The Pötschen Formation is of Late Carnian (Tuvalian) to Early Rhaetian age, as demonstrated by the presence of conodonts (MOSTLER, 1978). The Pötschenhöhe 'quarry' exposes beds of Early Middle Norian age (= Alaunian 2, *Himavatites hogarti* Zone) dated by ammonoids (TATZREITER, 1985), redeposited as big gliding block in a late Norian matrix with *Monotis salinaria* (LK, unpublished).

3.1.3. Locality 2 – Großer Zlambach

The Großer and Kleiner Zlambach are distributaries of the Traun River and name-giving for the Rhaetian Zlambach Formation. Though the formation displays an at least 150 m thick deep-marine succession, continuous sections are rare, due to common weathering of the soft sediments and a strong tectonic overprint with faults of unclear displacements making difficult a bed-by-bed correlation. The Kleiner Zlambach located north of the visited outcrop is the best exposed and less tectonised section but is unfortunately difficult to access (Fig. 9). Three closely neighbouring outcrops of the Großer Zlambach (Fig. 7; 47°37'47,5"N / 13°40'02,7"E) represent a partly folded and – though against each other fault bounded – lithologically complete Rhaetian sequence in far-reef basinal facies. The autochthonous background sedimentation of alternating marls and marly micritic limestone (Figs. 9 and 10) dominates here clearly the allochthonous carbonate sedimentation. An upward increasing thickness of the marls is characteristic for younger Rhaetian parts (Fig. 9). The allochthonous carbonate sedimentation consists of distal fine-grained turbidite, even if most of the beds do not show any characteristic turbiditic features. Except for the top black marls they contain only rarely a diverse biota derived from platform or reef environments (corals, dasycladacea, solenoporacea, sponges, bryozoans, hydrozoans, bivalves, brachiopods, ammonoids, gastropods, ostracods, foraminifers, echinoderms, radiolarian and Problematica). The autochtonous limestones show a rare fauna (some foraminifers, ostracods, conodonts, ammonoids, radiolarians). The first outcrop 2.1 displays the lower, limestone dominated part of the formation with the early to middle Rhaetian transition, whereas the boundary between the middle and late Rhaetian is visible at outcrop 2.2 where marls become more prominent. Black laminated marls with very rare allodapic coral-bearing layers of late Rhaetian age will be visible at outcrop 2.3 (Fig. 10).

3.1.4. Locality 3 – Steinbergkogel: Proposed Norian/Rhaetian GSSP section

The Steinbergkogel is a small, unnamed summit (1245 m above sea level, Fig. 7) 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 western-most salt mine gallery symbol (crossed hammers in Fig. 12), corresponding to the entrance of the Ferdinandstollen (Stollen = gallery in English) at an altitude of 1140 m. Access to Steinbergkogel is possible by a forest road that starts in the Echerntal and after 7 km reaches the Salzberg and the Ferdinandstollen from where the quarry Steinbergkogel with the Norian-Rhaetian GSSP candidate section can be seen, approximately 25 m away (Figs. 11 and 12). Alternatively one can reach the Steinbergkogel directly from Hallstatt (Fig. 7) by taking the cable car to Rudolfsturm (855 m), following a marked footpath along the prehistoric burial ground of the Hallstatt (Celtic) period, past some Salt mine buildings in the north-westerly direction towards the Plassen peak, and finally arriving at Ferdinandstollen (about a one hour walk). The proposed Norian-Rhaetian GSSP 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 (Fig. 11). Most of the classical Steinbergkogel ammonoid fauna (MOJSISOVICS, 1873–1902) may have

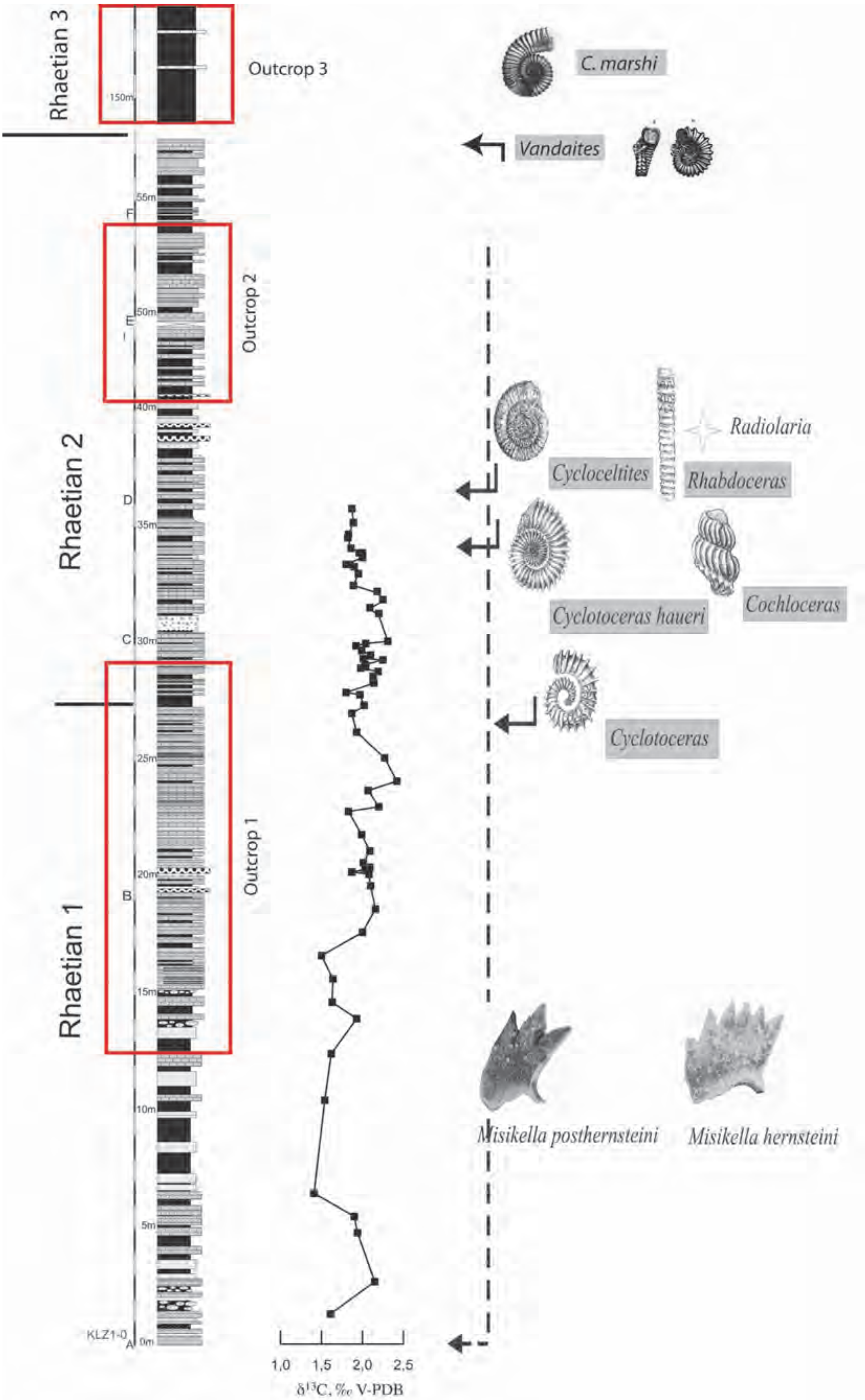
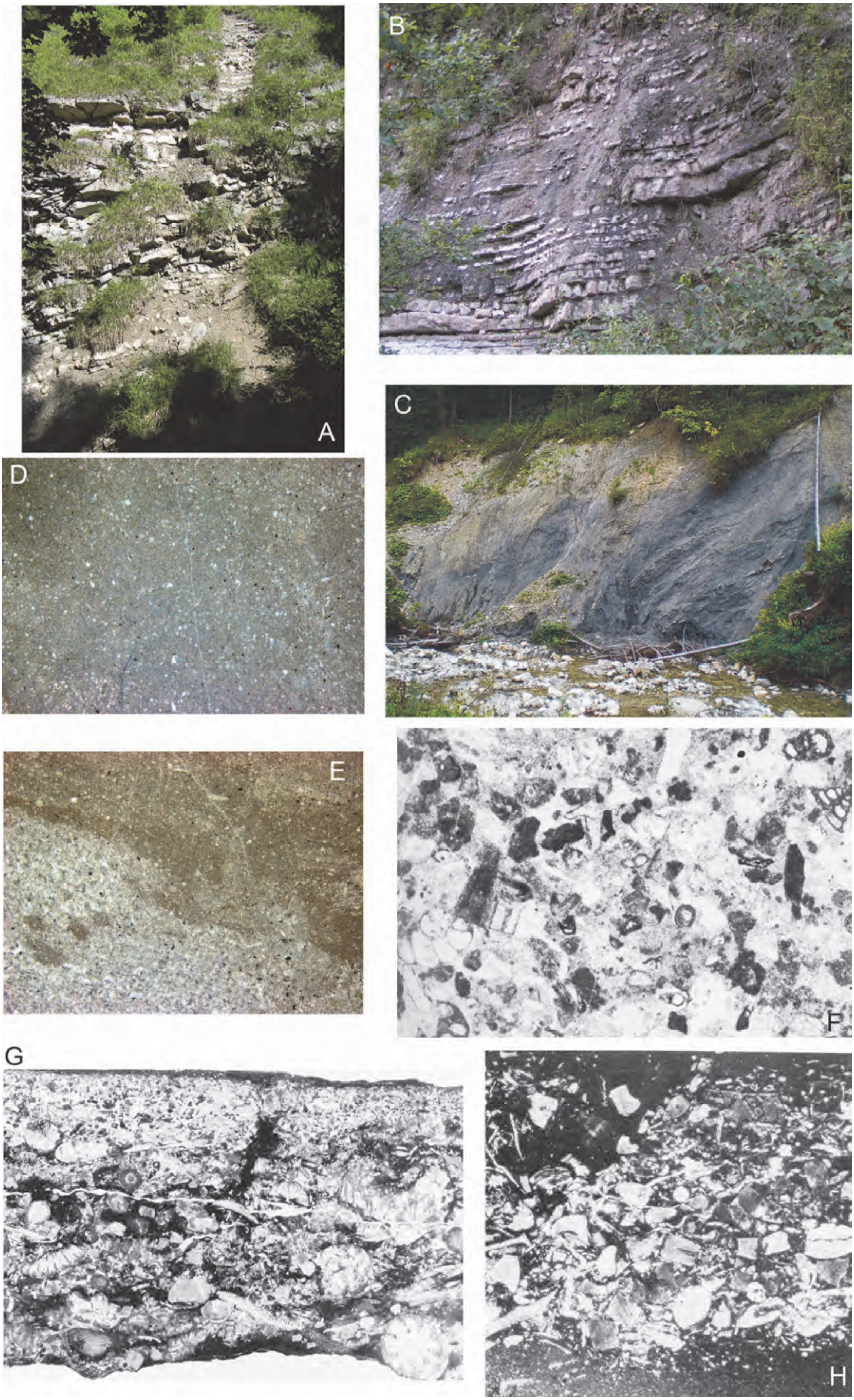


Fig. 9. Profil of the Zlambach Formation (Kleiner Zlambach) with the visited outcrop, carbon isotope curve and important biostratigraphic markers (from RICHOZ et al., 2012).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been collected by miners from that place, but DIENER (1926) mentions another fossil locality about 100 m on strike to the west (ST 2 in Fig. 12B). 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”. 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.

The Steinbergkogel is composed of a uniformly (70°N) dipping sequence starting with a thick whitish, massive and macroscopic unfossiliferous lower Norian Hallstatt facies type (*Massiger Hellkalk* Member) overlain by about 30-40 metres of bedded predominantly red (*Hangendrotkalk* Member) and in the top grey, fine-grained pelagic limestones (bioclastic wackestones) of latest Norian to earliest Rhaetian age; the upper half of the grey limestone (*Hangendgraukalk* Member)) shows a microfacies change to sponge spicules dominated wacke- and mudstones; it develops thin clay interbeds that have eased the quarrying of stones and indicate a gradual transition to grey marls of the Zlambach Formation. The proposed Norian-Rhaetian boundary interval corresponds to the basal part of the *Hangendgraukalk*. Stratigraphically below the quarry section, more than 20 m of red upper Norian limestones (ST 4 in Fig. 12B) contain several layers with *Monotis salinaria, Heterastridium*, ammonoids, and conodonts that allow a cross-correlation with the quarry sections (Fig. 13).

The Steinbergkogel quarry consists of 4 meters of medium to thin bedded micritic limestones with the proposed candidate section STK-A located at the eastern end (Figs. 11, 12). About 20 beds have been studied in detail, numbered from bottom to top as 103 to 122 (Fig. 14). Beds 108 to 112A (one meter thick) are of relevance to the Norian-Rhaetian boundary and differ 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. The Norian-Rhaetian GSSP is proposed at Bed 111A with the FAD of *Misikella posthernsteini,* 2.2 m above the base of the section. A low CAI of 1 excludes any thermal overprint and favours the preservation of the original palaeomagnetic signal and of a primary $\delta^{13}C$-record (Fig. 14). 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

← Fig. 10. A) Großer Zlambach, section GZ1 – Zlambach Formation, Lower Member. Alternation of limestone and marls with distinct slumping interval (Early Rhaetian); B) Großer Zlambach, Section GZ2- Zlambach Formation, Lower Member. Alternation of limestone and bituminous marls (Early Rhaetian); C) Großer Zlambach, Section GZ3- Zlambach Formation, Upper Member. Black laminated marls with thin allodapic limestone (Late Rhaetian); D) Bioturbated sponges spicules bearing mudstone with graded allodapic grainstone layers containing echinoderms, foraminifers and dasycladaceans bioclast (Zlambach Formation Lower Member, sample LL4-2 GZ1); E) Radiolarian and sponge spicule rich autochtonous wackestone higly bioturbated (Zlambach Formation Lower Member, sample L5 GZ1); F) Foraminiferal bioclastic packstone. Characteristi allochtonous sediment of distal turbidite (from MATZNER, 1986), magnification x 20; G) Echinoderm-packstone laying on a marly limestone with shell fragments, sponge spicules, ostracods and foraminifera, magnification x 3,5 (from MATZNER, 1986); H) Graded detrital reef limestone with densely packed corals, gastropods, solenoporaceans, dasycladaceans, microproblematica, foraminifera, ostracods, echinoderms and shell fragments and geopetal fabrics. Magnification x 2,7 (from MATZNER, 1986).

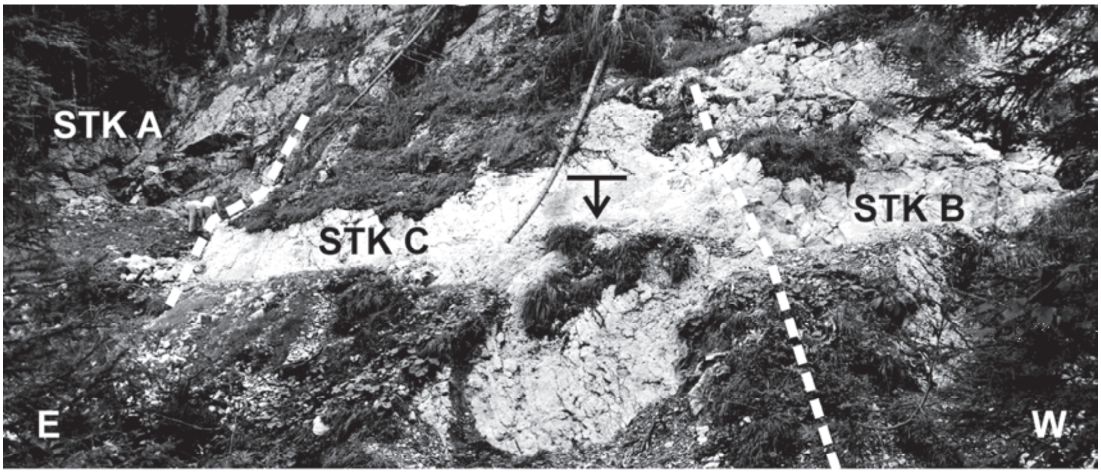

Fig. 11. Steinbergkogel quarry with sections A, C and B.

the lower Rhaetian considerably (KRYSTYN et al., 2007a) (Figs. 11, 12C, 15). The microfacies of Steinbergkogel's sections are quite homogenous, characterised by sparse fine-grained skeletal detritus of echinoderms (crinoids and echinoids), ammonites, bivalves, rare gastropods, ostracods, sponge spicules, as well as poorly-preserved radiolarians and benthic foraminifers in different proportions (Fig. 16). Small burrows are quite abundant in this section. The microfacies analyses did not reveal any marked facies change through the Boundary beds 108 to 112 and indicate a persistent low-energy, outer shelf, upper slope setting. The constant presence of stenohaline sessile organisms such as echinoderms indicates persistent, normal marine salinity conditions. The relatively diversified benthic fauna, together with high density of burrows, are generally interpreted to be due to oxic sea floor conditions.

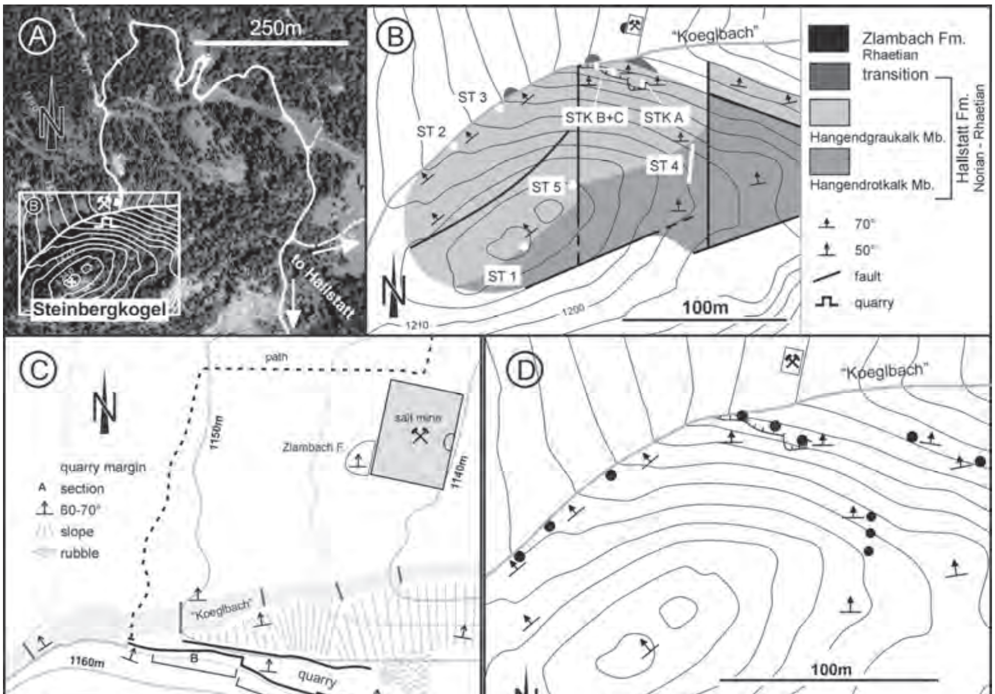

Fig. 12. Detailed Steinbergkogel maps. A) Aerial view; B) Geology with sections and fossil localities; C) Steinbergkogel quarry; D) Location of Norian-Rhaetian boundary exposures.

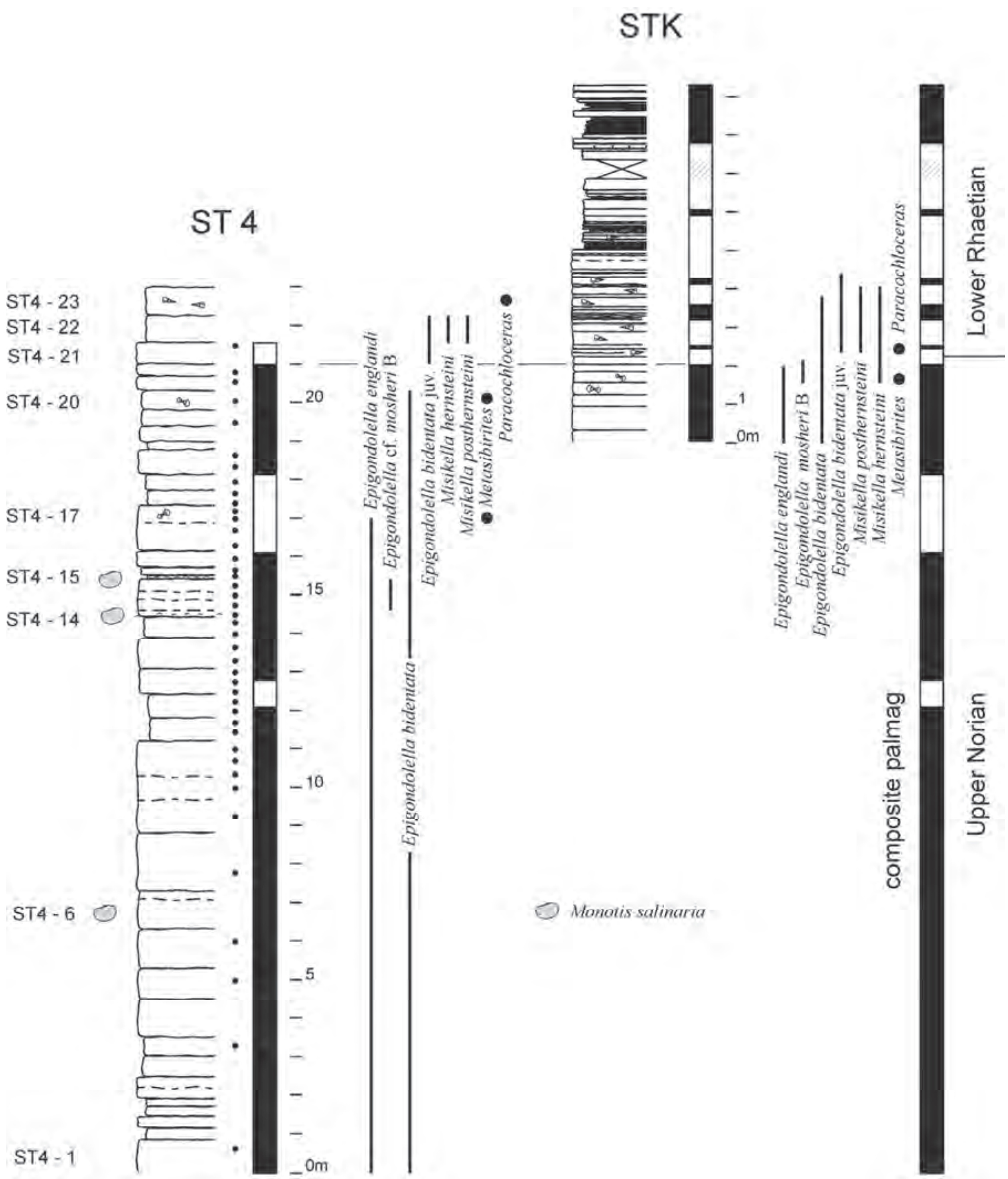

Fig. 13. Composite Upper Norian to lower Rhaetian magnetostratigraphy of the Steinbergkogel, with sections ST4, STK A and B/C (from RICHOZ et al., 2012).

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. 14). *Norigondolella steinbergensis*, usually the most frequent faunal element in this time interval is fortunately rare as well as ramiform elements. 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 becomes frequent from 111A onwards (Fig. 14). Bed 111A marks the FAD of *M. posthernsteini*, as phylogenetic successor of the fore-mentioned species, responsible for the

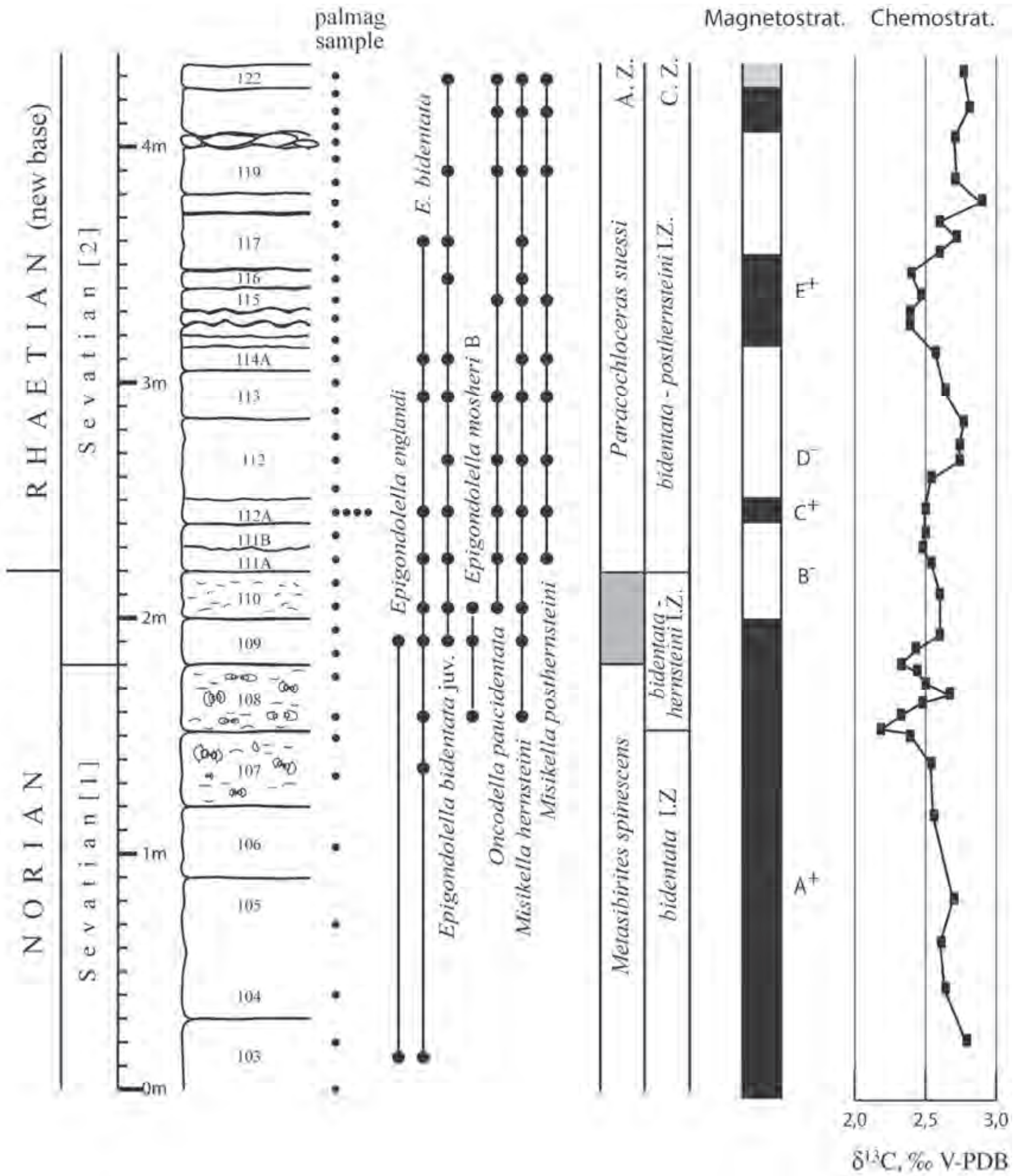

Fig. 14. Integrated bio-, magneto- and chemostratigraphy of GSSP candidate for the Norian-Rhaetian boundary section Steinbergkogel A. Note: Sevatian 1 and 2 refer to previous Upper Norian classification (from KRYSTYN et al., 2007b).

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 very rare at the beginning of the section, becomes frequent in bed 112, and rare again higher up in the section (Fig. 14). The initial infrequence highlights the problem of how to recognise the FAD of *M. posthernsteini* in biofacies less favourable and use of this event without additional control may cause uncertainties in regional or intercontinental correlations. Two conodont zones can be distinguished in the boundary interval of the proposed candidate section based on the successive appearances of species of the genus *Misikella*: 1) *Epigondolella bidentata* – *Misikella hernsteini* Interval Zone, characterised by the co-occurrence of common *E. bidentata* and rare *M. hernsteini* in beds 108 to 110 of STK-A and beds 11 to 12B of STK-C

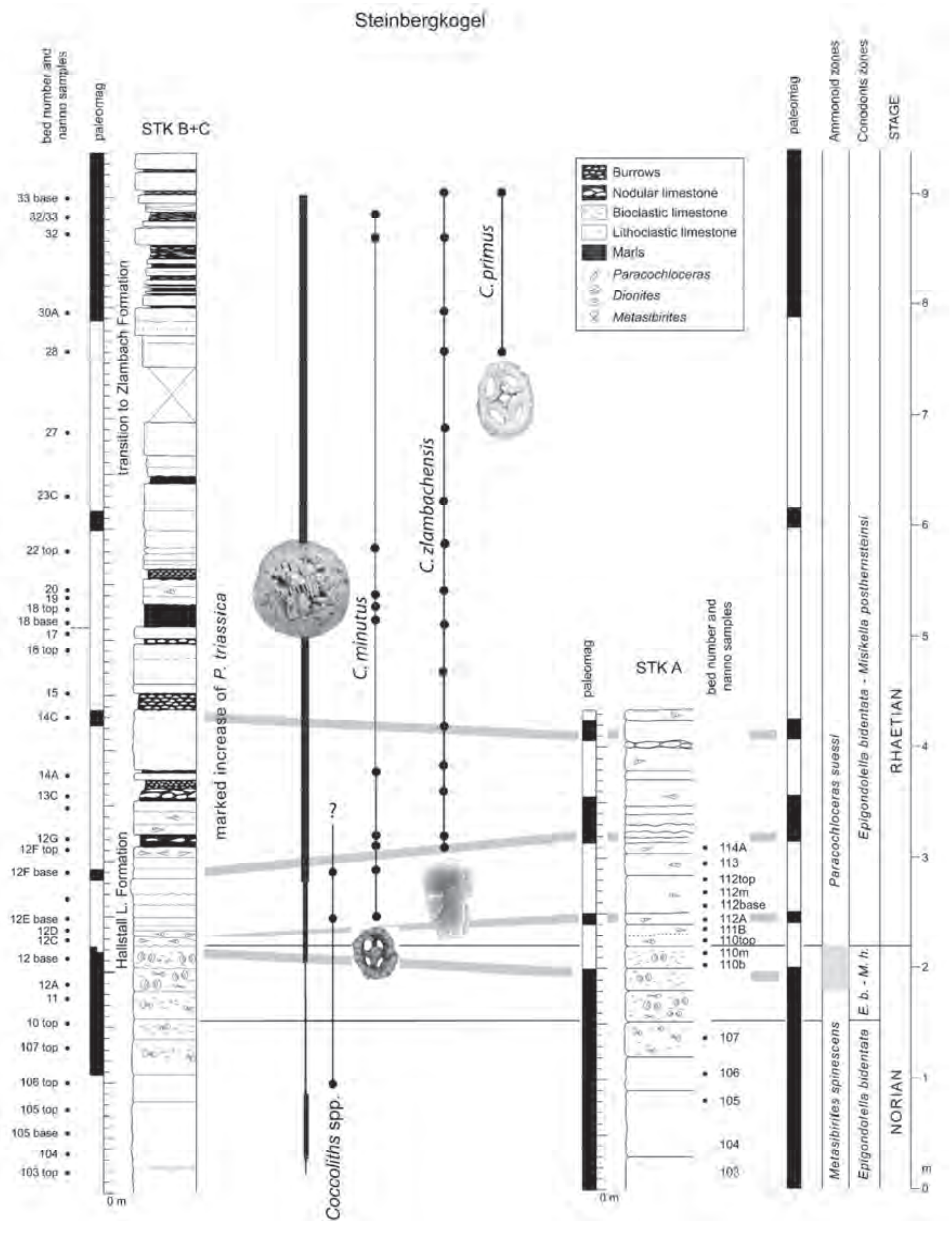

Fig. 15. Steinbergkogel A and B + C section, GSSP candidate for the Norian-Rhaetian boundary. Schematic lithology, sample location, magnetostratigraphy (black is normal polarity, white is reversed polarity) and most important calcareous nannofossil bio-events (from GARDIN et al., 2012).

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. 14). Normal sized *Epigondolella bidentata* becomes rare in Zone 2 and is usually replaced by juveniles resembling the genus *Parvigondolella* (Fig. 14). 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).

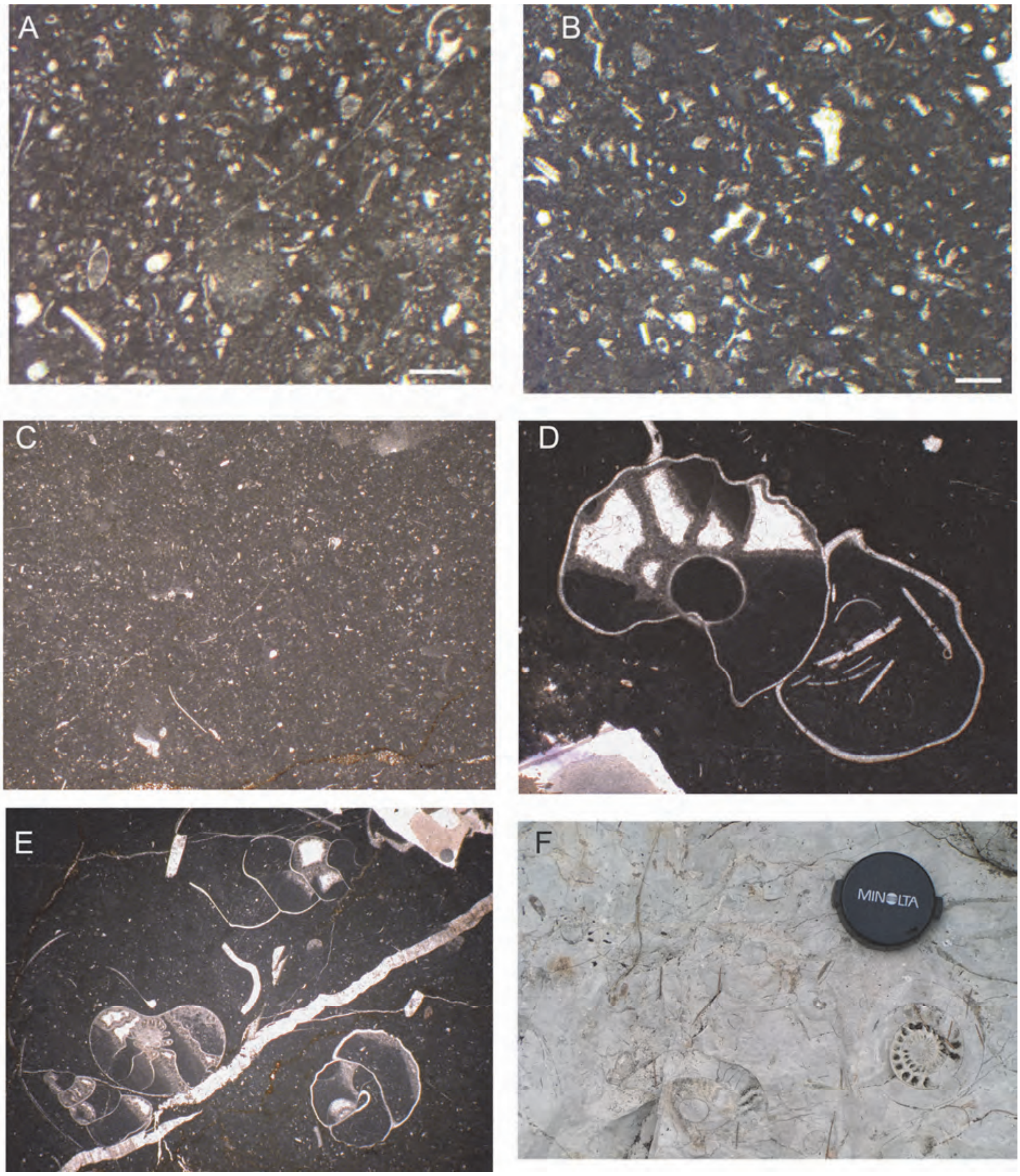

Fig. 16. A) and B) Bioclastic Wackestone with predominantly echinoderms and shell fragments (Norian, sample STK A/105, scale bar: 100 µm; GARDIN et al., 2012); C) Profil Bioclastic wackestone with predominantly sponge spicules and radiolarians (Rhaetian, sample STK B/12E, magnification x 5); D) Bioclastic wackestone with cross section through geopetaly filled Ammonoid (Metasiberites, approximately one centimetre) with geopetal filling (Latest Norian, sample STKC/11); E) Wackestone withsilicious sponge spicule and cephalopods (trochospiral Paracolocheras approximately one centimeter - Megaphyllites rich in geopetal structures (Earliest Rhaetian, sample STKC/12); F) Bioclastic rich rock surface with multiple cephalopods cross-sections (Bed STKB/10, scale 5 cm).

Concerning the ammonoids, *Metasibirites spinescens* is very common in beds 107 and 108 of STK-A and in 9 to 11 of STK-C, *Paracochloceras* (Fig. 16E) 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. The genus *Dionites* may have a range across the Norian-Rhaetian boundary and as such may not be boundary-diagnostic. More important is the correlative presence in bed 111 of *Sagenites reticulatus* and *Dionites caesar*. Combining all above cited faunal records permits the discrimination of two ammonoid zones (Fig. 14), a lower with *Metasibirites* (bed 107 to 108; Fig. 16D) 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. 14). Stratigraphically indifferent taxa including *Rhabdoceras suessi, Pinacoceras metternichi, Placites, Arcestes, Cladiscites, Paracladiscites, Rhacophyllites* and *Megaphyllites* are represented in all beds.

Monotids of the *Monotis salinaria* group are common in Steinbergkogel (KITTL, 1912; SPENGLER, 1919: 359) and almost restricted to the *Hangendrotkalk* Member where they appear in several layers within an interval of 10-15 m (Fig. 13). Of special interest is a single unhorizoned large specimen of *M. salinaria* preserved as grey micritic limestone. 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 occurrence of *Monotis salinaria* in the Hallstatt Limestone and, in agreement with the *Monotis* data from Hernstein, Lower Austria (MCROBERTS et al., 2008), its pre-Rhaetian disappearance.

Calcareous nannofossil assemblages at Steinbergkogel are the most abundant and diversified of the Austrian Alps up to now (GARDIN et al., 2012). The nannolith *Prinsiosphaera triassica* is frequent. The section is marked by the FO of *Crucirhabdus minutus* in bed 112 A and 12E of section STK-B/C. Small coccoliths spp. are observed just below the boundary. These are the oldest dated coccolith ever found until now. This important event is directly calibrated with the entry of ammonoid *Paracochloceras suessi* and conodont *Misikella posthernsteini*, (Fig. 15), just after the last occurrence (LO) of the ammonoids *Metasibirites* and of the bivalve *Monotis salinaria*. Further the section is marked by the FO of *Conusphaera zlambachensis* in sample 12G and the FO of *Crucirhabdus primulus* in sample 28 in sections STK-B/C. A slight increase in the abundance of *Prinsiosphaera triassica* is recorded across the Norian-Rhaetian boundary and continues higher up the section. Between the FA of *M. hernsteini* and the FAD of *M. posthernsteini* lies a prominent magnetic polarity change from a long Normal to a distinct Reversal which can be recognised in other Tethyan magnetostratigraphies. The $\delta^{13}C_{carb}$ record is well preserved but unfortunately no significant variations occur around the boundary (Fig. 14).