New biostratigraphic and palaeoenvironmental data on metamorphosed limestones from the northern margin of the Tauern Window (Eastern Alps, Austria)

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Abstract

A new lithostratigraphic unit, the "Drei Brüder Formation", within the Fusch facies in the northern part of the Tauern Window is described. These slightly metamorphosed limestones, which are closely associated with an underlying thick package of black phyllites, preserve primary features, such as bedding, erosional sedimentary structures, graded-bedding and cross-bedding. Due to the very low grade of metamorphism and weak deformation, trace fossils *(Alcyonidiopsis* isp. A and B, *Belorhaphe zickzack* (Heer), *Chondrites intricatus* (Brongniart), *Chondrites stellaris* Uchman, *Haentzschelinia* isp., *Helminthopsis* isp., *Hormosiroidea annulata* (Vialov), ?*Phymatoderma* isp., *Planolites* isp., *Thalassinoides* isp.) are well preserved. Foraminifera tests, including *Hedbergella* sp. and possibly *Praeglobotruncana* sp., complement the earlier finding of a *Lamellaptychus*. The trace fossil assemblage indicates the *Nereites* ichnofacies, which suggests deposition below the shelf for most of the Drei Brüder Formation. Sedimentological features suggest deposition in the outer part of a deep-sea fan, above the calcite compensation depth. The trace fossil *Beloraphe zickzack* and *Hedbergella* sp. indicate that the highest part of the Drei Brüder Formation cannot be older than latest Hauterivian. Re-determination of the aptychus to *Lamellaptychus beyrichi* (Opp.) em. Trauth, group A, allows a Tithonian to Berriasian age to be inferred for the lower parts of the formation.

Innerhalb der Fusch Fazies im nördlichen Tauernfenster wird eine neue lithologische Einheit, die nach der entsprechenden Berggruppe als Drei Brüder Formation bezeichnet wird, beschrieben. Sie ist eng mit einer unterlagernden mächtigen Abfolge von Schwarzphylliten verknüpft. Primäre Sedimentstrukturen wie Schichtung, Erosionsstrukturen, gradierte Schichtung und Kreuzschichtung sind gut erhalten. Die nur geringe Metamorphose und schwache Deformation erlaubte die Erhaltung verschiedener Spurenfossilien wie *Alcyonidiopsis* isp. A and B, *Belorhaphe zickzack* (Heer), *Chondrites intricatus* (Brongniart), *Chondrites stellaris* Uchman, *Haentzschelinia* isp., *Helminthopsis* isp., *Hormosiroidea annulata* (Vialov), ?*Phymatoderma* isp., *Planolites* isp., *Thalassinoides* isp. Foraminiferenbruchstücke mit *Hedbergella* sp. and möglicherweise *Praeglobotruncana* sp. ergänzen den früheren Fund eines *Lamellaptychus*. Die Vergesellschaftung der Spurenfossilien weist auf die *Nereites* Ichnofazies und damit auf eine Sedimentation des größten Teils der Drei Brüder - Formation unterhalb des Schelfbereichs hin. Den sedimentologischen Merkmalen entsprechend könnte die Drei Brüder Formation im äußeren Teil eines Tiefsee Fächers oberhalb der CCD abgelagert worden sein. Das Spurenfossil *Beloraphe zickzack* und *Hedbergella* sp. belegen, dass der höchste Anteil der Formation nicht älter als spätes Hauterive sein kann. Andererseits zeigt die Neubestimmung des *Lamellaptychus*, dass der stratigraphisch tiefere Anteil im Tithonian bis Berrias sedimentiert wurde.

1. Introduction

The importance of the stratigraphic control in interpreting the geological evolution of the internal, metamorphic parts of an orogen, in particular in the Eastern Alps, was highlighted more than 100 years ago by the discovery of the Tauern Window by Termier (1904). One of his key arguments was the superposition of Palaeozoic and high-grade metamorphic rocks onto calc-schists which Termier considered to be of Mesozoic age, by comparisons with those in the Western Alps. This correct assumption was based solely on lithological similarities, as fossil findings in the area, which became known as the Tauern Window, were at that time completely lacking. In metamorphosed and intensely deformed rock successions, findings of determinable and stratigraphically useful fossils are still rare events. Most stratigraphic constraints are achieved in such areas as the Alps by making comparisons with stratigraphically better known sections and successions (Lemoine, 2003). Thus, each new fossil finding is important for the revision and updating of stratigraphic schemes and may also be significant for tectonic interpretations.

2. Stratigraphic problems in the Tauern Window

The Tauern Window consists of a variety of metamorphosed igneous and sedimentary rocks, which underwent several metamorphic events (see Schuster et al., 2004 for a general overview). Despite this, some progress has been made in the biostratigraphy of the area in the last sixty to seventy years, following the first determinable finding of an ammonite in the Hochstegen Limestone, initially described by Klebelsberg (1940), later discussed by Mutschlechner (1956) and finally re-determined by Kiessling and Zeiss (1992). This contribution concentrates on the Mesozoic stratigraphy and leaves aside Palaeozoic fossils found recently in the Tauern Window (e.g. Reitz and Höll, 1988; Franz et al., 1991; Pestal et al., 1999). An overview of biostratigraphically significant fossil findings in the area is given in Table 1. Interestingly, these are concentrated at two stratigraphic levels: the Middle Triassic and the Late Jurassic/Early Cretaceous. Consequently, there is a lack of fossil findings from the Late Triassic to Middle Jurassic. Furthermore, depending on the scarce fossil findings, only a little is known about the depositional environments of the successions.

Due to the narrow biostratigraphic ranges of the fossil findings discussed above, combined with their spatially scattered occurrence, more general stratigraphic schemes rely on lithological similarities with dated successions outside the Tauern Window. For example, the "Seriengliederung der Mittleren Hohen Tauern" of Frasl (1958) is based exclusively on lithologies. Frasl (1958) distinguishes five series (or complexes in lithostratigraphic terms): two pre- and three post-Variscan. The latter include the Bündnerschiefer Serie, which comprises all post-Triassic rocks, although according to the lithostratigraphic rules (Höck, 2000), the term Bündnerschiefer Group is more appropriate. Despite the general consensus on the post-Triassic age, the stratigraphic range of this group is still uncertain and under discussion. Earlier workers, such as Frasl (1958), Frasl and Frank (1966), Frank (1969), Frisch et al. (1987), Thiele (1980) and later Ślączka and Höck (in press), favour a mainly Jurassic age, ranging up to the Early Cretaceous. Recently, however, other authors advocate an Early to Late Cretaceous age for most of the Bündnerschiefer Group (Koller and Pestal, 2003; Lemoine, 2003).

3. Geological Setting

Frasl and Frank (1966) subdivided the Bündnerschiefer Group into the Brennkogel-, Glockner-, Fusch- and Hochstegen-facies series. The northern and eastern part of Tauern Window is built up by the Fusch facies, which contains two different tectono-stratigraphic units. The structurally lower one, which is widespread in the eastern and northern part of the window, mainly comprises black phyllites, calcareous phyllites and several thick layers of metabasalts and metatuffs (e.g. Exner, 1956). The higher unit, which is restricted to the northernmost rim of the Tauern Window, east of Mittersill, contains breccias, sandstones and minor phyllites and calc-schists (see Ślączka and Höck in press, for details) and is sometimes referred as "Sandstein-Brekzien Decke" (Braumüller, 1939). This can be followed south of the Salzach Valley approximately from St. Johann in the east via Zell am See to close to Mittersill in the west. The findings of pteridophyte spores (Reitz et al., 1990) indicate an Early Cretaceous age (Tab. 1) for at least part of this unit. Both units are part of the Upper Penninic Nappes (Schmid et al., 2004).

At the boundary of these units, but clearly lying in the footwall, well-bedded, slightly metamorphosed limestones crop out between Taxenbach and Bruck a. d. Glocknerstrasse (Fig. 1), with the best outcrops lying on the northern slopes of the Stolzkopf, Schafelkopf and Breitkopf Mountains (Fig. 1). As these are commonly called the "Drei Brüder" ("Three Brothers"), this limestone is here referred to as the Drei Brüder Formation. The formation can easily be distinguished from other calcareous rocks in the surrounding area mainly by their well-preserved bedding and their coarse-grained calcarenitic composition. The outcrops can be followed at least from the western slope of the Langweidkopf to the northern flank of the Achenkopf and farther to the vicinity of Rauris (Fig. 1).

The southern slope of the Drei Brüder Mountains comprises an up to 2000m thick complex of black phyllites with some intercalations of calcareous schists (Rauris Phyllites of Frasl, 1958) underlying the Drei Brüder Formation. Field evidence indicates an increase of white micas in the limestones and an interbedding of the limestones and black phyllites at their boundary at many places, implying a primary sedimentary contact, although this may be tectonically overprinted locally. In

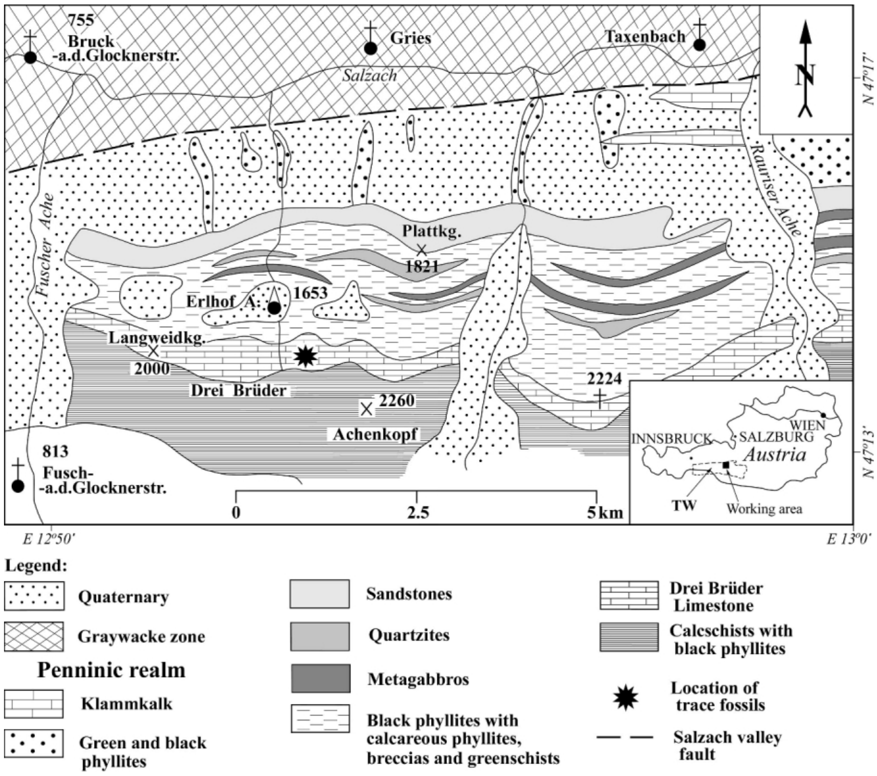

Figure 1: Location and geological map of the research area. All rock types of the Penninic realm are part of the "Bündnerschiefer Group".

Age	Western TW	Central TW	Eastern TW
E. Cretaceous			pteridophyte spore [10]
L. Jurassic	Radiolaria [7, 8] sponge spicules [7, 8] ammonite: *Perisphinctes* sp [4, 5, 6]	*Aptychus* [9], trace fossils	ammonite, corals [11]
M. Jurassic			
E. Jurassic			
L. Triassic			
M. Triassic	crinoids [1, 2] gastropods [2]	Dasycladacea [3]	
E. Triassic			

Table 1: Stratigraphically significant Mesozoic fossil discoveries in the Tauern Window (TW). The numbers refer to the authors: 1) Frisch (1975), 2) Kristan-Tollmann (1962), 3) Borowicka (1966), 4) Klebelsberg (1940), 5) Mutschlechner (1956), 6) Kiessling and Zeiss (1992), 7) Kiessling (1992), 8) Schönlaub et al. (1975), 9) Kleberger et al. (1981), 10) Reitz et al. (1990), 11) Höfer und Tichy (2005). The boundary between the Western and Central TW is defined by the Gerlos Pass and between the Central and Eastern TW by the Rauris Valley.

the eastern part of the mountains, the phyllites reach the crest and the upper part of the northern slopes. Farther to the west, the northern slopes (Fig. 2A) are formed by the Drei Brüder Formation (Sägmüller, 1980; unpubl. manuscript and geological map). The primary thickness of the formation is difficult to establish due to folding and thrusting, but is probably not more than 200-300 metres. The formation is overlain on a strongly tectonized contact by a clastic sequence containing muscovite bearing quartzites, various phyllites, greenschists and dolomite olistoliths, forming part of the Sandstein-Brekzien Decke (Fig. 2A, B; Braumüller, 1939).

Within the Drei Brüder Formation, thick- and medium-bedded limestones with very thin intercalations of calcareous shales (Fig. 2C) can be distinguished from thinner-bedded limestones intercalated with black calcareous shales. Close to the northern end, beds dip steeply to the north (Fig. 2A). There is a lack of sufficient data to establish the stratigraphic order of the sequence, although in a few cases sole marks, normal graded bedding and ripples indicate the rocks are in an upright position (Figs. 2D and 2F). However, our observations are limited to a restricted part of the succession and do not allow a more general conclusion. Moreover, the Drei Brüder Formation is slightly tectonized. Several folds of different amplitude and faults, some of which may be thrust faults, can be distinguished. The common, almost vertical or even overturned, bedding planes are cut by centimetre to decimetre spaced, less steeply dipping joints. A weak foliation, observed in some thin-sections, is probably sub-parallel to these joints and a microcleavage and flattened sparitic grains lie almost perpendicular or at a high angle to the bedding.

The trace- and microfossils described below were almost all found in loose blocks, mostly from two talus fields (locality 1 and 2 in Fig. 2B), with an unambiguous provenance, representing the northernmost (upper) part of the Drei Brüder Formation. The source of the Lamellaptychus, also from a loose block (Kleberger et al., 1981), lies farther to the south and probably represents a lower stratigraphic level within the Drei Brüder Formation.

4. Sedimentary features

Field relationships indicate that the trace fossils were derived from a thick- to medium-bedded succession, from the central part of the Drei Brüder Formation. Generally, the limestones are dark grey, medium- to thick-bedded (up to 1 m thick), locally very thick-bedded and almost pure (> 90% $CaCO_3$) medium to coarse-grained calcarenites. Locally, they contain fine-grained quartz, detrital mica grains and originally marly calcilutite intercalations (calcareous schists), up to a few centimetres thick. Rarely, fine-grained, massive, thick-bedded limestones with scattered clasts of schists and ferruginous shales occur (Fig. 2H). Recrystallization is commonly observed in thin-sections.

The bedding surfaces are distinctly sharp and rather smooth, probably at least partly due to shearing between the layers (Fig. 2C). However, primary erosional sedimentary structures such as groove marks, rare flute casts (Fig. 2D), brush marks and small erosional channels are occasionally preserved on lower bedding planes. The drag marks are generally oriented SE-NW and E-W whilst flute marks point to palaeo-currents flowing from the SE, in accordance with cross-stratification data (Fig. 2F).

Locally, normal graded-bedding can be seen. In some beds, it forms a couplet with the overlying parallel laminated beds; these can be interpreted as Bouma Tab divisions (Bouma, 1962), followed by fine-grained intercalations of Te divisions.

Commonly, the limestones display whitish pelitic laminae that are one to a dozen mm thick (Fig. 2E) and most of which are lenticular in cross-section. The laminae occur in the upper part of layers and are uniformly distributed or create bundles a few centimetre-thick. The latter could be an effect of bed amalgamation. Trace fossils are generally restricted to these laminae.

Cross-bedding is rare. In loose blocks, however, a hummocky cross-bedding in up to 60 cm thick sets occurs (Fig. 2I) in sandy calcarenites (Fig. 2B, locality 1). Some blocks with the hummocky cross-stratification also display graded bedding (Fig. 2G).

5. Body fossils

In the research area, only a few body fossils were discovered. Generally these are badly preserved, preventing their exact determination and consequently they could not be used to establish the exact age of the Drei Brüder Formation.

5.1 Belemnite guard

A single belemnite guard (Fig. 3A) was found in an isolated limestone slab in front of the Erlhof Alm hut, truncated almost axially by the slab surface. The guard is 33 mm long and up to 5 mm wide with slightly deformed margins. The apex is acute and the termination displays a tunnel about 2 mm wide. A taxonomic determination in this state of preservation is difficult; the order Belemnitida ranges up to the Eocene, but is very rare in the Palaeogene.

5.2 Microfossils

In thin-sections of limestones containing trace fossils, tests of calcareous foraminifers, generally badly preserved, were found. In a few cases, however, Prof. Adam Gasiński (Cracow, Poland) identified them as epipelagic forms of the genus *Hedbergella* (Fig. 3B-C) and questionable *Praeglobotruncana* sp. or *Rotalipora* sp. (Fig. 3D). These indicate an Early Cretaceous age, with first occurrences reported from the Hauterivian and Albian respectively. The presence of agglutinated foraminifera such as *Ammobaculites* sp. or *Glomospira* sp., has no stratigraphic and

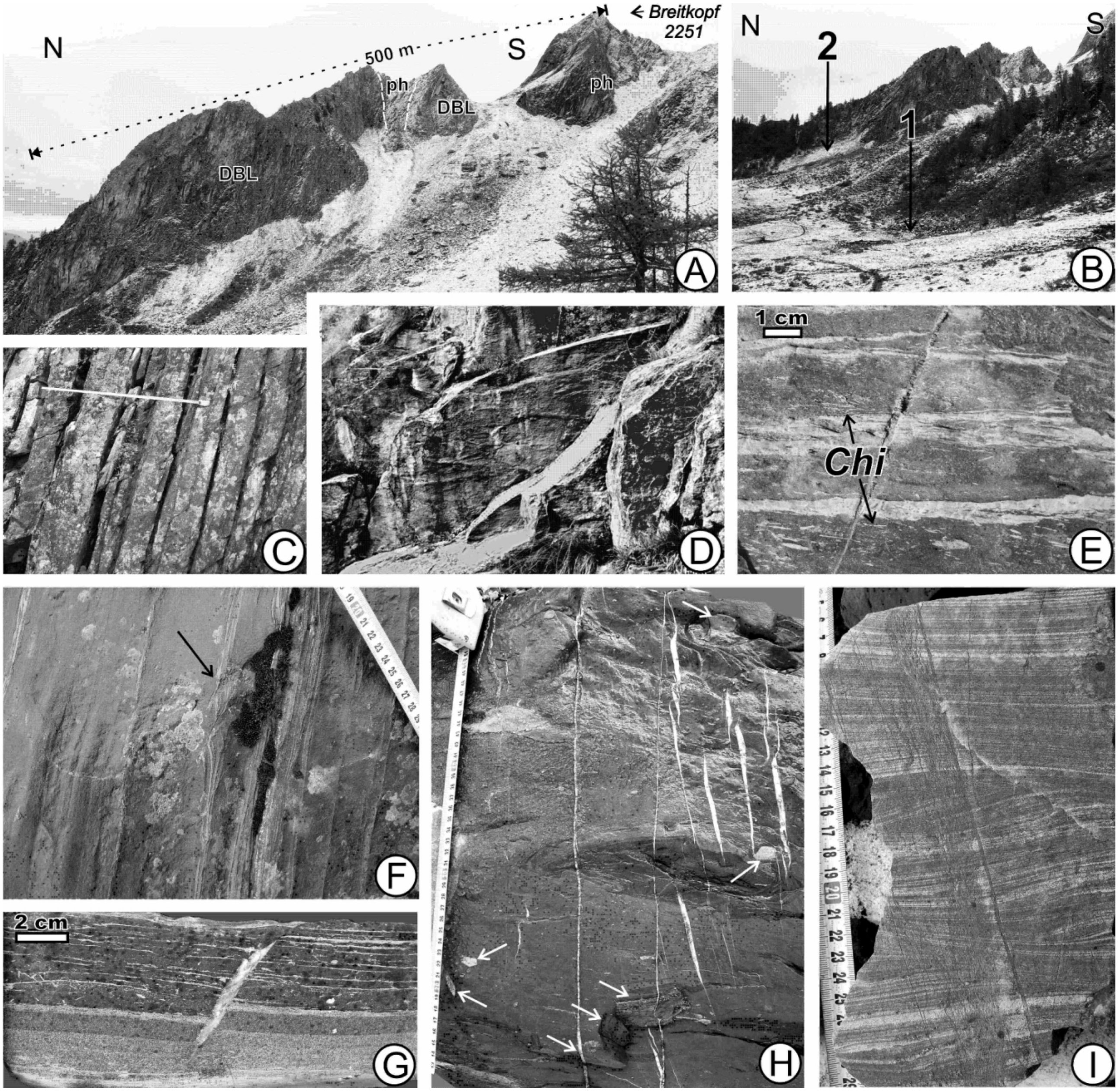

Figure 2: Section and some sedimentary features of the Drei Brüder Formation.
A. A panoramic view towards Breitkopf and its northern ridge from the touristic path from Erlhof Alm; DBF - Drei Brüder Formation; ph – black phyllites. The limestone beds are dipping almost vertically towards the north. The profile shows the whole visible thickness of the formation.
B. Two major block fields (locations 1, 2), where most of the trace fossils were collected; the blocks represent the stratigraphically highest part of the sequence; view from the west to the east.
C. Steeply dipping limestone beds to the north; intercalated with thin layers of calcilutite; the outcrop is presu-mably a part of the source-area of the blocks containing the trace fossils; the measurement tape is 1 m long.
D. Groove marks visible on the bottom of a limestone bed (middle part of the picture); the groove marks are oriented subparallel to the strike; view from the south.
E. Calcarenites (darker) alternating with thin calcilutite laminae (lighter); the latter were probably deformed during sedimentation; cross sections of *Chondrites intricatus* (Brongniart) (*Chi*), are visible, coll.#: 191P18a.
F. Lamination (generally lighter) in limestone beds; ripple lamination shown by the arrow; cm/mm scale.
G. A thin bed with graded-bedding and lamination; location 2 (Fig. 2B).
H. Block of fine-grained limestones with clasts; larger clasts shown by arrows; scale in cm/mm.
I. A thick sandy calacarenite with hummocky-cross lamination; loose block found at location 2 (Fig. 2B); scale in cm/mm.

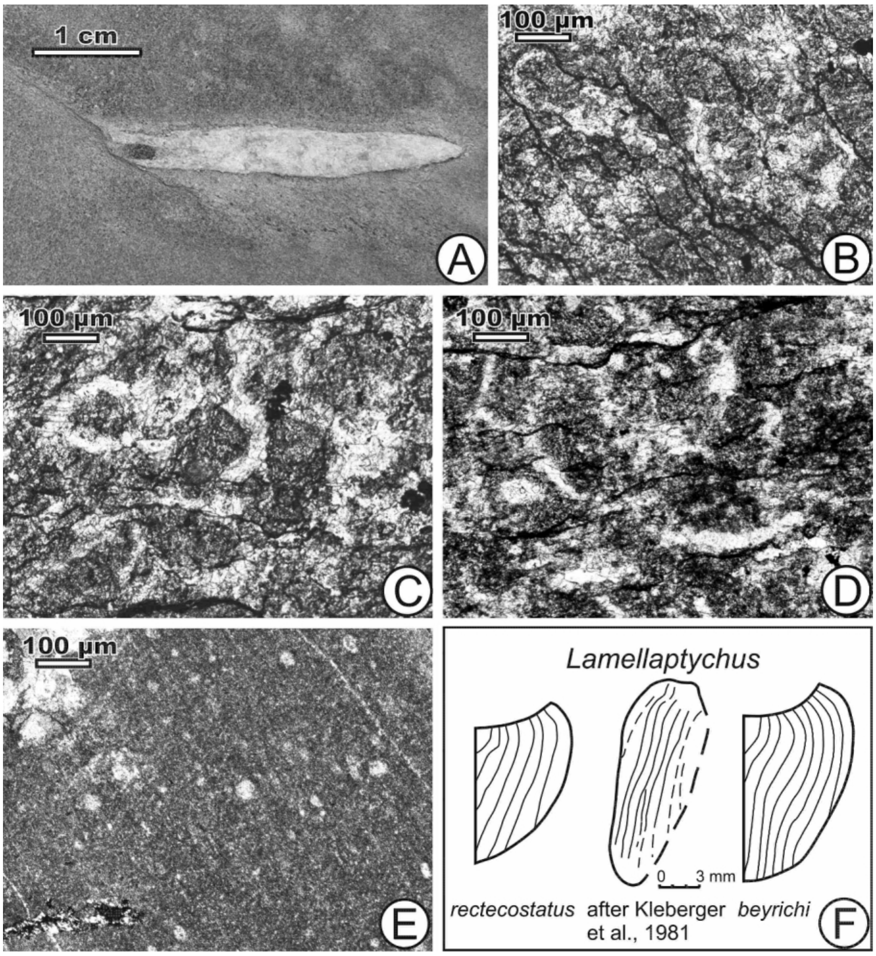

Figure 3: Body fossils from the Drei Brüder Formation.
A. Belemnite guard on a parting surface, field photograph.
B and C. Hedbergellid foraminifer tests (*Hedbergella sp. or Globigerinelloides* sp.) in thin-sections.
D. Foraminifer *Rotalipora* sp. or *Praeglobotruncana* sp.
E. Calcified ?radiolaria in thin-sections.
F. *Lamellaptychus* determined as *L.* cf. *rectecostatus* by Kleberger et al. (1981), redrawn from his pl. 1, and *L. rectecostatus* and *L. beyrichi* redrawn from Gąsiorowski (1959, 1962).

palaeobathymetric significance. In some places, fine-grained laminae in the limestones contain spheres that can be regarded as calcified radiolaria (Fig. 3E).

5.3 *Lamellaptychus* problem

Kleberger et al. (1981, pl. 1) identified *Lamellaptychus* cf. *rectecostatus* (Peters 1854) in the Drei Brüder Formation (Fig. 3F), based on the work by Gąsiorowski (1959, 1962). However, comparison of the discussed fossil to Gąsiorowski's drawings put the suggested specific determination in doubt. In *L. rectecostatus*, the course of ribs is more oblique to the symphysal edge (Gąsiorowski, 1962) than in the specimen from the Drei Brüder Formation, which is more similar to *Lamellaptychus beyrichi* (Opp.) em. Trauth, group A. The latter is characteristic for the Tithonian, although it was noted also from Berriasian (Gąsiorowski, 1962). A major problem for exact determination is that the umbilical part of the valve is partly destroyed.

6. Trace fossils

Trace fossils, which are the commonest evidence of biogenic activity in the Drei Brüder Formation, are preserved on natural, weathered, probably bedding or parting surfaces of limestone blocks in the talus below limestone exposures. They occur below spot elevation 1919 m as well as east and southeast of it in two major block fields (Figs. 1, 2B). The trace fossils are more common close to calcilutitic intercalations and in most cases are filled with lighter-weathering material than the dark background. Rarely, they form a very low relief and, in many cases, they are deformed as a result of tectonic shearing. The illustrated and complementary specimens are housed in the Institute of Geological Sciences of the Jagiellonian University (collection prefix 191P).

7. Synopsis of ichnotaxa

Ichnogenus *Alcyonidiopsis*
Massalongo 1856
Alcyonidiopsis isp. A
(Fig. 4A, C-E)

Material: Specimens 191P8, 6, 14, field observations.
Description: Straight or winding, strongly flattened curved cylinders, 2-3 mm or 3-5 mm wide, filled with muddy, pelletal sediment. The pellets are 0.2-0.4 mm across. Locally they are arranged in poorly outlined menisci (Fig. 4E). The cylinders can display crossings or overlaps.
Remarks: The presence of menisci is typical of *Taenidium* Heer 1877, but the menisci are local and poorly expressed. *Taenidium* should display regular meniscate filling (compare D'Alessandro and Bromley, 1987; Keighley and Pickerill, 1994). It seems that there is a transition between *Alcyonidiopsis* and *Taenidium*. *Alcyonidiopsis* is a typical pascichnion showing a wide stratigraphic and facies range (for discussion see Uchman, 1999).

Alcyonidiopsis isp. B
(Fig. 4A, B)

Material: Specimen 191P24, and field observations.
Description: Horizontal flattened cylinders, 11-15 mm wide, in one case 24 mm wide, filled with oval pellets, which are approximately 1.5 mm long and 1 mm wide. They are straight or only slightly curved at the scale of the specimens.
Remarks: The size of *Alcyonidiopsis* isp. B is much larger than *Alcyonidiopsis* isp. A, including the pellets.

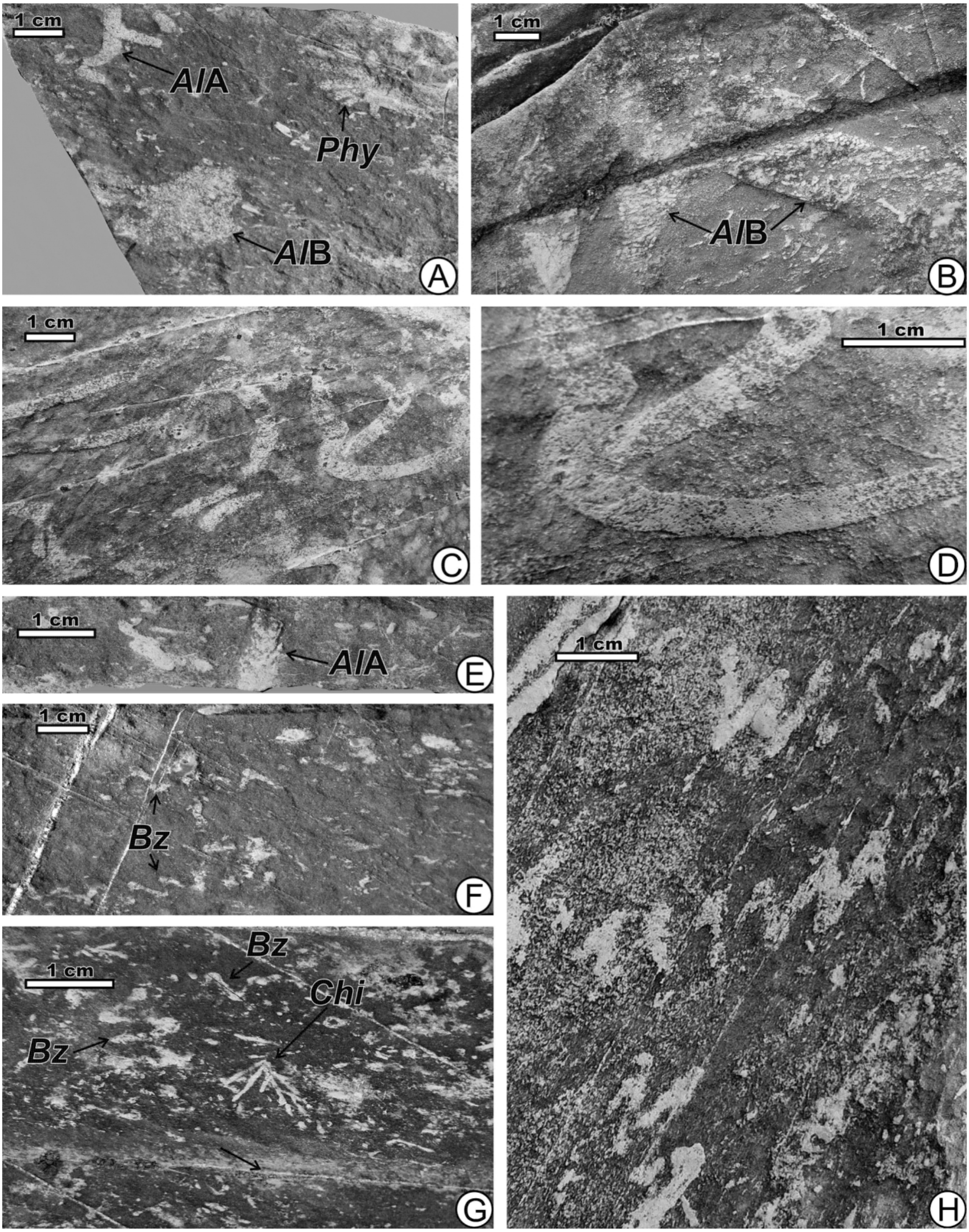

FIGURE 4: Selected trace fossils from the Drei Brüder Formation. Full reliefs on parting surfaces.
A. *Alcyonidiopsis* isp. A. (*Al*A), *Alcyonidiopsis* isp. B (*Al*B) and ?*Phymatoderma* isp. (*Phy*), coll.#: 191P8.
B. *Alcyonidiopsis* isp. B. (*Al*B). Small pellets are visible in the infill.
C. *Alcyonidiopsis* isp. A. Crossing full reliefs.
D. Detail of C. See small pellets in the filling.
E. *Alcyonidiopsis* isp. A. (*Al*A), coll.#: 191P6. See small pellets in the filling and faint meniscate structure.
F. *Belorhaphe zickzack* (Heer) (*Bz*), coll.#: 191P1.
G. *Belorhaphe zickzack* (Heer) (*Bz*) and *Chondrites intricatus* (Brongniart) (*Chi*), field photograph.
H. *Belorhaphe zickzack* (Heer), field photograph.

Ichnogenus *Belorhaphe* Fuchs 1895

Belorhaphe zickzack (Heer 1877)

(Fig. 4F-G, H)

Material: Specimens 191P1, 7, 9, 11.

Description: Angular meandering strings, about 1 mm wide. The string is wider (up to 2 mm) in the meander kinks (apices). The meanders display an apical angle of 30–100°, are 4-7 mm wide and 4–7 mm high. The wide range of apical angles probably results from tectonic shearing. The meanders are filled with lightweathering material in contrast to the black background.

Remarks: Typical agrichnion from the graphoglyptids, which is known from deep-sea sediments, mostly turbidites (see Seilacher, 1977; Uchman, 1998).

Ichnogenus *Chondrites* Sternberg 1833

Chondrites intricatus (Brongniart 1823)

(Figs. 2E, 4G, 5A-C)

Material: 191P1, 3, 6, 7, 10, 11, 12.

Description: A system of tree-like branching, markedly flattened tunnels, 0.3-1.0 mm in diameter. The tunnels form acute angles and show a phobotaxis. In many specimens, only branched or unbranched fragments of the tunnels are visible. In crosssection, they occur as patches of circular to elliptical spots and short bars. In most cases, the fill of the trace fossil is lighter than the host rock. In only one case, is the filling darker.

Remarks: This is the commonest trace fossil in the investigated deposits. *Chondrites* is a marine trace fossil with a wide stratigraphic range. It is typical of sediments deeper than the shoreface. *Chondrites* is probably produced by a chemosymbiotic organism penetrating periodically into sediments of the anoxic zone. For a more extensive discussion of this ichnogenus, see Fu (1991) and Uchman (1999).

Chondrites stellaris Uchman 1999

(Fig. 5D)

Material: 191P2.

Description: Small, straight, branching tunnels, 0.5-0.7 mm wide, up to 6 mm long, radiating from a central point. The tunnels are light in contrast to the dark background.

Remarks: This ichnospecies is characterized by a narrow range of morphometric parameters (width of tunnels and width of the burrow system) (Uchman, 1999), which fits well to the described specimens. This is the second occurrence of this ichnospecies, otherwise only known from its type locality in the Tristel Formation (Upper Barremian – Lower Aptian) of the Rhenodanubian Flysch, in the Bavarian Alps (Uchman, 1999).

Ichnogenus *Haentzschelinia* Vialov 1964

Haentzschelinia isp.

(Fig. 5E-F)

Material: Field observations.

Description: Small, slightly asymmetric rosettes composed of simple or rarely branched rays. The number of rays oscillates around 10. They are up to 18 mm long and about 2.5-3 mm wide. The rays radiate from a central, poorly outlined point. The branches form acute angles.

Remarks: *Chondrites stellaris* is distinctly smaller and displays more common branches and a more distinct asymmetry. *Haentzschelinia* isp. very much resembles the “Sternförmige Lebensspuren” described by Lobitzer et al. (1994, pl. 8, figs. 5-7) from the Oberalm Formation (Tithonian-Lower Berriasian) and Schrambach Formation (Middle Berriasian-Lower Valanginian) in the Northern Calcareous Alps near Salzburg. Schweigert (1998) ascribed them to *Haentzschelinia* but without specific determination. *Haentzschelinia* Vialov 1964 was included in *Dactyloidites* Hall 1886 by Fürsich and Bromley (1985) but Schweigert (1998) argued that in contrast to the symmetric radial *Dactyloidites*, *Haentzschelinia* displays an asymmetric pattern in outline of a half- or three quartercircle. *Haentzschelinia* is a marine fodinichnion ranging from the Late Triassic to Miocene.

Ichnogenus *Helminthopsis* Wetzel and Bromley 1996

Helminthopsis isp.

(Fig. 5F-G)

Material: A specimen in slab 191P29 and field observations.

Description: Horizontal, simple, slightly winding string, 1.5-3.0 mm wide. In the field, a larger form of the same morphology, 3-6 mm, was noted. Moreover, a fragmentary preserved slightly winding string, 4.5-8 mm wide was observed. It is tentatively included in *Helminthopsis*.

Remarks: *Helminthopsis* is a facies crossing repichnion. For the discussion of this ichnogenus, see Han and Pickerill (1995) and Wetzel and Bromley (1996).

Ichnogenus *Hormosiroidea* Schaffer 1928

Hormosiroidea annulata (Vialov 1971)

(Fig. 5H)

Material: Only field observations.

Description: A straight cylinder, 1 mm wide, with enlargements forming trapezoidal bodies that are up to 2 mm wide and 2 mm long. Only three enlargements are observed. They are located 5 and 6 mm apart.

Remarks: The enlargement wider on one side is a characteristic morphological element of *Hormosiroidea*. For discussion of this ichnogenus, see Uchman (1999).

Ichnogenus *Phymatoderma* Brongniart 1849

?*Phymatoderma* isp.

(Fig. 4A)

Material: 191P8.

Description: Asymmetric circle, straight ribbons, 1.5-2.0 mm wide, up to 15 mm long, spreading out from one point in a three-quarter circle. The ribbons are filled with small pellets.

Remarks: The pelletal fill and overall geometry suggest *Phymatoderma*, which is a fodinichnion known from deeper water marine fine-grained sediments (for discussion, see Fu, 1991; Uchman, 1999).

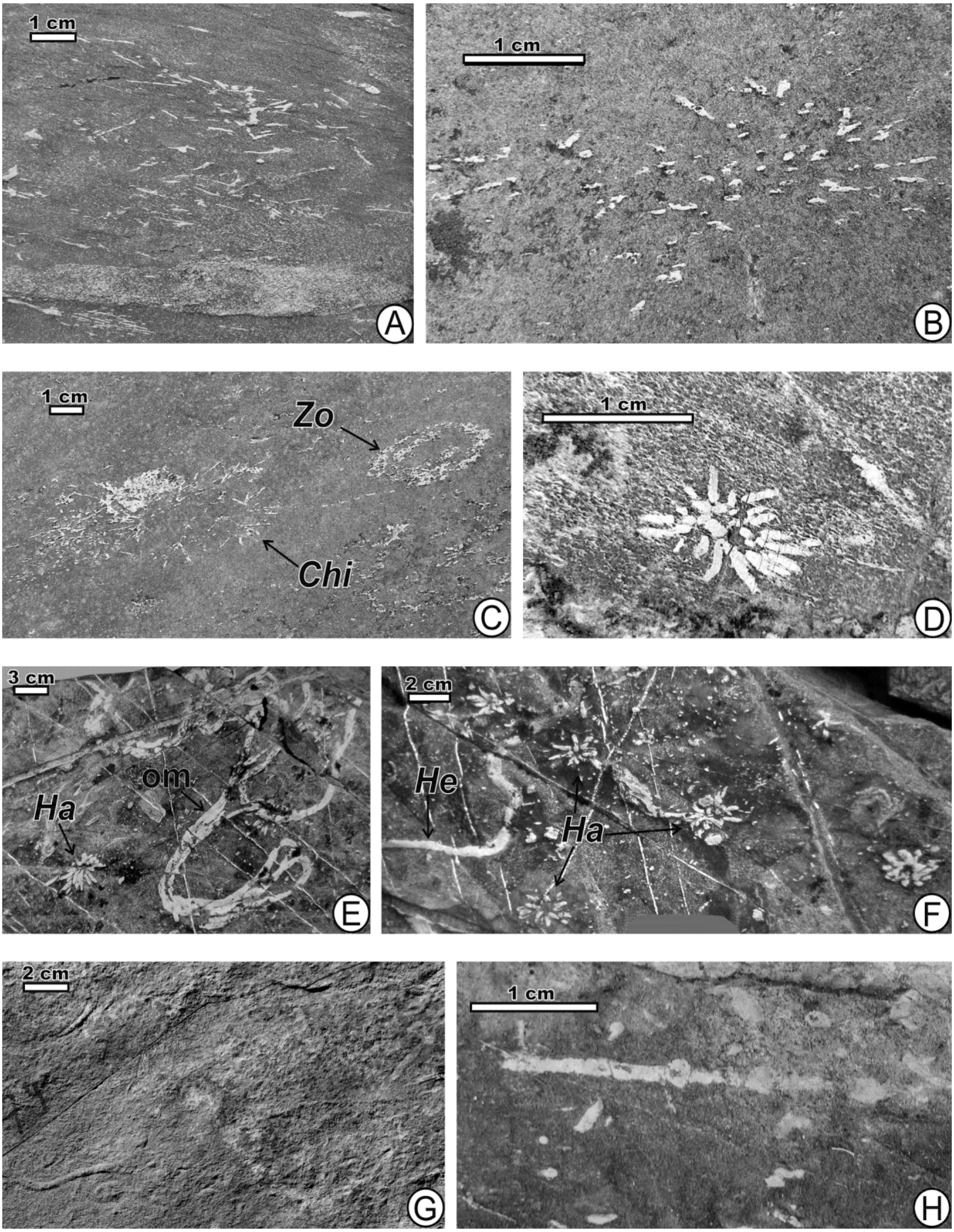

Figure 5: Other trace fossils from the Drei Brüder Formation.
A-B. *Chondrites intricatus* (Brongniart). Full relief on a parting surface. Field photographs.
C. *Chondrites intricatus* (Brongniart) (*Chi*) and ?*Zoophycos* isp. (*Zo*). Full relief on a parting surface. Field photograph.
D. *Chondrites stellaris* Uchman 1999, coll.#: 191P2. Full relief on a parting surface.
E. *Haentzchelinia* isp. (Ha) and the overlapping meanders (om). Full reliefs on a parting surface. Field photograph.
F. *Haentzchelinia* isp. (*Ha*) and *Helminthopsis* isp. (*He*). Full reliefs on a parting surface. Field photograph.
G. *Helminthopsis* isp., coll.#: 191P29. Convex full relief on a bedding plane.
H. *Hormosiroidea annulata* (Vialov). Full relief on a parting surface. Field photograph.

Ichnogenus *Planolites* Nicholson 1873

Planolites isp.

Fig. 6A, C

Material: 191P29.

Description: Horizontal simple (Fig. 6C) or slightly winding and branching strings (Fig. 6A), winding, branching strings, 1.0-1.8 mm wide, forming a full relief on a bedding plane. The strings display crossings and overlaps.

Remarks: *Helminthopsis* isp. displays a more distinct and regular winding course and is unbranched. *Planolites* isp. was described as *Sabularia* sp. by Kleberger et al. (1981), but the ichnogenus Sabularia is not recommended for further use (Uchman, 1998). *Planolites* is a facies crossing form. It was discussed by Pemberton and Frey (1982) and Keighley and Pickerill (1995) and interpreted as a pascichnion.

Ichnogenus *Thalassinoides* Ehrenberg 1944

Thalassinoides isp.

(Fig. 6B-C)

Material: 191P14, field observations.

Description: Endichnial, straight or slightly winding branched cylinders, 7-12 mm wide. Some of them are strongly flattened.

Remarks: *Thalassinoides* was produced by crustaceans, mostly decapods (Frey et al., 1984). For further discussion of this ichnogenus and its ichnotaxonomic problems, see Fürsich (1973), Ekdale (1992) and Schlirf (2000).

Ichnogenus *Zoophycos* Massalongo 1855

?*Zoophycos* isp.

(Figs. 5C, 6D-F)

Material: Form A: 191P20, 21. Form B: only field observations.

Description: Two forms of preservation, A and B, are recognized. A. Spirally coiled stripes, 2-4 mm wide. The coils contain up to two whorls and form an ellipse in outline, which is 15-45 wide and 35-100 mm long. B. Winding and locally looping ribbons on bedding surfaces, 2-10 mm wide, with a meniscate-like filling.

Remarks: Both preserved forms are probably horizontal sections of helical lobes of Zoophycos. The meniscate-like filling in form B can result from cross-section of spreiten. Zoophycos is a complex fodinichnial structure (e.g. Bromley and Hanken, 2003 and literature cited therein), known mostly from fine-grained sediments deposited below the shelf since the Jurassic (e.g., Olivero, 2003). However, shallow occurrences are known not only from pre-Jurassic times but also from the Cenozoic (Pervesler and Uchman, 2004).

Overlapping meanders

(Fig. 5E)

Material: Only field observations.

Description: Irregularly meandering ribbons, about 5 mm wide. They overlap on long distances.

Remarks: The overlapping on longer distances is the main difference between this trace fossil and *Helminthopsis* or *Gordia*.

8. Bathymetry and depositional conditions

The trace fossil assemblage of the Drei Brüder Formation contains the graphoglyptid *Belorhaphe zickzack* (Heer), which is typical of the *Nereites* ichnofacies. The other ichnotaxa are not limited to this ichnofacies, but are quite common or at least occasionally present in it. This also includes *Thalassinoides* (e.g. Uchman, 1999) or *Haentzschelinia* (Lobitzer et al., 1994). Thus, the trace fossil association as a whole points to the *Nereites* ichnofacies, which is typical of the deep-marine environment, below the shelf (e.g. Frey and Seilacher, 1980). *Zoophycos*, a typical member of the *Zoophycos* ichnofacies, can also occur in the *Nereites* ichnofacies. The general calcareous character of the deposits, without traces of solution indicates a deposition above the CCD. The presence of *Lamellaptychus* and belemnites indicate open, normal marine conditions.

Only some bedding planes contain trace fossils. This might be taken as an effect of selective metamorphic obliteration, but it can also be considered as a primary feature. The latter interpretation suggests that the sediment was colonised incidentally during continuous deposition or during incidental sedimentation when only some event beds were colonised from the top after their deposition. This latter scenario is more probable. The presence of graphoglyptids, with a typical K-selected style of colonisation (Ekdale, 1985) suggests longer periods of stability with low accumulation rates of the background sediments and oligotrophy (e.g. Ekdale, 1985; Uchman, 2003), as observed in many flysch deposits.

Colonization of only some beds may also suggest a low oxygen content in the sediments. Most of the trace fossils represent burrow systems connected to the sea floor (*Belorhaphe*, *Chondrites*, *Haentzschelinia*, *Thalassinoides*, ?*Zoophycos*), in which tracemakers can use oxygenated water from above the sea floor. In many cases, *Chondrites* occurs alone, typical of dysaerobic conditions (e.g., Bromley and Ekdale, 1984; Savrda and Bottjer, 1986). In contrast, however, *Alcyonidiopsis* and *Planolites* represent an actively filled burrow without connection to the sea floor; hence the tracemaker must use oxygen from pore waters. This indicates oxygenated sediments in some periods. The primary lamination seen in some beds (Fig. 2E-F) may be related to the change of anoxic conditions. The generally dark colour of the limestones corresponds well with such an interpretation.

The field evidence and microscopic data imply that the Drei Brüder Formation accumulated in a local deep-sea fan that is exposed today over a distance of at least a dozen kilometres, between the Fusch and Rauris valleys (see Fig. 1). Some sedimentary features, especially the probable Bouma (1962) divisions, suggest turbiditic flows for calcarenites, whereas calcilutites could have been deposited from very diluted (tails of) turbidity currents (Stow, 1985). Layers with contorted lamination and clasts are evidence of slump movements on various scales. They range from very local ones, embracing single laminae through more regional ones that involved whole layers, to chaotic ones with clasts (Fig. 2H), representing debris-flow deposits. The calcareous schists within the limestone were primarily marly claystones representing background hemipelagic sedimentation. The lack of calcirudites and the occurrence of only individual slump and debris-flow deposits indicate that only the more distal part of the fan is exposed (cf. Mutti and Ricchi Lucchi, 1975). The planktonic foraminifera *Hedbergella* sp. or *Globigerinelloides* sp. suggest external shelf-bathyal environments, confirming in general the bathymetric interpretation. However, single blocks of sandy calcarenites with hummocky cross-stratification suggest the existence of shoreface - upper offshore facies.

The observed sedimentary structures (flute casts, cross-bedding) imply a source-area for clastic material situated towards the SE, probably along the southern margin of the basin. Nevertheless, more systematic observations of the sedimentary structures along the whole profile are needed to properly establish the clastic source-area.

Generally, the Drei Brüder Formation shows some similarities with the lower part of the Cieszyn Limestone (Late Tithonian-Berriasian) from the Silesian Unit of the Carpathians, which are interpreted as submarine fan deposits (Malik, 1986), and to the Oberalm Formation (Upper Tithonian-Berriasian) in the

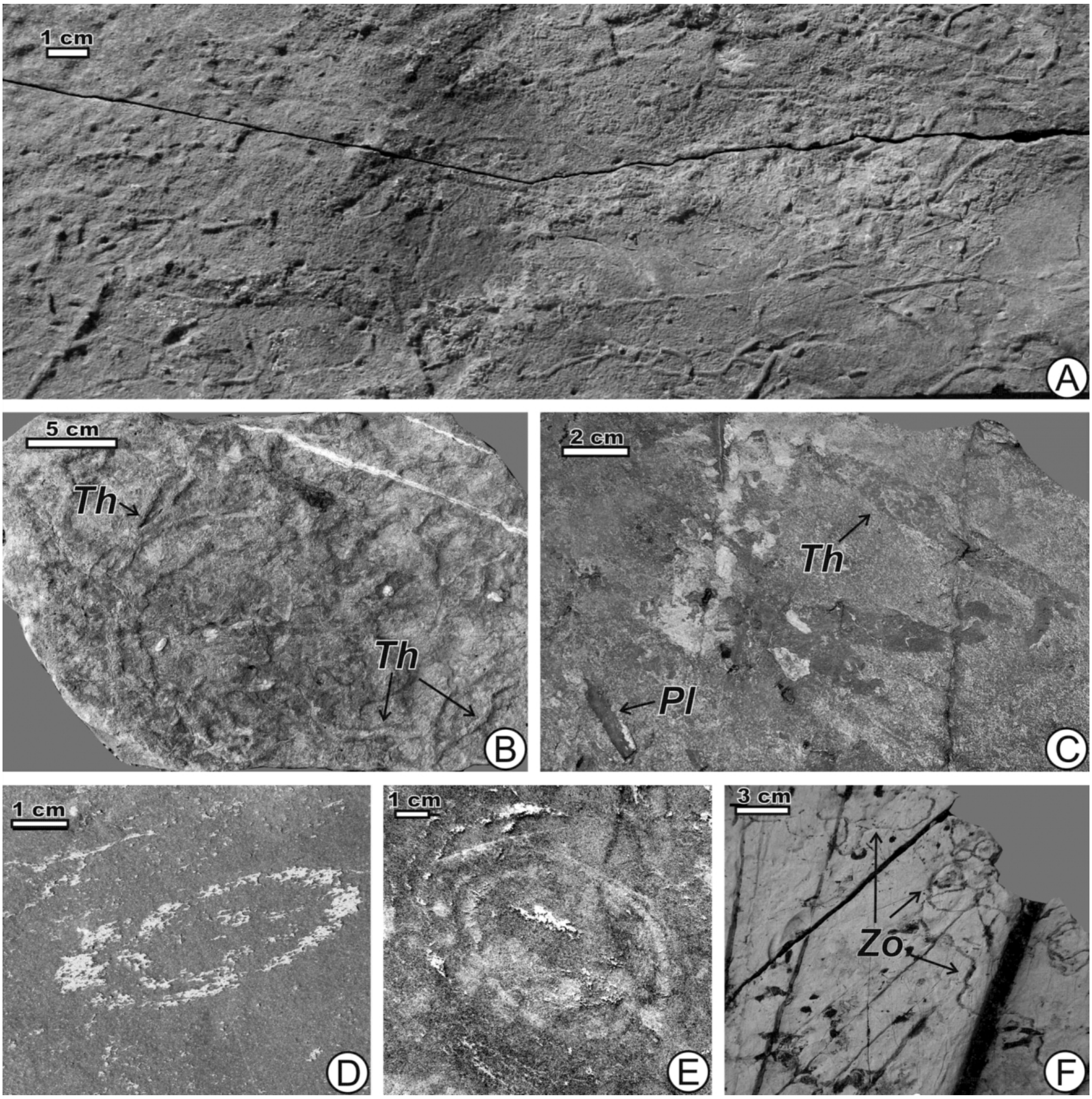

Figure 6: Some cylindrical and spreite trace fossils.
A. *Planolites* isp., coll.#: 191P29. Full reliefs on a bedding plane.
B. *Thalassinoides* isp. Full reliefs on a bedding plane. Field photograph.
C. *Thalassinoides* isp. (*Th*) and *Planolites* isp. (*Pl*). Full reliefs on a parting surface. Field photograph.
D. ?*Zoophycos* isp. A., coll.#: 191P21. Horizontal section of a helical structure on a weathered parting surface.
E-F. ?*Zoophycos* isp. Horizontal section of a helical structure on a weathered parting surface. Field photographs.

Northern Calcareous Alps, interpreted as shallow bathyal or outer shelf deposits (Lobitzer et al., 1994). The trace fossil assemblage contains numerous species in common with the latter unit (*Belorhaphe*, *Hormosiroidea*, *Alcyonidiopsis*, *Chondrites*, *Zoophycos*).

9. Stratigraphy

In a few instances trace fossils can be useful stratigraphic markers, especially in Palaeozoic shallow-marine sandstones (e.g. Crimes, 1968; Seilacher, 1970; 1994; 2000). However, for deep-seas sediments such an application is less obvious. However, the first occurrences of some trace fossil taxa can be used in this respect (Uchman, 2003; 2004).

The only stratigraphically important trace fossil in the Drei Brüder Formation is *Belorhaphe zickzack* (Heer). Its first appearance (Fig. 7) was described from the Tithonian part of the Kostel Formation (uppermost Kimmeridgian-Berriasian) in NW Bulgaria (Tchomumachenco and Uchman, 2001). *B. zickzack* occurs also in the Berriasian part of the Cieszyn Limestone in the Polish Carpathians (Książkiewicz, 1977) and in the Berriasian part of the Oberalm Formation and in the Schrambach Formation (Middle Berriasian-Lower Valanginian) in Austria (Lobitzer et al., 1994). Younger occurrences are known from the Upper Cieszyn Shale (Valanginian-Hauterivian), Polish Carpathians (Książkiewicz, 1977; Uchman, 2004). There are no younger occurrences of *B. zickzack* than the Eocene (see Uchman, 2003).

There are also reports of older occurrences of *Belorhaphe*, but these concern other ichnospecies or different ichnogenera. Pickerill (1980) illustrated *Belorhaphe* isp. from the Ordovician flysch of Canada, but not *Belorhaphe zickzack*. *Belorhaphe fulgur* Vialov (1963) from Silurian of Kazakhstan is more tightly spaced and smaller. Yang et al. (2001) described *Belorhaphe* isp. from the Triassic flysch of Miers Bluff Formation (Upper Triassic), in Antarctica, but its determination is questionable. Krawczyk et al. (1995) reported *Belorhaphe* isp. from the Szlachtowa Formation in the Pieniny Klippen Belt in Poland, but no figure is given, and the Toarcian-Aalenian age of this formation has recently been challenged and is now considered to be at least in part lower Cretaceous (Oszczypko et al., 2004). Diersche (1980) reported *Belorhaphe* from the Tauglboden Formation (Upper Oxfordian-Kimmeridgian) in Austria, but, again, no figure is given.

Chondrites stellaris has been previously documented only from the Tristel Formation (Upper Barremian – Lower Aptian) of the Rhenodanubian Flysch (Uchman, 1999) and hence is too rare to be used biostratigraphically (Fig. 7).

From the determined microfossils, *Hedbergella* sp. is the more important stratigraphically, as it was determined with a high degree of certainty. This has a stratigraphic range starting at the Hauterivian/Barremian boundary (Fig. 7) (Gradstein et al., 2004). Thus, this part of the Drei Brüder Formation cannot be older than latest Hauterivian. The questionable occurrence of *Praeglobotruncana/Rotalipora* needs to be confirmed by further investigations before it can be of reliable stratigraphic value. The southern, stratigraphically lower part of the profile, where *Lamellaptychus* was found, is probably older, most likely of Tithonian to Berriasian age (Fig. 7).

10. Conclusions

Our investigations in the northern part of the Tauern Window revealed a new lithostratigraphic unit, the Drei Brüder Formation. This is unique among many other post-Triassic lithologies in the Tauern Window as primary features, such as bedding, erosional sedimentary structures, graded bedding or cross bedding are preserved. Due to the weak metamorphism and deformation, well-preserved trace fossils and foraminifera were found, complementing the earlier finding of a *Lamellaptychus* (Kleberger et al., 1981). The trace fossils *Beloraphe zickzack* and *Hedbergella* sp. indicate that the highest part of the Drei Brüder Formation cannot be older than latest Hauterivian. If the existence of *Praeglobotruncana* were corroborated by further findings, it could indicate a late Aptian age. On the other hand, redetermination of the *Lamellaptychus* sample to *Lamellaptychus beyrichi* (Opp.) em. Trauth, group A, suggests a Tithonian to Berriasian age for the stratigraphically lower parts of the formation. This palaeontological evidence indicates a basin, existing for approximately 20 to 25 Ma, for the deposition of Drei Brüder Formation.

In contrast to most metasediments in the Tauern Window, the depositional palaeoenvironment of the Drei Brüder Formation can be deduced. The limestones accumulated as a deep sea fan below the continental shelf, but above the CCD, probably at shallow bathyal depths. This can be inferred from the presence of the *Nereites* ichnofacies and the continuous content of calcium carbonate. At least a part of the clastic sediments were deposited by turbiditic cur-

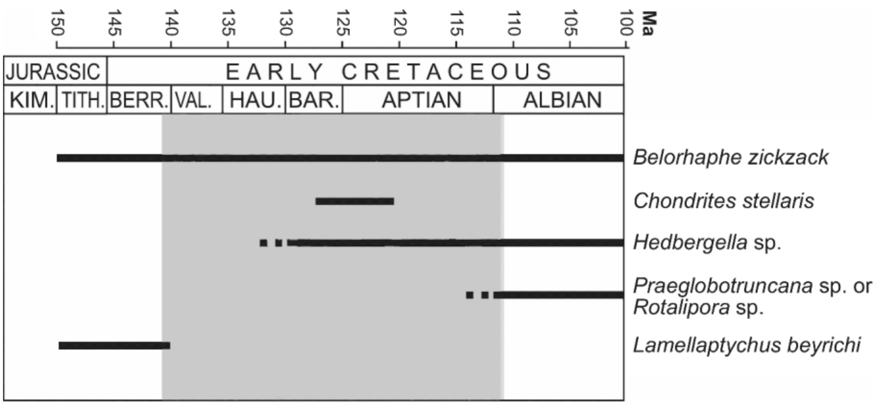

Figure 7: Stratigraphic ranges (shaded area) of trace fossils and foraminifera from sample localities of Drei Bruder Formation, shown of Fig. 2B and for the *Lamellaptychus* described by Kleberger et al. 1981; see text for further explanation.

rents. Short periods of shallowing are indicated by the presence of a hummocky cross-stratification. Poor oxygenation of sediments probably also occurred with temporary improvements of oxygenation enabling episodic colonisation by tracemakers.

The Drei Brüder Formation is also stratigraphically important for the Fusch facies succession. Part of the latter is dominated by black phyllites interbedded with calc-schists and basic metavolcanics and these are also intercalated with the Drei Brüder Formation. Further research is needed to demonstrate whether the black phyllites represent the base or the top of the Drei Brüder Formation. In the former case, a Jurassic age is indicated for the black phyllites; in the latter case, it is likely that the black phyllites represent at least an Albian/Cenomanian age. This would support the ideas put forward by Lemoine (2003), who postulates a Late Cretaceous age for a large part of the Bündnerschiefer.

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