EXCURSION 1

The Hallstatt pelagics – Norian and Rhaetian Fossillagerstaetten of Hallstatt

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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 more than 100 m with a mean sedimentation rate of 3 m per million years over a period of 40 Ma, from Middle to Late Triassic. In the middle Rhaetian, concurrent with the formation of the siliciclastic intraplatform Kössen basins, accumulation of pelagic limestone ceased and was replaced by grey and later blackish marls of the Zlambach Formation. This is in sharp contrast to the dinarid and southern Tethys margin where Hallstatt Limestone and/or pelagic carbonate deposition continued to the top of the Triassic (e.g. Csövar, Sicily, Greece, Turkey, Oman).

Two types of particularly different Hallstatt limestone sequences are known. The "normal" type is widespread and remarkably poor in megafauna, especially cephalopods. Biostratigraphy is based on halobiids or presently on more frequently occurring conodonts. 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 discontinous with corroded and Fe-Mn-oxid coated surfaces. Most of the common 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, these 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 as Fossillagerstätten from many Alpine mountain chains between 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 of or references to Upper Triassic chronostratigraphic and biostratigraphic subdivisions are designated herein (KRYSTYN et al. 1971a, b, KRYSTYN & SCHLAGER, 1971).

St.		ammonoid zone	locality
Rhaetian	M.	*Vandaites stuerzenbaumi*	ST1
	L.	*Paracochloceras suessi* (*Sagenites reticulatus*)	ST2, ST3, ST5, STK A-C
Norian	U.	*Sagenites quinquepunctatus*	ST4, STKA-C SK: Metternichi-Lager (P: VI)
	M.	*Halorites macer*	SK: Bicrenatus-Lager (P: III - IV)
		Himavatites hogarti	
		Cyrtopleurites bicrenatus	
	L.	*Juvavites magnus*	SK: Patens-Lager (P: II, 68/123)
		Malayites paulckei	SK: (P: I)
		[*Guembelites jandianus*] *Halobia styriaca*	Sommeraukogel (=SK) (P: XV)

Fig. 1: Norian to middle Rhaetian ammonoid zones and respective Fossillagerstaetten in Steinbergkogel and Sommeraukogel (localities numbers refer to fig. 5 and 12). The ammonoid-free *Guembelites jandianus* Z. is substituted by *Halobia styriaca*.

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 (Fig. 1). Centred around lake Hallstatt 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, Raschberg, Schneckenkogel near Bad Goisern as well the world famous locations of the Feuerkogel close to Bad Aussee and the Sommeraukogel above Hallstatt (Fig. 2). Together with the nearby Steinbergkogel, Sommeraukogel is further important as the type locality of the Hallstatt formation and the historical stratotype of the Norian stage (KRYSTYN et al., 1971). The region is also the richest source of Upper Triassic ammonites in the world. From the Sommeraukogel, close to a famous saltmine active since prehistoric times (Hall = Celtic word for salt), about 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 according to 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. Recent studies (KRYSTYN et al., 2007) have demonstrated the faunistic and biochronologic significance of the Steinbergkogel for documenting the Norian-Rhaetian boundary and defining a GSSP for the base of the Rhaetian stage.

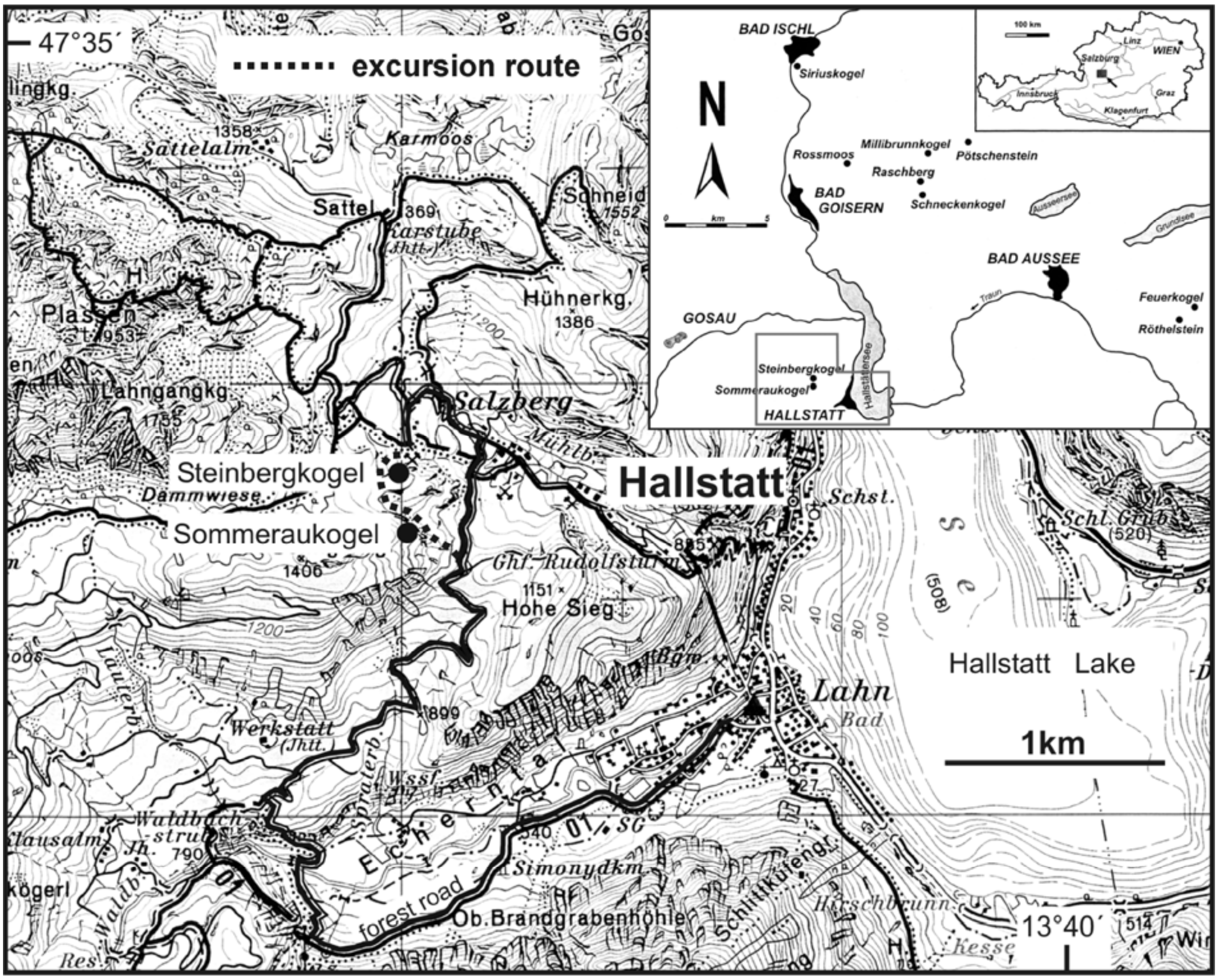


Fig. 2: Hallstatt map with excursion route and location of the Steinbergkogel and Sommeraukogel.

A comprehensive study on lithology, thickness and petrology of the Hallstatt Limestone of the Salzkammergut region was carried out by SCHLAGER (1969). According to him the Hallstatt sequence can be divided into several parts, each characterized by distinct lithologic features (fig. 3). Between these basic Hallstatt lithotypes and the coeval Reifling- and Pötschen limestones additional types of transitional character may occur, caused by variations in colour, bedding, flaser structures and content of clay minerals, as well as content and colour of chert-nodules/layers. The following summary is based on SCHLAGER (1969), KRYSTYN (1980) and MANDL (1984):

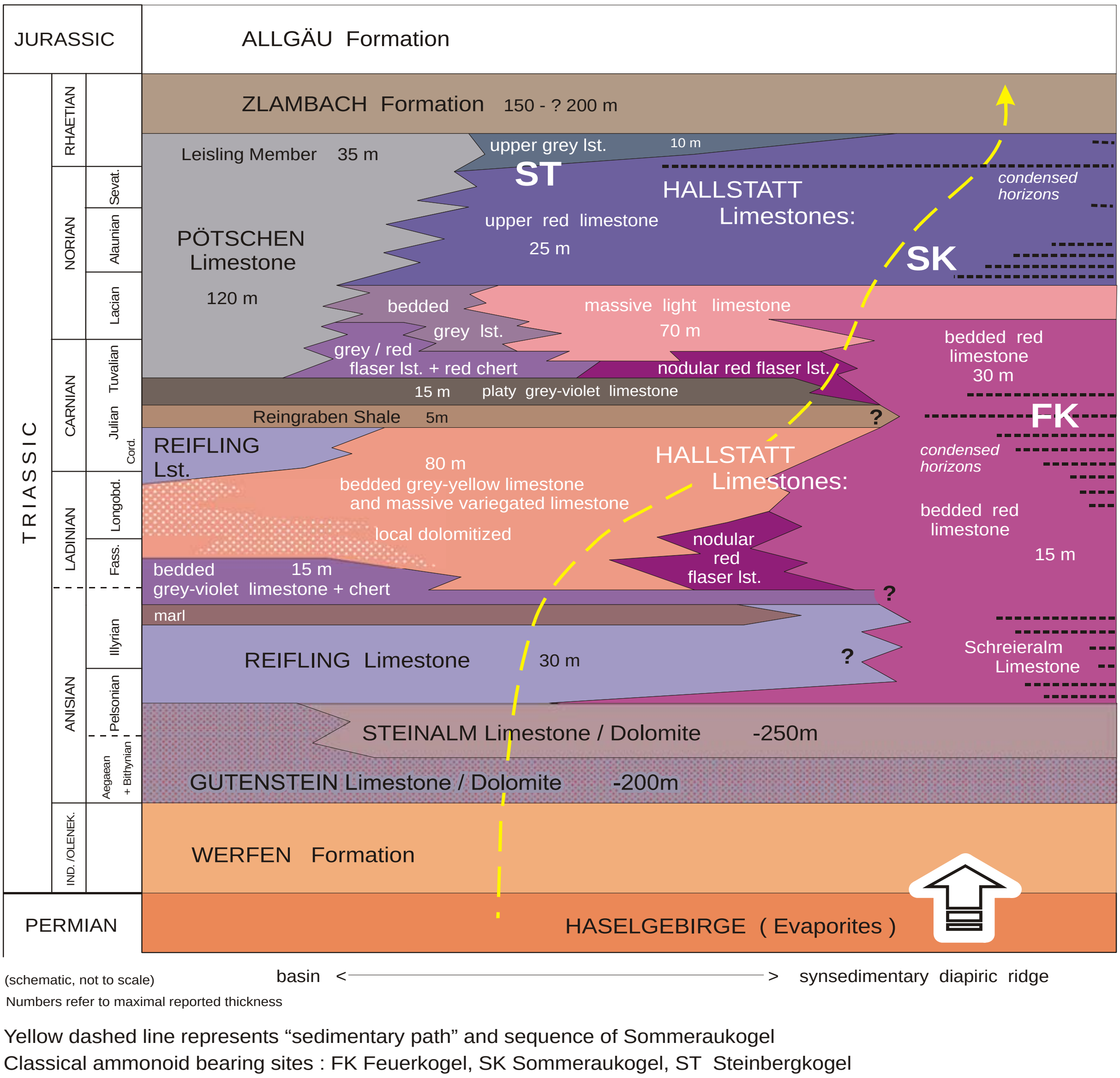


Fig. 3: Lithostratigraphy of the Hallstatt Triassic.

Grauvioletter Bankkalk (= greyish-violet bedded lst.): Well bedded to nodular bedded, 10 to 20 cm thick microsparitic to pelsparitic, in part siliceous limestone beds. At its base chert nodules may frequently occur. Colour and the brittle fracture are distinct features of this type which hardly can be mixed with any other limestone type.

Graugelber Bankkalk (= greyish-yellow bedded and massive lst.): Partly well bedded (10 to 20 cm), partly indistinct bedded limestone. Colour varies between greenish-grey, yellow and light brownish. Biomicrite to microsparite with pellets/peloids, filaments, intraclasts/

resedimentation and bioturbation. Often very similar to *Massiger Hellkalk* (= massive light limestone) but distinctly older (see fig. 3).

Roter Knollenflaserkalk (= red nodular flaser-limestone): Reddish and regularly bedded, nodular Flaser-limestone consisting of 10 to 30 cm thick beds separated by thin marly partings. In terms of microfacies this limestone is a biomicrite with bivalves and radiolarians as main constituents of the fauna. Formation of nodules and flaser structure is explained by pressure solution during an early diagenetic stage.

Roter Bankkalk (= red bedded limestone): Reddish to pink coloured biomicritic limestone with strong bioturbation causing mottled and irregular textures. Beds are 20 to 50 cm thick and well developed. Individual beds are mostly homogenous but locally interstratal reworking can be found. Particularly at Feuerkogel subsolution patterns with Fe-Mn crusts are frequent. In the upper part lateral changes may occur within short distances. The transition to the overlying massive "Hellkalk" is gradually; locally an alternation between both types occur.

Massiger Hellkalk (= massive light limestone): Irregularly thick bedded to massive micritic limestone. Colour predominantly white, grey or light pink. Another characteristic feature is the great thickness. First reports on this lithotype were published by Mojsisovics, 1905 from Raschberg ("Wandkalk") and from Sommeraukogel.

Hangendrotkalk (= upper red limestone): Platy to nodular bedded biomicritic limestone with mostly strong bioturbation pattern. Locally flaser-structure can be found but this feature is less dominating than in the *Knollenflaserkalk*. Subsolution patterns occur frequently, in particular at Sommeraukogel (thinning of individual beds in the direction of a submarine ridge).

The so-called *Hangendgraukalk* is regarded as a lateral equivalent of the *Hangendrotkalk*; apart from the colour, this type is also more argillaceous and usually thinner bedded. It replaces the uppermost Norian to Rhaetian portion of the *Hangendrotkalk* at Steinbergkogel near Hallstatt.

The Steinbergkogel

The Steinbergkogel is a small und unnamed summit (1245 m above sea level) situated in the south-western corner of sheet 96 (Bad Ischl), official topographical map of Austria 1:50,000. It is located just south of the westerly-most salt mine gallery symbol (crossed hammers in fig. 2), corresponding to the entrance of the Ferdinandstollen (Stollen = gallery in English) in an altitude of 1140 m.

There is a wealth of literature referring to invertebrate faunas of the Steinbergkogel. Ammonoids have been described by MOJSISOVICS (1873-1902), pelagic bivalves by KITTL (1912), gastropods by KOKEN (1897), brachiopods by BITTNER (1890) and conodonts by MOSHER (1968) and KRYSTYN et al. (2007a,b). A comprehensive faunal list is found in SPENGLER (1919) with reference to specific locations.

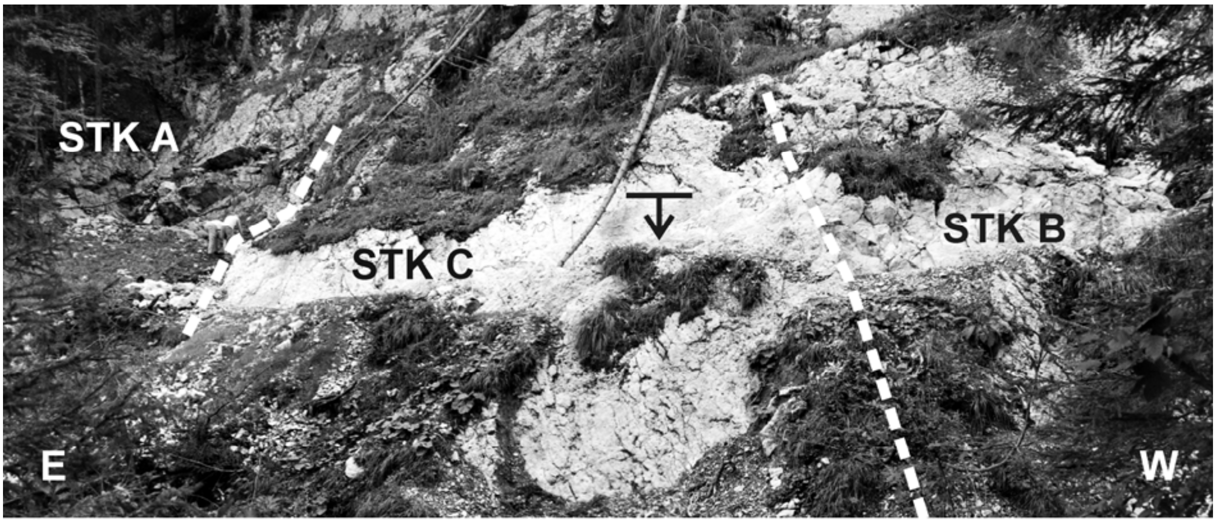


Fig. 4: STK quarry photo with sections A, C and B.

Access to Steinbergkogel is possible by a forest road that starts in the Echerntal and reaches after 7 km the Salzberg and the Ferdinandstollen from where the quarry STK with the candidate section for the NRB GSSP can be seen in a distance of 25 m when looking to the south (Fig. 4). Alternatively one can reach the Steinbergkogel directly from Hallstatt by taking the cable car to Rudolfsturm (855 m) and following then a marked footpath along the prehistoric burial ground of the Hallstatt (Celtic) period and some Salt mine buildings in north-westerly direction towards the Plassen peak to arrive at Ferdinandstollen within a one hour of walk. The proposed candidate (coordinates 47°33'50''N, 13°37'34"E) is exposed in a long abandoned quarry where blocks have been extracted to mantle the galleries of the salt mine. Most of the classical Steinbergkogel ammonoid fauna (MOJSISOVICS, 1873-1902) may have been collected by miners from that place, but DIENER (1926) mentions another fossil locality about 100 m on strike to the west (ST 2 in fig. 5). As the latter is of slightly younger age than the quarry rocks, the old faunal record may be of stratigraphically mixed origin in the sense of "rucksack-condensation".

The Steinbergkogel is composed of a uniformly (70°N) dipping sequence starting with a thick whitish, massive and unfossiliferous Lower Norian variety (*Massiger Hellkalk* Member) overlain by about 30-40 metres of bedded predominantly red (*Hangendrotkalk* Member) and in the top grey, finegrained pelagic limestones (bioclastic wackestones) of latest Norian to lower Rhaetian age (in new sense); the upper half of the grey limestone (*Hangendgraukalk* Member) develops thin clay interbeds that have eased the quarrying of stones and indicate a gradual transition to grey marls of the Zlambach Formation building usually only short-time exposures like the present one behind the Ferdinandstollen.

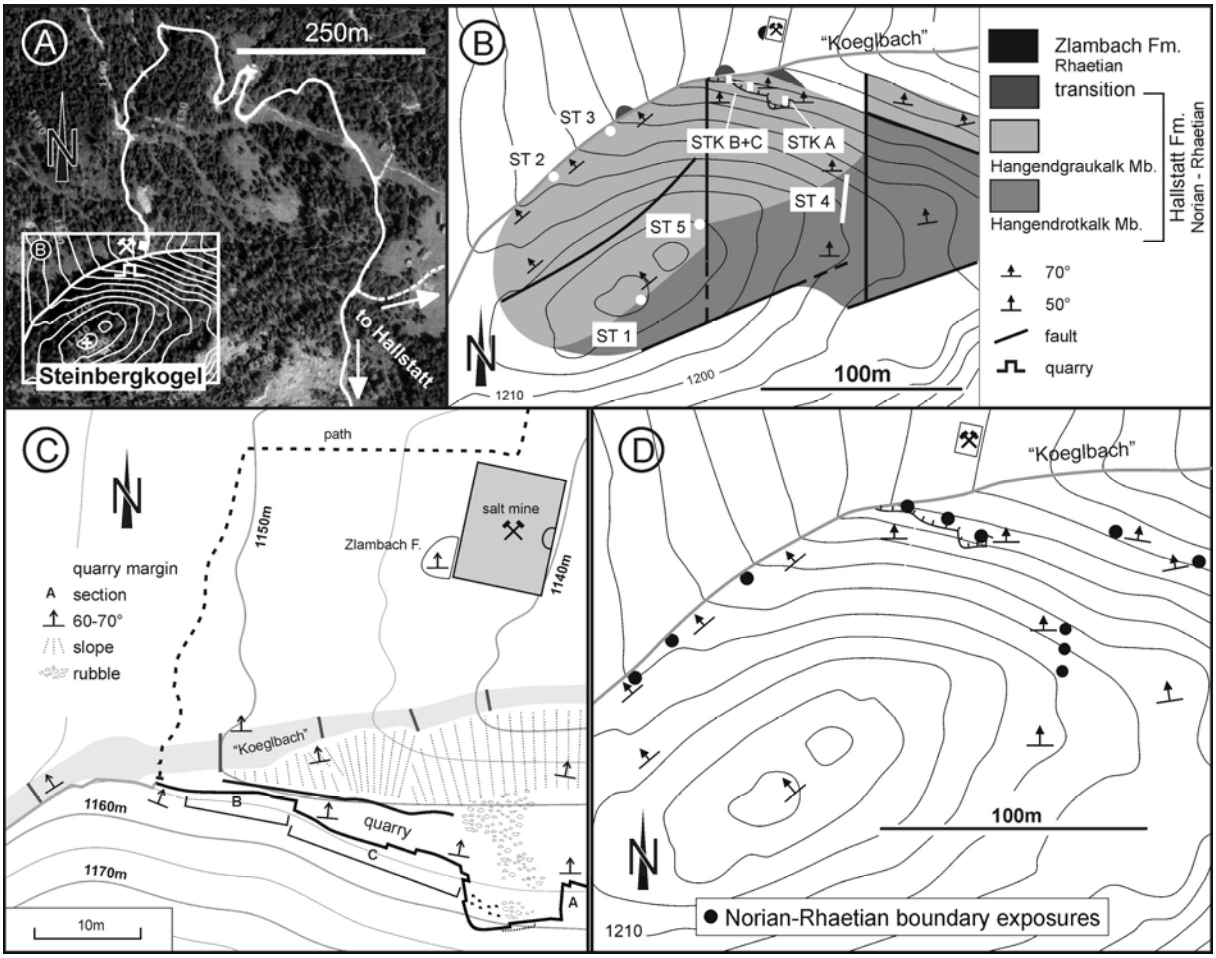


Fig. 5: Detailed Steinbergkogel maps: A) arial view, B) geology with sections and fossil localities, C) quarry STK and D) location of NRB exposures.

The important Norian-Rhaetian boundary interval corresponds to the basal part of the *Hangendgraukalk* and is well exposed along strike for 200-300 m along the northern footwall of the Steinbergkogel (fig. 5) close to and within a small ravine (Koegl creek) that follows the lithological boundary from compact limestones to the less resistent transition beds. Stratigraphically below the quarry section are more than 20 m of red Upper Norian limestones (ST 4 in fig. 5) containing several layers with *Monotis salinaria, Heterastridium*, ammonoids and conodonts that allow a cross-correlation with the quarry sections (fig. 6).

The STK quarry consists of 4 meters of medium to thin bedded micritic limestones with the proposed candidate section STK A located at the eastern end (Fig. 5). About 20 beds have been studied in detail, numbered from bottom to top as 103 to 122 (fig. 7). Of boundary relevance have been identified bed 108 to bed 112A representing one meter of thickness and differing from over- and underlying rocks by a high bioclastic fossil content made up of ammonoids and subordinate echinoderms. Above bed 113 the microfacies shifts to a shelly-poor, mud-dominated facies type. Rock colours change around bed 107 from red to grey and return locally to grey-reddish mixed above bed 115. A low CAI of 1 excludes any thermal overprint and favors the preservation of the original palaeomagnetic signal and of a primary $\delta^{13}C$-record (fig. 7). Another measured sequence 10 m to the west (STK C) with faunistically comparable results strengthens the biochronologic significance of section STK A and enlarges the palaeomagnetic database into the lower Rhaetian considerably (fig. 8).

To achieve stratigraphically reliable conodont ranges at least 10 kg of limestone have been dissolved from each bed between 108 and 112. This intense search has led to p-element recoveries of 50-100 specimens per sample, with *Epigondolella bidentata* dominating up to bed 110 and replaced by a *Misikella* dominance above (fig. 9). *Norigondolella steinbergensis*, usually the most frequent faunal element in this time interval is fortunately rare as well as ramiform elements. Taxonomic terminology for conodonts of the genus *Misikella* follows KOZUR & MOCK (1991) and ORCHARD (1991) for *Epigondolella* (including *Mockina*) *bidentata*. Increasing platform and size reduction in the latter species during its phylogenetic end phase (*Cochloceras* interval) leads to a predominance of small platform-less parvigondolellid forms in *Epigondolella* unfavourable environments. Those forms have been named *Parvigondolella andrusovi* KOZUR & MOCK or *Parvigondolella lata* KOZUR & MOCK and are described as diagnostic for a time interval younger than that of *E. bidentata*. In *Epigondolella* favourable facies “parvigondolellids” are, however, either fully (*P. andrusovi*) or for a major part (*P. lata*) time equivalent to *E. bidentata* and therefore considered here as morphological variants or ecostratigraphic morphotypes of the latter species (GALLET et al., 2007).

A first conodont event is seen in bed 108 where *Oncodella paucidentata* and *Misikella hernsteini* appear – without known forerunners identified only as FO dates. *Misikella hernsteini* is rare between bed 108 and 110 (max. 10%) but gets frequent from 111A onwards (fig. 9). Bed 111A marks the FAD of *M. posthernsteini*, as phylogenetic successor of the fore-mentioned species, responsible for the most diagnostic conodont datum in the section and probably the worldwide best-documented FAD of *M. posthernsteini* in co-occurrence with *Paracochloceras*. With just two specimens in 111A and four in 111B *M.*

posthernsteini is, however, very rare at the beginning but becomes frequent 30 cm above in bed 112 to get rare again higher up (fig.9).

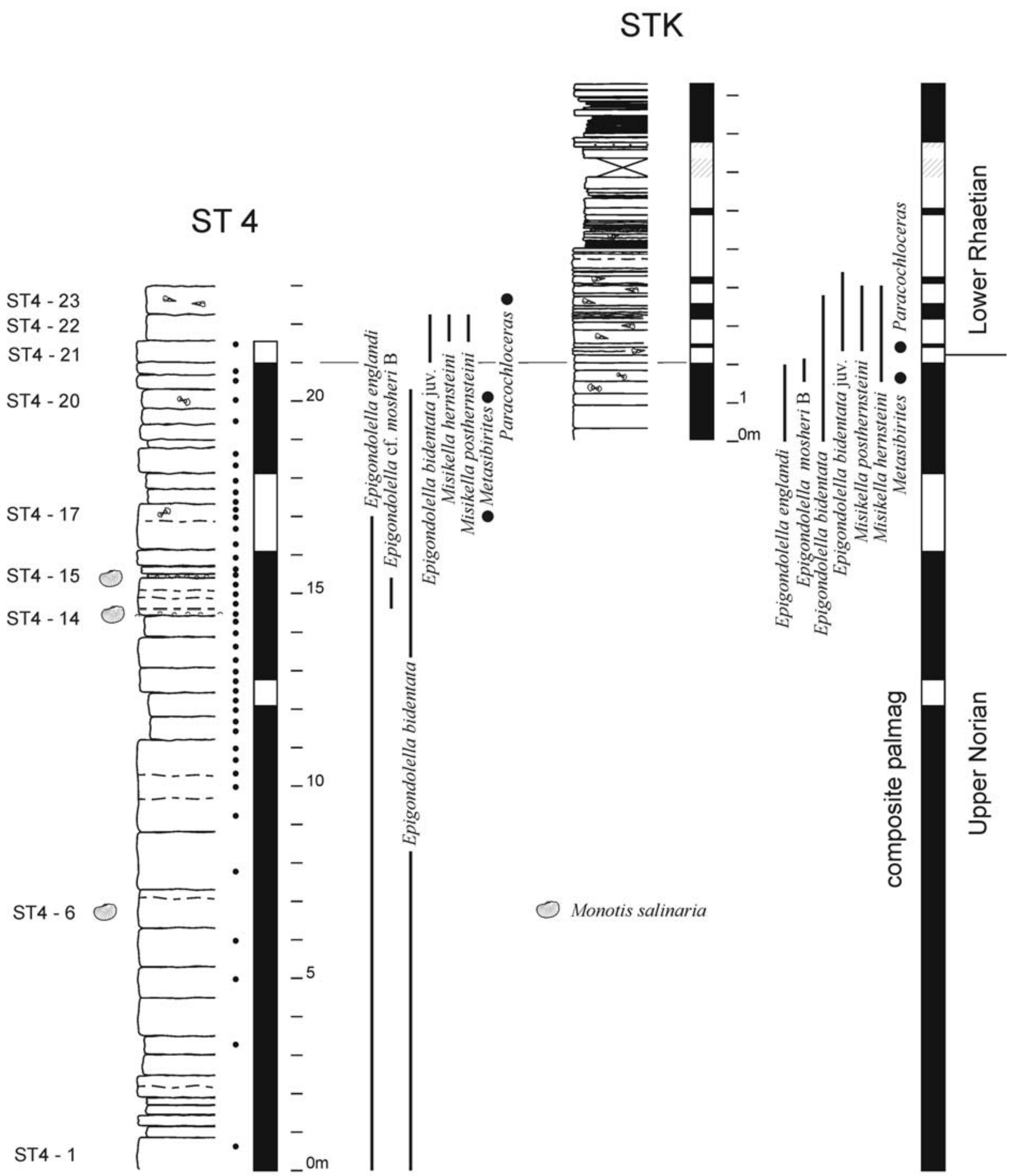


Fig. 6: Composite Upper Norian to lower Rhaetian magnetostratigraphy of the Steinbergkogel (combining sections ST4, STK A and B/C).

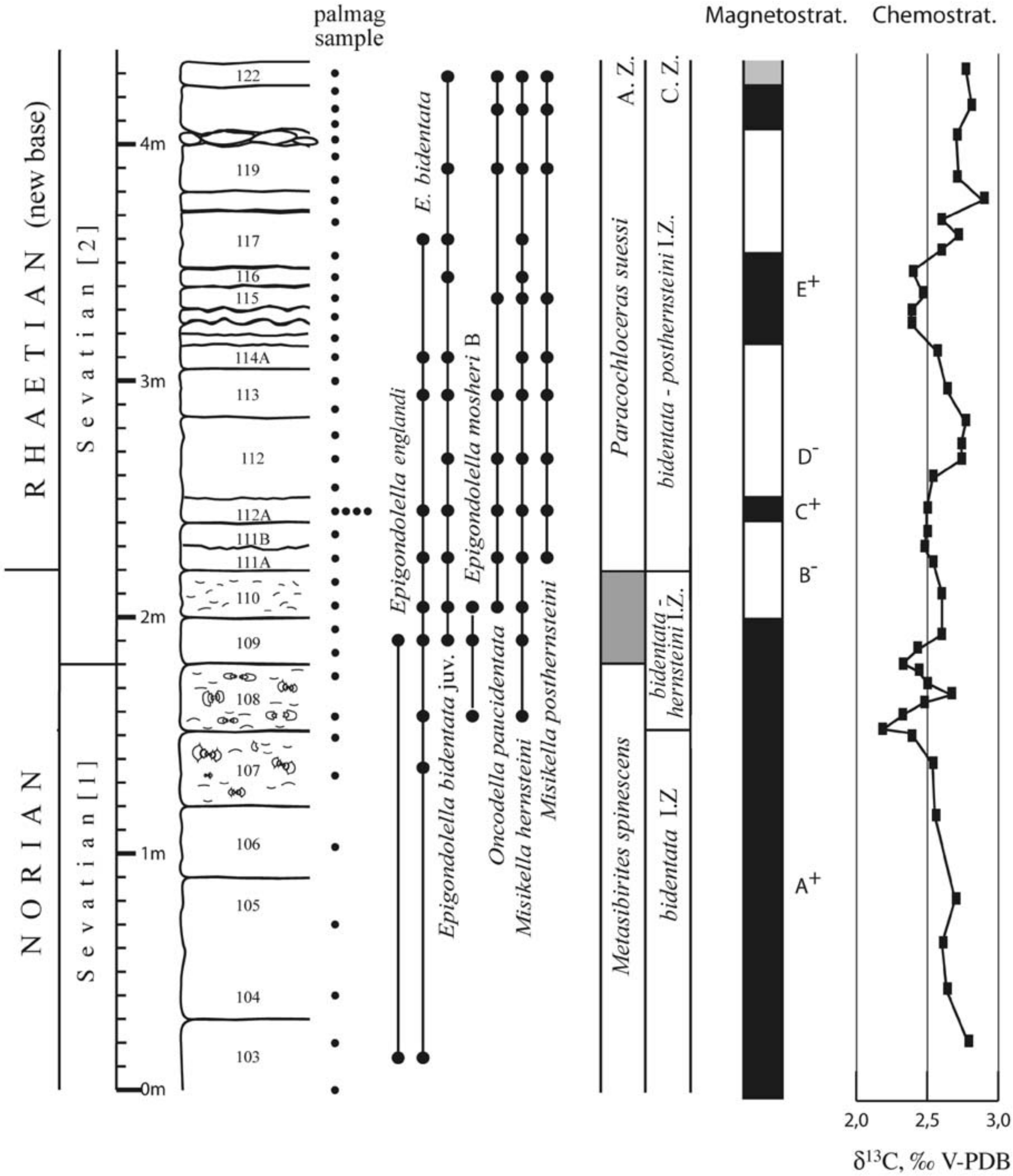


Fig. 7: Integrated bio-, magneto- and chemostratigraphy of GSSP candidate section STK A. Note: Sevatian 1 and 2 refer to previous Upper Norian classification (from KRYSTYN et al., 2007).

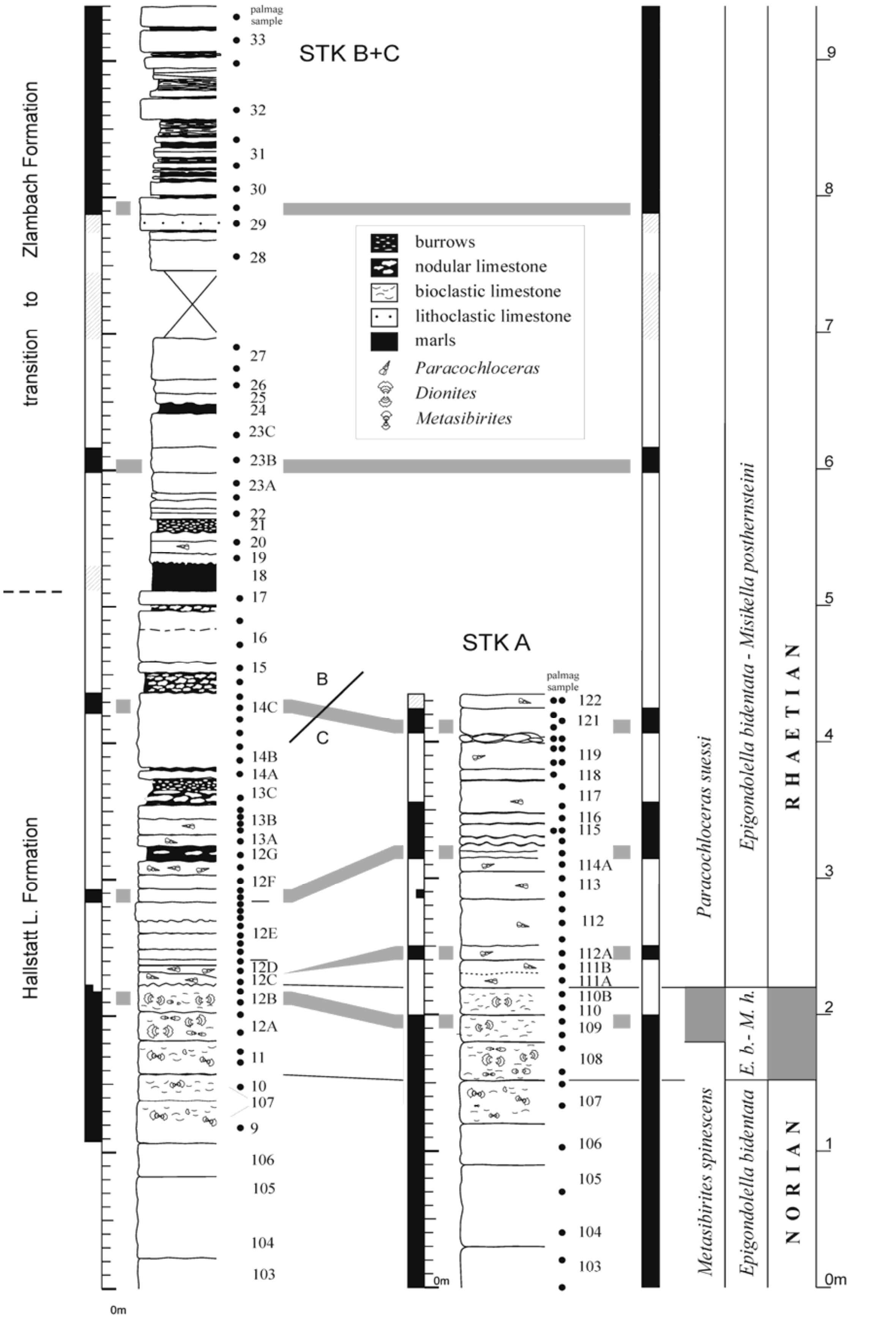


Fig. 8: Bio- and magnetostratigraphic correlation of section A with section B/C in quarry STK; note the high coincidence of bio- and magneto-events between the two sections.

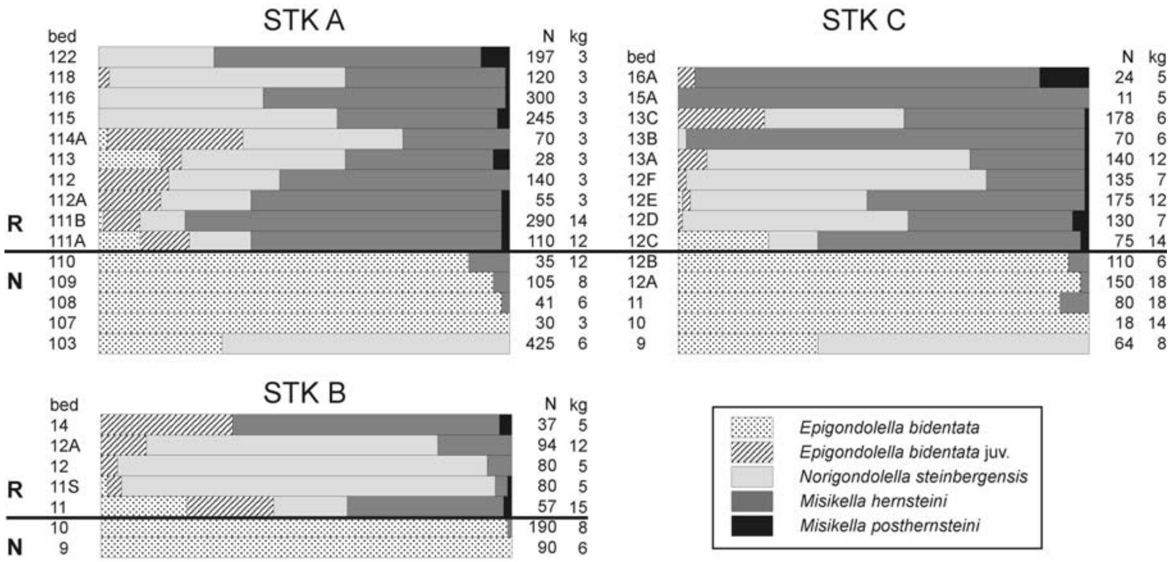


Fig. 9: Relative platform conodont abundances in the STK quarry sections. Note in all three sections the same distinct frequency change between *Epigondolella* and *Misikella* at the NRB and the overall rare occurrence of *M. posthernsteini* in the lower Rhaetian.

The initial infrequence highlights the problem how to recognize the FAD of *M. posthernsteini* in biofacially less favourable environments and use of this event without additional control may cause uncertainties in regional or intercontinental correlations.

Two conodont zones can be distinguished in the NRB interval of the proposed candidate section based on the successive appearances of species of the genus *Misikella*: 1) *Epigondolella bidentata – Misikella hernsteini* Interval Zone, characterized by the co-occurrence of common *E. bidentata* and rare *M. hernsteini* in beds 108 to110 of STK-A and beds 11 to 12B of STK-C respectively, and 2) *Epigondolella bidentata – Misikella posthernsteini* Interval Zone, from bed 111A resp. bed 12C onwards containing *M. posthernsteini* in low quantities compared to the very frequent *M. hernsteini* (fig.9). Bearing in mind the large sample size (more than 5 kg) it may be difficult to detect the base of zone 2 with “on average” sampling. Normal seized *Epigondolella bidentata* becomes rare in Zone 2 and is usely replaced by juveniles resembling the genus *Parvigondolella* (fig. 9). Considerable provincialism limits this zonation to the Tethyan realm where it has successfully been applied to sections in Austria (McROBERTS et al., 2008), Turkey (GALLET et al., 2007), Oman and Timor (KRYSTYN, unpublished data).

Vertical ranges of newly collected time-diagnostic ammonoids are shown in figure 10. *Metasibirites spinescens* is very common in beds 107 and 108 of STK-A and in 9 to 11 of STK-C, *Paracochloceras* starts in bed 111 resp. 12C and is frequently found up to bed 113 with rare occurrences till the top (bed 122) in STK-A, and further up in STK-B/C till bed 22. Other trachyostracean ammonoids are currently rare except for rare juvenile nodose sagenitids (110 and STK-B 11), *Dionites* (beds 109 and 110) and a tiny specimen of

Gabboceras from bed STK-B10 corresponding to bed 109. *Gabboceras* has recently been described by TAYLOR & GUEX (2002) from the basal Gabbs Formation of New York Canyon (Nevada) in a position that may closely match the NRB interval in Steinbergkogel. The genus *Dionites* may have a range across the Norian-Rhaetian boundary and as such may not be boundary-diagnostic. More important is a conodont-dated correlative of bed 111 in ST 2 that contains *Sagenites reticulatus* and *Dionites caesar*. Combining all above cited faunal records permits the discrimination of two ammonoid zones (Fig. 10), a lower with *Metasibirites* (bed 107 to 108) and an upper with *Paracochloceras* (from bed 111A upwards). An alternative and closely matching zonal scheme with *Sagenites quinquepunctatus* below and *Sagenites reticulatus* above seems also justified from these data. A remarkable evolutionary and biostratigraphically useful change is recorded in the family Arcestidae with several species newly appearing closely below the Norian – Rhaetian boundary (fig. 10). Stratigraphically indifferent taxa including *Rhabdoceras suessi, Pinacoceras metternichi, Placites, Arcestes, Cladiscites, Paracladiscites, Rhacophyllites* and *Megaphyllites* are represented in all beds.

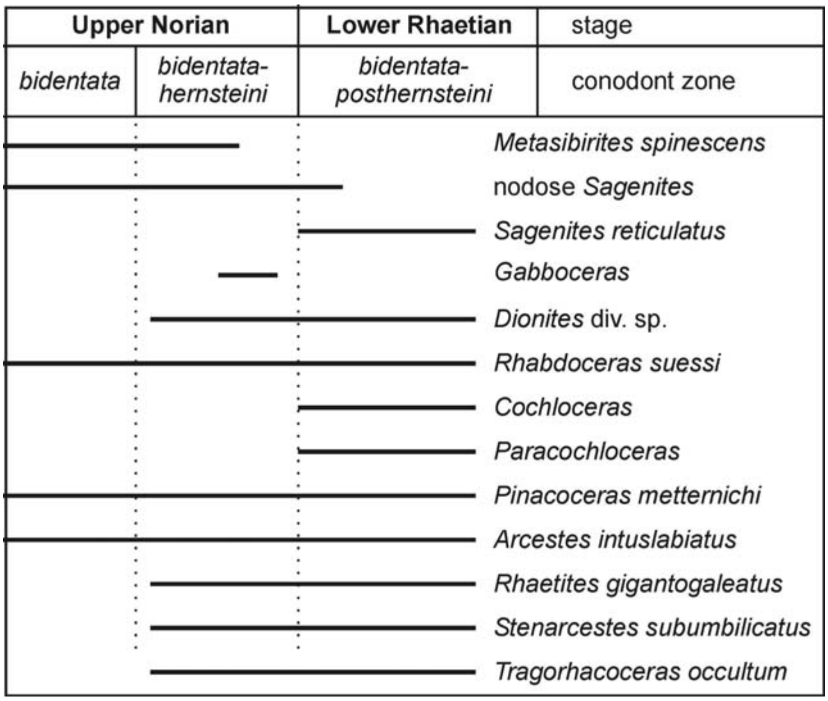


Fig. 10: Ranges of selected ammonoids around the NRB in quarry STK.

Monotids of the *Monotis salinaria* group are common in Steinbergkogel (KITTL, 1912; SPENGLER 1919, p. 359) and almost restricted to the *Hangendrotkalk* Member where they appear in several layers within an interval of 10-15 m (fig. 6). Of special interest is a single unhorizoned large specimen of *M. salinaria* preserved as grey micritic limestone and housed in the collections of the Center of Earth Sciences (of Vienna University). According to the

Steinbergkogel lithologies, this piece must have been derived from the short interval corresponding to beds 108 and 109. This supposed position would confirm the top-Sevatian occurence of *Monotis salinaria* in the Hallstatt Limestone and, in agreement with *Monotis* data from Hernstein, Lower Austria (McROBERTS et al., 2008), its pre-Rhaetian disappearance.

The Steinbergkogel bears beside the STK A and C sections three other ammonoid localities of high stratigraphic importance: 1) 40 m west of the GSSP candidate exposes a corresponding sequence at the western quarry end (STK B) a promising but still not exploited fossil bed (11) in the basal *Paracochloceras* interval; 2) in the Koegl creek 100 m to the northwest of the quarry lies locality ST 2 with a fossil-rich bed that due to a high *M. hernsteini*

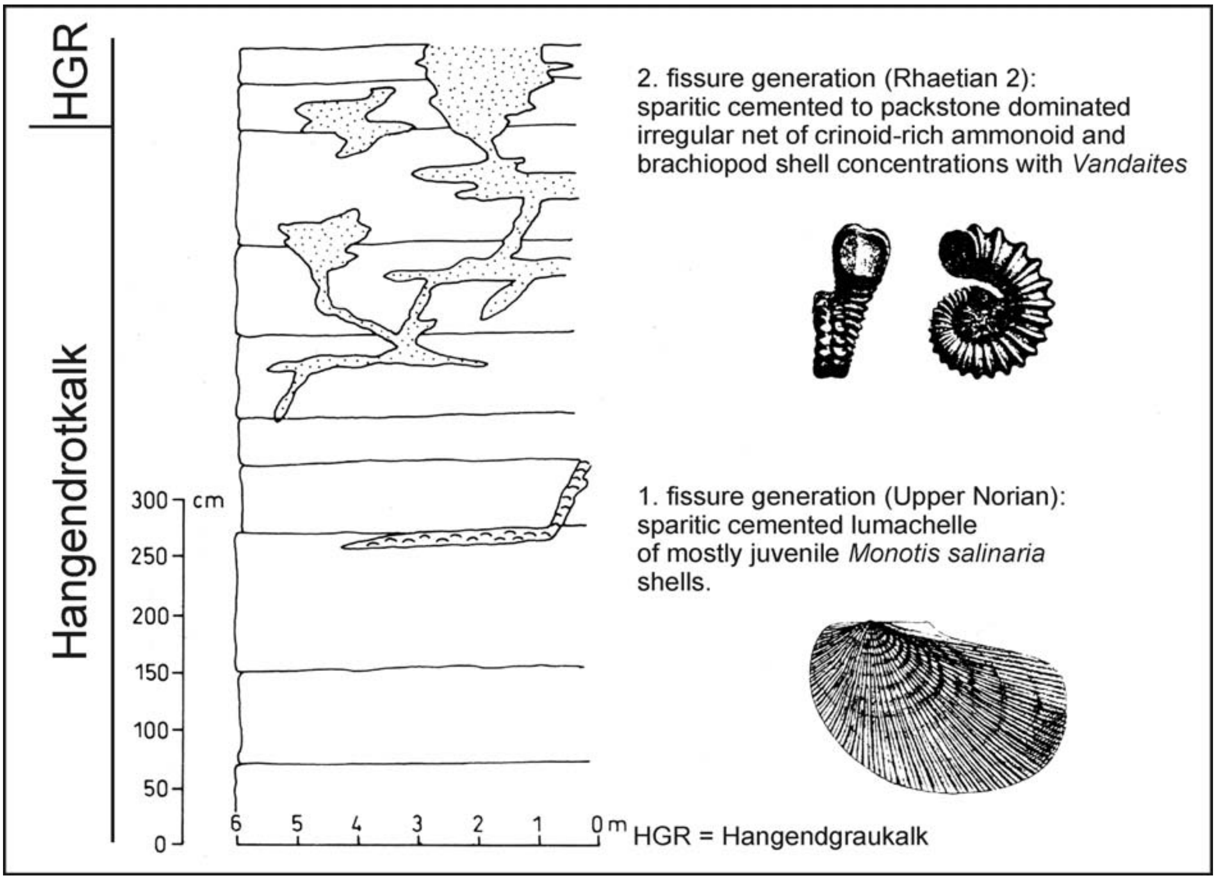


Fig. 11: Stratigraphic log of the middle Rhaetian Fossillagerstätte ST1 at the top of the Steinbergkogel (from KRYSTYN, 1991).

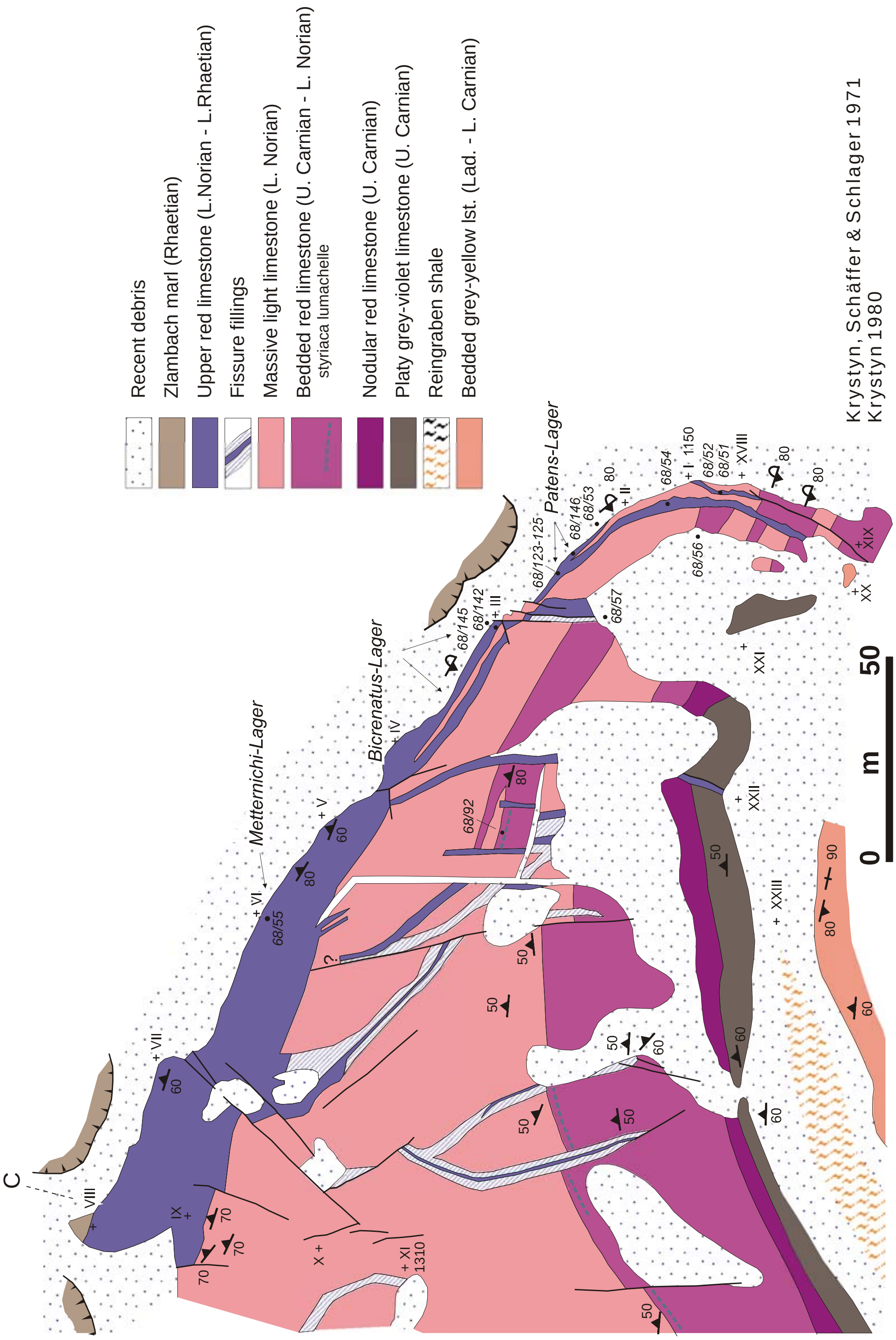
ratio should more likely correspond to the basalmost *bidentata-posthernsteini* I. Z. rather than to the earlier assumed *bidentata-hernsteini* I. Z. (KRYSTYN et al., 2007a); it has delivered *Dionites caesar* and a large *Sagenites reticulatus* and may be the original site of some of the *Sagenites* species described in Mojsisovics (1893) and 3) on top of the Steinbergkogel but without any stratigraphic connection to the GSSP candidate is a local neptunian dike (ST 1 in fig. 5) named by MOJSISOVICS (1893) as “Weisser Crinoidenkalk” with a unique ammonoid assocation containing *Vandaites* (formerly *Choristoceras*) *saximontanum* and *Cycloceltites arduini*. This is now known as the youngest fossil horizon of the Hallstatt Limestone equalled to the basal *Vandaites sturzenbaumi* Zone. The fossils occur in a vertical, up to 50 cm wide, irregular fissure system (fig. 11) that cuts through the whole *Hangendgraukalk* Member down to a level of at least 10 m below the transition from the Hallstatt to the Zlambach Formation (KRYSTYN, 1991). The fissure is easily distinguished from the surrounding red and micritic host rock by its light grey or whitish colour due to the matrix-poor grain-supported, shell- and crinoid-dominated fabric.

Sommeraukogel

On air distance just 200 m south of the Steinbergkogel located**,** the Sommeraukogel exihibits a more complete Hallstatt limestone sequence ranging in age from the Ladinian to the lower Rhaetian. Though separated by younger, Rhaetian and Liassic strata, the two sites have long been regarded as parts of a continuous sequence (SPENGLER, 1919). A more reasonable interpretation explains the Steinbergkogel as the original lateral continuation of the Sommeraukogel and its present separation by a left-lateral fault movement (KRYSTYN, 1980). Sommeraukogel and its western continuation, the Solingerkogel, together form a northeast – southwest striking asymmetrical anticline. Its northward steepening to over-tilted limb exposes the famous Norian fossil layers forming the historical stratotype of the Norian stage (KRYSTYN et al., 1971). All the classical faunal horizons are embedded in a Fe-Oxid rich condensation facies of the Hangendrotkalk, which thins out towards southeast in direction of a submarine ridge (Fig. 12). Both the thickness and age of the individual fossil layers (“Lager” in German) thus depends highly on their respective position in relation to the ridge top - the more distant they are the younger they get. Nearest to the ridge top, close to point (P) II of fig. 12, beds of the top-Lower Norian (Lacian 3) Patens-Lager (“Linse mit *Discophyllites patens*” sensu MOJSISOVICS) are developed.

Thirty meters to the west, between (P) III and IV of fig. 12, the Bicrenatus-Lager (“Linse mit *Cyrtopleurites bicrenatus*” sensu MOJSISOVICS) was located where an up to 4 m thick package of a complete Middle Norian (Alaunian 1 – 3) ammonoid sequence has largly been removed by historic collectors with the drill holes still visible. The next fossil locality follows 150 m to the west (P: VI) and contains Upper Norian (Sevatian) ammonoids and large heterastridians corresponding to the Metternichi-Lager of KRYSTYN et al., 1971. Another 100 m westerly (at P: VIII of fig. 12) the transition from lower Rhaetian Hallstatt Limestone, developed as thin-bedded red nodular limestone, to grey marls of the ?late Rhaetian Zlambach Formation (?*Choristoceras marshi* Z.) is exposed.

Fig. 12 (below): Geological map of the Sommeraukogel with position of the Norian Fossillagerstaetten (Patens-, Bicrenatus- and Metternichi-Lager) and the Rhaetian section at (P) VIII.



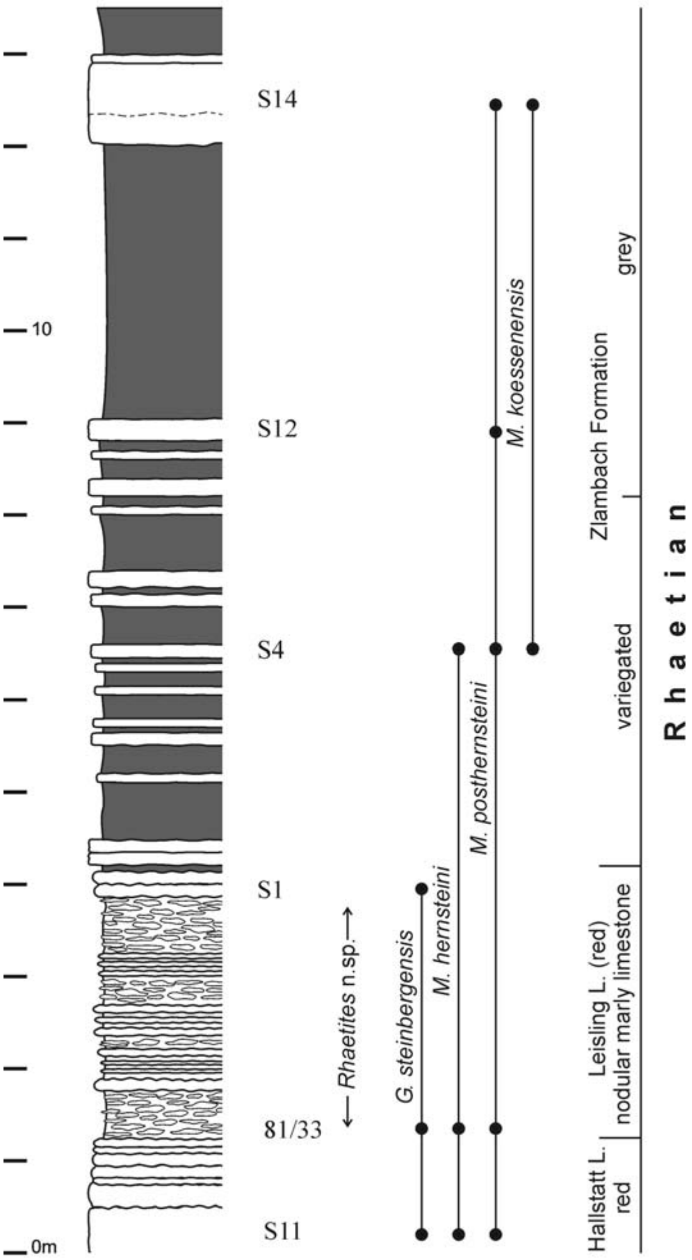


Fig. 13: Stratigraphic log with Rhaetian fossil data at (P) VIII, Sommeraukogel.

The Patens-Lager corresponds to the *Juvavites magnus* Z. and contains as common platform conodont *Epigondolella spatulata* (Hayashi). For most of the Alaunian no detailed ammonoid and conodont calibration has been possible due to missing exposure except for the upper Alaunian *Halorites macer* Z., which contains *Epigondolella abneptis* (Huckriede) and at the top *Epigondolella vrielyncki* KOZUR and *Epigondolella* n. sp. A (close to and a possible forerunner of *Epigondolella bidentata* MOSHER). The Rhaetian transition beds and Zlambach marls are poor in conodonts, dominated by species of the genus *Misikella* with rare *Norigondolella steinbergensis* (fig. 13).

Acknowledgments

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