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The Ordovician of the Southern Alps

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Content

Zur Bio- und Lithostratigraphie des Ordoviziums in den Südalpen

Zusammenfassung

Die Arbeit faßt den gegenwärtigen Kenntnisstand über das Ordovizium der Karnischen Alpen zusammen, wie er sich nach Neuaufnahmen auch des westlichen Teils auf den ÖK Blättern 196, Obertilliach und 195, Sillian darstellt. Danach dominierte hier nach einer vermutlich im Unterordovizium vorherrschenden pelitischen Sedimentation im Mittel- und älteren Oberordovizium ein bimodaler Vulkanismus, der sich auf Rhyodazite und Rhyolite bzw. mildalkalische Basalte zurückführen läßt, die zu Metavulkaniten umgewandelt wurden und heute als Porphyroide („Comelico Porphyroid") und Diabaslagergänge vorliegen. Dieser Vulkanitkomplex diente als Liefergebiet der vulkanoklastischen Gesteine der Fleons Formation, die im proximalen Bereich aus Konglomeraten besteht, an die vulkanogene Grauwacken und verschiedene quarzitische Gesteine anschließen. Am anderen distalen Ende wurde die Val Visdende Formation abgelagert. Dieses Modell wird sowohl durch Sedimentstrukturen und Sequenzen als auch durch Fossildaten gestützt. Östlich des Valentingrabens (ÖK 197, Kötschach) ist kein vulkanischer Einfluß mehr gegeben. Hier liegt das Hauptverbreitungsgebiet der lokal fossilreichen Uggwa Schiefer, die entweder das gesamte Caradoc dominieren oder im Hangenden von einer Sandsteinfolge abgelöst werden (Himmelberg Sandstein). Beide Schichtglieder werden zu Beginn (?) des Ashgills in Abhängigkeit vom Paläorelief von einem hauptsächlich aus Cystoideen und Bryozoen aufgebauten bioklastischen Flachwasserkalk („Wolayer Kalk") oder einem küstenferneren Flaserkalk („Uggwa Kalk") überlagert. Die gegen Ende des Ordoviziums weltweit einsetzende glazioeustatische Meeresspiegelabsenkung wirkt sich in den Karnischen Alpen im Erscheinen küstennaher gröberklastischer Sedimente („Plöcken Formation") aus, stellenweise fällt der Ablagerungsraum in der Folge für eine Dauer von etlichen Millionen Jahren trocken.

Nach den vorhandenen biofaziellen und lithologischen Daten bestehen im Oberordovizium vor allem Faunenbeziehungen zu den in niederen Breiten gelegenen Räumen von Baltica und Avalonia (Britische Inseln). Dennoch ist zeitweise auch ein Kaltwassereinfluß aus dem in höheren Breiten beheimateten nordafrikanischen Teil von Gondwana bemerkbar. Diese Verhältnisse sprechen unserer Ansicht nach im Oberordovizium für eine Einordnung des Ablagerungsraumes der Karnischen Alpen in einer Paläobreite zwischen 40 und 50° Süd. Diese Annahme stimmt mit neuen paläomagnetischen Daten gut überein.

Abstract

This paper summarizes the present knowledge of the Ordovician of the Carnic Alps based on both classical localities from the central part complemented by field results on the western sheets OEK 196, Obertilliach and OEK 195, Sillian. During the Lower Ordovician this area was characterized by pelitic sedimentation which was succeeded in the Middle (?) and Upper Ordovician by bimodal volcanics represented by rhyodacites and rhyolites and by mildly alkaline basalts, respectively. All lithologies are altered to metavolcanics and thus represent either porphyroids ("Comelico Porphyroid") or diabase sills. This volcanic complex acted as a source area for the volcaniclastic Fleons Formation comprising conglomerates in a more proximal and graywackes and different clastic rocks in a shoreline and fan-delta environment. Even more basinward the Val Visdende Formation was deposited. This depositional model is supported by sedimentary structures and fossil data. East of the Plöckenpass and the Valentin valley no volcanic influence has been found so far. This region is dominated by the fossiliferous Uggwa Shale of Caradocian age grading upward into the Himmelberg Sandstone. At the beginning of the Ashgill Series (?) both formations are succeeded by a limestone unit which consists either of cystoid and bryozoan bearing massive limestones in a more shallow water environment and flaser limestones in a more offshore setting. The former is named Wolayer Limestone, the latter Uggwa Limestone.

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The world-wide occurring glacioeustatic regression in the latest Ordovician can also be traced in the Carnic Alps. This event is represented by the appearance of coarse-grained bioclastic sandstones of the Plöcken Formation. On top of this horizon locally a significant disconformity may occur suggesting stratigraphic gaps at the base of the Silurian.

Based on the available lithological and faunistic data the Ordovician of the Carnic Alps reflects close relationships to Baltica and Avalonia which occupied a low to moderate latitudinal setting during this time. However, a temporary influence with cold water regions of northern Africa can also be recognized. In conclusion, at least for the late Ordovician it may be inferred that the Carnic Alps were located at a paleolatitude between 40 and 50° South. This assumption is strongly supported by palaeomagnetic measurements.

1. Introduction

It was in the mid-sixties when I was an undergraduate student of Professor FLÜGEL at Graz University that I started to rack my brain about a future thesis in historical geology. By that time he had not formally decided whether or not he would accept me as a candidate for a dissertation but it was rather clear that the only area to carry out a dissertation was the Carnic Alps of southern Carinthia. For many decades this region had been the "play ground" of the Department of Geology at Graz University resulting in numerous publications and rich fossil collections by the professors Franz HERITSCH, Karl METZ, Helmut FLÜGEL, Franz KAHLER and others.

Finally, in the course of an excursion to the Carnic Alps to collect graptolites in the surroundings of the Bischofalm during July 1966, Professor FLÜGEL proposed to me the area between Hoher Trieb, Lake Zollner and Bischofalm to be studied in detail for my thesis. He was particularly interested in a conodont-based study of the Lower Palaeozoic limestone successions. In addition he emphasized his great interest in an enigmatic occurrence of Ordovician rocks which had been recorded in this region since the discovery of Ordovician fossils by Karl METZ in the early thirties and which were subsequently described by NEKHOROSHEV (1936) and used by SPJELDNAES (1961) for palaeoclimatic implications. The actual exposures, however, were not known.

By that time coeval Upper Ordovician strata were already known from several other localities on the Italian part of the Carnic Alps (e.g., Uggwa, Stua Ramaz, Casera Meledis, Mt. Zermula, Chiadin di Lanza and Palon di Pizzul) and from conodont and shelly fossil-bearing localities in the Central Carnic Alps (e.g., Cellon, Himmelberg Alm, Lake Wolayer, Seekopf, Rauchkofel; see von GAERTNER 1931, WALLISER 1964).

In fact, the first fossils of Ordovician age had been already discovered by the famous Austrian geologist Eduard SUESS in the section near Rifugio Nordio in the Uggwa Valley almost 130 years ago. He handed them over to Guido STACHE from the Geological Survey, who in 1874 identified several taxa and published a comprehensive paper correlating the fossil-bearing "Strophonema Horizon" with occurrences in the Barrandian region which in terms of the British sucession belongs to the Caradocian Stage or Series. This exposure yielded by far the most abundant and diversified fauna of the early Upper Ordovician of the Carnic Alps (VAI 1971). They represent the hitherto oldest known megafossils in that area.

Up to the year 1966 in the Carnic Alps no other unambiguous fossil data of Ordovician age were available. Some questionable identifications of supposed Ordovician graptolites were later revised by Hermann Jaeger. A thick pile of sedimentary rocks underlying the Silurian in the Western Carnic Alps were only tentatively assigned to the Ordovician as they yielded no fossils.

In this article which is dedicated to my University teacher, Professor Helmut W. FLÜGEL, the present knowledge on the Ordovician of the Carnic Alps is summarized and reviewed; also, some new data are added from the Central and Western Carnic Alps obtained by the author and others.

2. The Ordovician of the Central and Southern Alps

Contrary to the Southern Alps, apparently much older rocks occur in the Northern Alps, i. e. in the Graywacke Zone. For example, remarkably well preserved acritarchs were reported from phyllitic slates in the vicinity of Kitzbühel, Tyrol (REITZ & HÖLL 1989) and in the Innsbruck Quarzphyllite (REITZ & HÖLL 1990). They suggest a Lower Ordovician age equivalent to the Tremadocian Series of the British succession. The supposed occurrence of Tremadocian graptolites (HABERFELNER 1931), however, has not been confirmed; it probably represents an artifact (JAEGER 1969).

The oldest megafossil assemblage of the whole Alps is of Upper Llandeilian age corresponding to the lower Berounian Series (a local Bohemian subdivision, see: HAVLICEK et al. 1987). It is derived from the locality Bruchnig half way up on the mountain Christofberg northeast of Klagenfurt, Carinthia. The fossils comprise mostly brachiopods which occur in tuffaceous shales on top of basic metavolcanic and pyroclastic rocks representing mildly alkaline within-plate basalts which have been altered to spilites (LOESCHKE 1989 a,b).

Mainly conodont-based data from the Styrian part of the Graywacke Zone were provided by FLAJS & SCHÖNLAUB (1976) from the Polster section. A summary report including the stratigraphy of the surrounding area was presented by SCHÖNLAUB (1982).

Within the Southern Alps an important fossil assemblage was recorded from arenaceous shales in the Central Carnic Alps in the early seventies and appears to be slightly younger than the one from Christofberg. Presumably, these strata correspond to the Zahorany Formation of the "middle" Berounian Series of the Barrandian which tentatively can be correlated with the middle or upper Caradocian of the British type area. The highly diversified fauna comprises brachiopods, bryozoans, trilobites, cystoids and very rare hyolithes (SCHÖNLAUB 1971, 1988, VAI 1971, MAREK 1976, VAI & SPALLETTA 1980, HAVLICEK et al. 1987).

In this report another small fauna from a locality near Lake Wolayer is added to the list of fossil-bearing outcrops. It is particularly important as it may bridge the two main lithofacies in the Upper Ordovician, i. e. the more basinal Uggwa Facies and its shallow-water counterpart named the Wolayer Facies. In reality, however, at this locality the two lithofacies seem clearly to be separated by a major fault zone.

3. A new Ordovician fossil locality from the Rauchkofel-Boden

The Ordovician fossils described in this paper occur on Rauchkofel mountain at an altitude of 2000 m. Access to this

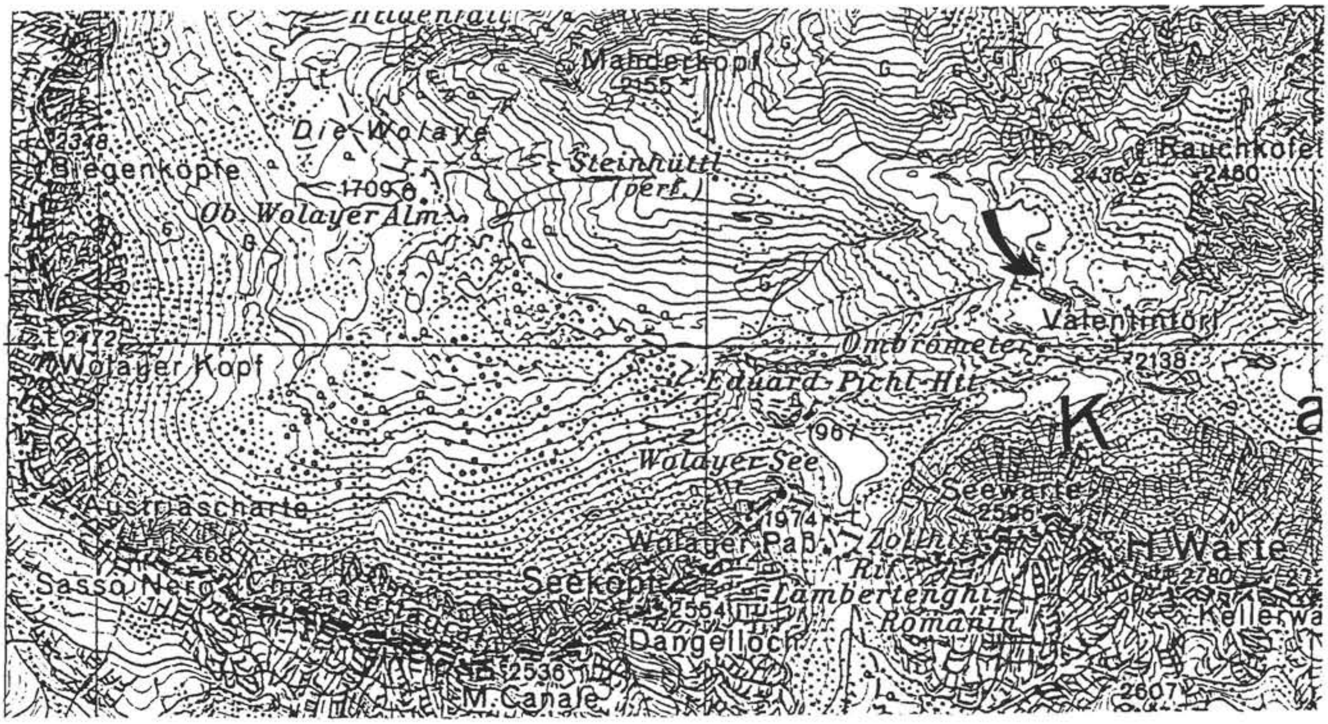


Fig. 1
Topographic map of the surroundings of Lake Wolayer with fossil bearing locality southwest of mountain Rauchkofel (see arrow). Adapted from topographic sheet ÖK 197, Kötschach-Mauthen.

locality is along the trail running from Lake Wolayer to the top of the mountain (see Fig. 1). The fossils described here were collected in a small creek some meters to the north and below the trail on the so-called third Rauchkofel-Boden. A first mention of the outcrop is indicated in the geological map of the scale 1:10000 added to the official geological map 1:50000, sheet 197, Kötschach (SCHÖNLAUB 1985a). For more details regarding the Ordovician stratigraphy we refer to the Guidebook published by the Geologische Bundesanstalt for its biennial Field Meeting 1985 (SCHÖNLAUB 1985b).

The lithology comprises intensively foliated dark-grey silty shales and laminated shales which in German literature are generally termed "Griffelschiefer". There is no doubt that they belong to the Upper Ordovician Uggwa Shales and the corresponding "Uggwa Facies" introduced by SCHÖNLAUB 1979 and defined by the same author in 1985. This lithology extends over several meters following the top of a small cliff which represents Upper Silurian limestones. Yet, the whole extent of the Uggwa Shales is difficult to assess due to an apparent fault zone between the two main Ordovician-Silurian facies forming Rauchkofel mountain, i. e. the Wolayer and the Uggwa-Plöcken facies. According to SCHÖNLAUB 1985a the outcrop attains a thickness of several meters; it is separated by faults from the surrounding siliciclastics of the Hochwipfel Formation.

The small collection of fossils comprises mainly brachiopods but also bryozoans, hyoliths and disarticulated cystoids were found. Unfortunatelly, the preservation is extremely bad due to the strong schistosity and all fossils occur as molds of ironhydroxid. So far the following taxa have kindly been identified by Dr. Vladimir HAVLICEK from Ustredni Ustav Geologicky in Prague (see Plates 1, 2):

Aegiromena aquila (BARRANDE)
Multicostella cf. *schoenlaubi* HAVLICEK & KRIZ
Porambonites cf. *magnus* (MENEGHINI)
Dolerorthis cf. *maxima* (VINASSA)

In addition some trepostomate and cryptostomate bryozoa and two representatives of the class Hyolitha were found (1 conch, 1 operculum). The latter may belong to the genus *Carinolites* sp. (see Plate 3).

The whole assemblage suggests a preliminary correlation with the Zahorany Formation of the middle Berounian Series of the Prague Basin (Barrandian) which corresponds to the middle or upper Caradocian Series in the British type area.

4. The Ordovican sequence in the Western Carnic Alps

As mentioned in the foregoing chapters, in the Central Carnic Alps the oldest megafossil-bearing strata indicate an early Upper Ordovician age (Fig. 2). In the Western Carnic Alps and in the Brixen Phyllite Complex, however, even older rocks may occur the age of which is not precisely known. The oldest part of this sequence may even be attributed to the Cambrian or Lower Ordovician.

In the Austrian part of the Southern Alps the Ordovician succession comprises weakly metamorphosed fine and coarse clastic rocks named the Val Visdende Group (Fig. 2). This more than 1000 m thick sequence is well exposed in the westernmost part of the Carnic Alps on both sides of the Austrian-Italian border on the topographic sheets Obertilliach and Sillian. The lithology ranges from shales and slates to laminated siltstones, sandstones, arkoses and quartzites. Laterally they intergrade with more than 300 m thick acidic volcanites and volcaniclastic rocks named the "Comelico-Porphyroid" (Fig. 2) and the psammitic to psephitic volcaniclastic sequence of the "Fleons Formation", respectively. Additional lateral equivalents in the Central Carnic Alps comprise the Himmelberg Sandstone and the Uggwa Shale. According to DALLMEYER & NEUBAUER (1994) detrital muscovites from the Himmelberg Sandstone are characterized by apparent ages

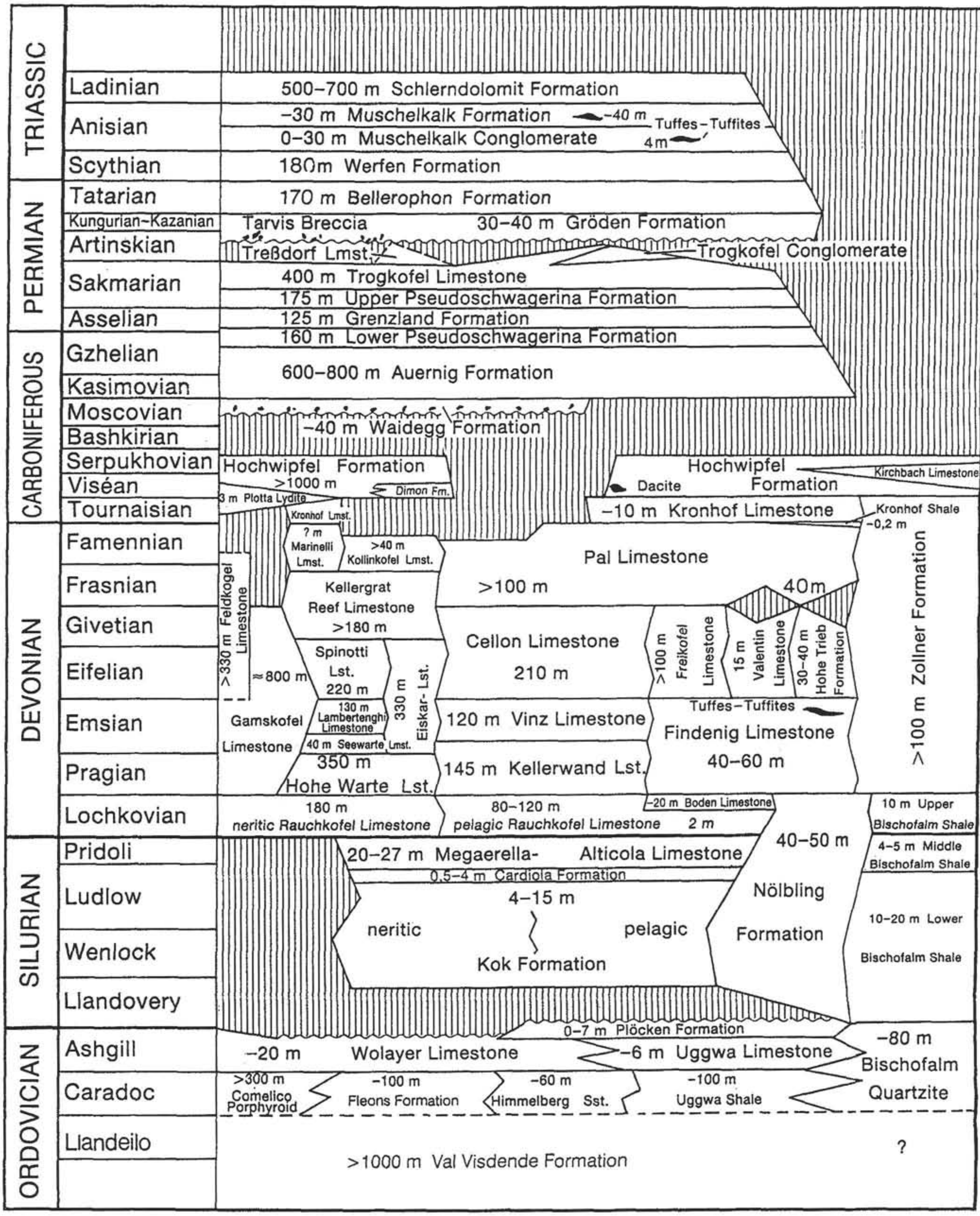


Fig. 2
Stratigraphic subdivision of the Paleozoic sequence of the Carnic Alps (from SCHÖNLAUB 1992).

($^{40}Ar/^{39}Ar$) of c. 600 to 620 Ma and may thus be derived from a source area affected by late Precambrian (Cadomian) metamorphism.

The Fleons Formation (Fig. 2) comprises quartzitic schists, quartzites, volcaniclastic greywackes and conglomerates, the latter being well exposed among the others north of Wildkarleck mountain and Roßkarspitze in the Leitental west of Porze. According to HINDERER 1992 sedimentary structures in the quartzitic and the greywacke members indicate an interaction between a wave-dominated coastal environment represented mainly by mature quartzites and locally developed fan deposits consisting of coarse and immature greywackes. In this scheme the underlying and also interbedded Val Visdende Formation is considered as a more off-shore deeper facies.

Based on their detritic components the greywackes can be subdivided into bimodal quartz-feldspar-rich and quartz-feldspar-poor types. The first is dominated by detritus from acidic volcanics, the second from basic volcanics plus metamorphic rocks. Consequently, the greywackes of the Fleons Formation are derived from three sources including acidic and basic volcanics which developed on a basement consisting of metasediments, few granitoids and ultramafites. While the contribution of basic volcanics can be related to mildly alkaline basalts well testified by occurrences of sills, the acidic input to the greywackes probably originated from the widely distributed Comelico metavolcanics ("Porphyroid"). According to HUBICH & LOESCHKE (1993) and MELI (1998) they represent pyroclastic flow deposits (ignimbrites) with a rhyodacitic to dacitic composition. The major element distribution, the REE patterns and discriminant diagrams suggest a crustal origin within a late orogenic tectonic setting. In terms of the plate tectonic position both the Comelico metavolcanics and the Fleons Formation can best be explained by a backarc or post collisional rifting regime which resulted in the contemporary formation of late orogenic acid volcanics and intraplate basalts (HINDERER 1992, HUBICH & LOESCHKE 1993, MELI 1998).

The Upper Ordovician (Caradocian) age of the Comelico metavolcanics and the Fleons Formation seems rather well established. Based on detailed mapping on the Obertilliach and Sillian sheets (OEK 196 and 195) several more or less undisturbed sections have been found ranging from the pelitic Val Visdende Formation to the Comelico metavolcanics, the Fleons Formation and a quartzitic member to strata of definitely Silurian age. The assumed Upper Ordovician age is further supported by fossil-bearing intercalations of Uggwa Shales within the Fleons Formation on Raudenspitze mountain (SCHÖNLAUB & FLAJS 1993). Also further to the east on the Kötschach sheet, at the base of the Mooskofel section and on Mauthner Alm bryozoan bearing shales are frequently interbedded with volcaniclastic rocks assigned to the Fleons Formation (SCHÖNLAUB 1985a,b). In particular, in a continuous section north of the Mooskofel mountain greywackes with rich volcanic debris are exposed which grade into quartzites, sandstones and fossiliferous shales. They are succeeded by the Uggwa Limestone of Ashgill age (latest Ordovician) and Silurian limestones and black marls (Fig. 2).

The spatial distribution of the above mentioned Ordovician rocks including the Ashgillian Uggwa and Wolayer Limestones is shown in the sketch of Fig. 3. This sketch is dominated by the bimodal volcanic sequence, which, however, only occurs west of the Wolayer valley except for a few outcrops close to the Mauthener Alm and north of Mooskofel. In the Central Carnic Alps these rocks are laterally replaced by sandstones, arenaceous shales and siltstones named the Himmelberg Sandstone and Uggwa Shale, respectively. Both facies reflect different water depths and thus environment.

This basal clastic sequence is overlain by an up to 20 m thick fossiliferous limestone horizon of early Ashgillian age. It displays two lithologies, namely the massive "Wolayer Limestone" and the argilliceous "Uggwa Limestone" with a thickness of only a few meters. According to DULLO (1992) the fossiliferous Wolayer Limestone is mainly composed of parautochthounous bioclasts from cystoids and bryozoans which laterally grades into the bedded wackestones of the "Uggwa Limestone" representing a more basinal setting of significantly reduced thickness.

In the Carnic Alps the global glacially induced regression during the late Ashgillian Hirnantian Stage is documented by marly intercalations and arenaceous bioclastic limestones of the Plöcken Formation which presumably corresponds to the graptolite zone of *Gl. persculptus* (SCHÖNLAUB 1996). If so the climax of the glaciation may have lasted during the early and middle Hirnantian Stage for not more than 0.5 to 1 million years. It resulted in channeling, erosion and local non-deposition. In fact, the succeeding basal Silurian strata generally disconformably rest upon the late Ordovician sequence.

5. Faunal links, palaeogeography and palaeoclimatic considerations

The Upper Ordovician fauna of the Carnic Alps, e.g. brachiopods, nautiloids, cystoids, ostracods, conodonts and vertebrate remains indicate closer links with Thuringia, Baltoscandia, Sardinia and the British Isles than to coeval cold-water associations of northern Africa and Spain (SCHÖNLAUB 1992, FERRETTI & BARNES 1997, FERRETTI 1997, BAGNOLI et al. 1998, BOGOLEPOVA & SCHÖNLAUB 1998).

Based on a detailed faunal analysis of brachiopods HAVLICEK et al. (1987) recognized a significant difference between the occurrences of the Alps and those from Morocco. Although both regions share some elements such as *Svobodaina ellipsoides, Gelidorthis meloui, Saukrodictya porosa, Aegiromena aquila aquila* and *Paterorthis paterina,* the presence of warm-water representatives of the genera *Dolerorthis, Iberomena, Longvillia, Porambonites, Eoanastrphia* a.o. in the Alps (Carinthia, Carnic Alps) indicate closer affinities to Sardinia, the British Isles and North Europe which both reflect a low-latitude position. Hence, an invasion of North European warm water brachiopods as far south as the Alps, Sardinia, Montagne Noire and Spain was supposed (HAVLICEK 1976, HAVLICEK et al. 1987). The new data presented in this paper are in agreement with the conclusions drawn above.

During the latest Ordovician Hirnantian Stage the faunal relationship with Baltoscandia can still be seen in the ostracod, echinoid and nautiloid fauna described by SCHALLREUTER (1990) and BOGOLEPOVA & SCHÖNLAUB (1998) from the Carnic Alps. This time, corresponding roughly to the glacial maximum, is, however, also characterized by a short-term cold-water influx from Gondwana (JAEGER et al. 1975). On a global scale the glacioeustatic event is associated with a regressive-transgressive cycle coupled with a severe mass extinction and the appearance of the Hirnantia fauna (WRIGHT 1968, BERRY & BOUCOT 1973, SHEEHAN 1973, 1975, 1979, 1988, JAEGER et al. 1975, BRENCHLEY & NEWALL 1980, SPJELDNAES 1981, BRENCHLEY 1984, 1995, BRENCHLEY & CULLEN 1984, RONG 1984, SCHÖNLAUB 1988, 1996, SHEEHAN & COOROUGH 1990, BRENCHLEY et al. 1994, MARSHALL et al. 1994, a.o.). Its distribution reflects a concentration in higher latitudes of the southern hemisphere but exceptions are known as well from the tropical belt and from northern low latitudes suggesting that this unique fauna was adapted to the cold climate and a cool sea which originated from the end-Ordovician glaciation.

The Upper Ordovician conodont fauna of the Alps is well known from detailed studies by WALLISER 1964, SERPAGLI 1967 and FLAJS & SCHÖNLAUB 1976 from the Uggwa Limestone of the Carnic Alps and various limestone units of the Graywacke Zone of Styria. This conodont association represents the *Hamarodus europaeus-Dapsilodus mutatus-Scabbardella altipes* (HDS)-Biofacies of SWEET & BERGSTRÖM 1984. Although

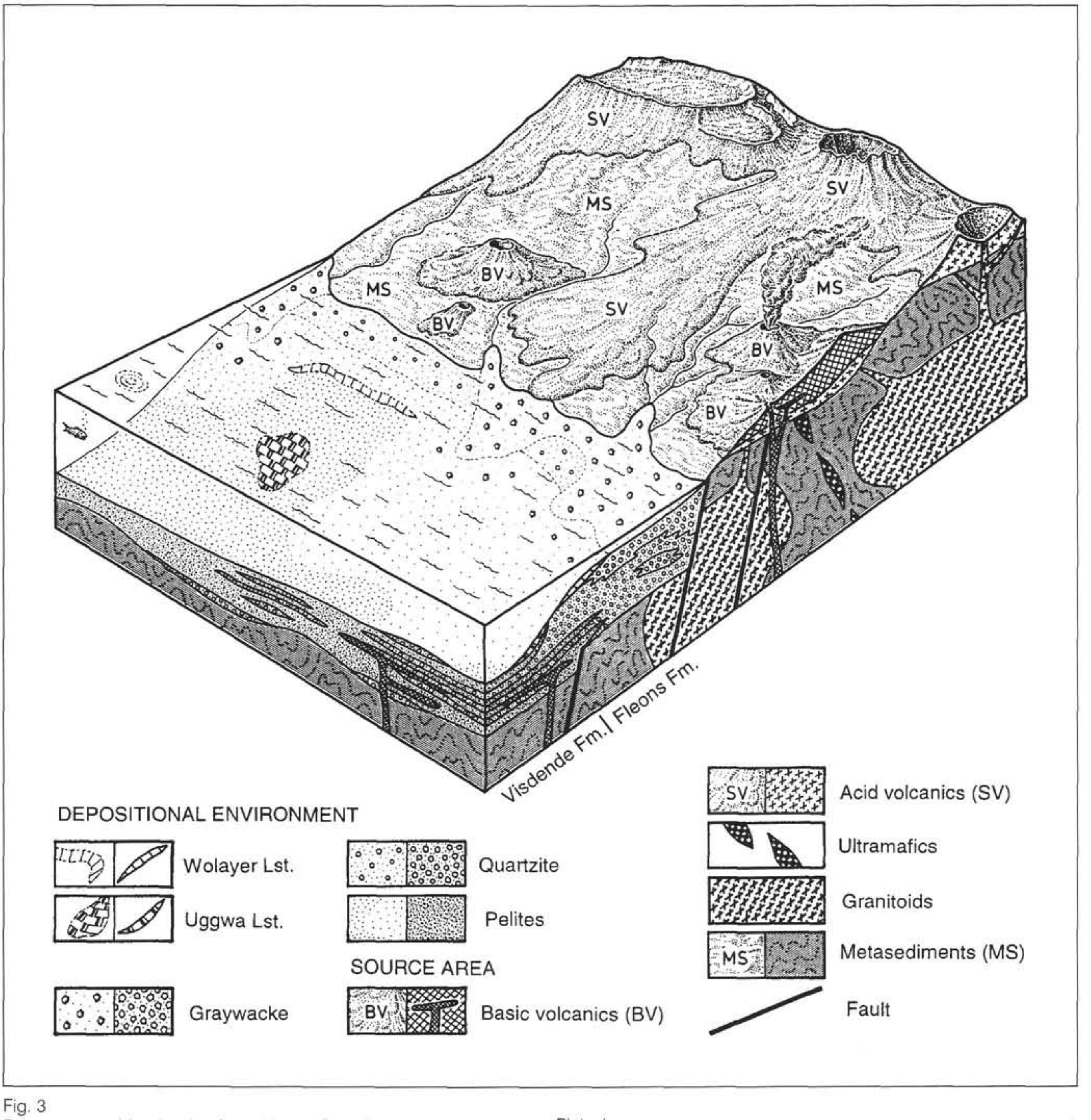


Fig. 3
Palaeogeographic sketch of the Upper Ordovician landscape and depositional environment in the Carnic Alps (based on HINDERER, 1992, modified).

their precise age within the early Ashgillian Series (or latest Caradocian) remains open the conodont bearing limestones clearly can be assigned to the *Amorphognathus ordovicicus* Zone. For details regarding the revised conodont association in terms of multielement taxonomy the reader is referred to the article of SCHÖNLAUB (1992).

According to BERGSTRÖM 1990 the comparison of conodonts between Baltoscandia and the Mediterranean area indicate only a moderate similarity. Common occurrences are specimens of *Amorphognathus, Scabbardella* and *Dapsilodus* while others appear to be restricted to continental Europe or North Africa. Obviously, the distribution of conodonts followed a similar pattern as concluded from other faunal data. This opinion has recently been confirmed by BAGNOLI et al. (1998)

Plate 1 →
(All photographs by Dr. J. Kriz, Prague)

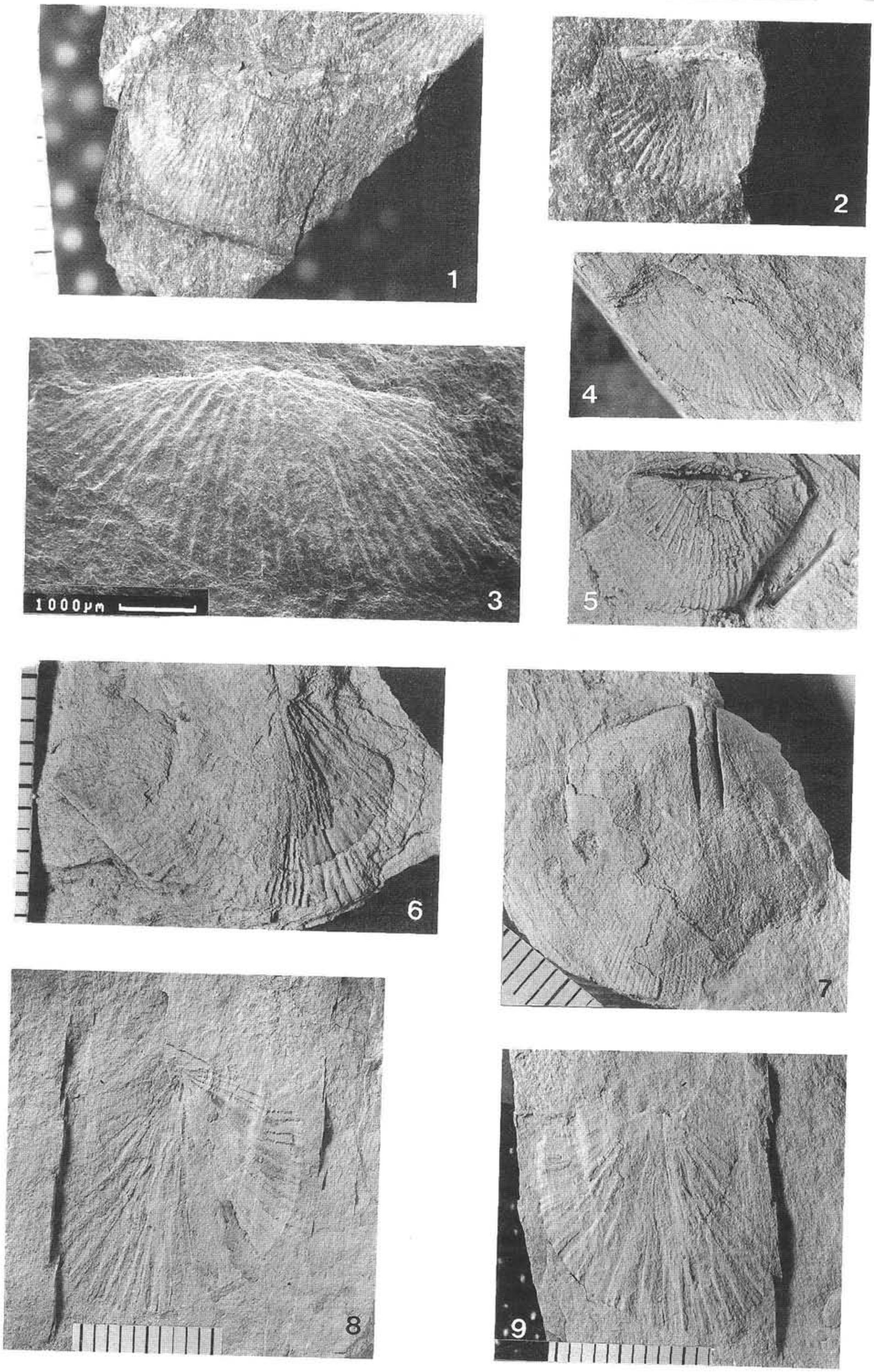
All illustrated fossils are from the Uggwa Shale (Caradoc) of locality Rauchkofel-Boden at an altitude of 2000 m.

Figs. 1-5
Aegiromena aquila (BARRANDE). 1) Internal mold of dorsal valve, GBA 1999/3/1, × 4.5; 2) internal mold of dorsal valve, GBA 1999/3/2, × 5; 3) internal mold of ventral valve, GBA 1999/3/3, for scale see bar; 4) internal mold of dorsal valve, GBA 1999/3/4, × 5.3; 5) external mold of dorsal valve, GBA 1999/3/5, × 5.8.

Fig. 6
Multicostella cf. *schoenlaubi* HAVLICEK & KRIZ. Dorsal (?) valve and external mold, GBA 1999/3/6, × 4.4.

Fig. 7
Porambonites cf. *magnus* (MENEGHINI). External and internal mold of dorsal valve, GBA 1999/3/7, × 3.2.

Figs. 8, 9
Dolerorthis cf. *maxima* (VINASSA). Internal molds of dorsal valve, GBA 1999/3/8, GBA 1999/3/9, × 2.6.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from the Valbertad section who repeat the special character of the conodont fauna of the Carnic Alps. Accordingly, distinctive representatives of the high-latitude Mediterranean Province seem to be missing in the Carnic Alps.

In a revised conodont study of the Kalkbank Limestone of Thuringia FERRETTI & BARNES (1997) concluded that this fauna closely resembles coeval conodonts from Libya, Spain and France which belongs to the cold-water realm of the Mediterranean Province. Apparently less close relations exist between the Carnic Alps and Sardinia. Conodonts from these two regions seem to be closer related to temperate faunas such as those in Britain.

In the Southern and Northern Alps, occurrences of carbonate rocks provide broad latitudinal constraints for the Upper Ordovician. Potentially useful though only of limited climatic significance is the distribution of limestones in the Carnic Alps, the Graywacke Zone and also in the Gurktal Nappe. From the latter two regions also a basic intraplate volcanism has been recorded in Llandeillan or pre-Llandeillan rocks indicating an extensional regime with rifting and subsequent plate motion (for references see SCHÖNLAUB 1992). In the Southern Alps such rocks have as yet not been recognized.

According to DULLO 1992 in the Carnic Alps the up to 20 m thick limestone horizons termed Wolayer and Uggwa Limestone, respectively (SCHÖNLAUB 1985a), represent grayish and whitish grainstones to rudstones and occasionally also bafflestones with abundant debris of cystoids and bryozoans and less frequently trilobites, nautiloids and conodonts. Cathodoluminescence studies displayed rare occurrences of coated grains. Of special significance, however, are dogtooth cements suggesting a vadose diagenetic environment for the Wolayer Limestone in contrast to the coeval and probably offshore Uggwa Lst. which is enriched in clay and shell fragments but decreased in the content of bryozoans and echinoderms. Based on conodonts these limestones were deposited most probably during the early Ashgillian.

The Upper Ordovician limestone horizons suggest a formation within the broader carbonate belt between latitudes of about 40 to 50° North and South where it was not only moderately warm but also adequate light was available (ZIEGLER et al. 1984, SCHÖNLAUB 1992). Such an environnment could rather be established in a temperate climatic zone and not in high latitudes as has been inferred in the revised paleogeographic reconstructions of SCOTESE & MCKERROW (1990). In the Ordovician of the Mediterranean Province contemporary carbonates are widely distributed and have been reported from many places in Southern and Southwestern Europe and Northern Africa (see SCHÖNLAUB 1992).

In summary, the available faunal and climate-sensitive lithic data from the Upper Ordovician of the Carnic Alps indicate a position between approximately 40 and 50° southern latitude instead of being placed around 60° South as has been employed in previous reconstructions. Originally this conclusion was based solely on the data presented in this report but subsequently was confirmed by palaeomagnetic measurements (SCHÄTZ, TAIT, BACHTADSE & SOFFEL 1997).

6. Conclusions and Summary

Although the database to establish a paleobiogeographic approach for the Northern and Southern Alps during the Ordovician is very limited and far from being sufficient some related trends in the interchange of past communities and in the geodynamic evolution of this area can clearly be recognized:

1. In a wider context carbonates first occur in the Lower Cambrian of Southern and Central Europe forming part of the northern margin of the supercontinent Gondwana. This distribution suggests a low latitudinal position and close faunal relationships between the individual occurrences within the Mediterranean faunal realm (SDZUY 1962, FREYER 1987, COURJOULT-RADÉ et al. 1992, MCKERROW et al. 1992). Yet, in the Alps the corresponding rocks have not been found.
2. For the following interval of at least 50 Ma neither sedimentary nor faunistic data are available in the Alps except for sparse acritarch data which seem to testify pelitic sedimentation in parts of the Alps during the Lower Ordovician. Yet, any conclusions drawn for this period have to consider the high drift rates inferred from palaeomagnetic measurements for the whole Lower Palaeozoic (TORSVIK et al. 1996).
3. Probably during the Llandeilian a rifting related basic volcanism occurred, first recognized in Middle Carinthia but supposedly also occurring at other places of the Alps except for the Southern Alps. Interestingly, this event seems to coincide with calc-alkaline igneous activity in other places of the northern margin of Gondwana such as the Ardennes, Wales and SE Ireland (KOKELAAR et al. 1984) when Avalonia started to rift off from Gondwana (COCKS & FORTEY 1982, MCKERROW & COCKS 1986, PICKERING 1989, SCOTESE & MCKERROW 1990). Opposing arguments concerning the position of Iberia were mainly put forward by PARIS & ROBARDET 1990, ROBARDET et al. 1990, ROBARDET et al. 1993 and GUTIÉRREZ-MARCO et al. 1998. For the Variscan Alps an analogous plate disruption and subsequent separation has already been assumed by LOESCHKE & HEINISCH 1993 and SCHÖNLAUB 1992, 1993.
4. A second major magmatic event occurred during the Caradocian (or early Ashgillian) and has been regarded as a backarc or postcollision related process (LOESCHKE 1989 a, HINDERER 1992, MELI 1998). In the Western Carnic Alps the bimodal volcanism formed the source area for various volcaniclastic rocks (Fleons Formation) and other psammitic rocks. East of Plöckenpaß no traces of volcanism have yet been found. This area functioned as a depocenter for the Uggwa Shales which locally grade into sandstones.
5. In accordance with palaeomagnetic data from Gondwana and Baltica it seems reasonable to conclude that these two magmatic events reflect the disruption of the northern margin of Gondwana and the subsequent rapid northward movement of individual terranes or microcontinents.
6. Upper Ordovician fossils, in particular most brachiopods, cystoids, ostracods, nautiloids and conodonts, are more closely related to coeval temperate water faunas of north-

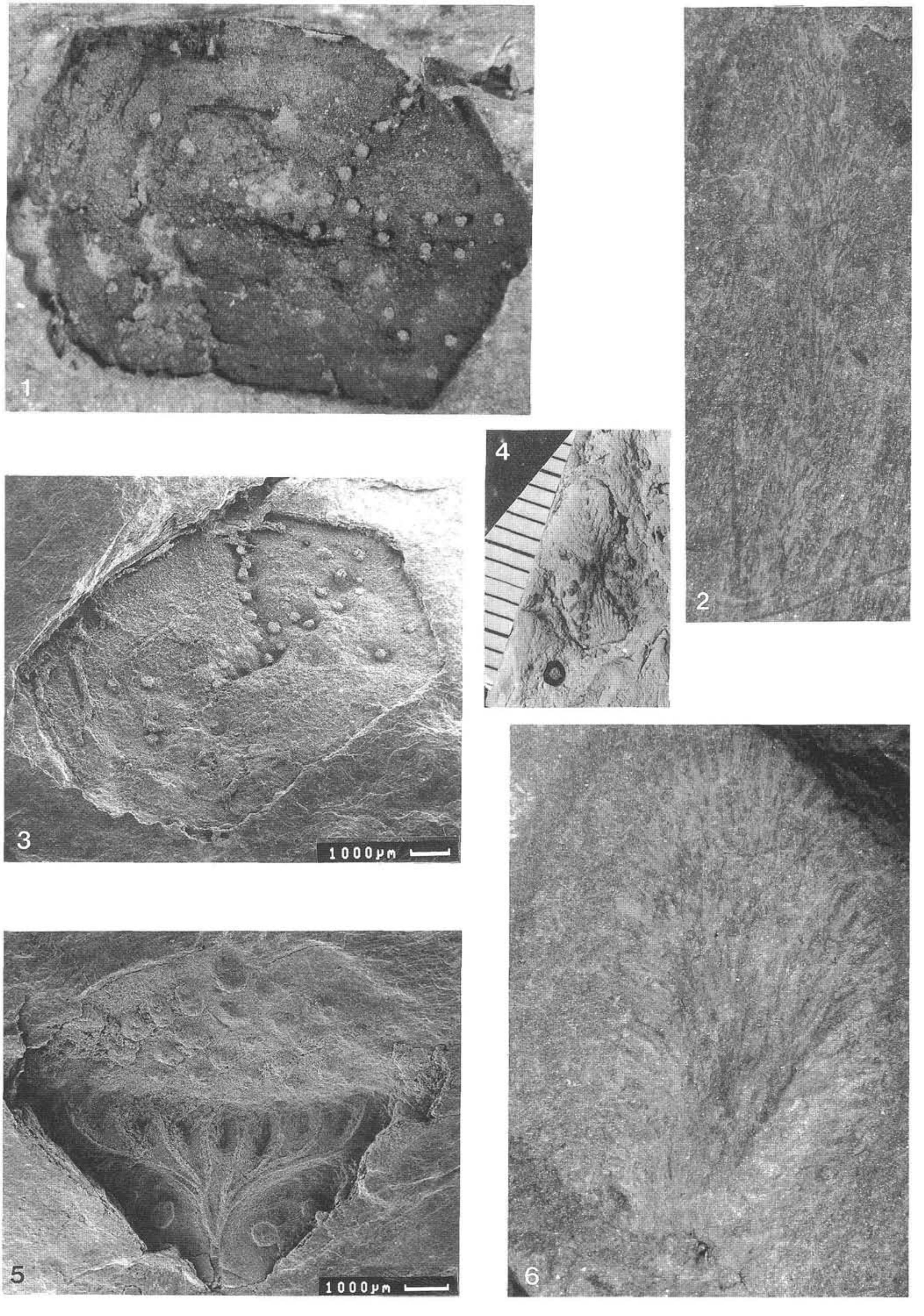
Plate 2 →
(All photographs by Dr. H. PRIEWALDER, GBA except Fig. 4 by J. KRIZ, Prague)

All illustrated fossils are from the Uggwa Shale (Caradoc) of locality Rauchkofel-Boden at an altitude of 2000 m.

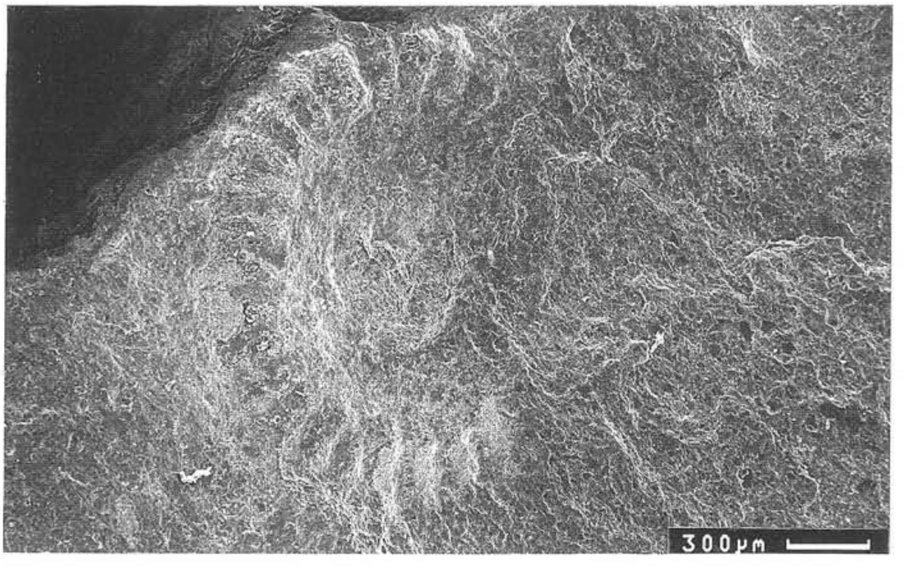
Figs. 1, 3, 4
Internal mold of plates of cystoids. 1) GBA 1999/3/10, total length 9 mm; 3) oblique view, GBA 1999/3/10, for scale see bar; 4) GBA 1999/3/12, for scale see bar.

Fig. 2, 6
Cryptostomate bryozoans. 2) GBA 1999/3/13, length 13 mm; 6) GBA 1999/3/14 length 15 mm.

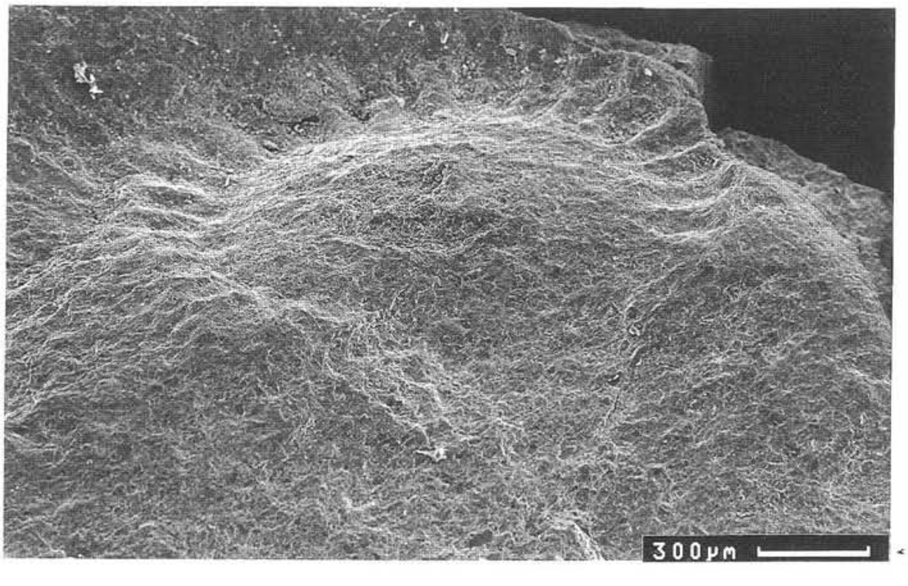
Fig. 5
Problematical mold of a cystoid plate or a bryozoan. GBA 1999/3/15, for scale see bar.


1
2
4
3
1000µm
5
1000µm
6


1



2



3

ern Europe, Great Britain and Sardinia than to northern Africa. Exceptions are, however, the occurrences of the African brachiopod species *Paterorthis paterina* in the Caradocian, the Ashgillian Hirnantia fauna and the brachiopod *Clarkeia* sp. which indicate a temporary minor cold water influence from a southern high-latitude region.

7. The oldest limestones occurring in the Carnic Alps are probably early Ashgillian in age. Their fossil content and microfacies indicate a moderately warm climate. Due to the short-term glacioeustatic event at the close of the Ordovician sea level dropped resulting in a regressive sedimentary sequence and local hiatuses which have been well documented in various sections across the Ordovician/Silurian boundary.
8. The best estimate for the palaeolatitudinal position of the Upper Ordovician of the Southern Alps and its relationship with adjacent areas is shown on the amended map of SCOTESE & MCKERROW (1990) for this time. The inferred position at roughly 50° southern latitude is based on the available faunistic and lithic data from the Southern and Northern Alps presented in the foregoing chapters. New palaeomagnetic measurements seem to confirm this conclusion.

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← Plate 3
(All photographs by Dr. H. PRIEWALDER, GBA)

The illustrated fossils are from the Uggwa Shale (Caradoc) of locality Rauchkofel-Boden at an altitude of 2000 m.

Fig. 1
Carinolites sp. ? Mold of the conch, length 6 mm. The mold of a polyclaviculate operculum of a hyolith is also shown. GBA 1999/3/16.

Figs. 2, 3
Mold of the polyclaviculate operculum of a hyolith shown on Fig. 1, oblique and lateral views.

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