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Stratigraphy, Biogeography and Paleoclimatology of the Alpine Paleozoic and its Implications for Plate Movements*)

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With 16 Text-Figures

Alpen
Paläozoikum
Biostratigraphie
Bioklimatologie
Biogeographie
Plattentektonik
Terranes

Contents

Stratigraphie, Biogeographie und Paläoklimatologie des alpinen Paläozoikums und Konsequenzen für Plattenbewegungen

Zusammenfassung

Das Konzept der Plattentektonik indiziert, daß Bewegungen zwischen einzelnen Kontinenten nicht nur in der Gegenwart feststellbar sind, sondern auch in der geologischen Vergangenheit stattfanden. Während das vierte verbesserte plattentektonische Modell „NUVEL-1" (C. DE METS et al., 1990) für die letzten drei Millionen Jahre von der Existenz von 12 größeren Platten ausgeht, die mit Geschwindigkeiten zwischen 1,5 und 3,5 cm/Jahr u.a. vom mittelatlantischen Rücken bzw. mit 10–17 cm/Jahr vom ostpazifischen Rücken wegdriften (K.C. MACDONALD, 1990) und ähnliche Driftraten anscheinend auch für die Bewegungen Eurasiens in den vergangenen 250 Millionen Jahren anzunehmen sind (durchschnittlich 3,8 cm/Jahr, siehe C.R. DENHAM & C.R. SCOTESE, 1987), ist die Anzahl der Platten und ihre Driftgeschwindigkeiten im Paläozoikum umstritten. Sie schwanken zwischen durchschnittlich 6,3 cm/Jahr und 10–23 cm/Jahr für Gondwana (C.R. SCOTESE & S.F. BARRETT, 1990 bzw. V. BACHTADSE & J.C. BRIDEN, 1990). Noch raschere Bewegungen mit bis zu 28 cm/Jahr sollen hingegen, allerdings in der Oberkreide, an den Grenzen zwischen der pazifischen und der nordamerikanischen Platte in Kalifornien stattgefunden haben (J.A. TARDUNO et al., 1990).

In der rund 300 Millionen Jahre langen Geschichte des alpinen Paläozoikums spiegeln sich ebenfalls Driftbewegungen wider. Für paläogeographische Rekonstruktionen eignen sich vor allem Klima-abhängige Gesteinsparameter, wie die Verteilung von Karbonatgesteinen, Riffbildungen und andere Flachwasserablagerungen, Oolithe, Evaporite, Kohlebildungen und Rotsedimente. Ebenso große Bedeutung haben bestimmte Organismengruppen, wie zum Beispiel Vertreter des Licht- und Temperatur-abhängigen sessilen Benthos und Algen. Hingegen lassen sich paläomagnetische Daten aus den Alpen aufgrund jüngerer Überprägungen für paläogeographische Überlegungen nicht heranziehen.

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Das in dieser Arbeit vorgestellte Szenario stützt sich auf eine umfangreiche Datenbank, die vom ausgehenden Proterozoikum bis ans Ende des Perms reicht; dazu kommen plattentektonisch relevante geochemische Indikatoren von verschieden alten Vulkaniten aus den Ost- und Südalpen. Die daraus abgeleiteten Driftbewegungen und das tektonische Geschehen sind einerseits im Einklang mit der Polwanderkurve (APWP) für Gondwana und Euramerika, weichen aber andererseits in Bezug auf die Paläolatituden des alpinen Altpaläozoikums nicht unbedeutend von den Kartendarstellungen bei C.R. SCOTESE & W.S. McKERROW (1990) ab.

Am Ende des Präkambriums und im Kambrium deuten die wenigen lithologischen und auf Fossilien beruhenden Daten Gemeinsamkeiten zwischen dem afrikanischen Teil von Gondwana und Südeuropa an. Altersmäßig fraglich datierte Reste ehemaliger ozeanischer Kruste sind vielleicht Hinweise auf Ozeane, die zu dieser Zeit einzelne Terrains getrennt haben mögen.

Im Laufe des Ordoviz schwächte sich der „nordafrikanische" Einfluß zugunsten von stärkeren Beziehungen zum warmen Nordeuropa ab. Als Argumente dienen faunistische und karbonatpetrographische Daten, die am Ende des Ordoviz eine Sedimentation in maximal 45° südlicher Breite wahrscheinlich machen.

Während des Silurs bestanden enge Beziehungen zu Süd-und Südwesteuropa und anderen Gebieten Mitteleuropas, hingegen fand nur ein schwacher Austausch mit Nordafrika statt. Das Vorkommen von Korallen, Ooiden, Stromatolithen und weitere biofaziell und biofaunistisch wichtige Merkmale deuten für die silurischen Alpen eine Position um rund 35° südlicher Breite an. Weiters wird die Möglichkeit von zwei terrainmäßig getrennten Ablagerungsräumen in den Süd-und Zentralalpen diskutiert.

Dieser Trend setzte sich im Devon fort. Es bestanden starke Gemeinsamkeiten mit dem hercynisch-böhmischen und uralotienshanischen Faziesbereich, hingegen waren kaum Verbindungen nach Nordafrika vorhanden. Neben diesen Gebieten fand aber auch ein Austausch mit den Devonvorkommen in der Eifel, Belgien, Frankreich und England statt. Die zahlreich vorhandenen Evidenzen deuten darauf hin, daß das alpine Devon

1) innerhalb des tropischen Gürtels von rund 30° oder weniger südlicher Breite zur Ablagerung kam,
2) äquatoriale Oberflächenströmungen die Verbreitung verschiedener Organismengruppen wesentlich beeinflußten und
3) in den Alpen – ähnlich dem Silur – zwei ursprünglich getrennte devonische Ablagerungsräume existierten.

Der Höhepunkt der variszischen Gebirgsbildung war im späten Mittelkarbon, d.h. zwischen der spät-namurischen Gastrioceras-Zone und dem oberen Miatchkovo der Moskau-Stufe. Im Gegensatz zum pelagischen Bereich mit seiner geringeren biogeographischen Aussagekraft unterkarbonischer Faunen ist das „Karbon von Nötsch" im Norden des Periadriatischen Lineaments von ungleich größerer Bedeutung. So zeigen sich im älteren Namur vor allem enge Beziehungen zum westeuropäischen Kohlenkalk, aber auch nach Spanien und bis nach Nordamerika. Darüberhinaus weisen exotische Kalkgerölle auf ehemals ausgedehnte mittelkarbonische Flachwasserschelfe hin, von denen in den Alpen vielleicht nur mehr die Veitscher Decke in der Grauwackenzone als letzter Rest übrig blieb. Allerdings ist diese Flachwasserentwicklung in Spuren auch in den Südalpen nachweisbar, sodaß sich die Frage stellt, ob diese Fazies über das Periadriatische Lineament hinweggriff, d.h. gleichsam zwischen den Zentral- und Südalpen „vermittelte" oder etwa beide Räume im Karbon verschiedene Mikroplatten repräsentierten. Wie dem auch sei, fest steht, daß im Anschluß an die variszische Amalgamation die biogeographischen Beziehungen der Südalpen sich jenen in den Zentralalpen anglichen. Damit wurden offenbar auch hier Verbindungen nach Westeuropa hergestellt.

Nichtsdestoweniger hat die spätvariszische Fauna eher kosmopolitischen Charakter und zeigt dementsprechend Beziehungen zu gleich alten Vorkommen in anderen randnahen Gebieten der Tethys. Dafür mögen in erster Linie oberflächennahe, äquatoriale Strömungssysteme verantwortlich sein.

Aufgrund von Klima-abhängigen Evidenzen glauben wir, daß die Zentralalpen im Karbon in unmittelbarer Nähe des Äquators lagen, an die sich die Südalpen südlich anschlossen. Kontinuierliche Norddrift während des Oberkarbons und des Perms führte dazu, daß sich nördlich des Periadriatischen Lineaments bereits im Unterperm semiaride bis aride Bedingungen einstellten, während dies in den Südalpen erst im Mittelperm der Fall war. Das wiederum bedeutet, daß die Alpen den Äquator zu verschiedenen Zeiten zwischen dem Karbon und dem frühen Perm kreuzten, je nachdem, welche Seite des Periadriatischen Lineaments betrachtet wird.

Abstract

The combined evidence from paleomagnetism, climate sensitive sediments and biogeography suggests that the plates on Earth have been in constant movement relative to the poles and relative to each other during the Phanerozoic and probably during older periods as well. Since the paleogeographic position of the Alps during the Paleozoic is not well constrained by paleomagnetic data the best evidence to infer the paleolatitudinal framework and to reconstruct the complex geological history for this area is provided by lithic paleoclimatic indicators, e.g., the distribution of carbonate rocks and carbonate buildups, oolites, evaporites, coal beds, red beds, and certain fossil data, e.g., the spatial and temporal distribution of temperature and light dependent shallow water benthos and algae. Based on a comprehensive data stock from a continuous record of Ordovician through Late Permian rocks supplemented by plate tectonic relevant geochemical data from well-dated volcanic rocks and a few data from the Late Precambrian for the early Alps a Paleozoic paleogeographic scenario is recognized which is consistent with the Apparent Polar Wander Path (APWP) of Gondwana and Euramerica for this time but slightly modified from the series of world base maps as presented by C.R. SCOTESE & W.S. McKERROW (1990) for this area.

Available lithic, and less founded fossil evidence suggests a common evolution of parts of Gondwana with Southern Europe during the terminal Precambrian and Cambrian. Remnants of oceanic crust though not well dated might even indicate former oceans separating individual terranes.

During the Ordovician, the former supposed relationship with northern Africa decreased. Instead the affinity to the warm water north European realm evidently became closer suggesting that the Alps were positioned in a moderately warm climate and within the carbonate belt of not more than 45° southern latitude as opposed to the conclusions reached by C.R. SCOTESE & W.S. McKERROW (1990) and others.

In the Silurian, the relationship of faunas from the Eastern Alps with coeval faunas from southern, central and southwestern European regions continued. As for the Ordovician, the affinity to northern Africa was remarkably loose during the Silurian. Corals, ooids and other distinct faunal and lithic occurrences in the Eastern and Southern Alps indicate

1) a setting of about 35°S for Silurian rocks in the Alps and
2) the option of two separate terranes for this interval.

Similarily, during the Devonian, faunas and floras showed strong affinities with Hercynian-Bohemian and Uralo-Tienshan occurrences and were less closely related to northern Africa. Moreover, similarities did also exist with the Eifelian Hills, Belgium, France and Great Britain. Available faunal, floral and lithic evidences are best explained by supposing
1) a paleolatitudinal setting within the tropical belt of some 30° or less,
2) the operation of equatorial gyres which aided the dispersal of many groups of organisms, and
3) the possible existence of at least two separate terranes during the Devonian.

In the sedimentary sequences, orogenic paroxysm was reached in the Middle Carboniferous, i.e. between the late Namurian Gastrioceras Zone and the Upper Miatchkovo. While Lower Carboniferous faunas of the Southern Alps are only of limited biogeographic significance, the famous "Carboniferous of Nötsch" located north of the Periadriatic Line appears of great interest. Its early Namurian fossil assemblage is closely related to the Western European Kohlenkalk facies and comparable with coeval occurrences in Spain and North America. Furthermore, exotic limestone clasts indicate the existence of a vast shallow platform environment in this or adjacent areas of the Alps of which, however, only small remnants have been preserved. Besides others, the Veitsch Nappe might have belonged to this shelf facies which characterized the Central Alps during the Carboniferous as opposed to the Southern Alps. Consequently, both domains may have represented two different microplates during the Carboniferous Period, and thus seem to confirm the suggested fragmentation of the predecessors of the Alps during the Lower Paleozoic. After the Carboniferous amalgamation the biogeographic pattern of the Southern Alps closely matched those from the former settings in the Central Alps and migration paths developed between the Southern Alps and Western Europe. The major part of the post-Variscan fauna, however, exhibits a cosmopolitan aspect with similarities to coeval occurrences along the margin of the Tethys Sea. As for the Devonian, dispersal of faunas and floras was much aided by the oceanic circulation system.

From paleoclimatic sensitive data it is inferred that the Central Alps were mainly confined to a humid equatorial belt during the Carboniferous, with the Southern Alps located further to the south. Progressive northward movement during the Late Carboniferous and the Permian resulted in semarid and arid conditions that began north of the Periadriatic Line apparently in the Lower Permian and in the Southern Alps in the Middle Permian. The Alps may thus have crossed the equator at different times between the Carboniferous and the Lower Permian depending on the plate position on either side of the Periadriatic Line.

1. Introduction

In the Paleozoic Era the relative position of continents and oceans can best be constrained by the combination of paleomagnetism, climate related lithic data and the biogeographical distribution of fossils.

In the last two decades, it was realized that the pre-Alpine central and southern Europe represents a continental collage formed by accretion of separate far travelled suspect blocks at different times during the Phanerozoic (e.g., C. BURRETT, 1972; R. RIDING, 1974; V. LORENZ, 1976; A. RAU & M. TONGIORDI, 1981; J.P.N. BADHAM, 1982; J.P.N. BADHAM & C. HALLS, 1975; W. ALVAREZ, 1976; P. MATTE, 1986, 1991; D. GEBAUER, 1986; J.-P. LEFORT, 1989; P.A. ZIEGLER, 1986, 1989; H.W. FLÜGEL, 1990). These models imply the existence of microplates or terranes resulting either from fragments of major continental plates during Late Silurian or Early Devonian or from a south European plate after collision between Gondwana and Laurussia during the Carboniferous. Their travelling paths, however, were difficult to reconstruct: Paleomagnetic data from Paleozoic sequences of mobile Europe, i.e., the Alpine belt, have clearly demonstrated that they rotated in relation to Africa as well as to stable Europe during the Alpine orogeny (H.J. MAURITSCH & M. BECKE 1987; E. MARTON et al., 1987). The sense of rotation could not be decided since the inclinations were too shallow.

Similarily, the mutual relationship between the Paleozoic terranes of southwestern Europe (Iberia, France, Germany, Bohemia) is still ambiguous. According to H. PERROUD (1983), V. BACHTADSE et al. (1983), H. PERROUD et al. (1984), H. PERROUD & R. VAN DER VOO (1985) and H.J. TORSVIK et al. (1990) some of these areas, in particular Spain and Armorica indicate a position at high southern latitudes during the Early Paleozoic consistent with a position adjacent to the north African margin of Gondwana (see C.R. SCOTESE & W.C. MCKERROW, 1990). While from these areas the only congruent pre-Devonian paleomagnetic data have been derived, in central and northern Europe extensive Late Paleozoic magnetic overprinting widely occurs. Also, paleomagnetically based data from the Baltic Shield are as yet insufficient and do not permit any conclusions about the width of the Tornquist Sea between Baltica and Gondwana in the Early Paleozoic (T.H. TORSVIK et al., 1990). In any way, as has been pointed out by R. VAN DER VOO (1988), for a long time the Paleozoic geography in this area has been controlled by collisions and divergences between Laurentia and Gondwana. During this time the intervening ocean the maximum width of which was in the Late Devonian about 2800 km (V. BACHTADSE & J.C. BRIDEN, 1990) and in the Carboniferous still some 2500 km (T. AIFA et al., 1990), was repeatedly shortened, consumed and reestablished. In the past such a wide "Prototethys Ocean" acting as a migration barrier in central Europe between faunas of southern Europe and Gondwana on one side and Euramerica on the other was assumed by several authors and challenged, however, by others (e.g., W.S. MCKERROW & A.M. ZIEGLER, 1972; H. JAEGER, 1975; A.J. BOUCOT, 1985, 1990; A.J. BOUCOT & J. GRAY, 1979, 1983; R. VAN DER VOO, 1979, 1982; M. ROBARDET et al., 1990; T.P. YOUNG, 1990).

Hence, paleomagnetic data may provide some help for the reconstruction of major continental plates during the Paleozoic. Its application for smaller plates, however, seems often poorly founded. Instead of relying on one single evidence, criteria derived from climate sensitive sediments and fossils contained in the stratigraphic record (e.g., carbonates, evaporites, coal, tillites) suggest more plausible results to assess paleolatitudes of certain areas or migration and communication paths of faunas and/or floras between individual occurrences of Paleozoic strata.

The present comprehensive study examines the Paleozoic sediments and the enclosed fauna and flora of the Alps and its relationship with coeval communities from adjacent regions. It is compiled from various parts of the Eastern Alps of Austria and covers a complete stratigraphic record from the Ordovician to the end of the Permian. The bulk of the material has been collected from the Carnic Alps, the remainder from Middle Carinthia, the surroundings of Graz and the Greywacke Zone of Styria and Tyrol. In other parts of the Alps available biostratigraphic control is sparse due to lack of fossils or metamorphism and thus they are excluded from this study.

Yet, increased knowledge and understanding of the faunal composition, its paleoecology, and interchange with coeval faunas from adjacent areas permit comparison not only in the Mediterranean Province but also with other parts of Euramerica and the world. These data thus provide additional evidence for paleogeographical reconstructions through time and may give a tool for testing paleogeographic reconstructions and perhaps answer the question if the observed changes in the sedimentary and biogeographic pattern can be related to, or interpreted as, the result of physical factors governed by plate movements. As far as the Alpine part is concerned, these results may also contribute to the revised world maps published by C.R. SCOTESE & W.S. MCKERROW (1990) to reconstruct the Paleozoic world.

2. Review of Paleozoic Plate Movement

The combined paleomagnetic, lithic, biogeographic and tectonic patterns of the sedimentary sequences suggest a continuously changing world during the Paleozoic (Fig. 2). The relative latitudinal position of different continents (or their fragments) may thus have important constraints for the nature of the sediments, the biogeographic zonation of fossils as well as for the magmatic-tectonic activity of the intervening areas depending on plate motion direction and its drift rate through time. Since there are no reliable paleomagnetic measurements for the Paleozoic strata of the Alps the faunal and floral evidence as well as the lithofacies analysis are the only relevant data to assess its relationship with adjacent areas. Geochronologically derived data are additional sources and may help to understand the crustal evolution of this complex area in relation to the changing plate configuration during the Paleozoic Era.

According to C.R. SCOTESE & W.S. MCKERROW (1990) the Late Precambrian is characterized by the breakup of a supercontinent composed of Laurentia, Baltica, Siberia and perhaps Kazakhstan, and the assembly of Gondwana, the latter being consolidated by continental collisions during the Pan-African event (W.Q. KENNEDY, 1964; D.C. ALMOND, 1984; L. CAHEN et al., 1984; R. SACCHI, 1989). A Late Precambrian Pangaea has been already suggested by P. MOREL & E.C. IRVING (1978), L.A. FRAKES (1979), G.C. BOND et al. (1984) and J.D.A. PIPER (1983, 1987) but raised controversy among others. Recently, however, new arguments were provided in favour of such an ancient supercontinent which may have existed at about 900 to 600 Ma, i.e., during the Late Proterozoic Era (see N.M. CHUMAKOV & D.P. ELSTON, 1989; J.L. KIRSCHVINK, 1991; P.F. HOFFMAN, 1988, 1991; E.M. MOORES, 1991; I.W.D. DALZIEL, 1991, and C.J.H. HARTNADY, 1991). It has been suggested that this "Ur-Gondwanaland" split apart at about 550 Ma. According to P.F. HOFFMAN (1991) the predecessor of Gondwana "turned inside-out" (Fig. 1).

Between these continental fragments new oceans formed during the Cambrian, i.e., the Iapetus Ocean separating Laurentia from Baltica and Siberia, respectively, and the Tornquist Sea between Baltica and Gondwana. This latter continent shifted continuously southward and, consequently, Cambrian trilobite faunas between Baltica and Gondwana remained isolated suggesting that both regions were separated by a wide ocean (A.R. PALMER, 1973; R. FEIST, 1984, 1986, 1988; J. BERGSTRÖM & D.G. GEE 1985).

Presently, the location of the Late Precambrian and Cambrian South Pole is not exactly known (R. VAN DER VOO, 1990; P.W. SCHMIDT et al., 1990). The best estimate is achieved by statistical methods rather than on paleomagnetic data and is based on the latitudinal frequency of carbonates and evaporites. Their distribution predicted a location of the South Pole northwest of the present Africa (C.R. SCOTESE & S.F. BARRETT, 1990). A carbonate belt, which consists mainly of Archaeocyathid limestones developed – inter alia – in Morocco, Spain, southern France, the Lausitz-Doberlug area of the Sudetes and Sardinia was thus placed within southern latitudes of at most 60 degrees. Climate sensitive lithic data from Sardinia, however, contradict this assumed setting, and more likely, record a shift of shelf carbonates from arid to humid tropical conditions within the Cambrian equatorial belt (T. COCOZZA, 1979; A. GANDIN, 1990; A. GANDIN & B. TURI, 1988; T. COCOZZA & A. GANDIN, 1990).

During the Ordovician carbonate sedimentation occurred widespread over Laurentia, Siberia, North China and the eastern part of Gondwana suggesting an equatorial position of these continents. The Iapetus Ocean and the Tornquist Sea became narrower and Avalonia (Ardennes and northern France, England, Wales, southeastern Ireland, Avalon Peninsula of Newfoundland, Nova Scotia, New Brunswick) started to rift off from western Gondwana (L.R.M. COCKS & R.A. FORTEY, 1982; K.T. PICKERING, 1989; J.v. HOEGEN et al., 1990; F. PARIS & M. ROBARDET, 1990 with opposing statements). This part of Gondwana, comprising Africa, southern Florida and South America, continued to shift in southern direction. It began to cross the South Pole by the Middle Ordovician (C.R. SCOTESE & S.F. BARRETT, 1990; V. BACHTADSE & J.C. BRIDEN, 1990).

In the Upper Ordovician a strong thermal gradient from carbonate dominated low latitude regions to clastic sedimentation in a cold to temperate water has been widely recognized (N. SPJELDNAES, 1961, 1967; A. WILLIAMS, 1969; V. HAVLICEK, 1976; P.J. BRENCHLEY, 1984; P.J. BRENCHLEY & B. CULLEN, 1984).

The Late Ashgillian Hirnantian Stage is characterized by a severe glaciation. An extensive ice cap covered the northern margin of Africa with periglacial sediments being spread over southwestern and parts of central Europe (e.g., M. ROBARDET & F. DORE, 1988; P.M. SHEEHAN, 1988; P.M. SHEEHAN & P.J. COOROUGH, 1990; T. YOUNG, 1990) suggesting that this area was at southern high latitudes and within 30 degrees of the South Pole.

During the Silurian a series of collisions occurred in northwestern Europe which culminated in the closure of the northern part of the Iapetus Ocean in the Late Silurian Scandian Orogeny. At that time carbonates became more widely distributed over equatorial eastern Gondwana, North China, Euramerica (Laurentia + Baltica) and central Europe. Southwestern Europe and western Gondwana, however, remained in a cold southern climate characterized by the low diversity *Clarkeia* Fauna of the Malvinokaffric Realm (L.R.M. COCKS, 1972; L.R.M. COCKS & A. FORTEY, 1990).

Interestingly, there is some discrepancy in the location of the South Pole between paleomagnetic results and paleoclimatic indications during the Late Ordovician and Silurian (Fig. 2). Based on paleomagnetic data from Niger (R.B. HARGRAVES et al., 1987), D.V. KENT & R. VAN DER VOO (1990) and V. BACHTADSE & J.C. BRIDEN (1990) placed the South Pole in southernmost Argentina. Such a position requires high plate motion rates of more than 15 cm per year. The best evidence determined by lithofacies pattern (C.R. SCOTESE & S.F. BARRETT, 1990) lies, however, in central Argentina and requires Gondwana to move with some 6 cm per year. In any case, these data reflect a relatively quick northward shift of western Gondwana from high polar latitudes in the Late Ordovician to warm temperate latitudes in the Silurian.

Paleomagnetic and faunal evidence from the Early Devonian suggest a slight southward shift of Euramerica in comparison to the Silurian which resulted in a close proximity or even contact with the western edge of Gondwana (C.R. SCOTESE, 1986; R. VAN DER VOO, 1988; J.D. MILLER & D.V. KENT 1988; J. NEUGEBAUER, 1988, B.J.

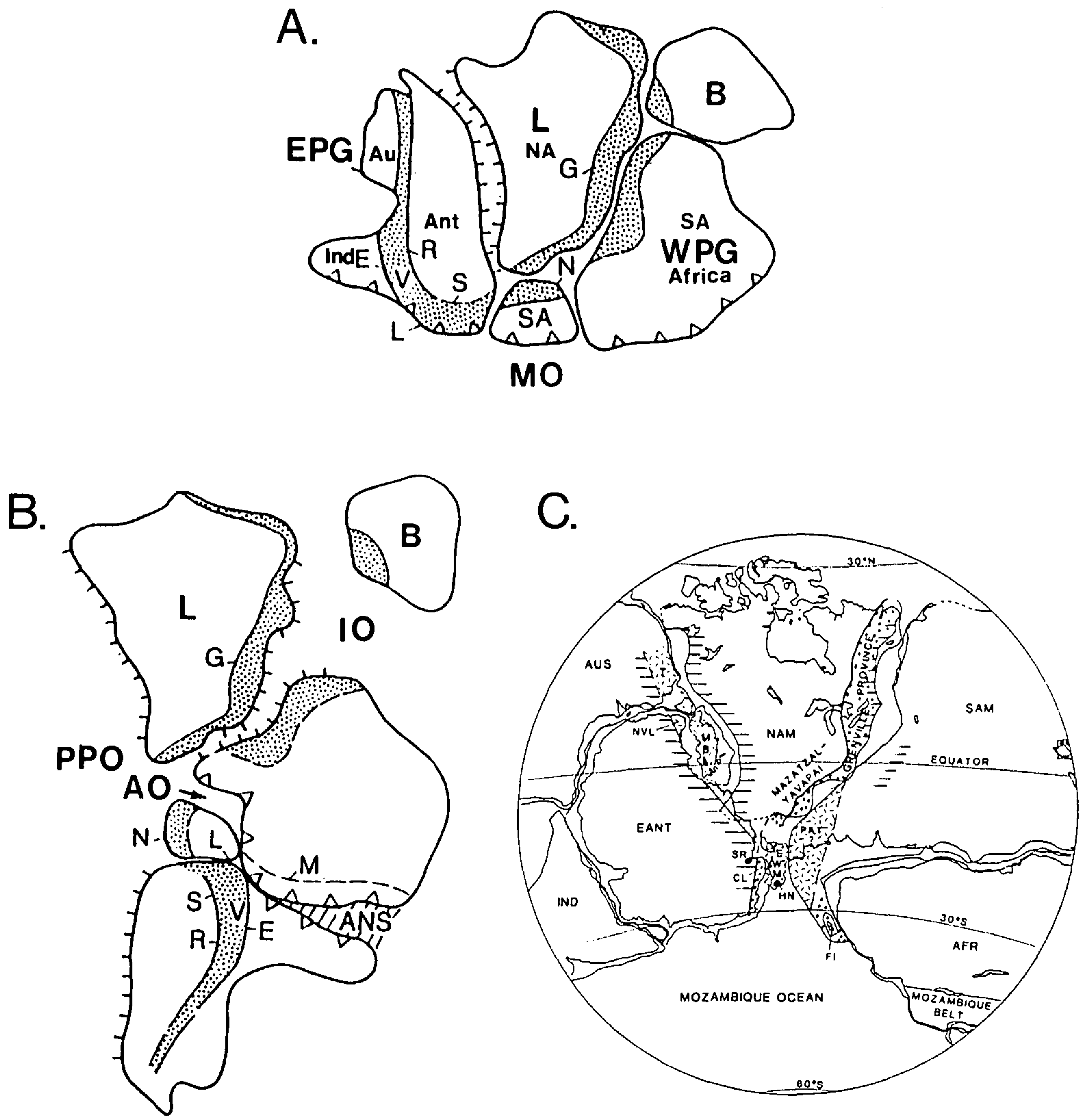

Fig. 1.
Late Proterozoic and Eocambrian continent reconstructions modified from P.F. HOFFMAN (1991) and C.J.H. HARTNADY (1991) (A, B) and I.W.D. DALZIEL (1991) (C).

A: The supposed supercontinent ("Ur-Gondwanaland" according to C.J.H. HARTNADY) in the pre-750 Ma old configuration with Laurentia (L) in the keystone position flanked by the East and West proto-Gondwanaland (EPG, WPG) and Baltica (B). The southern African block (SA) is located between EPG and WPG. Stippled areas represent the Grenvillian belts formed during assembly of this supercontinent. Hatched lines indicate the rift boundaries of the proto-Pacific Ocean (PPO) shown in Fig. 1B. Barbed lines indicate the external boundary between the supercontinent and the Mozambique Ocean.
G = Grenville; N = Namaqua; L = Lurio; S = Sverdrupfjella; V = Vijayan; E = Eastern Ghats; R = Rayner segments.
SA = South America; NA = North America; Ant = Antarctica; Au = Australia; Ind = India.

B: The 650 to 600 Ma old configuration of continents suggesting that the supercontinent has turned inside-out around the southern African hinge block. Note alignment of the former arcuate Grenville belts and closure of the Mozambique Ocean. Between former EPG and WPG the Mozambique metamorphic belt (M) was formed and the Arabian-Nubian Shield (ANS) was accreted. The Adamastor Ocean (AO) represents a continuation of the PPO and opened during convergence between WPG and EPG. Also the Iapetus Ocean (IO) starts opening between Laurentia (L), Baltica (B) and West proto-Gondwanaland (WPG).

C: The 570 Ma old Eocambrian supercontinent according to I.W.D. DALZIEL. Subduction of Precambrian oceanic lithosphere along the Mozambique suture resulted in the final amalgamation and consolidation of a smaller Gondwana supercontinent at about 500 Ma. Paleolatitudinal setting from paleomagnetic data and position of Laurentia relative to Gondwana based on continuation of Grenville belt into present East Antarctica (EANT).
AFR = Africa; AUS = Australia; IND = India; NAM = Laurentia; SAM = South America; CL = Coats Land; EWM = Ellsworth-Whitmore mountains; HN = Haag Nunataks; P = Patagonia terrane; SR = Shackleton Range; T = Tasman orogen; MBL = Marie Byrd Land; NVL = North Victoria Land.

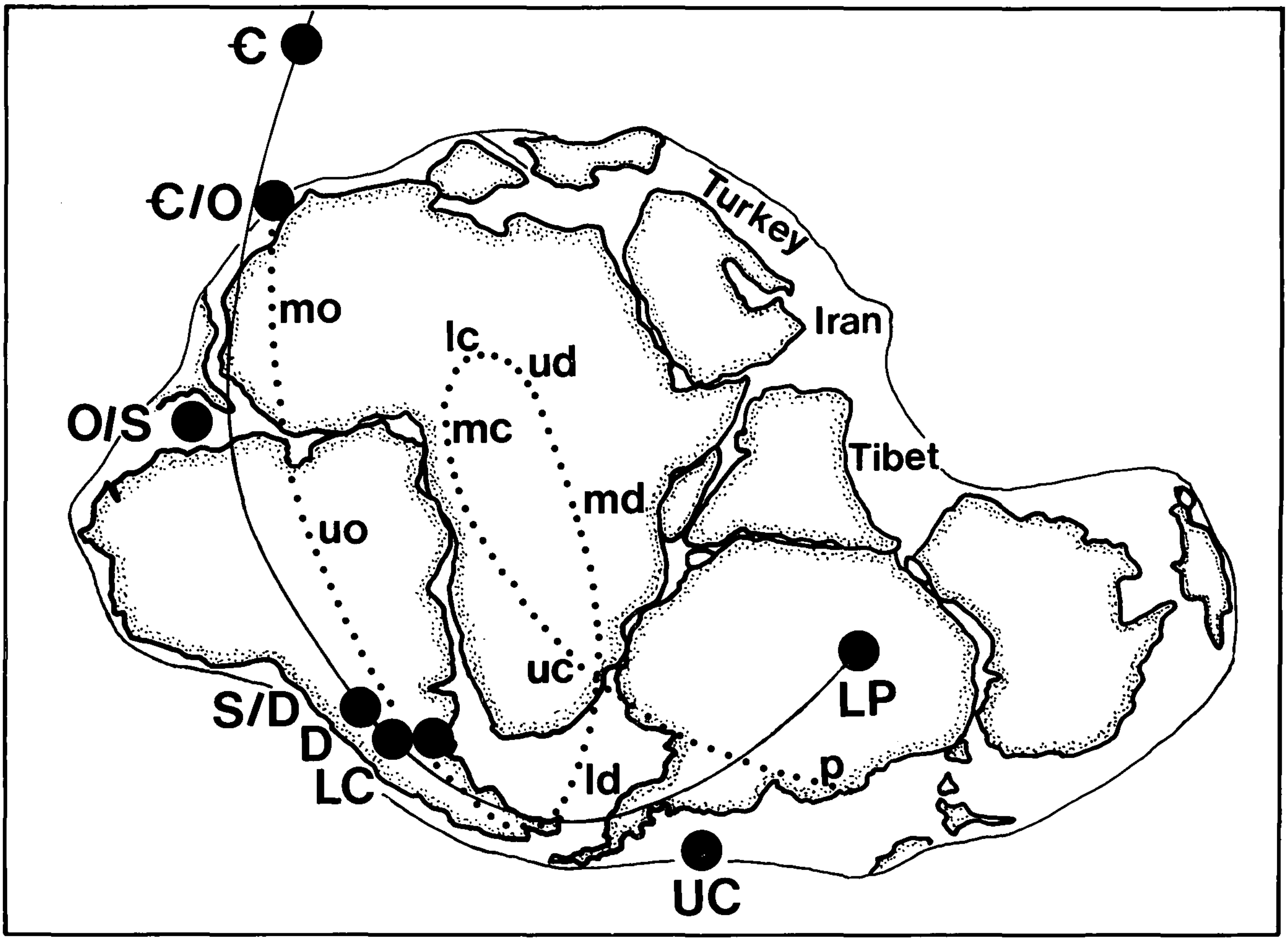

Fig. 2.
Comparison between Apparent Polar Wander Path (APWP) for Gondwana during the Paleozoic after V. BACHTADSE & J.S. BRIDEN (1990) (dotted line) and paleoclimatically determined pole positions after C.R. SCOTESE & S.F. BARRETT (1990) (solid line).
C = Cambrian; C/O = Cambrian/Ordovician; O/S = Ordovician/Silurian; S/D = Silurian/Devonian; D = Devonian; LC = Lower Carboniferous; UC = Upper Carboniferous; LP = Lower Permian; l = Lower; m = Middle; u = Upper.
Modified from C.R. SCOTESE & S.F. BARRETT (1990).

WITZKE & P.H. HECKEL, 1988; C.R. SCOTESE & W.S. MCKERROW, 1990; D.V. KENT & R. VAN DER VOO, 1990; G. YOUNG, 1990). Migration paths between the two supercontinents may then have existed across the narrow "Phoibic Ocean". In the north, however, newly formed mountain belts such as the Caledonides and parts of the Appalachians, developed in the Scandian and Acadian Orogenies, respectively, separated a Laurentian faunal province from a Central and Northern European province corresponding to the Rhenish-Bohemian Province (A.J. BOUCOT, 1985, 1990; A.J. BOUCOT et al., 1969, and others).

The Lower Devonian is characterized by a significant reversal of the general drift motion of Euramerica. The older primarily southward movement changed to a general northward drift of Euramerica (B.J. WITZKE, 1990). Gondwana, however, may have moved in the opposite direction. Possibly, this Devonian motion is expressed by the rapid excursion of the paleomagnetic APW path into central Africa although the database is still far from complete (V. BACHTADSE & J.C. BRIDEN, 1990; C.R. SCOTESE & W.S. MCKERROW, 1990). In any way, the Rheic Ocean separating northwestern from central and southern Europe and Gondwana was no longer a barrier for faunal migrations during the Devonian.

In the Carboniferous the closure of several oceans began, e.g., the Phoibic Ocean between western Gondwana and Euramerica, the Rheic or Mid-European Ocean between northern Europe and Gondwana and the Pleionic Ocean separating Baltica from Siberia (W.S. MCKERROW & A.M. ZIEGLER, 1972). It was completed with the assembly of Pangaea in the Late Permian Kazanian Stage.

Thick flysch deposits of Kulm type in central and southern Europe indicate active plate margins in several small terranes bordering Gondwana before collision and deformation reached the climax in the Namurian and Westphalian. According to J. NEUGEBAUER (1988) and T. AIFA et al. (1990) Gondwana rotated clockwise relative to northern Europe which resulted in an oblique transpressive shear zone and progressive deformation from northeast to southwest (see C.R. SCOTESE & W.S. MCKERROW, 1990). The final phase of Variscan deformation is recorded in the Ouchita Mountains of Oklahoma in the Early Permian. Also, at this time Kazakhstan collided with the Uralian margin of Baltica.

The northward movement of Gondwana appears well constrained in the paleomagnetic APW paths for Africa during the Carboniferous (V. BACHTADSE & J.C. BRIDEN, 1990): The southward drift until the Early Carboniferous was succeeded by continuous northward drift of both Gondwana and Euramerica from the Early Carboniferous to the Permian with minimum drift rates of 10 cm per year. According to B.J. WITZKE (1990) the motion of Euramerica was the most rapid latitudinal movement during the whole Paleozoic. The Middle Carboniferous "loop" in central Africa (Fig. 2) determined by paleomagnetic data is yet not matched by information from lithofacies (C.R. SCOTESE & S.F. BARRETT, 1990). The reasons might be the paucity of data between the Early and Late Carboniferous, the poor stratigraphic control or the lengthy interval of time between the data sets (30 Ma) during which the plates may have drifted considerably if the drift rate was high.

In the Permian the assembly of the northward drifting supercontinent Pangaea was largely completed. By the end of the Artinskian Stage the Kazakhstan, Tarim and Siberian plates were accreted to the Russian (Baltic) platform. Other blocks such as South China rotated and continued to move so that paleogeographical reconstructions in this part of the world are yet poorly constrained until the Late Triassic. Along the northern margin of Gondwana Turkey, Iran, Tibet and Shan Tai-Malaya started to rift off from Gondwana to form the microcontinent Cimmeria (A.M.C. SENGÖR, 1984, 1987; D.B. ROWLEY et al., 1985; S. NIE et al., 1990).

Conclusions

In the foregoing chapters we briefly reviewed the Paleozoic plate movements based on paleomagnetic and paleoclimatic evidence as outlined by C.R. SCOTESE & W.S. MCKERROW (1990) and supplemented by other evidences. With reference to central and southern Europe C.R. SCOTESE & W.C. MCKERROW (1990) argued that this area adjacent to the north African margin of Gondwana shifted through different latitudinal settings and thus climatic regimes over a period of more than 300 million years. During their motion the direction and rate probably varied (V. BACHTADSE & J.C. BRIDEN, 1990). As a consequence the intervening oceans widened or shortened and the subsiding sedimentary basins were either affected by compressional or extensional tectonics. From the APW path of V. BACHTADSE & J.C. BRIDEN (1990) which for the Lower Paleozoic period, i.e., from the Cambrian to

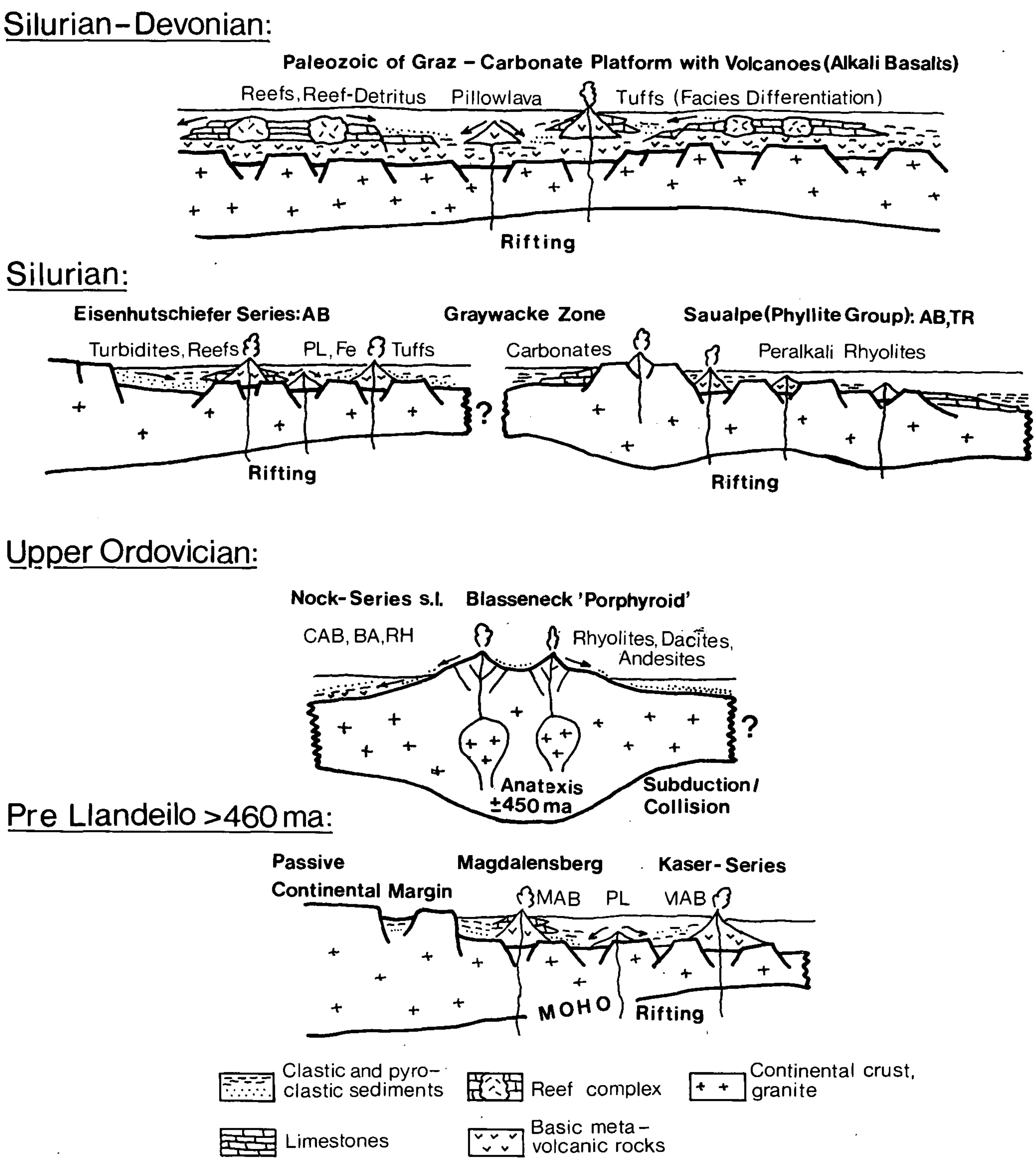

Fig. 3.
Ordovician to Devonian rifting and collision/subduction related volcanism in the Eastern Alps.
AB = Alkaline basalts; BA = Basaltic andesites; CAB = Calc-alkaline basalts; FE = Submarine hydrothermal iron ore deposits; MAB = Mildly alkaline basalts; PL = Pillow lava; RH = Rhyolites; TR = Trachytes.
Modified from J. LOESCHKE (1989a) with regard to new fossil data and chronology of events.

almost the end of the Silurian, lies closely parallel to the paleoclimatically determined APW path of C.R. SCOTESE & S.F. BARRETT (1990) it may be inferred that central Europe, and hence, also the Paleozoic sequences of the Alps, were affected by compression and/or shifted relatively rapidly from high to more temperate and lower southern latitudes. Contrary, in the Early Devonian the Mid-European Ocean widened and Africa started to cross over the South Pole a second time after the mid-Ordovician passage. This drift may have resulted in extensional basin tectonics and different latitudinal settings. During the Carboniferous and Lower Permian this pattern was followed by significant northward movements of western Gondwana; it resulted in contemporaneous compression along active plate margins and formation of thick flysch deposits which were strongly deformed during the Variscan Orogeny in the Late Carboniferous. Provided that the volcanic activities in the Eastern and Southern Alps are stratigraphically truely dated rifting and subduction/collision related volcanism (Fig. 3) is well consistent with these plate movements during the Paleozoic (H. HEINISCH, 1981; H. HEINISCH et al., 1987; H. FRITZ & F. NEUBAUER, 1988; U. GIESE, 1988; J. LOESCHKE, 1989a,b; P. SCHLAEGEL-BLAUT, 1990; H.P. SCHÖNLAUB, 1990).

3. Paleogeographical Constraints on the Alpine Paleozoic

In recent years, it has been suggested that the pre-Alpine basement was formed by accretion of several terranes (W. FRISCH & F. NEUBAUER, 1989). In fact, the existence of many, although volumetrically not significant occurrences of mafic and ultramafic rocks in different tectonic units of the Eastern Alps, might represent remnants of small oceans which may have separated these blocks adjacent to the north African margin sometimes during the Paleozoic (A.v. QUADT, 1985, 1987; W. FRISCH et al., 1987; W. FRISCH & D. RAAB, 1987; W. FRANK et al., 1987; U. GIESE, 1988; G. VAVRA, 1989; S. POLI, 1989; H. KRAIGER, 1989). This model, however, seems poorly founded: firstly, there is evidently a lack of true Ocean Floor Basalts as opposed to Within Plate Basalts and secondly, most if not all, of the respective sequences represent high to low grade metamorphic unfossiliferous rocks with only few radiometric data yet available (see summaries in, e.g., W. FRISCH et al., 1984, 1990; A.v. QUADT 1985, 1987; L.P. BECKER et al., 1987). Consequently, their age and primary geological setting has been a matter of ongoing discussion and inferred geodynamic models have been regarded as being preliminary since their conclusions have been partly controversial.

3.1. Late Proterozoic

According to D. GEBAUER et al. (1989) the metasedimentary precursors of the European Hercynides were deposited after the Pan-African Orogeny, i.e., between approx. 1000 and 600 Ma. Based on detrital zircons, crust-forming events, however, have been dated back as far as 3.84 billion years and are thus much older than previously assumed from Rb-Sr systematics (B. GRAUERT & A. ARNOLD, 1968; B. GRAUERT et al., 1973; E. JÄGER, 1977; Ph. VIDAL, 1977; Ph. VIDAL et al., 1981; F. SÖLLNER & B.T. HANSEN, 1987). The chronology of events recorded in individual zircon grains reveals a complex geological history that agrees well with the crustal evolution of the African craton and, hence, strongly supports the idea that the detrital sediments were supplied from Gondwana and not from Laurussia.

Apparently the oldest fossiliferous rocks of the Alps occur in the Habach Group of the Penninic domain of the Hohe Tauern region of Salzburg (E. REITZ & R. HÖLL, 1988). Another probably coeval microfossil assemblage was recently found in phyllitic rocks close to

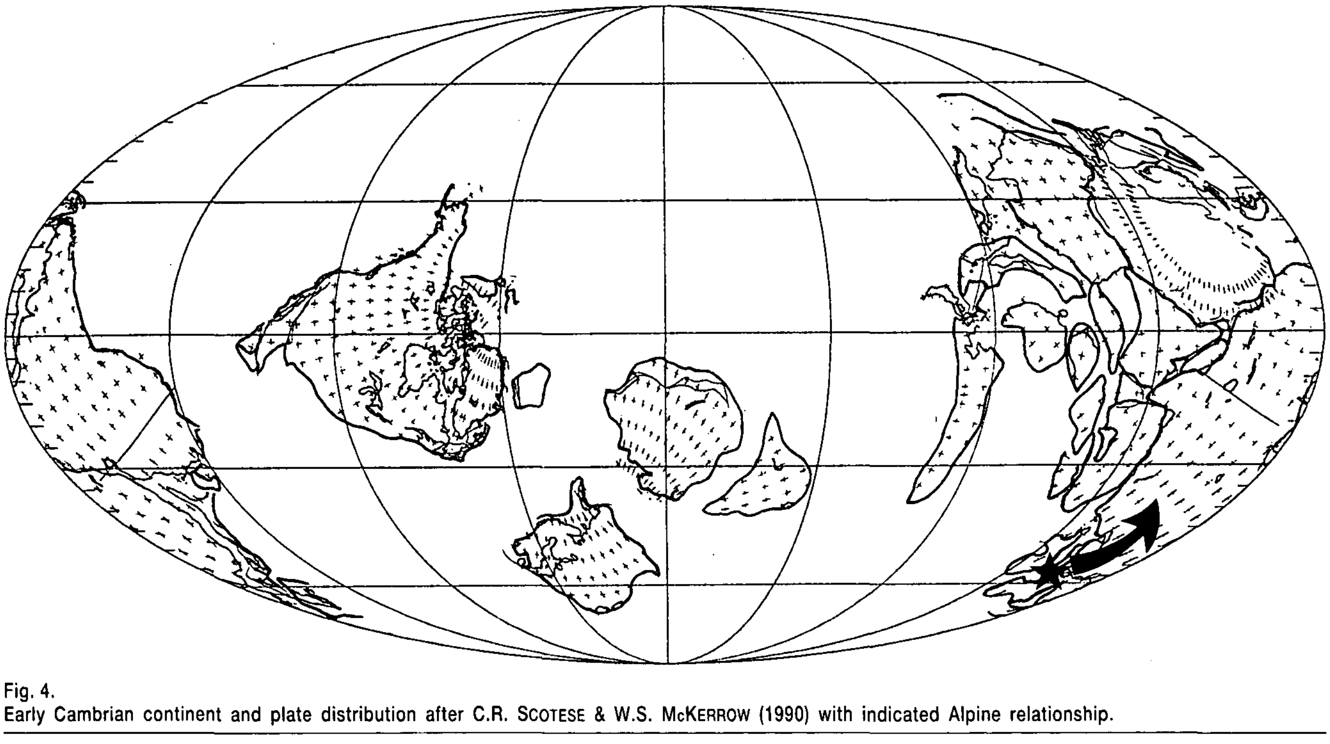

Fig. 4.
Early Cambrian continent and plate distribution after C.R. SCOTESE & W.S. MCKERROW (1990) with indicated Alpine relationship.

the northern margin of the Tauern Window and may correspond to parts of the Habach Group (E. REITZ et al., 1989). The latter, up to 1500 m thick, rock sequence comprises thick piles of metasediments and large volumes of metabasalts, metaandesites and other calc-alkalic volcanics which according to different authors either represent

1) an older oceanic back-arc sheeted-dyke complex followed by subduction-related island arc volcanics in a continental setting, with argillites of the Habach Phyllites on top of it (H. KRAIGER, 1989),
   or
2) represent an ensimatic island arc formed in an intraoceanic environment (W. FRISCH & D. RAAB, 1987).

According to W. FRISCH & F. NEUBAUER (1989) the Habach Group constitutes the Habach Terrane "floating somewhere in the Rheic Ocean". Based on U/Pb zircon ages A.v. QUADT (1985, 1987) concluded a magmatic activity in the Habach Group during the period from Late Cambrian to Early Ordovician (see also G. VAVRA, 1989).

The microfossil assemblage recovered from the black Habach Phyllites and its equivalents are organic-walled spheroidal acritarchs which appear to be diagnostic for the Late Riphean and Lower Vendian suggesting an age of approx. 670 Ma for the deposition of these sediments. Their restriction to this time interval, however, may be challenged due to new discoveries of large complex and ornamented acritarchs from 600 to 650 Ma old cherts and mudstones of the Pertatataka Formation in central Australia (W.L. ZANG & M.R. WALTER, 1989) which shed new light on the evolution and biostratigraphic zonation of Late Proterozoic acritarchs (see comment by A.H. KNOLL & N.J. BUTTERFIELD, 1989; J.W. SCHOPF, 1991). Moreover, new age constraints place the Riphean/Vendian boundary presently at approx. 620 million years as opposed to B.U. HAQ & F.W.B. VAN EYSINGA (1987).

Whether or not these findings are of climatic significance, or even display provincialism, is yet poorly understood in the Proterozoic. In the past such ornamented acritarchs were reported from many localities on different plates favouring wide geographic and temporal distribution on continental plates and in a plate margin environment instead of colonizing volcanic islands in an oceanic setting as suggested by W. FRISCH & F. NEUBAUER (1989) for the "Habach Terrane".

3.2. Cambrian to Ordovician

Fossiliferous rocks of Cambrian age have yet not been recognized in the Alps. All previous reports on such occurrences were misleading since they were not based on true fossils (see H.P. SCHÖNLAUB, 1979, p. 11, p. 39).

Remarkably well-preserved acritarchs do, however, occur in phyllitic slates near the base of the Graywacke Zone in the vicinity of Kitzbühel, Tyrol (E. REITZ & R. HÖLL, 1989, 1991) and in the Innsbruck Quarzphyllite (E. REITZ & R. HÖLL, 1990). They suggest an Early Ordovician age equivalent to the Tremadocian and Arenigian Series of the British succession, respectively. In contrast to this report the supposed occurrence of Tremadocian graptolites (E. HABERFELNER, 1931) has not been confirmed; it probably represents an artifact (H. JAEGER, 1969).

The oldest megafossil assemblage of the Alps is of Upper Llandeilo age corresponding to the lower Berounian Series of Bohemia (V. HAVLICEK et al., 1987). It is derived from the Gurktal Nappe (locality Bruchnig on the Magdalensberg, north of Klagenfurt, Carinthia; Fig. 5). The fossils comprise mostly brachiopods which occur in tuffaceous strata on top of basic metavolcanic and pyroclastic rocks. They represent mildly alkaline Within-Plate Basalts which have been altered to spilites (J. LOESCHKE, 1989a,b; Fig. 3).

The second important fossil assemblage was recorded from arenaceous shales in the Carnic Alps and appears to be slightly younger, i.e. Caradocian in age. The highly diversified fauna comprises brachiopods, bryozoans, trilobites, cystoids and very rare hyolithes (H.P. SCHÖNLAUB, 1971b, 1988; G.B. VAI, 1971; L. MAREK, 1976; G.B. VAI & C. SPALLETTA, 1980; V. HAVLICEK et al., 1987).

Interestingly, these two fossil sites, located to the north and the south of the Periadriatic Line, differ significantly from coeval cold-water Mediterranean associations, i.e., those from Bohemia and Morocco, although these regions and the Alps have some elements

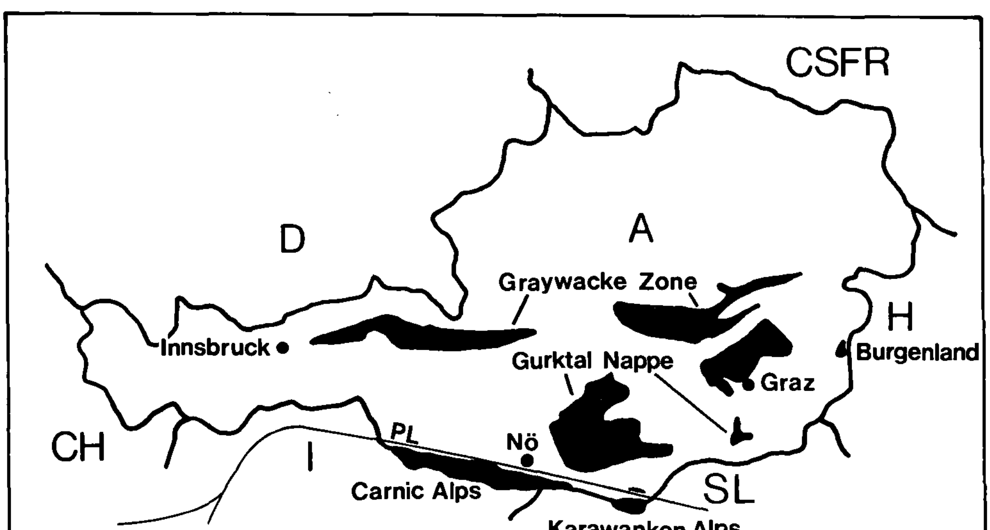

Fig. 5.
Main regions with fossiliferous Paleozoic strata in the Eastern Alps north and south of the Periadriatic Line (PL).
Nö = Carboniferous of Nötsch.

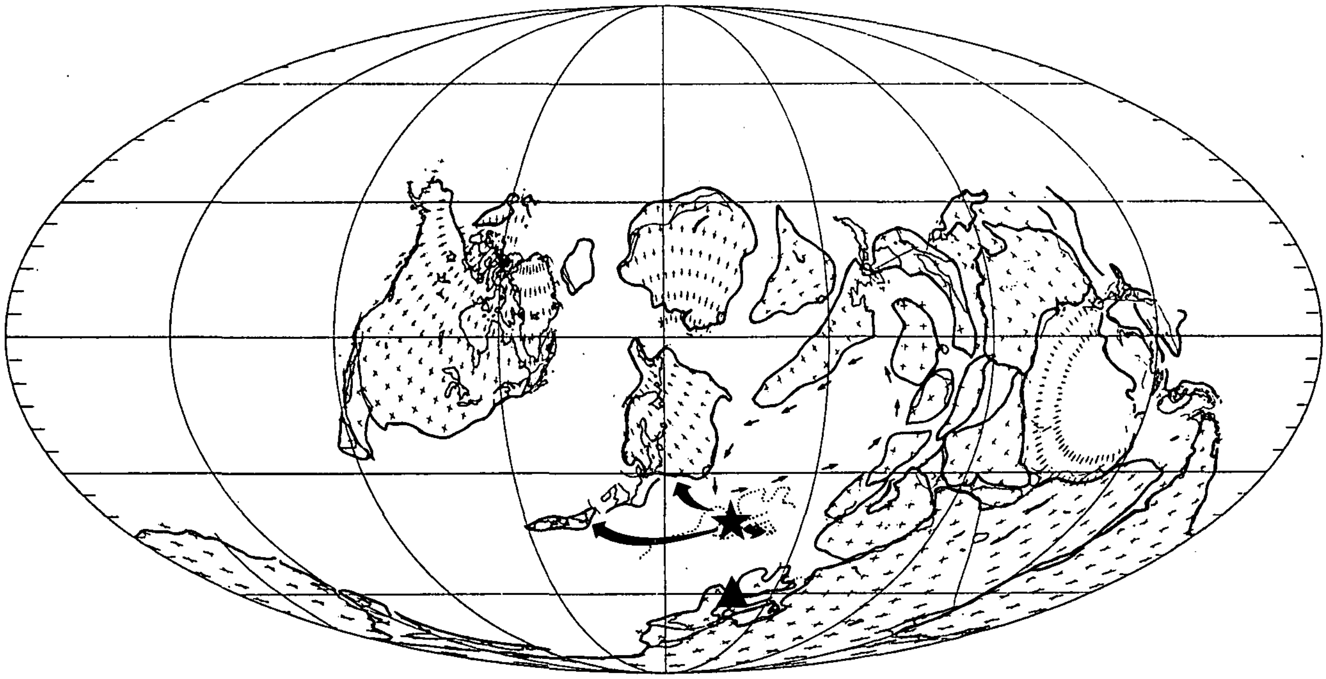

Fig. 6.
Latest Ordovician (Ashgillian) paleogeography.
Triangle indicates position of Southern Alps according to C.R. SCOTESE & W.S. MCKERROW (1990). The author's latitudinal setting is indicated by the star. Faunal relationships are shown by thick arrows and oceanic circulation system in the southern mid-European ocean by small arrows.
Modified from C.R. SCOTESE & W.S. MCKERROW (1990).

in common, for example, *Svobodaina ellipsoides, Gelidorthis meloui, Saukrodictya porosa, Aegiromena aquila aquila* and *Paterorthis paterina*. Instead, in their presence of warm water elements such as representatives of *Dolerorthis, Iberomena, Longvillia, Porambonites, Eoanastrophia* a.o. they exhibit a closer affinity to Sardinia, the British Isles and North Europe. This indicates an invasion of North European warm water brachiopods as far south as the Alps, Sardinia, Montagne Noire and Spain (V. HAVLICEK, 1976; V. HAVLICEK et al., 1987).

During the Hirnantian Stage, the supposed relationship with Baltoscandia can still be seen in the ostracod and echinoid fauna described by R. SCHALLREUTER (1990) from the Carnic Alps. This time, corresponding roughly to the glacial maximum, is also characterized by a cold water influx from Gondwana (H. JAEGER et al., 1975). On a global scale it is associated with a worldwide retreat of the sea coupled with a distinct interval of faunal extinction and the appearance of the widespread Hirnantia Fauna (A.D. WRIGHT, 1968; W.B.N. BERRY & A.J. BOUCOT, 1973; P.M. SHEEHAN, 1973, 1975, 1979, 1988; H. JAEGER et al., 1975; P.J. BRENCHLEY & G. NEWALL, 1980; N. SPJELDNAES, 1981; P.J. BRENCHLEY, 1984; P.J. BRENCHLEY & B. CULLEN, 1984; J. RONG, 1984; H.P. SCHÖNLAUB, 1988; P.M. SHEEHAN & P.J. COOROUGH, 1990 a.o.). Its distribution is concentrated in the higher latitudes of the Southern Hemisphere but exceptions do occur in a tropical belt and in northern low latitudes suggesting that this unique fauna was adapted to a glacially induced cold climate and consequently cooler waters at the close of the Ordovician.

The Upper Ordovician conodont fauna of the Alps is well known from detailed studies by O.H. WALLISER

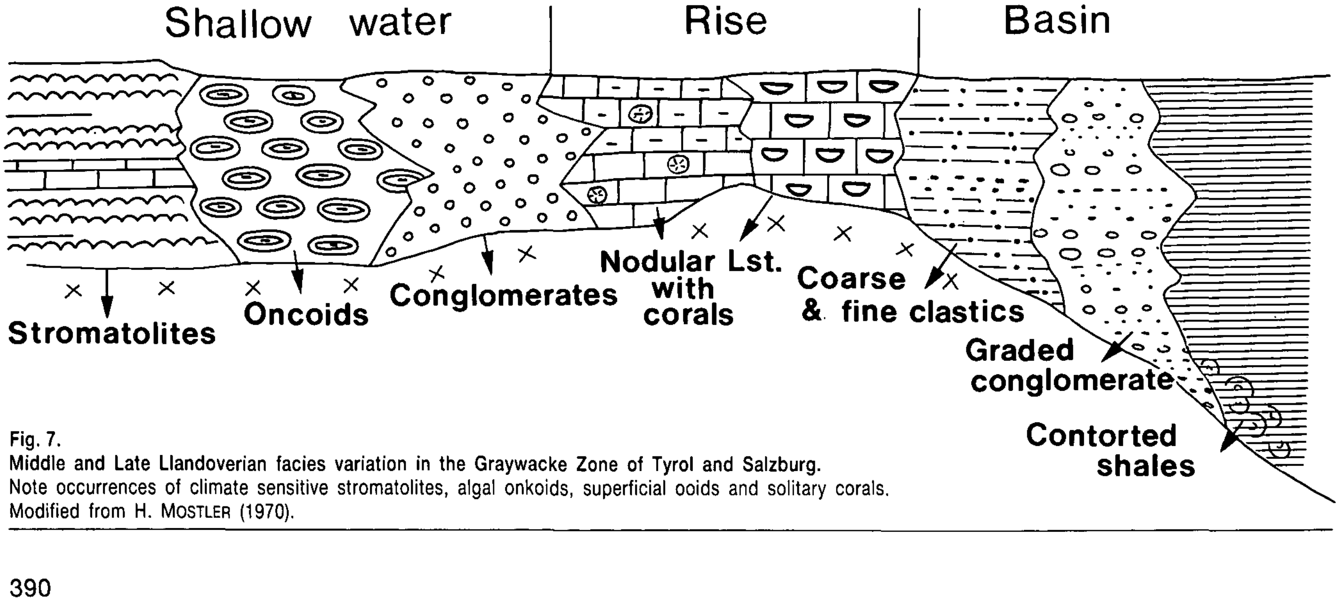

Fig. 7.
Middle and Late Llandoverian facies variation in the Graywacke Zone of Tyrol and Salzburg.
Note occurrences of climate sensitive stromatolites, algal onkoids, superficial ooids and solitary corals.
Modified from H. MOSTLER (1970).

(1964), E. SERPAGLI (1967) and G. FLAJS & H.P. SCHÖNLAUB (1976) from the Uggwa Limestone of the Carnic Alps and different limestone units of the Graywacke Zone of Styria. They were less well described from a few weakly metamorphosed occurrences in between (F. NEUBAUER, 1979; M.F. BUCHROITHNER, 1979; F. NEUBAUER & J. PISTOTNIK, 1984). Apparently, this conodont association represents the *Hamarodus europaeus Dapsilodus mutatus Scabbardella altipes* (HDS) Biofacies of W.C. SWEET & S.M. BERGSTRÖM (1984). Although their precise age within the uppermost Caradocian or early Ashgillian Series remains open the conodont bearing limestones clearly can be assigned to the *Amorphognathus ordovicicus* Zone. According to W.C. SWEET & S.M. BERGSTRÖM (1984) who tentatively revised the published conodont elements from the Carnic Alps in terms of the modern multi-element taxonomy, the Late Ordovician Uggwa Limestone is dominated by *Scabbardella altipes* (43 %), *Hamarodus europaeus* (17 %), *Amorphognathus* cf. *ordovicicus* (8 %) and *Dapsilodus mutatus* (2.4 %). Less abundant are *Plectodina alpina, Belodella pseudorobusta, "Prionoidus" ethingtoni* and *Strachanognathus parvus*. The occurrence of these species and the abundance of the others, in particular *Hamarodus europaeus*, varies from coeval faunas of Thuringia, Spain and France. Yet it seems unclear which factors are involved in these differences (J. DZIK, 1989).

A comparison between this fauna from the Carnic Alps and the two others from the Graywacke Zone is difficult to assess due to probably minor differences in age and state of preservation (G. FLAJS & H.P. SCHÖNLAUB, 1976). In particular, this is true of the large collection derived from the limestone lenses underlying the thick acid volcanics of the so-called Blasseneck-Porphyroid in the surroundings of Eisenerz, Styria (Fig. 8). Apparently, the revised conodont association represents the same general type as the one from the Carnic Alps in being equally dominated by *Amorphognathus* cf. *ordovicicus, Scabbardella altipes, Hamarodus europaeus, Dapsilodus mutatus* and perhaps *Plectodina alpina*; less abundant are *Belodella pseudorobusta, Panderodus* ssp. and certain elements which tentatively have been assigned to *Birkfeldia circumplicata*. Other differences between these two faunas were thoroughly reviewed by G. FLAJS & H.P. SCHÖNLAUB (1976).

According to S.M. BERGSTRÖM (1990) the "Coefficient of Similarity" (CS) between conodonts from Baltoscandia and the Mediterranean area has a value of 0.30 indicating moderate similarity between the two regions. For example, they share the occurrences of specimens of *Amorphognathus, Scabbardella* and *Dapsilodus* while others appear to be restricted to continental Europe or North Africa. Obviously, the distribution of Late Ordovician conodonts follows a similar pattern as inferred from megafossil assemblages and facies data. This led W.C. SWEET & S.M. BERGSTRÖM (1984) to conclude that the Mediterranean Province was a cold water realm in a polar or subpolar latitudinal setting.

In the Alps, occurrences of carbonate sediments 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 the Gurktal Nappe in between. According to W.C. DULLO (pers. comm. Nov. 1990 and this volume) the up to 20 m thick carbonate units, in the local stratigraphical schemes named Wolayer and Uggwa Limestone, respectively (H.P. SCHÖNLAUB, 1985a), represent greyish and whitish grainstones to rudstones and occasionally also bafflestones with abundant debris of cystoids and bryozoans and less frequently trilobites and nautiloids. Cathodoluminescence studies have revealed the rare occurrence of coated grains. Moreover, of special significance are dogtooth-cements suggesting a vadose diagenetic environment for the Wolayer Limestone in contrast to the coeval and slightly deeper Uggwa Lst. which is enriched in clay and shell fragments but decreased in the content of bryozoans and echinoderms. At about the Caradocian/Ashgillian boundary they succeed various clastic sequences which dominated the Early and Middle Ordovician interrupted by basic volcanics of presumably Llandeilloan age as well as of acid volcanics in the Caradocian.

In a general, climatically based, latitudinal framework these carbonate units suggest a position within the confines of the larger "carbonate belt", i.e., between latitudes of about 45° North and South where it was moderately warm and where there was adequate light penetration rather than high water temperature (A.M. ZIEGLER et al., 1984). Whether or not the Late Ordovician limestones from the Alps may represent cool water carbonates analogous to modern and Cenozoic carbonates off Southern Australia (N.P. JAMES & Y. BONE, 1991) is presently difficult to decide. More plausible, the nature of the corresponding sediments may have developed as the direct response to climatic changes during the Ordovician. For the Ashgillian P.D. WEBBY (1984) suggested a global climatic amelioration as the main cause for the increasing carbonate production. Alternatively, a progressive northward shift of the sedimentary basins into lower latitudes may also explain their temporal and spatial distribution (T.P. YOUNG, 1990). In the Ordovician of the Mediterranean Province contemporary carbonates are widely distributed and have been reported from Sardinia (G.B. VAI & T. COCOZZA, 1986; A. FERRETTI & E. SERPAGLI, 1991), Montagne Noire, the Massifs of Mouthoumet and Agly of Southern France (W. ENGEL et al., 1981), the Armorican Massif (F. PARIS et al., 1981; F. PARIS & M. ROBARDET, 1990; M. ROBARDET et al., 1990; M. MELOU, 1990), the Pyrenees (J.J.A. HARTEFELT, 1970; H. DURAN et al., 1984), Catalonia and other areas in Spain (W. HAMANN, 1976; M. HAFENRICHTER, 1980; H. DURAN et al., 1984; R.W. OWENS & W. HAMANN, 1990), Portugal (T.P. YOUNG, 1985, 1988, 1990) and from the Anti-Atlas of Morocco (J. DESTOMBES et al., 1985). Consequently, the Alpine occurrences of Upper Ordovician rocks suggest a position at considerably lower and more temperate latitudes than has been shown in the revised world maps of C.R. SCOTESE & W.S. MCKERROW (1990). More precisely, available faunal and lithic data from the Upper Ordovician of the Alps rather indicate a position between approximately 40 and 50° S instead of being placed around 60° S. This setting, still beyond the present day Darwin Point of some 35° (R.W. GRIGG, 1982), is consistent with the paleogeography of the West European Platform as proposed by T.P. YOUNG (1990).

Conclusions

Although the data base to establish a paleobiogeographic approach during the Cambrian and Ordovician Periods of Central and Southern Europe is sparse and far from being sufficient some related trends in the in-

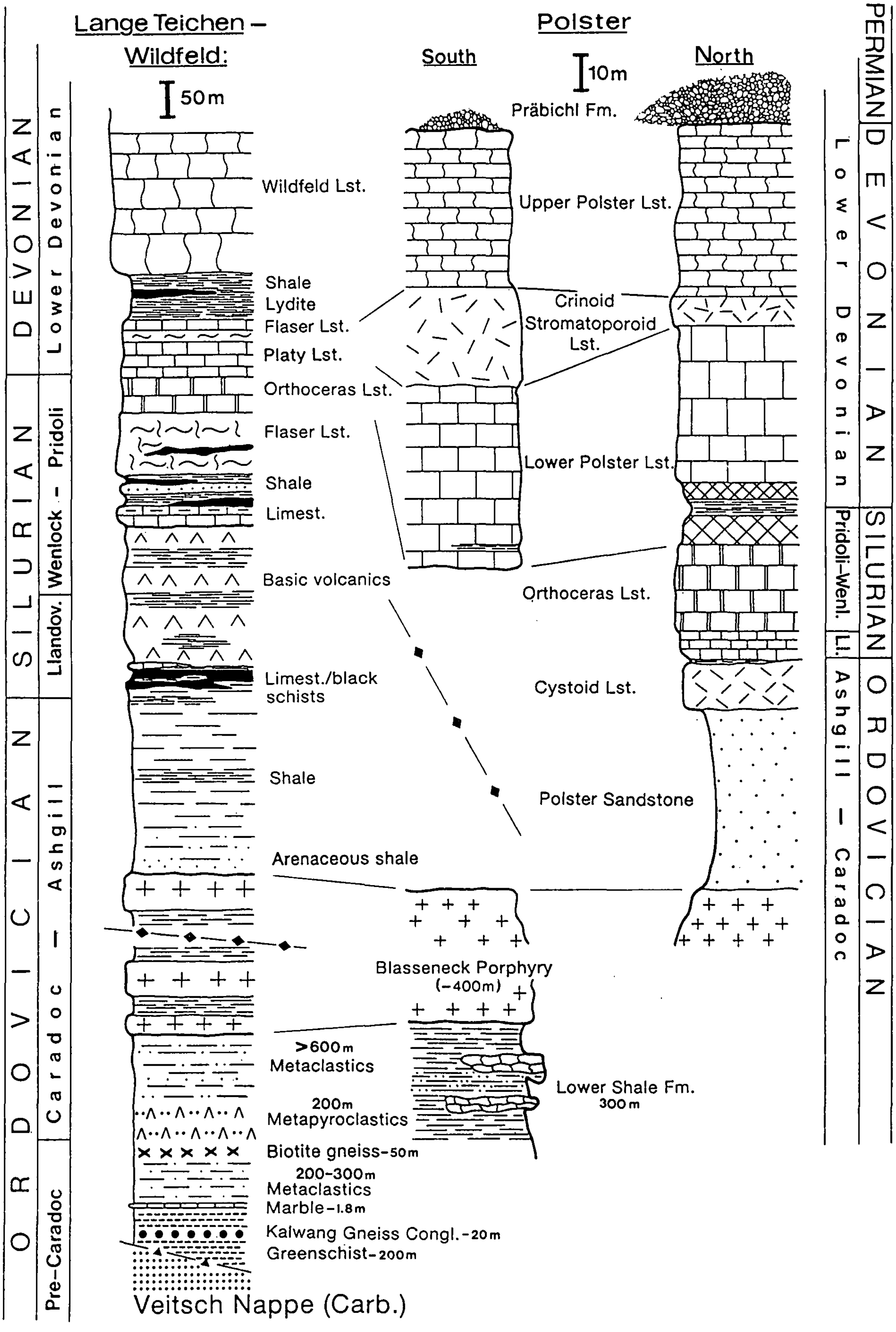

Fig. 8.
Stratigraphy of the Graywacke Zone of the Eisenerz Alps, Styria (H.P. SCHÖNLAUB, 1979).

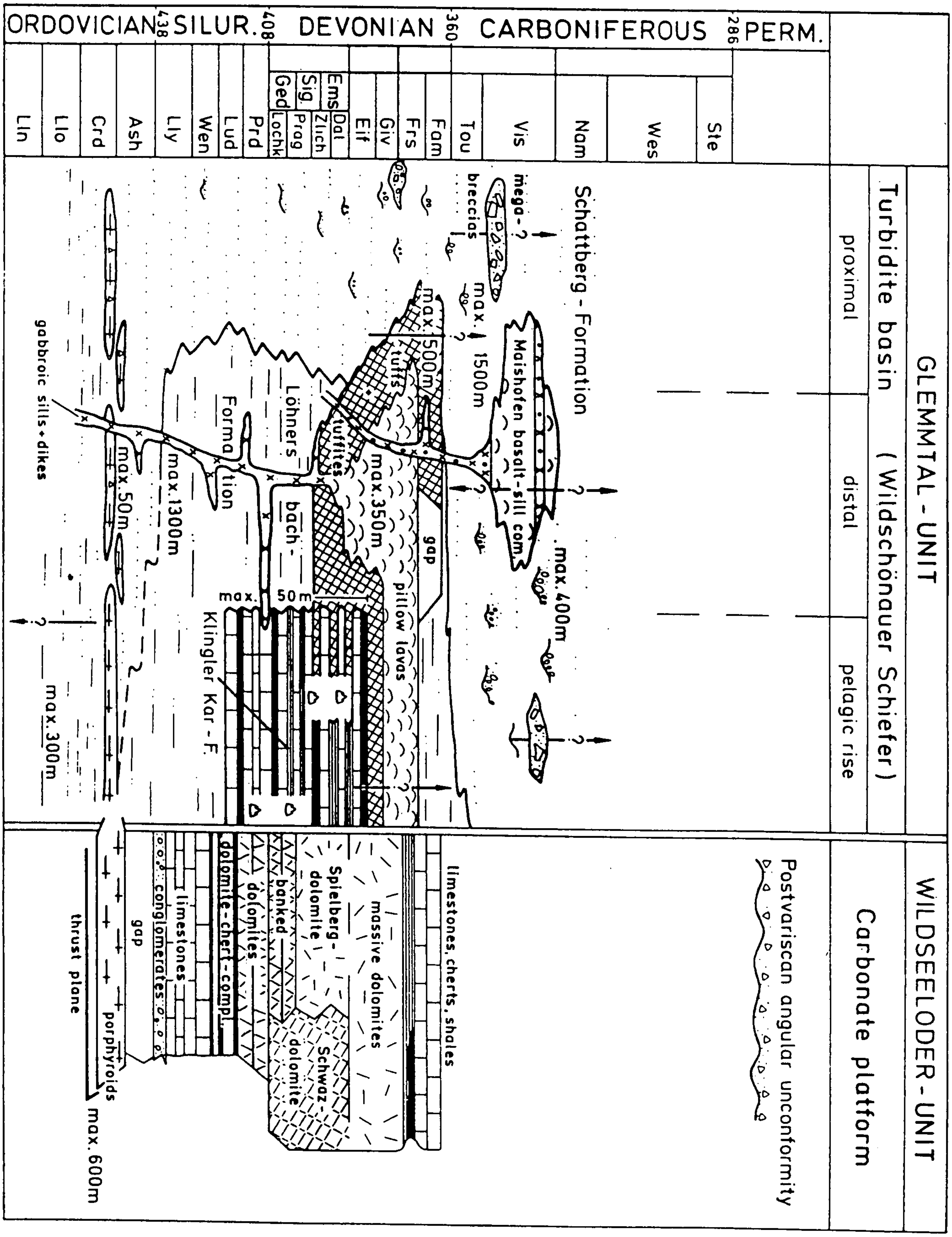

Fig. 9. Stratigraphy in the western part of the Graywacke Zone. After H. HEINISCH (1988).

terchange of past communities and in the geodynamic evolution of this area can clearly be recognized:

1. During the Cambrian and Lower Ordovician, thick clastic sequences are the dominating sediments in northern Africa and in the adjacent southern and central European depocentres. Though these rocks are of no, or only limited, climatic significance their inherited zircon population indicates Africa as source area.

2. Carbonates first occur in the Lower Cambrian of Southern and Central Europe suggesting a low latitudinal position and close faunal relationships between the individual occurrences within the Mediterranean faunal realm (K. SDZUY, 1962; G. FREYER, 1987). Yet, in the Alps the corresponding rocks have not been found. The oldest limestones are of Upper Ordovician age and occur in various parts of the Eastern Alps. Their fossil content and microfacies indicate a moderate climate in a temperate latitudinal setting.

3. Upper Ordovician fossils, in particular most brachiopods, cystoids, ostracodes and conodonts, are more closely related to coeval warm water faunas of northern 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 southern high latitudes.

4. Probably during the Llandeilo a rifting related basic volcanism occurred first recognized in Middle Carinthia but supposedly also occurring at other places in the Alps. Interestingly, this event seems to coincide with calc-alkaline igneous activity in the Ardennes, Wales and SE Ireland (B.P. KOKELAAR et al., 1984) when Avalonia started to rift off from Gondwana (L.R.M. COCKS & R.A. FORTEY, 1982; W.S. MCKERROW & L.R.M. COCKS, 1986; K.T. PICKERING, 1989; C.R. SCOTESE & W.S. MCKERROW, 1990; F. PARIS & M. ROBARDET with opposing statements). An analogous plate disruption and subsequent separation might well be assumed for certain parts of the Variscan Alps.

5. A second major magmatic event occurred in the Early Ashgillian and has been regarded as a collision-subduction related process (J. LOESCHKE, 1989a,b). In accordance with paleomagnetic data from Gondwana it seems reasonable to suggest that this event reflects the rapid northward movement of Africa and its final collision with an unknown microcontinent or terrane located to the north.

6. Our best estimate for the paleolatitudinal position of the Late Ordovician of the Alps and its relationship with adjacent areas is illustrated on the amended C.R. SCOTESE & W.S. MCKERROW (1990) map for this time (Fig. 6). This plate configuration is based on the data from the Alps presented in the foregoing chapters and seems well constrained by sedimentary and faunal evidence from the West and Central European Platform (M. ROBARDET et al., 1990; M. MELOU, 1990; T.P. YOUNG, 1990; F. PARIS & M. ROBARDET, 1990).

3.3. Silurian

In the Alps the Silurian Period is characterized by a wide range of different lithofacies (H.P. SCHÖNLAUB, 1979). The respective rocks are locally very fossiliferous and have long been known from the Carnic Alps of southern Carinthia and its eastern continuation, the Karawanken Alps, the Graywacke Zone of Styria, Salzburg and Tyrol, the surroundings of Graz, the Gurktal Nappe of Carinthia and Styria and from a few other places within the quartzphyllite complexes of the Eastern Alps.

Generally, three types of lithofacies, each with a distinct faunal assemblage, can be recognized:

1) Fossiliferous carbonate facies
The dominating lithologies are limestones and less frequently dolomites with a thickness of, at most, some 60 m. Although the equivalents of the Lower Llandovery are missing, for the remaining of the Silurian the fossil record from many sections of the Carnic Alps and the Graywacke Zone has indicated a complete but slightly condensed sequence. Fossil assemblages consist of varying abundances of nautiloids, trilobites, bivalves, brachiopods and scarce graptolites as well as of conodonts, foraminifera, acritarchs, chitinozoans, scolecodonts and ostracodes. During the last decades most, but by far not all, groups have been revised or are being studied presently. This facies is best represented by the Plöcken and Wolayer Groups of the Silurian of the Carnic Alps.

2) Graptolitic facies
It is characterized by black siliceous shales, cherts (lydites) and alum shales which prevail over quartzitic sandstones and greenish mudstones at the base and in the basal Pridolian, respectively. The thickness approximates that in the pure limestone facies. A continuous record of graptolites starting with the name bearer of the *Akidograptus acuminatus* Zone of the basalmost Llandovery and ending in the Upper Lochkovian has indicated continuous sedimentation during the Silurian and across its boundary with the Devonian. In particular this is true for the Carnic Alps; in other areas, e.g., the Graywacke Zone such a continuous record has, as yet, not been demonstrated and it seems difficult to assess due to poor preservation of all collections. During the last 25 years all graptolite faunas were revised by H. JAEGER and numerous new ones have been collected; he named the corresponding strata Bischofalm Formation.

3) Transitional facies
It comprises a mixture of the above mentioned two main rock types, i.e. an alternation of black shales and marls with black or dark grey limestone beds. Its faunal content is very poor and consists of graptolites and few conodonts and nautiloids. In the local stratigraphic scheme of the Carnic Alps this facies was named Findenig Facies.

All three main facies may intergrade to varying degrees depending on their setting in a distinct paleogeographical and paleotectonic environment with different amount of limestone production and fossil support. In particular, this regards the region occupied by the Gurktal Nappe in Carinthia and parts of Styria with its dolomite and marble rich facies, equivalent to several 100 metres thick clastic development in the same area (Fig. 13, F. NEUBAUER, 1979; F. NEUBAUER & J. PISTOTNIK, 1984). Moreover, in some other fossiliferous sequences basic volcanics and tuffs are intercalated which indicate rifting associated with intracontinental volcanism at various times during the Silurian (for summary remarks see H.P. SCHÖNLAUB, 1979, 1982; R. HÖLL, 1970; F. EBNER, 1975; M.F. BUCHROITHNER, 1979; F. NEUBAUER, 1979; F. NEUBAUER & J. PISTOTNIK, 1984; U. GIESE, 1988; H. FRITZ & F. NEUBAUER, 1988; J. LOESCHKE, 1989a,b).

Silurian faunas following the terminal Ordovician mass extinction event are generally regarded as cosmopolitan and hence provide only little evidence to determine the latitudinal position of individual plates (D.

JABLONSKI, 1986). This evaluation, however, may change if a varied, highly diversified, fossil association is considered together with lithic data from the host rock.

According to S.M. BERGSTRÖM (1990) most, if not all, post-Ordovician conodont localities lay between 40°S and 40°N paleolatitude. In the Wenlockian continental Europe was located at the margin of this belt consistent with our conclusions drawn for the Late Ordovician. For this time conodont evidence from the Carnic Alps and other areas of the Eastern Alps suggests close affinity to coeval faunas from central, southern and southwestern Europe. Comparable faunas from Britain and Gotland which occupied a more equatorial position seem, however, more diversified. These differences diminished towards the end of the Silurian. S.M. BERGSTRÖM (1990) concluded that the Pridolian was a time of minimal conodont provincialism during which coeval faunas from the Alps, Bohemia and Nevada showed striking similarities at the generic level.

In the Silurian the distribution of phyto- and zooplankton, i.e., acritarchs and chitinozoans displays a broad latitude-parallel-zonation. However, plotted on the new world maps of C.R. SCOTESE & W.S. MCKERROW (1990) the old phytoplankton data of F.H. CRAMER (1971) seem to reflect local environmental conditions rather than a biogeographic pattern (G.K. COLBATH, 1990).

Yet, from the Silurian of the Alps only few appropriate data are available (A. BACHMANN & M.E. SCHMID, 1964; H. PRIEWALDER, 1976, 1987; F. MARTIN, 1978). Accordingly, acritarchs from the Cellon section of the Carnic Alps suggest an intermediate position between the high latitude *N. carminae* and the tropical *Domasia-Deunffia* biofacies (J.B. RICHARDSON et al., 1981; H. PRIEWALDER, 1987). This paleolatitudinal setting is well constrained by other data presented here. As regards chitinozoans too little is presently known from the Alps. According to F. PARIS (1981, 1990) it appears that their Silurian distribution is essentially cosmopolitan.

Silurian trilobites from the Carnic Alps are closely related to Bohemia and other central European regions (W. HAAS, 1969; G.K.B. ALBERTI, 1970). Affinities to Morocco may exist but are, as yet, not studied in detail. Interestingly, in the succeeding Devonian the apparent distinction with North Africa except the Rabat area continued; instead, there appears a closer relationship with the Urals and Tienshan (G.K.B. ALBERTI, 1969).

A similar affinity is suggested from the analysis of brachiopods from the Carnic Alps. According to G. PLODOWSKI (1971, 1973) and L.R.M. COCKS (1979) the Silurian brachiopod fauna is more independent than previously supposed although it shows a weak relationship to Bohemia, Great Britain, the Urals and Central Asia but only loose contacts with Morocco.

According to T. KOREN (1979) most, if not all, Silurian to Lower Devonian graptolites occur within paleolatitudes of some 30–40°N and 30°S. As noted by W.B.N. BERRY (1979) Silurian graptolites show only very little endemism suggesting that interplate dispersal was possible and apparently occurred during the Silurian and Lower Devonian. Presumably, its distribution was mainly controlled by the character of the surface water plus ocean currents that overlaid the site at which graptolites are found. The distribution of graptolites may thus have very much depended on the size, shape and position of certain plates.

In 1962 C. ROMARIZ applied N. SPJELDNAES' original term of the "Mediterranean Province" for those graptolites which are characterized by large robust rhabdosoms and have been recorded from middle and late Wenlockian strata of Portugal, Spain, Sardinia and the Carnic Alps (see also M. GORTANI, 1922, and C. ROMARIZ et al., 1971). Many of these giant specimens are, however, tectonically deformed and did not represent a distinct biofacies (H. JAEGER, 1968, 1975; H. JAEGER & D. MASSA, 1965; S. BARCA & H. JAEGER 1990).

During the Ludlow and Pridoli an essentially uniform graptolite fauna developed in Europe. As pointed out by H. JAEGER (1976) and S. BARCA & H. JAEGER (1990) the changing environment of this time is portrayed in strikingly similar and closely contemporaneous shifting lithofacies between northern Africa and Baltica which exhibit, with minor local modifications, a characteristic and continuous range from black graptolite shales to limestones, e.g., the well known "Ockerkalk" of Thuringia. According to H. JAEGER (1975) and G.K.B. ALBERTI (1980) this change in facies was controlled by simultaneous sea-level rise and fall that affected a hypothesized single block along its passive margins.

Distribution of extinct cephalopods corresponds widely to their living habitats (J.A. CHAMBERLAIN et al., 1981) and was limited by the same physical barriers as the recent Nautilus. In the absence of a planktic larval stage (N.H. LANDMAN et al., 1983) dispersal took place as part of the vagrant benthos on shallow shelfes or over shallow open marine environments and not as part of the oceanic nekton. Structural studies of the shell (R.E. CRICK, 1988) have indicated that they were restricted to limits between 300 and 500 m water depths. This may explain why Ludlow faunas from North Africa and Laurentia show such striking differences suggesting that an exchange across the wide mid-European ocean was largely impossible (R.E. CRICK, 1990).

In the Alps, the oldest nautiloids not described yet occur in the Ashgillian Uggwa Limestone of the Carnic Alps. From the Late Llandovery onwards, nautiloids became the dominating organisms in the carbonate facies of the Southern Alps with rich abundances of orthocerids in the Late Wenlock and Early Ludlow (H. RISTEDT, 1968, 1969). The diversified faunas seem closely related to Bohemia and Sardinia. With decreased numbers nautiloids continue into the Pridoli and Lower Devonian.

In contrast to the Carnic Alps in the Graywacke Zone and in the Gurktal Nappe of Carinthia, very few nautiloids have been found despite the occurrence of very similar lithologies. This remarkable feature is, as yet, difficult to explain.

The distribution of other molluscs, in particular bivalves, corresponds largely to that of orthoconic nautiloids. According to J. KRIZ (1979) the Silurian cardiolids from the Southern Alps and the Graywacke Zone inhabited the warm equatorial zone or were dispersed through south equatorial currents. However, plotted on the modified base maps proposed by C.R. SCOTESE & W.S. MCKERROW (1990) the central and southern European faunas must either have occurred in slightly higher southern latitudes or the position of the respective plates is too high. In our opinion a position around 35°S would be the best estimate for the Silurian occurrences in the Alps (Fig. 10).

This view is strongly supported by other evidence: in the Silurian corals were prominent constituents of the shallow water environment in the tropical belt. After a crisis at the end of the Ordovician several orders among the Tabulata and the Rugosa diversified in the early Silurian. During this time only weak provincialism

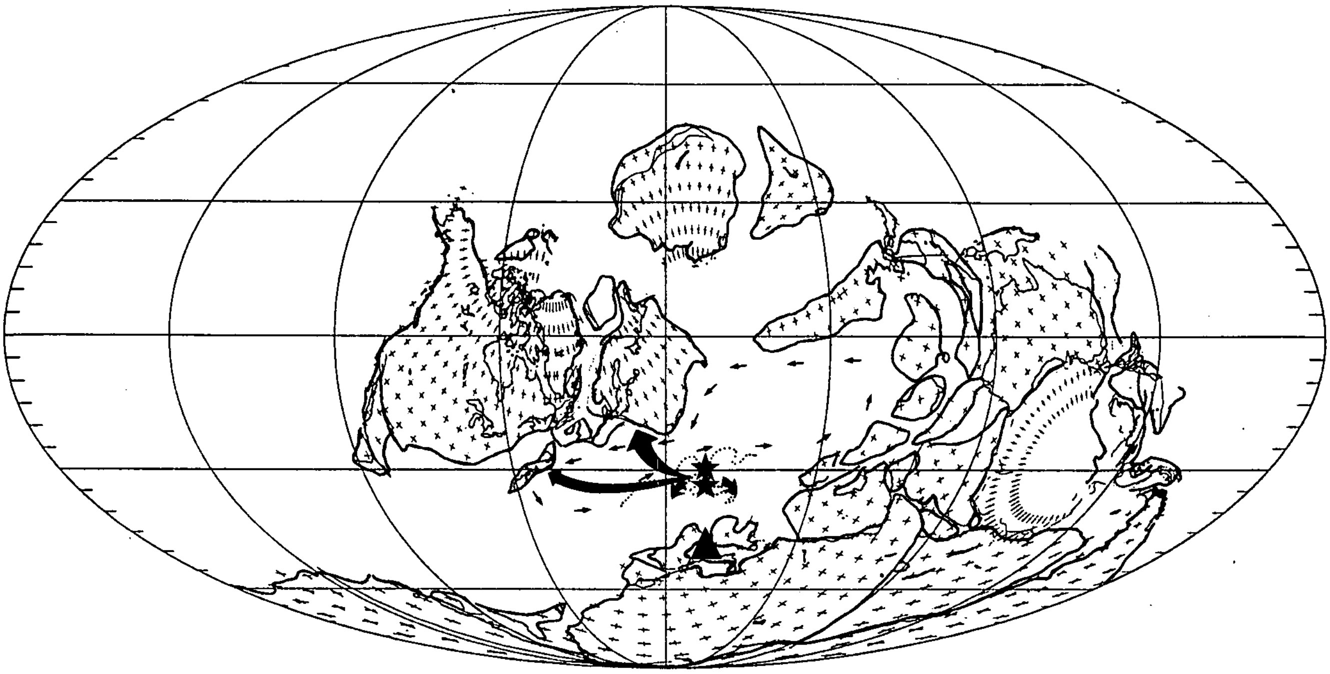

Fig. 10.
Middle Silurian (Wenlockian) paleogeography.
Triangle indicates position of the Alpine Silurian as suggested by C.R. SCOTESE & W.S. MCKERROW (1990). The author's latitudinal setting is shown by two stars for the Silurian of the Southern and Central Alps, respectively. Faunal relationships are shown by heavy arrows, the oceanic current system in the mid-European ocean by small arrows.
Modified from C.R. SCOTESE & W.S. MCKERROW (1990).

is apparent at the generic level (D. HILL, 1959; J.W. PICKETT, 1975; R.A. MCLEAN, 1977, 1985; D.L. KALJO & E. KLAAMANN, 1973; W.A. OLIVER, 1977). An explanation might be the assumed larval life-style of rugose corals so that long-living teleplanic larvae were capable of being transported by ocean currents 1000 km or more (R.S. SCHELTEMA, 1968, 1971, 1972; A.E.H. PEDDER & W.A. OLIVER, 1990).

Remarkably, rugose and tabulate corals occur abundantly in the Late Llandovery of Middle Carinthia (E. STREHL, 1962; M.F. BUCHROITHNER, 1979), in the Upper Silurian (Ludlow) of Graz (H. MENSINK, 1953; H.W. FLÜGEL & H.P. SCHÖNLAUB, 1972; F. EBNER, 1976) and are very rare in shallow water and locally superficial ooid bearing limestones in the Late Llandovery of the Graywacke Zone of Tyrol (Figs. 7,9; H. MOSTLER, 1966a, 1970; N. AL-HASANI & H. MOSTLER, 1969,). They are missing apparently in coeval strata of the Southern Alps. The inferred Silurian age of F. HERITSCH (1929) is actually Lower Devonian (Lochkovian).

We hardly believe that these coral-bearing bioclastic limestones represent the fossil counterpart of modern cold-water coral reefs such as the common *Lophelia* reefs found presently as far north as beyond the Polar Circle, in the Barents Sea and on the shelf off Mid-Norway at depths between 250 and 300 m and at water temperatures of 6°C (T. STROMGREN, 1971; N. MIKKELSEN et al., 1982). Rather they display excellent environmental indicators controlled by such physical factors like light, temperature, suspended sediment, salinity, water agitation and other agents (D.J.J. KINSMAN, 1964; T.P. SCOFFIN et al., 1989 and others). Modern and ancient buildups cannot exist beyond the "Darwin Point" of about 35° latitude (R.W. GRIGG, 1982), which is also the northernmost limit of corals in the present-day Pacific (G.W. TRIBBLE & R.H. RANDALL, 1986) and, more generally, carbonate production is light-limited to within 35° N and S (R.A. ZIEGLER et al., 1984). There is no objective reason against the idea that the Silurian of the Central Alps was positioned within these limits (Fig. 10). This conclusion was already drawn by A.J. BOUCOT (1975) and lately 1990 who subdivided the Silurian world into two main realms. The Carnic Alps correspond to the warm water North Silurian Realm characterized by limestones and rich shelly faunas in contrast to the cool and cold water high southern latitude Malvinokaffric Realm.

Conclusions

During the Silurian Period the Alpine occurrences of Silurian strata continued to shift into lower latitudes. Based on the evidence presented above the best position is estimated at approximate 30–35° southern latitude. Faunal relationships existed with southern Europe but apparently were closer to northern Europe. The affinities to southwestern Europe and northern Africa, however, decreased.

Paleomagnetic data from Gondwana seem to support the assumption of a rapid northward movement (V. BACHTADSE & J.C. BRIDEN, 1990; D.V. KENT & R. VAN DER VOO, 1990). It is associated with rifting-related volcanism through much of the Silurian. Interestingly, the Southern and Central Alps differ in two main aspects: the Silurian of the Central Alps, i.e., the development north of the Gailtal Fault, is characterized by warm water occurrences of rugose and tabulate corals in an environment which locally also contains superficial ooids. But these sequences yield only a few cephalopods as opposed to the Southern Alps with the opposite relationship suggesting, most plausibly, a farther south and slightly cooler environment. These differences may indicate two separate terranes or microcontinents prior to the Variscan deformation in the Alps.

3.4. Devonian

Fossiliferous rocks of Devonian age are among the first which have been recognized in pre-Triassic strata of the Alps in the last century. Such "classical" outcrops of Paleozoic strata comprise the surroundings of Graz, the Carnic Alps, the Graywacke Zone of Styria, Salzburg and Tyrol, Middle Carinthia and southern Burgenland (see Fig. 5). In addition, study of microfossils in the last three decades has provided many new data from scattered localities in other areas, particularly from those composed of greenschist-grade Paleozoic rocks.

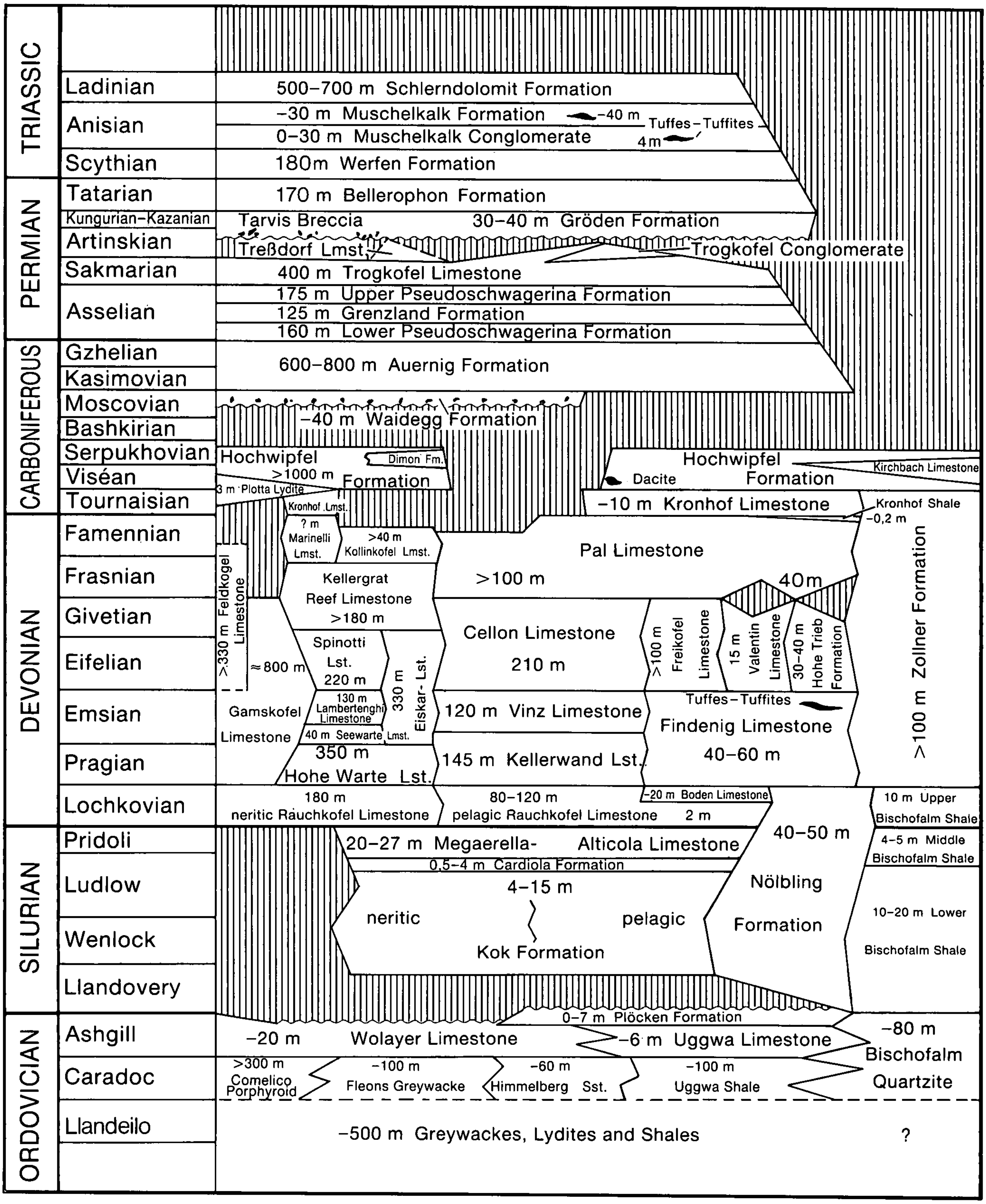

Fig. 11.
Stratigraphy of the Paleozoic sequences of the Carnic Alps.
After H.P. SCHÖNLAUB (1986), modified by L.H. KREUTZER (1991).

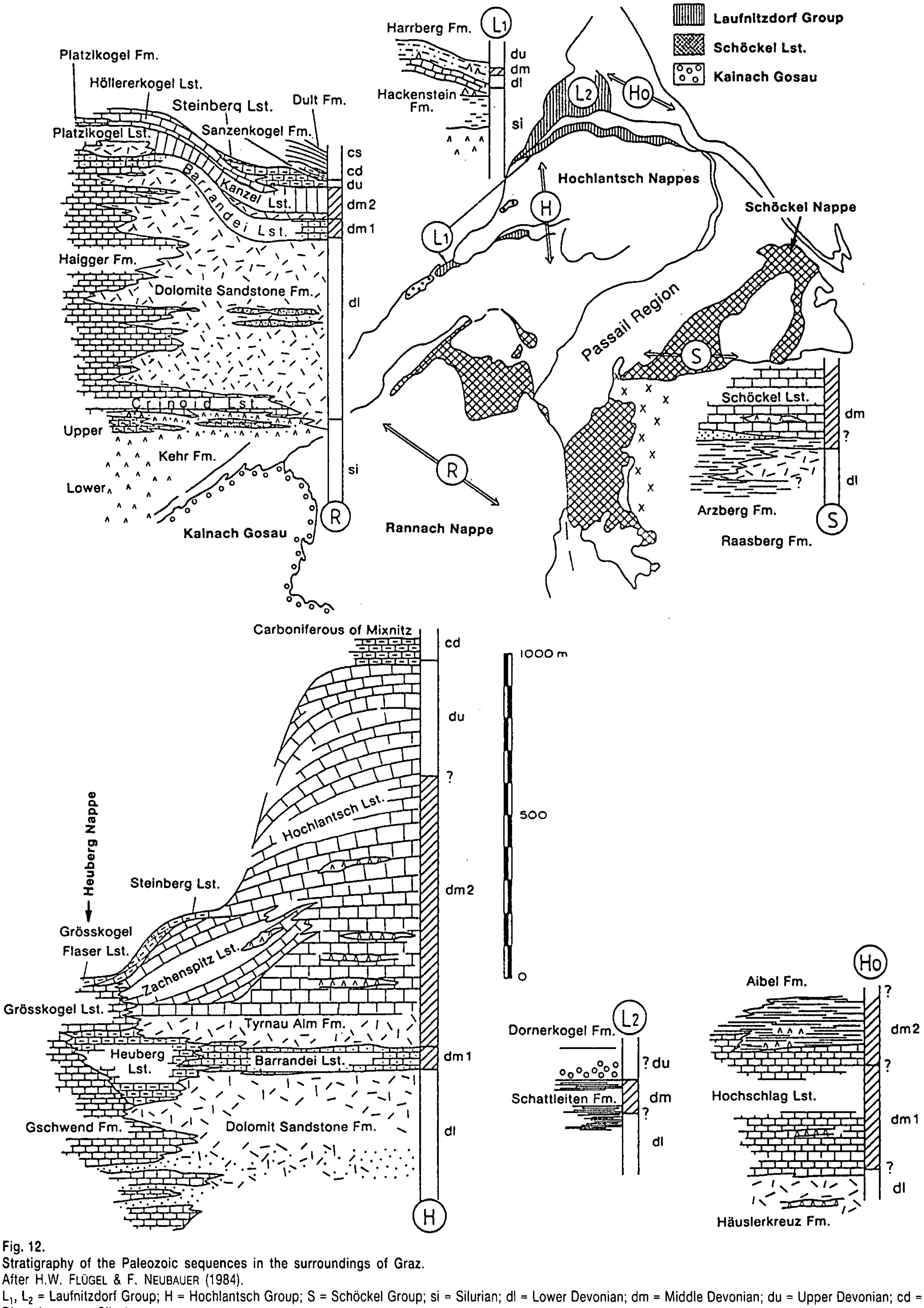

Fig. 12.
Stratigraphy of the Paleozoic sequences in the surroundings of Graz.
After H.W. Flügel & F. Neubauer (1984).
L_1, L_2 = Laufnitzdorf Group; H = Hochlantsch Group; S = Schöckel Group; si = Silurian; dl = Lower Devonian; dm = Middle Devonian; du = Upper Devonian; cd = Dinantian; cs = Silesian.

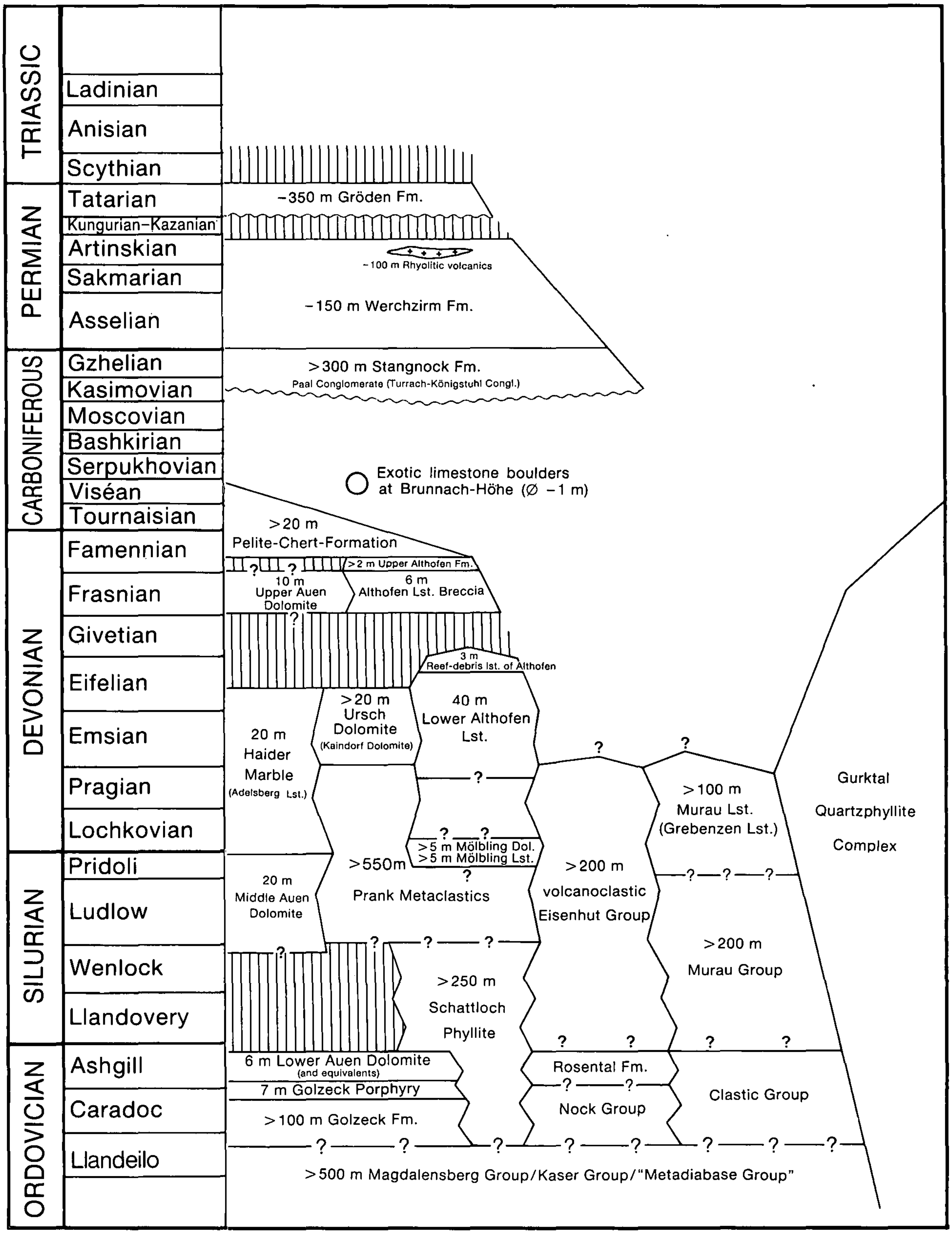

Fig. 13.
Stratigraphy of the northern part of the Gurktal Nappe.
Compiled from H.P. SCHÖNLAUB (1971a), F. NEUBAUER (1971, 1984), F. NEUBAUER & J. PISTOTNIK (1984), M.F. BUCHROITHNER (1979) and H. SCHLÖSER et al. (1990).

In the Alps the Devonian Period is characterized by abundant shelly fossils, variably thick carbonate sequences, reef development and interfingering facies ranging from coastal sediments to carbonate buildups, slope deposits, condensed pelagic cephalopod limestones to deep ocean off-shore shales (H.P. SCHÖNLAUB, 1971, 1980, 1985a; H.W. FLÜGEL & H.P. SCHÖNLAUB, 1972; T.P. BURCHETTE, 1981; L.H. KREUTZER, 1990, and others). In the Carnic Alps, for example, the ratio of thickness between shallow water limestones and contemporary cephalopod limestones is in the order of 1200 : 100 m and thus indicates differentially

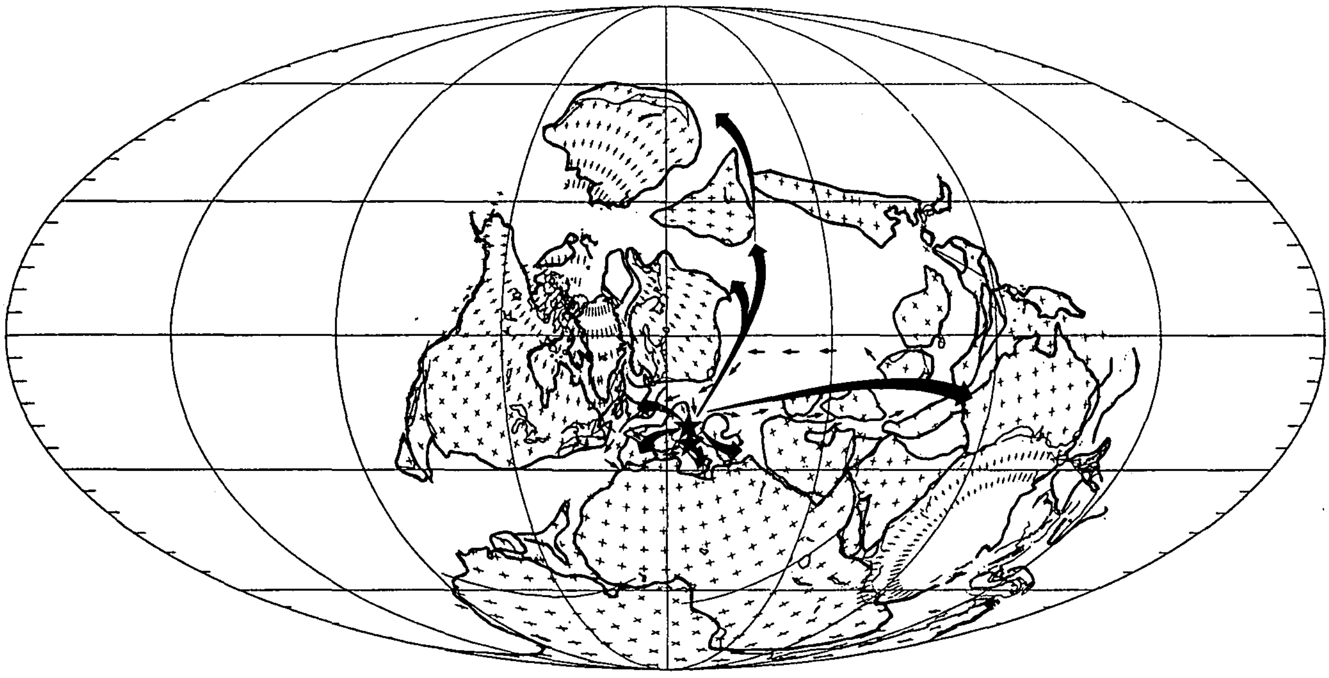

Fig. 14.
Middle Devonian paleogeography.
Two stars indicate position of the Alpine Devonian of the Southern and Central Alps, respectively, as suggested by the author in this paper. Faunal and floral relationships are shown by heavy arrows, the equatorial gyre system in the southern mid-European ocean by small arrows.
Modified from C.R. SCOTESE & W.S. MCKERROW (1990) and M.S. OCZLON (1990).

subsiding mobile basins affected by extensional tectonics (Fig. 11). Rifting-related volcanism in the Lower and Middle Devonian of the Graywacke Zone and the area near Graz, respectively, is well consistent with such a basin development (Fig. 3).

According to A.J. BOUCOT (1975, 1985, 1988) and his employment of a pangaeic paleogeography, the biogeographic pattern of the Devonian changed from a highly provincial level in the latest Early Devonian attributed to a global regression to cosmopolitanism in the Late Devonian. At the beginning of the Devonian the warm North Silurian Realm was replaced by the Old World Realm and the Eastern American Realm. The former developed from the Silurian Uralian-Cordilleran Region and from the European Province of the North Atlantic Region and can be divided into several subregions (previously named "magnafacies", according to H.K. ERBEN, 1962, 1964): Rhenish-Bohemian, Uralian, South China, Tasman-New Zealand, and Cordilleran. Similarly, the Eastern American Realm can be divided into several provinces resulting in an overall moderate level of longitudinal provincialism in a warm climate. Both Realms contrasted with the cool climate Malvinokaffric Realm which was characterized, during the Lower and Middle Devonian, by the same characteristics as during earlier periods.

In the Alps only a few groups from essentially two areas, i.e., the Carnic Alps and the surroundings of Graz, have been investigated in terms of biogeographic relationships (Figs. 11,14).

During the Lower Devonian (Lochkovian to Emsian Stages) faunas and floras showed strong affinities to both the Hercynian-Bohemian and to the Uralo-Tienshan Faunal Provinces and remarkably poor similarities with northern Africa except the Rabat area (G.K.B. ALBERTI, 1969, 1982). Such a relationship is less clearly displayed by more cosmopolitan planctic groups like graptolites, conodonts and dacryoconarids the migration of which primarily was affected by ocean currents (H. JAEGER, 1968, 1975, 1978, 1988; H.W. FLÜGEL et al., 1977; P.H. HECKEL & B.J. WITZKE, 1979; G. KLAPPER & J.G. JOHNSON, 1980; H.P. SCHÖNLAUB, 1980, 1985a; G.K.B. ALBERTI, 1985) and, more distinctly, by the benthos. For example, brachiopods from the *Karpinskia* Beds are known from the Barrandian region, the Urals (A.J. BOUCOT, 1975; A.J. BOUCOT et al., 1967; G.B. VAI, 1973, 1975), Altai and Kazakhstan (for more details see S. LATZ, 1989); similarly, corals show a strong affinity to Extra-Malvinokaffric Realms like the Urals and the Altai mountains but show no similarity to the Eastern North American Realm (A. FERRARI, 1968; G.M. KODSI, 1971; L.H. KREUTZER, 1990; A.E.H. PEDDER & W.A. OLIVER, 1990); the distinct *Hercynella*-gastropod community is typical of the Old World Realm and occurs in the Upper Koneprusy Limestone of Bohemia and also in the Urals, although the relations with both regions appear less close than had been suggested previously (R.B. JHAVERI, 1969; R.B. BLODGETT et al., 1990); finally trilobites, although to some extent endemic, represent a mixed Hercynian-Uralo-Tienshan association which exhibits only a weak affinity to northern Africa (H.K. ERBEN, 1966, 1969; G.K.B. ALBERTI, 1967, 1969, 1981; K. BANDEL, 1969; H. ALBERTI, 1978; I. ELLERMANN, 1989), and codiacean algae of the *Lancicula* Beds of P. PALLA (1966, 1967) (= *Hercynella*-Seewarte Limestone of R.B. JHAVERI, 1969) are found in Chios (Greece), Kusnetsk Basin (southern Siberia) and New South Wales in Australia. According to J. PONCET (1990) they were dispersed by subtropical ocean currents.

From the Middle and Upper Devonian only few biogeographical relevant data are yet available. They confirm the general opinion of decline of endemism and provincialism and the appearance of cosmopolites at the beginning of the Middle Devonian. This has been inferred from the distribution of ammonoids in general (M.R. HOUSE, 1971, 1973) and from the Carnic Alps (M. HOUSE & J.D. PRICE, 1980; D. KORN, 1992), trilobites (R. FEIST, 1992), brachiopods (A. FERRARI & G.B. VAI, 1973), corals (A. FERRARI, 1968; P. KÜSTER, 1987; P. KÜSTER-OEKENTORP & K. OEKENTORP, 1992) and algae, e.g., the genus *Girvanella* and the problematical algae *Renalcis* (L.H. KREUTZER, 1989; G. RANTITSCH, 1990).

The Paleozoic outcrops in the surroundings of Graz have long been famous for the rich occurrences of fossils in particular brachiopods and rugose and tabulate corals (Fig. 12); less abundant are trilobites, bivalves, gastropods and stromatoporoids (H.W. FLÜGEL, 1975a). Among many endemic species mainly of corals some are of biogeographic significance. In accord with sedimentological evidence from the underlying Dolomitsandstein-Formation (A. FENNINGER & H.-L. HOLZER, 1978) the Eifelian brachiopods from the Barrandei Formation indicate a strong Rhenish-Hercynian (i.e., neritic-pelagic) interchange, even in spite of taxonomic uncertainties, and thus immigration of Rhenish elements (H.W. FLÜGEL, 1971), while some others, e.g., the cosmopolitan genus *Zdimir*, suggests a relationship to the Ardennes, the Eifelian Hills, France, Bohemia, Urals, Siberia (Kusnetsk Basin) and Ferghana (A.J. BOUCOT & A. SIEHL, 1962). Whether or not there was a migration channel across Moravia as suggested by I. CHLUPAC (1971) and challenged by R. SCHÖNENBERG (1973) and H.W. FLÜGEL (1975a) is yet not certain. Furthermore, corals from the succeeding Givetian *Calceola* Formation seem equally to be related to the Eifelian Hills, but in addition they exhibit also some affinities to the Kusnetsk Basin of Southern Siberia and Nepal (H.W. FLÜGEL, 1971). Rather of limited biogeographic significance are, however, the rarely occurring representatives of the genus *Calceola* which is a typical Old World Realm coral (W.A. OLIVER, 1964; D. HILL & J.S. JELL, 1969; A.J. BOUCOT, 1988). Stromatoporoids too represent to a high degree cosmopolites during the Devonian (C.W. STOCK, 1990). As for corals and algae, however, they can be used as major indicators of warm temperatures of the Devonian seas (P.H. HECKEL & B.J. WITZKE, 1979). In addition to these reports the Eifelian strata of Graz contains one of the very few occurrences of an algal microflora in southern Europe. It consists of *Zeapora gracilis, Litanaia graecensis* and *Pseudopaleoporella lummatonensis* (H.W. FLÜGEL, 1959; B. HUBMANN, 1990). This flora indicates

1) a paleolatitudinal setting within the tropical belt of some 30°,
   and
2) similarities to the east, e.g., the Urals, Siberia, Australia, and to the west, e.g., the Eifelian Hills, Belgium, France and Great Britain.

Conclusions

Since the first introduction of Phanerozoic world maps by A.G. SMITH et al. (1973) and subsequently by C.R. SCOTESE et al. (1979, 1985), C.R. SCOTESE (1984, 1986) and others, the quality of the reconstructions have considerably improved. In particular this is true for the Devonian Period for which the paleogeographical reconstruction successfully has been based on a combination of paleomagnetic, faunistic and climate sensitive lithic data in recent years. The alternative approach of a pangaeic based paleogeography of A.J. BOUCOT (see A.J. BOUCOT & J. GRAY, 1979, 1983; A.J. BOUCOT, 1985, 1988, 1990) received also much merit but inevitably raised many questions and criticism.

In order to test the proposed models and to confirm the supposed paleolatitude as the major control of the spatial faunal distribution the complete data base for the Devonian of the Alps can be employed.

There is general consent that the Devonian calcareous sediments were deposited in the tropical belt within paleolatitudes of 30°S or less. Such an assumption is based on thick occurrences of carbonate buildups and associated limestones composed of typical microfacies types, fabrics and components (e.g., oncoids, coated grains, ooids), and all kinds of "guilds" (J.A. FAGERSTROM, 1987, 1988), e.g., abundant rugose and tabulate corals, massive and dendroid stromatoporoids, algae and stromatolites, suggesting warm agitated sea waters for most of the Devonian. Studies of the diagenetic environment and the cement stratigraphy closely support this inferred position (G. GALLI, 1985; L.H. KREUTZER, 1989; G. RANTITSCH, 1990). Even stronger arguments in favour of a low latitudinal setting have been expressed by A. FENNINGER & H.-L. HOLZER (1978, p. 139) who recorded tepee structures and vadose pisolites from the Dolomitsandstein Formation in the surroundings of Graz and concluded a hypersaline environment in an arid climate.

At first look it appears difficult, if not impossible that these groups should have been capable of travelling over such long distances and/or crossing the supposedly wide and deep Mid-European ocean that separated, for example, Siberia and the Urals from the Alps during the Devonian. More easily, however, migration could be achieved between other central European regions, e.g., from the Alps to Bohemia, the Eifelian Hills, the Harz Mountains, the Ardennes and England. The hazards of fauna travelling, however, have long been recognized (P.E. CLOUD, 1961) and have been discussed at length for the widely distributed Lower Paleozoic trilobites (e.g. W.T. DEAN, 1967; A.R. PALMER, 1972; J.L. CISNE, 1973; H.B. WHITTINGTON & C.P. HUGHES, 1972, 1973; H.B. WHITTINGTON, 1973; R.J. ROSS, 1975; L.R.M. COCKS & R.A. FORTEY, 1982, 1990, and others).

Amongst the first, R.J. ROSS (1975) emphasized the operation of coriolis forces in the Lower Paleozoic. Comparable to the present-day ocean circulation systems in surface waters, they caused two equatorial gyres in which organisms (trilobites) with long-lasting larval stages were caught and transported along the margins of the seas to split eventually and to continue in other directions. However, this improved circulation pattern of favourable ocean surface currents operated not only during the Cambrian and Ordovician but aided the dispersal of trilobites and of many other groups during the Devonian as well, for example conodonts (G. KLAPPER & J.G. JOHNSON, 1980), corals (A.E.H. PEDDER & W.A. OLIVER, 1990), stromatoporoids (C.W. STOCK, 1990), algae (J. PONCET, 1990) and probably many others too (A.J. BOUCOT, 1988, 1990). Strong currents may even affect the bottom sediment and produce erosion and non-deposition or reworking and accumulations of clastic sediments; such deposits have been described in modern environments as contourites (C.D. HOLLISTER & B.C. HEEZEN, 1972; J.B.P. LOVELL & D.A.V. STOW, 1981).

Independently from our study of faunal relationships between the Alps and adjacent or more distant areas for the Middle Devonian M.S. OCZLON (1990) convincingly postulated such a South Equatorial Current along the southern margin of Laurussia being deflected to the North Gondwana Current at the contact between Gondwana and Laurentia (see C.R. SCOTESE & W.S. MCKERROW, 1990). We believe that these two currents can be held responsible for the distinct exchange of faunas between Siberia, Kazakhstan, the Urals and the Alps on one side and Bohemia, Greece and Australia on the other. The surroundings of Graz may equally have been influenced by this current when it flowed through central Europe and passed the Eifelian Hills and parts of Belgium. Likewise, such a current direction might also explain the low affinity between the Alps and northern Africa during the Devonian (Fig. 14).

For the Devonian it may be speculated whether or not the surroundings of Graz were located in lower latitudes than the Southern Alps. Some evidence in favour of such an idea is indicated in climatic sensitive sediments and also in the close relationship to the Rhenish-Hercynian Province. In contrast to this development the Southern Alps represent a highly mobile subsiding basin affected by tensional tectonics throughout the Devonian. Possibly, thinning of the crust during this time is the result of the temporary southward movement of Africa relative to the South Pole which described a rapid excursion ("loop") into central Africa (see Fig. 2).

3.5. Carboniferous

The Carboniferous Period of the Alps is generally subdivided into the final Variscan series representing a Lower Carboniferous pelagic development in the Tournaisian and succeeding flysch deposits of Visean and Namurian age, and the post-Variscan transgressive cover sediments of Late Carboniferous and Permian age. Both groups of rocks are separated by the Variscan unconformity. Based on new and revised data on conodonts and fusulinids in the Southern Alps, the pre-Variscan strata were deformed between the late Namurian *Gastrioceras*-Zone and the Upper Miatchkovian of the late Middle Carboniferous in the Russian terminology (F. KAHLER, 1983; H.P. SCHÖNLAUB, unpubl.), the latter corresponding to the West European Westfalian D Substage.

From the older cycle only few biogeographically relevant data are yet available which mostly comprise cosmopolitan groups like goniatites and some pelagic trilobites. According to D. KORN (in H.P. SCHÖNLAUB et al., 1988) and D. KORN (1992) across the Devonian/Carboniferous boundary a complete succession of ammonoids occur which indicate continuous pelagic sedimentation in an open marine pelagic environment comparable to many other places in the world, e.g., Rhenish Massif, Sauerland, Moravia, Southern France or South China. Similarly, trilobites are related to those in Cornwall and North Devon as well as to the Rhenish Massif, Frankenwald, Montagne Noire, the Sudetes, Poland, the Urals, Kazakhstan and southeast China (R. FEIST, 1992, this volume). Some of these faunas are characterized by blind or reduced eyes indicating benthic forms of moderately deep waters; some, however, represent fully blind trilobites not known yet from elsewhere in the Variscan basin (G. HAHN & R. KRATZ, 1992, this volume). Nevertheless, loose relations do exist to those in Sauerland, Thuringia, Poland and England.

Floras from the Culmian Hochwipfel flysch of the Carnic Alps are of little biogeographic significance. According to H.W.J. VAN AMEROM et al. (1984) these new discoveries indicate similarities to the Erzgebirge (Chemnitz), Silesia, Thuringia, CSFR, the Black Forest, France and Scotland.

In contrast to these reports and, hence, of special interest is the so-called "Carboniferous of Nötsch", north of the Gail valley and west of Villach in Carinthia. With regard to its lithology and the rich and diversified fossil content the Carboniferous of Nötsch has long been regarded as being unique and distinct within the entire Alps. The latest Visean or, more probably, early Namurian fossil assemblage (H.P. SCHÖNLAUB, 1985b) comprises brachiopods, trilobites, gastropods, bivalves, crinoids, corals, bryozoans, foraminifera, ostracodes, plants and algae; yet, only a small part has been studied.

According to G. & R. HAHN (1973) the trilobite fauna is characterized by its special Tethyan aspect with some similarity to coeval occurrences in the Veitsch Nappe of the Graywacke Zone of Styria. Subsequently this view was rejected by G. HAHN & R. HAHN (1987) when they recovered additional trilobites showing a strong relationship with the Kohlenkalk of Belgium. They then concluded a mixing of Asiatic-Australian, i.e., Tethyan and West-European trilobites. Based on additional rich material, however, G. SCHRAUT (1990) finally emphasized a strong affinity to the Western European Kohlenkalk facies and even to North America, and less close similarities to Asia and Australia. Even ostracodes follow these suggested pathways and show affinities to the Cantabrian Mountains, the western Pyrenees, England and North America.

The rich faunal and floral association of the Carboniferous of Nötsch represents a shallow water environment characterized by full marine conditions, agitated water, penetration of light and significant nutrient supply. Temporarily, however, this environment was replaced by thick gravity flows named Badstub-Breccia which were formed as proximal inner fan or slope deposits along an active plate margin (H.P. SCHÖNLAUB, 1985; K. KRAINER & A. MOGESSIE, 1991).

Such an inferred plate margin position seems strongly corroborated by other evidence. According to E. FLÜGEL & H.P. SCHÖNLAUB (1990) in the Carboniferous of Nötsch as well as in the Hochwipfel Formation of the Southern Alps (Carnic Alps) there occur exotic limestone clasts of varying microfacies-types. They indicate a shallow carbonate water setting of an open marine and restricted shelf environment during the Visean. Presumably, this platform development existed north of the Gailtal Line and adjacent to a supposed land area. Yet, no relics of this platform have been preserved. The only records are some limestone clasts and paleoenvironmentally significant fossils such as the heterocoral *Hexaphyllia mirabilis* (DUNCAN), the algae *Pseudodonezella tenuissima* (BERCHENKO), the foraminifera *Howchinia bradyana* (HOWCHIN) and abundant conodont faunas corresponding to the *Eumorphoceras*-Stage E2 of the basal Namurian. Recently in other parts of Carinthia apparently coeval limestone clasts of boulder size were found (H. SCHLÖSER et al., 1990).

Litho- and biofacies of these exotic limestone clasts exhibit strong affinities to the Kohlenkalk facies of various parts of Europe (Belgium, France, England, Poland), but also to Hungary, the eastern and southern Carpathians, the Pyrenees, southern Spain, northern Africa, the Donets Basin and the Urals (E. POTY, 1981; H.-G. HERBIG, 1986; E. FLÜGEL & H.-G. HERBIG, 1988; F. EBNER, 1990; D. HENNINGSEN & H.-G. HERBIG, 1990; H. SCHLÖSER et al., 1990). Moreover, the supposed setting on an active continental margin and its formation through successive erosion of an accretionary wedge during a collision of two different plates reflect a remarkable coincidence between the Eastern Alps and the western part of the Mediterranean.

Besides the lowermost Carboniferous, during which the end-Devonian climate prevailed the available paleoclimatic data from the Southern Alps, the Carboniferous of Nötsch and the Veitsch Nappe of the Graywacke Zone suggest an increase of temperature and humidity during the Visean. Of particular significance is a widespread emersion that occurred in the lengthy *Scaliognathus anchoralis*-conodont-Zone, i.e., at the Tournaisian/Visean boundary prior to the deposition of transgressive cherts and the succeeding flysch deposits. It resulted in a variety of buried paleokarst features like an extensive relief and small-scale disconformities, mixed faunas, coated fissures, collapse breccias, caves with internal fillings and mineralizations which recently have been recognized in the Carnic Alps and most probably also occurred in the Graywacke Zone and the surroundings of Graz (H.P. SCHÖNLAUB, 1991).

In the Southern Alps Late Paleozoic sediments unconformably overlie the Variscan flysch and other basement rocks of varying age, i.e., different Silurian and Devonian strata (Fig. 11). According to F. KAHLER (1983), the oldest transgressive sediments are Middle Carboniferous in age and, more precisely, correspond to the *Fusulinella bocki* Zone of the Upper Miatchkovo of the Moscow Basin. This Late Paleozoic cover comprises clastic and calcareous shallow marine sediments of the Auernig Formation in the Upper Carboniferous (Kasimovian and Ghzelian Stages) followed by various Lower Permian shelf and shelf edge deposits. They represent differentially subsiding platform and outer shelf settings and are characterized by transgressive-regressive cycles that lasted from the Westfalian to the Artinskian Stage of the Lower Permian.

Upper Permian sediments rest disconformably upon the Lower Permian and its equivalents in the Dolomites, or, farther west on phyllites of the Variscan basement. They indicate a transgressive regime starting with red beds of the Gröden Formation and followed by the Bellerophon Formation of the Late Permian. This formation represents a carbonate ramp which gently dips to the southeast, but is located far east from the Permian shoreline exposed in the Dolomites of Northern Italy in the west.

Even more restricted was the extent of the sea in the Late Carboniferous. In the Upper Miatchkovo the westernmost transgressive sediments were deposited near Lake Zollner in the central Carnic Alps. From there the transgression continuously progressed in western direction to reach Forni Avoltri and the region of the Seikofel north of the Sexten Dolomites during the Upper Carboniferous.

This whole area is very close to segments of the Periadriatic Fault Zone in the Lesach and Gail Valleys, immediately in the north. The prominent fault separates the predominantly marine post-Variscan sequences of the Southern Alps from clastic terrigenous Upper Carboniferous and Permian sediments of the Central Alps (Fig. 5).

The marine post-Variscan sequences of the Southern Alps have long been famous for their abundant and highly diverse fossil groups. During the last few years the major part of the fauna and flora has been reinvestigated and new material was collected. Based upon these studies the following conclusions can be drawn (Fig. 15): fusulinids are of typical "Paleotethyan" and thus, apparently of cosmopolitan aspect showing similarities with coeval faunas in many other parts of the world, e.g., the Dinarides (Serbia, Velebit, Montenegro, Albania), the Bükk Mountains of Hungary, northern Africa (Tunis), Turkey (Anatolia), Iran (Elburs), Afghanistan, Indochina, South China, as well as to the Moscow and Donets Basins, the Urals, Ferghana, Mongolia, Pamir, Greenland, northern California and Texas (F. KAHLER, 1939, 1955, 1974, 1983; F. & G. KAHLER,

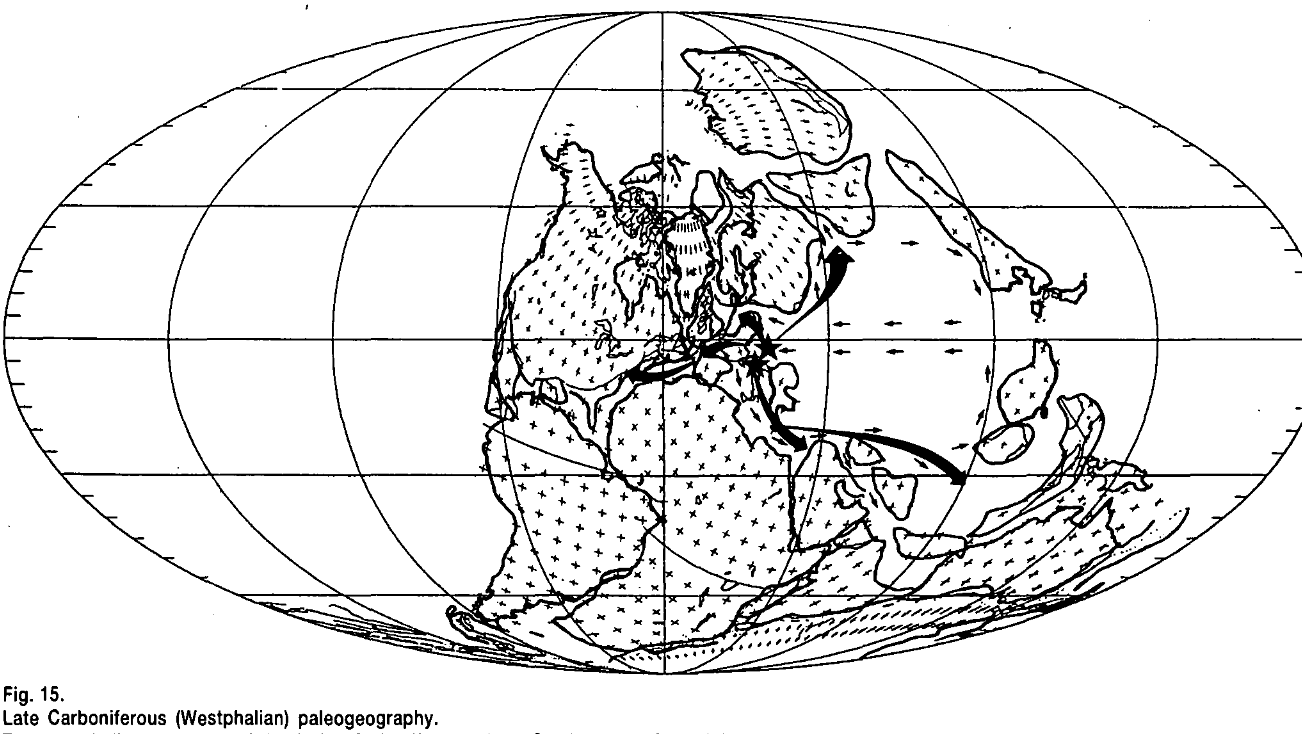

Fig. 15.
Late Carboniferous (Westphalian) paleogeography.
Two stars indicate position of the Alpine Carboniferous of the Southern and Central Alps, respectively, as suggested by the author in this paper. Faunal and floral relationships are shown by heavy arrows, the equatorial gyre system by small arrows.
Modified from C.R. SCOTESE & W.S. MCKERROW (1990).

1982); trilobites are closely related to the Karawanken Alps and the Cantabrian Mountains of northern Spain and less close to the Urals, the Moscow and Donets Basins (G. HAHN & R. HAHN, 1977, 1987; G. HAHN et al., 1989); brachiopods are equally related to these regions as they have many species in common as opposed to the weak links with North America (K.L. GAURI, 1965; A. RAMOVS, 1972; C.F. WINKLER PRINS, 1971, 1983, 1984); the ostracod fauna too suggests a close similarity with the Cantabrian Mountains of Asturia and reflects a shallow marine and low energy environment (G. RUGGIERI, 1966; B. FOHRER, 1990; G. BECKER, 1978); sphinctozoans appear well comparable to those from New Mexico, Texas and the Cantabrian Mountains (H.-W. KÜGEL, 1987); the rich coral faunas have yet not been revised but it appears that it is closely related to Eastern Europe, East Asia and China (F. HERITSCH, 1936, 1943); in addition, Lower Permian faunas are of low diversity (W. HOMANN, 1971); calcareous algae often occur as massive algal wackestones attributed to lense-shaped algal mud-mounds which consist of low diversity phylloid algae (*Epimastopora, Archaeolithophyllum, Eugonophyllum*) and the dasycladacean *Anthracoporella* and others (E. BUTTERSACK & K. BOECKELMANN, 1984; K. BOECKELMANN, 1985) which appear of no biogeographic significance.

During the last twenty years in the Eastern Alps more than 60 localities with Upper Carboniferous and Early Permian plants were studied together with revisions of old collections (for summary see Y.G. TENCHOV, 1980; A. FRITZ & M. BOERSMA, 1990; M. BOERSMA & A. FRITZ, 1990). Besides implications for the paleoclimate and for the local facies development no distinct paleofloristic-biogeographic relationships can be inferred. Yet, its main importance is the potential for correlating West-European continental with Tethyan marine sequences which has been demonstrated for a good deal from floras of the Carnic Alps.

Conclusions

As a response to the Variscan Orogeny dramatic changes affected the Alps during the Carboniferous Period. In the Southern Alps the climax of deformation occurred between the Late Namurian and the Late Westphalian Stages, or, in the Russian terminology, between the Early Bashkirian and the Middle or Late Moscovian Stages.

In the Central Alps, however, deformation and metamorphism evidently occurred earlier. This conclusion seems well founded from radiometric ages and from the transgressive molasse-type sediments within the Gurktal Nappe, the Carboniferous of Nötsch and the Veitsch Nappe of the Graywacke Zone. Moreover, we presented evidence that these scattered occurrences might represent the last remains of an originally vast shelf characterized by various platform sediments as opposed to the Southern Alps with contemporary flysch deposits.

During the Carboniferous this northern development was biogeographically more closely related to Western Europe and even to North America than to Eastern Europe or Asia. In particular, there appears a striking similarity with the Cantabrian Mountains, the western Mediterranean and to the "Kohlenkalk" regions of England, Belgium and Poland.

Consequently, we suspect that the Southern and Central Alps represented two different microplates during the Lower Carboniferous. This assumption confirms the suggested fragmentation of the predecessors of the Alps which has been concluded in this report from the analysis of older rocks and faunas. If at all and how much they were separated is presently difficult to decide. Yet, it is worth mentioning that reworked amphibolite clasts in the Badstub Breccie of the Carboniferous of Nötsch are metamorphosed tholeiitic ocean floor basalts (T. TEICH, 1982; K. KRAINER & A. MOGESSIE, 1991) suggesting an enigmatic oceanic crust in this area of the Alps some time during the Paleozoic.

Soon after collision and amalgamation of the two plates the biogeographic patterns of the Southern Alps began to match those from the former settings in the Central Alps indicating migration of faunas and floras into the newly established Southern Alps domain where they found remarkably favourable environmental conditions. F. & G. KAHLER noted already 1982 that this new sedimentary cycle started approximately at the same time as sedimentation of the marine fusulinid-bearing strata of the Cantabrian Mountains ceased. In the light of new research, however, marine rocks of Stephanian age and *Triticites* bearing Late Kasimovian strata have been recognized there (E. MARTINEZ-GARCIA & R.H. WAGNER, 1971, 1984; E. MARTINEZ-GARCIA, 1984).

Most, if not all, suggested faunal and floral migration paths of fusulinids and other groups along the northern shelf margin of the Tethys Sea, the Ural Sea and the Arctic region to North America as well as to analogous occurrences on the southern shelf appear well constrained by the revised world maps of C.R. SCOTESE & W.S. MCKERROW (1990) for the Late Carboniferous. Possibly, dispersal of planctic groups was aided by warm subequatorial gyres which were blocked and deflected at the contact between Laurussia and Gondwana (Fig. 15; A.M. ZIEGLER et al., 1981; C.A. ROSS & J.R.P. ROSS, 1985; P.H. KELLEY et al., 1990).

Potentially useful climate-sensitive sediments of Carboniferous age comprise in the Veitsch Nappe of the Graywacke Zone several tens of metres of graphite and related rocks as well as limestones and dolomites which supposedly formed in a temporary hypersaline environment (L. RATSCHBACHER, 1984). Furthermore, at many localities plants occur in rich abundances and diversity; up to a few metres thick coal seams, however, are mainly restricted to the Carnic Alps and the Gurktal Nappe. In the former they are interbedded with locally rich occurrences of corals, fusulinids, algal mud-mounds and oncoid limestones consistent with the inferred low latitudinal position close to the equator and humid climatic conditions for the Middle and Late Carboniferous of the Alps. Nonetheless, it should always be kept in mind that the O_2-concentration of the Carboniferous atmosphere is still unsettled and may have varied between 13 and 35 % of the present 21 % level (H.D. HOLLAND, 1990).

According to J.N.J. VISSER (1990), J.J. VEEVERS & C. MCPOWELL (1987), M.V. CAPUTO (1985), M.V.CAPUTO & J.C. CROWELL (1985), M.J. HAMBREY & W.B. HARLAND (1981) and A. BOUROZ et al. (1978) the continental glaciation in the Southern Hemisphere started diachronously in the Namurian A or near the Namurian A/B boundary, i.e., in the Serpukhovian, and caused a high-latitude cooling and a contemporary equatorial warming episode. Recently, however, J. LANG et al. (1991) reported glacial deposits from the Visean of

Niger suggesting an even earlier onset of the Carboniferous ice age. P.H. KELLEY et al. (1990) assumed that this climatic alteration resulted in changes of latitudinal diversity patterns coupled with migration of different organisms, for example brachiopods. The well-known "Auernig-cyclicity" in the Late Carboniferous of the Carnic Alps may certainly be explained as a glacial rebound although alternative proposals have also been made (e.g., G.M. FRIEDMAN, 1989); evidently, it was of no consequence to the biogeographic distribution of fauna and flora of that region.

At the beginning of the Carboniferous the apparent polar wander path (APWP) shows a change in the drift direction from a Devonian southward movement to a continuous and rapid northward drift of Gondwana with minimum drift rates of 10 cm/a^{-1} (Fig. 2; R. VAN DER VOO, 1988; D.E. KENT & R. VAN DER VOO, 1990; V.BACHTADSE & J.C. BRIDEN, 1990). This rapid movement of Africa over the South Pole is held responsible for the final disappearance of the Mid-European or Rheic Ocean besides several other oceans and the collision between Gondwana and Laurussia in the Namurian (e.g., W.S. MCKERROW & A.M. ZIEGLER, 1972; J. NEUGEBAUER, 1988; C.R. SCOTESE & W.S. MCKERROW, 1990). As mentioned, the collision of the Southern Alps with the central part of the Eastern Alps can also be related to this motion; it occurred, however, slightly later at the end of the Namurian or at the beginning of the Westfalian Stage, i.e., in the Bashkirian or early Moscovian.

3.6. Permian

During the Permian, the facies pattern of the Carboniferous Period continued without any recognizable breaks. As for the latter the marine facies was restricted to the Southern Alps but progressive shifting of the shoreline towards the west indicates an expanding and deepening sea as far west as the Italian Dolomites.

In the Southern Alps the marine Permian sediments are up to 1150 m thick (Fig. 11). They comprise Lower Permian shallow water limestones and clastics. They contain abundant fossils, e.g., foraminifera, fusulinids, calcisponges, corals, bryozoans, brachiopods, gastropods, bivalves, ostracodes, echinoderms, calcareous algae, plants and trace fossils suggesting a warm climate and predominantly full marine conditions on a shallow subsiding platform setting of the inner and outer shelf (E. FLÜGEL, 1974, 1980, 1981; W. BUGGISCH et al., 1976; W. BUGGISCH, 1980).

The Permian sequence starts with the Lower Pseudoschwagerina Limestone representing a protected inner shelf environment and characterized by local algal mud-mounds; followed by the Grenzland Formation of a near-shore high-energy environment in an intertidal to subtidal setting; and succeeded by the Upper Pseudoschwagerina Limestone characterized by more diversified faunal and floral associations of subtidal offshore and outer shelf areas.

The most distinct formation of the Lower Permian is the following massive and locally bedded Trogkofel Limestone the thickness of which varies between 170 and 330 m. According to E. FLÜGEL (1980, 1981, 1989) this unit represents biopelsparites and intrabiosparites with low diverse algae of the problematical type *Tubiphytes* and *Archaeolithoporella*, bryozoans, echinoderms, calcisponges, fusulinids, encrusting foraminifera and rare corals. Based on fusulinids a Sakmarian to Upper Artinskian age has been suggested for the Trogkofel buildups considering that the overlying Tressdorf and Goggau Limestones are included in this group (F. KAHLER, 1980; E. FLÜGEL, 1981).

Study of microfacies has shown that the Trogkofel Lst. represents algal/cement reefs which consist of biogenic algal crusts alternating with cement crusts of microbial origin. According to E. FLÜGEL (1981, 1989) carbonate precipitation was bacterially induced and took place at the shelf edge as opposed to contemporary bedded limestones with high diversified fossil groups which were deposited in protected and open shelf lagoonal settings with temporary high energies.

Lower Permian sediments are characterized by transgressive and regressive trends. The Goggau Lst. on top of the Trogkofel Lst. represents the final stage of this cyclicity indicating an inner shelf environment. The regression culminates in the succeeding Tarvis Breccia and is documented in freshwater algal limestones and freshwater clasts (W. BUGGISCH & E. FLÜGEL, 1980; E. FLÜGEL, 1980; E. FLÜGEL & E. FLÜGEL-KAHLER, 1980; E. FLÜGEL & S. KRAUS, 1988).

At the end of the Lower Permian, destruction of the carbonate platform resulted in the 2 to 20 m thick Tarvis Breccia. Presumably, erosion of more than 180 m thick strata, reworking and formation of this breccia occurred in the Misellina fusulinid zone of the marine realm, i.e., at or near the boundary between the Lower and Upper Rotliegend of the continental Permian, and hence may be related to the Saalic Phase (F. KAHLER, 1980).

A remarkable facies change is recognized at the base of the Middle Permian when the former carbonate dominated facies was replaced by the 0–800 m thick transgressive clastics of the Gröden Formation. They represent thick continental deposits in South Tyrol (e.g., F. MASSARI et al., 1988) and highly bioturbated marine sediments of less than 100 m thickness in the Carnic and Karawanken Alps (W. BUGGISCH, 1978).

In the Late Permian, the Gröden Formation is succeeded by the 170 m thick Bellerophon Formation. In the Carnic Alps this unit starts with basal evaporites (rauhwackes and bituminous dolomites; on the Italian side also with laminated gypsum and gypsum nodules), followed by fossiliferous dolomitic rocks and terminated by ostracod and radiolarian wackestones. According to W. BUGGISCH (1975) the occurrences in the Carnic Alps represent an intermediate position between the open marine environment to the east and coastal sabhkas in the west. In this latter area a coastal evaporitic sequence ("facies fiamazza") and a lagoonal-neritic facies ("facies badiotica") have long been known (B. ACCORDI, 1959; R. ASSERETO et al., 1973). It was finally suggested that these two facies represent cyclic evaporites of a shallow lagoon-sabhka complex (A. BOSELLINI & A.L. HARDIE, 1973).

The Permian fauna and flora show close affinities to adjacent areas in southeastern Europe (Fig. 16, Slovenia, Velebit in Croatia, Montenegro, Chios), Turkey, Iran (Elburz), Afghanistan, Oman, East Asia (Vietnam, Thailand, Japan, China), Eastern Europe and Western Asia (Moscow Basin, the Urals, Transcaucasia, Ferghana, Bashkiria) and also to Spain,

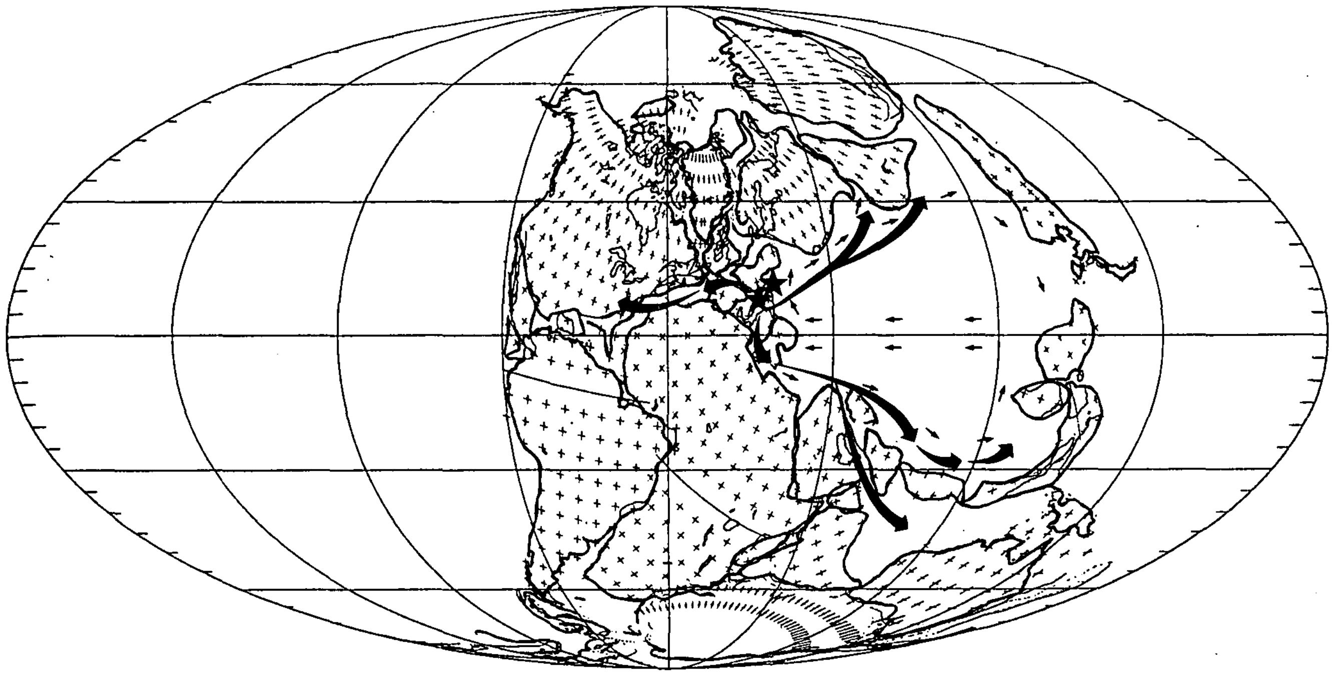

Fig. 16.
Late Permian (Kazanian) paleogeography.
Two stars indicate position of the Alpine Permian of the Southern and Central Alps, respectively, as suggested by the author in this paper. Faunal and floral relationships are shown by heavy arrows, the equatorial gyre system of the Tethys by small arrows.
Modified from C.R. SCOTESE & W.S. MCKERROW (1990).

Alaska, British Columbia, California, New Mexico, Texas, Kansas and other areas of the mid-West (F. KAHLER, 1939, 1955, 1960, 1962, 1973, 1974, 1980, 1983, 1989; E. FLÜGEL, 1966; W. HOMANN, 1972; E. FLÜGEL & E. FLÜGEL-KAHLER, 1980).

The Permian climate of the Southern Alps can be inferred from several lines of evidence: the oldest Permian evaporites (gypsum, salt, bituminous sediments) and pedogenetic calcretes occur in the Middle Permian Gröden Formation suggesting semiarid conditions for this time (R. ASSERETO et al., 1973; W. BUGGISCH, 1978; W. BUGGISCH et al., 1976; G.G. ORI & C. VENTURINI, 1981; E. FARABEGOLI & G. VIEL, 1982; C. BROGLIO LORIGA et al., 1986, 1988; M.A. CONTI et al., 1986; F. MASSARI et al., 1988). At the Bletterbach-Butterloch section of Radegno, South Tyrol, they are associated with ooids, algal crusts and foraminifera. These evaporites grossly portray the "coal belt" which is characterized by cm to dm thick allochthonous coal layers interbedded with marine faunas and evaporitic layers suggesting a hot semiarid but not arid climate (P. LEONARDI, 1948). Furthermore, R. ASSERETO et al. (1973) claimed that aridity is indicated by unaltered feldspars in sandstones, the stream network, rich occurrences of plants and tetrapod footprints as well as analysis of quartz in conglomerates (R. DAL CIN, 1965). A seasonally arid climate has also been concluded from early diagenetic Pb-, Zn-, Cu-, and U-mineralizations and the formation of dolomite, magnesite and barite indicating aggressive groundwaters (H. WOPFNER, 1984).

Towards the end of the Permian the climatic pattern was even more pronounced: due to the shallow Bellerophon Sea and a low-gradient topography, an extended evaporitic basin with high salinity developed in the Dolomites. Here anhydrite, gypsum, salt and aphanitic dolomite alternating with shale beds were deposited in sabhka-type regressive cycles (R. ASSERETO et al., 1973; A. BOSELLINI & L.A. HARDIE, 1973).

In contrast to this southern domain, north of the prominent Alpine geosuture of the Periadriatic Line continental deposits were widely deposited during the Permian, forming the base of the transgressive sequences of the Middle and Upper East Alpine tectonic units. Lack of fossils in these strata does not permit any precise age assignments nor any conclusive statements concerning paleobiogeography. Based on faunal or floral evidences only a few data are yet available from Lower Permian or uppermost Stephanian floras of Carinthia, i.e., from the localities Stangnock, Kötschach, Ulrichsberg, Christofberg, Wunderstätten and Pum, from the Kristberg Formation of the Montafon region of Vorarlberg, and from the "Perm von Zöbing" in the southeastern Bohemian Massif (F. THIEDIG & D. KLUSSMANN, 1974; W. VASICEK, 1977; Y. G. TENCHOV, 1980; H.W.J. VAN AMEROM et al., 1982; M. BOERSMA & A. FRITZ, 1990). Also, spores may be useful to date weakly metamorphosed rocks of Late Carboniferous or Lower Permian age or help to distinguish between Upper Permian and Lower Triassic sediments (W. KLAUS, 1974, 1980; E. PLANDEROVA & A. PAHR, 1983).

Tetrapod footprints found in the Laas Formation at its type locality near Kötschach, Carinthia (G. NIEDERMAYR & E. SCHERIAU-NIEDERMAYR, 1980) have a considerable potential for paleobiological and paleoenvironmental analysis and interpretations as they may provide evidence of shoreline location, paleoslope, water depth and sediment supply but also about the trackmaker (M.G. LOCKLEY, 1986). Contrary to the Southern Alps (see M.A. CONTI et al., 1975–1986, P. CEOLONI et al., 1988) the tracks which up to now have been recognized in the Austrian Alps are by far too few to contribute very many details to this subject. Other trace fossils are exceedingly rare in the Austrian Alps although bioturbation is a common feature of Permian sediments (H. PIRKL, 1961; H. MOSTLER, 1972; G. RIEHL-HERWIRSCH, 1972; G. NIEDERMAYR & E. SCHERIAU-NIEDERMAYR 1982; G. NIEDERMAYR, 1985; R. HESS, 1983; K. KRAINER, 1989).

The depositional framework of the Permian sequence north of the Periadriatic Line comprises various unfossiliferous clastic sediments of molasse-type ranging from conglomerates to fanglomerates, coarse-grained sandstones, shales, mudstones and magnesite. According to G. NIEDERMAYR (1975, 1985), E. ERKAN (1977), G. NIEDERMAYR & E. SCHERIAU-NIEDERMAYR (1982), K. KRAINER (1984, 1985), H. SYLVESTER (1989) and others, they represent ephemeral braided and meandering stream deposits of alluvial plains, in the lower part, which are progressively replaced by coastal sabhkas and intertidal clastics above. This lithology suggests an overall arid to semiarid climate with minor evaporation. The red colour resulted from primary clay minerals cemented by secondary dispersed hematite which originated from destructed Fe-minerals (K. KRAINER, 1984; H. SYLVESTER, 1989).

In the northern Alps the evaporitic series include anhydrite and gypsum interbedded with shales and sandstones (Ramsau and Radmer type, respectively, according to E. ERKAN, 1977). Based upon spores an Upper Permian age has been proposed for these rocks (W. KLAUS, 1974, 1980). They overlie a thick unfossiliferous clastic complex which apparently was deposited in a predominantly continental and temporarily aquatic environment with minor marine incursions. According to G. NIEDERMAYR et al. (1979, 1983, 1989) a saline to hypersaline environment was responsible for the formation of magnesite in playa lakes and coastal sabhkas frequently occurring in the Permian to Lower Triassic sequences of the Eastern Alps.

G. RIEHL-HERWIRSCH (1972) concluded that a humid Late Carboniferous climate with karstification was followed by semihumid conditions in the Rotliegend. Based on trace-element chemistry G. KURAT et al. (1974) even proposed a relatively dry climate and lateritic weathering during the Permian. Rich floral occurrences in interbedded red and grey-greenish sediments of the basal Werchzirm Formation of Carinthia indicate that red bed sedimentation started in the lowermost Permian (K. KRAINER, 1990). These basal clastics are followed by predominantly red beds suggesting that the change from a semiarid to an arid climate approximates the boundary between the Carboniferous and Permian Periods.

Conclusions

With regard to lithofacies and climate sensitive data the Permian sequences of the Eastern and Southern Alps reflect profound differences (Fig. 16).

The facies relationship of the Permian of the Southern Alps has recently been summarized by H. WOPFNER (1984) and by the Italian IGCP 203 Group in 1986 (Field Guide-Book on Permian and Permian-Triassic Boundary in the South-Alpine Segment of the Western Tethys, Soc. Geol. Ital., Brescia). In this synthesis data from the Bergamasc, the Etsch and the Carnia Basins are compiled.

The Bergamasc Basin consists of three troughs which are filled with up to 2000 m of Permian siliciclastic and acid volcanics of the freshwater continental Collio Formation and the equivalents of the Bozen Quartzporphyry and the Gröden Formation, respectively. Rich plant remains clearly indicate a Sakmarian to Early Artinskian age for the Collio Formation being thus partly time-equivalent with the Tregiovo Formation in the Southern Dolomites (G. CASSINIS, 1966a,b, 1986; H. MOSTLER, 1966b; H. HAUBOLD & G. KATZUNG, 1975; W. REMY & R. REMY, 1978). Apparently corresponding sediments of Lower Permian age occur in the Val Müstair of south-eastern Switzerland and are named Ruina Formation (R. TRÜMPY & R. DÖSSEGGER, 1972; R. DÖSSEGGER & W.H. MÜLLER 1976).

The Bozen Volcanics characterize the middle Etsch (Adige) Basin. The intermediate to acid ignimbrites are more than 2000 m thick and cover an area of more than 2000 km². Radiometric data yielded an age around 270 million years corresponding roughly to the Sakmarian/Artinskian boundary (P. LEONARDI, 1967; C. GHEZZO, 1967; H. MOSTLER, 1982; C. D'AMICO et al., 1980; C. D'AMICO, 1986, and others).

In the western part of the Etsch Basin the Bozen Volcanics are locally overlain by the greyish-greenish and up to 160 m thick Tregiovo Formation which in turn is succeeded by the red Gröden Formation. In other parts this latter unit rests on the Bozen Volcanics or crystalline basement rocks. The Gröden Formation has generally been regarded as a rough lateral equivalent of the Verrucano Lombardo and the Monte Mignolo Sandstone, respectively, and represents a wide spectrum of depositional features characterizing fluvial sediments. Its base is formed by the Waidbruck Conglomerate and its equivalents to the east, i.e. the Sexten and Tarvis Breccias, respectively. Following F. KAHLER (1975) most authors regard the Gröden Formation as Middle Permian in age (see above). At its base in the marine sequences a stratigraphic gap may occur but has not been ascertained yet biostratigraphically.

The distribution of climate sensitive data from the Southern Alps indicate a humid climate for the Carboniferous and Early Permian Periods. Evidently, at the beginning of the Middle Permian, this pattern changed when the dominating greyish-blackish (greenish) sediments abruptly changed to red beds, with temporarily appearing evaporites, suggesting semiarid or even arid conditions that lasted at least to the end of the Permian (for details see above).

In the Eastern Alps north of the Periadriatic Line, this change in climate may have occurred earlier in the Permian. Plant remains from the Laas and the Werchzirm Formations indicate the onset of arid conditions in the basalmost Rotliegend corresponding to the early Asselian in the marine sequence. An overall humid climate, however, prevailed throughout the Middle and Late Carboniferous.

Whether or not this different climate pattern reflects different latitudinal settings of the Southern and Central Alps, remains open. However, from the continuous northward shift of Gondwana through the Permian, it seems reasonable to assume and not merely to speculate, that a northern realm crossed the equatorial wet belt and approached an arid climatic belt earlier during the Permian than the Southern Alps located an unknown distance farther south.

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