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Palaeontological Highlights of Austria

WERNER E. PILLER[1], GUDRUN DAXNER-HÖCK[2], DARYL P. DOMNING[3], HOLGER C. FORKE[4], MATHIAS HARZHAUSER[2], BERNHARD HUBMANN[1], HEINZ A. KOLLMANN[2], JOHANNA KOVAR-EDER[2], LEOPOLD KRYSTYN[5], DORIS NAGEL[5], PETER PERVESLER[5], GERNOT RABEDER[5], REINHARD ROETZEL[6], DIETHARD SANDERS[7], HERBERT SUMMESBERGER[2]

28 Figures and 1 Table

Introduction

The oldest known fossils in Austria date back into the Ordovician. From this time on a broadly continuous fossil record is preserved up to the Holocene. Since an encyclopaedic or monographic presentation is impossible within this volume, nine case studies of different stratigraphic levels (Fig. 1) were selected to call attention to this remarkably good fossil documentation. These case studies include records on invertebrate fossils from several time slices from the Late Palaeozoic to the Miocene, as well as on vertebrates from the Miocene and Pleistocene and on plant fossils from the Devonian and Early Miocene. This selection was based on several aspects, which are of palaeoecologic, palaeobiogeographic, evolutionary, or stratigraphic importance or a combination of these disciplines.

Devonian Calcareous Green Algae

(BERNHARD HUBMANN)

Two major occurrences of Devonian calcareous green algae are discernible within Austria: in the Palaeozoic of Graz and in the Carnic Alps (Fig. 2). In both areas, the Devonian green algae appear in discrete layers often associated with accumulations of reef-building organisms (corals and stromatoporoids), or are concentrated in well-defined patches within some layers. Despite these prominent occurrences, Devonian green algae are not well-known. Most previous studies focused on the description of mound-building Carboniferous to Permian calcareous algae from the Carnic Alps (HOMANN 1972, FLÜGEL & FLÜGEL-KAHLER 1980).

In the Graz Palaeozoic nappe complex calcareous green algae are known from Emsian to Eifelian limestones within the uppermost tectonic nappe. They are well-preserved and locally make up the major part of the rock (HUBMANN 1990). Besides *Zeapora gracilis,* distinguished by large rounded cortical filaments, *Pseudolitanaia graecensis* and *Pseudopalaeoporella lummatonensis* occur (Fig. 3). *Pseudolitanaia graecensis* is built up of straight thalli containing club-shaped filaments and *Pseudopalaeoporella lummatonensis* is characterized by a typically poorly-calcified medullar zone and delicate cortical filaments.

There are two localities known with autochthonous algal occurrences in the Graz Palaeozoic. One is characterized by *Pseudopalaeoporella lummatonensis* with dispersed thalli of *Pseudolitanaia*. Contrary to all expectations, these algae are found in marly lithologies suggesting very bad environmental conditions for photoautotrophic organisms. The other locality exhibits *Zeapora* mass occurrences within carbon-rich limestones (HUBMANN 1993, 2000).

Comparable occurrences in the Carnic Alps are not known. Algae are found scattered in pure limestones, here. Austria's oldest halimedacean green algae occur in Lochkovian strata (PALLA 1966, 1967; HUBMANN 1994): *Paralitanaia carnica,* together with the typically bowl-shaped lanciculoid *Lanciculella gortanii* and *Quasilancicula wolfi* (Fig. 3). From Eifelian to Givetian limestones we know examples of *Pseudopalaeoporella lummatonensis.* The latter is the only algal taxon which is in common in both the Carnic Alps and the Graz Palaeozoic (HUBMANN & FENNINGER 1993), suggesting biogeographic relations during Middle Devonian times. The two areas are disconnected today by the most prominent fault system of the Eastern Alps, the Periadriatic Lineament, separating the Southern Alpine from the Austroalpine Zone.

The occurrence of *Pseudopalaeoporella lummatonensis* may be of importance to large-scale biogeographic correlations. Both Austrian occurrences, those of the Carnic Alps and the Graz Palaeozoic, are interpreted as remnants of shallow marine environments with algal life belonging either to the northern shelf areas of Gondwana or to peri-Gondwanan terranes. With the exception of the Cantabrian moun-

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Address of the authors

[1] Institut für Geologie und Paläontologie, Karl-Franzens-Universität Graz, Heinrichstrasse 26, A-8010 Graz, Austria
[2] Naturhistorisches Museum, Geologisch-Paläontologische Abt., Burgring 7, A-1014 Wien, Austria
[3] Laboratory of Paleobiology, Department of Anatomy, College of Medicine, Howard University, Washington, D.C. 20059, U.S.A.
[4] Forschungsinstitut Senckenberg, D-60325 Frankfurt/Main, Germany
[5] Institut für Paläontologie, Universität Wien, Geozentrum, Althanstrasse 14, A-1090 Wien, Austria
[6] Geologische Bundesanstalt, Rasumofskygasse 23, A-1031 Wien, Austria
[7] Institut für Geologie und Paläontologie, Universität Innsbruck, Innrain 52, A-6020 Innsbruck, Austria

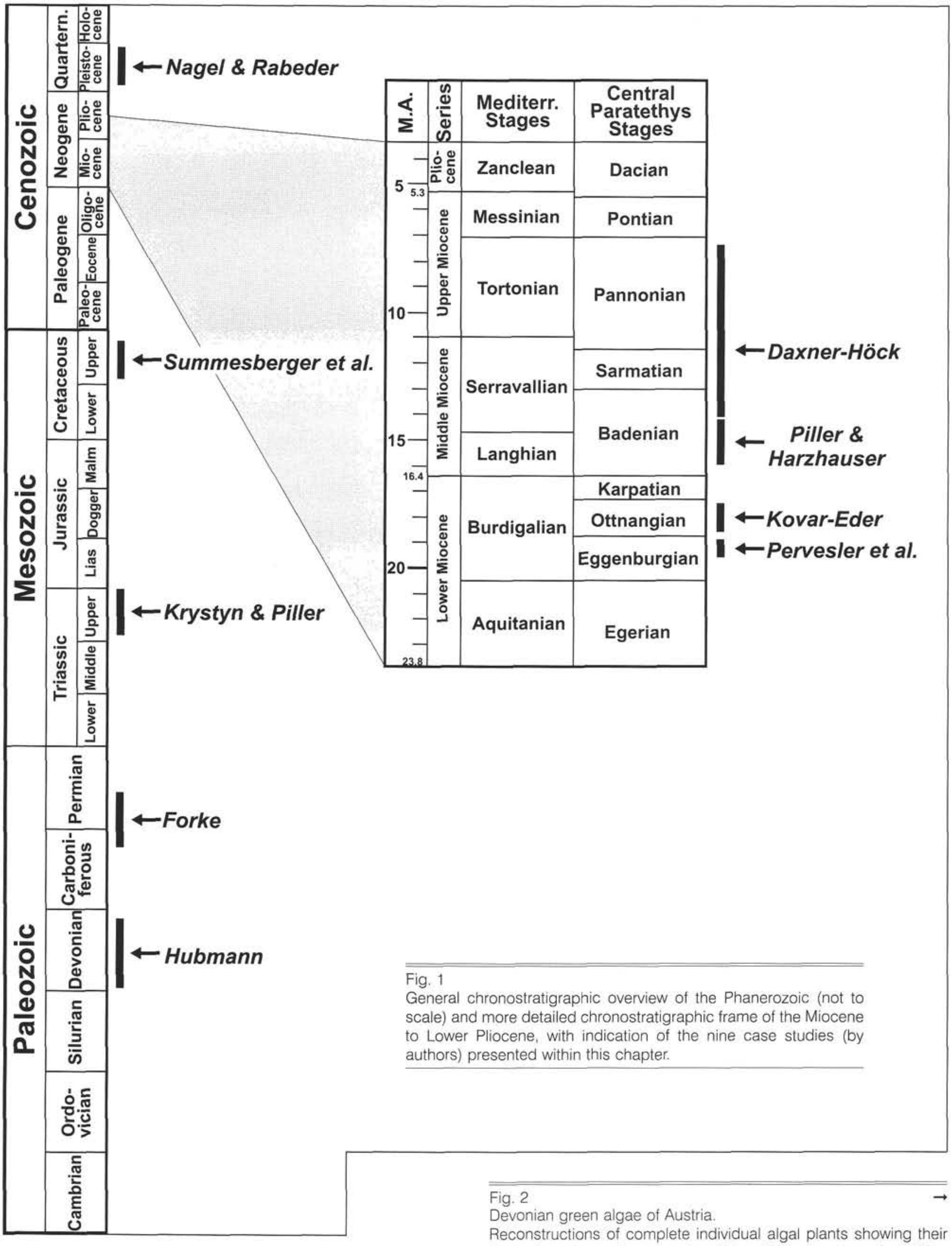
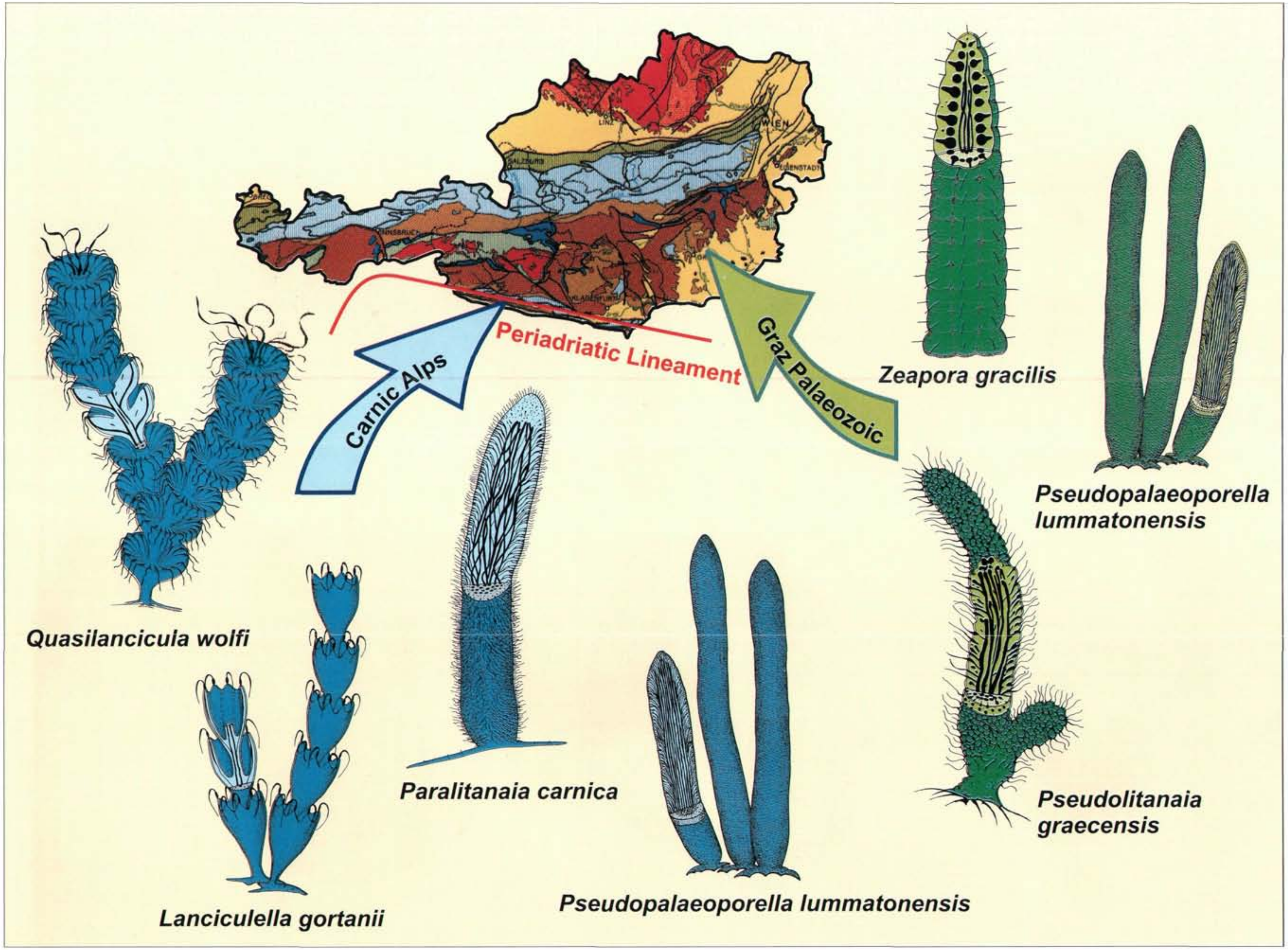


Fig. 1
General chronostratigraphic overview of the Phanerozoic (not to scale) and more detailed chronostratigraphic frame of the Miocene to Lower Pliocene, with indication of the nine case studies (by authors) presented within this chapter.

Fig. 2 →
Devonian green algae of Austria.
Reconstructions of complete individual algal plants showing their internal anatomy in cut parts. Note differences in colour. Blue coloured specimens belong to the "Southalpine Flora" of the Carnic Alps and green coloured to the "Austroalpine Flora" of the Graz Palaeozoic. Arrows point to main algal type locations on a simplified geological map of Austria.


Periadriatic Lineament
Carnic Alps
Graz Palaeozoic
Zeapora gracilis
Pseudopalaeoporella lummatonensis
Quasilancicula wolfi
Paralitanaia carnica
Pseudolitanaia graecensis
Lanciculella gortanii
Pseudopalaeoporella lummatonensis
LINZ
WIEN
SALZBURG
EISENSTADT
INNSBRUCK
KLAGENFURT

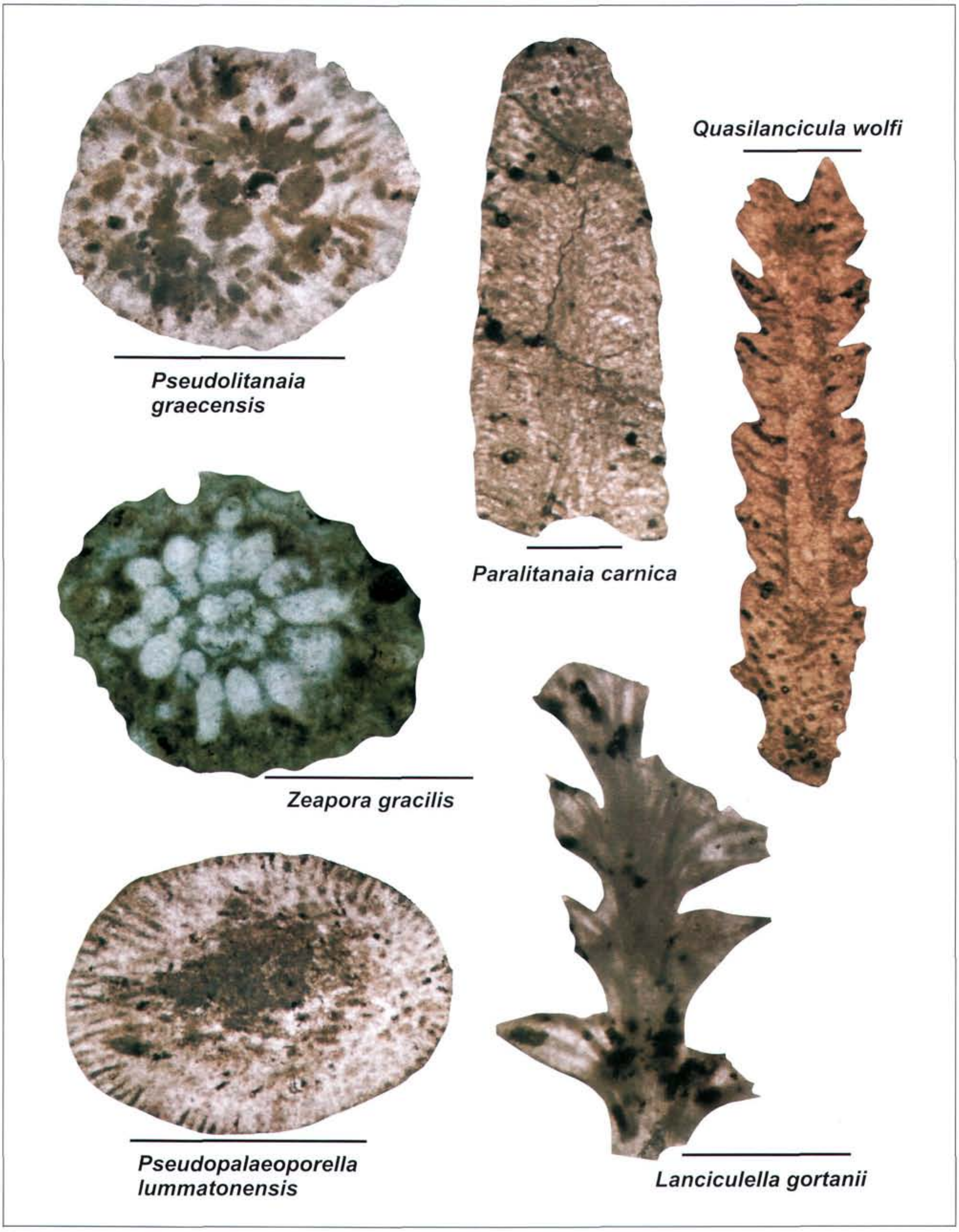


Fig. 3
Microphotographs of Austria's Devonian green algae. Scale bar: 1 mm.
Pseudolitanaia graecensis (Hubmann 1990), *Zeapora gracilis* Penecke 1894, *Pseudopalaeoporella lummatonensis* (Elliott 1961) in cross sections. Specimens originate from the Barrandei-Limestone (Eifelian) of the Graz Palaeozoic.
Paralitanaia carnica Hubmann 1994, *Quasilancicula wolfi* (Johnson 1964), *Lanciculella gortanii* (Palla 1966) in longitudinal sections. Specimens originate from the Rauchkofel-Limestone (Lochkovian) of the Carnic Alps.

tains, several other findings of *Pseudopalaeoporella lummatonensis* belong to similar environments at the northern margin of the Rheic Ocean (i.e., Rhenohercynian Zone, Russian platform). This suggests that the depositional basins of the Carnic Alps and the Graz Palaeozoic were interconnected, and implies a biogeographic association of North Gondwana with the ancient northern hemisphere during the Devonian.

Late Palaeozoic Fusulinaceans from the Carnic Alps (HOLGER C. FORKE)

Soon after the Variscan orogeny the eastern part of the Southern Alps was flooded by a shallow, tropical sea. Following this transgression a group of larger benthic foraminifera, the fusulinaceans, colonized the area. They flourished and rapidly evolved in this westernmost part of the Palaeotethys during the Late Carboniferous and Early Permian, some of them reaching a large size (up to 3 cm in length). At the end of the Early Permian tectonic movements led to a regression of the sea and it was only during the Late Permian that the fusulinaceans had a short comeback in the Southern Alps before they died out completely close to the P/T – boundary.

Their rapid evolution, wide distribution and frequency in the shelf sediments of the Late Palaeozoic make the fusulinaceans a preferential group for biostratigraphic subdivisions. The distinct palaeobiogeographic distribution patterns of families and genera help to improve plate tectonic reconstruction during the Carboniferous and Permian.

Due to the well-preserved and rich fossil fauna, the fusulinaceans of the Carnic Alps were already objects of investigation in the last century. Starting with the first discovery by SUESS (1870), brief descriptions given by STACHE (1874) and GORTANI (1906) followed and a classical monograph was written by SCHELLWIEN (1898). Later on, the study of fusulinaceans of the Carnic Alps was intimately connected with the names of Franz and Gustava Kahler, documented in their more than 60 years continuous work (for full references, see FLÜGEL & MÖRTL 1997). They were the first to describe the foraminifers from measured stratigraphic sections. They elaborated a biozonal scheme for the Late Palaeozoic sediments of the Carnic Alps (KAHLER 1986) and tried to correlate them with fusulinacean faunas of Middle Asia, the Southern Urals and the Donets basin (KAHLER 1939, 1974, 1984, 1992).

Palaeobiology, Palecology

The fusulinaceans are characterized by a multilayered, microgranular wall and a commonly planispirally involute arrangement of chambers. The wall is composed of equidimensional, subangular grains of calcite and seems to be rather secreted than agglutinated (GREEN et al. 1980; HAGEMANN & KAESLER 1998). The test shape is variably discoidal or globular, but predominantly spindle-shaped (fusiform). Their external structures are rather poor and uniform. Axial, sagittal and sometimes tangential sections are necessary to study their internal features, which are essential for the determination of taxa.

The life cycle of the fusulinaceans is still not well understood, but megalospheric forms predominate in most genera. Few microspheric specimens are reported in some genera, characterized by their skew-coiled inner volutions.

The ecological requirements are difficult to assess, because the fusulinaceans are exclusively Palaeozoic in age. Comparisons with Recent foraminifers like the alveolinids, having similar size and shape, can be misleading. The possible mode of life is deduced from accompanied facies analysis. Different groups within the fusulinaceans can be related to various environments ranging from clastic influenced near shore habitats to lagoonal, outer shelf or biohermal facies types (e.g., ROSS 1969). From these data, an epibenthic life in shallow water is inferred and a symbiosis with algae is discussed (ROSS 1972).

Biostratigraphy

In the Late Palaeozoic sediments of the Southern Alps the fusulinaceans take the leading role as index fossils for biostratigraphy, because other important groups, like conodonts or ammonoids are rare or absent. Furthermore, some large and characteristic fusulinaceans can be easily distinguished with a hand lens in the field, serving as a powerful tool for mapping geologists.

The biostratigraphic subdivision of the sediments in the Carnic Alps is based on three major intervals recognizable in the evolution of the family Schwagerinidae (Fig. 4). The phylogenetic lineage from *Protriticites*→*Montiparus*→*Rauserites* (characterized by the developing keriothecal wall structure, the gradual loss of tectoria and increasing size of the test) and their coexistence with other fusulinacean genera enables us to establish several faunal assemblages in the lower part of the Auernig Group (DAVYDOV & KRAINER 1999, FORKE & SAMANKASSOU 2000). The upper part of the Auernig Group and the lower part of the Rattendorf Group (Lower *"Pseudoschwagerina"* Limestone, LPL) are dominated by large schwagerinids with irregularly folded septa belonging to the genus *Daixina*. Their test shape tends to change from elongated fusiform species in the Auernig Group to inflated, almost globular species in the LPL, separated as subgenus *Daixina (Bosbytauella)*. Additionally, the first appearance of species of the *Rugosofusulina stabilis* group, of the genera *Rugosochusenella* and *"Occidentoschwagerina"* is characteristic for the LPL (Figs. 4, 5) (KAHLER & KRAINER 1993, FORKE et al. 1998). These genera become widespread in the third interval, and are accompanied by a peculiar fauna of highly inflated Schwagerinidae, probably belonging to several independent lineages (Figs. 4, 6). This third interval comprises the Grenzland Fm., Upper *"Pseudoschwagerina"* Limestone and Trogkofel Limestone.

During the latest Carboniferous and Early Permian (Rattendorf Group) the fusulinaceans underwent a rapid diversification and occupied different ecological niches. Careful examination of all stratigraphic horizons within the sections are necessary to obtain insight into the whole fossil fauna and to establish a refined biozonal scheme. Several faunal assemblages of the three intervals are closely related to specific facies types and the appearance of species and genera then merely depends on changes of the depositional environment.

The next major step in the evolution of the fusulinaceans, with the first appearance of ancestral and early representa-

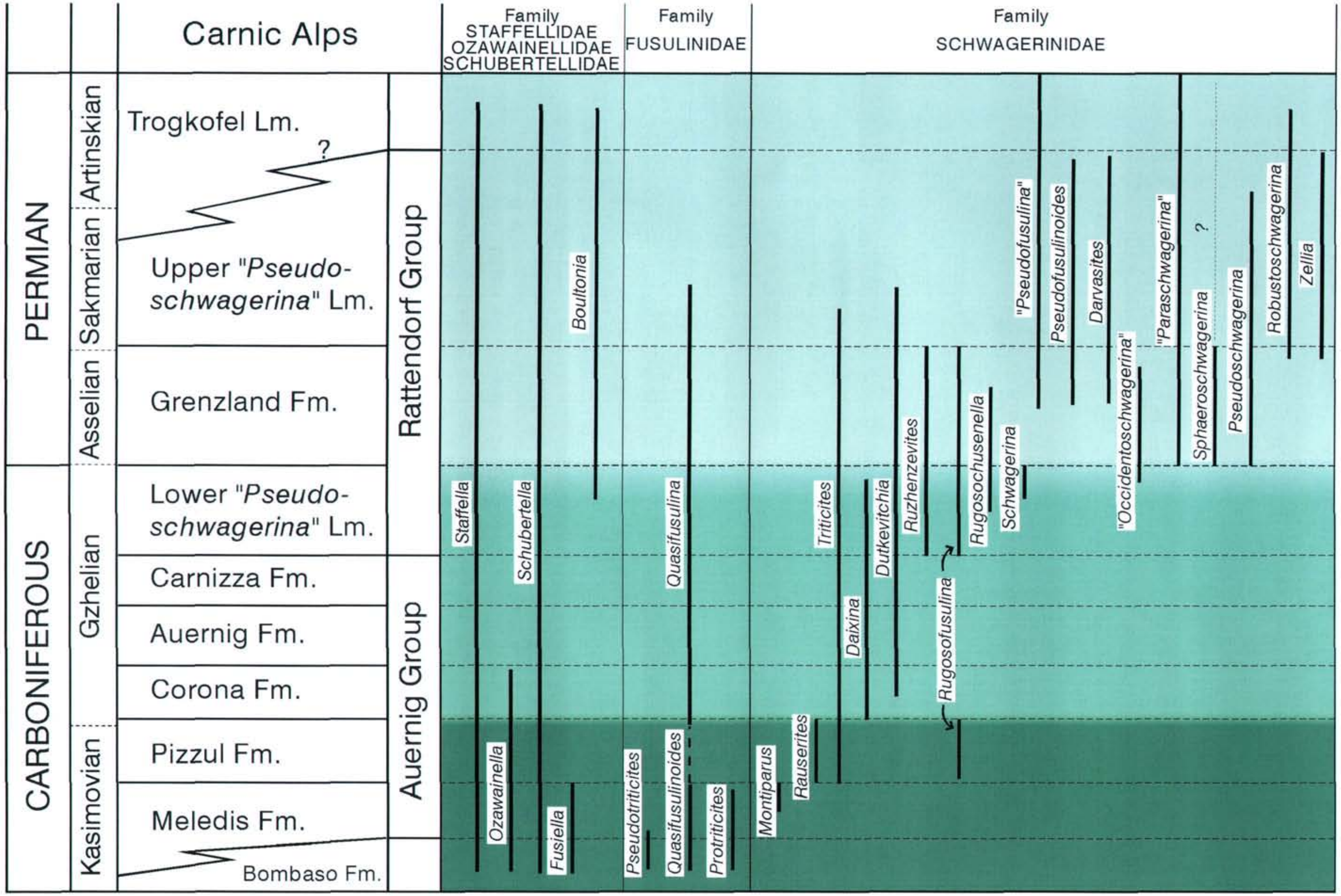


Fig. 4
Ranges of fusulinacean genera in the Upper Carboniferous to Lower Permian sediments of the Carnic Alps, Austria/Italy.

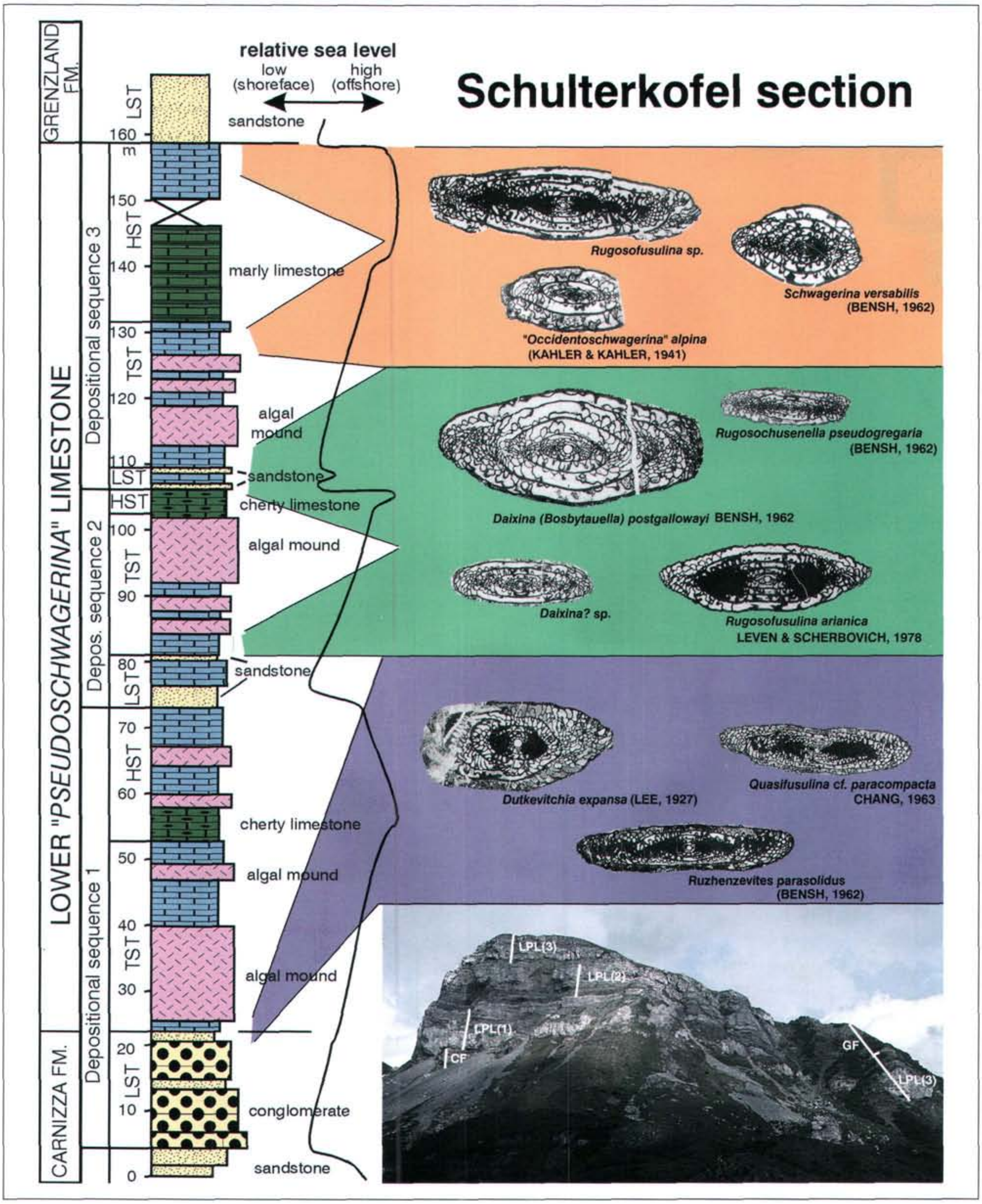


Fig. 5
Distribution of fusulinacean assemblages in the Lower *"Pseudoschwagerina"* Limestone of the Schulterkofel section, Carnic Alps, Austria/Italy (data from Forke et al. 1998). HST: highstand systems tract; TST: transgressive systems tract; LST: lowstand systems tract.

tives of the verbeekinid family, can only be traced in the Southern Alps in deposits of isolated outcrops along the Italian border (Goggau Limestone) and boreholes of the Adriatic Sea (Sartorio & Rozza 1991).

Palaeogeography

During the Late Carboniferous and Early Permian several palaeobiogeographic provinces developed, depending on how geographic or palaeoclimatic barriers evolved through

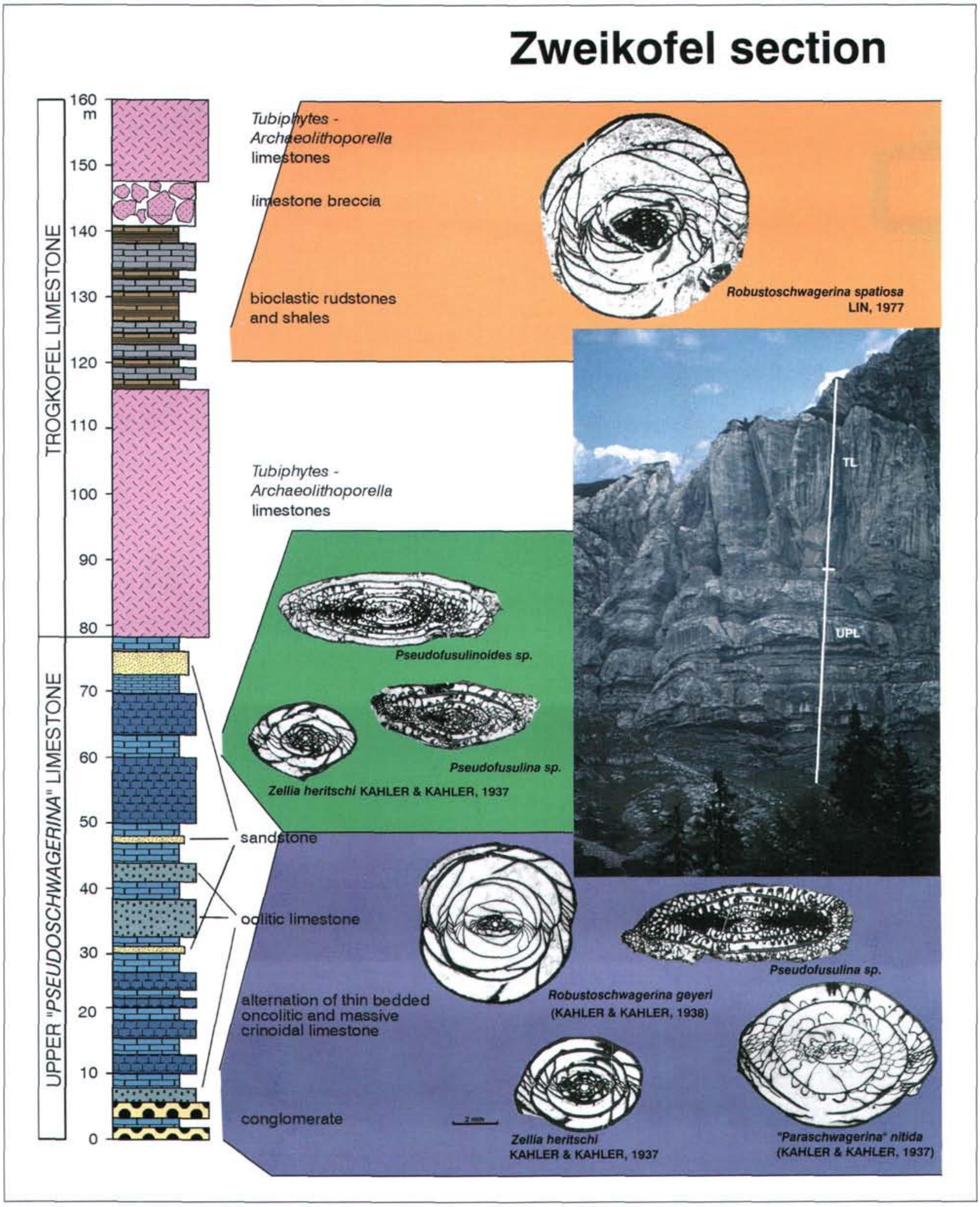


Fig. 6
Distribution of fusulinacean assemblages in the Upper „*Pseudoschwagerina*" Limestone and Trogkofel Limestone of the Zweikofel section, Carnic Alps, Austria.

this time (Fig. 7). The most extensive and complex one is the Palaeotethys Province. The Franklinian and Uralian Province stretches along the western, northern and eastern shelf of the Euramerican craton and is connected with the Palaeotethys Province along the Pre-Urals trough. The third is the Midcontinent-Andean Province, formed by the southern part of North America and the northern parts of South America. A fourth province encloses some displaced ter-

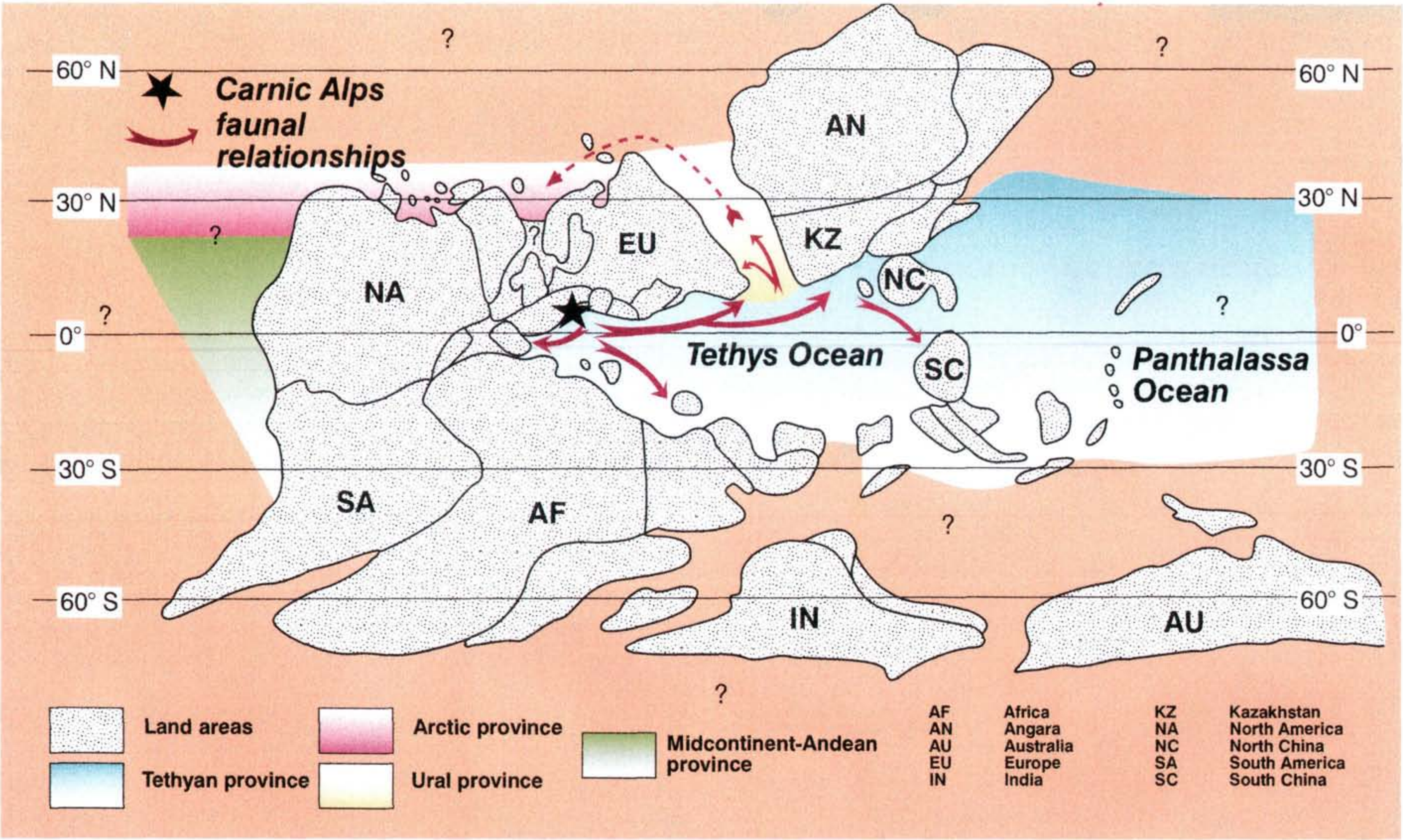


Fig. 7
Palaeogeography of the Late Carboniferous and faunal relationships of fusulinaceans from the Carnic Alps, Austria/Italy.

ranes along western North America, probably located somewhere within Panthalassa during the Late Palaeozoic (ROSS 1967).

The Carnic Alps were situated in the westernmost part of the Palaeotethys Province. The fusulinacean fauna were located in the lower part of the Late Carboniferous strata (Kasimovian) and are closely related to the fauna of the Cantabrian Mountains and Middle Asia (VILLA et al. in press) and, to a lesser degree, also to the fauna of the Russian Platform. During the Gzhelian and Asselian widespread faunas occur, which migrated up to the Northern Urals and Spitsbergen and perhaps even to North America. During the Sakmarian the faunal connections with the Urals ceased. This could have been caused either by the closure of the Pre-Urals trough in the south or by the northward shift of Pangaea. The migration of the fusulinacean faunas from and to the Carnic Alps then becomes restricted to the Palaeotethys.

Austria as the World Famous Window to Triassic Tropical Sealife

(LEOPOLD KRYSTYN, WERNER E. PILLER)

Parallel to the collision of the two landmasses of Gondwana and Laurasia in Late Palaeozoic time the Tethys ocean was born as a palaeogeographic, palaeoclimatic and especially palaeobiogeographic entity. When introducing this name in 1893, the great Austrian genius of geology E. SUESS referred primarily to Neumayr's ideas on the "Centrales Mittelmeer" (Central Mediterranean Sea). But one of the major arguments for the Tethys was the astonishing similarity between Austrian and Himalayan Triassic ammonite faunas. However, what was then believed as a continuous oceanic realm between Gondwana and Laurasia from the Palaeozoic till the late Mesozoic is now seen in a very different way. The Permo-Triassic Tethys alone has a remarkable and, for the non-specialised reader, confusing plate tectonic history. Within its proper limits, a so-called Neotethys ocean was created at the expense of the Palaeotethyan one (Fig. 8). New seafloor spreading south of the northdrifting Gondwana-fragmented Cimmerian blocks led to the subduction of the Palaeotethys ocean beneath Laurasia (ŞENGÖR 1984, STAMPFLI et al. 1991). Two fundamentally different Triassic Tethyan margins are the important result of this tectonic history, a narrow active margin to the north and northeast, respectively (= A of Fig. 8) and a wide passive one along the southern and western shore (= P of Fig. 8). According to currently popular reconstructions (DERCOURT et al. 1993, BESSE et al. 1998), the Neotethys ocean extended from less than 25° south of the equator to about 30° north. It had an elongated shape of more than 10,000 km length and about 3,000 km width. During the Triassic, the sea-level reached an all-time low and the earth is generally recognised as having had a warm and extremely arid climate indicated by the extensive deposition of evaporites far from the equator. Uniform tropical conditions therefore prevailed in the Tethys ocean with 25-30 °C sea surface temperatures. Bottom water temperatures must have been well above 10 °C, if the assumption of an island barrier diminishing bottom water exchange between Tethys and Panthalassa ocean is correct. All these points may explain the high degree of faunal similarity, as well as of biotic diversity

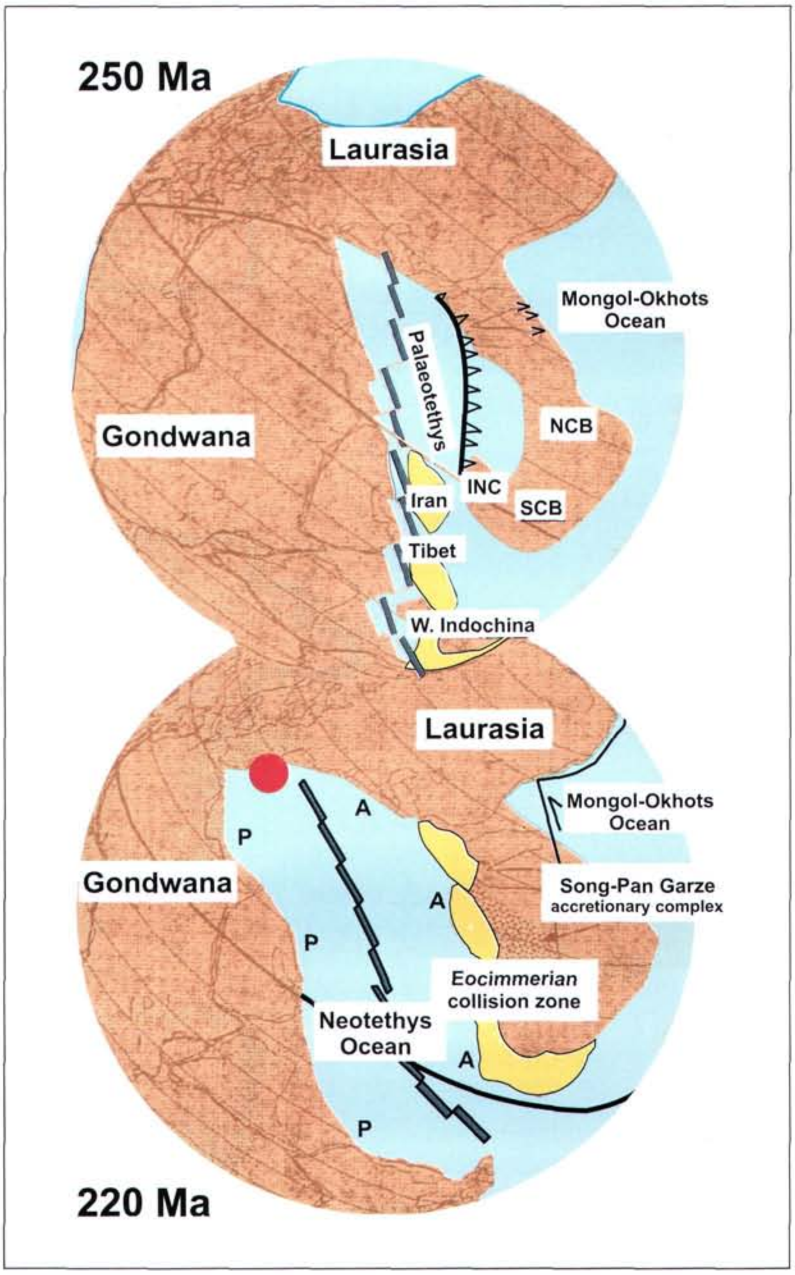


Fig. 8
Palaeogeography of the Tethys during the time slices 250 Million years and 220 Million years b. p. (A = active margin of the Neotethys, P = passive margin of the Neotethys, INC = Indochina block, NCB = North China Block, SCB = South China Block, red dot = approximate position of the Northern Calcareous Alps).

throughout the Tethys, both in the shallow water reef, as well as the pelagic (Hallstatt) environments.

Austria's Northern Calcareous Alps together with the Southern Alps and the Dinarids formed an up to 300 km wide and approximately 500 km long shelf strip at the western Tethys end (red spot of Fig. 8). Along this, as well as other parts of the Tethyan passive margin, belts of marine sedimentation were arranged in a characteristic shore-parallel fashion. They are illustrated below by classical Upper Triassic Alpine sedimentary environments (Fig. 9) and, in more detail, in MANDL (this volume). The near-shore zone was the **Keuper** belt, which served as the deposition site of hypersaline or extreme shallow marine siliciclastics. Seaward followed broad **Dachstein carbonate platforms** flanked by reefs towards open shelf basins. The Dachstein reefs produced large masses of skeletal and non-skeletal carbonate detritus, which were deposited mostly along the platform margins and on the attached basin floors. Further offshore only a small amount of periplatform sediments (e.g., Gosausee Lmst. in Fig. 9) reached the pelagic **Hallstatt facies** belt. The latter is now generally regarded as evidence for the contiguity of an ocean and is used as a tool for delineating the Gondwanian margin towards the deep sea of the Tethys.

Both Dachstein and Hallstatt "formations" (and facies) were established in Austria by the mid-1850s, and since then the Austrian Calcareous Alps have been and are still the classical study site of those facies belts (comprehensive bibliography in TOLLMANN 1976, 1985; FLÜGEL & FLÜGEL-KAHLER 1992, MANDL this volume). The type area of Dachstein and Hallstatt "formations" is the Salzkammergut, a mountainous lake terrain with a landscape of scenic beauty located in the Northern Calcareous Alps to the southeast of Salzburg.

The study of Triassic fossils of Austria goes back roughly 200 years, with the main research epoch during the second half of the 19th century. Between 1840 and 1930 F. v. Hauer (1822-1899), E. v. Mojsisovics (1839-1907), A. Bittner (1850-1902), F. Frech (1861-1917), C. Diener (1862-1928) and G. Arthaber (1864-1943) monographed thousands of invertebrate species from the reefal and the pelagic facies belt now known to occur all along the shelves of the Tethys ocean.

Upper Triassic Reefs and platforms – Bahamian analogues

Particularly in the Norian, the huge carbonate platforms represent a fossil counterpart to the modern Bahamian carbonate system. The bedded Dachstein Limestone together with the Hauptdolomite make up the majority of the extensive carbonate plateaus of the Northern Calcareous Alps, reaching to more than 2,000 m in thickness (compare to MANDL, this volume). These units reflect a variety of shallow water facies (ooid ridges, oolithic facies, grapestone facies, foraminiferan and algal facies, mud facies, pellet mud facies: PILLER 1976, HOHENEGGER & PILLER 1975, DULLO 1980) changing laterally into muddy tidal flats with the typical "loferites" (first described from the bedded Dachstein limestone: FISCHER 1964) and supratidal areas with lateritic palaeosols. The frequently regular vertical arrangement of these deposits led to the formation of the well-known "Lofer cyclothem" (FISCHER 1964; recent review in ENOS & SAMANKASSOU 1998). The most characteristic macroinvertebrates in these shallow subtidal environments are mass occurrences of megalodontid and dicerocardiid bivalves – frequently in live position.

In many places the extensive carbonate platforms are framed by reef systems (e.g., Hoher Göll: ZANKL 1969; Gosaukamm: WURM 1982; Hochkönig: SATTERLEY 1994). Contrary to steep modern Bahamian shelf edges, the margins represent a ramp geometry. Areas between reefs are characterized by ooid shoals with bars and bioclastic sediments. The reefs are mainly preserved as accumulations of allochthonous or subautochthonous reef blocks or rubble of reef biota. For the first time in earth history, scleractinian corals make up an important part of the former reef framework, however, sponges are even more dominant in many localities (KIESSLING et al. 1999). Besides these dominant biota a great diversity of reef dwellers like foraminifera, molluscs, brachiopods, echinoids, and solenoporacean algae occur; the major representatives of the binder guild are microbial mats.

In the Late Norian – Rhaetian, concurrent with the formation of siliciclastic intraplatform Kössen basins (Fig. 9), the carbonate platforms open and are widely covered by coral (*Retiophyllia* div. sp.) biostromes and in some localities mud mounds and smaller reefs occur (SCHÄFER 1979, SENOWBARI-DARYAN 1980, BERNECKER et al. 1999). The most famous (textbook) examples are the Steinplatte near Waidring (Fig. 10), representing, however, a rather complicated setting (OHLEN 1959, PILLER 1981, STANTON & FLÜGEL 1989), and the reef in Adnet near Salzburg (BERNECKER et al. 1999). With these Rhaetian buildups the first scleractinian dominated reefs in earth history were created. Parallel to the formation of the terrigenous Kössen basins, the Zlambach marls were deposited within the Hallstatt facies (Fig. 9). Excellent preservation of allochthonous reef biota occurs within these marls (e.g., RONIEWICZ 1989).

Hallstatt facies

The Hallstatt facies of Austria consists mostly of red, subordinately also whitish to grey bedded wackestones rich in filaments (juvenile shells of pelagic bivalves) and echinoderms (microcrinoids). It accumulated a thickness of 100 m with a mean sedimentation rate of 3 m per million years (Ma) over a period of 35 Ma, from Middle to Late Triassic. This "normal" type of Hallstatt limestone deposition is widespread and remarkably poor in megafauna, especially cephalopods. Biostratigraphy is based on frequently occurring conodonts and many Triassic conodont taxa originated from it (HUCKRIEDE 1958, MOSHER 1968). Rich cephalopod faunas usually dominated by ammonites are found in another type of Hallstatt limestone. It consists of red bioclastic limestone layers that are only centimetres thin and laterally often discontinuous with corroded and Fe-Mn-oxid coated surfaces. Most of the frequent cephalopod shells are fragmented, but the rare complete ones are excellently preserved and due to their thin black Mn-coating, often extractable in nearly perfect condition. As long as sediment accumulation is not below 10-20 cm per Ma, this limestones may record a sequence of several ammonite zones in less than one meter thickness still without stratigraphic condensation (KRYSTYN 1991). This is the famous fossil-rich Hallstatt facies known from many Alpine mountain chains between

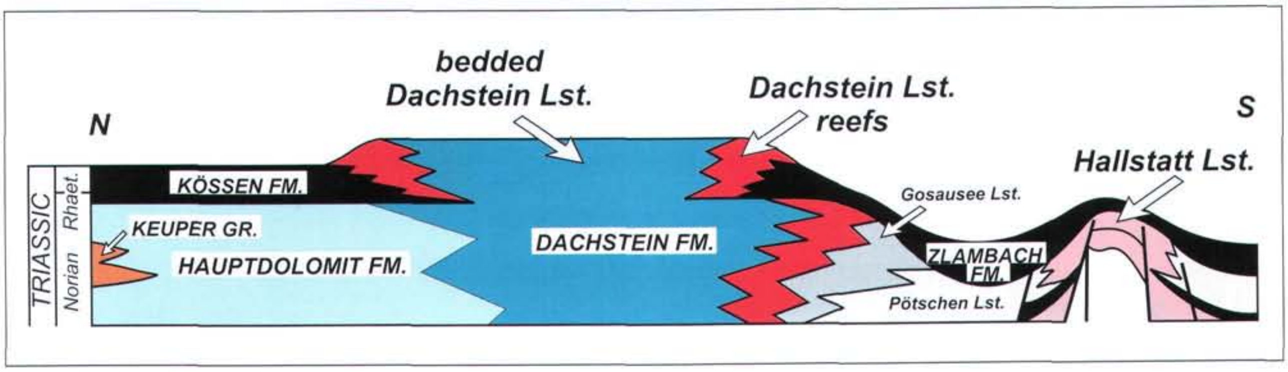
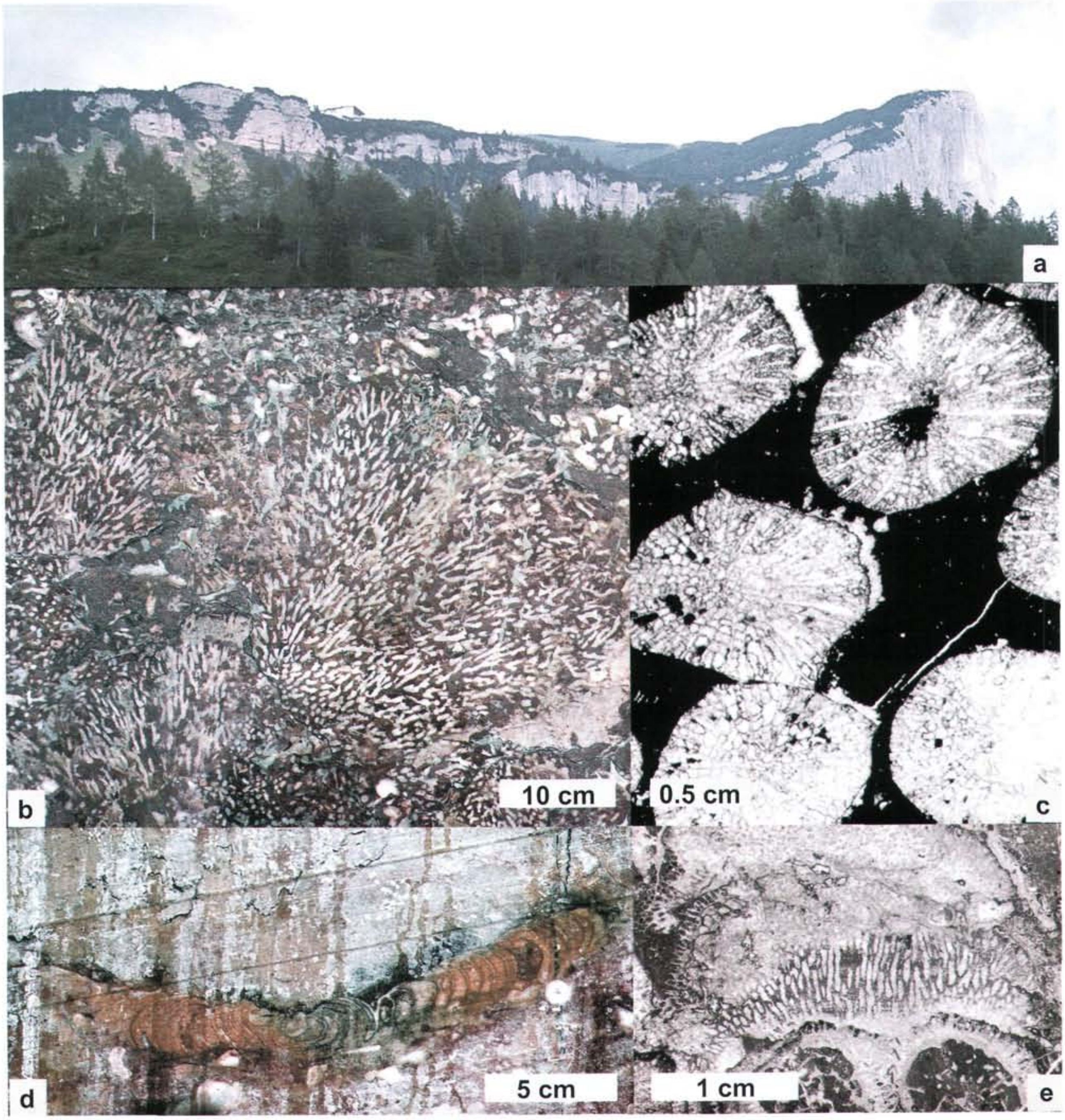


Fig. 9
Schematic Upper Triassic (Norian-Rhaetian) facies reconstruction of the Northern Calcareous Alps (after Mandl this volume).



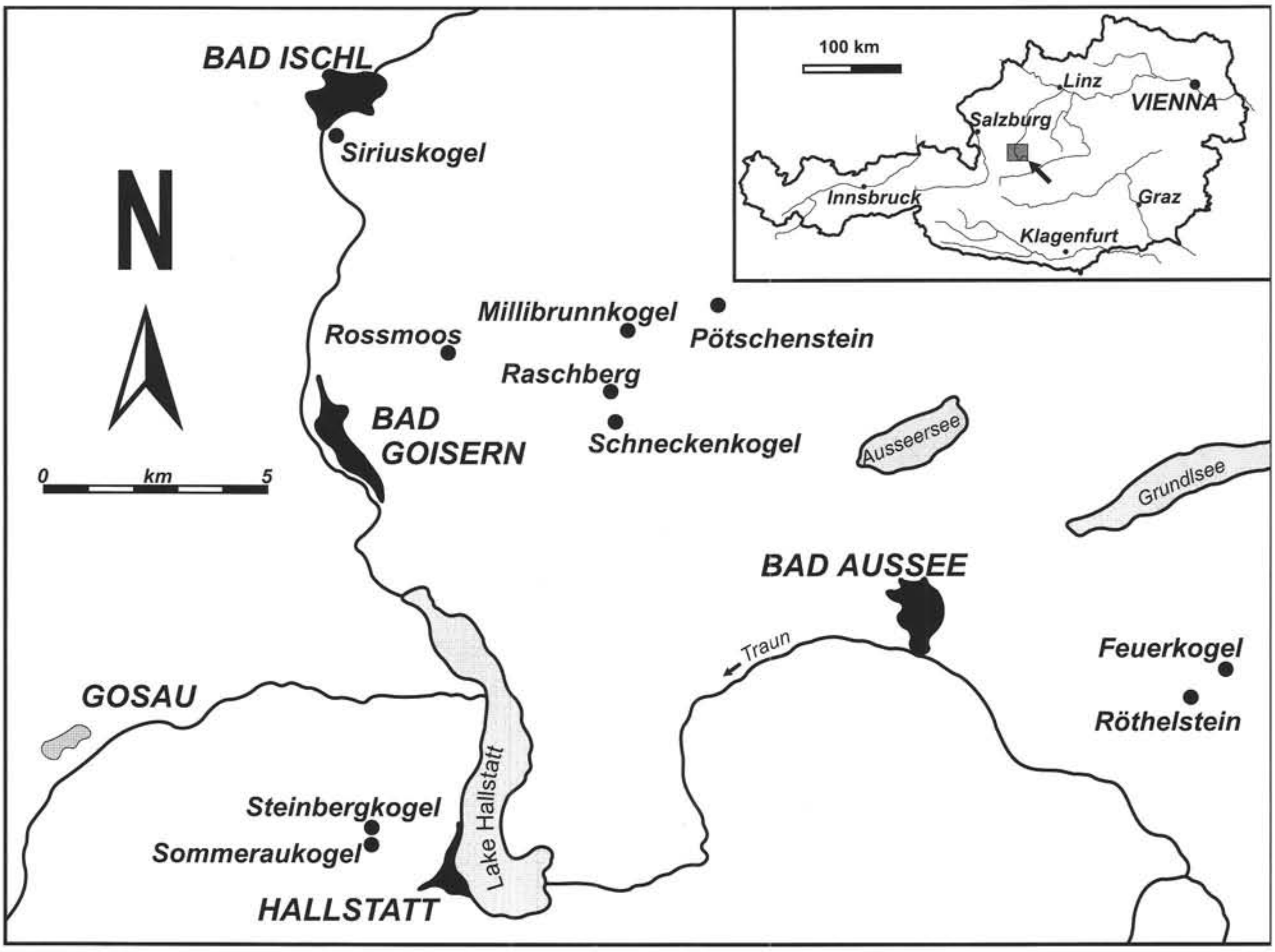


Fig. 11
Location map showing the most important Hallstatt Limestone fossil sites in Austria.

the Alps and the Indonesian island of Timor (e.g., Dinarids, Hellenids, Taurus Mountains, Oman Mountains, Himalayas).

The specific stratigraphic importance of the cephalopod-rich Hallstatt facies of the Salzkammergut is due to the fact that stratotypes or references to Upper Triassic chronostratigraphic and biostratigraphic subdivisions are designated herein (KRYSTYN et al. 1971a, b, KRYSTYN & SCHLAGER 1971). All Upper Triassic substages, except that of the Lower Carnian, are defined in the Salzkammergut. Of currently 13 Upper Triassic Tethyan ammonoid zones in use, 10 are described from the Salzkammergut. The region is also the richest source of Upper Triassic ammonites in the world. Centred around the Hallstatt lake within a radius of about 15 km, there is a bulk of fossil localities (DIENER 1926, KRYSTYN et al. 1971a), such as e. g. Siriuskogel, Millibrunnkogel, Schneckenkogel including the world famous locations of the Feuerkogel near Bad Aussee and the Sommeraukogel near Hallstatt (Fig. 11). Together with the nearby Steinbergkogel, Sommeraukogel is important further as the type locality for the Hallstatt formation.

The Feuerkogel, about 15 km to the east of Hallstatt, has delivered more than 500 ammonoid species of Carnian to Norian age (MOJSISOVICS 1873-1902, DIENER 1921, 1926). This location is by far the richest in ammonoid fauna of any single place in the world! From the Sommeraukogel, located above the town of Hallstatt (Fig. 12), close to a famous saltmine, active since prehistoric times (Hall = Celtic word for salt), another 100 Norian ammonoid species have been named by MOJSISOVICS (1873-1902) in his spectacular monograph. Compared on a genus level, the Austrian input to the knowledge of Upper Triassic ammonites is even larger. Of roughly 140 Tethyan ammonoid genera known in the early 1980's (TOZER 1981, 1984), 90 or nearly two third of the genera (65%) have been described from the Hallstatt Limestones of the Salzkammergut; the Himalayas follow next with 25 genera (20%). Half of the remaining 15% have been found in the Hallstatt facies of Timor (Indonesia) and only 7% (10 genera) have been described from the other 20,000 km of Tethyan strands. The study of the Austrian Hallstatt faunas is still not finished, with many new taxa yet to be described. Their documentation will further enlarge the faunal record of the Salzkammergut, as well as extend our knowledge of the pelagic life of the Triassic.

← Fig. 10
a) General view of the western side of the Rhaetian Steinplatte reef complex. – b) Adnet Tropfbruch quarry (Upper Rhaetian): sawed vertical surface with large scleractinian coral colonies *(Retiophyllia)*. – c) Adnet Tropfbruch quarry (Upper Rhaetian): thin-section photograph of a cross-section of a *Retiophyllia*-colony. – d) Adnet Tropfbruch quarry (Upper Rhaetian): sawed vertical surface with platy sphinctozoid sponge. – e) Steinplatte: thin-section photograph showing various sponges (base: sphinctozoid sponge, overgrown by chaetetid sponges).

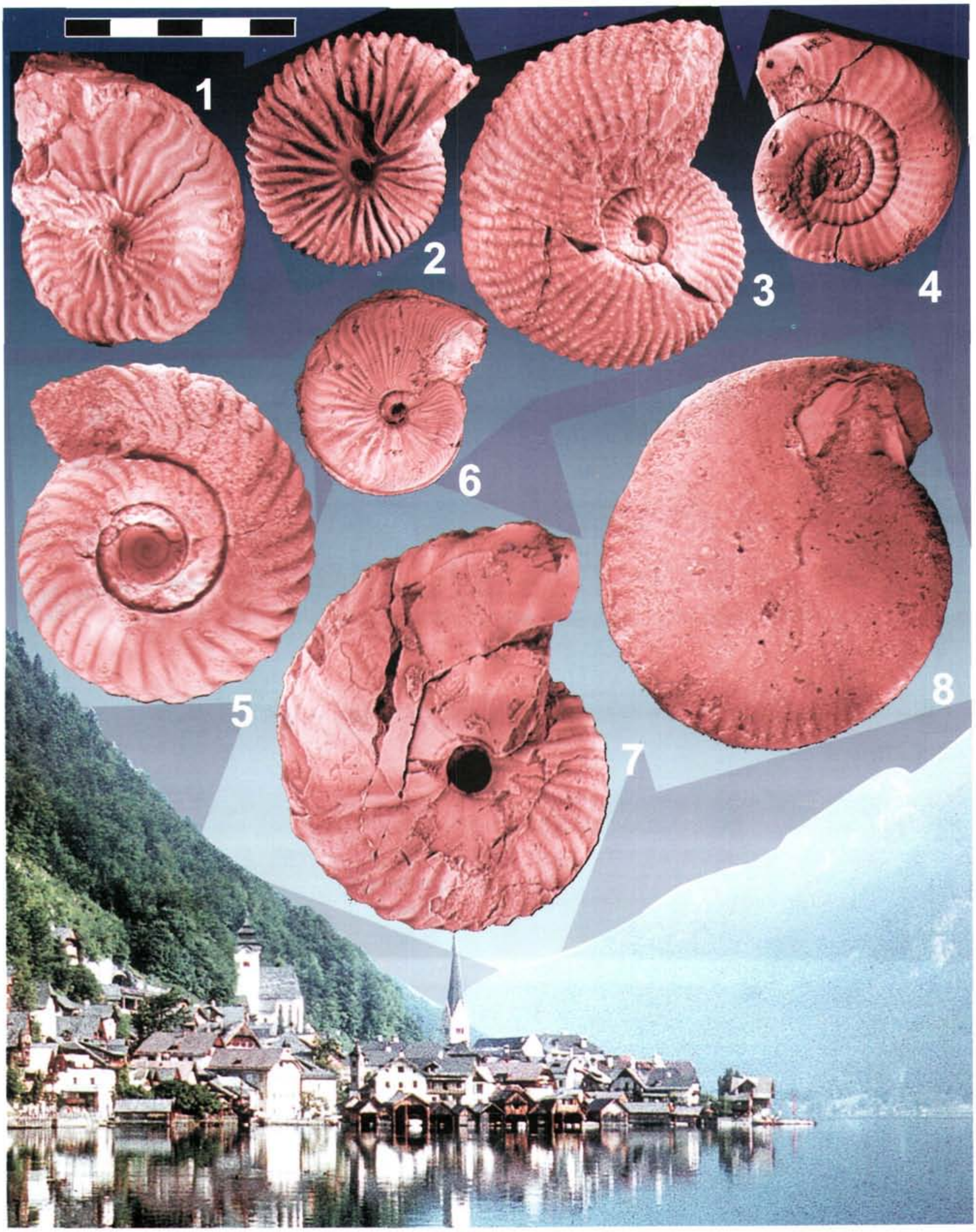


Fig. 12
View of Hallstatt with Upper Triassic ammonites from the Hallstatt Limestones of the Salzkammergut (scale = 5 cm).
1) *Cyrtopleurites bicrenatus* (HAUER), Bicrenatus zone (S) – 2) *Juvavites stoliczkai* (MOJSISOVICS), Magnus zone (S) – 3) *Austrotrachyceras triadicum* (MOJSISOVICS), Austriacum zone (F) – 4) *Ectolcites pseudoaries* MOJSISOVICS, Hogarti zone (S) – 5) *Tropites subbullatus* (HAUER), Subbullatus zone (F) – 6) *Parathisbites scaphitiformis* (HAUER), Hogarti zone (S) – 7) *Guembelites philostrati* DIENER, Jandianus zone (F) – 8) *Halorites macer* MOJSISOVICS, Macer zone (S). Localities: S = Sommeraukogel, F = Feuerkogel. – 1, 4, 6, 8: Geological Survey Coll. Vienna, others Institute of Palaeontology Coll., University of Vienna.

Deciphering the Gosau Group – a Challenge for Cretaceous Palaeontology

(HERBERT SUMMESBERGER, DIETHARD SANDERS,
HEINZ A. KOLLMANN)

The mixed siliciclastic-carbonatic Gosau Group – named after the village Gosau in Upper Austria (Fig. 13) – is renowned for its fossil content all over the world. Monographs on corals by Reuss, Felix and Oppenheim, on bivalves by Zittel, on ammonites by Hauer and Redtenbacher, on gastropods by Zekeli and on vertebrates by Bunzel have contributed to this reputation (KOLLMANN & SUMMESBERGER 1982). On a world wide scale, the spectrum of depositional environments and fossil assemblages render the Gosau Group one of the keys for understanding the relationship among tectonic movements, sedimentology, palaeoecology, evolution and biostratigraphy in the Upper Cretaceous/ Paleogene interval.

The Gosau Group was deposited in extension- and strike-slip controlled depocenters on top of the northern, accretionary margin of the Austroalpine microplate (WAGREICH & FAUPL 1994). The highly fossiliferous Lower Gosau Subgroup (Upper Turonian to Campanian; Fig. 14) consists of terrestrial to deep neritic deposits. The Upper Gosau Subgroup (Santonian to Eocene) is composed of bathyal to abyssal deposits.

The Gosau Realm – a Tethyan-Boreal Transition Area?

During the Late Cretaceous, the area of the Austroalpine tectonic unit was situated at 30-32° N (MAURITSCH & BECKE 1987). This extrapolates to a distance of approximately 1,800 km from its present position, which is about 47° N. It was part of a climatic belt with monsoonal atmospheric circulation (PARRISH & CURTIS 1982, PRICE et al. 1995). Sediments and fossils of the Lower Gosau Subgroup indicate prevalent tropical to sub-tropical, humid to sub-humid atmospheric conditions. Small-scale cycles in non-marine successions record short-term climatic changes.

Gastropod assemblages of the inner shelf shallow water environments of the Lower Gosau Subgroup containing actaeonellid and nerineacean gastropods are typically Tethyan (SOHL 1987, KOLLMANN 1992). The diversity is comparable to other Tethyan occurrences (KOLLMANN et al. 1998). In contrast to this, the rudist fauna, which generally is understood as a Tethyan element, is impoverished, compared to the South Tethyan realm (peri-Adriatic platforms) and the North Tethyan shelves in southern France and in the Pyrenees (SANDERS et al. 1997). Assemblages of the Northern Calcareous Alps are distinguished by a predominance, both in diversity and abundance, of hippuritids over radiolitids. In the Central Alpine Gosau Group, which palaeogeographically was situated during deposition further south, rudist genera and species of South Tethyan affinity are present (KÜHN 1960). Thus, a palaeobiogeographic boundary was intermittently situated in the area of the Austroalpine tectonic unit (SANDERS 1998).

The impoverishment of the rudist assemblages is interpreted as a transitional status between the Tethyan and Boreal realms. This is supported by the benthic foraminiferal assemblages. Carbonate shelf successions of the Lower Gosau Subgroup are characterized by lituolacean, textulariacean and miliolid foraminifera. Compared to penecontemporaneous peri-Adriatic carbonate platforms and those of Southern France and the Pyrenees, benthic foraminiferal assemblages of the Lower Gosau Subgroup are impoverished. Common Tethyan elements (e. g., *Dicyclina, Rhapydionina, Pseudocyclammina, Accordiella, Broeckinella, Spirocyclina*) are absent. Finally, middle shelf and neritic assemblages of foramol composition indicate a co-occurrence of Tethyan and Boreal mollusc taxa (see KOLLMANN 1992, DHONDT 1987, SANDERS et al. 1997, CHRISTENSEN 1997, 1998).

The rich and diverse fauna of planktic foraminifera of the hemipelagic marls of the Upper Gosau Subgroup is Tethyan in its composition (HERM 1962). Nevertheless, rare findings of *Belemnitella* in slope and transitional deposits indicate a migration of boreal elements (CHRISTENSEN 1997) into deep-water environments and therefore a restricted vertical reproduction of realms.

The Lower Gosau Subgroup – a Wealth of Facies

The sequence development during deposition of the Lower Gosau Subgroup was mainly controlled by fault-induced subsidence related to the dynamics of the Alpine accretionary wedge (SANDERS et al. 1997). Its exceptionally wide range of facies and diversity of fossil assemblages (WAGREICH & FAUPL 1994) is due to several factors: The articulated morphology of the older substratum, facies compartmentalization in the terrestrial to marine shelf environment, high rates of both subsidence and sediment accumulation, mixed siliciclastic-carbonate deposition and environmental changes. Patterns of sequence development of the Lower Gosau Subgroup and change of biotic assemblages within a sequence stratigraphic frame have been described by SANDERS et al. (1997). Two shelf types with different depositional history have been distinguished (Fig. 15):

Type A shelves are characteristic of the early development of the Lower Gosau Subgroup, and show little direct evidence for syndepositional faulting. Commonly, they were relatively steep, wave-dominated, with a siliciclastic sedimentation. Mainland beaches and barrier beaches in front of restricted-marine to freshwater marshes (Fig. 15a) or of fan deltas occurred. In open lagoons, nerineids, actaeonellids, radiolitids, sponges, calcareous green algae, miliolid and lituolacean foraminifera thrived. In areas of intermittently reduced siliciclastic input of the inner shelf, coral-rudist mounds and -biostromes accumulated locally. On the outer shelf to upper slope, mainly silts and muds with ammonites, epifaunal and infaunal non-rudist bivalves (inoceramids, nuculaceans) and with planktic and benthic foraminifera were deposited (SANDERS et al. 1997).

Rocky shores and gravelly carbonate beaches developed along transgressive coasts without river deltas or fan deltas. In areas of low siliciclastic input, regressive carbonate shelves developed (Fig. 15b). Their inner shelf facies belt shows a development of skeletal mounds (hermatypic scleractinians, rudists) and rudist biostromes. It is followed landwards by a dissipative shore zone of bioclastic dunes, an open lagoon with rudist biostromes and, at their landward end, narrow microtidal marshes (SANDERS et al. 1997). Biostromes of hippuritids and/or of radiolitids are common

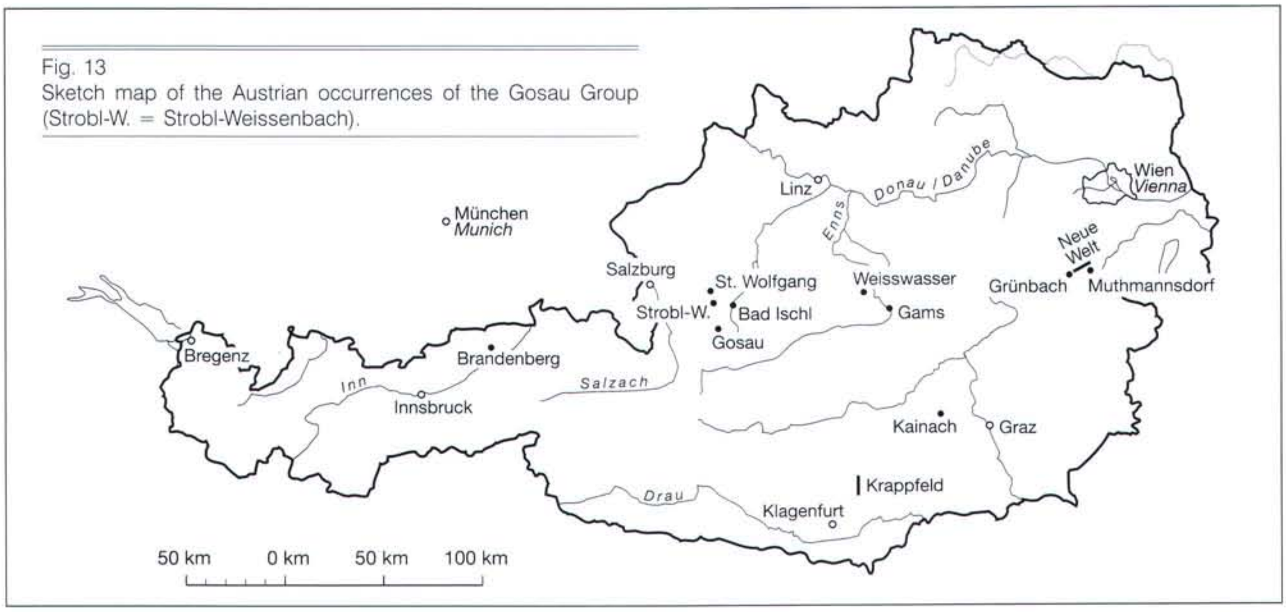


Fig. 13
Sketch map of the Austrian occurrences of the Gosau Group (Strobl-W. = Strobl-Weissenbach).

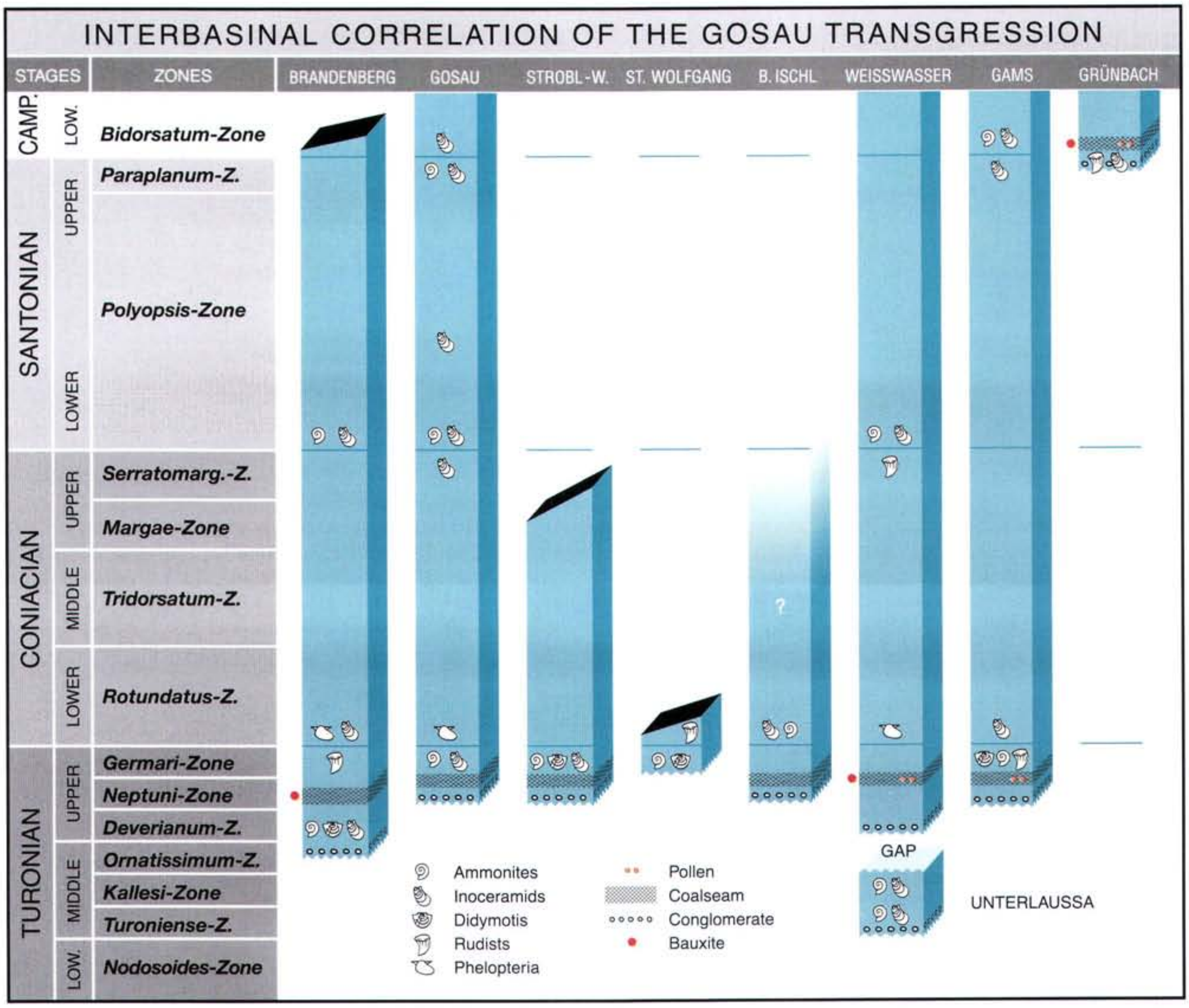


Fig. 14
The age of the transgression of the Gosau Group (SUMMESBERGER & KENNEDY 1996); (Strobl-W. = Strobl-Weissenbach; B. Ischl = Bad Ischl).

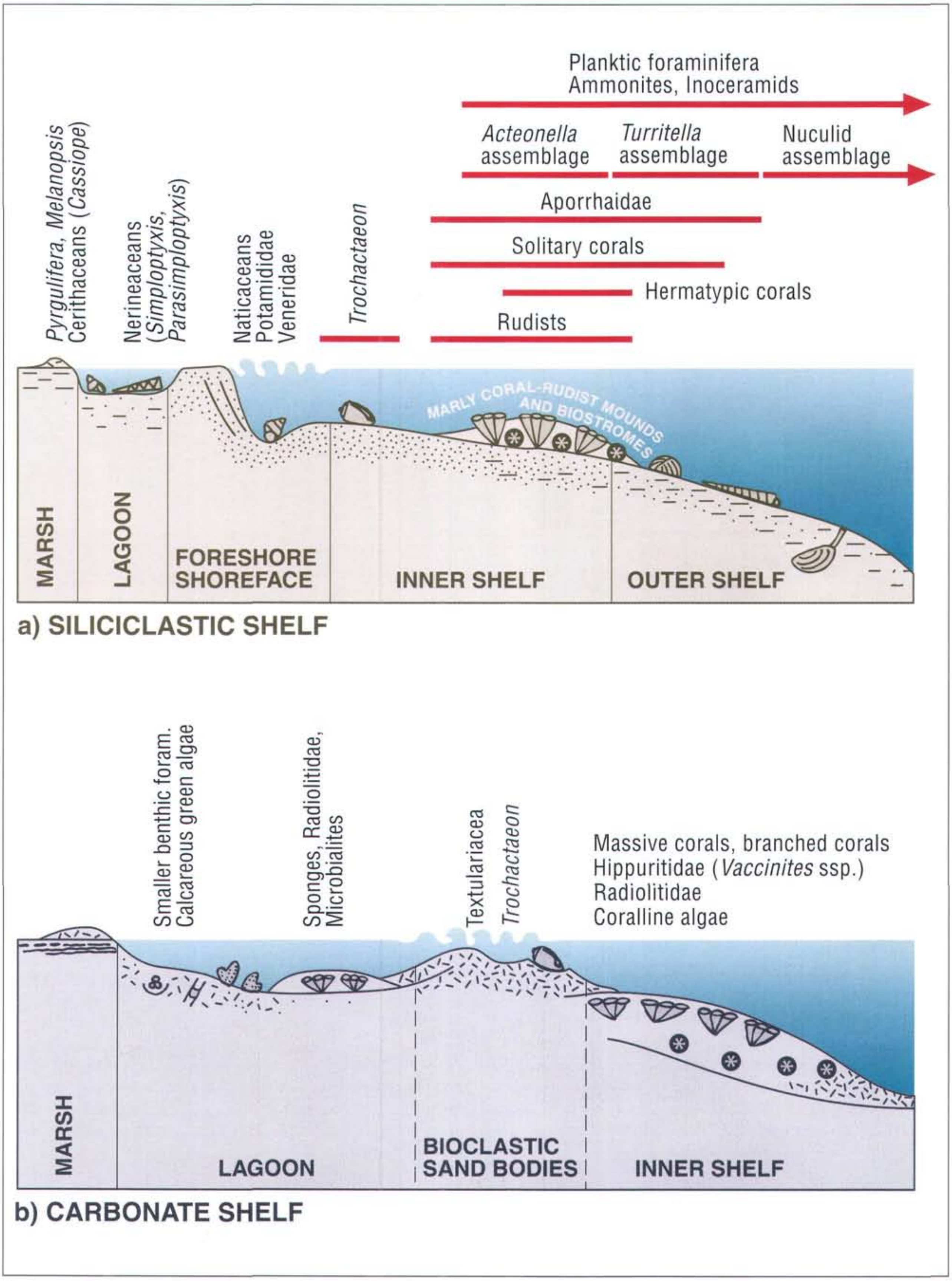


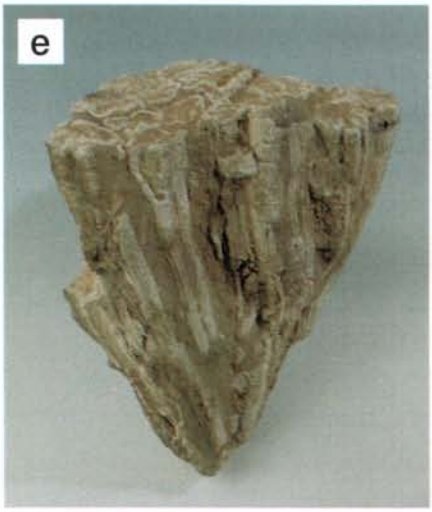
Fig. 15
Reconstruction of the fossil assemblages of type A of the Lower Gosau Subgroup at the a) siliciclastic shelf (top) and b) at the carbonate shelf (bottom) (SANDERS et al. 1997).


a


b


c


d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both within successions deposited from carbonate shelves and from siliciclastic lagoonal to inner shelf environments (SANDERS & PONS 1999). SANDERS et al. (1999) have further recorded a reef of densely packed, large scleractinians of Santonian age. In the mid to outer shelf environment contemporaneous to the carbonate shelves, mainly siliciclastic silts and muds were deposited.

Assemblages of scleractinian corals are represented by both colonial and solitary forms. Corals are either constituents of biostromes and skeletal mounds to more than 10 meters thick or occur, typically in high abundance as isolated specimens in siltstones to marls that have been deposited in an open lagoonal to inner shelf environment (BEAUVAIS 1982, HÖFLING 1985, BARON-SZABO 1997). The coral assemblages are similar to those of the North Tethyan shelves of southern France and the Pyrenees, as well as to the South Tethyan realm in Slovenia and Serbia (TURNSEK 1997, BEAUVAIS 1982, BARON-SZABO 1997).

Type B shelves (not figured) are characterized by a rocky to gravelly shore. It slopes steeply over a narrow shoreface into a deep, muddy shelf. The shore deposits of these shelves contain abundant fragments of coralline algae, echinoids, branched bryozoans, articulate brachiopods, epibenthic ostreans and lagenid foraminifera. Rudists and particularly hermatypic corals are very rare to absent. Organic-rich, muddy silts to silty muds characterize the deep shelf environment. Fossil assemblages contain infaunal and epifaunal bivalves (nuculids, exogyrids, large flat inoceramids), echinoids, gastropods (naticids, turritellids), ammonites, rare crinoids, both benthic and planktic foraminifera, and siliceous sponges.

Type B shelves developed in late stages of of the Lower Gosau Subgroup. Commonly, they were preceded by subaerial exposure and karstification, faulting and deep erosional truncation. Both the substratum and the successions show direct evidence for syndepositional faulting. Shortly afterwards, a marked acceleration of subsidence led to deposition of the Upper Gosau Subgroup.

The Upper Gosau Subgroup – a Story of Drowning

The Upper Gosau Subgroup consists of deep-water clastics and hemipelagic slope deposits. The boundary towards the Lower Gosau Subgroup is diachronous. The biostratigraphic position of the boundary varies between Upper Santonian and uppermost Campanian within an interval of 12 Ma. It is characterized by an unconformity and a small but significant stratigraphical gap in some basins.

Hemipelagic marls are rich in planktic foraminifera (>90%). They occur together with benthic foraminifera of the upper to middle bathyal zone (FAUPL & WAGREICH 1992). Turbiditic deep water associations were intermittently deposited below the local CCD (WAGREICH & FAUPL 1994). In other localities marly limestones which are rich in planktic foraminifera indicate a depostion above the CCD.

In K/Pg boundary sites within deep water facies of the Gosau group a well-developed boundary clay (PREISINGER et al. 1986, LAHODYNSKY 1988) is present.

The Gosau Group in the Global Network of Biostratigraphy

The fossils of the Gosau Group (see examples in Fig. 16) provide palaeobiogeographical and palaeoecological and biostratigraphic evidence. The most common biomarkers of the outer to middle shelf environments are ammonites, inoceramids, planktic foraminifera and nannoplankton (SUMMESBERGER et al. 1999). Typically, several groups of biomarkers are present. Their biostratigraphic resolution is commonly at biozone to substage level.

Shallow-water carbonates have yielded assemblages of benthic foraminifera and rudists. Initial results in dating the terrestrial to marginal-marine successions of the Lower Gosau Subgroup by means of palynomorphs are promising. They provide good evidence of a Campanian age of the diverse, angiosperm-dominated flora of Grünbach and the dinosaur fauna of Muthmannsdorf both situated in the basin of Neue Welt (Fig. 13; DRAXLER 1997).

Lower Miocene Seacows from Austria

(PETER PERVESLER, REINHARD ROETZEL, DARYL P. DOMNING)

The seacow *Metaxytherium krahuletzi* DEPÉRET, 1895, was a halitheriine dugongid which populated shallow marine areas with seagrasses in the Central Paratethys and adjacent Lower Miocene seas of Europe. With reference to the molar patterns and the size of the tusks this plant-eating mammal was not only feeding on leaves, but also on shallow buried rhizomes of seagrasses and was probably an ecological generalist (DOMNING & PERVESLER in press). The deflection of its rostrum is comparable to that of the bottom-feeding Recent Dugong and indicates the same feeding strategy as for the *Metaxytherium krahuletzi*. The type material and nearly all known specimens have been collected from outcrops in the shallow marine Burgschleinitz Formation of the Eggenburg Bay (Fig. 17) (ABEL 1904, DAXNER-HÖCK 1971, PERVESLER et al. 1995, 1998) and are of Late Eggenburgian age.

Upper Oligocene to Lower Miocene sediments are widespread along the eastern border of the Bohemian Massif in Lower Austria. These sediments are terrestrial to marine in origin and are erosive residuals of a former closed sediment cover on the eroded crystalline basement. Tertiary tectonics (active to the present day) reactivated old fracture systems within the crystalline and created small basins (e.g., Horn Basin, Eggenburg Bay).

← Fig. 16
a) *Cunnolites* sp.; x 0.6. In general, the solitary coral *Cunnolites* is present in monospecific or paucispecific assemblages. Its modern analogue is represented by the genus *Fungia*. – b) Late Cretaceous gastropod mass occurrences of the genera *Nerinea* and *Trochactaeon* occurred in proximal inner shelf environments. Windischgarsten/Upper Austria; x 0.1. – c) *Megalonoda reussi* (HOERNES), Turonian, Gams/Styria; x 0.9. – d) *Cladoceramus undulatoplicatus* ROEMER; Lower Santonian, Brandenberg/Tyrol. Large flat inoceramid bivalves inhabited mud bottoms of the outer shelf. x 0.2. – e) Bouquet of *Hippurites* sp.; *Hippurites* is most commonly subordinate in abundance, but locally is present in paucispecific thickets; x 0.25. – f) *Barroisiceras haberfellneri* (HAUER), the lectotype, Gams/Styria. Late Turonian; x 1. – a) – e) stored at the Museum of Natural History, Vienna; f, stored at the Austrian Geological Survey, Vienna.

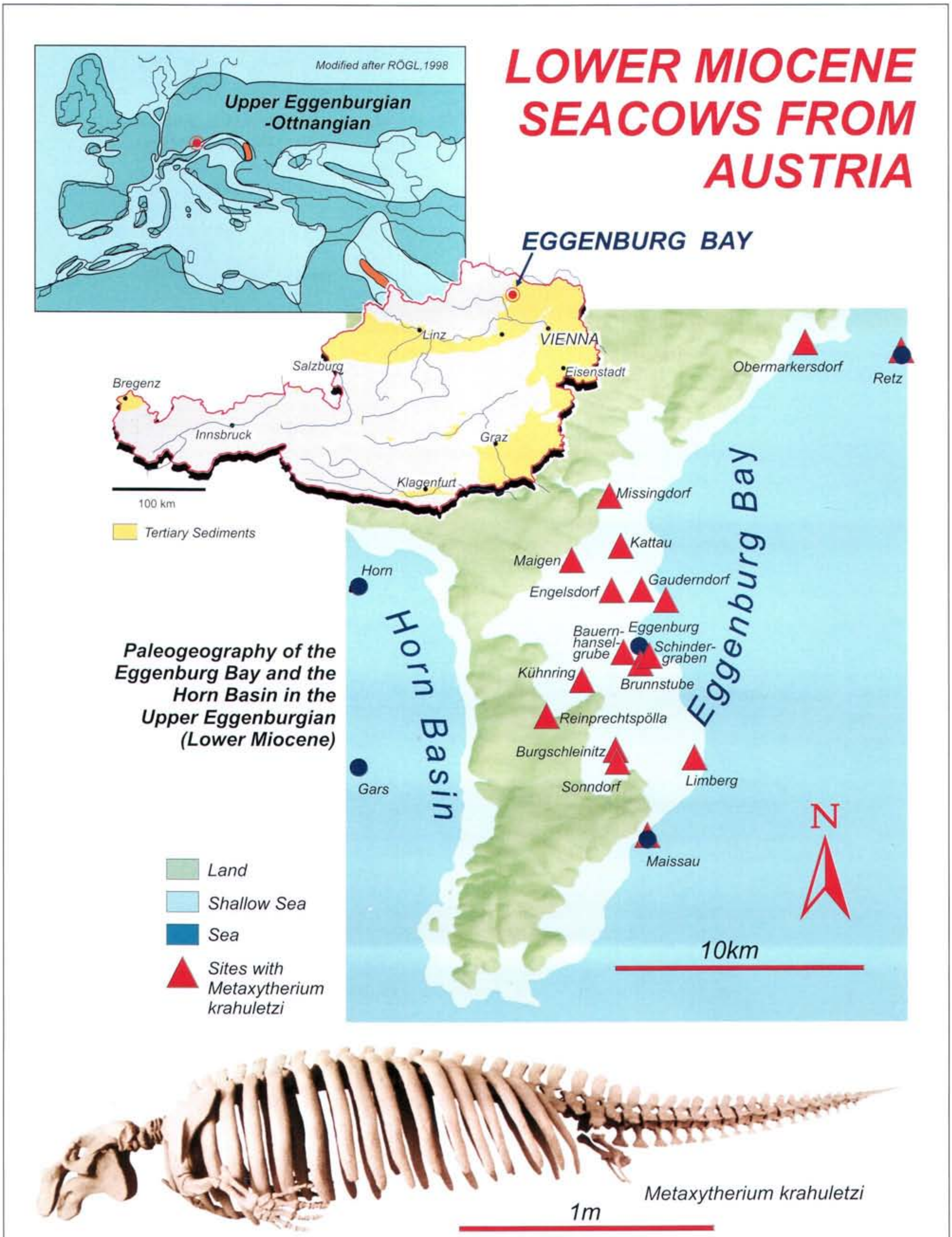


Fig. 17
Skeleton (bottom) and occurrences of Lower Miocene *Metaxytherium krahuletzi* in the Eggenburg Bay and palaeogeographic reconstruction of the Mediterranenan and Paratethys (top).

The Burgschleinitz Formation consists of alternating, poorly sorted medium to fine sands with intercalated gravels. Sedimentary structures such as cross-bedding, lamination and current ripples, as well as typical molluscs and trace-fossils of the *Ophiomorpha* type indicate deposition in intertidal to shallow subtidal areas. Frequent coquinas, escape structures, hummocky cross-stratification and crystalline block layers, mostly containing bones of vertebrates, can be interpreted as the result of heavy storm events. The sediments of the Burgschleinitz Formation are primarily the result of a wave dominated, storm influenced shallow marine facies deposited in bays sheltered by islands formed of crystalline rock.

The Burgschleinitz Formation in the Kühnring sandpit consists of silty medium to fine sands deposited in the shallow marine sublittoral environment of a narrow bay open to the northwest. The foraminifera and molluscs in these sands are typical settlers on marine sandbottoms with seagrass. The top of this formation is a coarse clastic facies with bones of *Metaxytherium krahuletzi, Schizodelphis sulcatus, Brachyodus onoideus, Tapirus* sp. and teeth of crocodiles, breams and sharks like *Carcharocles megalodon* (DOMNING & PERVESLER in press, PERVESLER et al. 1995, 1998). Lithology of the inverse graded coarse layer at the base of a coarse clastic facies shows all the characteristics of a debris flow. This sediment body slid from the crystalline elevation into the shallow marine bay and probably filled an area of 60,000 m^2 with a 0.7 to 2.3 m thick layer, deplanating the relief. The debris flow integrated crystalline components from the near hinterland, as well as better reworked sediment portions and molluscs from the shallow marine areas. The top of the debris flow is covered with crystalline slabs 10 to 50 cm in diameter, occasionally up to 80 cm. Several more or less articulated skeletons of the seacow *Metaxytherium krahuletzi* (five adults and two juveniles) were found anchored by the crystalline slabs upon this debris flow. The fact that all sirenian bones were deposited exclusively on the debris flow proves that the animals belonged to the same population and died coincidentally.

Shallow marine sediments of the Burgschleinitz Formation in the old sandpits near Sonndorf contain two distinct layers with *Metaxytherium krahuletzi* bones. The lower bone layer is intercalated into a mollusc-shell-layer consisting of subtidal molluscs and also contains fossils of cirripeds, decapods, sharks, rays and fishes (Osteichthyes). The seacow specimens of this layer are more or less isolated bones belonging to *Metaxytherium krahuletzi*. The base of the upper bone layer is a mollusc-shell-layer with molluscs from the intertidal. The bone layer itself contains not only seacows, but also bones of *Brachyodus* and turtles and the teeth of sharks, rays and braces. The *Metaxytherium krahuletzi* remains, mostly ribs and vertebrae, but also skull fragments from adult and juvenile individuals, are dispersed over the horizon with no evidence of any articulation.

The *Metaxytherium krahuletzi* bone layers in the Eggenburg Bay seem to derive from mass mortality events and are always connected with increasing hydrodynamic energy in shallow marine nearshore depositional areas (deeper intertidal or shallow subtidal). Heavy storm events could have caused the death of these herbivorous animals by damaging their food resource.

Oberdorf N Voitsberg (Styria, Austria) – a Key Section in the Vegetation History of Early Miocene European Continental Deposits (JOHANNA KOVAR-EDER)

The Köflach-Voitsberg lignite area is situated at the northwesternmost margin of the Styrian Basin, 30 km W of Graz (Fig. 18). Oberdorf, the last Austrian opencast mine in operation, was subject to detailed, joint geoscientific investigations. The basin fill there has a thickness of about 300 m and is part of the Köflach/Voitsberg Formation (Fig. 18d). According to the sedimentological results, the deposits are exclusively of fluvial/lacustrine origin (HAAS 1998, 1999). The largely xylo-detritic and detrito-xylitic main seam of about 30 m thickness originated in a non-marine lowmoor (KOLCON & SACHSENHOFER 1998, 1999). Vertebrate assemblages at roughly 100-105 m have been dated to the Early Miocene, Ottnangian (Central Paratethys stage), MN 4 (Neogene mammal zone). The polarity change 13 m above the main seam was therefore correlated to C5Dr/C5Dn of the Geomagnetic Polarity Time Scale, 17.6 M.a. (DAXNER-HÖCK et al. 1998, MAURITSCH & SCHOLGER 1998). A tuffite at the base of the main seam can probably be correlated to the "Lower Rhyolite Tuffs" in the Pannonian Basin, indicating a (Late) Eggenburgian/Early Ottnangian age of this part of the sequence (HAAS 1999).

Assemblages of dispersed plant organs (leaves, fruits/seeds, and pollen/spores) were preserved in different parts of the sequence. The detailed palaeoenvironmental reconstruction is partly based on the systematic evaluation of the plant assemblages at all fossiliferous levels (HAAS et al. 1998).

A number of plant species have never been described before, e.g., some members of the tea family (KOVAR-EDER & MELLER 2000). Others are reported from Austria for the first time, e.g., *Magnolia liblarensis* (magnolia), *Cephalotaxus* (plum-pine), several laurel species and *Viola* (violet).

In the case of certain woody plants such as *Trigonobalanopsis* (beech family) and *Cercidiphyllum* (Katsura), vegetative and reproductive organs are preserved.

In the sediments at the base of the main seam, *Trigonobalanopsis* is best represented by leaves, cupules and pollen (KOVAR-EDER et al. 1998a, MELLER et al. 1999). These evergreen trees were probably common in the species-diverse hinterland forests.

Mass occurrences of *Cercidiphyllum* (KATSURA) leaves are bound to the hanging wall sediments, where they are frequently associated with fruits (Fig. 19a, c). Even fragments of twigs with adherent short shoots have been discovered in the fossil state for the first time (Fig. 19b); pollen grains of *Cercidiphyllum* have also been determined (KOVAR-EDER et al. 1998b).

The plant assemblage from the tuffite at the base of the main seam partly resulted from a volcanic eruption that coincided with the season in which many woody plants were flowering; deciduous ones were leafless or in the state of opening their buds; fruits and seeds had not yet developed. Buds/bud scales, lumps of immature pollen and leaves of evergreen woody species were stripped off their mother plants and quickly deposited in a backswamp together with ash and lapilli. Other plant material already accumulated in the backswamp previous to the tephra fall out (KOVAR-EDER et al. a, submitted; Fig. 20).

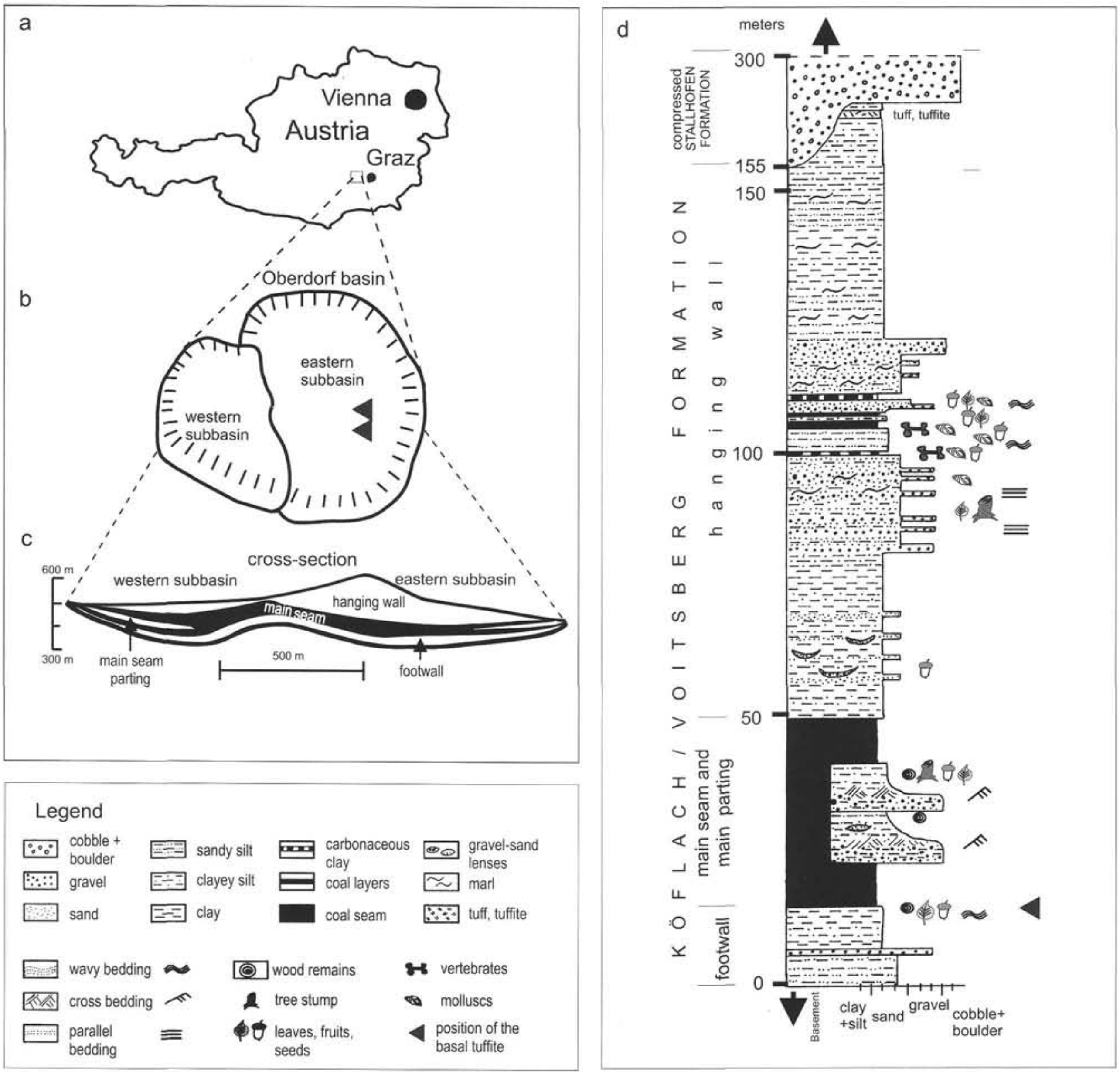


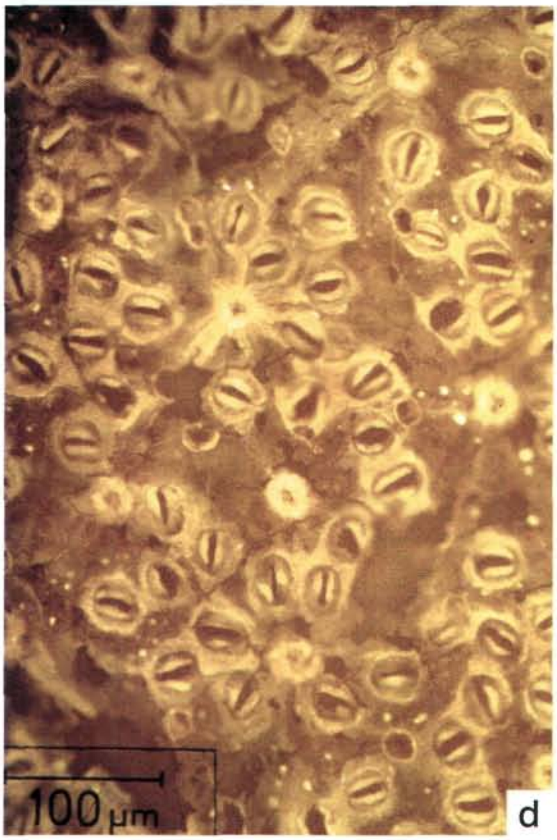
Fig. 18
a) Geographic setting of the Köflach-Voitsberg lignite area. – b) The opencast mine Oberdorf. – c) Schematic cross-section through the Oberdorf opencast mine. The main seam is split towards the W in the western sub-basin and towards the east in the eastern sub-basin. – d) Standard profile of the Köflach/Voitsberg Formation in Oberdorf (from HAAS et al. 1998, slightly modified). The vertebrate-bearing layers were found at 100-105 m. The polarity change C5Dr/C5Dn was observed in the lower part of the hanging wall sequence, 13 m above the main seam.

In the lowlands around Köflach-Voitsberg, extensive wetlands of marginal fluvial facies developed during the depositional phase. Swampy facies (Fig. 21) are best documented in clayey/lignitic sediments. Generally only few woody taxa prevail. *Glyptostrobus europaeus* (swamp cypress family, Fig. 19h) and *Quercus rhenana* (an evergreen oak relative, Fig. 19d) are most characteristic. They are accompanied by *Myrica* (wax myrtle, Fig. 19g), *Nyssa* (tupelo), *Rubus* (blackberry), and a few others (KOVAR-EDER 1996, MELLER 1998).

Sandy and silty/marly sediments from the main seam parting in the western sub-basin and the hanging wall in the eastern sub-basin offered the best insight into the composition of riparian forests (KOVAR-EDER & MELLER 2000 and in press): *Sequoia, Cercidiphyllum, Alnus* (alder), *Fraxinus* (ash tree, Figs. 19e, f), *Acer* (maple), *Salix* (willow), *Pterocarya* (wingnut), and *Prunus* (prune) are important trees and shrubs here. Aquatic plants, both submerged forms and

Fig. 19 →
a) and c) *Cercidiphyllum crenatum* (KATSURA), a leaf, c fruit. – b) *Cercidiphyllum* twig fragment with a short shoot bearing several growth rings. – d) Lower leaf surface of *Quercus rhenana* (evergreen oak relative), a characteristic swamp element in Oberdorf (fluorescence microscopy). – e) Leaflet of *Fraxinus ungeri* (ash tree). – f) *Fraxinus* winged fruit. – g) Leaf of *Myrica joannis* (wax myrtle). – h) Twig of *Glyptostrobus europaeus* (swamp cypress family). Scale bar 1 cm except in d) where it is 100 μm.


a



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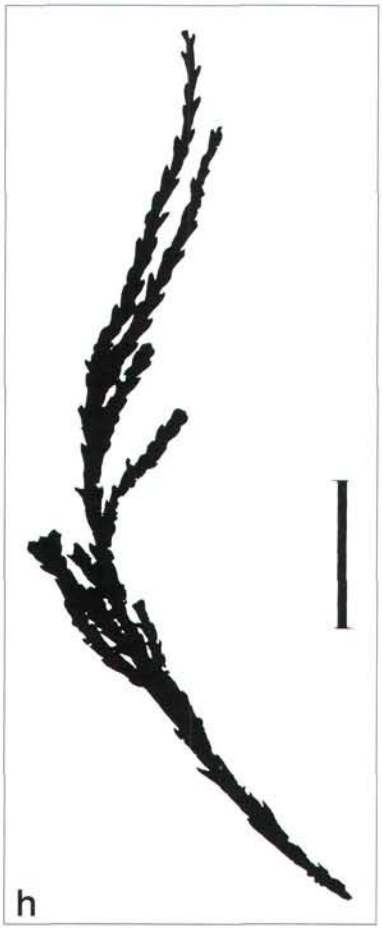
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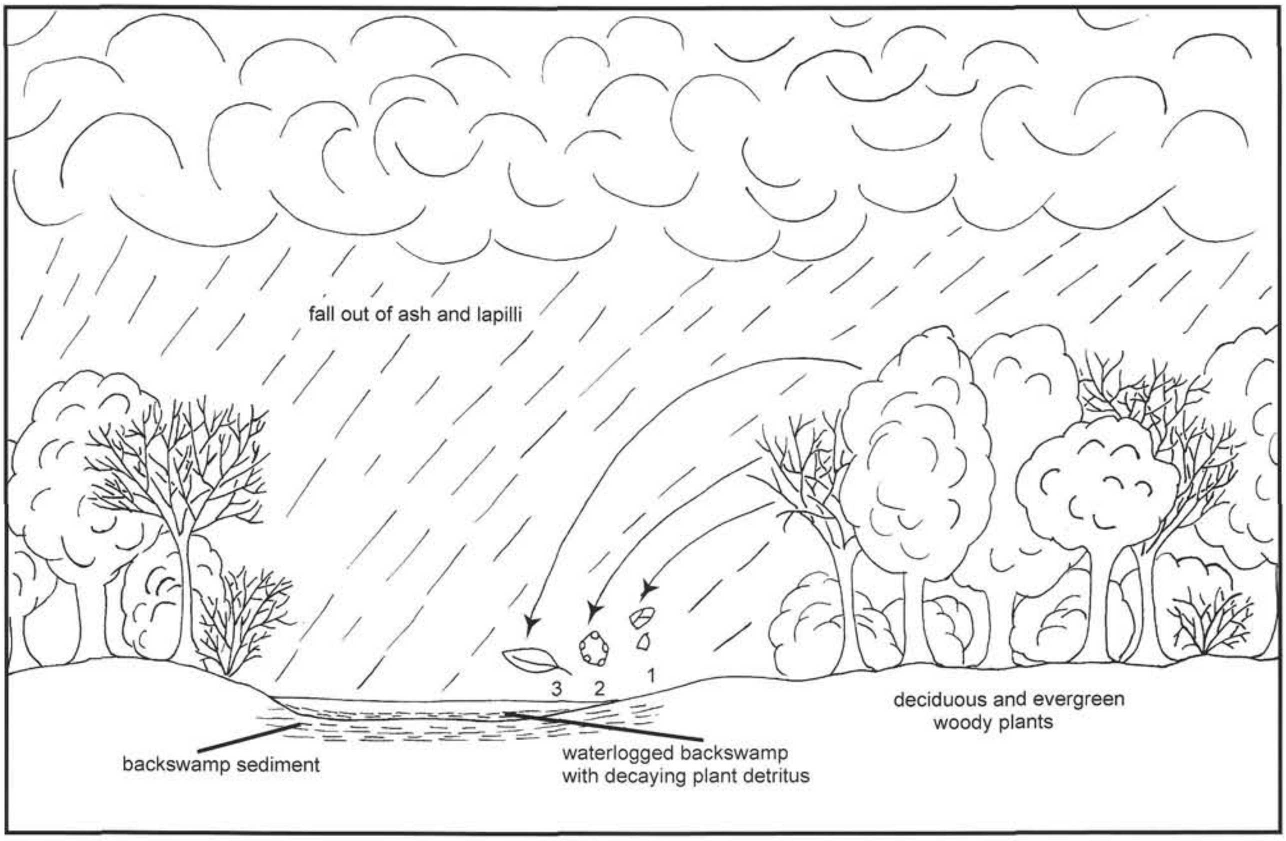

Fig. 20
Possible scenario that led to the formation of the plant assemblage recovered from the tuffite at the base of the main seam. 1 – buds/bud scales, 2 – pollen/pollen lumps, and 3 – leaves of evergreen woody plants were stripped off their mother plants due to a volcanic eruption during "springtime". Together with lapilli they were embedded in a waterlogged backswamp sediment that contained already decaying plant material.

those with floating leaves, as well as plants with reed-like associations, are generally rarer and species poorer in Oberdorf than in other European lignite areas. However, those discovered in the hanging wall sequence are indicative of ponds and lakes: *Potamogeton* (pondweed) and Characeae.

Frequent fusain fragments in many horizons indicate forest fires, as known from sub-tropical and tropical swamps today.

While the plant assemblages of the Oberdorf sequence distinctly trace facial changes within the wetland area during the depositional time, the composition of the hinterland forests remains virtually unchanged.

Species diverse, mostly evergreen forests covered natural levees and hills surrounding the Köflach-Voitsberg lowlands, as the Alpine orogen had not yet fully evolved. The sediments from the base of the main seam show a distinctly stronger allochthonous influence versus the greater autochthonous influence in the seam partings and the hanging wall sediments. Therefore the species spectrum of the hinterland forests is better represented in the plant fossil record at the base of the main seam than in any other part of the sequence. The laurel family is documented by eight species; others, such as the Symplocaceae and Juglandaceae (walnut family) are similarly diverse. Members of the Fagaceae (beech family), Ulmaceae (elms), Mastixiaceae (related to the dogwood family), Rutaceae (citrus family), Theaceae (tea family), Sapotaceae (sapote family), Ebenaceae (ebony family), and Sterculiaceae (chocolate family) were components of these forests. They provide first evidence for rich Younger Mastixioid vegetation from Austria (MELLER et al. 1999, ZETTER 1998). These hinterland forests show a close relationship to those described from Bohemia, Bavaria and Saxony of the Early/Middle Miocene.

The different wetland and hinterland biotopes were favourable habitats for amphibians, lizards, snakes, mammals and birds. Their teeth and bones have been found in the hanging wall sequence. Interesting representatives include rhino, pig, cervids and flying squirrels (DAXNER-HÖCK et al. 1998, HAAS et al. 1998, Fig. 21). The latter required high trees for gliding. Generally, forest dwellers prevail, supporting the interpretation of the plant fossil record.

These forest communities required warm, humid, subtropical climatic conditions similar to those occurring today in the ecotone between the mixed mesophytic forest and the evergreen broad-leaved forest region of E- and SE-Asia, with climatic conditions of 14-17 °C mean annual temperature and 1,000 to 2,000 mm annual precipitation (DAXNER-HÖCK et al. 1998).

The comparison of Oberdorf with other Early/Middle Miocene European lignite deposits revealed an even higher floristic variability of peat-forming plant associations than thus far expected (KOVAR-EDER et al. b, submitted).

Acknowledgements: The investigations were financed by the Austrian Science Fund, project 10337 GEO.

Fig. 21
Reconstruction of a swamp forest biotope with big *Glyptostrobus europaeus* trees (swamp cypress family), rhino, cervids and flying squirrels (plant reconstructions by W. Lumpe, Dresden; animal reconstructions from DAXNER-HÖCK et al. 1998).

Badenian (Middle Miocene) Ecosystems

(WERNER E. PILLER, MATHIAS HARZHAUSER)

The Vienna Basin, located between the Eastern Alps, the West Carpathians and the western part of the Pannonian Basin (Fig. 22), is embedded in the very complex tectonic evolution of the east Alpine area (DECKER 1996, DECKER & PERESSON 1996) and represents one of the best studied pull-apart basins of the world (ROYDEN 1985, 1988, WESSELY 1988). Besides its importance from a tectonic point of view the Vienna Basin was – similar to other European Tertiary Basins (e.g., Paris Basin, London Basin, Mainz Basin) – the focus of early geological studies particulaly due to its rich fossil content (e.g., STÜTZ 1807, PREVOST 1820, SUESS 1885, SCHAFFER 1907). Another important aspect, which distinctly enhanced our stratigraphic, sedimentologic and tectonic knowledge involved the large hydrocarbon reservoirs, which were explored during the last 60 years.

The Vienna Basin is part of the Paratethys, which formed together with the Mediterranean Sea after the disappearance of the Tethys ocean (see STEININGER & WESSELY, this volume). Due to its isolated position for most of the time a regional stratigraphic stage system different from that of the Mediterranean had to be established (e. g., RÖGL & STEININGER 1983, SENES & STEININGER 1985, STEININGER et al. 1988, 1990, RÖGL 1998).

The pull-apart mechanism became active during the Karpatian (STEININGER et al. 1986, SEIFERT 1992, DECKER 1996). Older sediments (Eggenburgian – Ottnangian) at the base of the northern part of the Vienna Basin belong to an earlier piggy-back basin of the Molasse cycle (STEININGER et al. 1986, PILLER et al. 1996, DECKER 1996). Between the Karpatian and Pannonian (comp. Fig. 1) the subsidence in the central Vienna Basin reached up to 5.5 km (WESSELY et al. 1993). The interplay of highly active synsedimentary tectonics with rapid changing trans- and regression cycles (RÖGL & STEININGER 1983, RÖGL 1998) produced a complex facial pattern inside the basin, depending on distance from land and on position of particular tectonic blocks.

The basement of the basin is built by those Alpine-Carpathian nappes bordering the basin on the surface (comp. block diagram in Figs. 23-25). The Neogene sediment fill of the basin reaches a thickness of up to 6,000 m. At the base mainly clastic sediments are developed representing fluvial facies. A fully marine development over the entire basin was established only in the Early Badenian (Lower Lagenid Zone). These sediments consist not only of clastics, but also carbonates were deposited. This facial development with local coral reefs and widespread coralline algal limestones is restricted to the Badenian since during the Sarmatian a reduction in salinity and/or increase in alkalinity (RÖGL

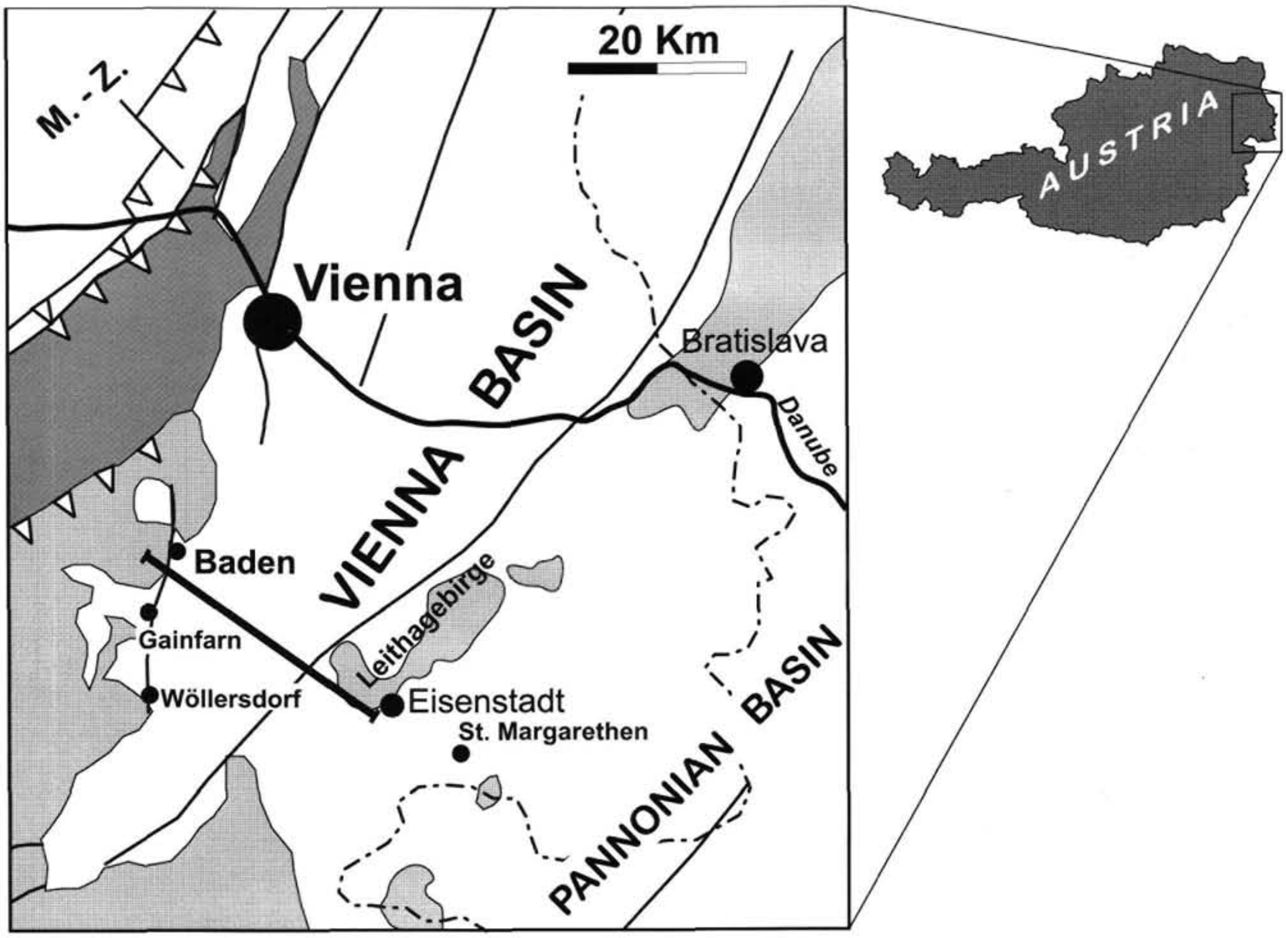

Fig. 22
Location map and highly simplified tectonic structures of the southern Vienna Basin and western Pannonian Basin. The shaded areas framing the basin are part of the Alpine – Carpathian nappe systems. M.-Z.: Molasse Zone. The black line between S' Baden and Eisenstadt marks the section shown in the block diagram of Figs. 23-25.

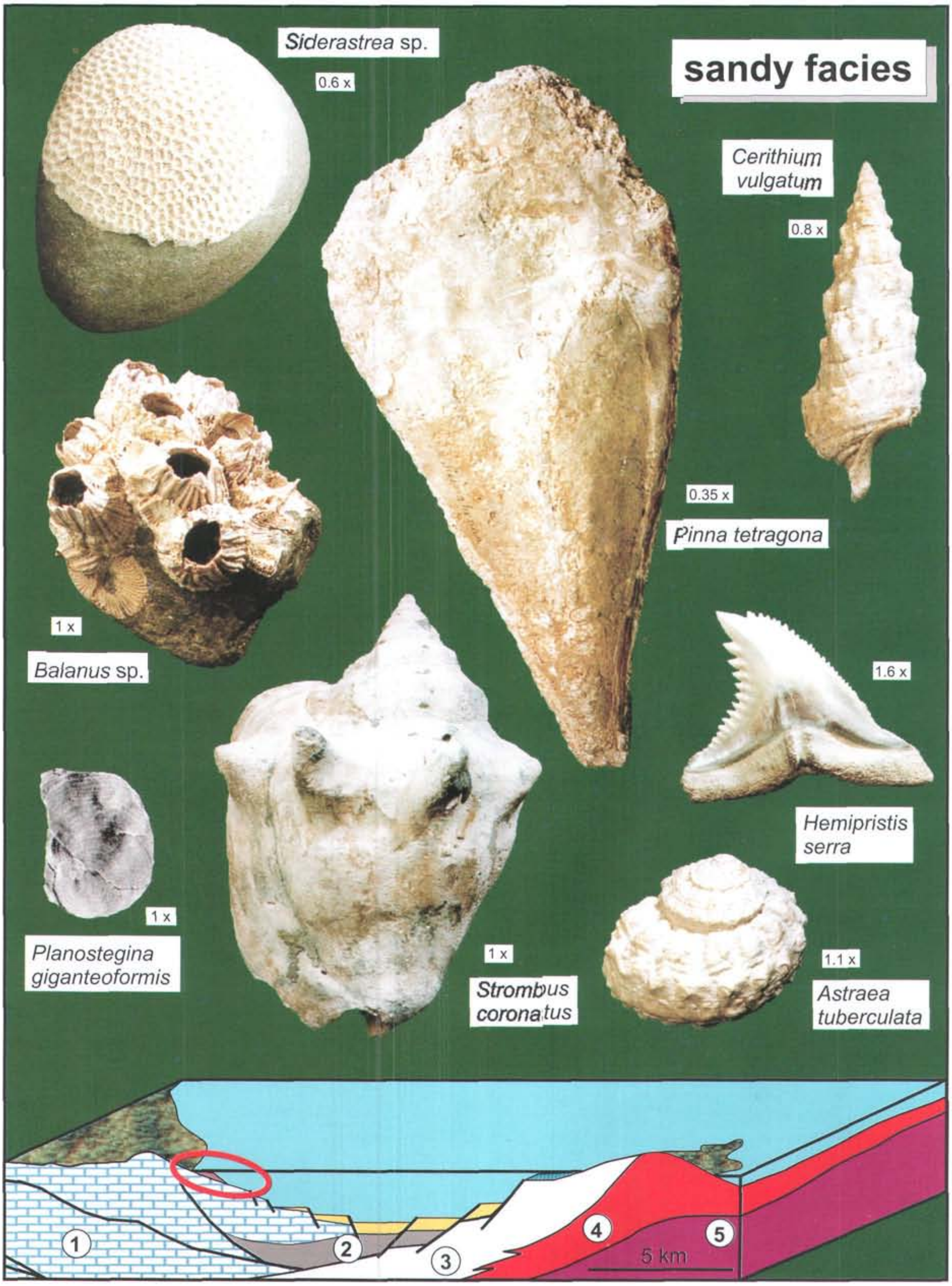

Fig. 23
Typical Badenian biota of the sandy facies (Gainfarn Sands), particularly of the western margin of the Vienna Basin (red ellipsis in the basal block diagram of figure). The front face of the block diagram represents the section between S' Baden and Eisenstadt (marked in Fig. 22) and is a reconstruction of the Vienna Basin during the Badenian after KOLLMANN et al. (1982). The Miocene sediments are shown in yellow (central basin), light blue (Leitha Limestone at the western flank of the Leithagebirge) and pink (sandy facies along the western margin – red ellipsis). All other signatures represent rocks of the Alpine – Carpathian nappe systems forming the basement of the basin (1: Northern Calcareous Alps, 2: Greywacke Zone, 3: Mesozoic of the Central Alps, 4: Crystalline of the Central Alps, 5: Crystalline of the Carpathians).

1998) already started leading to non-marine and subsequently continental conditions in the Pannonian – Pontian. Although tectonic subsidence was high, the basin was rapidly filled due to the short distance to the source of clastic sediments; the basin cycle is therefore limited to the Middle Miocene.

The general biostratigraphic subdivision (PAPP et al. 1978) into Lower Badenian (Lower and Upper Lagenid Zone), Middle Badenian (*Spiroplectammina* Zone) and Upper Badenian (*Bulimina-Bolivina* Zone, *Rotalia* Zone) is based on typical foraminiferal assemblages, reflecting in fact an ecostratigraphic sequence. This sequence documents a salinity reduction in the uppermost Badenian. The zonal scheme works well in central basinal sections, in marginal positions, however, reliability is limited. Besides these assemblages, planktic foraminifers and certain benthic groups are also of special importance, e.g., uvigerinids, bolivinids and to some extent calcareous nannoplankton (e.g., STEININGER 1977, FUCHS & STRADNER 1977, PAPP et al. 1978, HAUNOLD 1995).

Due to the major marine transgression at the beginning of the Middle Miocene (RÖGL & STEININGER 1983, 1984, RÖGL 1998), subtropical biotas entered the Paratethys. Within the Vienna Basin, facial and biotic development roughly reflects a distinction between marginal and central basin facies.

The most complex facies pattern is developed along the basin margins in dependence on the hinterland and coastal morphology. In general, siliciclastics and carbonates can be differentiated, both exhibiting a rich facial and biotic diversity. The western border of the southern Vienna Basin is highly influenced by the clastic sediment input from the Northern Calcareous Alps. Around the Leithagebirge (Fig. 22), which was an island, a chain of islands or a shoal during the Badenian, autochthonous carbonate sediments dominate (irrespective of sometimes thick basal transgressive deposits).

The coastal development along the western margin shows strong fluvial influx at some locations, expressed by thick conglomerates dominated by material derived from the Northern Calcareous Alps as well as the Flysch Zone. The conglomerates and their components sometimes contain biota such as pebble-incrusting coralline algae, oysters, balanids and corals (Fig. 23). In some places, steep rocky shores with large boulders are also preserved, exhibiting dense settlement by boring bivalves. Wide coastal or marginal areas are covered by sands (Gainfarn Sands) with a rich and excellently preserved fauna (Fig. 23) dominated by molluscs such as *Cerithium, Xenophora, Pinna* and *Strombus*, partly reflecting sea-grass settlement. The soft bottom of the sandflats was inhabited by a vast number of venerids, glycymerids and the index fossil *Megacardita jouanetti* (BASTEROT). Conids and turritellids are represented in exceptional diversity and proper preservation has even allowed for the reconstruction of a fossil symbiosis between hydractinians and hermit crabs.

The basinal facies, the Baden Tegel, is a marl with variable sand and clay content. Intercalated into the marls are sandy layers. This latter material is gravitationally transported from marginal sources. The marls and sandy interbeddings are highly fossiliferous, containing extremely rich microfauna (foraminifers, ostracods) and macrofauna, as well as calcareous nannoplankton. Both micro- and macrofauna have been well-documented since the 19th century (e.g., D'ORBIGNY 1846, REUSS 1849, KARRER 1861, HÖRNES 1856, 1870, HÖRNES & AUINGER 1879). Macrofossils are represented by solitary scleractinians, brachiopods, decapod crustaceans, molluscs, fish remains (teeth and otoliths) and cetaceans. In the sediments of the Lower Badenian the foraminiferal fauna is extremely rich, containing not only planktic and smaller benthic representatives but in the sandy interbeddings also larger forms as *Amphistegina, Planostegina* and *Borelis melo*. The high diversity and good preservation of molluscs (gastropods, bivalves, scaphopods; Fig. 24) is remarkable. Their composition is strongly predominated by Turridae and other carnivorous snails associated with infaunal bivalves and thin-shelled pectinids and reflects soft-bottom communities in deeper circumlittoral environments. A marked decrease in herbivorous forms probably indicates a reduction in light-intensity. In these habitats of weak agitation and fine sedimentation muricids display remarkable fragile ornamentations. The depositional depth of this fine-clastic material can be interpreted as being not deeper than 50-200 m (PAPP & STEININGER in: PAPP et al. 1978, TOLLMANN 1985). Although subsidence of the basin during the Badenian was very rapid, the relatively shallow water depth can be explained by a high sedimentation rate leading to a sediment accumulation of approx. 1,500 m in the central basin during the Badenian (e.g., WESSELY 1988).

The most widespread facies unit along the Leithagebirge and the Ruster Höhenzug, as well as at certain sites along the western margins of the Vienna Basin with reduced terrigenous input (e.g., around Wöllersdorf), is the Leitha Limestone. The name of this unit was already established by KEFERSTEIN (1828) and is also well-known outside the Vienna Basin. The unit was redefined by PAPP & STEININGER in: PAPP et al. (1978), who considered the broad facial range. Due to its high abundance of coralline red algae (Fig. 25), this Leitha Limestone is also well-known as *Nullipora* or *Lithothamnium* Limestone. The first description of a fossil coralline red algae out of this limestone – *Nullipora ramosissima* REUSS 1847 – is historically important. The original material of this taxon was recently rediscovered and the species was assigned to the genus *Lithothamnion* (PILLER 1994). In general, the limestone is characterized by the occurrence of coralline algae in various growth forms (Fig. 25), ranging from rhodolith dominated types to branched facies (maërl). Coral buildups of limited size are developed only locally. Such buildups are rare along the western margin of the Vienna Basin due to the high terrigenous input and are represented only by small patch reefs. The best-developed coral buildups are present at the southern tip of the Leithagebirge, where the limestones reach the greatest spatial extent and the thickest sequences (about 50 m). Due to the island position no major terrigenous influx restricted coral growth here. Particularly at the southern tip of the Leithagebirge water currents or relatively strong waves favoured their growth. The corals are represented mainly by various taxa of *Porites*, accompanied by *Tarbellastraea*, *Caulastrea*, *Acanthastrea* and *Stylocora* (PILLER & KLEEMANN 1991) (Fig. 25).

Additionally, typical faunal elements of the Leitha Limestone are thick-shelled bivalves such as *Macrochlamis nodosiformis* (SERRES) and ostreids, forming beds up to five meters thick. Among echinoids infaunal clypeasterids, which lived shallowly burrowed in the loose algae debris are

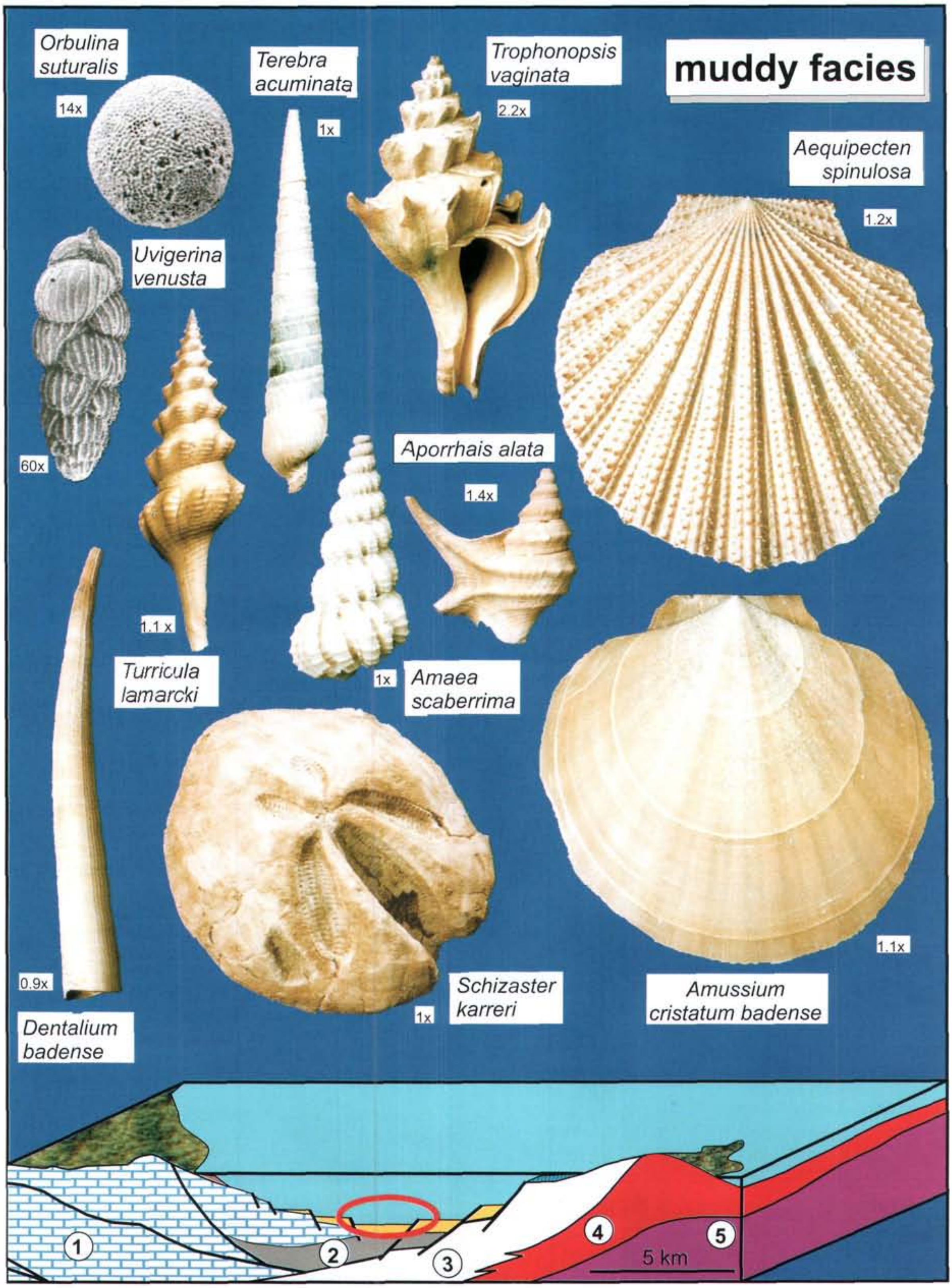

Fig. 24
Typical Badenian biota of the muddy facies (Baden Tegel) of central basinal sediments (red ellipsis in the basal block diagram of figure). For further explanations see Fig. 23.

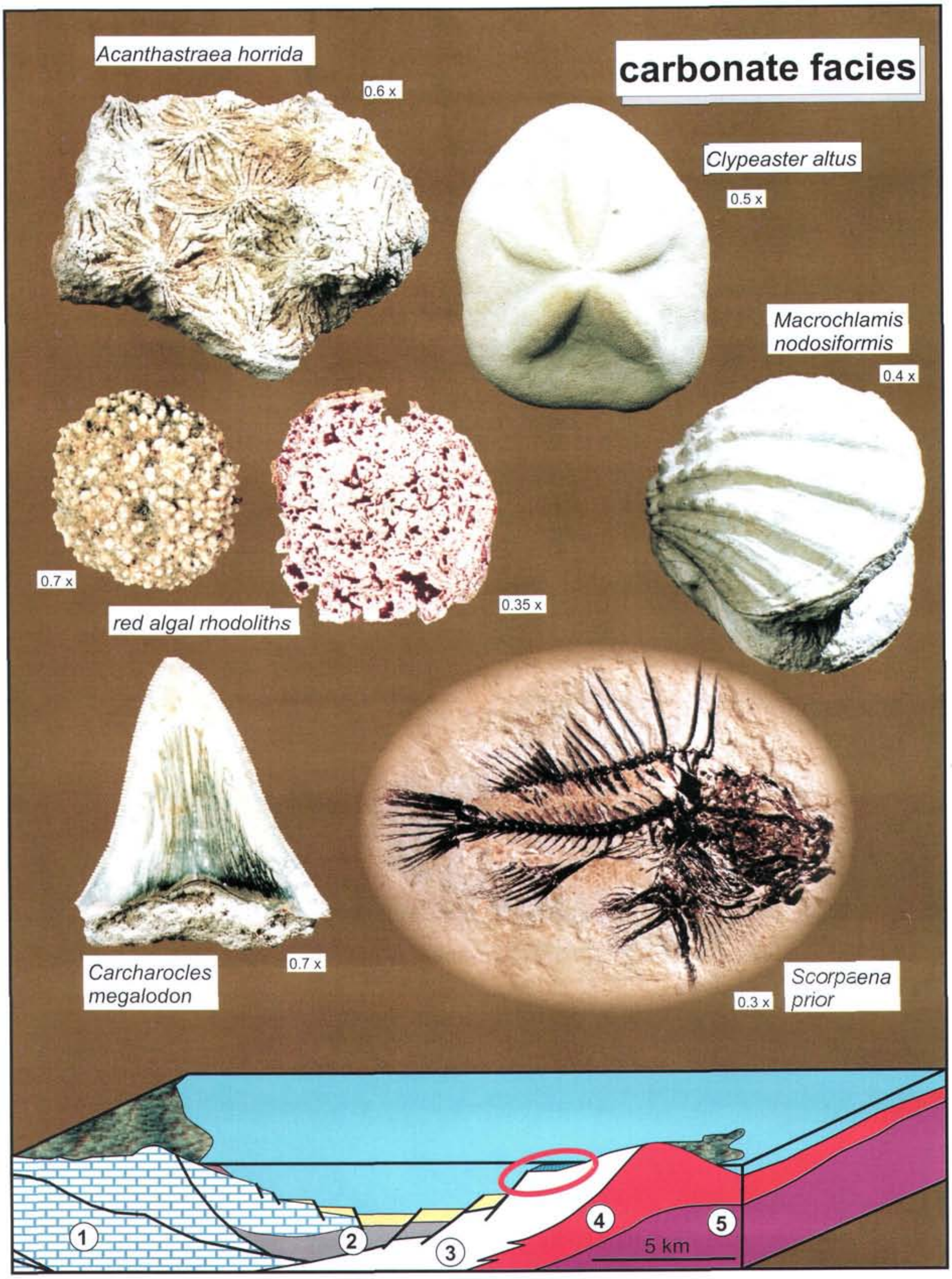

Fig. 25
Typical Badenian biota of the carbonate facies (Leitha Limestone), particularly at the western margin of the Leithagebirge (red ellipsis in the basal block diagram of figure). For further explanations see Fig. 23.

common, as well as large shark remains (Fig. 25) and crustaceans (BACHMAYER & TOLLMANN 1953).

An exceptional "Fossillagerstätte" occurs at St. Margarethen in Burgenland (Fig. 22), where an excellently preserved fish fauna occurs (SCHULTZ 1993, CHANET & SCHULTZ 1994) in fine-grained, partly laminated, marly limestones. Besides scorpenids (Fig. 25), the oldest known parrot fish is also recorded from here (BELLWOOD & SCHULTZ 1991). The depositional environment was recently interpreted as very shallow marine, partly representing a flooded intertidal flat (PILLER et al. 1996).

Miocene Primates from Austria

(GUDRUN DAXNER-HÖCK)

Catarrhine primates came from Africa and appeared for the first time in Europe at the end of the Early Miocene. They had a wide distribution across Western and Central Europe and Southwest Asia during the Middle and Late Miocene.

In Austria their existence has been demonstrated in the Molasse Zone in Upper and Lower Austria, as well as from the Vienna basin northeast and southeast of Vienna, and in the "Lavanttal" (Carinthia) and Aflenz Basin (Styria), which

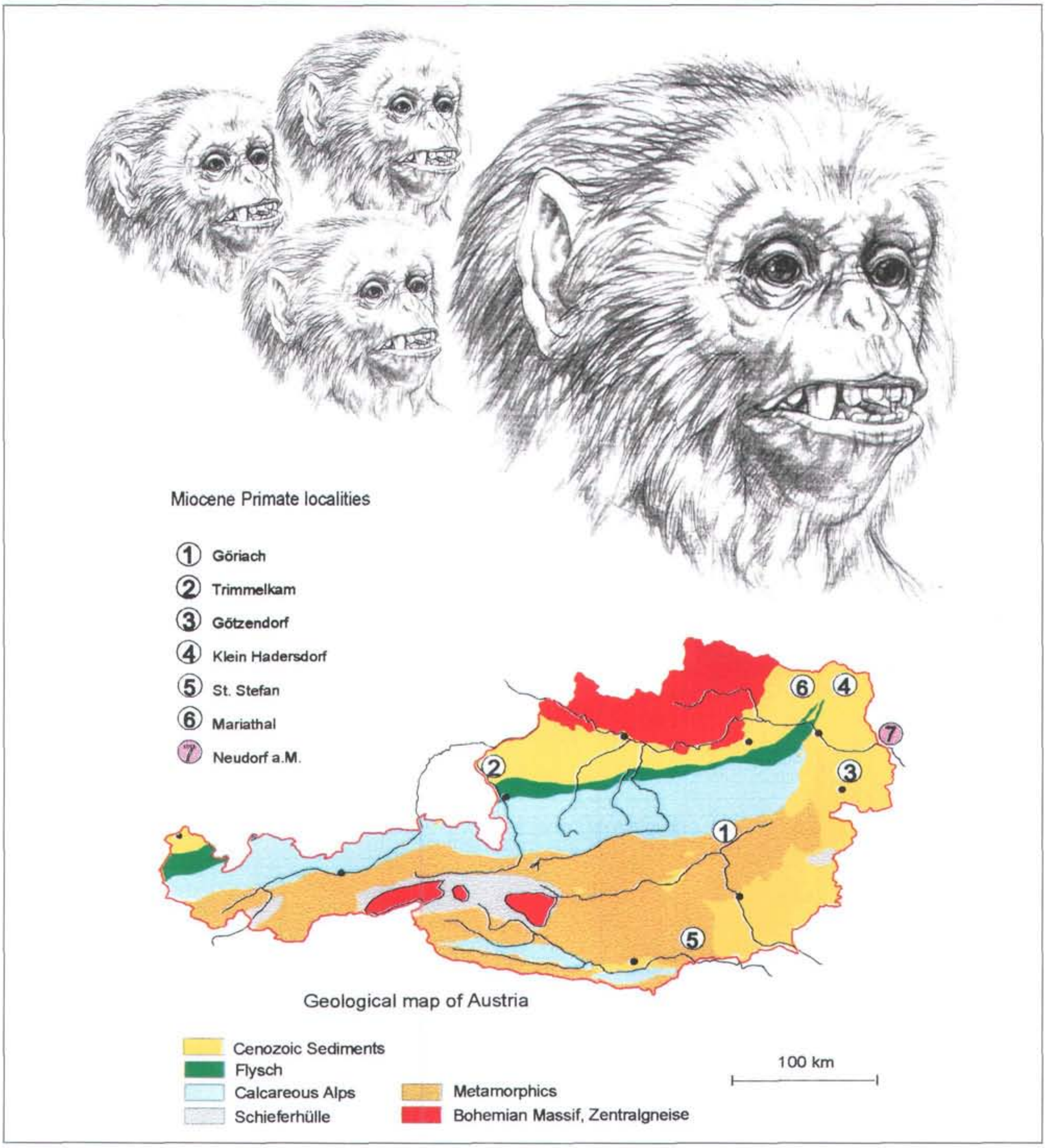

Fig. 26
Geographical position of Miocene primate localities from Austria and Slovakia.

Table 1
Basic data on Miocene Primates from Austria.

Miocene Primates from Austria

	age	**locality**	**lithology**	**figure**	**collection**	**main references:**
						ANDREWS et al. 1996
Pliopithecidae						and ZAPFE 1969
Pliopithecinae						
***Pliopithecus platyodon* BIEDERMANN 1863**	Badenian	Göriach, Styria	lignite	fig. 1/1	NHMW, MJOG,	
* *Hylobates antiquus* GERVAIS	MN 6 ?				MOUL, PMBE,	* HOFMANN 1893
					NHMB	
Crouzeliinae						
***Plesiopliopithecus lockeri* ZAPFE 1961**	Badenian	Trimmelkam, Upper Austria	lignite	fig. 1/2	MHNS	
* *Pliopithecus (Plesiopliopithecus) lockeri*	MN 6 ?	(type locality)				* ZAPFE 1961
***Anapithecus hernyaki* KRETZOI 1975**	Pannonian	Götzendorf, Lower Austria	sand,	fig. 1/3	NHMW,	
* *Dryopithecus brancoi* (SCHLOSSER)	MN 9		fluvial		SCHW	* ZAPFE 1989
Hominidae						
Dryopithecinae						
***Griphopithecus darwini* (ABEL 1902)**	Badenian	Klein Hadersdorf, Lower Austria	sand,	fig. 1/4	PIUW	
* *Austriacopithecus weinfurteri*	MN 6 ?		delta			* EHRENBERG 1937
* *Austriacopithecus abeli*						* EHRENBERG 1937
***Dryopithecus carinthiacus* MOTTL 1957**	Sarmatian	St. Stefan , Carinthia	lignite	fig. 1/5	LMKK	
* *Dryopithecus fontani carinthiacus*	MN 8 ?	(type locality)				* MOTTL 1957
***Dryopithecus carinthiacus* MOTTL 1957**	Pannonian	Mariathal, Lower Austria	sand,	fig. 1/6	PIUW	
* *Dryopithecus brancoi* (SCHLOSSER)	MN 9		fluvial			* THENIUS 1982

Abbreviations:
NHMW - Naturhistorisches Museum, Wien (A)
NHMB - Naturhistorisches Museum, Basel (CH)
MHNS - Haus der Natur, Salzburg (A)
MJOG - Landesmuseum Joanneum, Graz (A)
MOUL - Montanuniversität, Leoben (A)
SCHW - Coll.Schwengersbauer, Mannersdorf (A)
PIUW - Paläontol. Inst. Univ., Wien (A)
LMKK - Kärntner Landesmuseum, Klagenfurt (A)
PMBE - Paläontologisches Museum, Berlin (D)

* first description

are two intramontane basins in southern and central Austria (Fig. 26/1-6, Table 1). Six Austrian vertebrate faunas have been recorded from lignite mines, river sediments and delta deposits, which yielded fossil primate remains. There is some evidence that only one species is present in each site. The lignite deposits from Trimmelkam, Göriach and St. Stefan represent swampy forest areas, in which pliopithecids or hominids lived. The sands of Klein Hadersdorf are interpreted as delta sediments. They contained hominid limb bones. The faunas of Götzendorf and Mariathal yielded pliopithecid and hominid remains, respectively. These were imbedded in sands, which characterize a marginal fluvial environment. Special mention must be given to two famous primate localities of Devinska Nova Ves (Neudorf a. d. March) from Slovakia, which are situated close to the easternmost border of Austria (Fig. 26/7). The type locality of *Pliopithecus vindobonensis* stems from this area. It is the well-known fissure "Neudorf Spalte". A few teeth of *Pliopithecus antiquus* and *Griphopithecus darwini* were located in the marine sands of "Neudorf-Sandberg", which is a second site of the Devinka Nova Ves area (ANDREWS et al. 1996).

In Austria some primate species are represented by isolated teeth only: *Anapithecus hernyaki* from Götzendorf and *Dryopithecus carinthiacus* from Mariathal. *Dryopithecus carinthiacus* from St. Stefan and *Plesiopliopithecus lockeri* from Trimmelkam have been identified by jaws, while *Pliopithecus platyodon* from Göriach is based on an extensive collection of jaws, skull fragments and isolated teeth which originated from at least ten individuals (ZAPFE 1969). Although postcranial hominid remains are generally rare, *Griphopithecus darwini* from Klein Hadersdorf is documented by a humerus and an ulna only.

According to the European record, the extinct primates – the pliopithecins, the crouzeliins and the dryopithecins – ranged in Austria from the Middle to the Late Miocene. Their first records were in the Badenian, i. e., *Pliopithecus platyodon* from Göriach, *Plesiopliopithecus lockeri* from Trimmelkam and *Griphopithecus darwini* from Klein Hadersdorf. *Dryopithecus carinthiacus* from St. Stefan is of Sarmatian age. *Anapithecus hernyaki* from Götzendorf and *Dryopithecus carinthiacus* from Mariathal were recorded for the last time in the Pannonian.

The Cave bear: Gentle Giant of the Alps

(DORIS NAGEL, GERNOT RABEDER)

Large quantities of fossil teeth and bones have been found in caves throughout Europe, from the Pyrenees to the Urals and from the Abruzzen to the Harz mountains. They belong to a type of bear, which differs from the living brown bear in many aspects and was classified in 1794 as a separate species – *Ursus spelaeus* – the cave bear.

The cave bear is mainly a European speciality. More than 30 cave bear sites are known in Austria alone (DÖPPES & RABEDER 1997; Fig. 27) and some of these caves are situated at an altitude of 2,000 m or more (Salzofen, Ramesch-Knochenhöhle, Brettstein, Brieglersberg, Schreiberwand-Höhle, etc.).

The abundance of cave bear remains and the possibility of radiocarbon dating, as well as uranium-series dating, allow us to deal with this extinct animal both zoologically and palaeontologically. Questions like biostratigraphy, palaeobiogeography, palaeoclimatology, mode and speed of evolution, way of living (hibernation, food preference), sexual dimorphism, size variation and interaction with humans can now be answered. A short summary is given here.

The evolutionary line from *Ursavus* to *U. etruscus* to *U. deningeri* leading to *U. spelaeus* is well documented in Austrian caves and sites (Fig. 27). The cave bear weighed up to 900 kg and thus was larger than any living bear today (Fig. 28). The increase of cusps per tooth and the enlargment of occlusal surfaces – suited to grinding functions – is an adaptation to a herbivorous way of live. The rapid evolution from an omnivorous ancestor to a herbivorous cave bear, documented in various sites and profiles, took less than 150,000 years: Radiocarbon and uranium-series dates constrain these palaeontological results. This evolutionary speed is unrivalled among mammals.

In some cases up to 92% of the pollens found in caves are from Asteraceae. We assume that these are remains of the cave bear diet, which passed the digestive system (e.g., *Armeria, Artemisia, Centaurea, Geranium, Knautia, Scabiosa* and *Trifolium*).

The only herbivorous bear today is the Great Panda but it inhabits areas with a temperate climate. The cave bear had to face long winters. There are only two solutions to this problem: migration or hibernation; the cave bear chose the latter, which saved him about 95% of the needed energy. The abundance of cave bear bones in caves are mostly the remains of individuals, which did not survive the winter. This frequent occurrence and their statistical relevance make the cave bear the most important animal in mammalian palaeontological evolutionary research.

Cave bears had an obvious accentuated sexual dimorphism, in which females were about 15% smaller than males. Measurements of the canines prove not only this difference in size but also the male/female distribution in the fossil sites: it is nearly equal, with slightly more females. This corresponds with the results of studies concerning recent brown bear populations.

The coincidence of cave bears with Palaeolithic stone artefacts left by humans only proves a mutual interest in caves as a shelter and it is unlikely that the caves were inhabited simultaneously. The excavations of over 20 caves in Austria, with thousands of fossil teeth and bones revealed no evidence so far to substantiate the "cave bear cult" (BÄCHLER 1923, 1940, PACHER 1997).

Figs. 27 + 28 see next page

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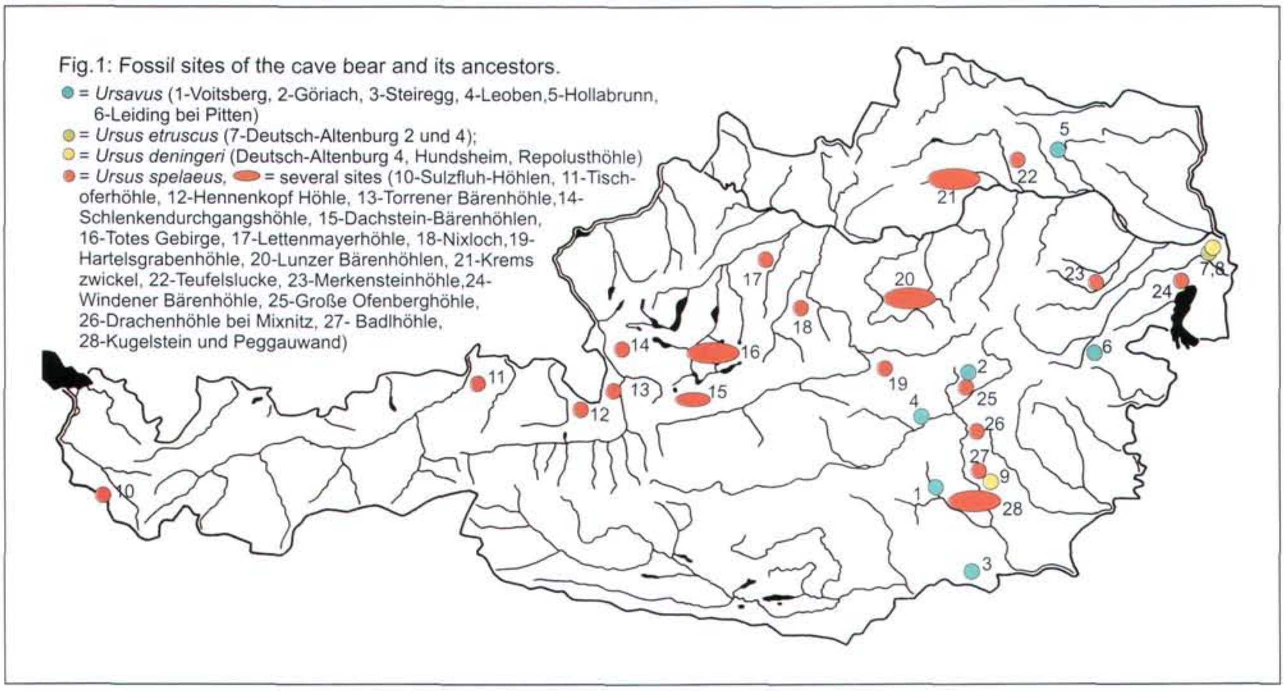

Fig. 27
Fossil sites of the cave bear and its ancestors in Austria.

Fig. 28
Reconstruction of a cave bear. Original in the Bündner Naturmuseum, Chur, Switzerland (Copyright Bündner Naturmuseum, Chur).

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Autor(en)/Author(s): Piller Werner E., Daxner-Höck [Daxner] Gudrun, Domning Daryl P., Forke Holger C., Harzhauser Mathias, Hubmann Bernhard, Kollmann Heinz Albert, Kovar-Eder Johanna, Krystyn Leopold, Nagel Doris, Pervesler Peter, Rabeder Gernot, Roetzel Reinhard, Sanders Diethard, Summesberger Herbert

Artikel/Article: Palaeontological Highlights of Austria. 195-233