; Samankassou 1997). Sea-level fluctuations are evident.

The two mound types encountered in the Grenzland Formation are thin, of low diversity, and were constructed



				Dominant mound fossils	Paleoecological conditions	Diversity
L. PERMIAN	Sakmarian	Rattendorf Group	UPL	4C Sponges-*Tubiphytes* 4B *Archaeolithoporella*-Sponges 4A *Archaeolithoporella*-*Tubiphytes*-Bryozoans	1. marine 2. mostly carbonates 3. moderate water depths, within wave base, subaerial exposure 4. warm water?	Moderate-High
	Asselian		GF	3B Rugose Corals 3A Phylloid Algae	1. marine 2. siliciclastics-carbonates 3. very moderate water depths, within wave base, subaerial exposure 4. warm water	Low
U. CARBONIFEROUS	Gzhelian		LPL	2B Phylloid Algae 2A ***Anthracoporella***	1. marine 2. mostly carbonates 3. below wave base 4. warm water	Low
		Auernig Group		1E ***Anthracoporella*-*Archaeolithophyllum*** 1D Phylloid Algae 1C *Archaeolithophyllum*-Bryozoans-Brachiop. 1B ***Rectangulina*** 1A **Auloporid Corals**	1. prodeltaic-marine 2. carbonates-siliciclastics 3. moderate water depths, within wave base 4. cooler water	High
	Kasimovian					
	Moscovian	Bombaso Fm.		---		

Fig 11: Distribution of algal mounds in the Upper Carboniferous/Lower Permian succession of the Carnic Alps (from Samankassou, 2003).

by phylloid algae and rugose corals. A very shallow, siliciclastic-dominated depositional environment is inferred. The broken fossils and presence of ooids may indicate shallow-water conditions, above or close to the wave base. Intervals of subaerial exposure evidenced by breccia, collapse, and fractures are recorded at the tops of the mounds. Warm-water conditions are inferred (Samankassou 2003).

Zweikofel Formation

The Zweikofel Formation exhibits shallowing-up cycles of 5-7 m thickness. Cycle boundaries are traceable in some sections. The cyclic patterns differ within the basin, but the different sections could be correlated using the frequently occurring fusulinids (Forke 2002). Ooid- and oncoid-bearing facies and frequent fusulinids (especially *Zellia*) are characteristic features to all studied sections. Algal biostromes, or small buildups are restricted generally to the lower part of the Zweikofel Formation (e.g. Trogkar, Garnitzenbach). Variations in microfacies, biotic associations and geochemical composition have been pointed out by Flügel (1974). The lateral variations in cyclic patterns could be explained by a differentiated shelf and sea-bottom morphology at time of deposition. High-frequent sea-level fluctuations are superposed on these morphological variations (Samankassou 1997).

Zweikofel Formation mounds have more diverse fossil associations than those of the Grenzland Formation and grew in moderate water depth, below wave base. Subaerial exposure horizons are common at the top of the buildups, recording sea-level falls below actual sea floor or mound accretion to sea surface. The latter seems unrealistic as mounds lack a shallowing-upward trend in vertical facies evolution. Furthermore, subaerial exposure directly atop subtidal mound facies implies a rapid sea-level fall.

Using the lower Permian fossil associations from the Midcontinent North America (Toomey and Cys 1979; Wahlman 1988, 2000) for comparison, warm-water conditions can be inferred. The higher diversity may be explained by the overall trend of increasing biodiversity from the latest Carboniferous to the early Permian (Wahlman 2000).

Trogkofel Formation

The Trogkofel Formation does not exhibit cyclic patterns, most part of it consisting of massive limestone. The Trogkofel Formation includes reefs that differ from those of the previous formations. Large parts of the massive carbonates correspond to "*Shamovella*/*Archaeolithoporella*-cement reefs" (Flügel 1981). These types are the thickest reefs of the Late Paleozoic sequence in the Carnic Alps. They are characterized by the interaction of encrusting organisms (algae, sponges, bryozoans) and synsedimentary cementation, supported by microbial and algal activities forming an organic framework (Edwards and Riding, 1989). This reef type exhibits strong similarities with the depositional and diagenetic fabrics of the Permian Reef Complex in Texas and New Mexico. Reefs of the Trogkofel Formation are not included in the excursion program, but they will be in vicinity of different stops.

Carbonate buildups: Summary and open questions

Biodiversity is highest in carbonate-siliciclastic environments and moderate water depths close to wave base. Surprisingly, the higher diversity mounds occur in the Auernig Formation that was influenced by cool water. As biodiversity is supposed to be lower in cool-water settings, these results do not fit previous models. The thickest mounds occur in intervals of highest accommodation space (Schulterkofel Formation), where the principal mound constructor was the dasyclad alga *Anthracoporella* (Flügel 1987, Krainer 1995, Samankassou 1998). Mounds of the algae *Rectangulina*, *Anthracoporella* and of auloporid corals are only known from the Carnic Alps. The reason for this limitation is not clear; more studies are needed to evaluate the full geographic extent of these mounds.

No evidence of vertical zonation during mound growth was observed. Vertical changes in sediments and fossils mirror extrinsic controls, specifically changes in water temperature, sea-level fluctuations, and siliciclastic input, rather than reflecting ecological succession. These unstable physical factors, which imply unstable ecological parameters, may partly explain the dimensions of the mounds, the domination of buildups by opportunistic biota (mainly algae), and the overall low biodiversity of buildups.

The basal deposits at the contact between pre-Variscan basement and post-Variscan sedimentary cover in the Carnic Alps

According to Venturini (1990), the Variscan Orogeny is characterized by asymmetric fold- and thrust tectonics with N 120°-140° E oriented folds and faults, due to a N 210° E trending steady stress. The generally S-verging main structures are overprinted by a N-verging backfold system. Additionally, fault tectonics has affected the areas, probably related to the uplift of the Paleocarnic chain during the Moscovian. In a third deformational phase, km-sized open antiforms developed along N 120° striking thrust planes, which overprinted older structures.

Vai (1979) estimated that the Variscan compression resulted in a 75-80% crustal shortening. This value would be even higher, if the Alpine tectonics (with nappe structures of post-Variscan deposits) is additionally considered.

The complex Variscan tectonics resulted in facially and stratigraphically differing sequences within a close distance. According to the known data, it can be assumed that the Tethyan sea transgressed over a small-scaled structured landscape, rather than a peneplain. This assumption is confirmed by biostratigraphic data from the basal deposits above the erosional surfaces, which supplied different ages from early Kasimovian in the area of Lake Zollner and Auernig, middle Kasimovian at Cima

Fig. 12: Angular unconformity at Collendiaul (stop 1 of excursion)

Val di Puartis to late Kasimovian at the Monte Cavallo (Rosskofel)-Creta di Rio Secco (Trögl) massif.

From the west (Collendiaul) to the east (Nassfeld), the contact between pre-Variscan basement and post-Variscan cover is characterized by the following main lithologies.

Sandy shales above Devonian lydites (Fig. 12)

Classical angular unconformity at Collendiaul south of the Rösser Hütte. Moderately steep dipping sandy shales (ss 160/50 E) lying discordantly above steep dipping, almost vertical, light-colored, bedded radiolarites (ss 145/75 E) of the Zollner Formation (Upper Devonian). The basal beds show a cm-deep erosional surface without any traces of transported extraclasts (Fenninger et al., 1976).

Lydite breccia/conglomerate above Silurian cherts (Fig. 13)

Sections at the right bank of the outflow of the Lake Zollner, surroundings of Lake Zollner, and Leitenkogel. Up to 20 m thick lydite breccias/conglomerates, which are clast-supported in the lower part and matrix-supported above. In all localities the contact to the underlying pre-Variscan basement is present, which is composed of Silurian-Devonian deposits of the Bischofalm and Zollner Formations (Fenninger et al., 1976, Schönlaub, 1985a). After the lithostratigraphic subdivision of Venturini (1990) the basal lydite breccias/conglomerates are called the "Pramollo Member" of the "Bombaso Formation". However, the type section of the "Pramollo Member" belongs to the pre-Variscan Hochwipfel Formation and do neither lithologically, nor stratigraphically correlate with the basal lydite breccias/conglomerates in the surroundings of Lake Zollner.

Therefore, the name "Collendiaul Formation" has been proposed (Schönlaub & Forke, 2005) for the widespread and well mappable basal breccias and conglomerates and the section on the right bank of the outflow of Lake Zollner has been defined as type section. The base of the lithostratigraphic unit is easily recognizable with the erosional unconformity on the pre-Variscan basement, and the top of the unit is defined by the transition to the basal siltstones and shales of the overlying Auernig Formation ("Meledis" Member).

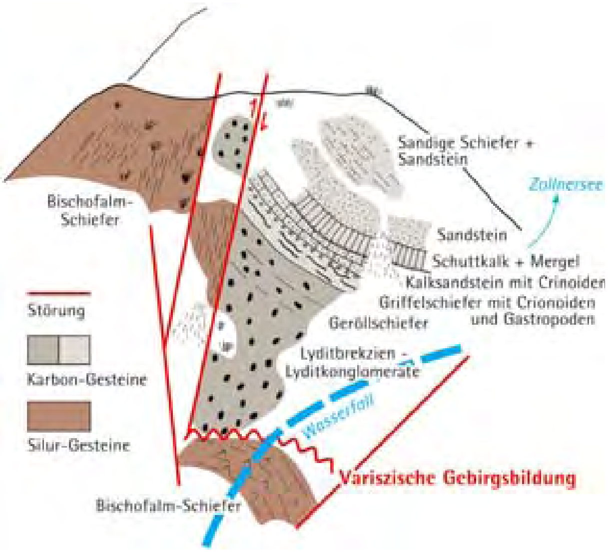


Fig. 13: Section on the right bank of the outflow of Lake Zollner with sketch-map.

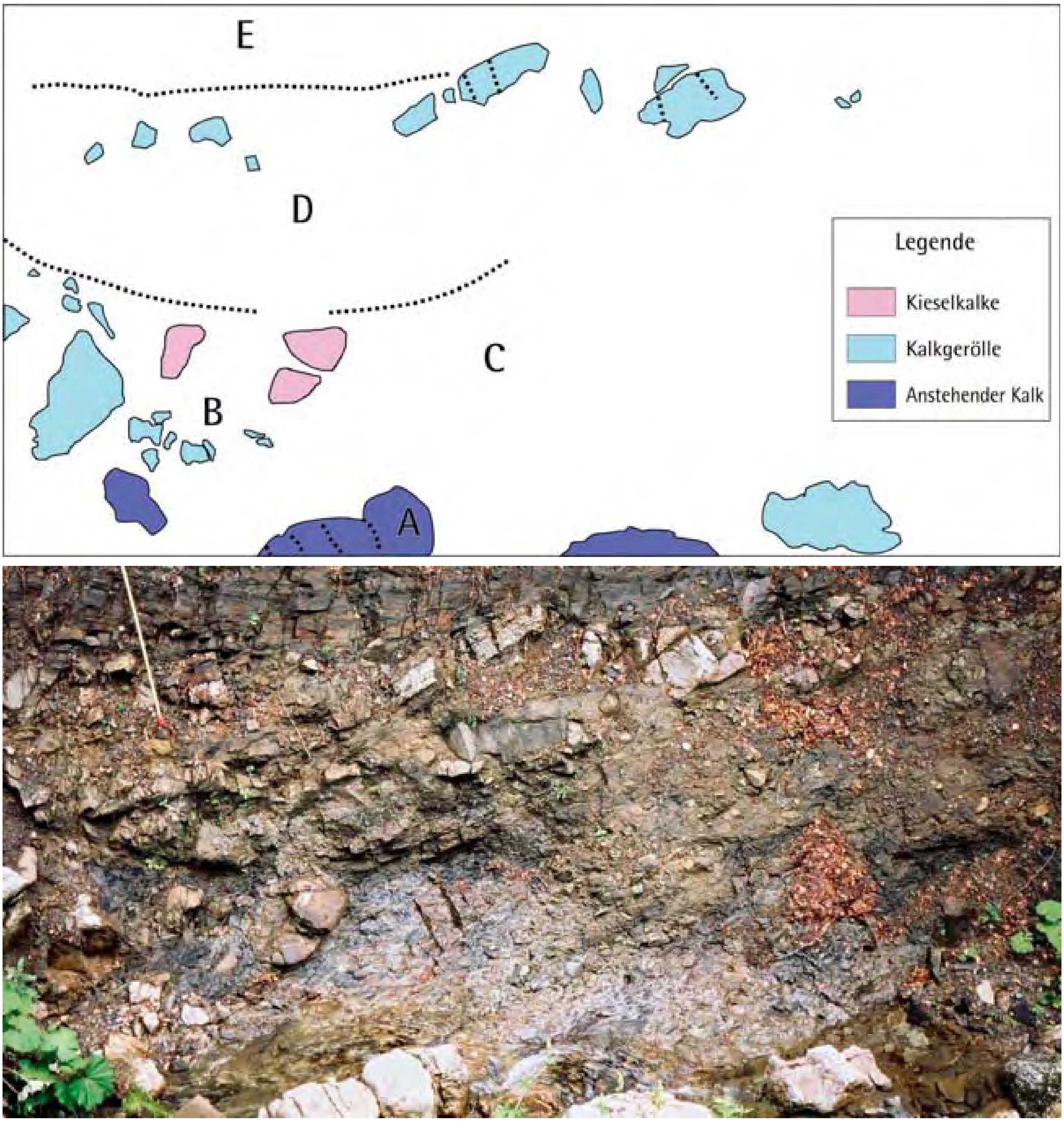


Fig. 14: Basal post-Variscan succession at the Malinfier creek with sketch map. below: outcrop after cleaning in the year 1992. above: A - top of the Lower Devonian limstones, B - reworked limestone pebbles, C - pebble-bearing horizon, D - channel deposits with angular sandstone and lydite pebbles, E - fine sandstones with intercalated layers of pebbles and siltstones of the "normal" sedimentation.

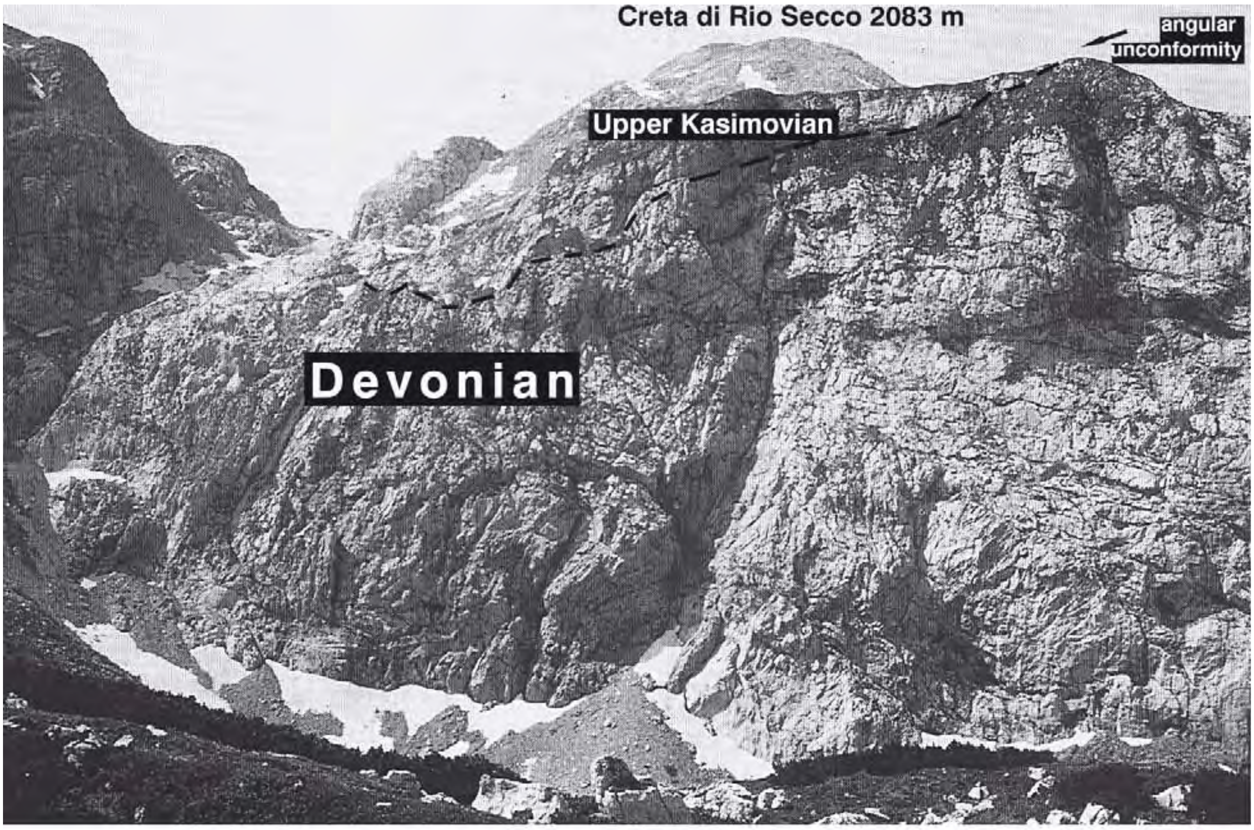
Limestone breccias on Devonian limestones (Fig. 26)

Section E of Cima Val di Puartis in about 1750 m altitude. The basal breccia is rich in limestone clasts, which derive from the underlying Devonian limestones. The locality has been described and figured in several publications (Venturini, 1990; Krainer, 1990, 1992; Flügel & Krainer, 1992, Davydov & Krainer, 1999). The 10-15 m thick basal breccia has been interpreted as fault-related submarine debris flow of a fan-delta, grading into matrix supported fine conglomerates and fossiliferous sand-/ siltstones (basal Auernig Formation). The basal breccia represents the calcareous analog to the siliceous Collendiaul Formation and has been named Malinfier (Marchbach) Formation.

Limestone breccias are also known from several outcrops along small ravines and along the street from the Straniger Alm to the Waschbühel ridge, but developed predominantly as fine conglomerates (Fenninger et al., 1976, Schönlaub, 1991).

Pebble-bearing shales above Devonian limestones (Fig. 14)

Section in the Malinifier (Marchbach) ravine south of the Straniger Alm at an altitude of 1570 m. The contact is



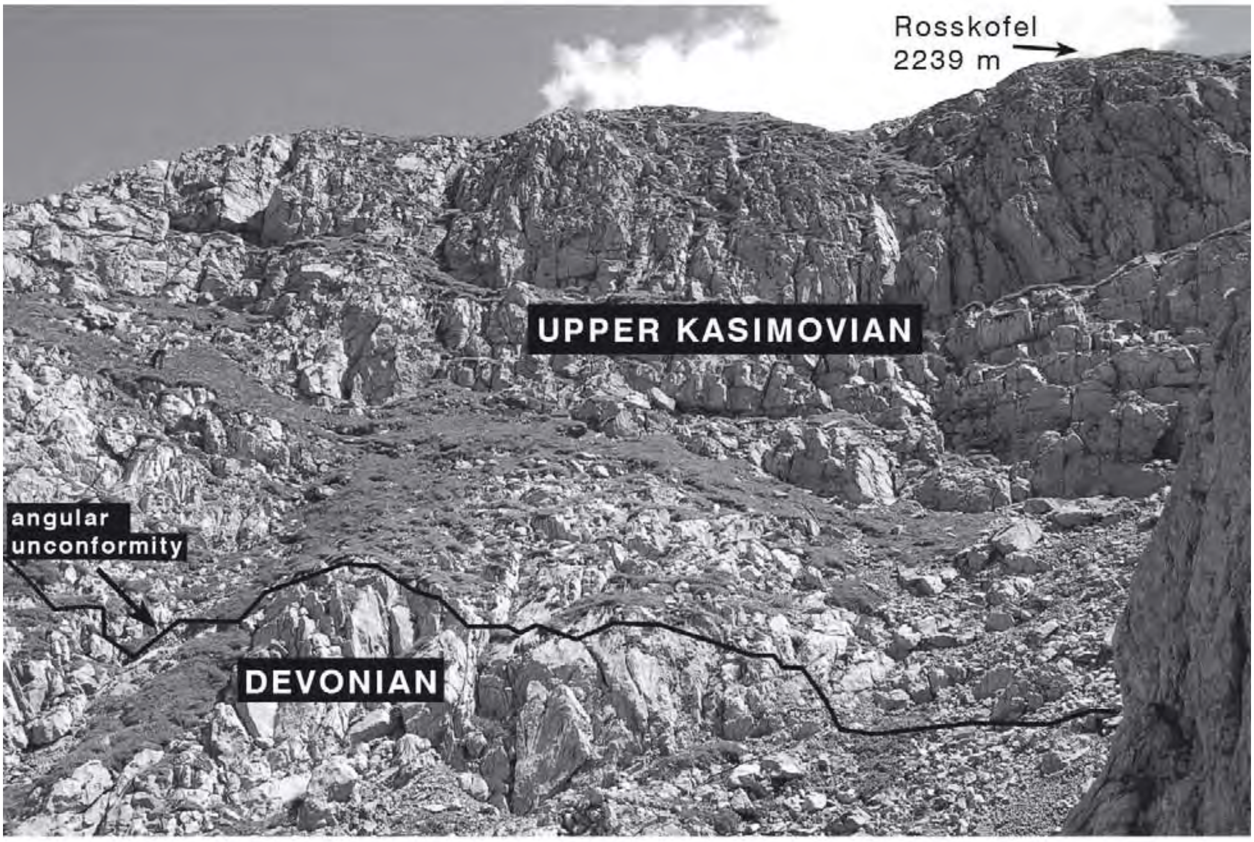


Fig. 15: Limestone to limestone contact (Devonian/Upper Carboniferous) at the northern cliff of the Creta di Rio Secco (Trögl) and at the southern side of Monte Cavallo (Rosskofel).

exposed about 250m south of the Italian border (Fenninger et al., 1976). Moderately steep dipping, coarse-bedded limestones of the Lower Devonian (ss 110/60 N) disintegrate laterally and vertically into m-sized isolated blocks floating in a matrix of silty shales. Larger limestone blocks are restricted to the lower 2 m.

Above the basal horizon follow pebble-bearing shales with reworked greywacke, lydite, sandstone, siltstone, and limestone pebbles. They are embedded as loosely packed, poorly sorted, subrounded clasts up to 12 cm in a silty-sandy matrix.

Channel deposits (1.3 m deep and 3.5 m wide), eroded into darkbrown to black silty shales. The sediment infilling consists of coarse, angular pebbles (lydite and sandstone) at the base, and sandstones with lydite, limestone and sandstone clasts above. With a sharp discontinuity follow shales, a 60 cm thick pebble-bearing horizon laterally grading into sandstones. The matrix is fine brecciated to sandy, pebbles are predominantly sandstone.

The upper part of the succession can be subdivided into the following units:

10 cm black shales
40 cm densely pack pebble layer
90 cm black siltstone with intercalated pebble-layers
32 cm platy sandstones (ss 40/42 NE)
50 cm black siltstones with isolated pebbles
70 cm densely packed, poorly sorted pebble-bearing horizon.

The outrop is terminated with black siltstones. In the reported section of Krainer (1990), ca. 50 m higher along the creek, several clayey algal limestone beds, thin layers of massive limestones, a brachiopod coquina, and an aulo-porid coral mound has been desribed above.

Whereas the lower part with the coarse blocks belong to the Malinfier Formation, the upper part with fine clastics has been ascribed to the basal Auernig Formation.

Limestone to limestone contact (Fig. 15)

Creta di Rio Secco (Trögl)-Monte Cavallo (Rosskofel) massif. A detailed description of the section on the southern side of the Rosskofel summit has been provided by Fenninger et al., 1976. The boundary between the Devonian-Lower Carboniferous limestones of the pre-Variscan basement and the Upper Carboniferous cover is marked often only by a color change from darkgrey to yellowish, or a thin stylolithic clay-rich seam. The 4-5 m thick massive limestone at the base grade into grey, approx. 20 m thick well bedded limestones with occasional chert nodules, overlain on top of the sequence by fine quartz conglomerates.

An almost identical situation can be found at the northern slope of the Creta di Rio Secco massif (Forke, 2001). Upper Carboniferous sediments, gently dipping to SE, rest with an uneven (probably karstic) surface on the folded Devonian limestones. The contact between Upper Carboniferous and Devonian sediments is difficult to trace in the steep cliff on the northern slope of Creta di Rio Secco. The transition is marked by a distinct change of color of the limestones. The underlying Devonian limestones in the section SEC are massive, dark-grey with rare macrofossils (mostly *Amphipora*). The overlying Upper Carboniferous deposits are composed of a yellowish, monomict limestones breccia. The limestone clasts consist of recrystallized wacke- to packstones with common phylloid algae, smaller foraminifers, and rare fusulinoideans. The individual clasts show a rather good fitting, and are cemented by clear, yellowish sparite. It probably represents a collapse breccia through a later partial dissolution of the limestones.

The upper part of the section starts with 7.5 m of massive limestones (wackestone) with various fossil remains (echinoderms, fusulinoideans, and algae). It is followed by 7 m of thin-bedded limestones (wacke- to packstone) with abundant echinoderm and bryozoan debris. The upper 25 m of the section are composed of massive wackestones, yielding diverse fossil assemblages with crinoid ossicles, bryozoans, fusulinoideans and subordinate algae, brachiopods, and ostracods. The matrix displays a strong bioturbation (worm tubes). In places, small biohermal structures with tabulate corals, coralline sponges and dasyclad algae (*Anthracoporella*) were identified in the field.

Dark-red patches of silt (quartz) and clay material occur with a spotty distribution in the massive limestones of the upper part of the section. Although not studied in detail, they seem to represent infillings of clastic material during a later karstification process of the limestones. On top of the section, limestones are locally covered by sandstones.

In general, the section shows a deepening trend from algal dominated wacke- to packstones at the base to mud-dominated sediments, rich in echinoderm and bryozoan debris.

Limestone breccia above Hochwipfel Formation (Fig. 16, 17)

The Auernig Limestone Breccia is exposed about 100m WNW of the Auernig Alm over a distance of ~1km to the ESE. It crops out at the street curve and the mountain slope above, along a distinct ridge forming a 30 m cliff in the forest, further to the upper Auernig creek and Sorgente creek, which both drain into the Bombaso river.

The locality has been described already by Selli (1963) and Venturini (1990). Whereas Selli has assigned the limestone breccia to the “Pizzul Formation”, Venturini regarded the sequence as an equivalent of the Malinfier Member, resting on his Pramollo Member. Both together represent the Bombaso Formation. According to his fusulinoidean data he assumed a late Kasimovian-early Gzhelian age for the limestone breccia.

The Auernig Limestone Breccia consists of coarse- and fine-grained clasts. The individual limestone clasts can often hardly be seen in the field due to the weathered surface covered by lichens, but are clearly revealed in thin sections.

The thickness of the breccia varies from 12 m on the lateral sides to more than 30m in the cental part (SE of the Auernig Alm).

Around the Auernig Alm the lower part of the sequence consists of a bedded, coarse breccia. The middle part is well-bedded, fine-grained, composed of rounded cm-sized extraclasts, followed by yellowish, fine-grained, and indistinctly bedded limestones.

In the first ravine to the SE, the lower part is represented by angular, m-sized limestone blocks, interstices are filled with finer clasts and silt. It is followed by bedded limestone with extraclasts and another coarse limestone breccia.

In the second ravine, about 250m ESE from the Auernig Alm, the limestone breccia is already reduced to about 20m thickness. Macroscopically, breccia layers are not visible in this grey and reddish, massive to indistinctly bedded limestones, but have been revealed in thin sections. Mixed conodont faunas from Upper Devonian and Lower Carboniferous confirm the composition of different limestone clasts.

E of the second ravine the limestone breccia continued along a distance of about 150m, but does not reach the third ravine. Further to the east, siltstones with thin interlayers of Anthracoporella-bearing marls and clay-rich limestones rest discordantly on shales and debrites of the Hochwipfel Formation.

Characteristic of the Hochwipfel Formation are the repetitive clast-supported debris flows and matrix-supported mudflow layers, which are interbedded between platy, massive, partly graded sandstones and dark-grey shales. The up to 30m thick layers yield well rounded, but poorly sorted clasts (up to 50 cm in diameter) of sandstone, lydite, quartz, and common limestone clasts. Beside the reworked Devonian to Lower Carboniferous limestones, "exotic" oolithe clasts are present, which have been described by Schönlaub & Flügel (1990) to be derived from a peritidal shelf platform. Identified fossils in the various limestone clasts are goniatites, corals, foraminfers, algae, crinoids, and common conodonts (e.g. *Paragnathodus nodosus*, *Gnathodus bilineatus bollandensis*, *Gn. girtyi*, *Cavusgnathus naviculus*)). In the sandstone beds, macroplants (*Archaecalamites*) and unidentified stem remains have been encountered.

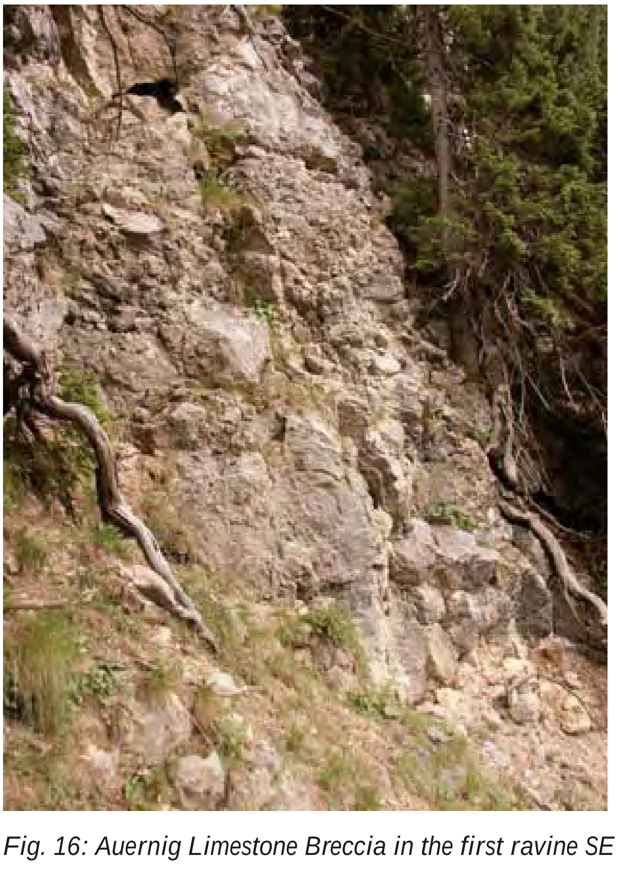
The siliciclastic succession has an exposed thickness of 400m and represents turbidites, intercalated by submarine debris flows and mudflows. They developed from high-densitiy gravity flows, which have been shedded temporarily and locally from an uplifting metamorphic hinterland across a shelf platform into a Lower Carboniferous flysch basin.

Similar successions of the Hochwipfel Formation are known from the southern side of the Hohe Warte north of the Marinelli Hütte, east of the upper Tschintemunt Alm in the Angerbach valley, between Köderhöhe and Laucheck, south of the Frondell Alm, south and southwest of Hochwipfel. (Schönlaub, 1985c, 1987). They most probably represent submarine channel deposits due to the limited occurrences, the grain structure, and rock composition.

However, it is not yet clear, whether the succession represents a submarine deep sea fan, or was deposited along the basin slope.

Age of the Auernig Limestone Breccia

From all localities conodont samples were taken, which yield predominantly mixed faunas of the late Upper Devonian to the *Scaliognathus anchoralis* Zone of the late Tournaisian. Exceptions are some large *Amphipora*-



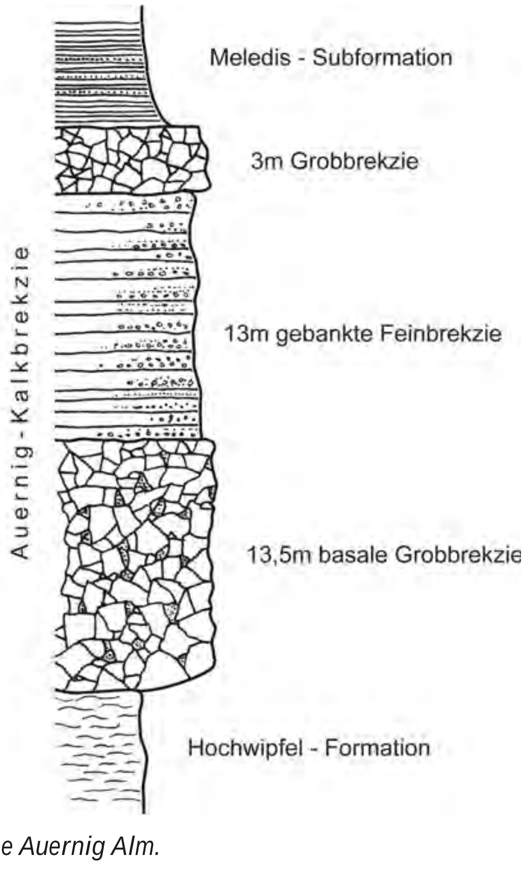


Fig. 16: Auernig Limestone Breccia in the first ravine SE of the Auernig Alm.

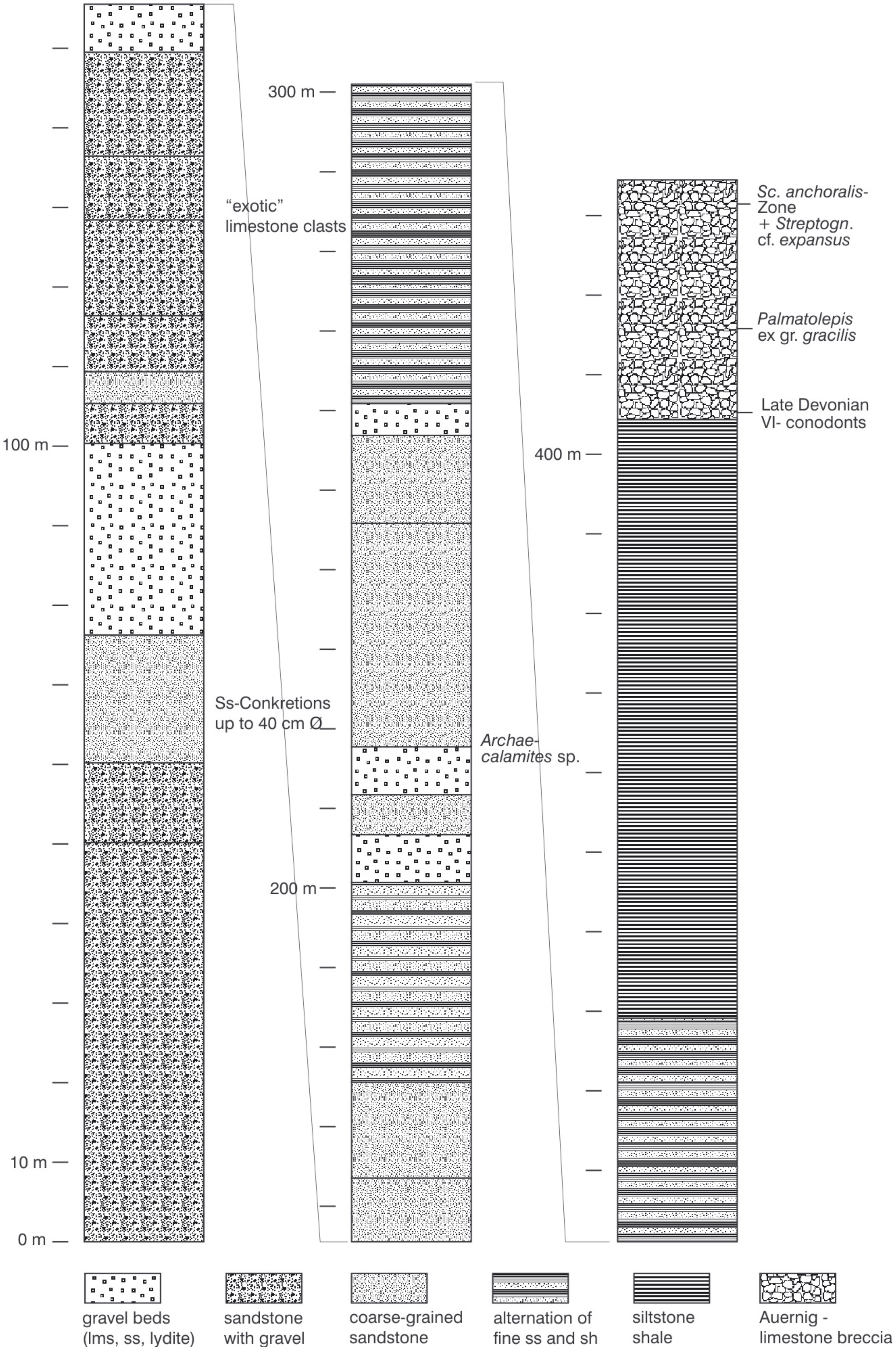


Fig. 17: Section of the Hochwipfel Formation below the Auernig Limestone Breccia in the first ravine SE of the Auernigalm.

bearing limestone clasts, which may represent late Middle to early Late Devonian.

Of particular interest are the uppermost parts of the limestone breccia, which yielded conodonts and sporadic fusulinoideans in the interstices. The presence of *Idiognathodus* cf. *expansus*, *Swadelina*? cf. *makhlinae*, and *Fusulina* (*Quasifusulinoides*) sp. indicates at least lower Kasimovian (Krevyakinian) for the formation of the Auernig Limestone Breccia.

Interpretation

The derivation of the large limestone blocks needs a further explanation. They probably represent a proximal fan-like debris flow with minor distances of transport. The Rosskofel-Malurch massif consisting of a Devonian-Lower Carboniferous succession can be considered as a source area for the blocks. Of particular interest is the inverse succession, which has been reported by Spalletta (1981) at the NE foothill with Lower Carboniferous limestone intercalations. The overturn must be a result of the Variscan tectonics, as evidenced by the flat-lying Upper Carboniferous deposits on top of the Rosskofel massif.

The lense-like geometry of the Auernig Limestone Breccia between the underlying Hochwipfel Formation and the overlying Auernig Formation, led us to the interpretation of an extensive fan deposit along the foothill of the escarpment of the Rosskofel-Malurch massif. The limestone clasts are probably the product of rock slides during the tilting of the huge Rosskofel carbonate body. As a result of high relief energy and enduring uplift the material has been transported into the basin. During the incipient Upper Carboniferous transgression the material has been cemented and interstices are filled with fine material, until the typical “Auernig” sedimentation took place with the alternation of shales, sandstone, and limestones.

Part II Field Trip

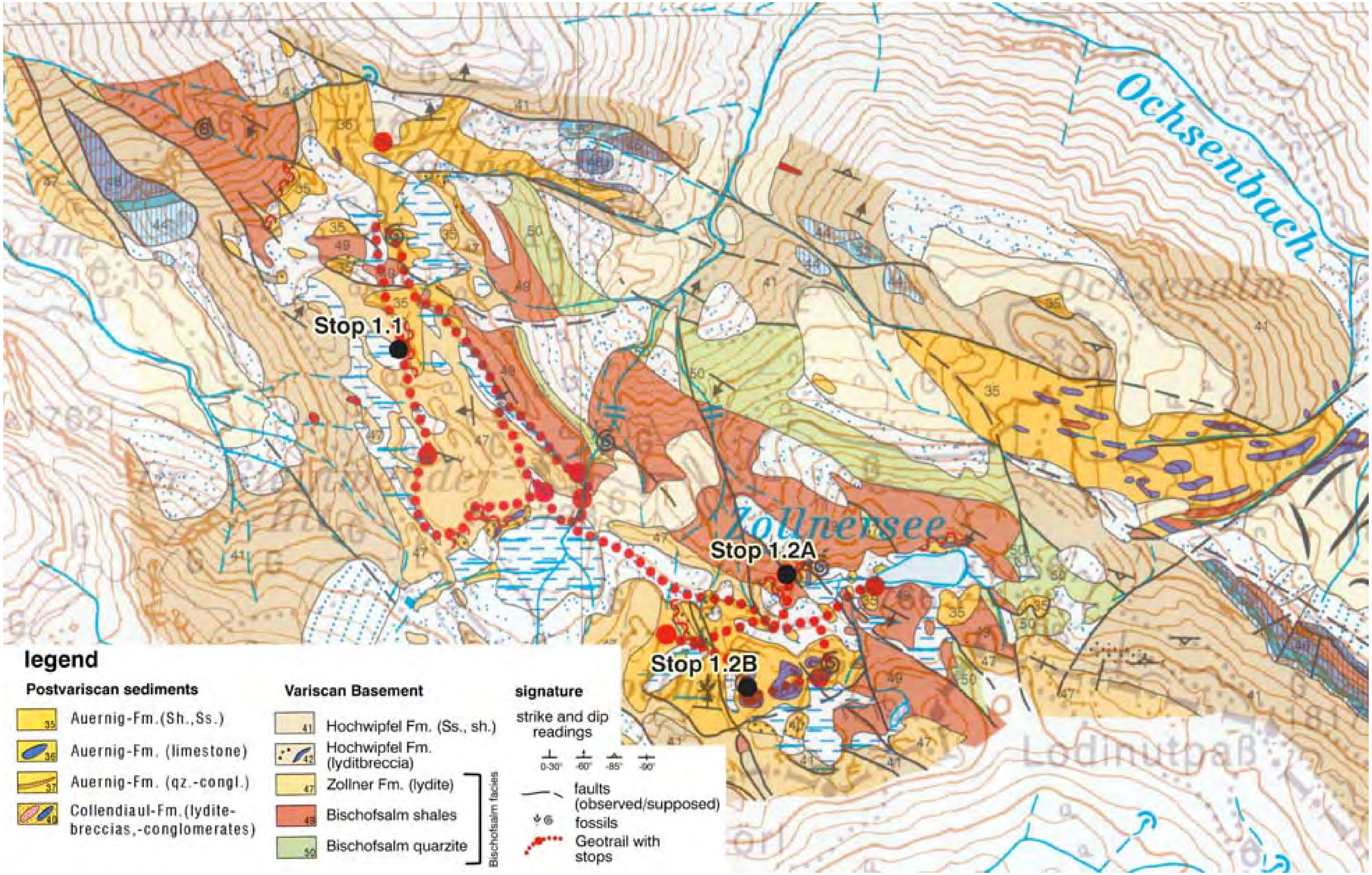


Fig. 18: Geological scetch-map of the area around Lake Zollner with stops during the excursion.

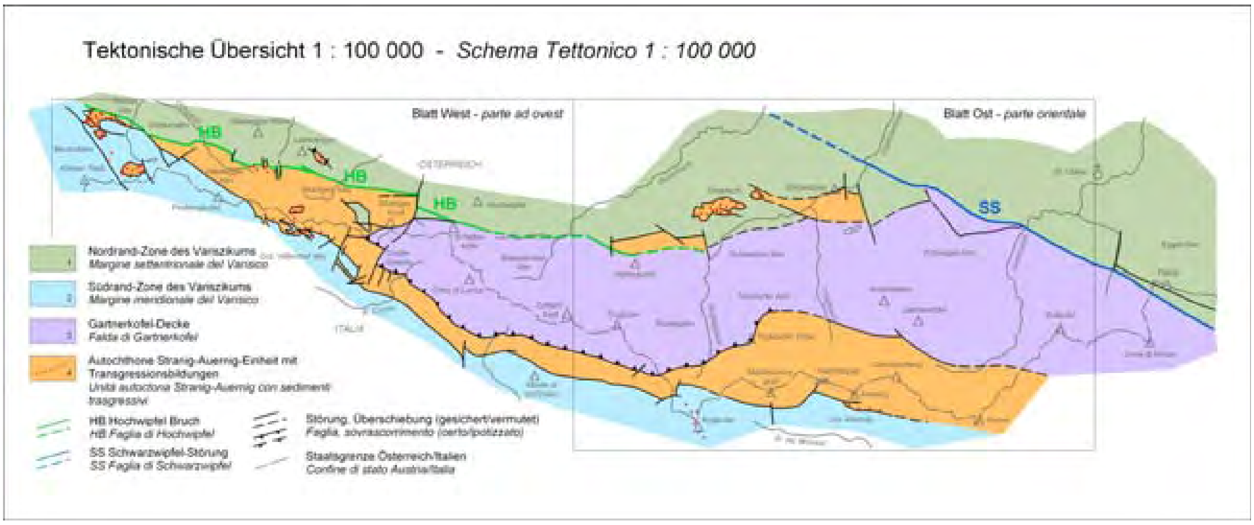


Fig. 19: Tectono-sedimentary scetch-map of the post-Variscan sedimentary basin of the Carnic Alps.

Day 1 (31. July 2006)

Stop 1.1 Collendiaul south of Zollnerhöhe

ÖK sheet 197, Kötschach, 13°4'1"E/46°36'33"N; Geological Map Kötschach 1:50.000, 1:10.000 (Schönlaub, 1985c)

Angular unconformity between Devonian lydites of the Zollner Formation and basal clastics (sandstones, shales) of the Auernig Formation (cf. p. 20, fig. 12).

Stop 1.2A Right bank of the river outflow west of Lake Zollner (section WF).

ÖK sheet 197, Kötschach, 13°36'07"E/46°37'05"N; Geological Map Kötschach 1:50.000, 1:10.000 (Schönlaub, 1985c)

Lydite breccias (Collendiaul-Formation, Uppermost Moscovian?-Lower Kasimovian) resting with an angular unconformity on Silurian Bischofalm shales. Above are shales, limestones, and sandstones of the basal Auernig Formation (Lower Kasimovian, Krevyakinian) (cf. p. 20, fig. 13, 20).

Siltstone – Mudstone

The lydite breccias of the Collendiaul Fm. are overlain by about 5 m of dark-brown, thin-bedded to fissile shales. In the lower part, limestone nodules occur occasionally. In the middle part, thin siltstone and sandstone lenses are intercalated. The shales become fossiliferous in the upper part with small crinoid ossicles and shell fragments. The uppermost few centimeters are composed of a black, very fine-grained and soft mudstone.

Bedded, impure limestone with shale intercalations

The 2 m thick unit consists of an alternation of 10-20 cm thick limestone beds and dark shales. Centimeter-sized extraclasts (radiolarian cherts of the underlying Zollner Fm.) occur in the limestones. They consist of bioclastic wackestone and packstone with high diverse fossil content. The relative biodiversity seems to increase upwards. Many bioclasts are recrystallized; some are broken. Stylolites occur in some layers.

Layers with algal wackestone alternate with bioclastic packstone, often showing a sharp contact. indicating possible storm-influences. The limestones, therefore, probably represent tempestites.

Sandstone

The limestone – shale alternation of the underlying unit is followed by several meters of massive, crude and indistinctly laminated sandstones.

Fossil content (fig. 20):

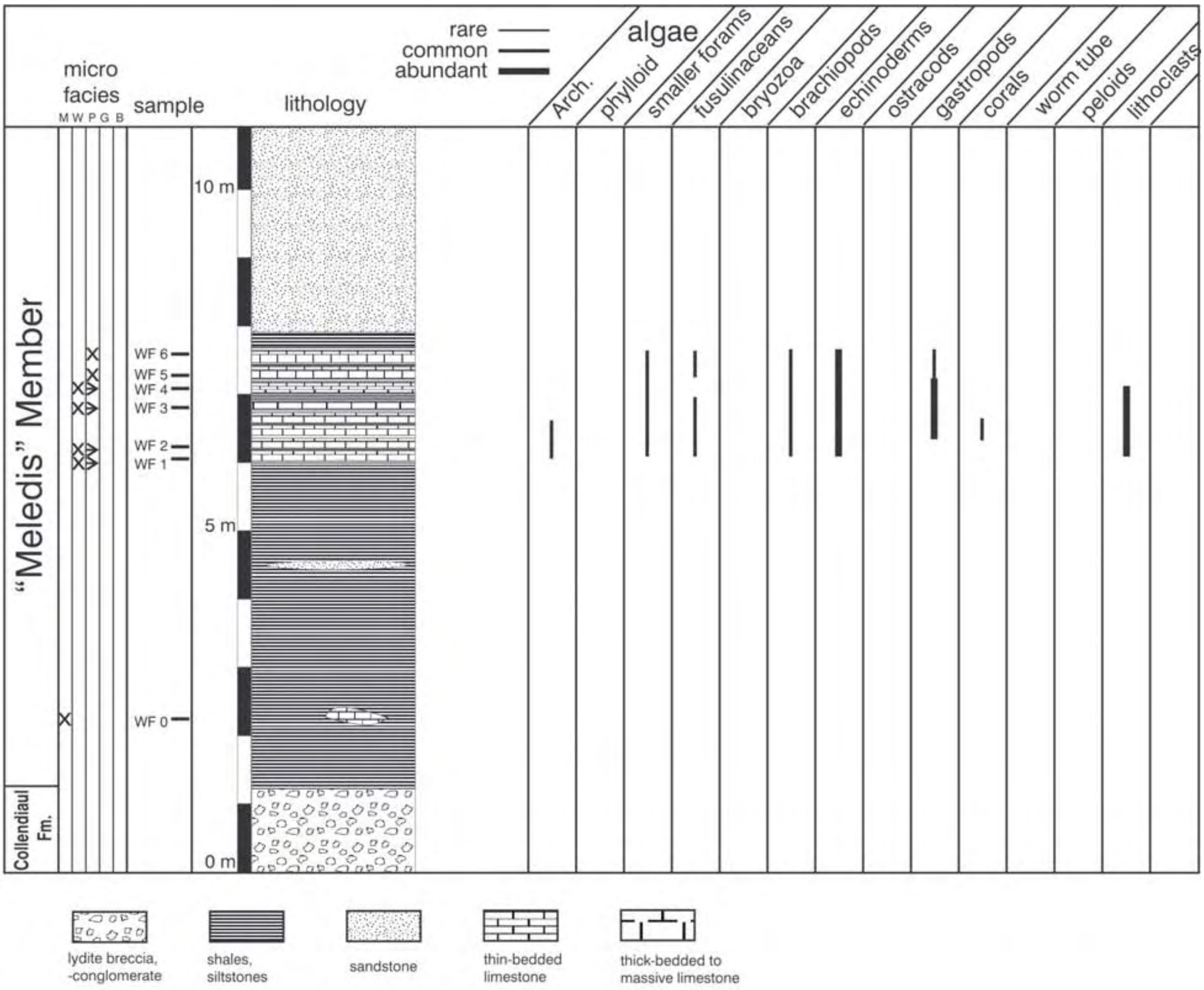
The fossil content is high diverse with algae, fusulinids, smaller foraminifers, brachiopods, gastropods, crinoid debris, solitary corals, microproblematica, and, rarely, ostracodes, bryozoans, and coralline sponges.

Identified fossils:

Fusulinids: *Staffella* sp. (WF 1), *Schubertella* sp. (WF 2-4), *Fusiella* cf. *lancetiformis* (WF 3-5), *Ozawainella mosquensis* (WF 3-5), *Protriticites* aff. *permirus* (WF 2-4), *Fusulina* (*Quasifusulinoides*) *juvenatus* (WF 1-5), *Beedeina* (*Pseudotriticites*) *asiaticus* (WF 3-5).

Additionally reported by Davydov & Krainer (1999): *Schubertella donetzica*, *Sch. magna*, *Sch. pseudoglobosa*, *Fusulinella rara*, *Protriticites ovatus*, *Beedeina consobrina*, *B. siviniensis*, *B. ulitinensis*, *B. nytvica*, *Quasifusulinoides quasifusulinoides*, *Q. fallax*, *Q. pakhrensis*, *Q. kljasmica*.

Fig. 20: Lithology, microfacies, and fossil associations of the sections at the right bank of the outflow of Lake Zollner and of the the limestone hills in southeastward direction (from Forke & Samankassou, 2000).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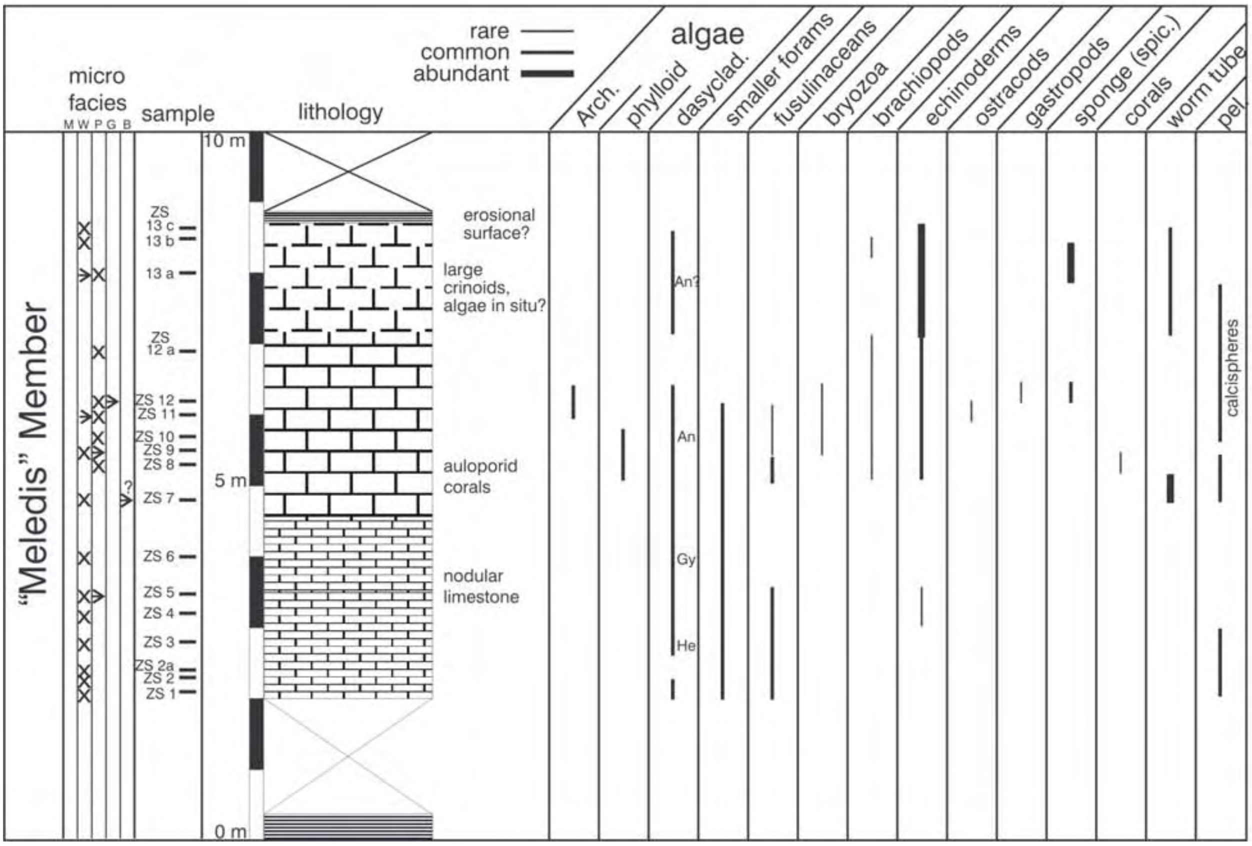
phylloid
smaller forams
fusulinaceans
bryozoa
brachiopods
echinoderms
ostracods
gastropods
corals
worm tube
peloids
lithoclasts
"Meledis" Member
Collendiaul Fm.
10 m
5 m
0 m
WF 6
WF 5
WF 4
WF 3
WF 2
WF 1
WF 0
lydite breccia, -conglomerate
shales, siltstones
sandstone
thin-bedded limestone
thick-bedded to massive limestone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fusulinaceans
bryozoa
brachiopods
echinoderms
ostracods
gastropods
sponge (spic.)
corals
worm tube
pel.
"Meledis" Member
10 m
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ZS 3
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ZS 1
?
erosional surface?
large crinoids, algae in situ?
auloporid corals
nodular limestone
An?
An
Gy
He
calcispheres

Conodonts: *Hindeodus minutus* (WF 3), *Idiognathodus* cf. *expansus* (WF 3-6), *Swadelina*? *makhlinae* (WF 5).

Smaller foraminifers: *Tuberitina*, *Calcitornella*, *Paleotextularia*, *Biseriella*, *Bradyina*, *Endothyra*.

Algae: *Herakella* sp., *Archaeolithophyllum* sp., *Eflugelia* sp.

Stop 1.2B Limestone hills south of the Lake Zollner (section ZS).

The succession of stop 1.2.A can be continued at the southern side of the Lake Zollner with about 7 m of bedded to massive limestones above basal shales (Kasimovian: Krevyakinian-Khamovnikian) (fig. 20, 21).

Fig. 21: The limestone hills south of the Lake Zollner (section ZS).

Nodular-bedded limestone

Two microfacies types could be differentiated within the nodular bedded limestone: bioclastic wackestone and peloidal clotted boundstone.

Wackestone: The identifiable fossils are algae (*Herakella*, phylloid algae, *Atractyliopsis*, *Gyroporella*), fusulinids, smaller foraminifers (*Tuberitina*, *Calcitornella*, *Climacammina*, *Cribrogenerina*), bryozoans, echinoderms, and, rarely, ostracodes. Irregular, partly anastomosing sets of stylolites are common. As observed from thin sections, specific fossils seem to occur in specific beds (e.g. fusulinaceans and algae in samples ZS 4 and ZS 5 respectively, originating from two different beds).

Boundstone: The main biota are the coralline sponge *Peronidella*, agglutinated worm tubes, smaller foraminifers (*Bradyina*); rarely phylloid algae, *Shamovella*, and brachiopods. Stylolites are significantly less common in comparison to wackestone described above.

Thick-bedded limestone

It consists of packstone, boundstone, and, underrepresented (in one sample only), grainstone. It is fossil-rich and the biodiversity is high: Fusulinids, abundant algae (*Atractyliopsis*, *Epimastopora*, *Herakella*, rarely, *Anthracoporella* and *Archaeolithophyllum*), echinoderms, auloporid corals, smaller foraminifers, ostracodes, calcispheres, coralline sponges (*Peronidella*), sponge spicules, and rare gastropods, brachiopods and bryozoans. Large algal thalli enclose pores filled with cement within the boundstone facies. Calcite-filled fractures and stylolites are common.

Massive limestone

The massive limestone is composed of wackestone and packstone. Coralline sponges, algae, smaller foraminifers, *Shamovella*, bryozoans, agglutinated worm tubes, calcispheres (possibly algal spores), crinoids, and brachiopods are the fossils encountered. Peloidal clotted areas occur in a single thin section. Impregnation of hematite occur in the lowermost part.

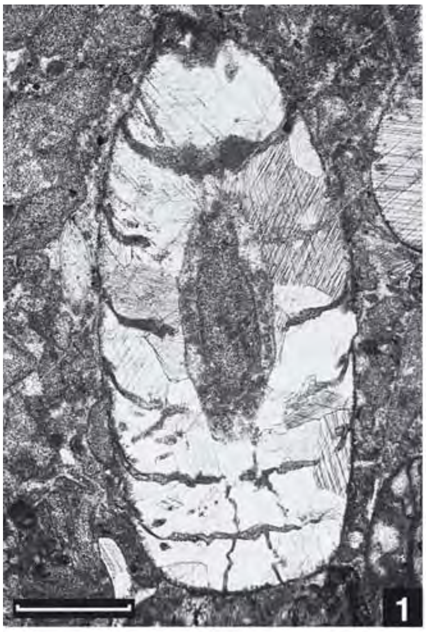
The top of the section is generally eroded, but in a few places the massive limestones are capped by a thin layer of shaly siltstones.

Identified fossils (fig. 20):

Fusulinids: *Staffella* sp. (ZS 5), *Schubertella* sp. (ZS 2a, 5, 8, 9, 14), *Fusiella* cf. *lancetiformis* (ZS 8, 9, 14), *Fusiella* cf. *rawi* (ZS 15), *Ozawainella mosquensis* (ZS 14), *Protriticites* aff. *ovatus* (ZS 1, 2a-5, 7-9, 14), *Protriticites*? *pramollensis* (ZS 14-15), *Protriticites*? *inflatus* (ZS 15), *Fusulina* (*Quasifusulinoides*) ex. gr. *fusiformis* (ZS 10). (Samples ZS 14 and 15 were taken from the top of the second limestone hill to the east, Geotrail Stop 11)

Additionally reported by Davydov & Krainer (1999): ZS 1-3 (ZO 1-3): *Pr. globulus*, *Pr. globulus turkestanensis*, *Pr. pseudomontiparus*, *Pr. ovoides*, ZS 14, 15 (ZO 19-26): *Pr. ovatus*, *Pr. pseudomontiparus*, *Pr. sphaericus*, *Pr. subschwagerinoides*, *Praeobsoletes burkemensis*, *Montiparus montiparus*, *M. paramontiparus*, *M. umbonoplicatus*, *M. priscus*, *M. rhombiformis*, *M. likharevi*.

Conodonts: *Streptognathodus neverovensis* (ZS 12)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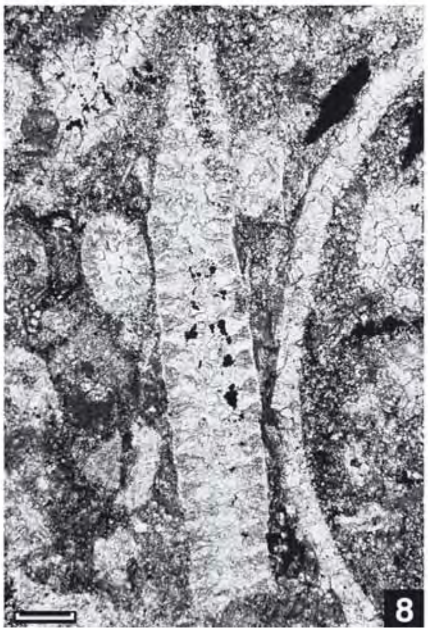
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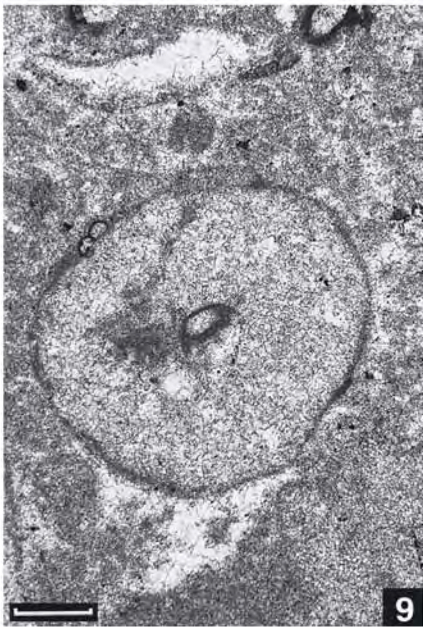
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(previous page)

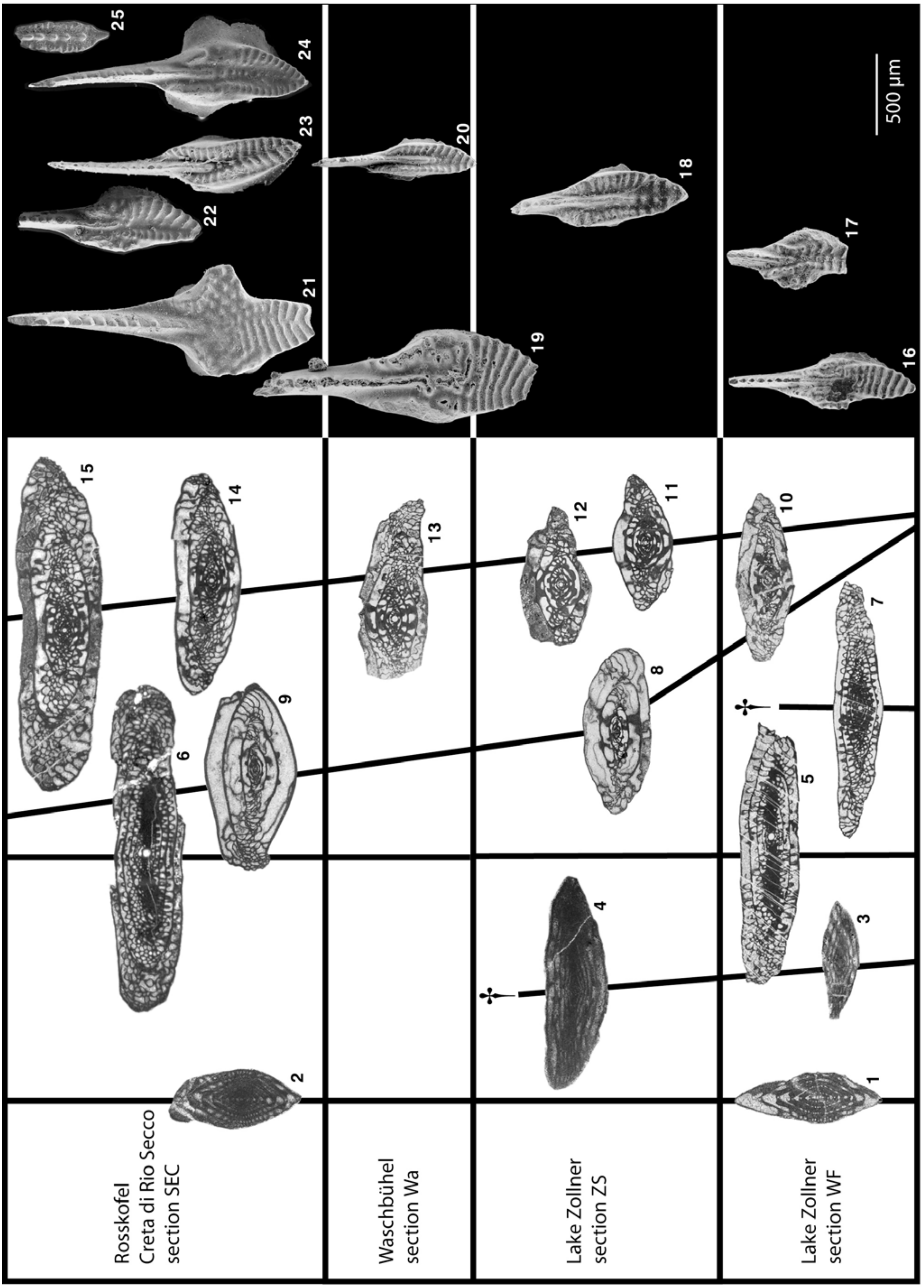
Fig. 22: Algae of the lower part of the Auernig Group
(Kasimovian, Late Carboniferous: Carnic Alps, Austria/Italy)

1-6 Different sections of *Herakella* thalli. Note segmentation in fig. 1, cylindrical medulla in fig. 2, and the asymmetrically annulated and metaspondyl thallus in fig. 3-6. Fig. 1, 2: sample ZS 5; Fig. 3-5: sample AO 3; Fig. 6: sample WF 3. Scale bar is 1 mm.
7 *Beresella* sp.; the cortex is typically perforated at regular intervals by blind-ending cortical branches. Sample AO 3. Scale bar is 1 mm.
8 *Dvinella* sp.; typical, long, cylindrical thallus. The cortex is characterized by blind-ending pores separated by clear intervals. Note the characteristic triangular “dark rings”, the former pores. Sample AO 3. Scale bar is 0,5 mm.
9 *Shamovella* sp.; microproblematicum, consisting of a massive, cylindrical thallus (?) and cement-filled cavity (?). Sample ZS 5. Scale bar is 0,5 mm.

(next page)

Fig. 23: Fusulinoideans and Conodonts from the lower part of the Auernig Formation (sections Lake Zollner WF-ZS-SWH, Cima Val di Puartis CI/P, Waschbühel ridge WA, Rosskofel Lu-SEC-CRS), Kasimovian. (modified from Forke & Samankassou, 2000; Forke, 2001; Luppold, unpubl.).

1 *Ozawainella mosquensis* RAUZER-CHERNOUSSOVA, 1951; sample WF 3, x 20.
2 *Ozawainella* cf. *kumpani* SOSNINA, 1951; sample CRS/S 1, x 20.
3 *Fusiella* cf. *lancetiformis* PUTRJA, 1939; sample WF 3, x 20.
4 *Fusiella* cf. *rawi* LEE, 1927; sample ZS 15, x 20.
5 *Fusulina* (*Quasifusulinoides*) *juvenatus* KIREEVA, 1963; sample WF 3, x 7,5.
6 *Quasifusulina eleganta* SCHLYKOVA, 1948; sample Ro 2, x 7,5.
7 *Beedeina* (*Pseudotriticites*) *asiaticus* BENSH, 1972; sample WF 3, x 7,5.
8 *Protriticites*? *inflatus* BENSH, 1972; sample ZS 15, x 7,5.
9 *Tumefactus* aff. *expressus* (ANOSOVA, 1969); sample Lu 5a, x 7,5.
10 *Protriticites* aff. *permirus* (BOGUSH, 1963); sample WF 3, x 7,5.
11 *Protriticites* aff. *ovatus* PUTRJA, 1948; sample ZS 9, x 7,5.
12 *Protriticites*? *pramollensis* (PASINI, 1963); sample CI/P 4, x 7,5.
13 *Montiparus subcrassulus* ROZOVSKAYA, 1950; sample 96 (collection Prof. Kahler), x 7,5.
14 *Rauserites* sp. 1 ex gr. *rossicus* (SCHELLWIEN, 1908); sample Lu 5a, x 7,5.
15 *Rauserites* sp. 2 ex gr. *rossicus* (SCHELLWIEN, 1908); sample CRS/S 1, x 7,5.
16 *Idiognathodus* cf. *expansus* STAUFFER & PLUMMER, 1932 sample WF 5, x 50.
17 *Swadelina? makhlinae* (ALEKSEEV & GOREVA; 2001); sample WF 5, x 50.
18 *Streptognathodus neverovensis* GOREVA & ALEKSEEV, in press); sample ZS 12, x 50.
19 *Idiognathodus toretzianus* KOZITSKAYA, 1978; sample WA 2I, x 50.
20 *Streptognathodus* aff. *elegantulus* STAUFFER & PLUMMER, 1932; sample WA 2I, x 50.
21 *Idiognathodus magnificus* STAUFFER & PLUMMER, 1932; (collection Luppold) , x 50.
22 *Streptognathodus zethus* CHERNYKH & RESHETKOVA, 1987; (collection Luppold) , x 50.
23 *Streptognathodus elegantulus* STAUFFER & PLUMMER, 1932; sample Ro/A/14, x 50.
27 *Streptognathodus pawhuskaensis?* HARRIS & HOLLINGSWORTH, 1933; (coll. Luppold), x 50.
25 *Gondolella* cf. *elegantula* STAUFFER & PLUMMER, 1932, (coll. Luppold), x 50.


Rosskofel
Creta di Rio Secco
section SEC
Waschbühel
section Wa
Lake Zollner
section ZS
Lake Zollner
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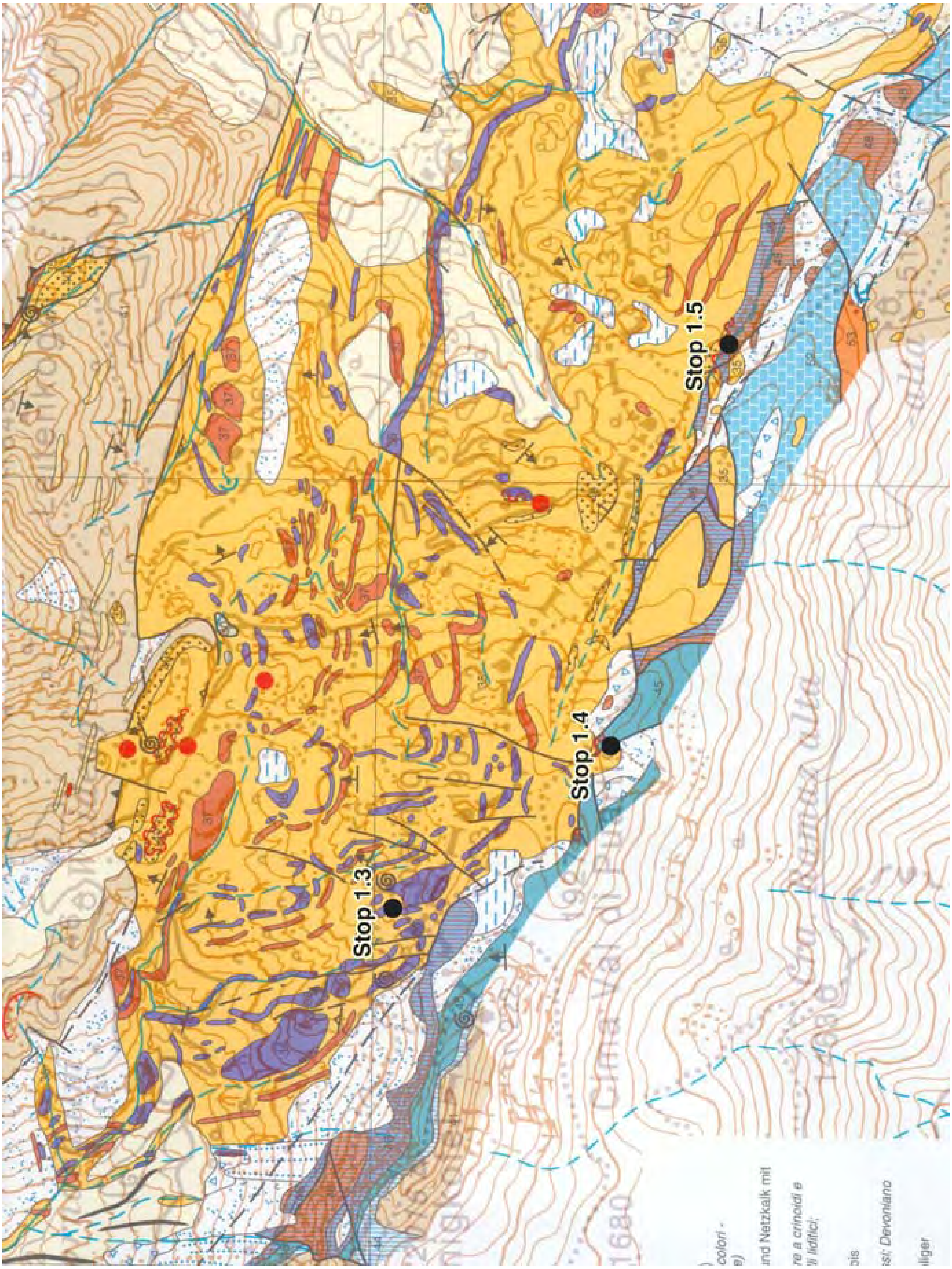


Fig. 24: Geological scetch-map of the area around Waidegger and Straniger Alm with stops during the excursion.

Stop 1.3 Waschbühel ridge

Type section of the “untere kalkarme Schichtgruppe” and lower part of “untere kalkreiche Schichtgruppe” sensu Heritsch et al. (1934). (Kasimovian, Khamovnikian-Dorogomilovian) (fig. 25).

Identified fossils:
Fusulinids: *Montiparus subcrassulus*
Conodonts: *Streptognathodus* cf. *confragus*, *Str.* aff. *elegantulus*, *Idiognathodus toretzianus*

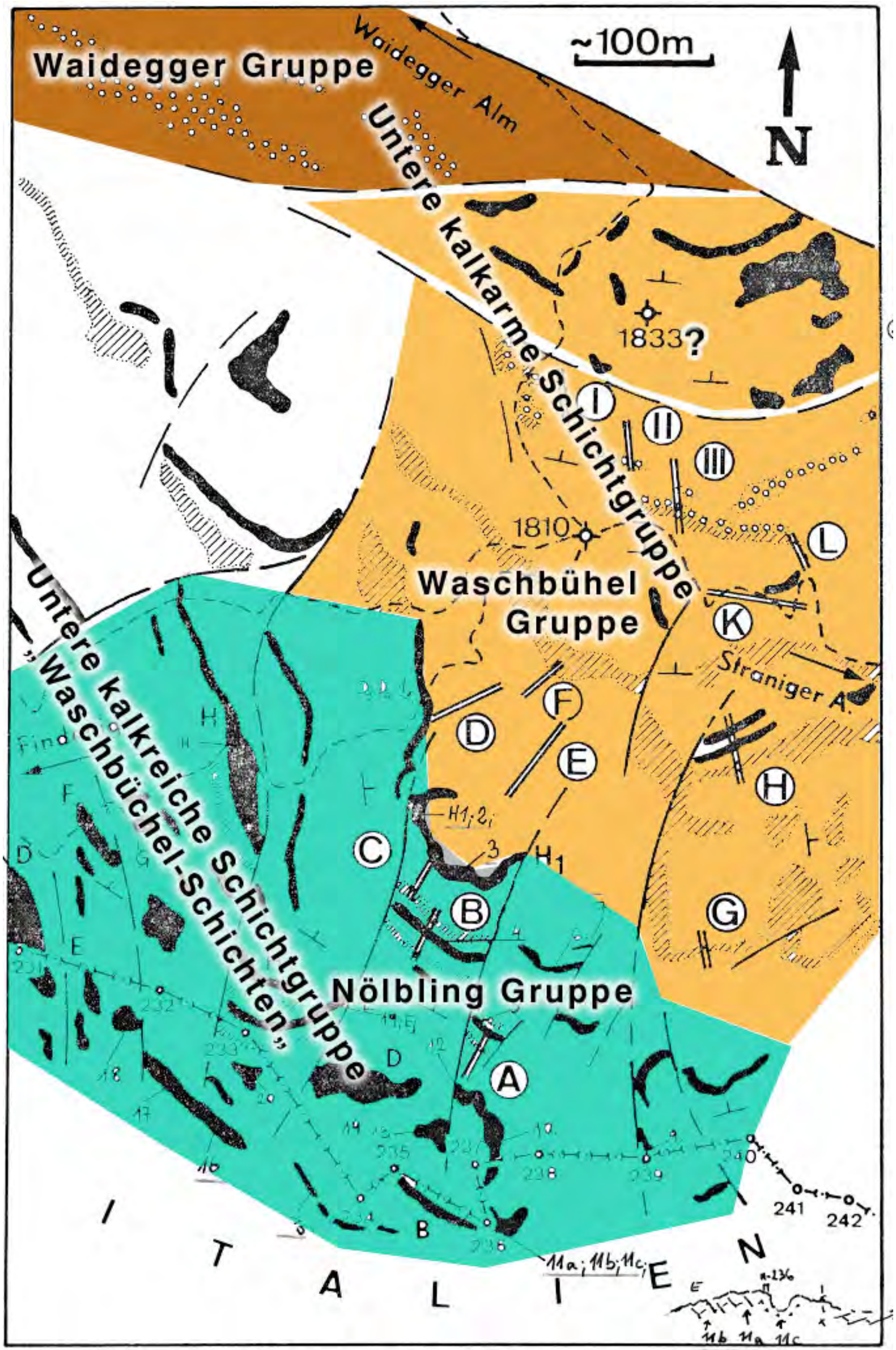


Fig. 25: Type section of the lower part of the Auernig Formation along the Waschbühel ridge. Lithologic subdivisions according to Heritsch et al., 1934 and Fenninger et al., 1971 (modified from Fenninger et al., 1971).

Stop 1.4 Cima Val di Puartis

ÖK sheet 198, Weißbriach, 13°7’20"E/46°35’24"N; Geological Map Weißbriach 1:50.000 (Schönlaub, 1987)

Basal Auernig Formation (Kasimovian, Krevyakinian? - Khamovnikian) (fig. 26).

The section has an exposed thickness of about 10 m and is characterized by a fining-upward trend, consisting of (a) a basal breccia unit, overlain by (b) fine-grained sandstones and conglomerates, (c) dark fossiliferous siltstones and shales with calcareous sandstones and coarse siltstones, and (d) and dark fossiliferous siltstones with intercalated bedded algal limestones and a small auloporid mound.

The basal breccia (Malinfier Fm) is interpreted to represent distal fan-delta deposits formed by submarine debris flows. Fine-grained conglomerates and fossiliferous sandstones overlying the breccia and intercalated within the fossiliferous siltstones are interpreted as turbidite layers. The small auloporid coral mound and bedded algal limestones, intercalated in the upper part of the sequence, formed in an open shelf low-energy environment below wave base.

Fusulinids in the bioclastic beds show a unique preservation due to hematite-rich staining of the wall probably during early diagenesis. Layering of the wall is obscured, but the pores piercing the wall and the secondary deposits, are extremely well visible.

Identified fossils:

Fusulinids: *Protriticites*? *pramollensis*, *Protriticites*? *inflatus*, *Montiparus*? sp.

From Davydov & Krainer (1999):

VP-6: *Pr. globulus*, *Pr. pseudomontiparus*, *Pr. sphaericus*, *Pr. semikhatovae*.

VP-8: *Pr. globulus*, *Pr. pseudomontiparus*, *Pr. rotundatus*, *Pr. ovoides*.

VP-10: *Pr.* cf. *globulus*, *Pr. pseudomontiparus*, *Pr. rotundatus*, *Pr. ovoides*, *Pr. lamellosus*.

VP-16: *Montiparus paramontiparus*, *M. umbonoplicatus*.

VP-17: *Montiparus montiparus*, *M. umbonoplicatus*, *M. likharevi*.

VP-18: *Obsoletes timanicus*, *Montiparus montiparus*, *M. umbonoplicatus*, *M. likharevi*, *M. paramontiparus*, *M. rhombiformis*.

Stop 1.5. Marchgraben south of the Straniger Alm (optional)

ÖK sheet 198, Weißbriach, 13°7'20"E/46°35'24"N; Geological Map Weißbriach 1:50.000 (Schönlaub, 1987)

Contact between lower Devonian limestones (flaser bedding) and pebble-bearing shales and siltstones. Malinfier Formation and basal Auernig Formation (cf. p. 21, fig. 14).

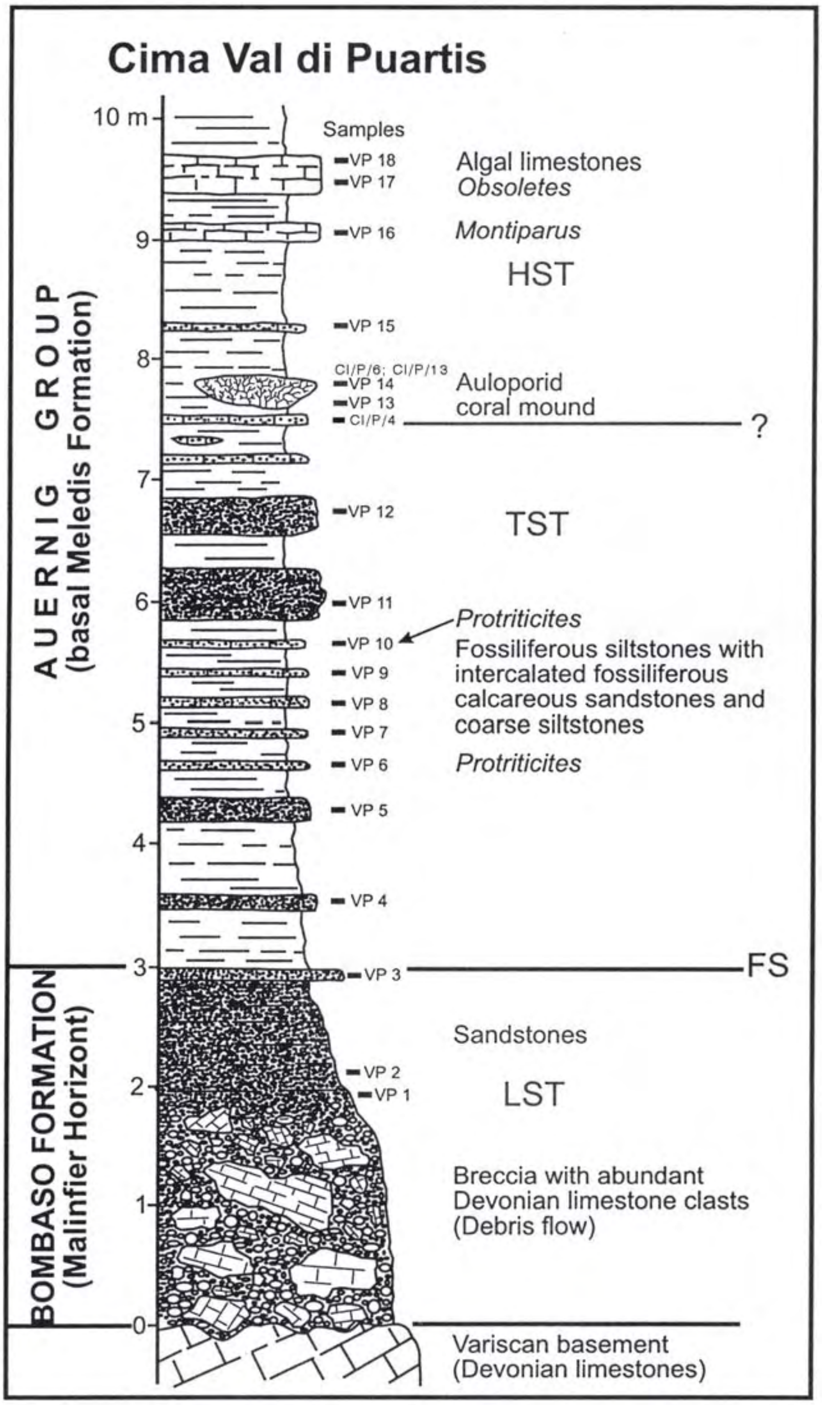


Fig. 26: section Cima Val di Puartis (modified from Davydov & Krainer, 1998).

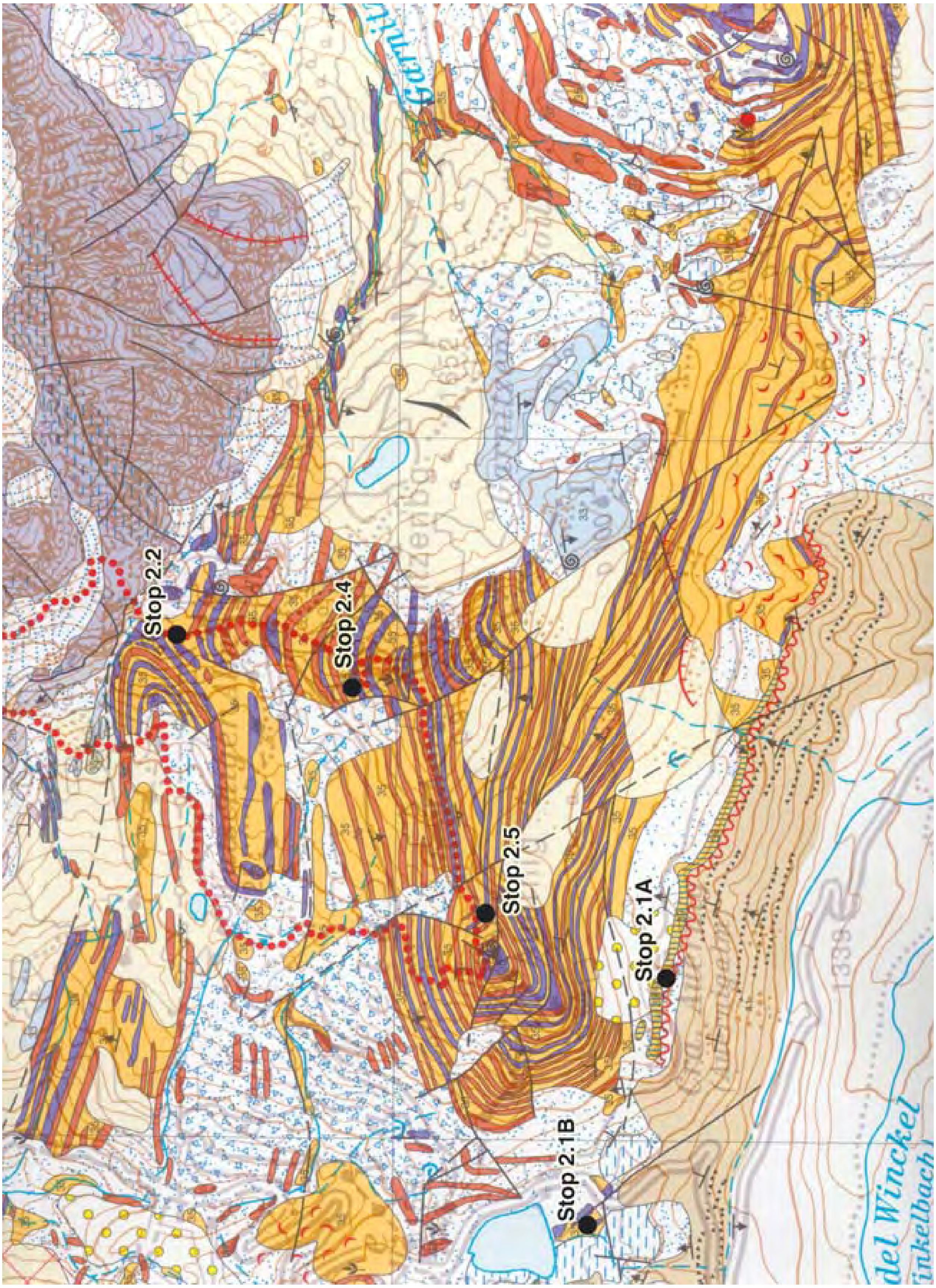


Fig. 27: Geological scetch-map of the area around the Gartnerkofel, and the mountains Auernig and Krone with stops during the excursion.

Tuesday, 01. August 2006

Stop 2.1. Auernigalm und surroundings – Naßfeld

ÖK sheet 198, Weißbriach, 13°17’13"E/46°33’17"N; Geological Map Weißbriach 1:50.000, 1:10.000 (Schönlaub, 1987)

Stop 2.1A Auernig Limestone Breccia

Auernig Limestone Breccia in the surroundings of the Auernig Alm. Contact to the underlying Hochwipfel Formation in the first ravine E of the Auernig Alm. Discussion of the genesis and age of the Auernig Limestone Breccia (cf. p. 23-26, figs. 16, 17).

Stop 2.1B Basal sediments of the Auernig- Formation

This locality has first been mentioned by Pasini, who described the new species *Protriticites*? *pramollensis* (Pasini, 1963) (fig. 28).

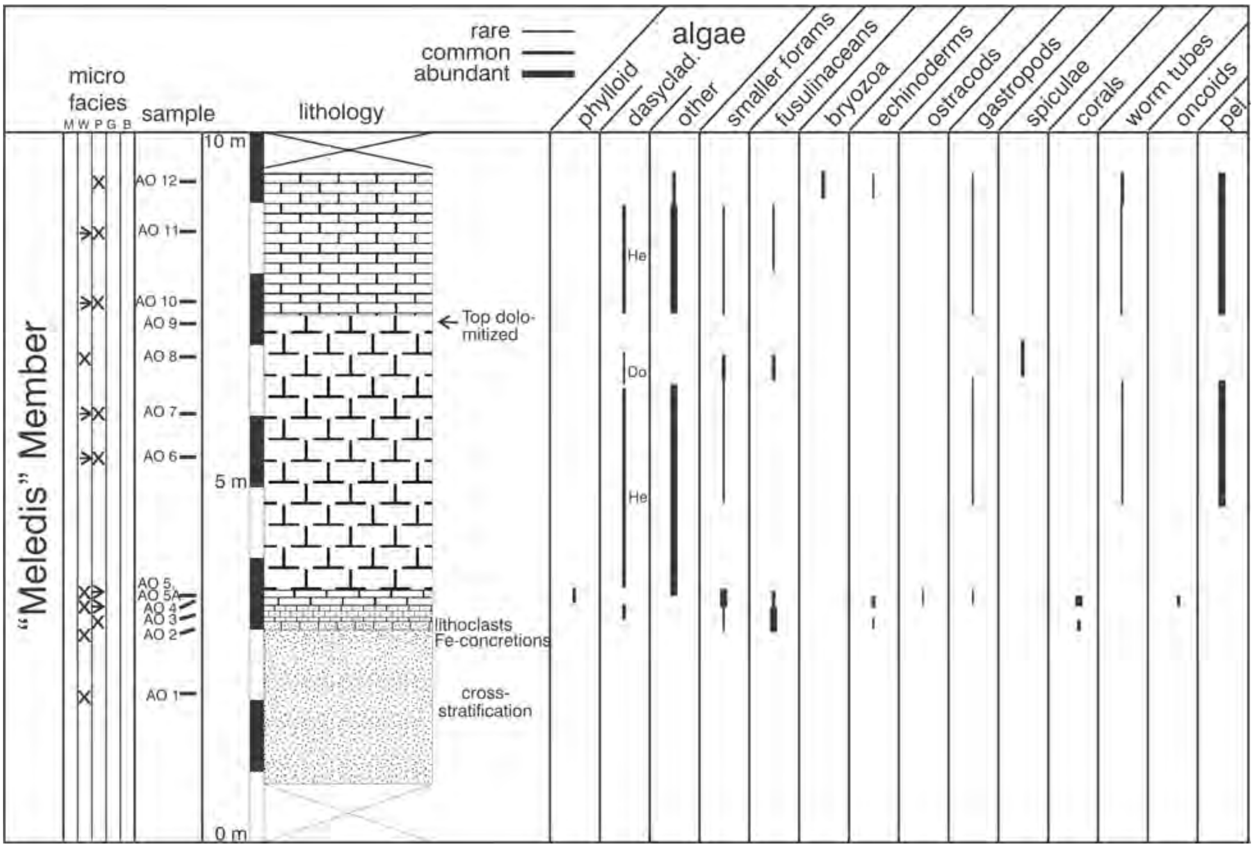


Fig. 28:Lithology, microfacies, and fossil associations; section at the foothill of mountain Auernig (Stop 2.1B).

Fine-grained sandstone

The light brown, hummucky cross-bedded sandstone is up to 2.50 m thick. The top contains dark brown ferrogenous nodules. It is poorly laminated, with dark minerals enriched at the top of laminae. It is mainly composed of poor to subangular rounded quartz grains. Fractures up to 20 cm are characteristic. Irregular, partly anastomosing sets of stylolites are common.

Fine-grained calcareous sandstone

This bed is only 10 cm thick. Quartz, the dominant constituent of this sandstone, is similar in form to that described above. Approximately one third of the sediment consists of abraded fusulinids, crinoid debris, auloporid corals, and extraclasts. Extraclasts, up to 15 cm in diameter, consist commonly of calcisphere-bearing wackestone. Variegated opaque minerals are frequent. Mica is abundant towards the top.

Sandy limestone

This 20 cm thick bed consists of bioclastic packstone. It is fossil-rich, with fusulinids, algae (*Herakella, Beresella*), smaller foraminifers, ostracodes, and gastropods. Fossils in this microfacies are better preserved in comparison to those of beds described above. Stylolites are frequent.

Dark, nodular bedded limestone

The dark nodular limestone is 20 cm thick and is composed of two beds. The lower bed is an oncolithic wackestone with a diverse fauna and flora: auloporid corals, fusulinids, smaller foraminifers, crinoid debris, brachiopods, phylloid algae, rare bryozoans, and rare specimens of the problematic alga *Eflugelia*. Most of oncoid nuclei consist of auloporid corals, rarely of algal fragments and crinoids. The upper bed consists of packstone with algae (principally *Rectangulina*), fusulinids, smaller foraminifers, gastropods, and, rarely, worm tubes and trilobites. Stylolites are frequent.

Massive limestone

The dark-grey massive limestone is four meter thick. It consists of algal wackestone and packstone. The algae *Rectangulina* and *Beresella* constitute more than 90 % of the total biota. The remaining fossils are smaller foraminifers, gastropods, and sponge spiculae. The matrix is peloidal, showing clotted structures. The uppermost top is dolomitized.

Grey nodular bedded limestone

The nodular limestone is two meters thick. It consists of bioturbated wackestone and packstone, similar to microfacies of the massive limestone described above. The biodiversity is higher towards the top with phylloid algae, *Eflugelia*, fusulinids, bryozoans, crinoid stems, and worm tubes additionally to fossils described above. Peloids are more frequent compared to the massive limestone described above.

Fig. 29: Aerial photograph of the Nassfeld area.

Identified fossils:
Staffella sp., *Fusiella* cf. *rawi*, *Protriticites*? *pramollensis* (Pasini, 1963).

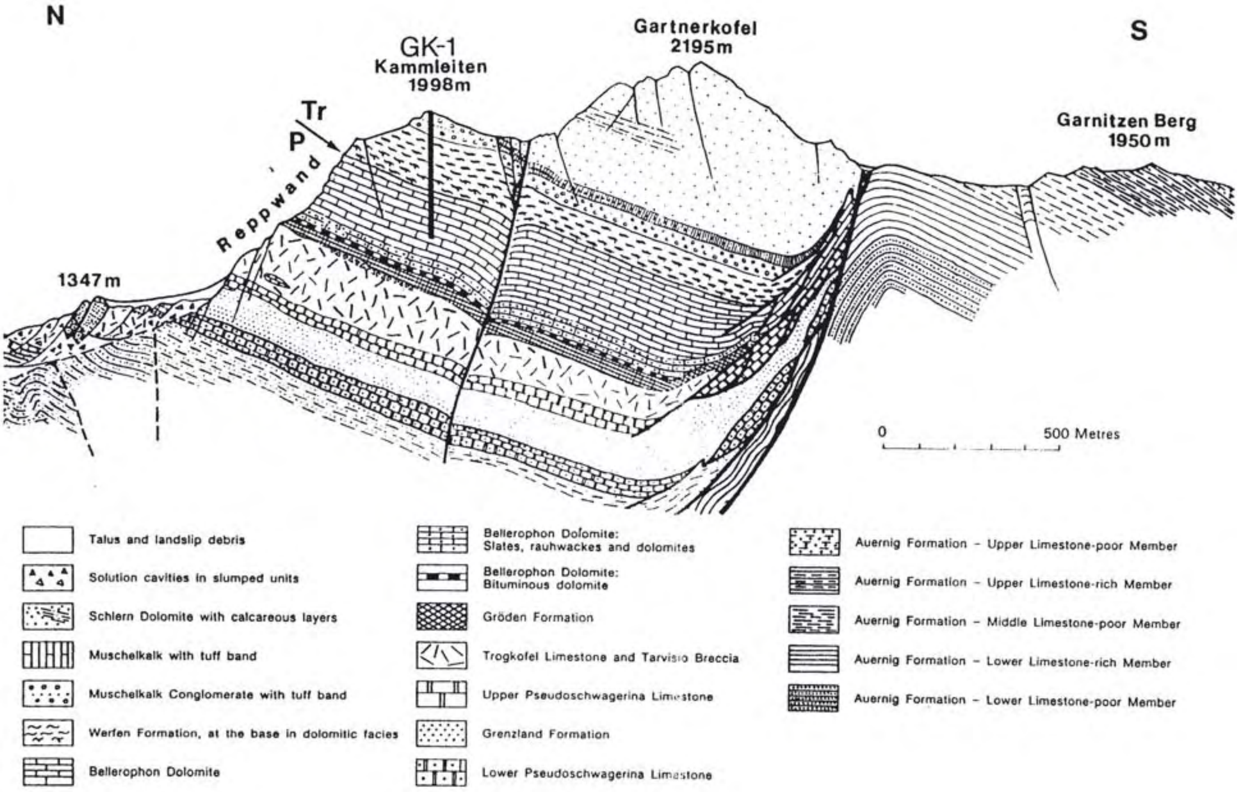
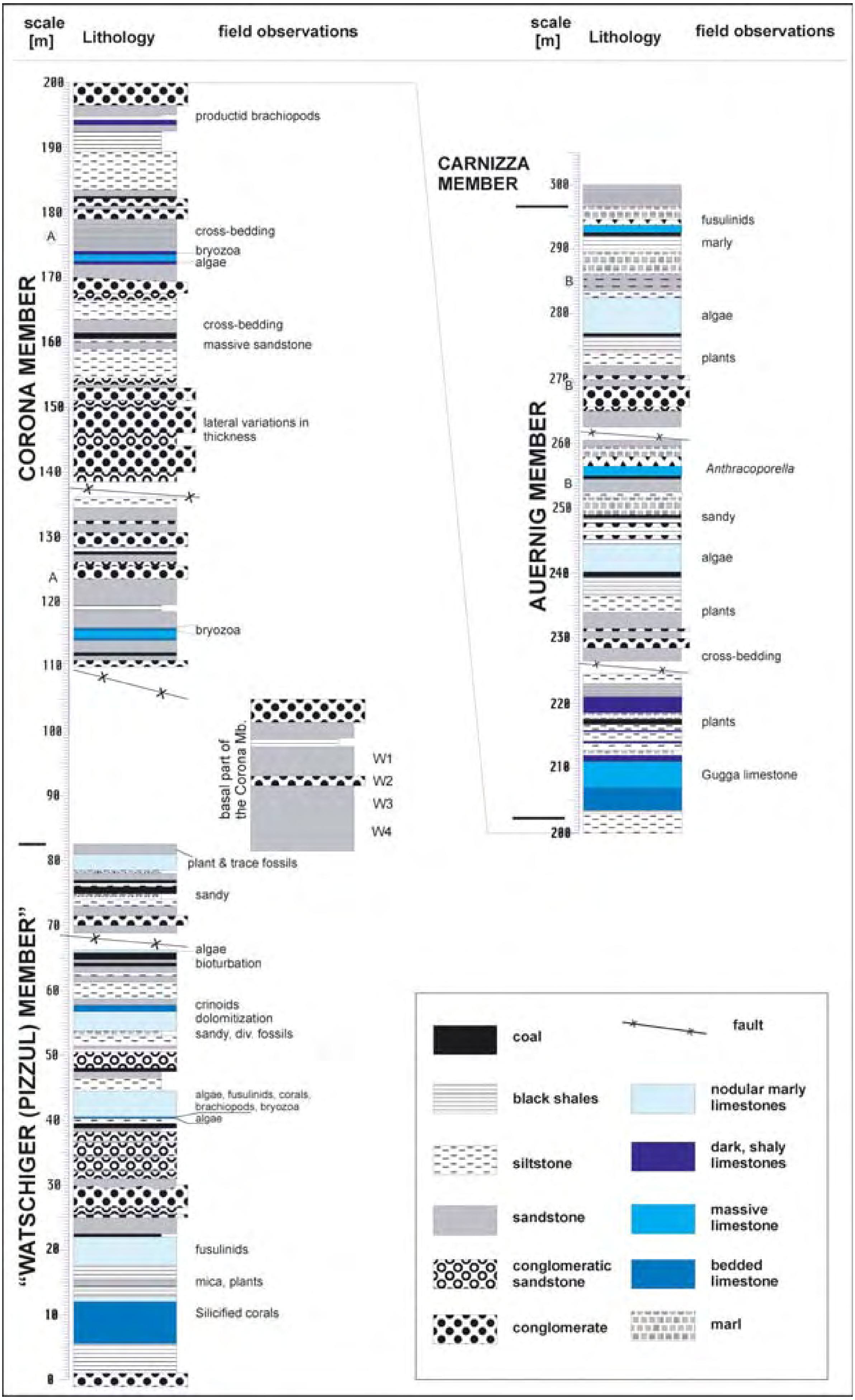


Fig. 30: N-S cross section from Reppwand-Kammleiten-Gartnerkofel to the Garnitzen. Note the Gartnerkofel core (GK-1) drilled for the analysis of the Permian/Triassic boundary event in 1986 on top of the Kammleiten.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Lithology
field observations
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190
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0
CORONA MEMBER
"WATSCHIGER (PIZZUL) MEMBER"
productid brachiopods
cross-bedding
bryozoa
algae
cross-bedding
massive sandstone
lateral variations in thickness
bryozoa
basal part of the Corona Mb.
W1
W2
W3
W4
plant & trace fossils
sandy
algae
bioturbation
crinoids
dolomitization
sandy, div. fossils
algae, fusulinids, corals, brachiopods, bryozoa
algae
fusulinids
mica, plants
Silicified corals
CARNIZZA MEMBER
AUERNIG MEMBER
300
290
B
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270
B
260
B
250
240
230
220
210
200
fusulinids
marly
algae
plants
Anthracoporella
sandy
algae
plants
cross-bedding
plants
Gugga limestone
coal
fault
black shales
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siltstone
dark, shaly limestones
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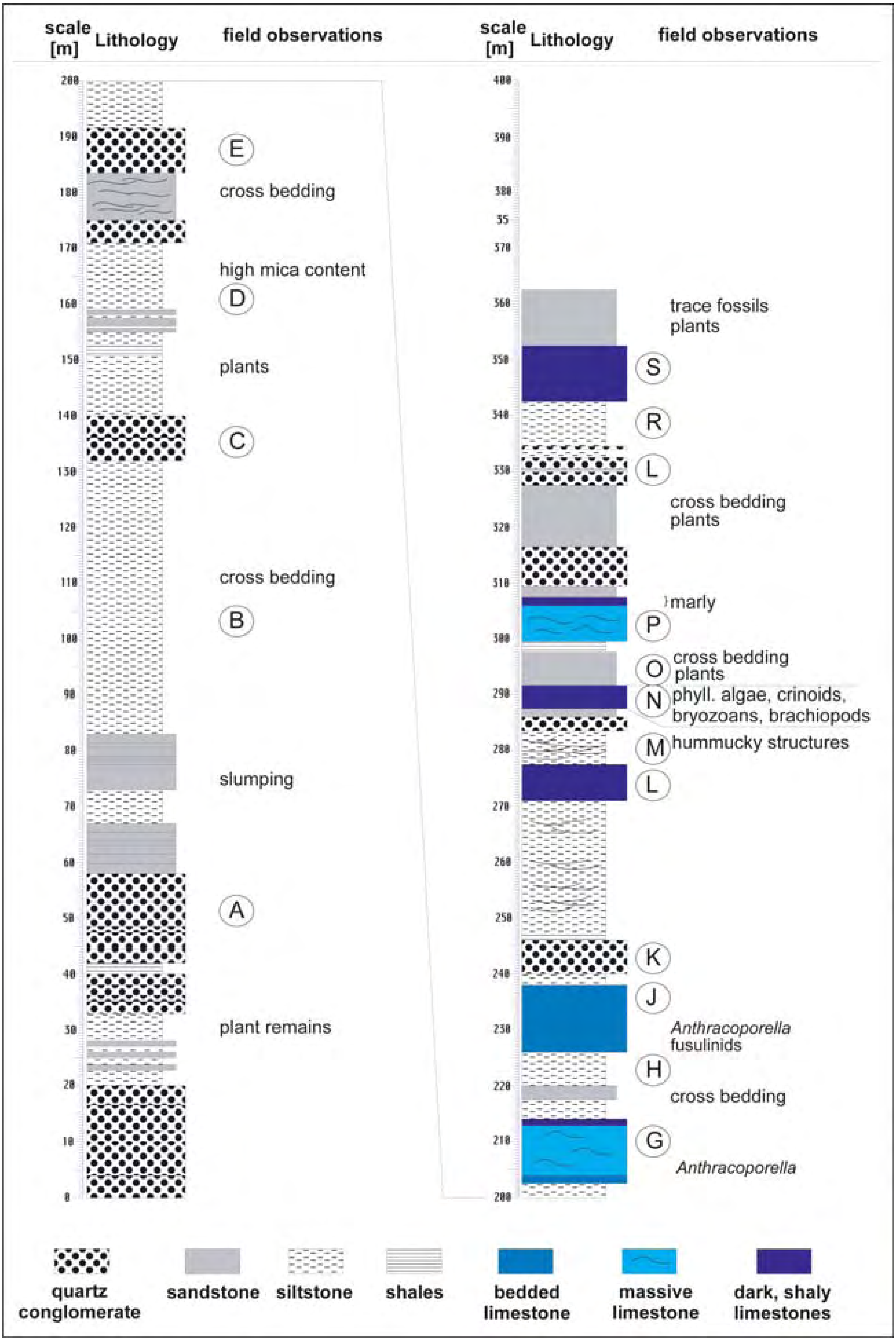

Fig. 31: Composite sections of the upper part of the Auernig Formation at the southern slope of the Auernig Mountain and along the ridge from Gugga to Garnitzen (previous page) (modified from Samankassou, 1997).

Stop 2.2 Mountain station of the Gartnerkofel-chairlift, 1902 m

ÖK sheet 198, Weißbriach, 13°17'58"E/46°34'2"N; Geological Map Weißbriach 1:50.000, 1:10.000 (Schönlaub, 1987)

Overview about the geology of the surrouding area with emphasis on the Late Paleozoic rocks and the Gartnerkofel Drilling Project. On the Kammleiten (1997 m) a scientific core was drilled in1986 to analyze the P/T boundary (fig.30).

Panoramic view along the Gail valley (with the "Gailtal-fault" as a part of the Periadriatic Line), Gailtalkristallin and Drauzug, as well as the Hohe Tauern in the background, representing the deepest exhumed parts of the Eastern Alps.

The summit of the Gartnerkofels (2195 m) consists of the Schlern Dolomite with a thickness of more than 500 m. On the Austrian side, they represent the youngest rocks in the Carnic Alps. The Schlern Dolomite is composed predominantly of massive limestones, only in the southern cliff bedded limestones are intercalated. Beside rare conodonts the dolomites contain algal remains (*Diplopora annulata* and *Teutloporella nodosa*) and very rarely corals. The Gartnerkofel unit is separated from the Auernig section by a prominent fault with vertical displacements of several 100 m.

Stop 2.3 Saddle south of the mountain station, 1856 m

ÖK sheet 198, Weißbriach, 13°18'1"E/46°33'54"N; Geological Map Weißbriach 1:50.000, 1:10.000 (Schönlaub, 1987)

The conglomerates (fig. 32) are composed of 3-4cm sized well rounded pebbles (more than 90 % quartz). The provenance of this quartz pebbles is unknown, but derived probably from a pegmatitic source in the metamorphic hinterland, which may have been situated north and west of the Gail valley. This assumption fit with Variscan cooling ages in this area of 310 Ma pointing to emersion and subsequent erosion of metamorphic cover rocks in the hinterland and transport of siliciclastic material into the transgressing epicontinental sea.

Fig. 32: Quartz conglomerates on the northern side of the Garnitzen.

Stop 2.4 Gugga, 1928 m

ÖK sheet 198, Weißbriach, 13°17'58"E/46°33'46"N; Geological Map Weißbriach 1:50.000, 1:10.000 (Schönlaub, 1987)

Typical Auernig-Cyclothem with a prominent algal-mound (fig. 31).

The succession starts at the base with quartz-rich conglomerates, overlying hummocky cross-stratified sandstones. Above the conglomerates follows a 10 - 20 cm thick siltstone-shale-horizon with abundant plant debris (Stefan). Fritz & Boersma (1990) described 16 taxa from this locality (e.g. *Alethopteris bohemica*, *Odontopteris brardii*, and *Pecopteris feminaeformis*). This interval is overlain by several meter of siltstone with intercalated fine sandstones.

Above this clastic unit, the 16 m thick Gugga limestone follows, which displays distinct bedding at the base and in the upper parts. The central part is predominantly massive consisting of an algal mound of *Anthracoporella* wackestones and bafflestones. The bedded limestones belong to the Intermound facies consisting of bioclastic wacke- to packstones. Fusulinoideans are common in the bedded limestones (Kahler, 1983, 1985, 1986).

On top of the limestone, fine sandstones are covering the underlying sediments. In former times, limonitic stained brachiopods have been found (Productids and Spiriferids). The sandstones represent the regressive part of the cyclothem.

Stop 2.5 Auernig, 1853 m

ÖK sheet 198, Weißbriach, 13°17'14"E/46°33'31"N; Geological Map Weißbriach 1:50.000, 1:10.000 (Schönlaub, 1987)

This locality represents one of the scientifically most interesting places in the Carnic Alps. The Carboniferous succession at the western and southern flank of mountain Auernig with the repetitive alternations of conglomerates, sandstones, shales, and limestones has attracted geologists already at the end of the 19th century. Schellwien (1892), Frech (1894) and Geyer (1896) investigated this area and introduced letters, respectively numbers for the individual beds. The uppermost limestone bed was labelled with the letter "s". Schellwien (1898) studied the fusulinoideans from the Auernig section and established several new species. Holotypes of *Daixina communis* and *Dutkevitchia multiseptata* derived from bed s that of *Daixina alpina* from bed g (fig. 37). The fauna belongs biostratigraphically to the *Daixina vasilkovskyi* Subzone, (upper part of the *Daixina sokensis* Zone).

Bed s yields selectively silicified remains of organisms (ostracodes, smaller foraminifers, fusulinids, bryozoa,

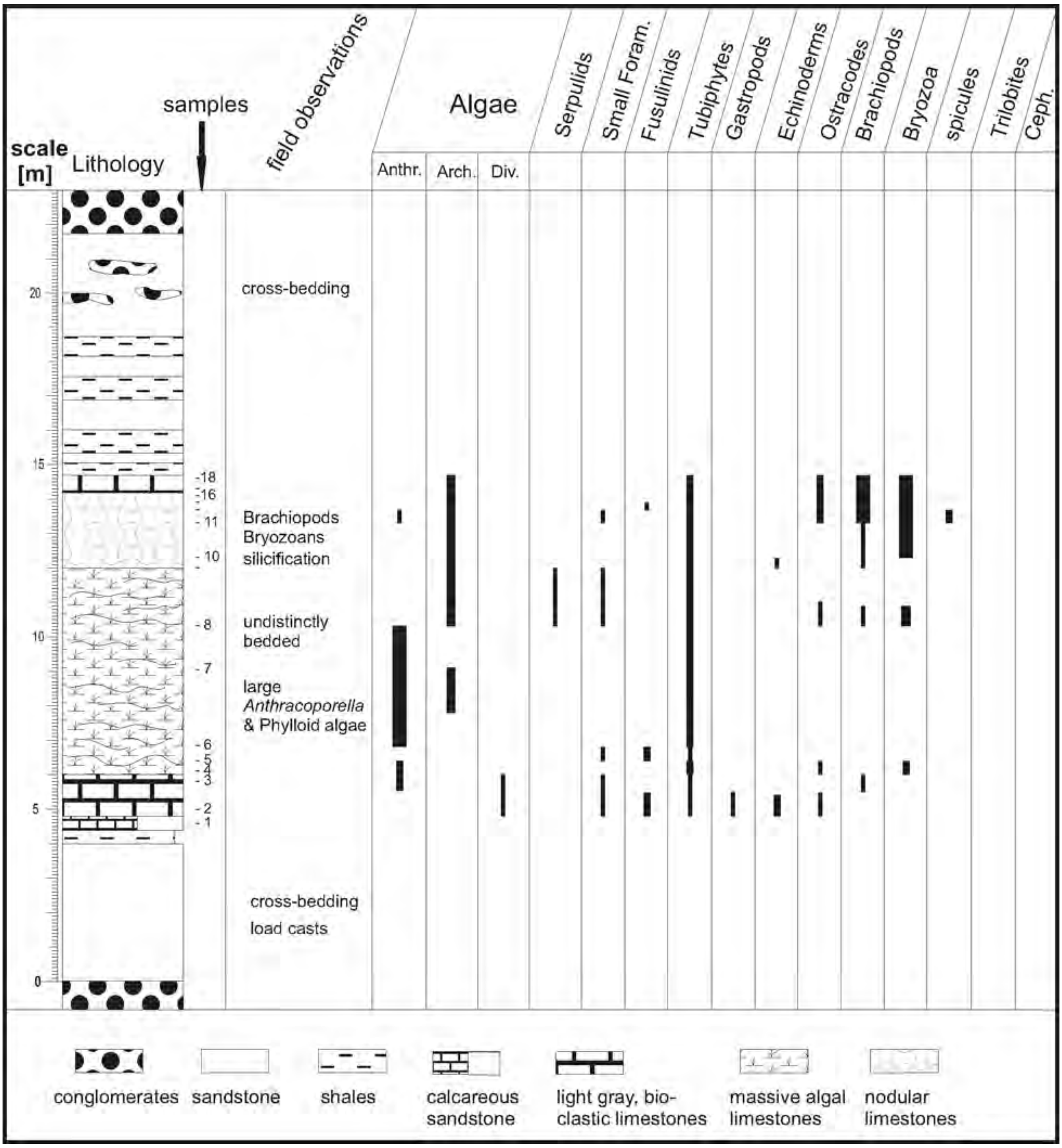

Fig. 33: Lithology, microfacies, and fossil associations of the section along bed s at the Auernig.

brachiopods, and even fragments of calcareous algae), which can easily be isolated from the matrix by dissultion in acetic or even formic acid (fig. 34, 35).

The kind of silicification (1:1 from $CaCO_3$ to SiO_2) led to a unique preservation of the fossils. Ostracodes with their delicate ornamented surfaces are preserved (fig. 36). The fauna consists of 62 species, 75% belong to the more or less unornamented order Podocopida, 25% to the distinctly ornamented order Palaeocopida. It has been supposed that they have lived in a nearshore, shallow-marin, and low energy environment (Becker, 1982; Bless; 1983; Fohrer, 1991).

In fusulinoideans, the keriothecal wall structure and also the "septal pores" (apertures) are preserved in detail. Partial silicification of tests, or broken specimens allow to study the internal structures in a three-dimensional way under the SEM and the functional morphology has been discussed by Leppig et al. (2005) (fig. 38, 39).

Different types of microfacies occur (1) massive autochthonous algae-wackestones (with *Archaeolithophyllum missouriense* and/or *Anthracoporella* in growth position) (2) bioclastic wackestones, packstones and grainstones. The latter display a markedly higher biodiversity.

The section measured along bed s diplays a typical Auernig-cyclothem: It starts with a transgressive "fining-upward" sequence of conglomerates, hummocky cross-bedded sand- and siltstones, which grade upwards into bedded and massive limestones. In the upper part the limestones are followed by sandstones with conglomeratic beds, representing the regressive part (fig. 33).

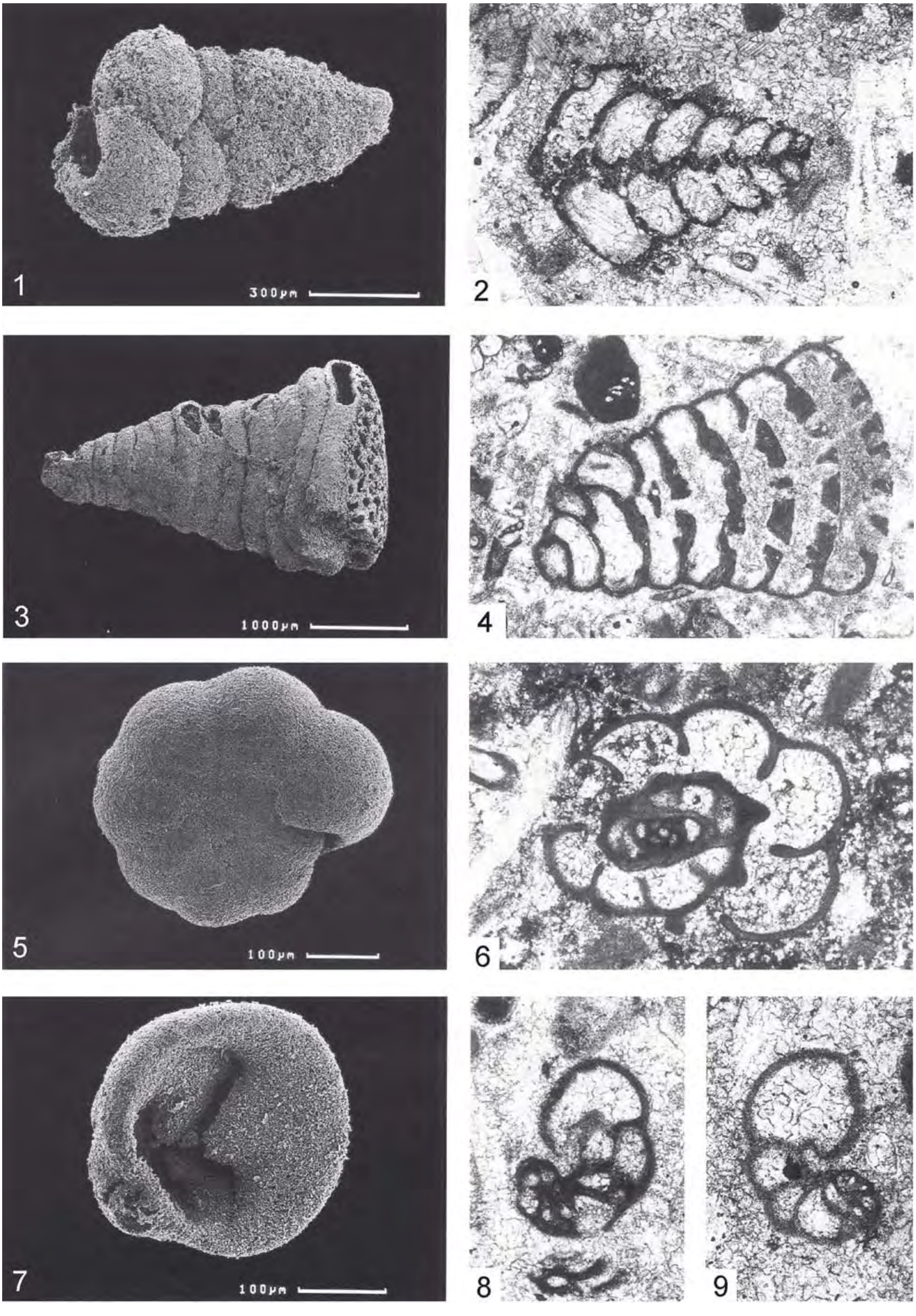

Fig. 34: Smaller foraminifers from the “bed s” limestone, Auernig section (modified from Fohrer, 1991). 1, 2, *Palaeotextularia* sp.; 3, 4, *Cribrogenerina* sp.; 5, 6, *Endothyra* sp.; 7-9, *Biseriella* sp.

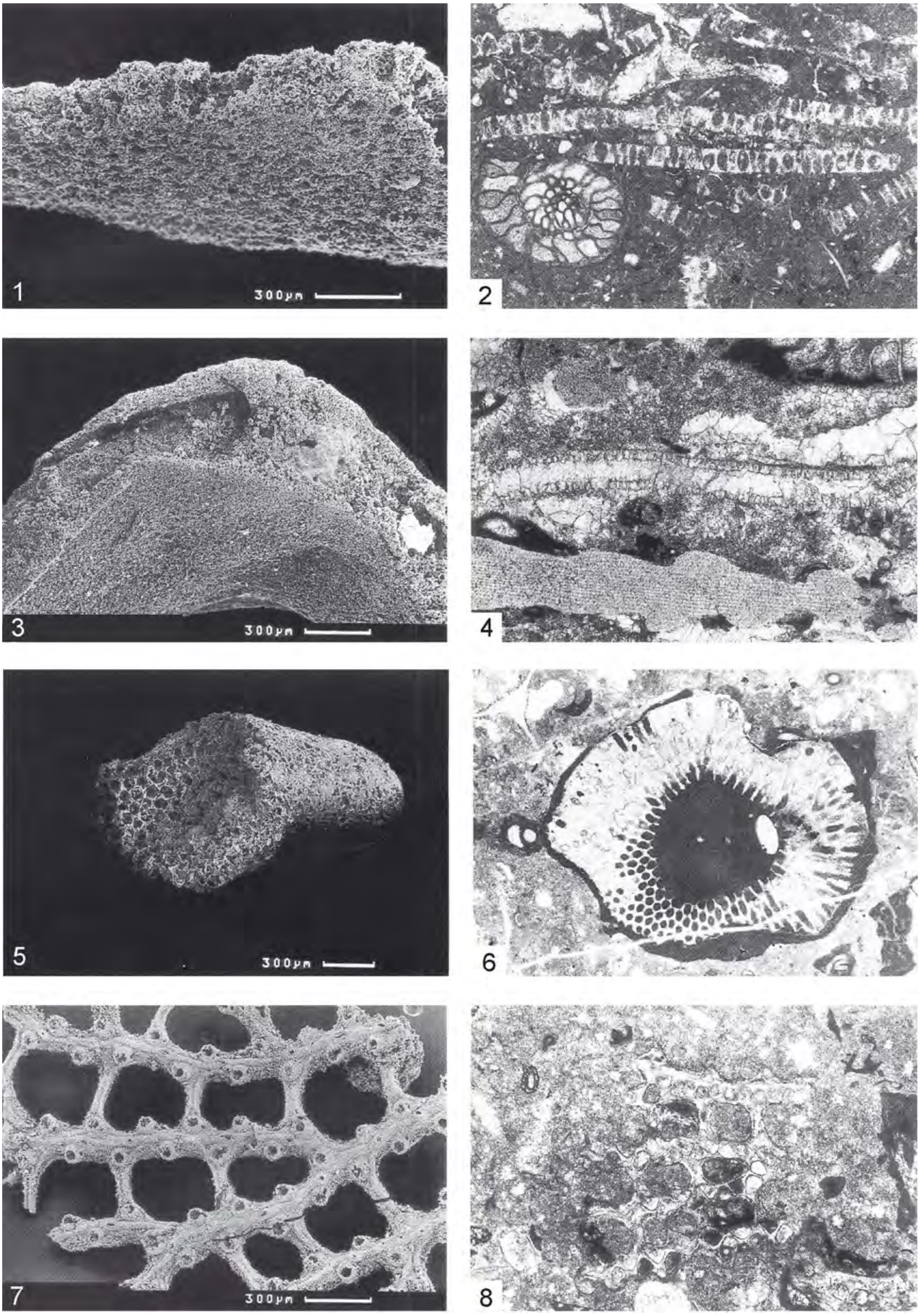

Fig. 35: Calcareous algae and bryozoans from the “bed s” limestone, Auernig section (modified from Fohrer, 1991). 1, 2, *Epimastopora* sp.; 3, 4, *Eugonophyllum* sp.; 5, 6, *Anthracoporella spectabilis* Pia, 1920; 7, 8, *Fenestella* sp.

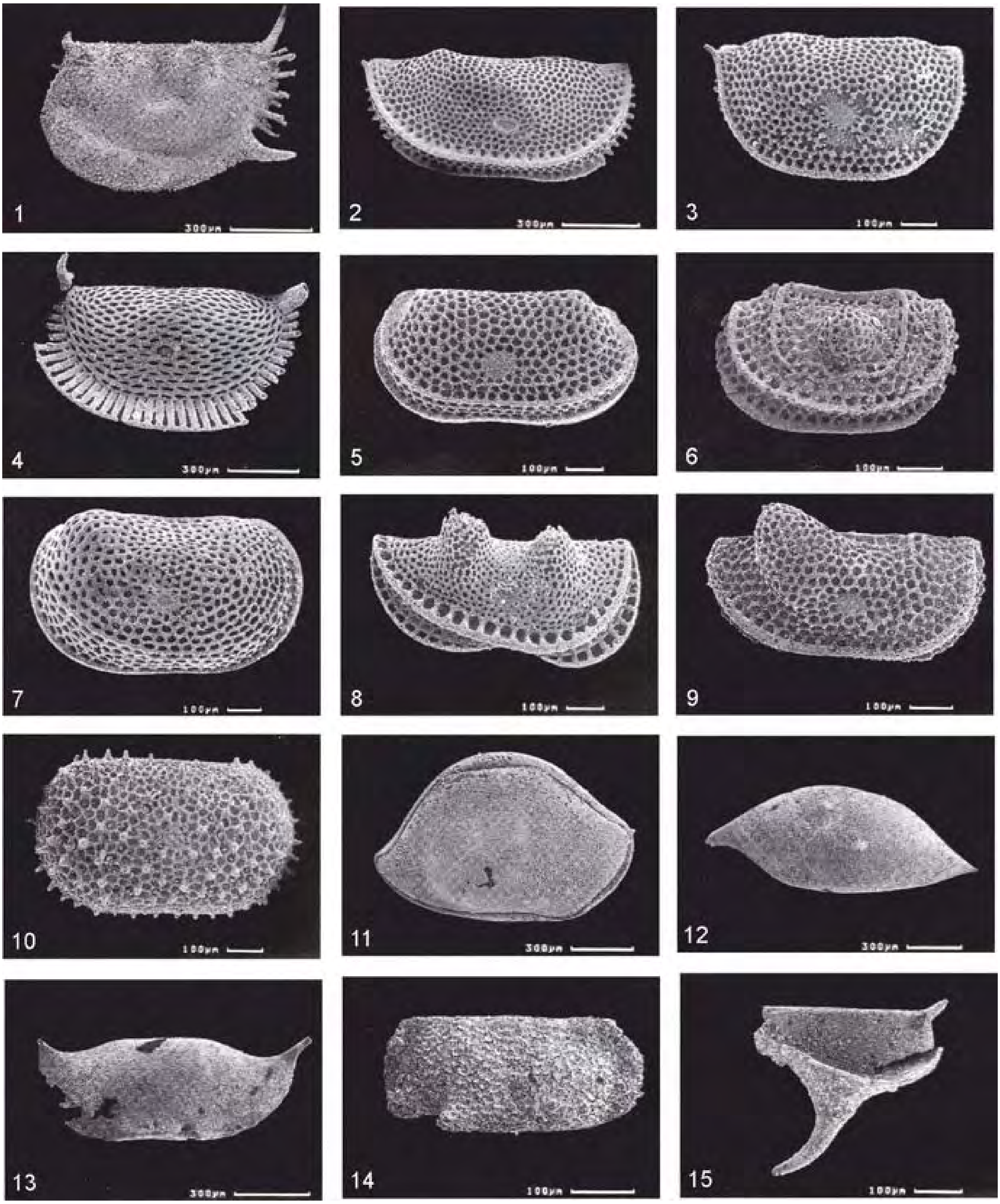

Fig. 36: Silicified ostracodes from the “bed s” limestone, Auernig section (modified from Fohrer, 1991). 1, *Hollinella (Hollinella) ulrichi* (Knight, 1928); 2, *Aurikirkbya hispanica* Becker, Bless and Sánchez de Posada; 3, *Aurikirkbya carinthica* Sánchez de Posada and Fohrer, 2001; 4, *Coronakirkbya pramolla* Sánchez de Posada and Fohrer, 2001; 5, *Knightina* aff. *bassleri* Kellett, 1933; 6, *Amphissites (Amphissites) centronotus* (Ulrich and Bassler, 1906); 7, *Shleesha* cf. *pinguis* (Ulrich and Bassler, 1906); 8, *Kellettina carnica* Ruggieri and Siveter, 1975; 9, *Semipetasus unicornus* Fohrer, 1991; 10, *Roundyella simplicissima* (Knight, 1928); 11, *Bairdia* sp.; 12, *Acratia* sp.; 13, *Acanthoscapha* sp.; 14, *Monoceratina* sp.; 15, *Tricornina* sp.

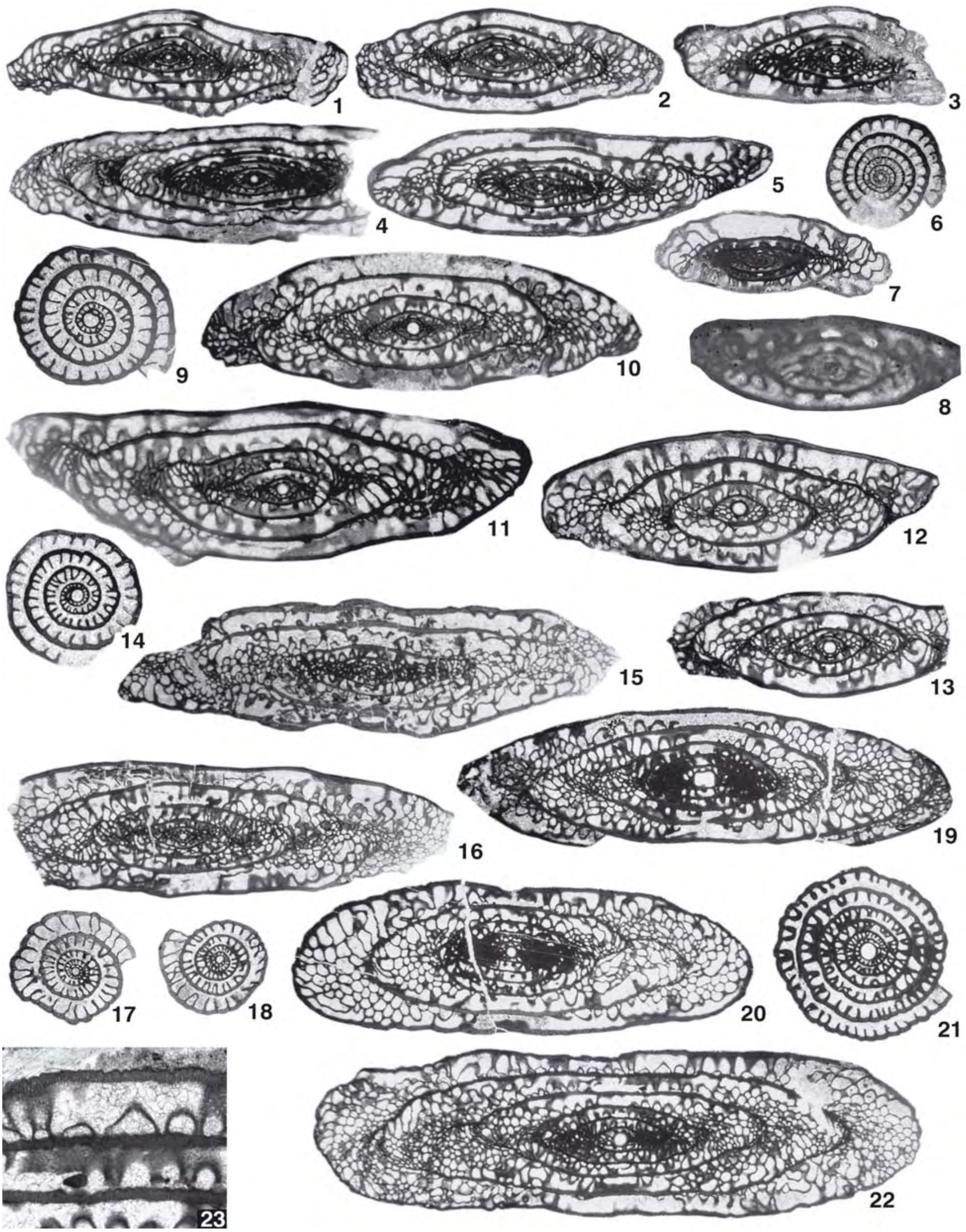

Fig. 37. Fusulinoideans from the Auernig section (bed g and bed s) and from the Garnitzen section (bed 116 and bed 148) of the Auernig Formation (from Forke, 2006).

1-3 “*Triticites*” cf. *immutabilis*, bed s, bed 148.
4-6 “*Triticites*” sp. A., bed s, bed 148.
7-8 “*Triticites*” sp. B., microspheric specimen, bed 148; 8 enlargement of the inner part with askew coiled first volution x 35.
9-14 *Daixina communis*, bed s.
15-18 *Daixina alpina*, bed g.
19-23 *Dutkevitchia* aff. *multiseptata*, bed 116; 23 enlargement of the wall to show small-scaled rugosity of the tectum, x 25. magnification of all specimens x 9, except 8, 23.

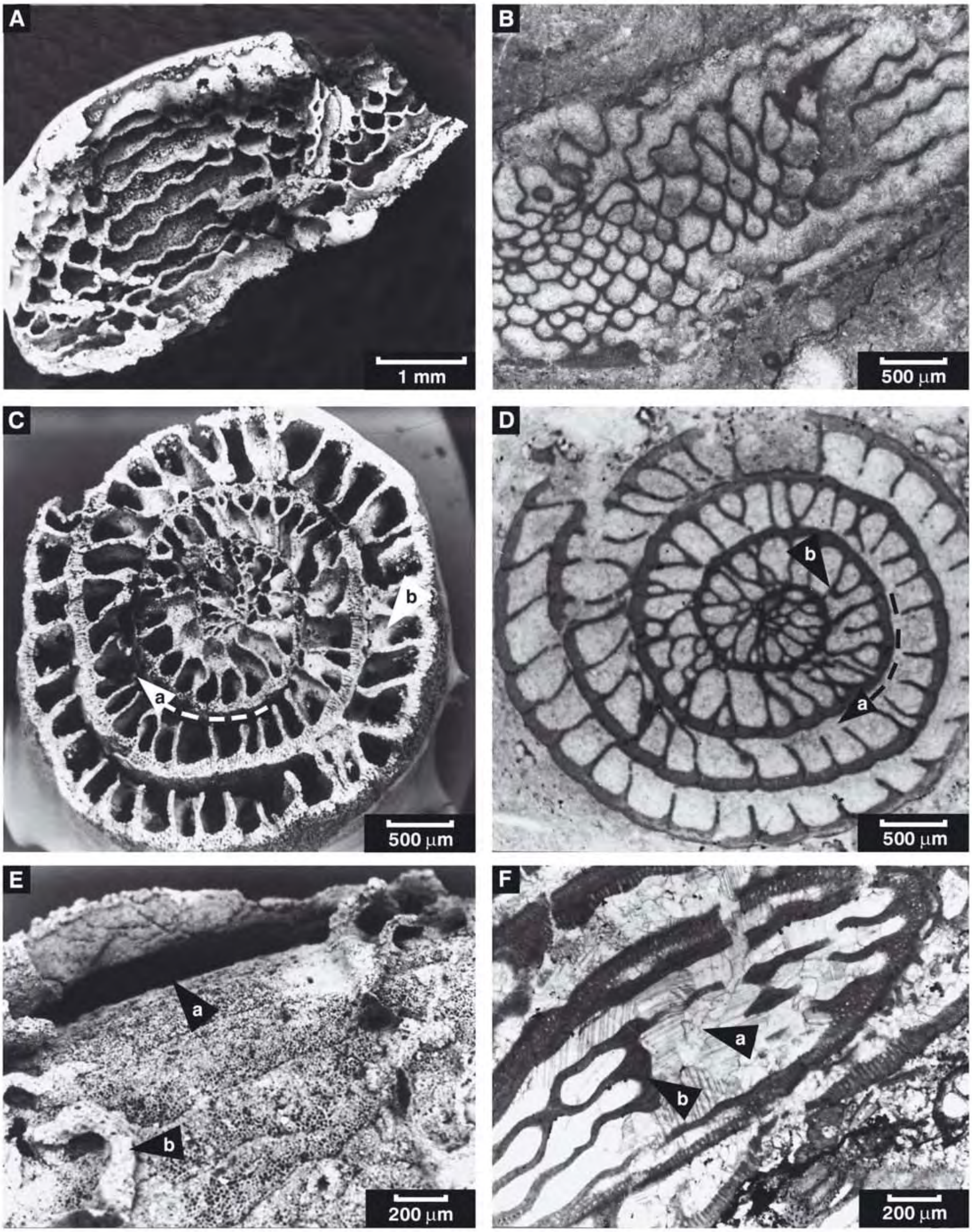

Fig. 38: 3D- (SEM) and 2D- (thin-section) documentation of structural elements in silicified specimen from bed s (from Leppig et al., 2005)

A *Dutkevitchia multiseptata,* view from outside on one individual into the ultimate whorl

B *Dutkevitchia multiseptata*, tangential to slightly oblique section. Septal fluting is less pronounced in the right corner caused by slightly oblique section

C 3D: *Daixina communis*, slightly transverse section. Tunnel (arrow a), “bridge” caused by septal fluting (arrow b)

D 2D: *Daixina communis*, slightly transverse section. Tunnel (arrow a), “bridge” (arrow b)

E 3D: *“Triticites”* cf. *immutabilis*, view on the penultimate whorl. Tunnel (arrow a), choma (arrow b)

F 2D: “*Triticites*” cf. *immutabilis*, tangential section. Tunnel (arrow a), choma (arrow b)

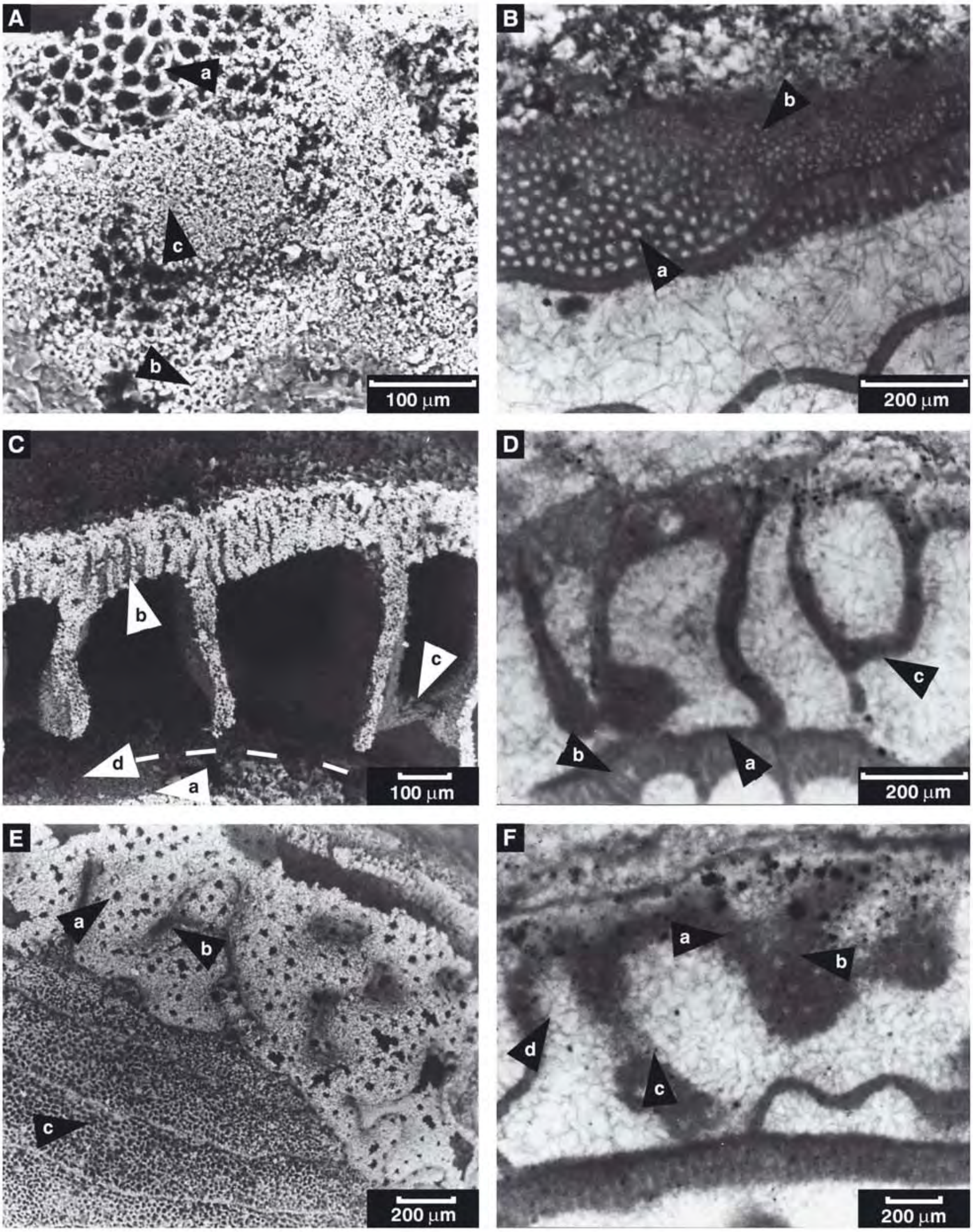

Fig. 39: 3D- and 2D-documentation of structural elements (continued)

A 3D: View on spirotheca. Lower (inner) keriotheca (arrow a), upper (outer) keriotheca (arrow b), tectum (arrow c)

B 2D: Tangential section. Lower (inner) keriotheca (arrow a), upper (outer) keriotheca (arrow b)

C 3D: Equatorial view. Tectum (arrow a), keriotheca (arrow b), “bridge” between two septa (arrow c), tunnel (arrow d)

D 2D: Equatorial section. Tectum (arrow a), keriotheca (arrow b), “bridge” between two septa (arrow c)

E 3D: *Daixina communis*, view on the last whorl with last septum. Septal pore (arrow a), irregular septal fluting causing a depression (arrow b), keriotheca (arrow c)

F 2D: *Daixina alpina*, tangential section through the ultimate and penultimate whorl. Septal pore (arrow a), depression in the septum caused by irregular fluting (arrow b), keriotheca (arrow c), tectum (arrow d)

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