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

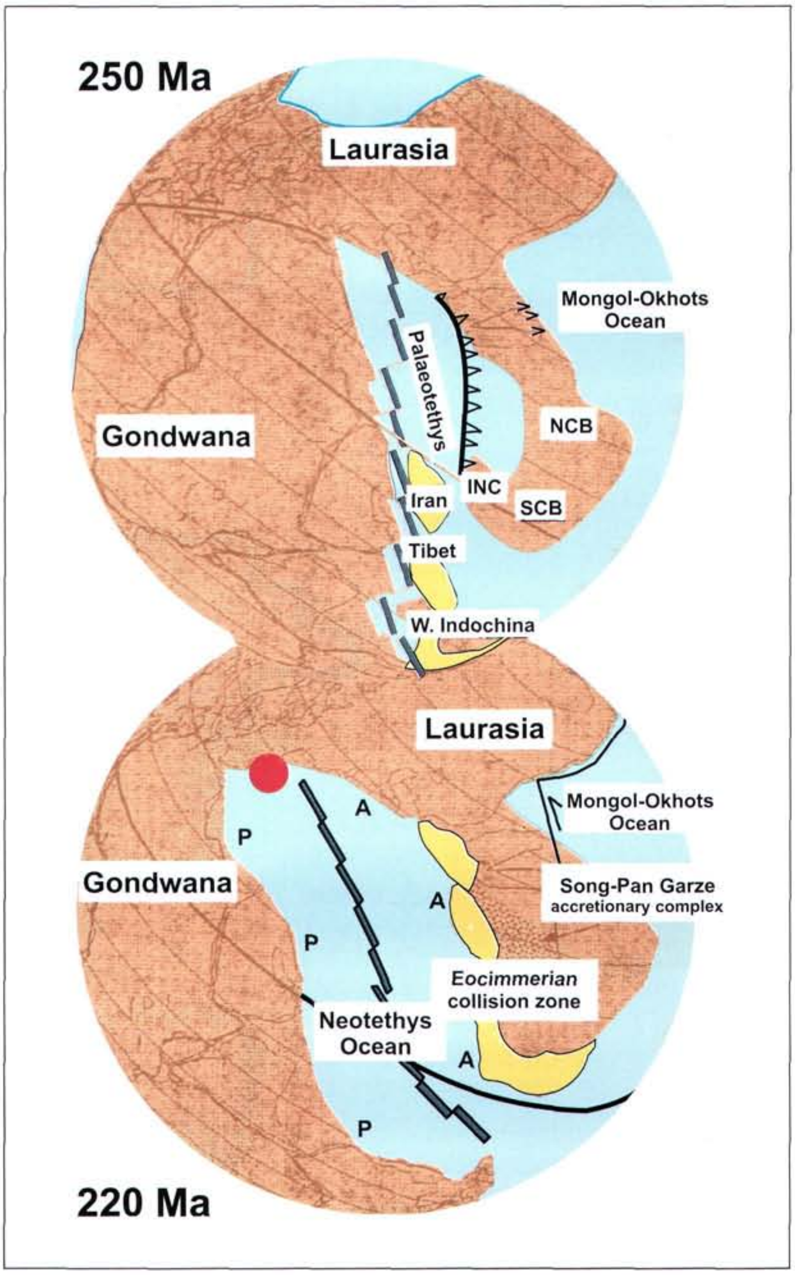


Fig. 8
Palaeogeography of the Tethys during the time slices 250 Million years and 220 Million years b. p. (A = active margin of the Neotethys, P = passive margin of the Neotethys, INC = Indochina block, NCB = North China Block, SCB = South China Block, red dot = approximate position of the Northern Calcareous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

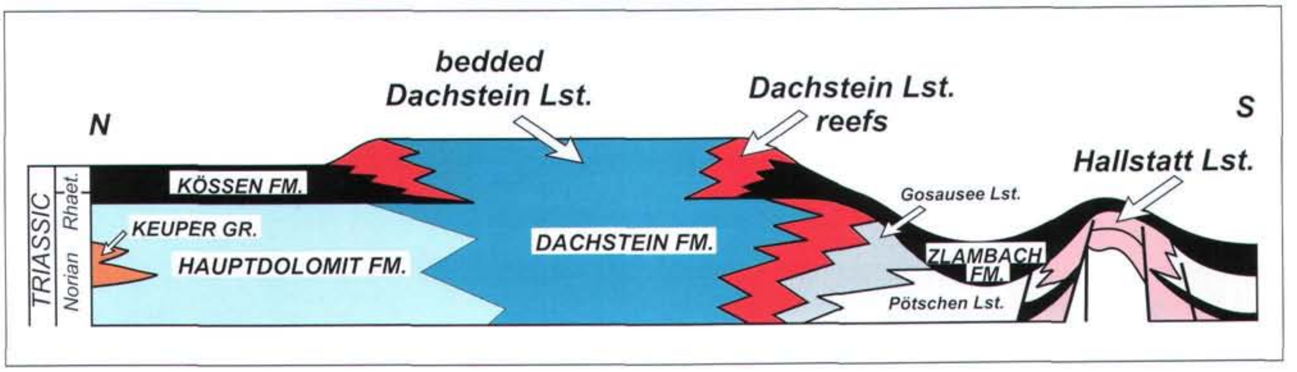
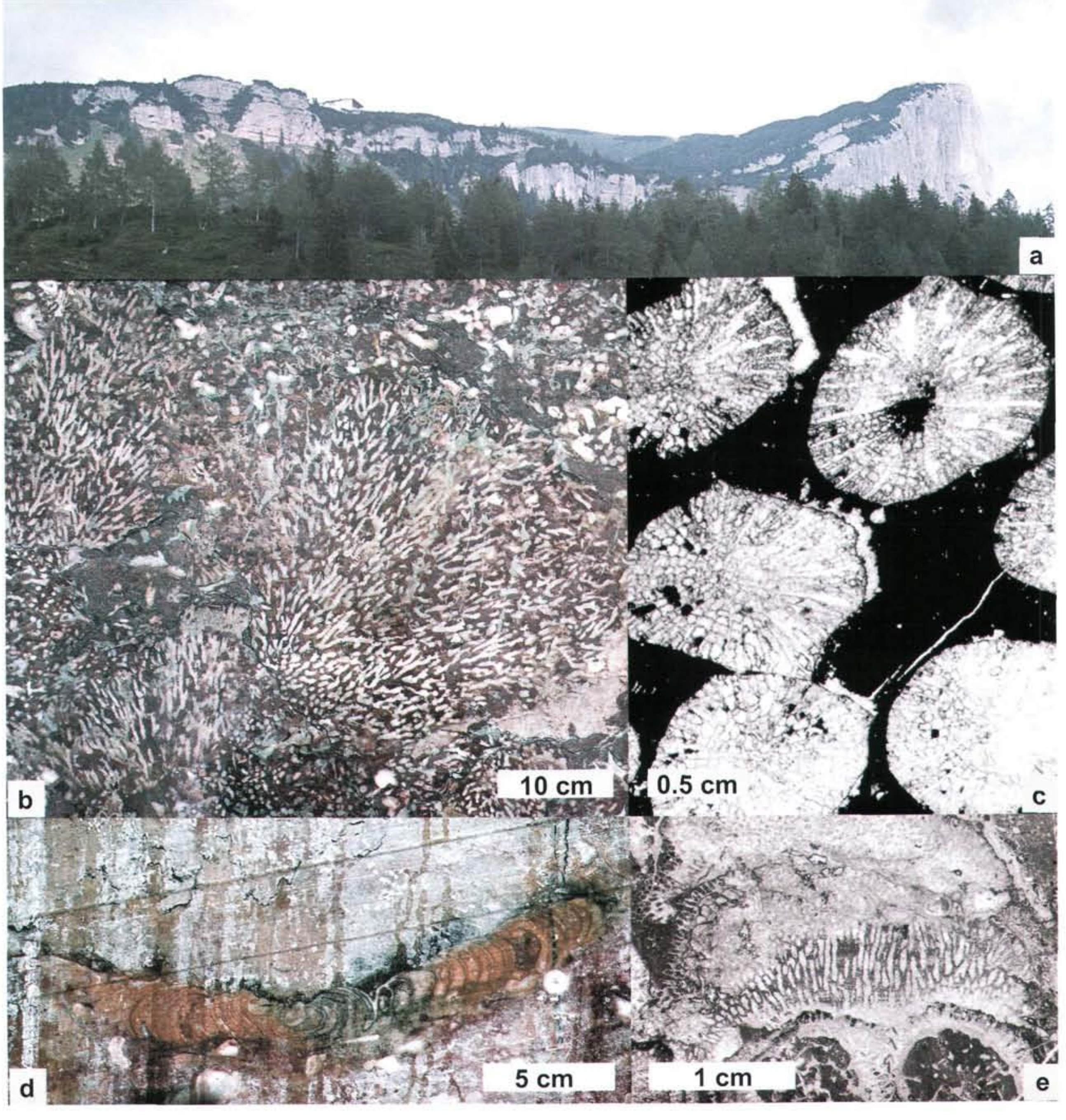


Fig. 9
Schematic Upper Triassic (Norian-Rhaetian) facies reconstruction of the Northern Calcareous Alps (after MANDL this volume).



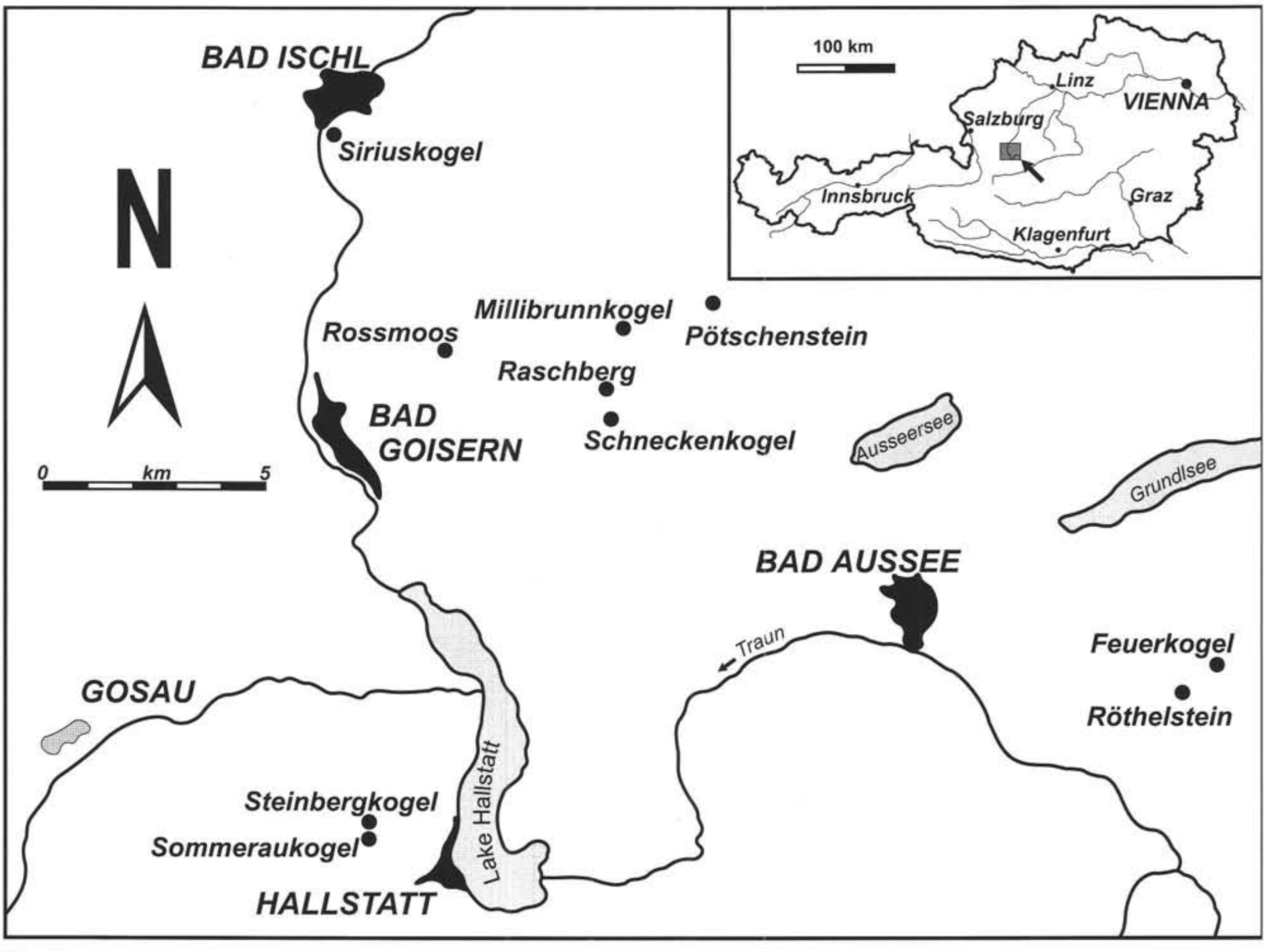


Fig. 11
Location map showing the most important Hallstatt Limestone fossil sites in Austria.

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).

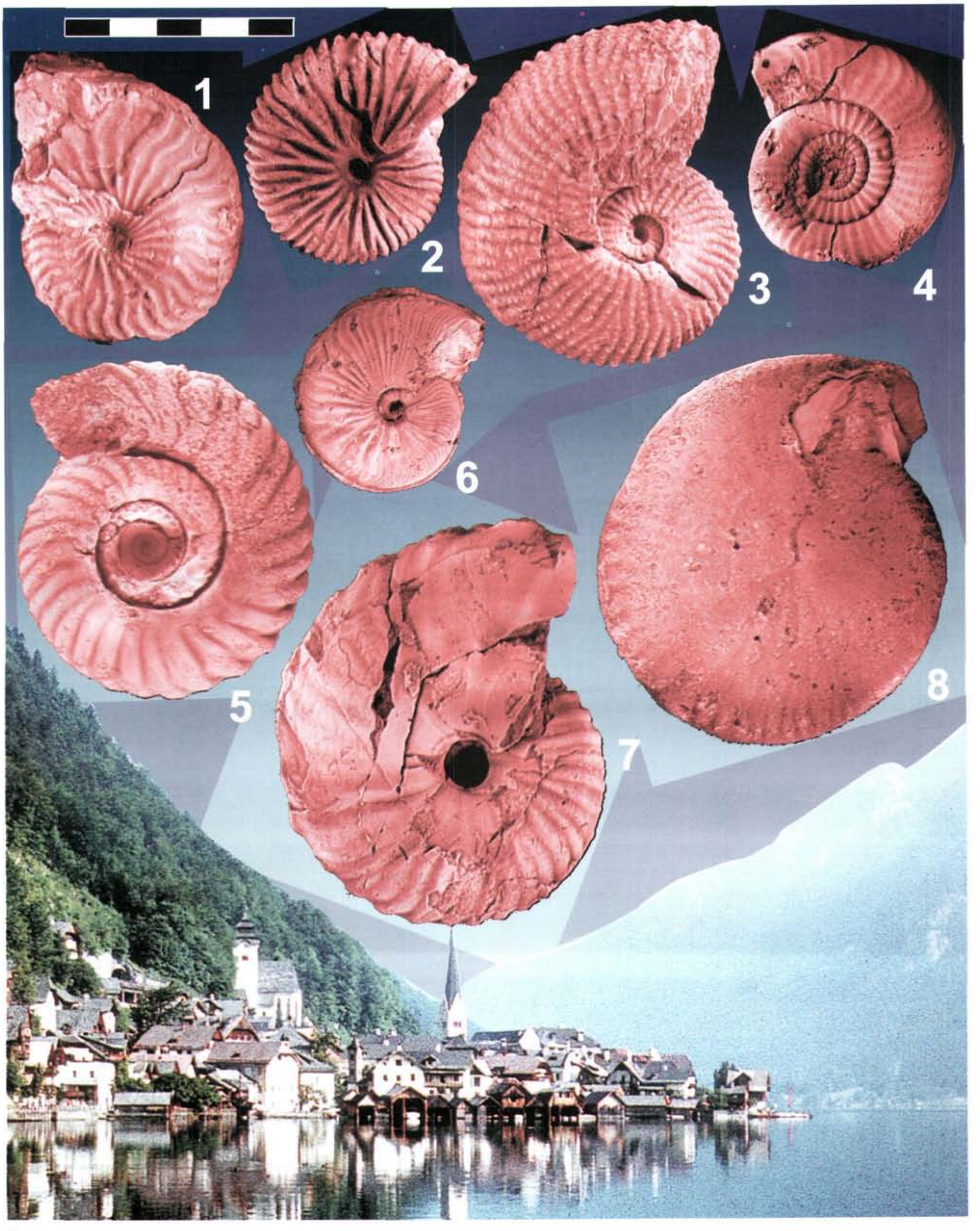


Fig. 12

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.