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Stratigraphic Analysis of Marine Carbonates in the Hochmoos Formation (upper Santonian) in Gosauschmied, Upper Austria

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Kevin Kearney, BSc

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Abstract/Zusammenfassung

Abstract

The Upper Cretaceous sediments of the Lower Gosau Subgroup (LGS) in the Gosau basin straddling the border between the federal states of Upper Austria and Salzburg near Gosau and Russbach are well known for their fossil abundance and their wide spectrum of lithologies, ranging from marls to sandstones, conglomerates, calcarenites and limestones. The Hochmoos Formation in the LGS constitutes one of the most varied formations in the region and consists of coastal and shallow-marine deposits and structures, including small biostromes or reefs that were primarily composed of rudists (Höfling, 1985; Wagreich, 1988; Sanders and Höfling, 2000). An as-yet-unstudied occurrence of the Hochmoos Formation near Gosauschmied at the SE edge of the Gosau basin was subjected to a thorough stratigraphic analysis, including profile description, structural measurements, microfacies analysis, isotope measurements and assessment of micro- and macrofossil content. The purpose was to investigate the facies distribution and possible deposition scenarios for this occurrence of the Hochmoos Formation, position it temporally in the late Santonian and early Campanian periods and compare it to other occurrences of the Hochmoos Formation in the Gosau basin and other LGS sites with rudist colonies in the Northern Calcareous Alps (NCA).

Strontium isotope analysis ($^{87}\text{Sr}/^{86}\text{Sr}$) from representative sections of the study area ranged from 0.707485 (oldest value) to 0.707549 (youngest value) and, based on values obtained by Wolfgring and Wagreich (2018) for the Santonian/Campanian boundary at the Postalm near Gosau, indicates an uppermost Santonian age, with the youngest sediments possibly extending into the Campanian. The succession of lithologies, inclusions and fossil content show initial transgressive activity in a fan delta environment, followed by a deeper marine environment and progradational stacking of limestone beds in the Highstand Systems Tract (HST), leading eventually to rudist colonies in an inner shelf and partially lagoonal milieu. Eventually, at the inception of the Falling Stage Systems Tract (FSST), there is resumption of terrigenous inflow, resulting again in a fan-delta milieu with large clasts of Dachstein limestone, quartz and chert, but exclusively on the west side of the study area. On the east side of the study area, the preponderance of bioclastic (detrital rudist) limestone and only isolated occurrences of in situ rudist biostromes indicate a high-energy marine environment that was only intermittently protected from destructive storm events and wave activity. Compared to other LGS outcrops in the NCA that contain rudist and rudist-coral biostromes, there is only a paucity of in situ bioconstructions in Gosauschmied that would point to a calm milieu. Further, the low count of benthic foraminifera and the occurrence of only isolated corals point toward a primarily high-energy environment with parautochthonous transport of bioclastic detritus. Divergent lithologies, different outcrop orientation and markedly disparate fossil content on the west vs. east sides of the study area point toward deposition in originally different

environments (proximal vs. distal) with an ensuing post-depositional syncline running in between and along the valley floor. An alternative explanation for these differences could be a fault between the two sides of the study area, though there is no current evidence to support this view. The Hochmoos Formation sediments at Gosauschmied were laid down unconformably onto the Triassic/Jurassic basement, as reworked clasts of Dachstein limestone and other terrigenous content (chert, quartz) attest. No other LGS formations are exposed in the area except for overlying marls of the Bibereck Formation to the west and north of the study area. With a maximum thickness of 68m, the overall extent of the Hochmoos Formation at Gosauschmied is slightly greater than comparable outcrops (Schmiedsippel, Katzhofgraben) at the SE basin edge, but much less than the nearly 300m at the basin's center or the 170m thickness observed in Rigaus-Abtenau. This is due to the synsedimentary tectonic activity consisting of normal fault subsidence over a distance of 10-14km in a WNW-ESE direction, producing a vertical throw of nearly 900m from basin center to perhaps 20-30m at the basin edge (Wagreich and Decker, 2001). Therefore, while synsedimentary tectonics strongly determined the facies distribution and thickness of the Hochmoos Formation at Gosauschmied, the overall facies succession provides clear evidence of a eustatic sea-level cycle that was simultaneously tectonically enhanced.

Zusammenfassung

Die oberkretazischen Ablagerungen der Unteren Gosau-Subgruppe (LGS) im Gosaubecken im Grenzbereich der Bundesländer Oberösterreich und Salzburg nahe bei Gosau und Rußbach sind für ihren Fossilreichtum und das breite Spektrum an Gesteinsarten (z.B. Mergel, Sandsteine, Konglomerate, Kalksandsteine und Kalksteine) bekannt. Die Hochmoos-Formation innerhalb der LGS stellt eine der vielfältigsten Formationen in dieser Region dar und besteht aus küstennahen und seichtmarinen Ablagerungen und Strukturen, inklusive kleinen Biostromen/Riffen, die überwiegend aus Rudisten aufgebaut wurden (Höfling, 1985; Wagreich, 1988; Sanders und Höfling, 2000). Ein bislang nicht genauer untersuchtes Vorkommen der Hochmoos-Formation nahe bei Gosauschmied am SE-Rand des Gosaubeckens wurde einer gründlichen stratigraphischen Analyse unterzogen, inklusive Profilaufnahme, Strukturmessungen, mikrofazieller Analyse, Isotopenmessungen und Evaluierung des Mikro- und Makrofossilgehalts. Das Ziel dieser Untersuchungen war die Feststellung der Faziesverteilung zusammen mit möglichen Depositionsszenarien für dieses Vorkommen der Hochmoos-Formation. Weiters sollte dieses Gebiet zeitlich im Spät-Santonium bis Früh-Campanium positioniert und mit anderen Vorkommen der Hochmoos-Formation im Gosaubecken, sowie mit anderen LGS-Lokalitäten mit Rudistenbiostromen in den Nördlichen Kalkalpen verglichen werden.

Die Analyse von Strontiumisotopen ($^{87}\text{Sr}/^{86}\text{Sr}$) aus repräsentativen Abschnitten des Untersuchungsgebiets zeigte Werte von 0,707485 (ältester Wert) bis hin zum jüngsten Wert von 0,707549. Basierend auf neulich gewonnenen Werten von Wolfgring und Wagreich (2018) für die Santonium/Campanium-Grenze auf der Postalm nahe bei Gosau, deutet die Strontiumanalyse in

Gosauschmied auf ein Alter im späten Santonium bis möglicherweise frühestes Campanium für die jüngsten Ablagerungen. Die Abfolge der Lithologien, Klasten und Fossilien zeigen eine anfängliche Transgression in einem Fan-Delta-Environment, gefolgt von einem tiefermarinen Ablagerungsmilieu mit progradierenden Stapelungen von Kalksteinbänken im Highstand Systems Tract (HST), was dann zur Bildung von Rudistenkolonien am inneren Schelf und teilweise im inneren lagunären Milieu führte. Beim Beginn des Falling Stage Systems Tract (FSST) fand erneut ein Eintrag terrigener Klasten statt, was allmählich wieder zu einem Fan-Delta-Milieu mit großen Komponenten aus Dachsteinkalk, Quarz und Chert führte, aber ausschließlich auf der Westseite des Gebiets. Auf der Ostseite des Gebiets deuten das häufige Vorkommen von Rudistentrümmerkalk und die nur selten vorkommenden Rudistenbiostrome in Wachstumsposition auf ein hochenergetisches marines Milieu hin, welches nur phasenweise vor zerstörenden Sturmereignissen und Wellenaktivität geschützt war. Verglichen mit anderen Aufschlüssen der LGS mit Rudisten- und Rudisten-Korallen-Biostromen gibt es in Gosauschmied nur seltene Beispiele von biokonstruierten Gefügen, die auf ein eher ruhiges Milieu hindeuten würden. Weiters zeigen die geringe Anzahl an benthischen Foraminiferen und die nur isolierten Korallen auf ein hochenergetisches Milieu mit parautochthonem Transport von bioklastischem Schutt. Die verschiedenen Lithologien, divergierende Orientierungen und stark unterschiedliche Fossilgehalte der Aufschlüsse im Westen des Untersuchungsgebiets gegenüber der Osthälfte deuten auf eine Ablagerung in ursprünglich unterschiedlichen marinen Bereichen (proximal vs. distal) hin, gefolgt von der späteren Entwicklung einer Synklinale, die zwischen beiden Hälften bis hinunter zum Bach im Talboden läuft. Eine alternative Erklärung dieser Unterschiede könnte auch eine Störung zwischen den beiden Hälften des Untersuchungsgebiets sein, obwohl es derzeit keine klaren Hinweise gibt, die diesen Schluss untermauern würden. Die Sedimente der Hochmoos-Formation beim Gosauschmied wurden diskordant auf dem triassisch-jurassischen Basement abgelagert, was durch Dachsteinkalkgerölle und andere terrigene Klasten (Hornstein, Quarz) bezeugt wird. Mit Ausnahme des Mergelvorkommens der überlagernden Bibereck-Formation westlich und nördlich des Untersuchungsgebiets sind keine der übrigen LGS-Formationen in diesem Gebiet aufgeschlossen. Mit einer maximalen Mächtigkeit von 68m stellen die Aufschlüsse der Hochmoos-Formation beim Gosauschmied ein mächtigeres Vorkommen als vergleichbare Profile (Schmiedsippl, Katzhofgraben) am SE-Beckenrand dar, aber viel reduzierter als die beinahe 300m-mächtigen Sedimente des Beckenzentrums bei Gosau oder die 170m-mächtigen Abfolgen bei Rigau-Abtenau. Dies ist auf synsedimentäre tektonische Aktivität zurückzuführen, welche durch Abschiebungen entlang einer Länge von ca. 10-14km in WNW-ESE-Richtung einen vertikalen Versatz von beinahe 900m im Beckenzentrum und in etwa 20-30m am SE-Beckenrand verursacht hat (Wagreich und Decker, 2001). Während also synsedimentäre tektonische Aktivität die Faziesverteilung und Mächtigkeit der Hochmoos-Formation stark bestimmt hat, zeugt die generelle Faziesabfolge deutlich von einem eustatischen Meeresspiegelzyklus, welcher simultan tektonisch verstärkt wurde.

Abbreviations

BW	Black and White
CCD	Calcite Compensation Depth
DGS	Department of Geodynamics and Sedimentology
FSST	Falling Stage Systems Tract
HST	Highstand Systems Tract
LGS	Lower Gosau Subgroup
LST	Lowstand Systems Tract
MFS	Maximum Flooding Surface
NCA	Northern Calcareous Alps
SB	Sequence Boundary
TST	Transgressive Systems Tract
UGS	Upper Gosau Subgroup

1 Introduction & Objectives

The Upper Cretaceous and Paleogene sediments of the Gosau Group are among the most significant in the Northern Calcareous Alps (NCA) and are extensively distributed throughout the NCA (see appendix A) and in isolated locations in the Central Alpine region (Kainach and Krappfeld). Beginning in the Late Cretaceous, the NCA Gosau Group sediments were deposited unconformably upon the Upper Austroalpine nappe complex (Wagreich and Faupl, 1994). One of the most extensive and most notable occurrences of Gosau Group sediments in the NCA can be found in the Gosau basin at the border area of Upper Austria and Salzburg, where most of the type localities for the Gosau Group are located. The Gosau basin covers an area of approximately 80km² with a width of roughly 8km and a length of about 10km and straddles the Salzburg-Upper Austrian border in the Gosau-Russbach-Pass Gschütt area (Wagreich and Decker, 2001). The Gosau Group sediments range temporally from about 90 Ma to 50 Ma and are divided into two distinct subgroups: the Lower Gosau Subgroup (LGS), ranging from 90 Ma to about 81 Ma (upper Turonian to lower Campanian) and the Upper Gosau Subgroup (UGS), ranging diachronously from 81 Ma to roughly 50 Ma (lower Campanian to mid Eocene) (Wagreich, 2003). The Upper Cretaceous Lower Gosau Subgroup (LGS) consists of alluvial/terrestrial and transgressive shallow-marine sediments that reach a total thickness of about 1000 m (Sanders and Höfling, 2000) in the Gosau Basin. These are primarily found in an E-W-oriented section of the basin stretching from Gosau Vordertal across the Gschütt Pass and over to Russbach in Salzburg (Wagreich, 1988).

Although the preponderance of LGS outcrops are to be found in the northern part of the Gosau basin, there are also significant sediments of the Hochmoos Formation (upper Santonian) at Gosauschmied south of Gosau Hintertal, as well as the Untersberg Formation (lower Campanian) further south of this area, and at Schmiedsippl at the east rim of the basin. In addition, a relatively small occurrence of the Bibereck Formation (lower Campanian) can be found directly north and west of the main outcrops of the Hochmoos Formation (095 St. Wolfgang im Salzkammergut 1:50 000, GBA, 1982), with a second, even smaller occurrence transgressing onto the Untersberg Formation, which was studied extensively by Trenkwalder (1999). To date, however, no exhaustive stratigraphic analysis of the Hochmoos Formation in Gosauschmied has been undertaken.

The study area in Gosauschmied comprises outcrops of the Hochmoos Formation with total dimensions of approximately 1km W to E and a half kilometer N to S, extending from the Geotrail in the west (N 47.550556, E 13.508395) to the top of the Rabenkogel near the rock-climbing area in the east (N 47.550047, E 13.521416), and from the settlement at Gosauschmied in the north (N 47.551089, E 13.515548) to the amusement park Urzeitwald in the south (N 47.547496, E 13.511068) (a more precise delineation of the study area is included in section 2.2 below). The

Gosausee highway cuts diagonally through the area; and its construction in the 1980s directly produced many significant outcrops belonging to the Hochmoos Formation. The water reservoir behind the Gosauschmied power station is also a prominent feature of the landscape and, together with the Gosau brook that issues from it, divides the Hochmoos Formation at Gosauschmied into two separate areas (see Figure 1 below for overview satellite image of the study area).

The objectives of this thesis are threefold:

- 1) To undertake a thorough stratigraphic analysis of three selected outcrops in the Hochmoos Formation in Gosauschmied.
- 2) To investigate the entire study area in this part of the Gosau basin and determine holistic facies development from base to top in the various sections.
- 3) To correlate the different outcrops to each other and develop one or more deposition scenarios that take into account lithology, structural data, tectonics, isotope data and overall macro- and microfossil content. To this end, comparisons will be made with other occurrences of the Hochmoos Formation in the Gosau basin and to similar LGS structures throughout the NCA to correlate lithofacies, fossil assemblages and possible deposition scenarios.

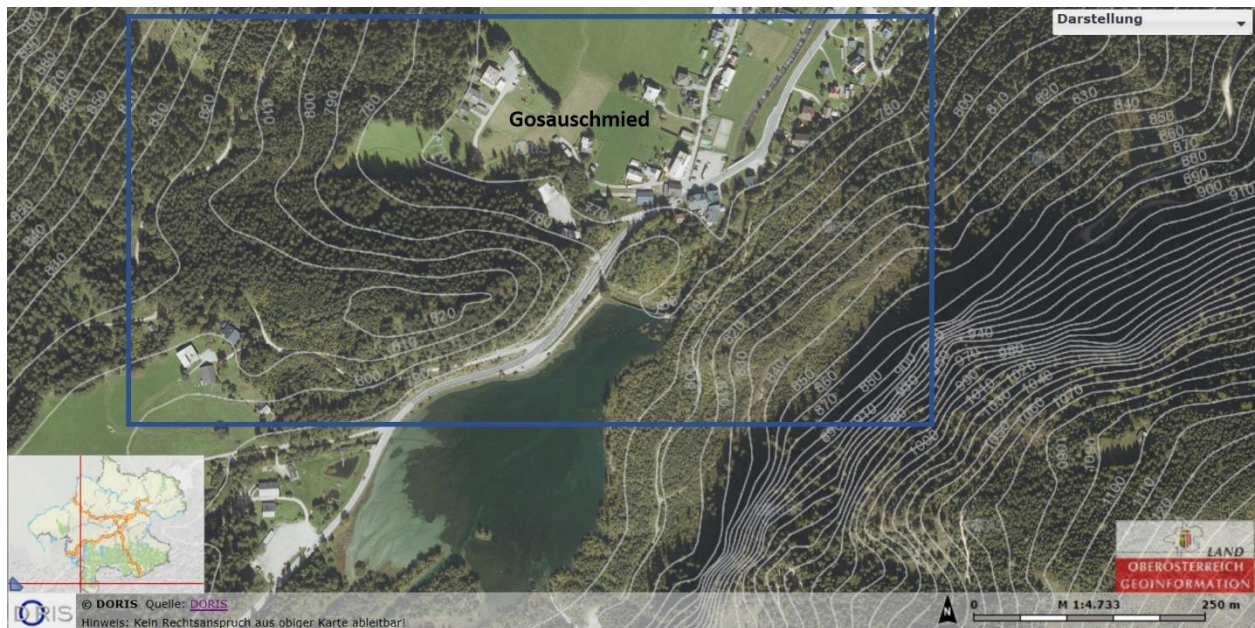


Fig. 1: Extent of study area enclosed in the blue frame. Base map obtained from Digitales Oberösterreichisches Raum-Informations-System [DORIS], accessed on 15 January 2020.

2 Background

2.1 History of the Gosau Group and Current Status of Research

The Upper Cretaceous and Paleogene sediments of the Gosau basin constitute the type locality for the entire Gosau Group, which is widely distributed throughout the NCA. Moreover, the Gosau basin provides the type locality for many of the most significant formations comprising the Gosau Group. Initial attempts at describing and classifying the Gosau formations were undertaken in the late 18th century and early 19th century (cf. Wagreich, 1988). The first usage of the term “Gosau rock formations” was made by Lill von Lilienbach (1830, S. 189) and initiated an intensive investigation into the Gosau sediments, particularly with respect to the abundant fossil content in the LGS. Other early works in the Gosau region, primarily with respect to macrofossils, were undertaken by Zekeli (1852) and Zittel (1866).

A more exact lithostratigraphic classification (based upon the work of Reuss, 1854) was achieved by Weigel (1937) and Brinkmann (1934). Successive works focused primarily on the great abundance of fossil deposits in and near Gosau and Russbach, including: Beauvais, 1982; Summesberger, 1979, 1985; Kollmann, 1980; Kollmann and Summesberger, 1982; Höfling, 1985; Weiss, 1975, 1977 and Dhondt, 1987 (cf. Wagreich, 1988). Contemporaneously, sedimentological investigations into the UGS were undertaken by Lahodynsky (1981, 1983).

A foundational study based on a thorough sedimentological facies model of the LGS was undertaken by Wagreich (1986, 1988) to illuminate the geologic-geodynamic development of the area from the Coniacian to the early Campanian. This was followed by further related works, including: Faupl and Wagreich, 1992; Wagreich, 1991, 1992, 1993 and 1995 and Faupl and Wagreich, 1994 (cf. Trenkwalder, 1999).

The chronostratigraphy for the Gosau formations in the LGS underwent some modifications through further biostratigraphic work undertaken by Summesberger and Kennedy (1996), Tröger and Summesberger (1994), as well as lithofacies and heavy mineral analysis by Wagreich (1998) (cf. Wagreich, 2003).

In-depth work from a biostratigraphic and sequence stratigraphic perspective (with an emphasis on paleogeography and deposition scenarios) was undertaken by Sanders (1996, 1997, 1998, 1999 and 2001), including significant collaborative efforts with colleagues active in the Gosau Group: Sanders and Baron-Szabo (1997), Sanders and Pons (1999) and Sanders and Höfling (2000).

Significant recent contributions have included efforts in boundary stratigraphy, with an emphasis on establishing a correlation to potential GSSPs between the Santonian and Campanian at two localities in the Gosau region, one being Schattau (Wagreich, Summesberger and Kroh 2010),

and the other being Postalm (Wolfgring and Wagreich 2018), both in the Federal State of Salzburg, Austria, between Abtenau and Gosau. A multidisciplinary study including lithostratigraphy, biostratigraphy and chronostratigraphy was undertaken by Summesberger et al. (2017) to integrate data and analyses from multiple projects to achieve a more thorough stratigraphic understanding of the Hochmoos and Bibereck Formations near Schattau.

2.2 Geographical and Geological Setting of the Study Area

As indicated in the introduction, the study area is located in the southern portion of the Gosau basin near Gosauschmied. Figure 2 shows the Austroalpine geological setting and a schematic geographical overview of the location in southern Upper Austria near the border with Salzburg.

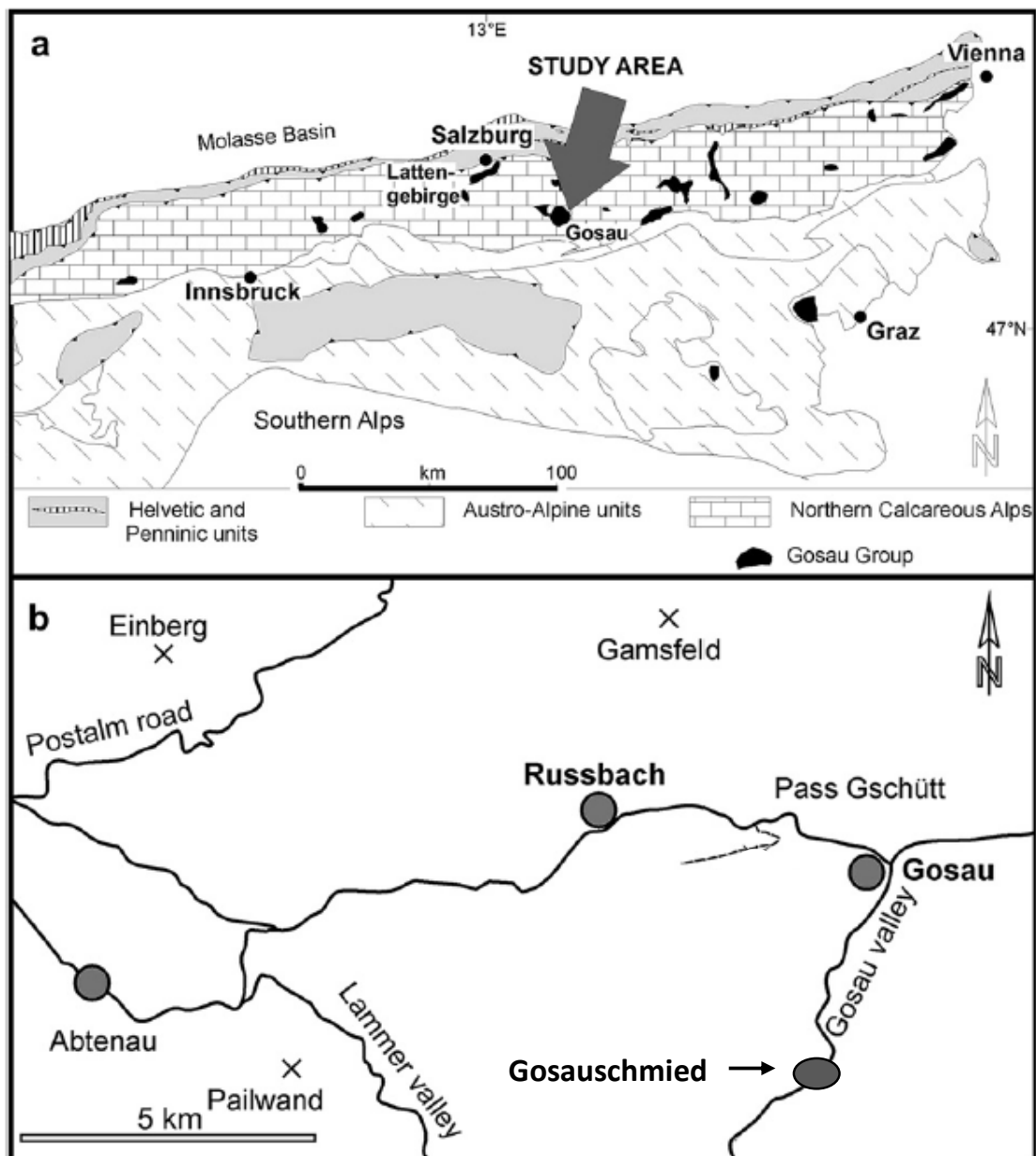


Fig. 2: a) Schematic geological map of the Eastern Alps; b) Overview map of position of Gosauschmied in the Gosau Basin (adapted from Wagreich et al., 2010, p. 182)

The municipality of Gosau (767m) extends roughly 13km along the Gosau brook, which flows south to north through the valley, then cuts sharply east and drains into Lake Hallstatt. Figure 3 is a satellite overview of the portion of the Gosau basin depicting the Gosau valley, the border between Upper Austria and Salzburg and the position of Gosauschmied in the south.

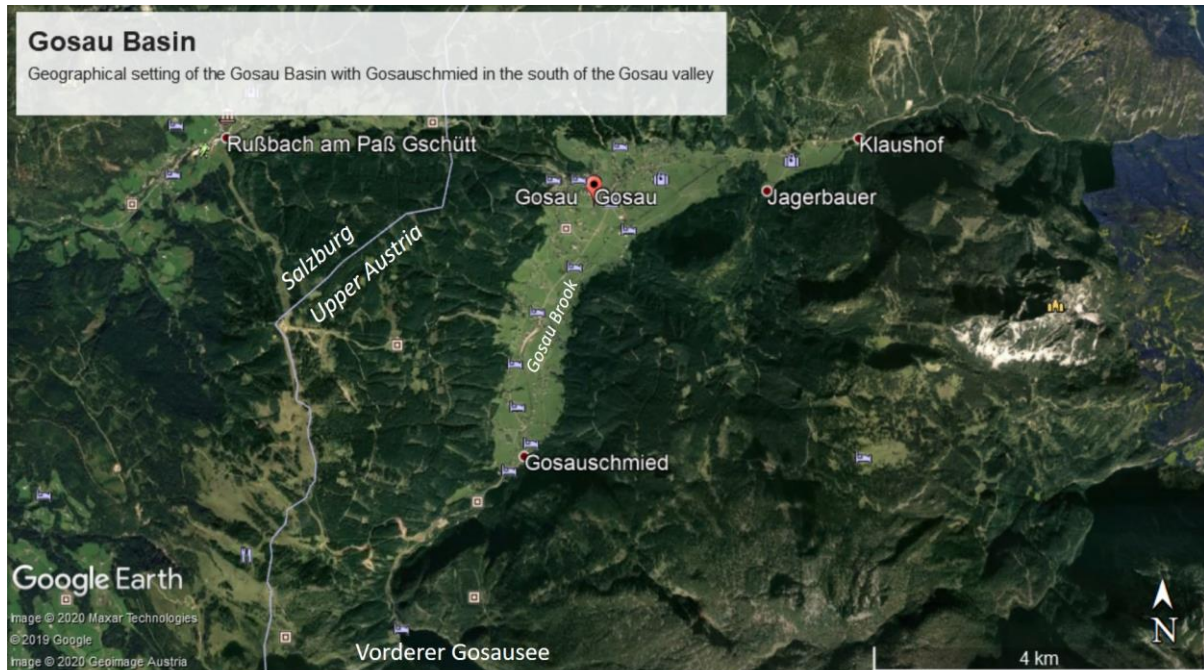


Fig. 3: Geographical setting of the Gosau Basin with Gosauschmied in the south. Image from Google Earth, accessed 11 January 2020.

At Gosauschmied, the valley narrows; and the Gosau highway rises up to the Vorderer Gosausee (Lower Gosau Lake) at 930m elevation with the Dachstein mountain and the Gosaukamm as south and west backdrops, respectively. The Gosau valley is a part of the Upper Austrian Salzkammergut region, and the mountains in this area constitute the Salzkammergut-Voralpen (SKV). The north of the valley is bordered by the Hochkalmberg-Russberg of the Osterhorn Unit, while the south rim of the valley is made up of the Plassen and the Schwarzkogel mountains. The dominant Gosaukamm (Donnerkogel 2055m, Grosswand 2415m) runs along the western border of the valley to the Gschütt Pass between Upper Austria and Salzburg (<https://de.wikipedia.org/wiki/Gosau>, accessed 11 January 2020). Figure 4 provides a 3-D schematic view of the area near Gosauschmied and the alpine backdrop of the study area.

Historically, Gosauschmied represented the last outpost before ascent into the high alpine region known as the Kalk Hochalpen (KH), represented in this region by the Dachstein Massif reaching 2995m altitude. The village was the location of an important blacksmith operation in the 17th century and hence was given the name Gosauschmied (the forge at Gosau).



Fig. 4: Schematic 3D rendering of Gosauschmied and the alpine backdrop to the south.

<https://earth.google.com/web/@47.53816981,13.49613851,867.34032652a,2553.50727216d,35y,58.53871085h,60.01145333t,0r> , accessed on 11 January 2020.

The study area for this thesis includes the entire Hochmoos Formation at Gosauschmied and peripheral areas of adjacent formations, most notably the Bibereck Formation to the north and west of the Hochmoos Formation. Figure 5 below shows the extent of the study area.

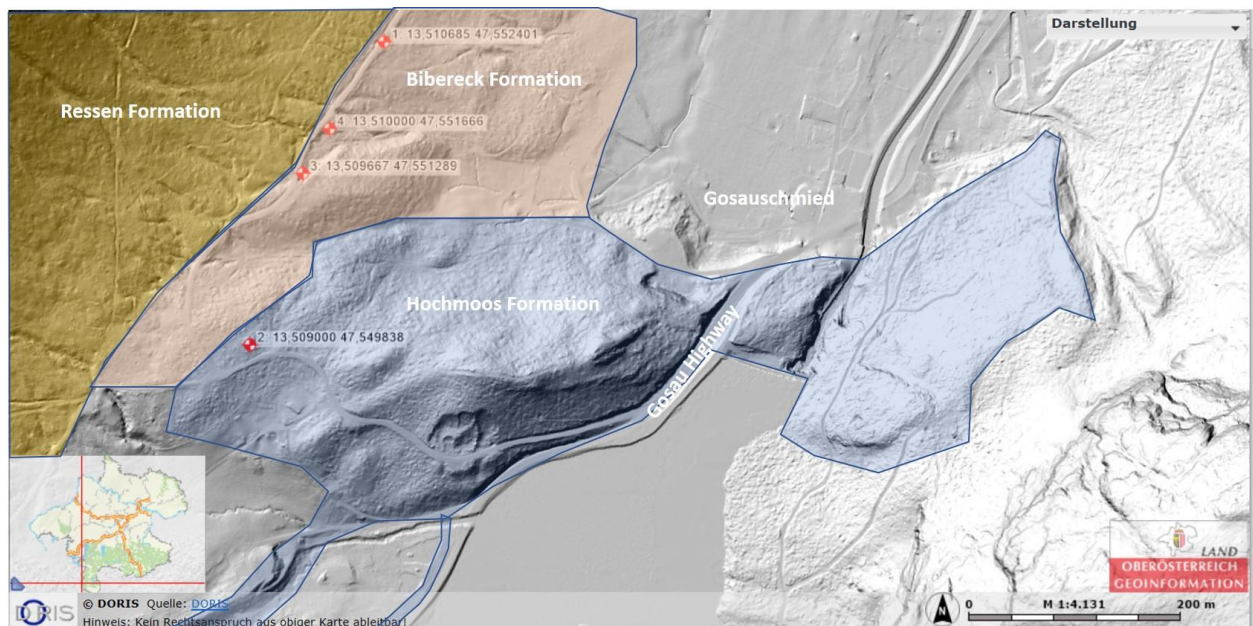


Fig. 5: Overview of the study area in Gosauschmied. The light blue highlighted area constitutes the extent of the Hochmoos Formation with the Bibereck Formation to the north and west. Base map obtained from Digitales Oberösterreichisches Raum-Informationssystem [DORIS], accessed on 15 October 2019. Extent of formations established during field work.

2.3 Paleogeography and Tectonic Development of the Gosau Group

The Northern Calcareous Alps (NCA) comprise a significant portion of the Upper Austroalpine Nappe stack and consist primarily of extensive Triassic carbonate sediments of marine (Western Tethys) origin. The Eastern Alps originated within the northwestern Tethys paleogeographic belt due to repeated convergence between the European and the African plate and intervening microplates (most importantly, the Austroalpine microplate and the Adriatic plate) (Wagreich et al., 2008). During the Late Cretaceous, the accretionary wedge of the NCA was sheared off from its basement and entered a phase of tectonic subsidence that, apart from one constrained, but significant period of uplift, continued at varying rates into the Eocene. During the Late Cretaceous, the NCA deformational belt was located at approximately 32° N according to paleomagnetic measurements. This is roughly 1800km to the south of their current position at about 47° N (Wagreich and Faupl, 1994). Figure 6 shows the position of the NCA in the NW Tethys during the Eoalpine (Cretaceous) orogeny.

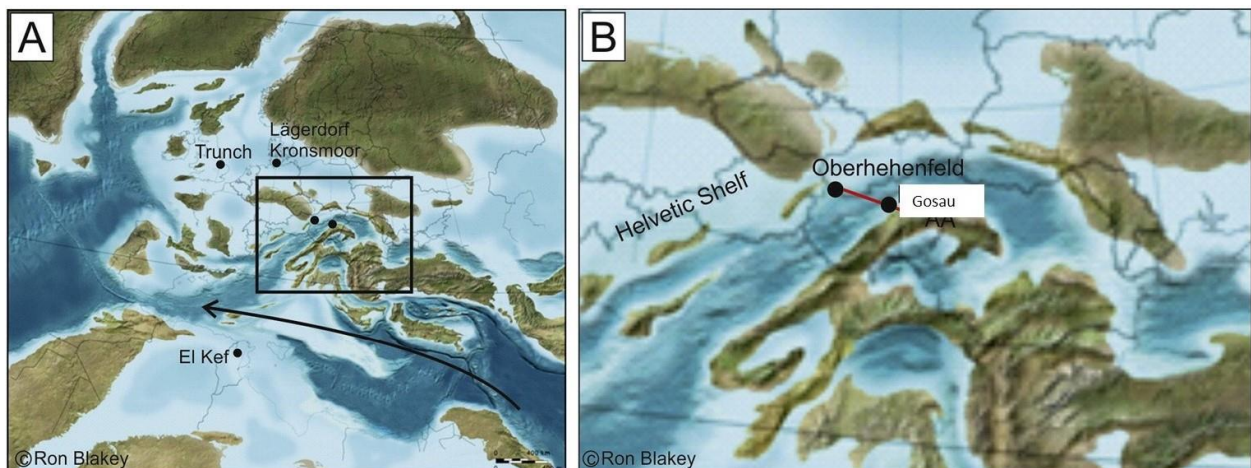


Fig. 6: A) Large scale overview of the Tethys in the Late Cretaceous. B) Palaeotectonic position of the NCA within the Eoalpine deformational belt in the Alpine Tethys/Penninic Ocean (adapted from Neuhuber et al., 2016). The position of Gosau is indicated on the front edge of the accretionary wedge.

The subsidence of the N-NW-moving accretionary wedge led to deposition of the Gosau sediments on the submerging flanks of what, in the Late Cretaceous, were structural island arcs of primarily Triassic origin in the Western Tethys. Today's Dachstein Massif, upon which the Gosau sediments in the Gosau basin are unconformably overlain, was part of such a Triassic structural island arc in the NCA deformational belt during the Late Cretaceous. The subsidence rates during the Turonian to late Santonian varied considerably from those of the Campanian to the Eocene (Wagreich and Faupl, 1994). Rates for three representative areas with Gosau sediments are depicted in Figure 7 below.

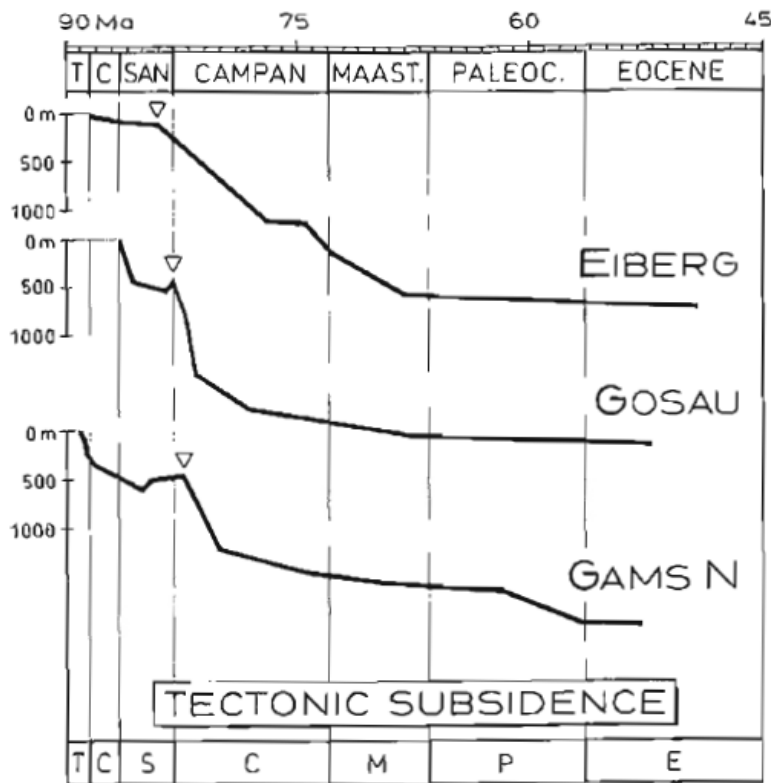


Fig. 7 Curves showing tectonic subsidence of three separate occurrences of Gosau Group sediments. The procedure for backstripping was based upon Bond and Kominz (1984) and Wildi et al. (1989). The inverted pyramids mark an instance of significant uplift and subaerial erosion, followed by rapid subsidence into bathyal depths. The two subsidence cycles correspond to sedimentation of the Lower and Upper Gosau subgroups (from Wagreich and Faupl, 1994, p. 247).

These varying subsidence rates account for the starkly different nature of the sediments in the Lower Gosau Subgroup (LGS) and the Upper Gosau Subgroup (UGS). In the LGS, which ranges temporally from the late Turonian to the early Campanian, subsidence rates were comparatively modest and produced alluvial/terrestrial and shallow marine carbonate sediments containing a wealth of Upper Cretaceous fossils. Towards the end of the Santonian and the beginning of the Campanian, a relatively brief period of tectonic uplift occurred, resulting in marine regression and subsequent subaerial erosive activity in the uppermost LGS sediments. The UGS, subsequent to this brief uplift, is marked by precipitous subsidence (indicated by the inverted pyramids in the chart in Figure 7), which, in turn, led to marine depths in the bathyal to abyssal range, descending even below the Calcite Compensation Depth (CCD) (Wagreich and Faupl, 1994). Schematically, this tectonic development of uplift, deformation, erosion and subsidence can be seen in Figure 8 below, which shows the process of the Penninic Ocean subducting below the Austroalpine microplate in the course of the Eoalpine Orogeny (Wagreich, 2003). Consequently, UGS formations are largely void of macrofossil content and consist of deep-water clastics and hemipelagic marls overlying the LGS unconformably (Wagreich and Faupl, 1994). In total, Gosau Group sediments attain local thicknesses of 2500m, as in the area around the town of Gosau. The prevalence of Gosau formations, however, has been rendered sparse due to erosional forces subsequent to the tectonic uplift of the Austroalpine Nappe and the resulting post-orogenic subaerial exposure (see Appendix A for distribution of the Gosau Group throughout the NCA). Specific tectonic forces relevant to the Gosau basin and the study area will be discussed later in this thesis.

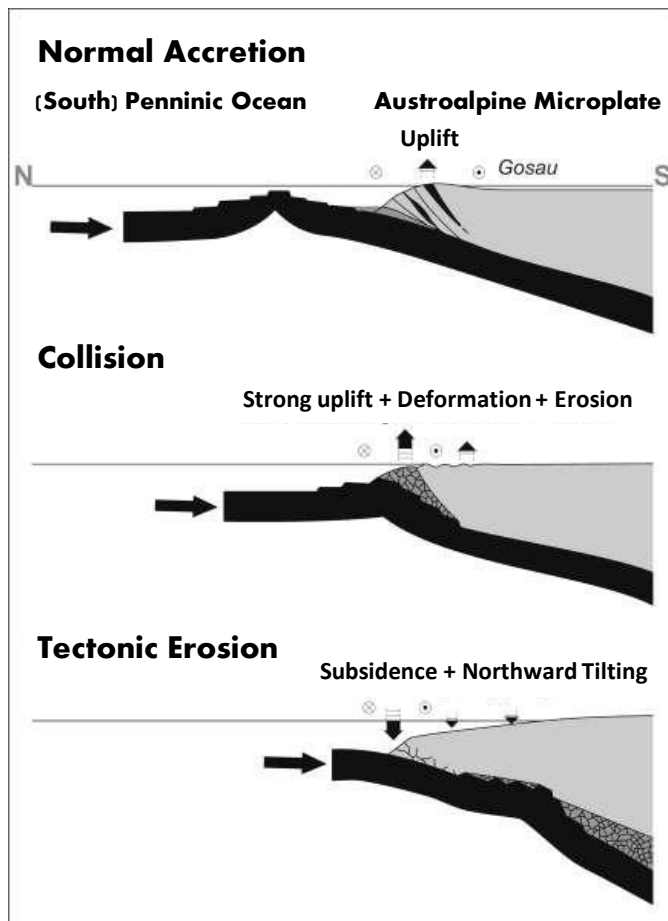


Fig. 8: Schematic plate-tectonic development depicting the subsidence of the Gosau basin to bathyal and abyssal depths through tectonic erosion and the subduction of the Penninic Ocean beneath the Austroalpine microplate (modified from Wagreich 1993, 1995, 2003).

2.4 The Gosau Group Formations in the Gosau Basin

As stated, the Gosau Group sediments in the Gosau basin provide not only the type locality for the entire Gosau Group, but also contain many of the most important type localities for the individual formations comprising the Gosau Group. In this section, the relevant Gosau Group formations will be discussed and highlighted, based upon the foundational work by Weigel (1937), who defined and named the majority of the regional formations in use today, and further refinements and extensions provided by Kollmann (1982, in Plöchinger 1982), Summesberger (1985), Wagreich (1988, 1998), Tröger and Summesberger (1994), and Summesberger and Kennedy (1996) (cf. Wagreich, 2003).

In the Gosau basin, the Gosau Group sediments include eight distinct formations, with five belonging to the Lower Gosau Subgroup and three belonging to the Upper Gosau Subgroup. Figure 9 on the following page provides an overview of the eight formations in an idealized succession, including name, chronostratigraphic stage, subgroup, lithology, key fossil content and overall thickness of the formations and component members (Summesberger et al., 2017).

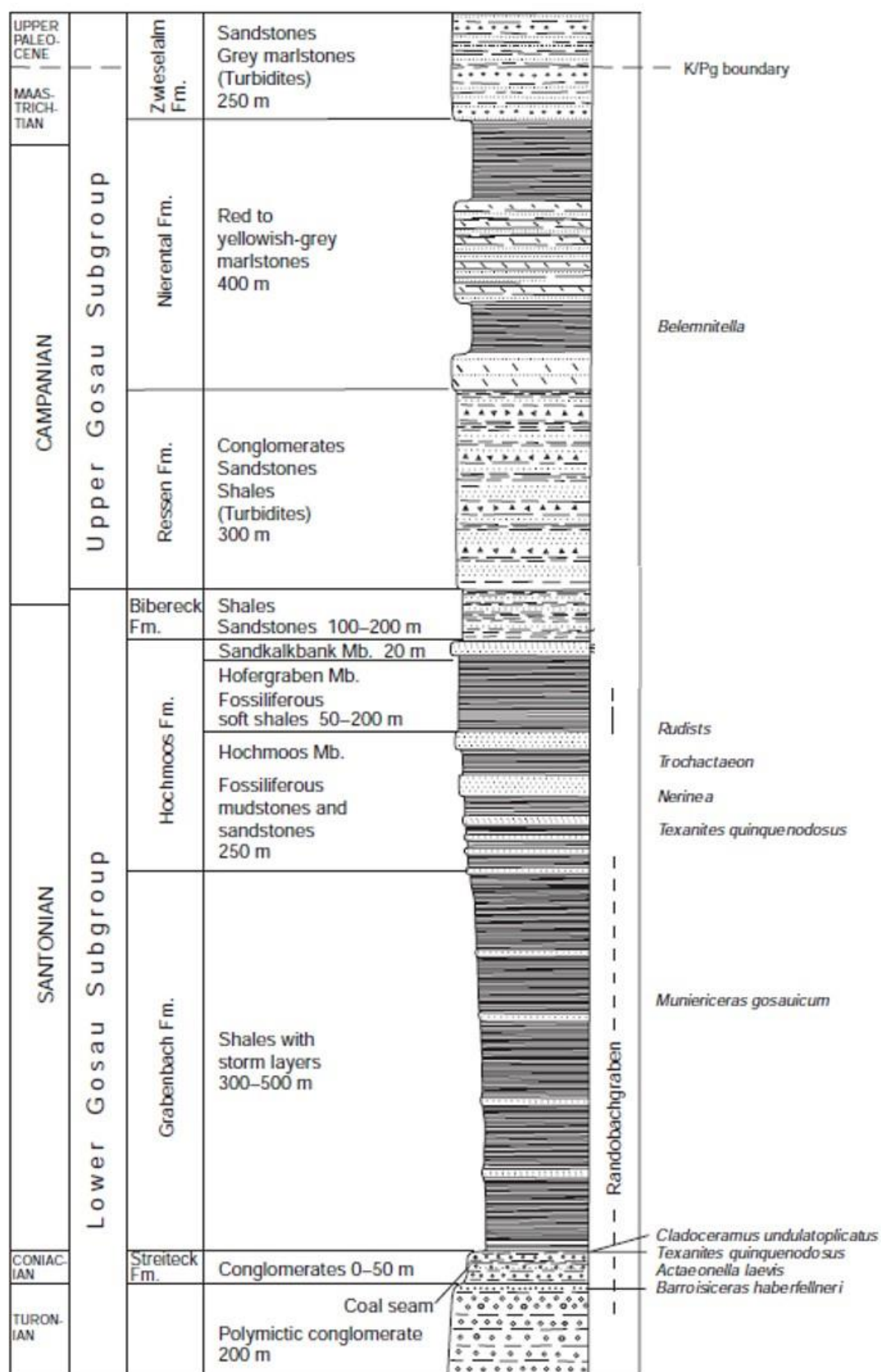


Fig. 9: Idealized stratigraphic representation of the eight Gosau Group formations in the Gosau basin (adapted from Summesberger et al., 2017, p.155) with the Kreuzgraben Formation at the bottom in the upper Turonian.

In the following section, each Gosau Group formation is briefly discussed to provide an overall context for the current work. Most of this information has been extracted from Wagreich (2003), but also includes references to other authors and papers where appropriate.

Lower Gosau Subgroup

Kreuzgraben Formation – The base of the Gosau Group in the Gosau basin is formed by the upper Turonian Kreuzgraben Formation, which consists of coarse, reddish-colored conglomerates with sporadic sandstone and clay layers intercalating. The most notable outcrops of this formation can be found in the type-locality Kreuzgraben north of Gosau Vordertal. The conglomerate beds in this formation can attain thicknesses of several meters and are mainly the result of debris flows on a massive scale covering alluvial fans. Erosional troughs and sediment morphology indicate that the direction of this debris flow was likely north to south. Due to the alluvial/terrestrial nature of these sediments, there are rare instances of coal deposits and fresh waters molluscs. The reddish color of the sediments points toward a tropical-subtropical climate during this period and the attendant iron-rich lateritic soils.

Streiteck Formation – While the red conglomerates of the Kreuzgraben Formation point to terrestrial/alluvial deposits, the uppermost Turonian-Coniacian Streiteck Formation that follows shows a first significant marine transgression and consists of sequences of marls, sandstones and conglomerates. Prominent outcrops can be found east of Russbach, in the Stöcklwaldgraben and the Randograben. The marls and sandstones contain the first marine fossils in the Gosau Group, including corals, marine snails, bivalves and ammonites. These point toward a phase of tectonic subsidence and marine transgression after the initial uplift of the NCA.

The conglomerates of the Streiteck Formation evidence the typical characteristics of nearshore alluvial fans that flowed directly into the sea and formed fan-deltas. Sandy beaches and calm lagoons with clay and marly deposits formed between such small river deltas (Wagreich, 1988). The transgression of the Penninic Ocean is presumed to have progressed from a direction north of the NCA (Wagreich and Faupl, 1994).

Grabenbach Formation – The marine transgression that began during the late Turonian to Coniacian expanded in the course of the Santonian (roughly 86 to 83 Ma) to include a much greater expanse of the northward moving NCA. This included the entire area between Gosau and Abtenau, but did not yet include parts south of Gosau in the area around the Dachstein, such as the Plankenstein plateau.

The Grabenbach Formation that follows the Streiteck Formation consists mainly of soft gray marls and shales that issued from muddy flows deposited onto the seafloor in deep, offshore shelf environments at about 30 to 150m depth. Macrofossil content is rather low and is restricted to molluscs such as inoceramids and rare ammonites. Striking features of the Grabenbach Formation are the recurring layers of sandstone that point toward catastrophic storm events in

these shallow coastal shelves (Wagreich 1988). These so-called “hurricane layers” can be compared to present-day deposits found in the Gulf of Mexico or in the North Sea issuing from similar major storm events in these regions (Wagreich 1998).

Hochmoos Formation – the upper Santonian Hochmoos Formation is the most varied interval in the succession of Gosau Group formations. As the coastal shelf areas gradually filled with sediment during the Santonian, the waters became shallower and led to coastal and shallow-marine deposits and structures, including small reefs that primarily consisted of rudists (Höfling, 1985; Sanders and Höfling, 2000), which grew in colonies in the marine substrate and often in cohabitation with Late Cretaceous corals. In the Gosau basin, significant outcrops containing rudist limestone can be found at the Wegscheidgraben near the Pass Gschütt, at Oberstöckl near Russbach and in various places near the village of Gosauschmied. The rudist limestone outcrops near Gosauschmied constitute a major focus of this paper and will be elaborated upon in subsequent sections. Other important fossils of the Hochmoos Formation include the famous Gosau snails (*Trochacteon*), which make up the well-known snail-wall (Schneckenwand) north of Russbach (Kollmann and Summesberger, 1982).

During this late Santonian period, rivers frequently carried gravel and sand deposits into delta regions that created sandy beaches and clastic carbonate sediments. Major storm events intermittently occurred and destroyed the reefs and beaches in these shallow waters, creating parautochthonous assemblages of fossil detritus that are known locally as “Trümmerkalk” or detrital limestone.

At the end of the period defining the Hochmoos Formation, a prominent sequence of calcarenites (Sandkalkbank) was deposited in the basin center that contained a plethora of marine snails, bivalves and ammonites (Kollmann, 1980; Dhondt, 1987).

The Hochmoos Formation is divided into two distinct members based upon the presence or absence of the heavy mineral chromium spinel (according to Wagreich 1986, 1988): the lower Hochmoos Formation consists of sediments rich in chromium spinel, while the upper Hochmoos Formation is void of this mineral.

To the south of the outcrops of the Hochmoos Formation near Gosauschmied, there is a significant occurrence of the so-called “Untersberger Marmor”, which is informally referred to as the **Untersberg Formation**, but is not strictly part of the Gosau basin succession. These consist primarily of fine to medium-grained breccias with detrital rudist limestone (Kollmann, 1982, in Plöchinger, 1982) and have many similarities to the detrital rudist limestone outcrops found near Gosauschmied. The Untersberg Formation can be found above the Dachstein limestone south of Gosauschmied and was extensively deposited under transgressive conditions in the late Santonian to earliest Campanian. This formation was the subject of a thorough study by Trenkwalder (1999).

Bibereck Formation – After the shallow water period of the Hochmoos Formation, which partially led to a brief period of uplift and some subaerial erosion of the NCA, a period of rapid subsidence ensued in the early Campanian (83-81Ma) that led to depths of between 1000 to 1500m and possibly more. The marls that had previously been deposited on the shelf domain morphed into deep-sea marls consisting primarily of calcareous planktonic microfossils (foraminifera and coccoliths) (Wagreich, 1998).

This rapid subsidence of the NCA to bathyal and abyssal depths was due to plate-tectonic forces at the north edge of the Austroalpine microplate, upon which the NCA was situated. It is probable that the subduction of the Penninic Ocean beneath the Austroalpine microplate caused the front edge of this plate to be driven downward by a process known as “tectonic erosion” (see Fig. 8 above), thereby causing such rapid subsidence and subsequent northward tilting of the NCA (Wagreich and Decker, 2001).

Upper Gosau Subgroup

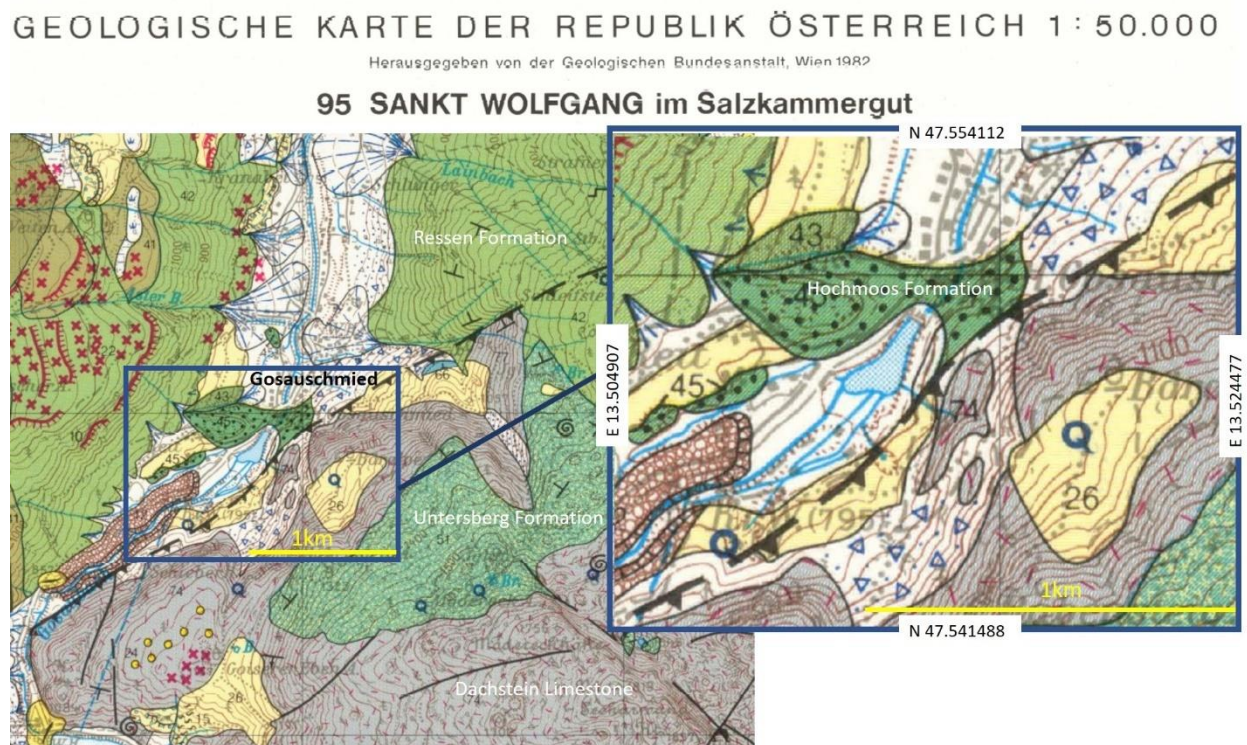
Ressen Formation – The Bibereck Formation is the last of the LGS and is overlain by the deep-water clastics and hemi-pelagic marls of the Ressen Formation (Wagreich and Faupl, 1994), which is logically the oldest of the UGS formations, covering roughly the first half of the Campanian. The sediments of the Ressen Formation are characteristic of those resulting from turbidite events frequently caused by earthquakes at shelf margins. The formation consists primarily of thick sandstone beds that evidence a fining upward in which the heavier and coarser components settle first and are subsequently overlain by lighter, finer shale and clay components. These rocks have served as the source of the famous Gosau grindstones and can be found in old quarries, as well as in ravines and trenches west of Gosau Mittertal.

Nierental Formation – Among formations in the Gosau basin belonging to the Gosau Group, the Nierental Formation is the only one with a type locality NOT in the Gosau region, but rather in the Berchtesgaden area. This formation spans the late Campanian and early Maastrichtian (78-70 Ma, Wagreich and Krenmayr, 1993) and consists primarily of red and light-gray deep marine calcareous marlstones full of calcareous plankton (Wille-Janoschek, 1966). The red color is due to oxidizing conditions on the ocean floor. Significant outcrops can be found west of Falmberg Alm near Gosau (Kollmann, 1982, in Plöschinger, 1982) and at Abtenau/Postalm (Wolfgring and Wagreich, 2018).

Zwieselalm Formation – The final Gosau Group formation to be found in the Gosau basin is the Zwieselalm Formation, named for the eponymous Zwieselalm locality south and west of Gosauschmied. After the fine calcareous marlstones of the Nierental Formation, these sediments show a return to coarser sandstones and marlstones issuing primarily from deep-marine turbidite activity. The Zwieselalm Formation spans the time from the early Maastrichtian (about 70 Ma) to the mid-Eocene (50 Ma) and crosses the Mesozoic-Cenozoic boundary. In two separate places

in the Elendgraben locality, there is even evidence of the Chicxulub asteroid impact event at the Cretaceous-Paleogene boundary (Preisinger et al., 1986; Lahodynsky, 1988), which not only precipitated the end of the non-avian dinosaurs, but also caused the extinction of major marine fauna such as the ammonites, the reef-building rudists and various plankton groups.

Figure 10 below is an excerpt from the Geological Map 095 St. Wolfgang (Plöchinger, 1982) showing the study area and the relevant formations and geological structures in the near vicinity. In the course of the field work, it was determined that portions of the geological map are in need of revision: these points will be discussed later in this thesis.



Excerpt of Legend from 095 St. Wolfgang im Salzkammergut

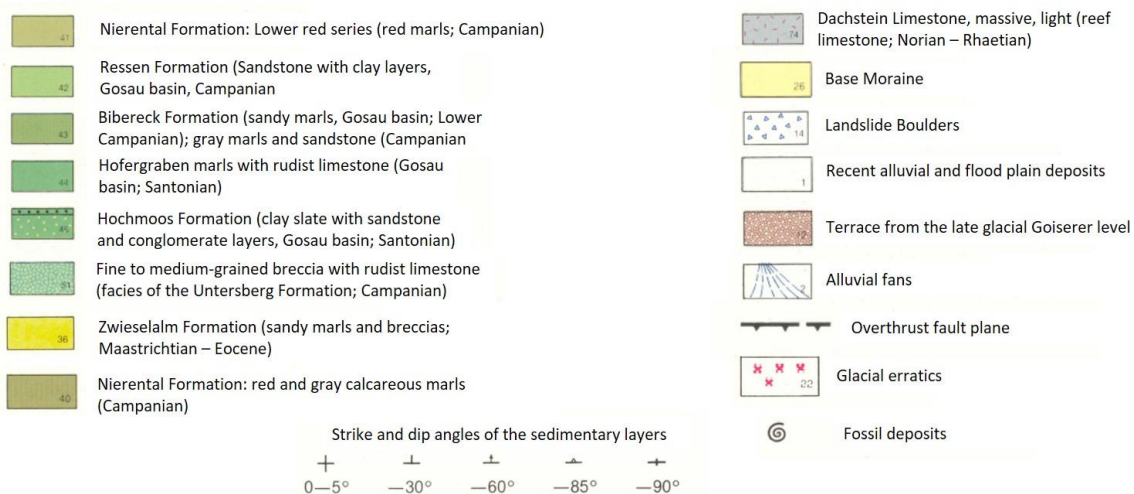


Fig. 10: Excerpt from geological map 095 St. Wolfgang im Salzkammergut (GBA, Plöchinger, 1982)

3 Materials and methods

3.1 Stratigraphic Survey Work and Profile Description

The field work for this thesis included nine separate visits to the study area from late May to early November of 2019. These included:

22-23 May 2019: initial visit to the study area with Michael Wagreich; agreement on the outcrops to be surveyed (A, B and C); full discussion of objectives and next steps; survey work on profiles A and C, including: description and measurement of outcrop beds, geological compass measurements, collection of relevant samples. Investigation of area immediately above profiles A and C.

28-29 June 2019: after obtaining authorization to investigate profile B from the Austrian Federal Forests, the emphasis was on a thorough profile of this outcrop with the same process described above. Profiles A and C were once again checked for accuracy. A small occurrence of the Hochmoos Formation to the north in a residential area was also investigated.

09-10 July 2019: work continued on profile B with recapitulation of previous survey work, additional samples, collection of some non-in-situ samples of relevant macrofossils in the outcrop.

24-25 July 2019: field work focus on the area of the Gosau brook below the hydroelectric dam (authorization provided by the Upper Austrian Energie AG), including: collection of samples, compass measurements, photo documentation. Investigation of the area above and below profile B to assess changes in lithology and macrofossil content.

03-04 September 2019: field work focus on areas between and around profiles A, B and C, including the anticline (extent and orientation); faults; the area north of profile B and in the forest above profiles A and C.

18-20 September 2019: joint visit with Michael Wagreich and Diethard Sanders; review of field work to-date; discussion of potential deposition scenarios; agreement on further steps; additional work on profile B to correct initial errors in the survey work.

03-04 October 2019: field work focus on the area behind profiles A and C, including samples, compass measurements and photos; further structural measurements on profile A, the area between A and C, and profile C; investigation of structural platform north of profile B.

14 October 2019: field work focus on entire area north of profile B extending to the road and east to the end of the Hochmoos Formation; excursion through the boundary between the Bibereck and Hochmoos Formation to the north and west of the study area.

02 November 2019: field work focus on profile C; collection of macrofossil specimens and outcrop samples; investigation of outcrops similar to C south of profile C.

All samples were collected and marked with a relevant description and stored for further analysis. Two different compasses were used for the structural measurements: a Breithaupt borrowed from the Department of Geodynamics and Sedimentology (DGS) at the University of Vienna and a 3B Scientific U73005 structural compass (personal device).

3.2 Sample and Thin Section Preparation and Analysis

A total of 99 separate thin sections were prepared from the collected samples, including:

- 17 from profile A
- 57 from profile B
- 7 from profile C
- 13 from the area behind profiles A and C
- 4 from the area between profiles A and C
- 1 from a macrofossil near profile B

The relevant rock samples were cut into sizes of roughly 4 x 4 x 1cm for submission to the thin-section laboratory at the DGS of the University of Vienna. The resulting sample was adhered to a glass slide (5 x 5cm) using a resin ARALDITE AY 103-1 and a hardener ARADUR HY 951, then cut to a total thickness of 0.3mm. Silicium Carbide powders ranging in grain size from 220 to 600 and 1000 µm were used to grind the thin section to the target thickness of 60 µm.

Thin section analysis was undertaken with a total of 6 different microscopes, three of which included photomicrography features for high-quality and detailed photos. These included:

- 1) Olympus SZX 10 stereomicroscope outfitted with a ProgRes C5 camera from Jenoptik at the Institute for Geology, University of Innsbruck
- 2) Leica MC170 HD with the Leica application suite 4.4.0 from Leica Microsystems Ltd (DGS, University of Vienna)
- 3) Leica DFC450C LAS Core with the Leica application suite 4.4.0 from Leica Microsystems Ltd (DGS, University of Vienna)
- 4) Wild Heerbrug Photomakroskop M400 (DGS, University of Vienna)
- 5) Nikon Optiphot2-Pol Binocular Microscope (DGS, University of Vienna)
- 6) Carl Zeiss Epiplan reflected light microscope (DGS, University of Vienna)

Photos were taken with the built-in cameras and, for overview shots, through the lens of the microscope with a Samsung Galaxy S9+ smartphone. Scales were either automatically registered by the cameras or subsequently measured and incorporated into the images.

The complexity of the contents revealed in the thin sections required assistance from sedimentology and paleontology subject matter experts. The following individuals provided insight into crucial aspects of the different lithological and fossil components in the thin sections:

Diethard Sanders: carbonate classification according to Dunham (Dunham, 1962), terrigenous components, stylolite structures, secondary diagenetic features, as well as fossil components such as rudists, corals, echinoids, serpulid worms, foraminifera, boring sponges, arthropods and gastropods.

Felix Schlagintweit: microfossils, particularly foraminifera.

Rosemarie Christine Baron-Szabo: identification of Late Cretaceous coral taxa.

Some samples obtained during the field work were not used for the creation of thin sections, but were cut open to provide greater insight into lithology, structure, inclusions and macrofossil content. Other samples were collected for use in isotope analysis. HCl (5%) was applied to a representative collection of samples to assess carbonate content qualitatively.

A marl sample taken from the stratigraphically oldest bed of the study area was ground up and dissolved in a 1:1 H₂O₂ solution for three days. Two fractions were sieved from the resulting slurry at 0.5mm and 0.125mm, then dried overnight in an 80°C kiln. The dried samples were then analyzed using the Carl Zeiss Epiplan reflected light microscope at the University of Vienna.

3.3 Macrofossil Analysis

In addition to microfacies analysis via thin sections, macrofossils were also collected and analyzed to identify the genus and, if possible, also the species of specimens in the outcrops of the Hochmoos Formation at Gosauschmied.

3.4 Chronostratigraphy and Stable Isotope Analysis

A total of 41 bulk carbonate samples were selected and prepared for carbon (¹³C/¹²C) and oxygen (¹⁸O/¹⁶O) isotope measurement, including 17 from profile A, 18 from profile B and 6 from profile C. Great care was taken to ensure that no material was taken from secondary diagenetic sections of the rock. Adequate sample amounts (about 100 µg) were pulverized from the rock specimens using a traditional power drill and sealed in plastic vials for delivery to the lab. The actual measurement was undertaken using a ThermoFinnigan Delta_{plus}XL mass spectrometer equipped with a Gas-Bench II at the Institute of Geology (University of Innsbruck), following the procedure described in Spötl and Vennemann (2003) (Wolfgring and Wagemann, 2018). The results were calibrated against NBS 19, CO1 and CO8 standard reference materials and are reported on the VPDB (Vienna Pee Dee Belemnite) scale (Wolfgring and Wagemann, 2018)

Regarding ⁸⁷Sr/⁸⁶Sr ratio measurements, three samples were taken from rudist shells in profile B and submitted for testing in July of 2019. An additional two measurements were made of a rudist sample from profile C and a limestone sample at the top of the ridge behind profiles A and C. The results were received in mid-January 2020. Hence, a total of five ⁸⁷Sr/⁸⁶Sr measurements were obtained for correlating the ages of the separate outcrops. The shells were

analyzed to ensure no diagenetic material corrupted the primary calcite of the fossils, and 200-300µg of powdered material was extracted using a dentist's power drill and stored in a small plastic vial. Strontium was separated by standard ion exchange chromatography. Samples were measured on a Triton mass spectrometer at the geochronological laboratory of the Department of Lithospheric Research, University of Vienna (Wolfgring and Wagerich, 2018). The precision of the measurements is in the range of +/- 0.000005; and raw ratios were adjusted according to a NIST 987 standard value of 0.710248 as recommended by McArthur et al. (2001) (Wolfgring and Wagerich, 2018).

4 Results

4.1 The Study Area, General Geological Setting and Outcrops

As stated, the selected study area consists of the Hochmoos Formation south of Gosauschmied and the areas directly adjacent in order to understand the total context. The Hochmoos Formation is situated on two limestone/carbonate elevations that dip toward the Gosau brook flowing through the valley and the reservoir behind the dam of the hydroelectric power station. Moreover, the Gosausee highway cuts through the Hochmoos Formation on the west side of the brook, creating two separate areas that were previously joined on this side of the natural valley structure. The hill on the west side of the area reaches an elevation of 831m, while the ridge on the east side of the area attains an elevation of around 840m at its boundary with the Quaternary sediments. Both sections of the area rise out of the Gosau basin directly south of Gosauschmied. The lowest point in the study area (765m) is where the brook flows under the bridge at the highway in Gosauschmied. Figure 11 provides an overview with laserscan technology from the Upper Austrian Digital Survey Information System (Digitales Oberösterreichisches Raum-Informationssystem [DORIS]).

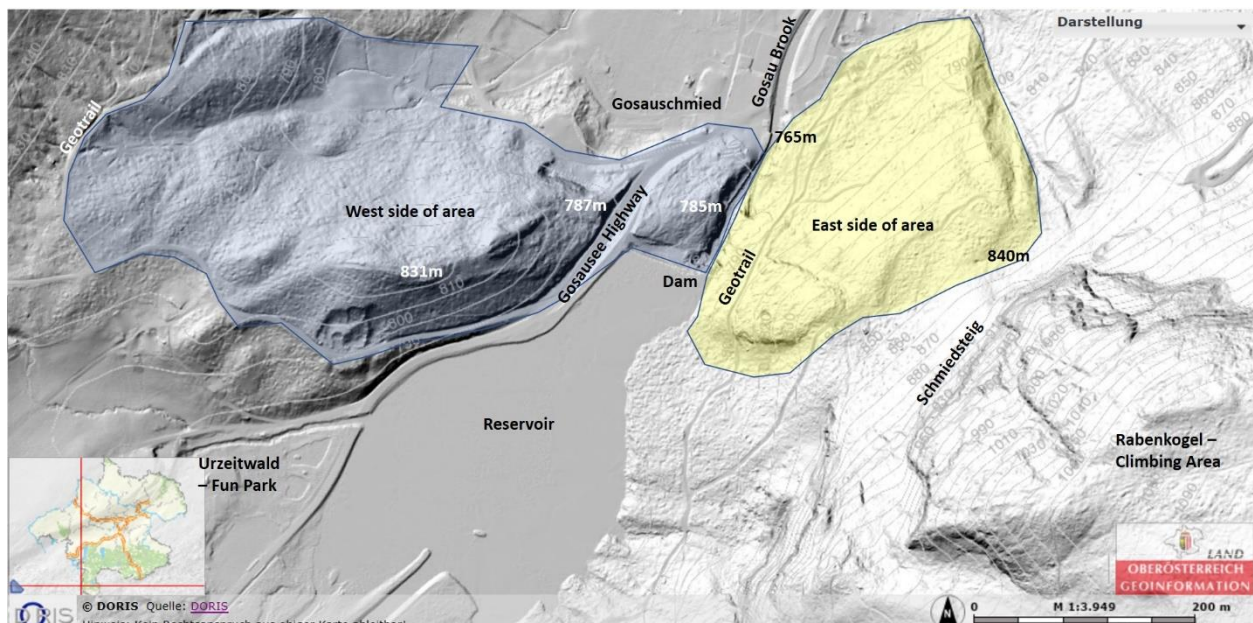


Fig. 11: Overview of west and east sides of study area with key structures, places, topography and elevation indicated. Morphologically and structurally, the two sides of the area dip toward the brook running N-NW through the valley and northward toward the Gosau Basin. The reservoir is at around 781m. (Digitales Oberösterreichisches Raum-Informationssystem [DORIS] – accessed on 15 Jan. 2020.)

As Figure 1 in the introduction shows, the terrain has substantial forest coverage and heavy underbrush with only limited paths traversing through it. The reservoir, the dam and the ravine

through which the brook flows also pose challenges to a full understanding of the area's geology. At the top of the east side of the area, a trail to and from the climbing area runs down and around to the Geotrail, which circles the reservoir and cuts back to the west side in a loop. As the map indicates, the terrain rises steeply to the SE of the area and, after roughly 20 meters of Quaternary deposits beyond the end of the Hochmoos Formation at around 840m, transitions into an imposing wall of Dachstein limestone, rising to over 1100m and providing great recreational possibilities for climbing enthusiasts. Large boulders of Dachstein limestone can be found at the base of this cliff, resulting from rockslides off the sheer face of the structure, some of which can be attributed to past glacial activity. Figure 12 below shows a picture of a Dachstein limestone boulder (not in situ) near the climbing area.



Fig. 12: Dachstein Limestone boulder near climbing area – Photo taken 02 September 2019

As indicated, the construction of the Gosausee highway and the dynamiting that broadened the road created significant exposure of the Hochmoos Formation that includes profile A and a large portion of profile C. Likewise, the hiking trail (Geotrail) in the east side of the area was built through a prominent ridge in the terrain and exposed an important section of profile B.

The Hochmoos Formation in this section of the Gosau Basin represents a unique occurrence of this formation because the sediments are almost exclusively carbonates with a high preponderance of limestone, as will be illuminated in the following sections.

Figure 13 below is a close-up of Figure 11 above showing the position of the principal outcrops selected and studied in detail. The top of the dam has been selected as a central point of reference, with GPS coordinates and altitude marking this spot.

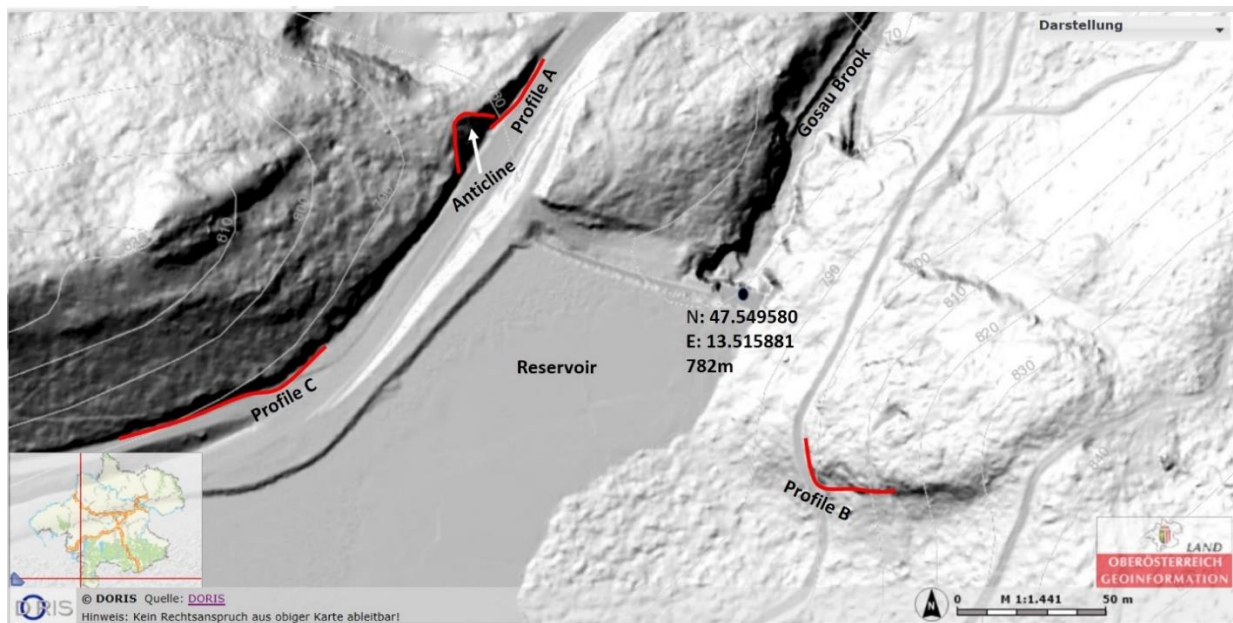


Fig. 13: Overview of the study area (zoom in on Figure 11) showing the positions of the outcrops studied in-depth. The anticline next to profile A is a prominent feature in the study area and will be analyzed in more detail later in this paper. (Digitales Oberösterreichisches Raum-Informations-System [DORIS] – accessed on 15 Jan. 2020.)

In structuring the presentation of the results, it was deemed most appropriate and informative to begin with the stratigraphically oldest sediments, which are represented by the core of the anticline, then develop the stratigraphic succession on the west side of the area from base to top, including both profiles A and C and the areas surrounding these outcrops. This will be followed by a similar stratigraphic overview of the east side of the study area, including profile B and the area surrounding this outcrop. Subsequent to this, the area in between the west and east side along the Gosau brook and at the outlet of the power station will be discussed. Lastly, to conclude the stratigraphic overview, an additional section will be devoted to the boundaries between, and the extent of, the Hochmoos and Bibereck Formations at Gosauschmied, with a final section addressing the macrofossils collected in the study area.

4.1.1 Anticline

The anticline is one of the most significant and, in many respects, helpful geological structures in the study area, although partially covered by concrete for stabilization of the terrain. It was exposed in the course of the road works that created the Gosausee highway from Gosauschmied to Lake Gosau. Figure 14 (next page) provides a composite image of the anticline exposed on the west side of the highway.

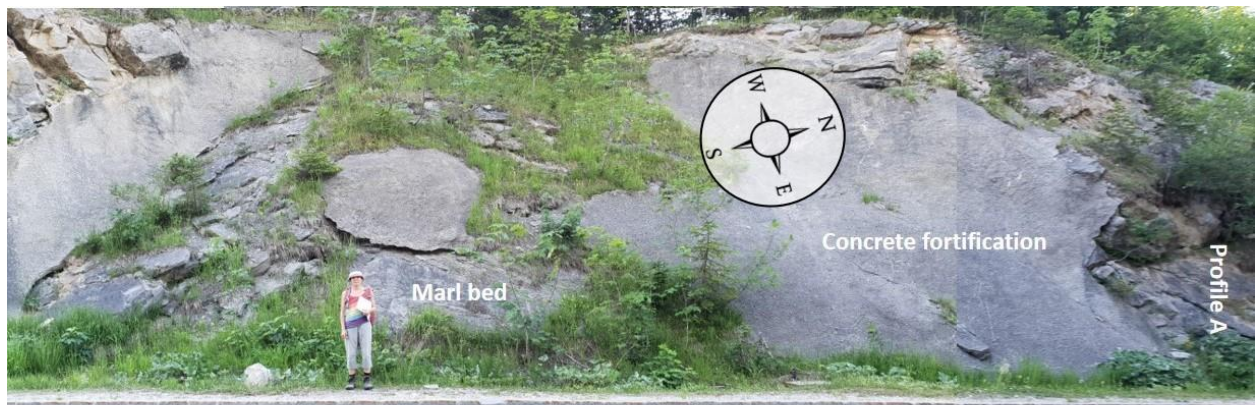


Fig. 14: composite photo of the anticline in the study area.

As can be seen in the photo (Figure 14), the anticline actually includes the base of profile A, which constitutes the north end of the anticline and will be discussed in more detail in the subsequent section. The core of the anticline contains the oldest sediments in the study area, consisting of carbonate marls, transitioning gradually to clastic carbonates (calcarenite and carbonate conglomerate beds as evidenced in the first 7 beds of profile A), and is finally overlain by peloid limestone, which can be found on both the north and south sides of the anticline and on the top extending into the forest.

The anticline extends from west to east through the study area, and this is evident not only due to the structure, but also the lithology, which is unique in the study area amid the limestone sediments that otherwise comprise the vast majority of outcrops. Figure 15 below is a composite image of the extent of the core of the anticline on the east side of the Gosausee highway.



Fig. 15: Composite photo of the anticline on the east side of the Gosausee highway (the red line marks the extent of sandy, clastic carbonates. The two yellow lines mark a fault zone to be discussed in a subsequent section)

The sediments on top of the east side of the highway are also peloid limestones (packstone to grainstone), so this is clearly an extension of the west side of the highway, but at a lower elevation: the top of the anticline on the west side of the highway is 787m altitude, but only 782m on the east side of the highway. A further eastward extension of the core of the anticline was found on the west side of the Gosau brook: here, three beds of calcarenite in a nearly horizontal orientation (hence mirroring the top of the anticline on both sides of the highway) were located with a height of about 1.5m and a length of 8-9m. This instance of the core of the anticline is at 772m. Measuring lengths and altitudes of these three exposed parts of the anticline and the distances

in between them allows for the construction of an overall projection of the core of the anticline through the study area, as can be seen in Figure 16 below.

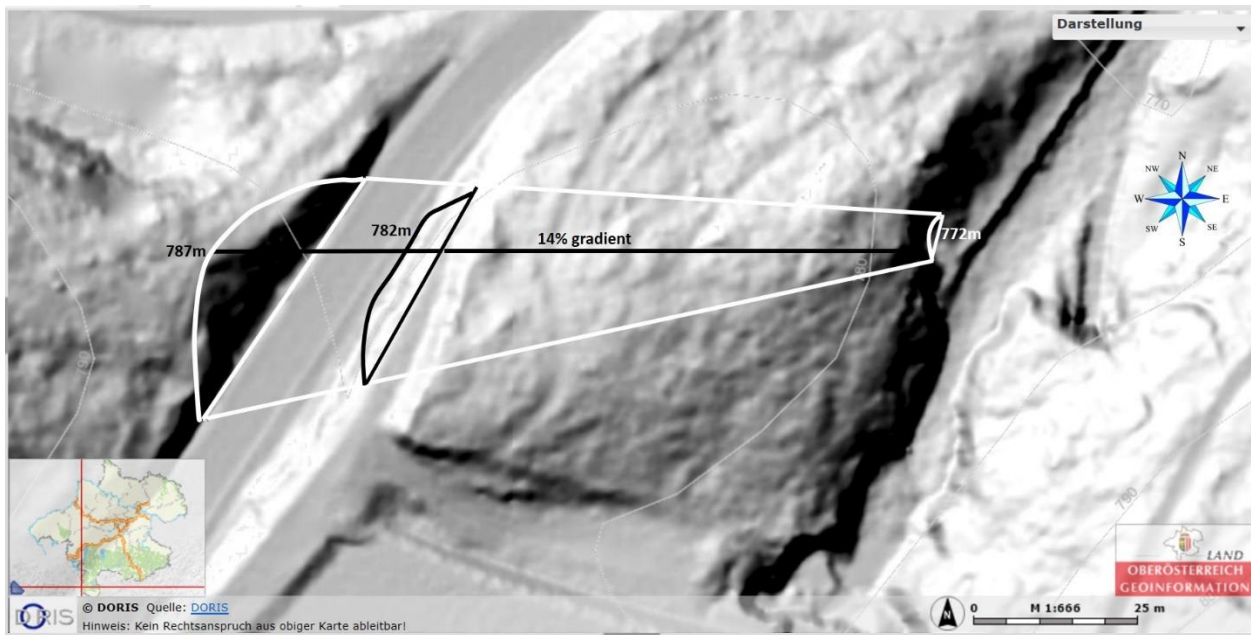


Fig. 16: Projection of the anticline through the study area. From Digitales Oberösterreichisches Raum-Informationssystem [DORIS], accessed on 06 September 2019

This construction shows that the anticline is dipping from west to east toward the Gosau brook at a gradient of roughly 14%. There is no evidence of the anticline on the east side of the Gosau brook, as it either ceases at this point or is no longer exposed. A further extension westward of the anticline from the west side of the Gosausee highway can be intuited in the prominent ridge rising up the hill behind profile A (see Figure 13). Structurally, the anticline and the ridge divide the west side of the study area into northern and southern sections: outcrops to the north all have a N/NE orientation, while outcrops on the south side all have a S/SE orientation. The gradient up the ridge is certainly not constant, but has an overall 20% rise from the top of the core of the anticline (787m) running W/SW to the top of the ridge (830m) over a distance of 212m. Since the anticline is no longer exposed west of the highway, there can be no definitive proof of this hypothesis; but this idea appears to have considerable merit and will be discussed further in the chapter on overall structure of the study area.

As indicated, the carbonate marls at the core of the anticline comprise the oldest sediments in the study area. Samples were extracted from this bed to assess lithology and fossil content. First, the samples evidence considerable carbonate content when subjected to 5% HCl solution. Small calcareous tests and shell fragments were also clearly identifiable on the surface. A portion of one sample from the marl bed at the core was ground up and dissolved in 1:1 H₂O₂ for three days, then sieved at fractions of 0.5mm and 0.125mm and dried overnight. Under a direct light microscope, the sieved fractions could be seen to contain mainly terrigenous components (grains of clay and calcite), but also a significant number of calcareous tests and

shell fragments. Most of these were fractured and overgrown and hence could not be associated with any organism. In addition, these fragments were very fragile and crumbled when pressed by a metal stylus. Figure 17 below shows images of several intact microfossils, which consist of ostracods and foraminifera.

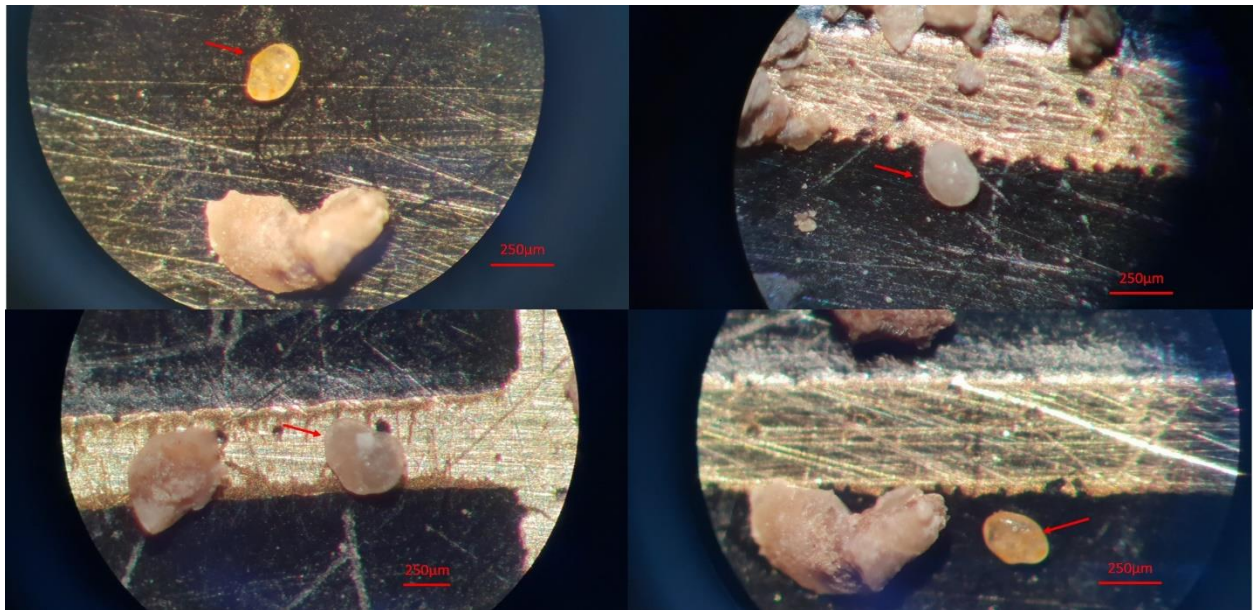


Fig. 17: Single microfossils in the marl bed. Lower left is a foraminifera (genus unidentifiable, but appears to be a miliolid), the other three are ostracods.

The structural importance of the anticline will again be touched upon in chapter 5 in the discussion section.

4.1.2 Profile A

Macro Overview and Structure

As noted, profile A (N 47.550141, E 13.514879, 780m) is located on the west side of the Gosausee highway as the road exits Gosauschmied to the south and runs up toward Lake Gosau. It consists of an initial sequence of sandy (calcarenite) and conglomerate carbonate beds with varying clastic content, followed by a thin marl layer and then a series of massive medium- to dark-gray limestone beds. The dip-direction is N-NE, tending toward true N at the end of the profile, while the dip angle is variable and ranges from 33° to 62°. Fossil content is low and, in some beds, non-existent. Figure 18 below shows the first part of profile A up to the calcareous marl layer at bed 8. As mentioned in the previous section, these beds are part of the core of the anticline and are mirrored on the south side of the anticline, as can be seen in Figure 14 above.

In total, profile A consists of 24 beds and has a thickness of a bit more than 17m. It extends along the Gosausee highway for 23.75m and has a height of between 6 and 7m at its highest point. The outcrop is no longer exposed at its most NE point. Profile A represents the NE section of the prominent anticline in the area. Bed 1 of profile A was selected as the first evident sedimentary bed visible to the north of concrete fortification structures laid down across the anticline to prevent land- and rockslides onto the road. A portion of this concrete fortification can be seen at the left edge of Figure 18.



Fig. 18: Initial section of profile A. Red lines indicate first eight beds.

A total of 17 compass measurements were taken in profile A to determine overall orientation of the individual beds. These can be seen in the Schmidt diagram depicted in Figure 19 below. Profile A is on the north side of the anticline; and, structurally, all outcrops and beds to the north of the anticline dip N/NE at varying angles, with the tendency for steeper inclinations closer to the core of the anticline, which harbors the oldest sediments in the study area. The beds composing profile A are hence younger than those at the core of the anticline.

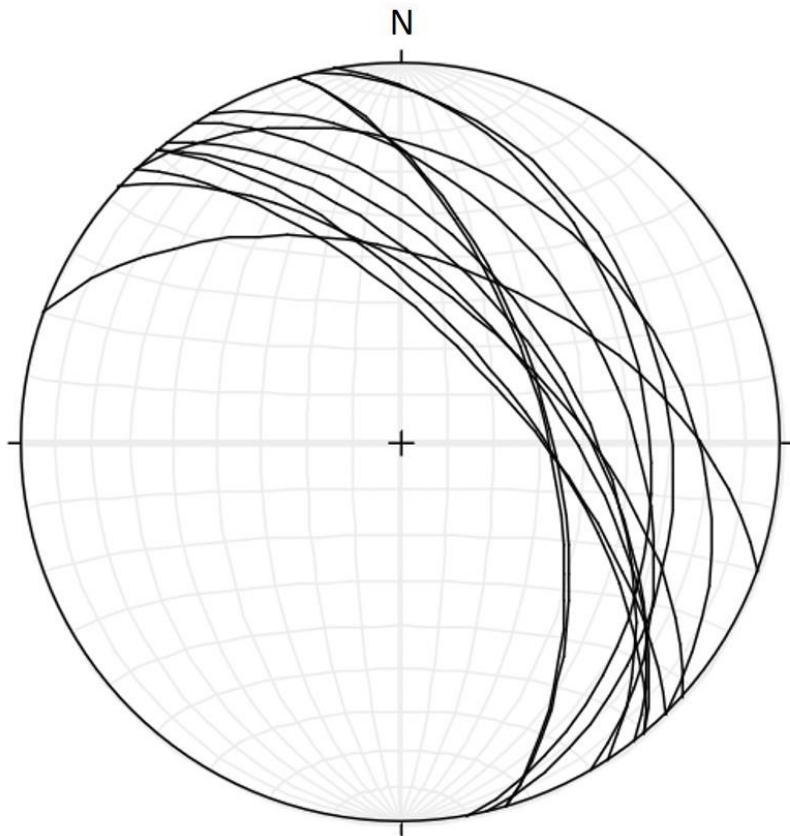


Fig. 19: Compass measurements from profile A range from dip direction of N/NE to a more N direction in beds 20-24. Dip angles range from 33 to 62.

Below are a number of additional images (Figure 20) showing various beds of profile A, including a panorama view capturing the entirety of the outcrop.

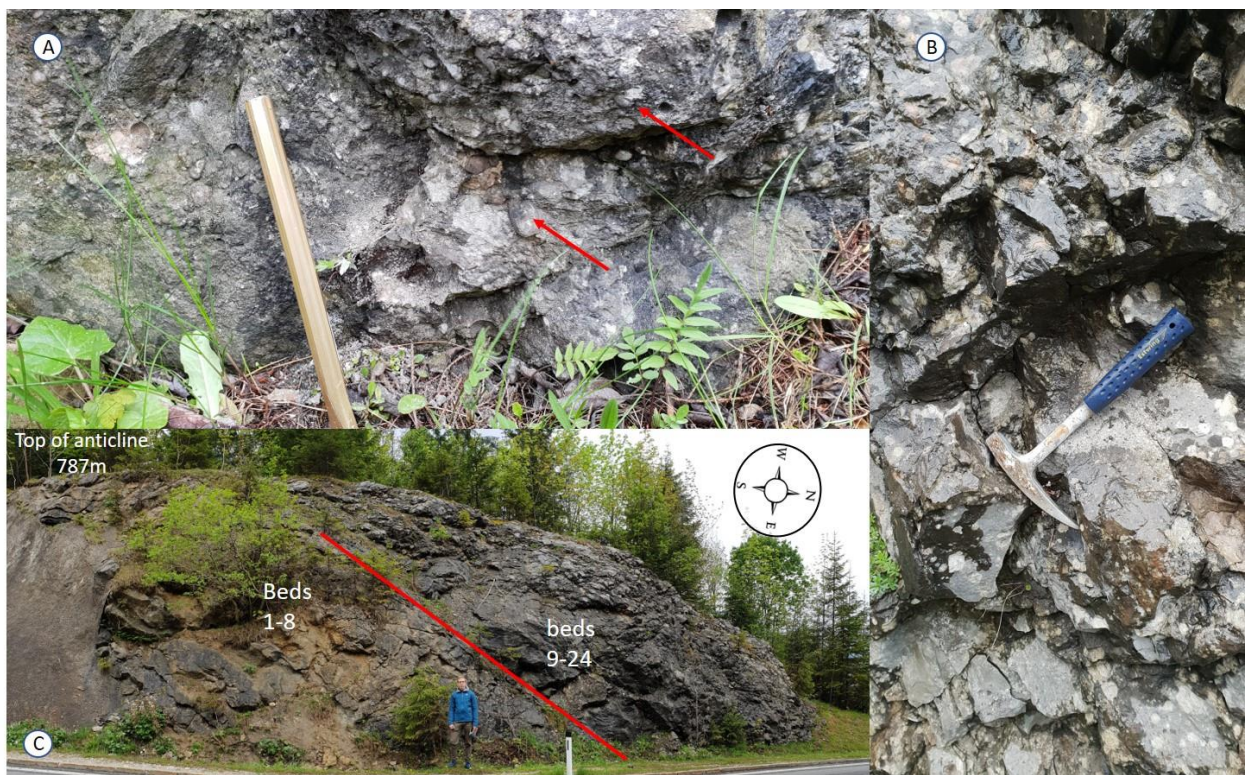


Fig. 20 (preceding page): A – base of bed 5 where sample was extracted, red arrows point toward visible conglomerate components in the surface, chisel 30cm long. B – bed 15, peloid limestone with no visible terrigenous content, packstone. C – panorama view of profile A with line showing transition from clastic carbonate sediments to limestone. The concrete fortification of the anticline is visible in the left of the picture. The top of the anticline at 787m is indicated in the upper left-hand corner.

The stratigraphic column for profile A can be seen in Figure 21 below.

Profile A -- Hochmoos Formation						
BED NR.	AGE	NOTES	SCALE (m)	LITHOLOGY	STRUCTURES / FOSSILS	BIOTUREATION
				rud wacke pack grain rud & bound LIMESTONES		
Bed 24	Upper Santonian	Peloid limestone, grain to packstone, monocrystalline quartz	17			
Bed 23		Peloid limestone, packstone				
Bed 22		Peloid limestone, dissolved brachiopod	16			
Bed 21		Peloid limestone, packstone				
Bed 20		Echinoid spine, rudist fragments, benthic foraminifera	15			
Bed 19		Medium gray peloid limestone, open shelf facies, small lithoclasts and bioclasts				
Bed 18		Packstone, limestone similar to bed 17	14			
Bed 17		Medium-gray limestone, packstone, echinoid fragment, bioturbated, bivalve fragments, fine sand and silt.				
Bed 16	Upper Santonian	Medium-gray limestone, packstone	13			
Bed 15		Medium-gray limestone, packstone				
Bed 14		Medium gray peloid limestone, singular quartz crystals, echinoid fragment, small benthic foraminifera, small radiolite fragment, well-sorted, packstone to grainstone, low fossil content	12			
Bed 13		Medium to dark gray limestone, cluster of radiolites, ostracoda, probably allochthon, calcite intrusions, high peloid content	11			
Bed 12		Medium gray limestone with carbonate lithoclasts and jagged peloid components. Well-sorted. Foraminifera	10			
Bed 11		Dark limestone with minor marl content, packstone	9			
Bed 10		Dark limestone with some marl content and fossils	8			
Bed 9		Dark limestone with some marl content	7			
Bed 8	Upper Santonian	Carbonate Marl layer	6			
Bed 7		Calcareenite with large single clasts. Medium grained matrix				
Bed 6		Calcareenite bed with carbonate lithoclasts	5			
Bed 5		Large calcarenite bed with carbonate lithoclasts				
			4			
			3			
Bed 4		Bed with dolostones and dolomite matrix, rudstone	2			
Bed 3		Fine-grained conglomerate, rudstone, dolomite matrix with glassy rhomboid structures	1			
Bed 2	Upper Santonian					
Bed 1		Sandy, clastic limestone with intraclasts				

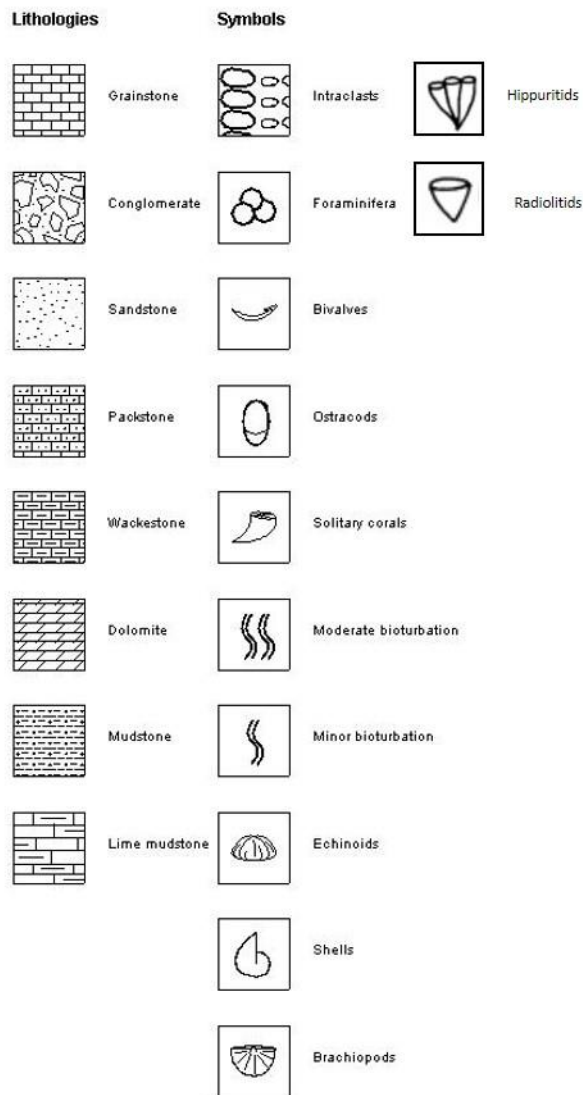


Fig. 21: Stratigraphic column of profile A (preceding page) with legend of lithologies and symbols to the left.

Microfacies – Profile A

A total of 17 thin sections were created from Profile A samples that afforded insight into lithology, facies development, possible deposition environment and fossil content. During the collection of samples in the field, there were no evident macrofossils (in contrast to profile B and the lower part of profile C). The first 7 beds were clearly carbonate sediments with a high proportion of terrigenous and clastic content. The thin sections created from these first 7 beds have some fossil content, but this is primarily restricted to singular benthic foraminifera. From bed 1 through bed 5, the terrigenous clasts are medium to coarse-grained and consist of sand, quartz, chert (possibly of Jurassic origin) and carbonate lithoclasts from Dachstein limestone, often containing Triassic fossils, such as involutinida and biserial agglutinating (textularida) foraminifera. When applied, 5% HCl indicated high calcium carbonate content in every sample except bed 4, which later analysis showed to be highly dolomitized. A total of 5 thin sections were produced from these first 5 beds and can be seen in the overview in appendix B. The following three Figures

(22, 23a, 23b and 24) provide a selection of 12 images from these thin sections, with key features indicated in the descriptions. The thin section number is in brackets next to the image letter.

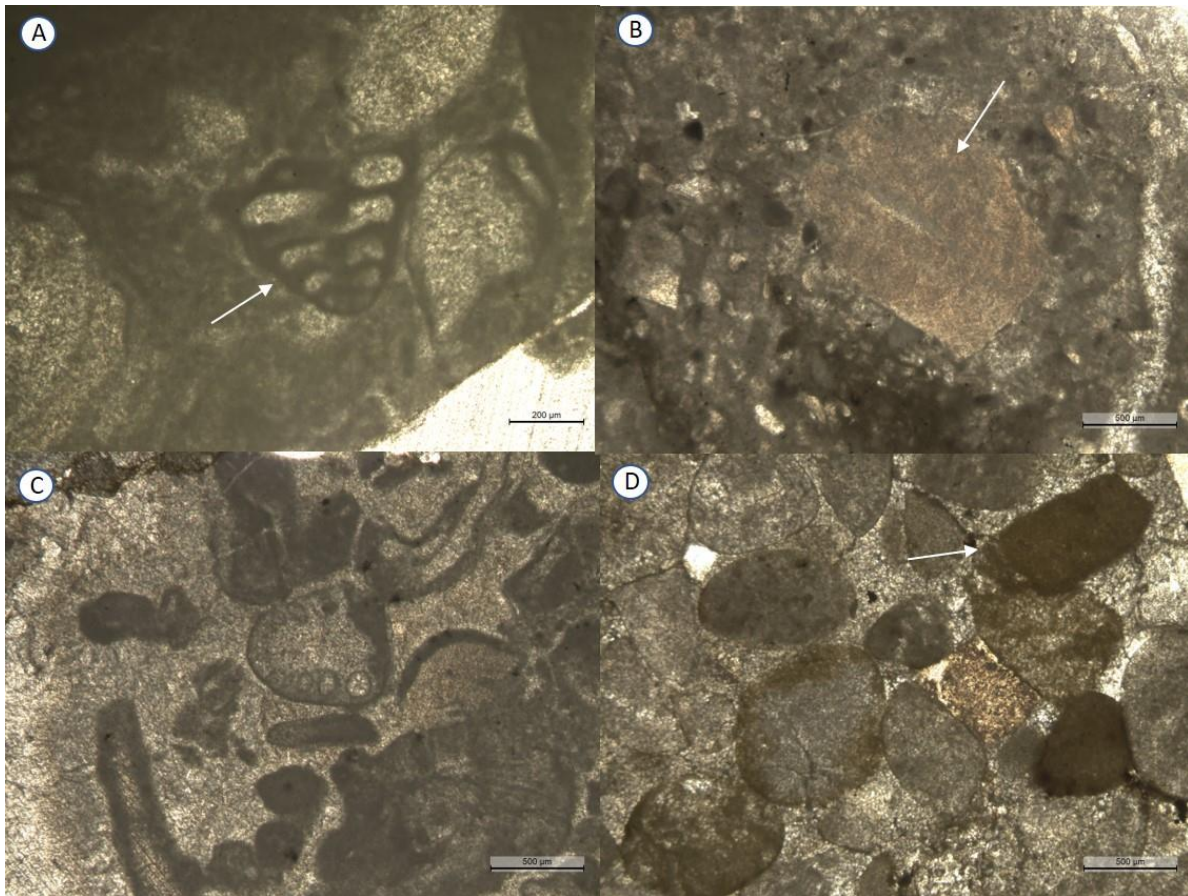


Fig. 22: A (A1) – bed 1, *textularida* (white arrow) from a lithoclast of Dachstein limestone. B (A1.1) – bed 1 showing a bivalve fragment (white arrow). C (A1) – bed 1, Triassic fossil fragments inside Dachstein limestone. D (A3.1)– bed 3, various terrigenous components in fine-grained conglomerate, including chert (white arrow), quartz, dolostones, indicative of transgression in a fan-delta milieu.

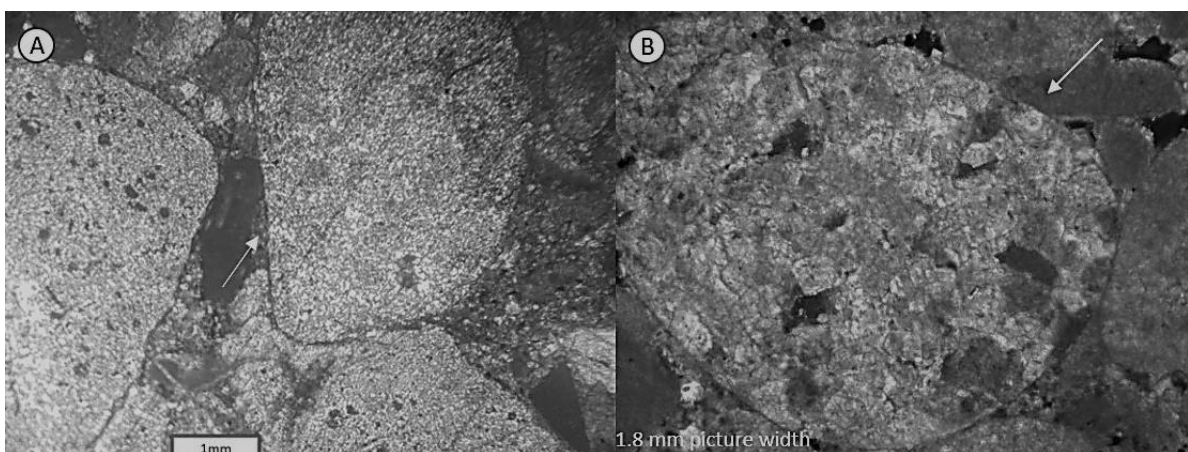


Fig. 23a: A (A3.1, BW) – bed 3, large clasts of quartz (white arrow). B (A4, BW) – bed 4, large dolostone clast with irregular components (white arrow). BW = Black-and-White thin section photograph

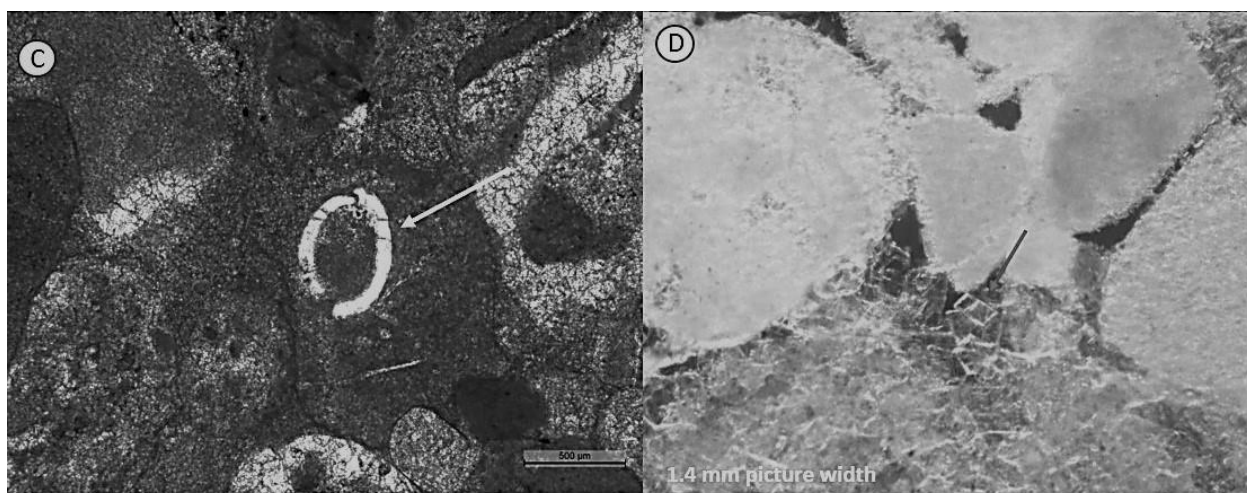


Fig. 23b: C (A3.1, BW) – bed 3, ostracod fossil (white arrow). D (A4, BW) – bed 4, dolostone clasts within dolomite matrix (rhomboid crystals, black arrow).

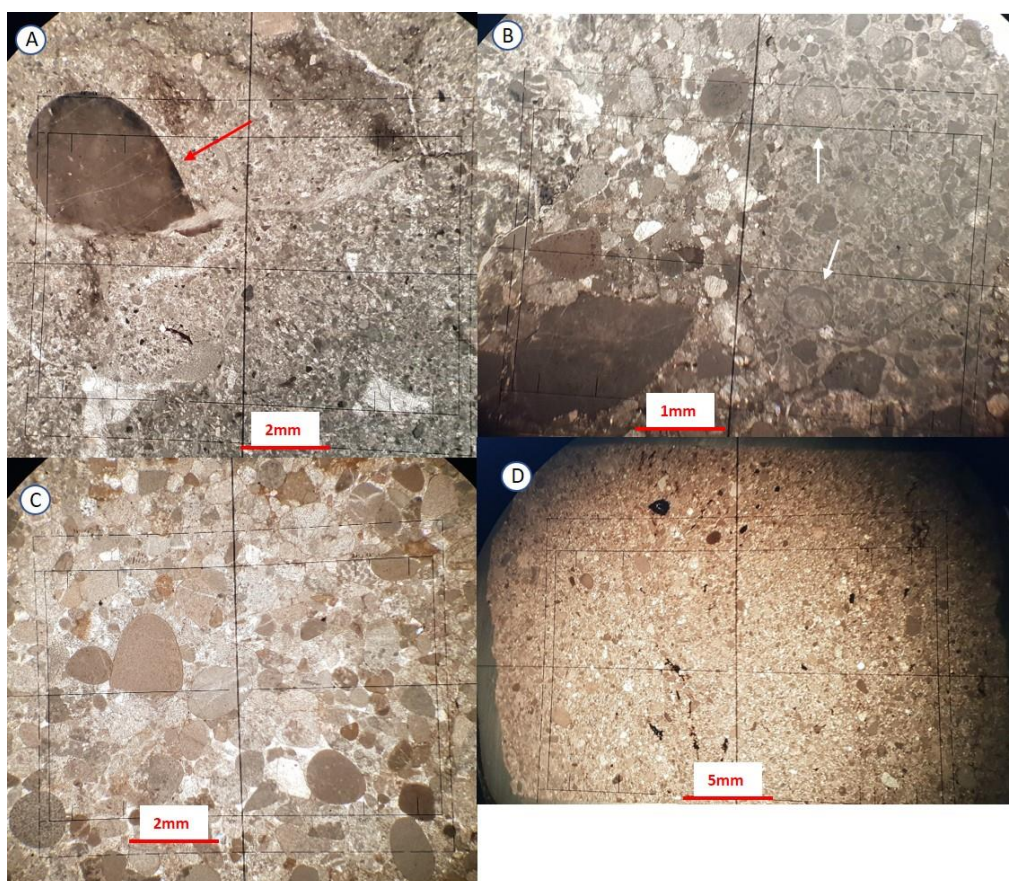


Fig. 24: A (A1) – bed 1, overview of rock fabric with large chert clast in upper left corner (red arrow). B (A1.1)– bed 1, close-up of Dachstein limestone clast showing *involutinida* foraminifera of Triassic provenience (white arrows). C (A3.1) -- bed 3, overview of fabric with various terrigenous clasts (siliciclastic and carbonate lithoclastic content with pelsparite and dolomite in the interstitial spaces). D (A5) -- bed 5, overview of fabric, very little cement, grainstone, carbonate-lithic arenite with clasts of chert, carbonate sand and mono-crystalline quartz (silt-sized).

Beds 7-13 in profile A represent a transition from clastic carbonate to a much purer limestone lithology with only limited terrigenous content. After a thin calcareous marl layer at bed 8, beds 9-13 gradually transition into dark-gray to medium-gray peloid limestone with, initially, some marl content that totally disappears by bed 14. Fossil fragments appear to be allochthonous, and there are only small and scant instances of Dachstein limestone. Figures 25-28 below are images from thin sections in this part of profile A.

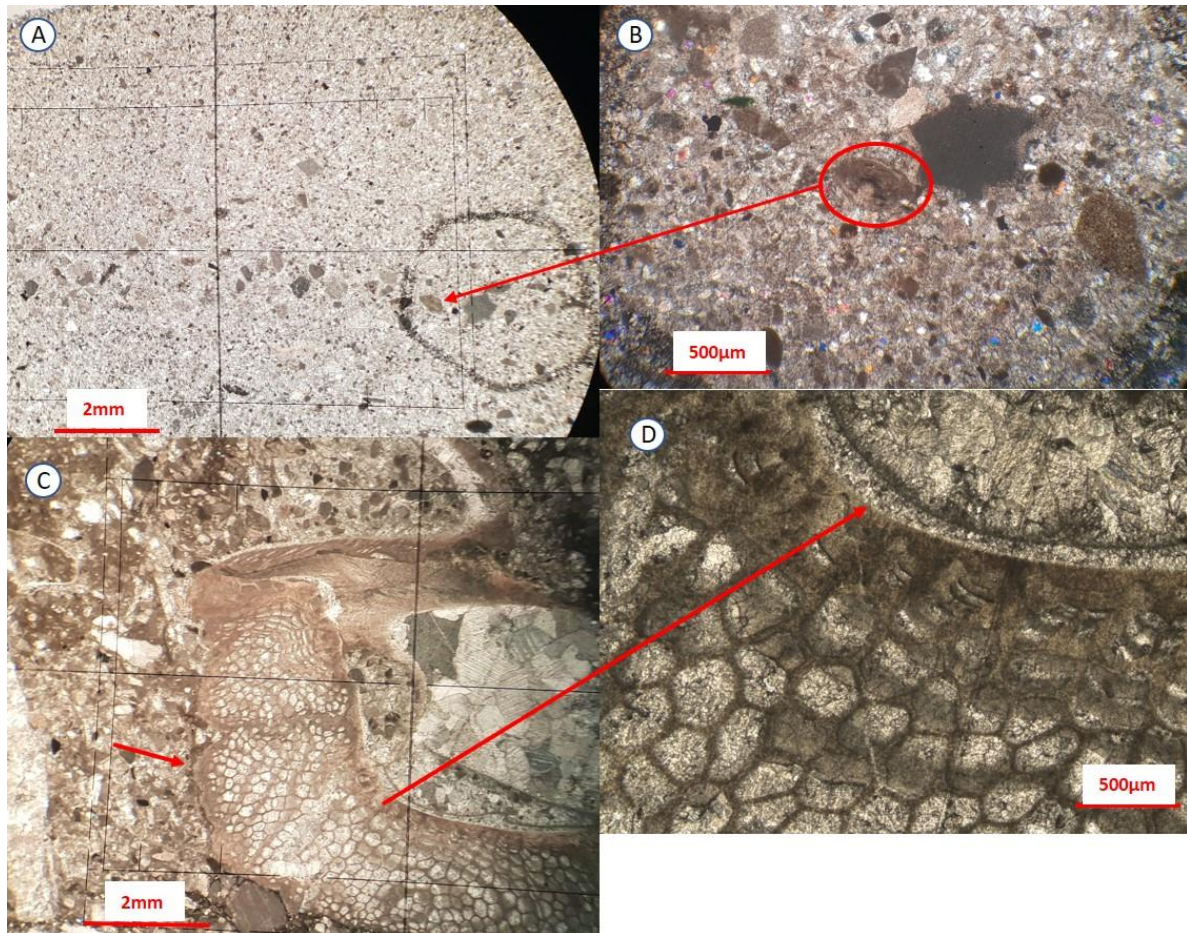


Fig. 25: A (A7) – bed 7, overview of lithology, visible sand, chert and lithoclasts in a clear line of sedimentation, *Nummofallotia cretacea* (Schlumberger 1900) (red arrow) next to clast of chert (Felix Schlagintweit, personal communication, October 2019). B (A7) – bed 7, close-up of circle in image A showing *Nummofallotia cretacea* (inside red circle), crossed nicols polarization showing interstitial micrite. C (A10.1) – bed 10, micrite-filled radiolitid fragment (red arrow) with sparite crystals at center. D (A10.1) – bed 10, close-up of radiolitid fragment from image C with infilling sparite crystals (red arrow).

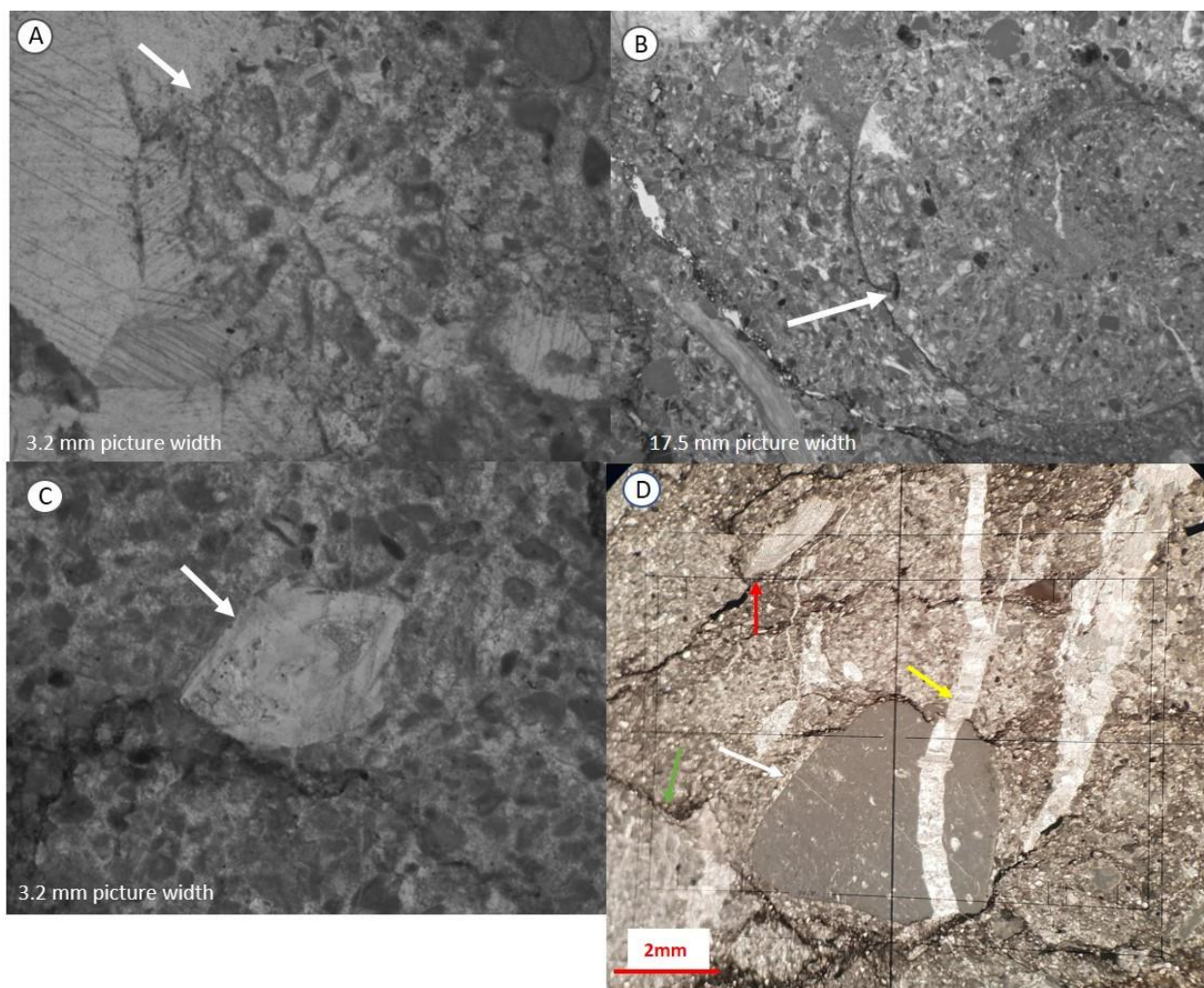


Fig. 26: A (A10, BW) – bed 10, coral fragment (*Cladacora* sp., white arrow). B (A10, BW) – bed 10, dissolved gastropod (white arrow). C (A12.2, BW) – bed 12, *Nummofallotia cretacea* (white arrow). D (A10) – bed 10, clast of Dachstein limestone (white arrow) with secondary calcite vein (yellow arrow), small radiolitic fragment (red arrow) and multiple stylolites (green arrow).

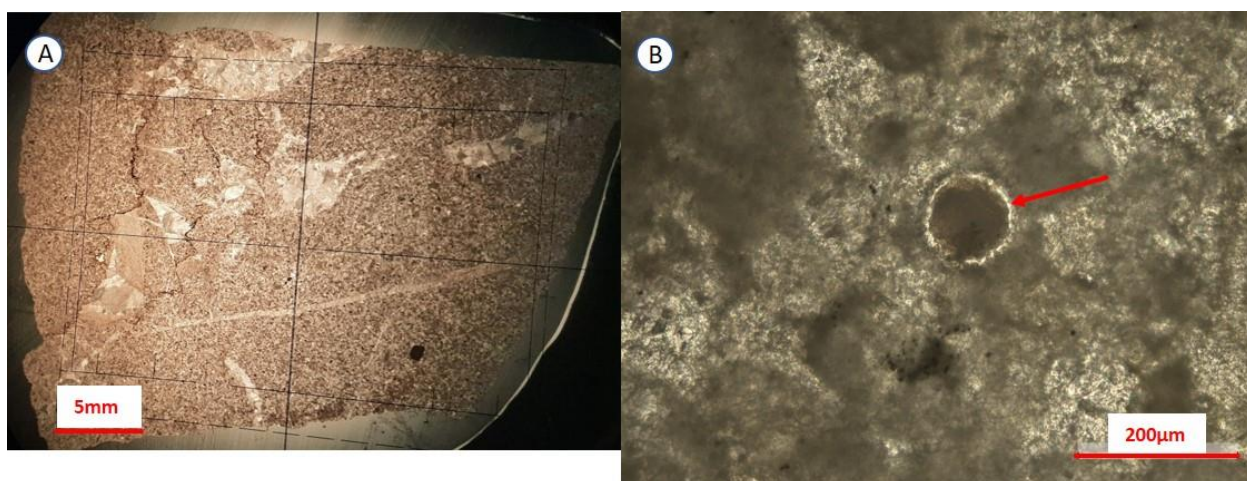


Fig. 27: A (A12.1) -- bed 12, overview of fabric with fine-grained, but irregular peloid components and calcite/sparite crystals. B (A13) – bed 13, ostracod (red arrow).

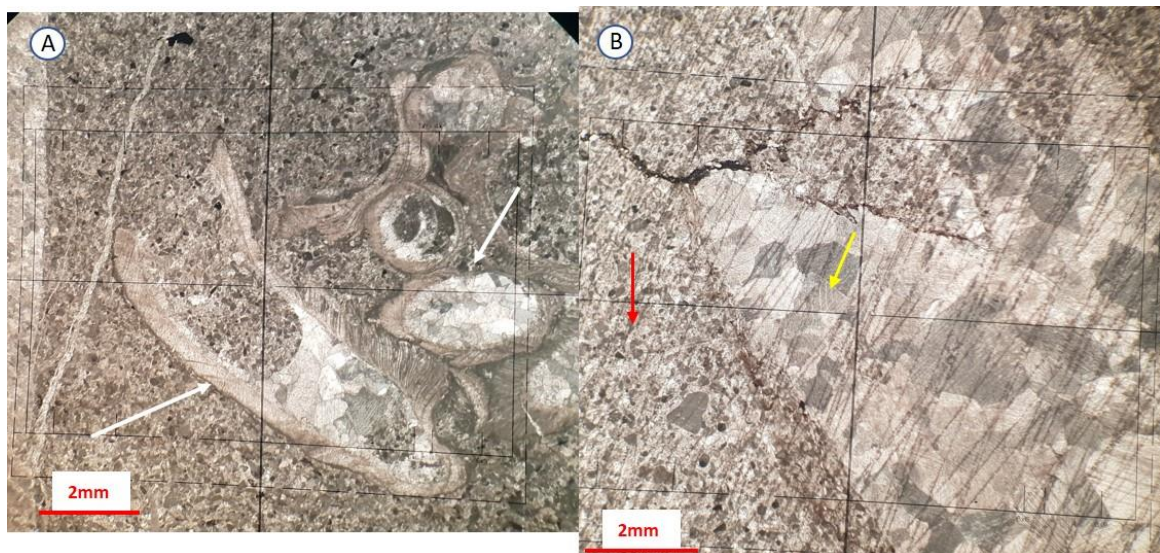


Fig. 28: A (A13) – bed 13, radiolite fragments (white arrows) filled with sparite crystals in fine-grained peloid limestone. B (A12.2) -- bed 12, fine-grained peloid limestone with irregular components (red arrow) and sparite infilling with large calcite crystals exhibiting clear lamination (yellow arrow).

As of bed 14, profile A transitions into a rather monotone succession of medium-gray peloid limestone beds with almost no terrigenous components and very low fossil content: apart from a few scattered foraminifera and biogenic fragments, there is little to distinguish the different beds from each other. The final bed in the profile, #24, is the least differentiated. Figures 29, 30 and 31 below show some thin sections from this final part of profile A.

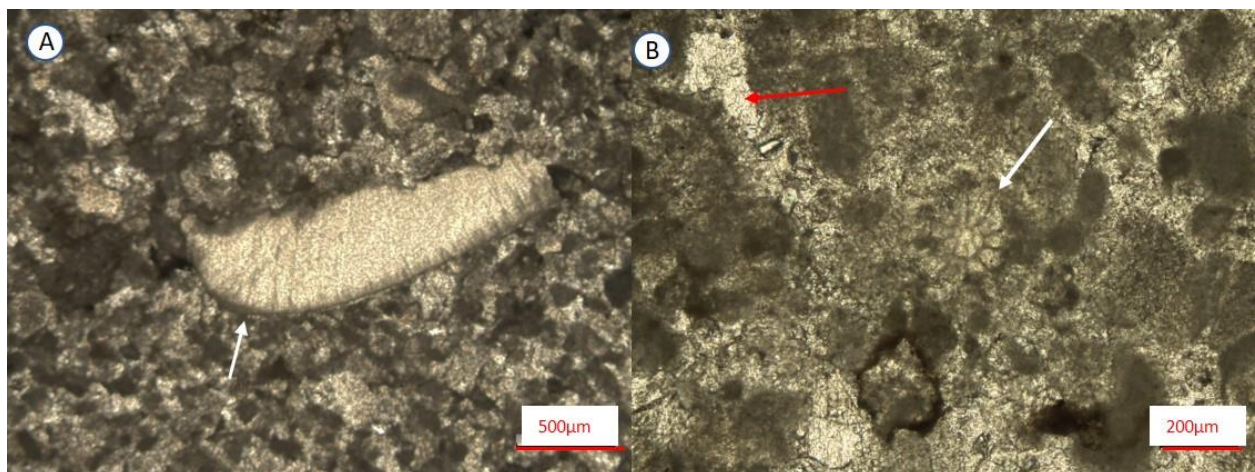


Fig. 29: A (A14) – bed 14, echinoid fragment in limestone of irregularly-shaped peloid components. B (A14) – bed 14, planspiral foraminifera (white arrow) and micrite cement (red arrow) in packstone matrix.

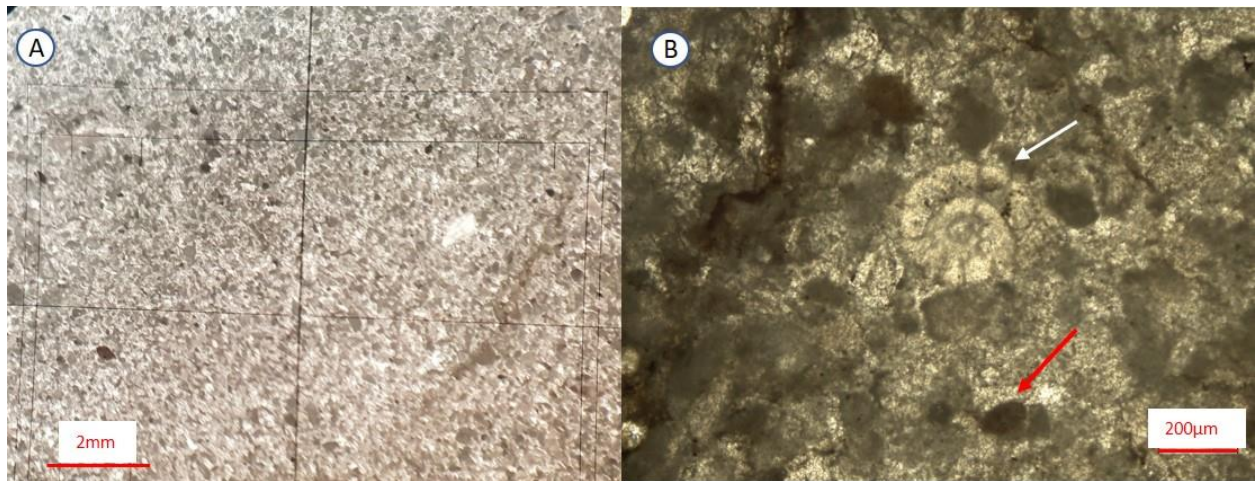


Fig. 30: A (A19.1) – bed 19, fine-grained packstone lithology pointing to deposition in open shelf environment, small chert clasts, micrite cement. B (A20) – bed 20, planspiral foraminifera (white arrow) in packstone of peloid limestone (red arrow indicates individual peloid component).

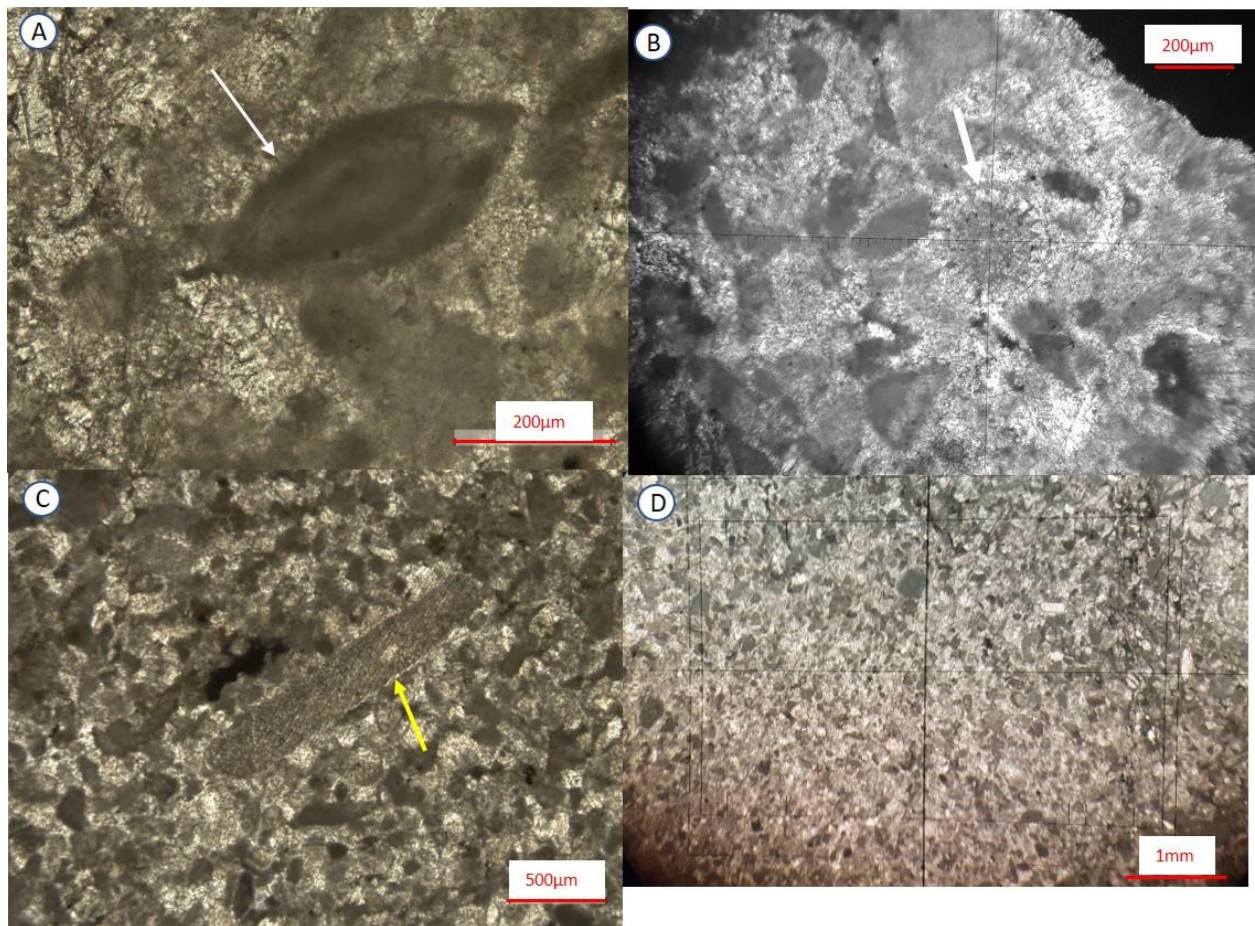


Fig. 31: A (A20) – bed 20, *Quinqueloculina* sp. (miliolid, hyaline foraminifera – white arrow). B (A20, BW) – bed 20, sea urchin spine (white arrow). C (A20) – bed 20, echinoid fragment (yellow arrow). D (A24) – bed 24, overview of peloid limestone lithology, with packstone to grainstone fabric, micrite matrix and fine-grained peloids and small clasts.

4.1.3 Profile C

Macro Overview and Structure

Profile C (N 47.549332, E 13.513960) consists of very thick, nearly horizontally-positioned dark marly limestone beds. It is located south of the anticline and approximately 87 meters up the road from profile A. Although the beds, upon first inspection, do not appear to have any fossil content, closer analysis shows the presence of both macro- and microfossils. Profile C is made up of six beds of varying thickness and totals up to 6.5m. The dip direction is S/SE at relatively moderate angles (25-48°), which is in line with all outcrops on the south of the anticline and ridge. Figure 32 below provides an overview of beds 1 and 2 in profile C:



Fig. 32: Photo of profile C at N 47.549332, E 13.513960 along the Gosausee highway

Profile C stretches for 76 meters along the Gosausee highway and around the corner on a forest road. The first beds (1-4) eventually descend beneath the soil and are no longer exposed in later sections of the outcrop. Figure 33 below provides a panorama view of profile C as it stretches around the corner and up the forest road. Bed 1 submerges beneath the topsoil, while further up the hill, bed 3 emerges. The arrows indicate the further extension of the individual beds. This pattern is repeated for all six beds.

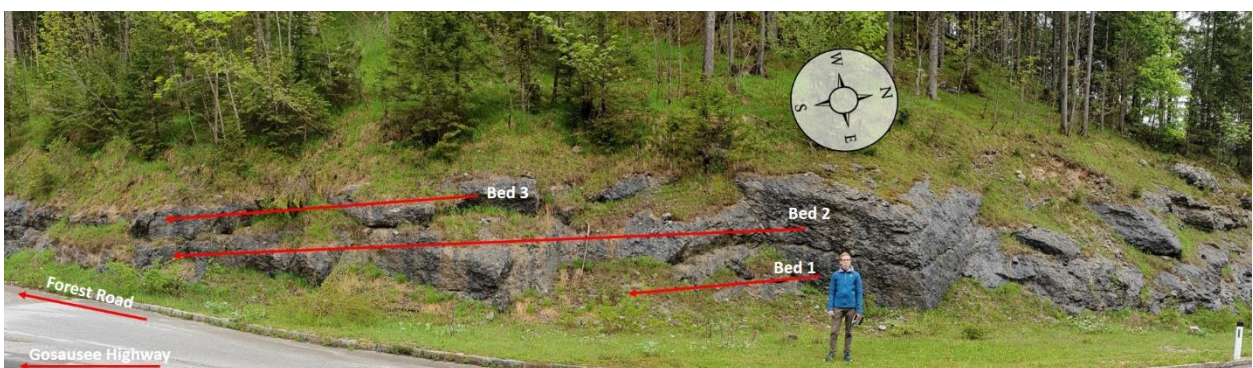


Fig. 33: Panorama view of profile C where the forest road branches off from the Gosausee highway.

Beds 1 and 2 have significant slickenside surfaces, and the exterior is, in places, covered with a thick calcite crust. The lithology is dark, marly limestone that is much more brittle than the peloid limestone of profile A. The orientation of the beds shows that they are part of a larger subterranean outcrop structure that stretches up into the forest on the hill behind it, as will be discussed in a later section. It is likewise logical to conclude that the sediments have a continuation eastward across the road and beyond. This will also be investigated later in this paper.

Profile C is south of the anticline and hence dips S/SE, as do all outcrops on this side of the anticline and the ridge. The dip angles are moderate at between 25° and 48°. Below in Figure 34 is the stereographic projection for profile C.

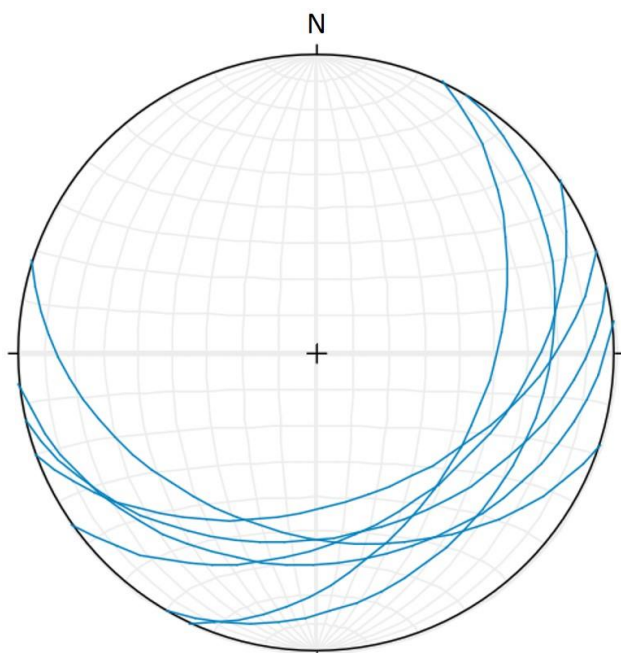


Fig. 34: Stereographic projection of profile C compass measurements in the Schmidt diagram

The first two beds in profile C have the greatest fossil abundance; in fact, important rudist macrofossils were identified in the face of bed 1 and weathering out of both beds 1 and 2. The thin sections were likewise astonishingly rich in fossil specimens and had much in common with the rudist limestone found in profile B, though the samples from which they were created were much darker on the surface (due to marl content). The remainder of the profile C beds also have fossil content, but in a diminishing fashion as the sediments get younger (bed 1 = oldest, bed 6 = youngest). Regarding macrofossils, Diethard Sanders located a significant *Durania* sp. (*?austensis*) during field work in summer of 1997; and a similarly large *Durania* sp. fragment was extracted from bed 1 of profile C during field work on 23 May 2019. A further *Durania* sp. was identified at the base of beds 1 and 2, having weathered out of the face, indicating that this particular genus of radiolitid is very prevalent in this locality. Photos of these specimens can be seen in Figure 35 below.

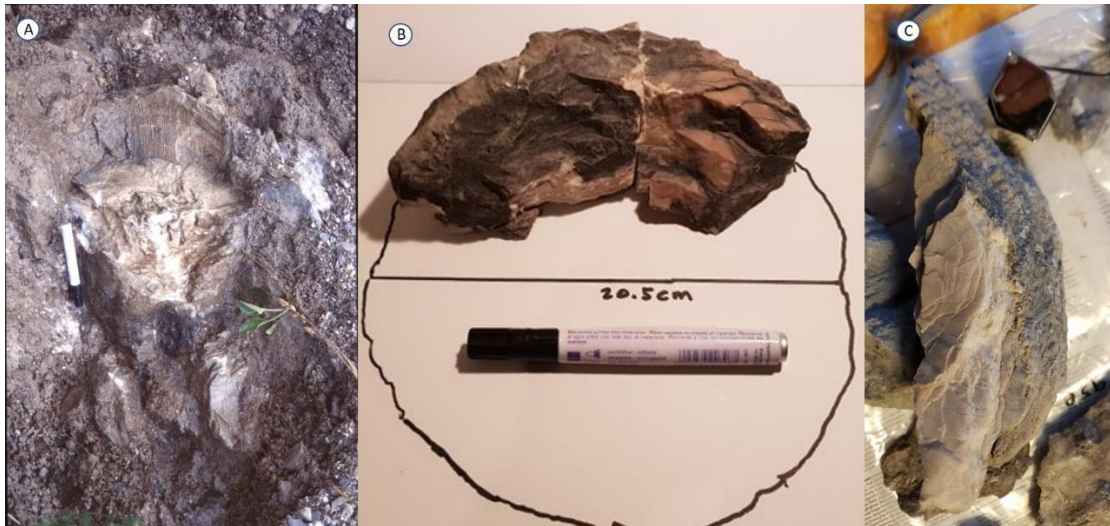


Fig. 35: A – Photo by Diethard Sanders in summer of 1997, in situ *Durania* sp. near the base of profile C. B – photo of *Durania* fragment extracted from bed 1 on 23 May 2019. C – *Durania* fragment identified at the base of beds 1 and 2 (not in situ).

Of the three profiles surveyed for this thesis, profile C has the fewest beds and a thickness of only 6.5m, making it also the least extensive. However, it has the greatest lateral exposure length at 76m. Figure 36 below provides an overview in ten different sections and should be read from right to left and top to bottom. Each of the individual beds emerges at some point from the top layer of soil and then eventually submerges again and is no longer exposed. Bed 1 was defined as the starting point, though there are a few beds to the north of Bed 1 that could legitimately be considered an extension of profile C (beds -1, -2, etc.). It is evident that the sediments have a continuation in the woods behind the outcrop; and these were investigated, as well, and will be covered in the following section.



Fig. 36: Large-scale overview of Profile C: the picture at the top right shows the beginning of the outcrop, while the picture at bottom left shows the end of the outcrop. The orientation of the outcrop changes as it bends around the forest road to the west.

The stratigraphic column of profile C can be seen below in Figure 37.

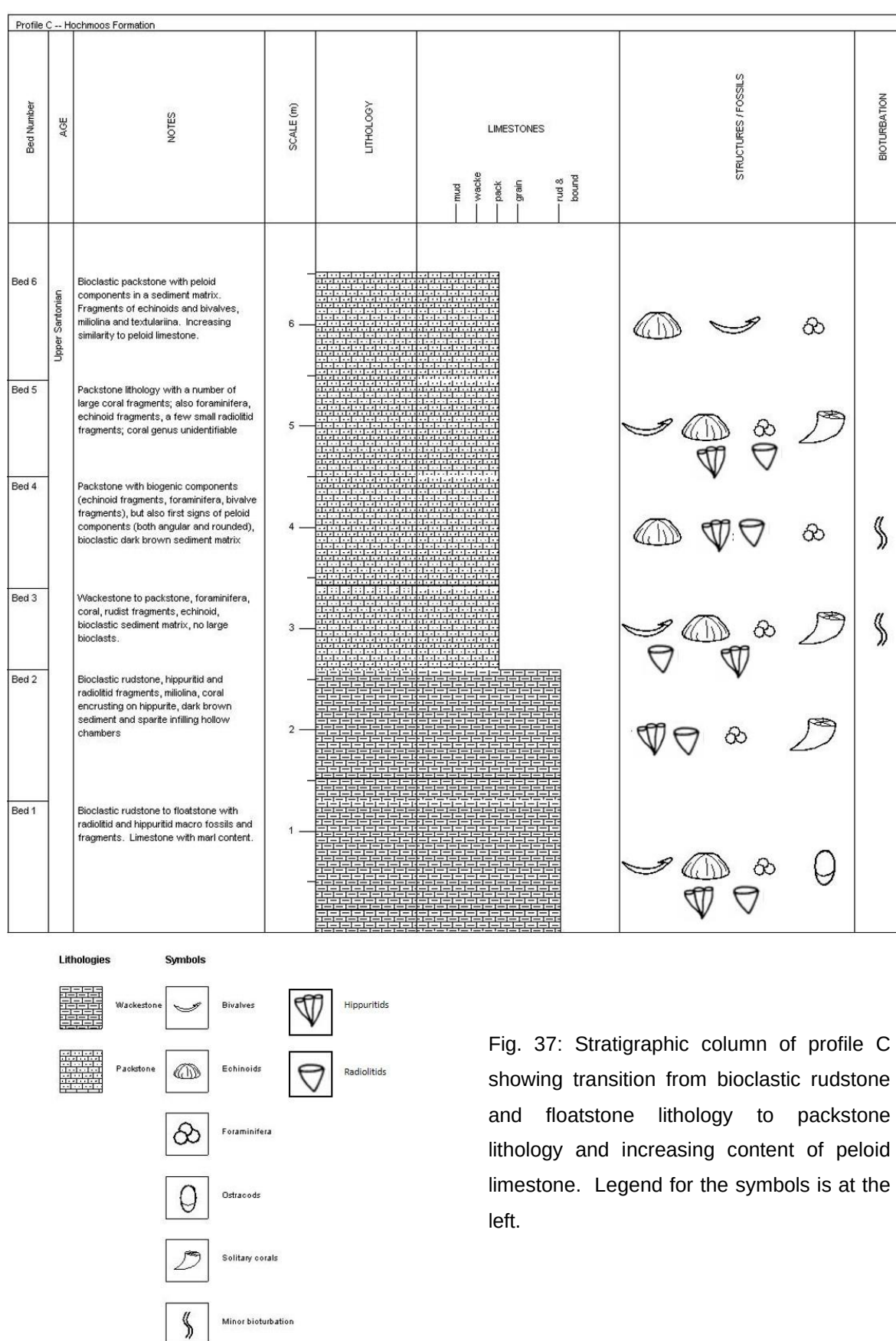


Fig. 37: Stratigraphic column of profile C showing transition from bioclastic rudstone and floatstone lithology to packstone lithology and increasing content of peloid limestone. Legend for the symbols is at the left.

The lithology of profile C is compact and tends toward bioclastic wackestone and packstone and only rarely rudstone and floatstone (beds 1 and 2). The larger biogenic components gradually disappear from the older to the younger beds in the outcrop. Ultimately, bed 6 has more features in common with outcrops found in the woods above profile C than with beds 1 and 2 at the base.

Microfacies Analysis – Profile C

Profile C represents a transition from bioclastic limestone with rich fossil abundance at the base (beds 1 and 2) to a hybrid bioclastic/peloid limestone at the top (bed 6). This transition is, of course, gradual; and there are important fossils throughout the outcrop; but they become smaller and less numerous in the higher (younger) strata of profile C. At the same time, the abundance of peloids and other clastic components becomes greater. The presence of significant joints with calcite crystals in the outcrop also shows that there must have been high levels of secondary diagenetic and tectonic processes after these sediments were laid down. As mentioned, the thin sections from the first beds of profile C have more in common with profile B than profile A. By bed 6, this situation is reversed. Below in Figures 38-42 are characteristic examples of microfacies images captured from profile C.

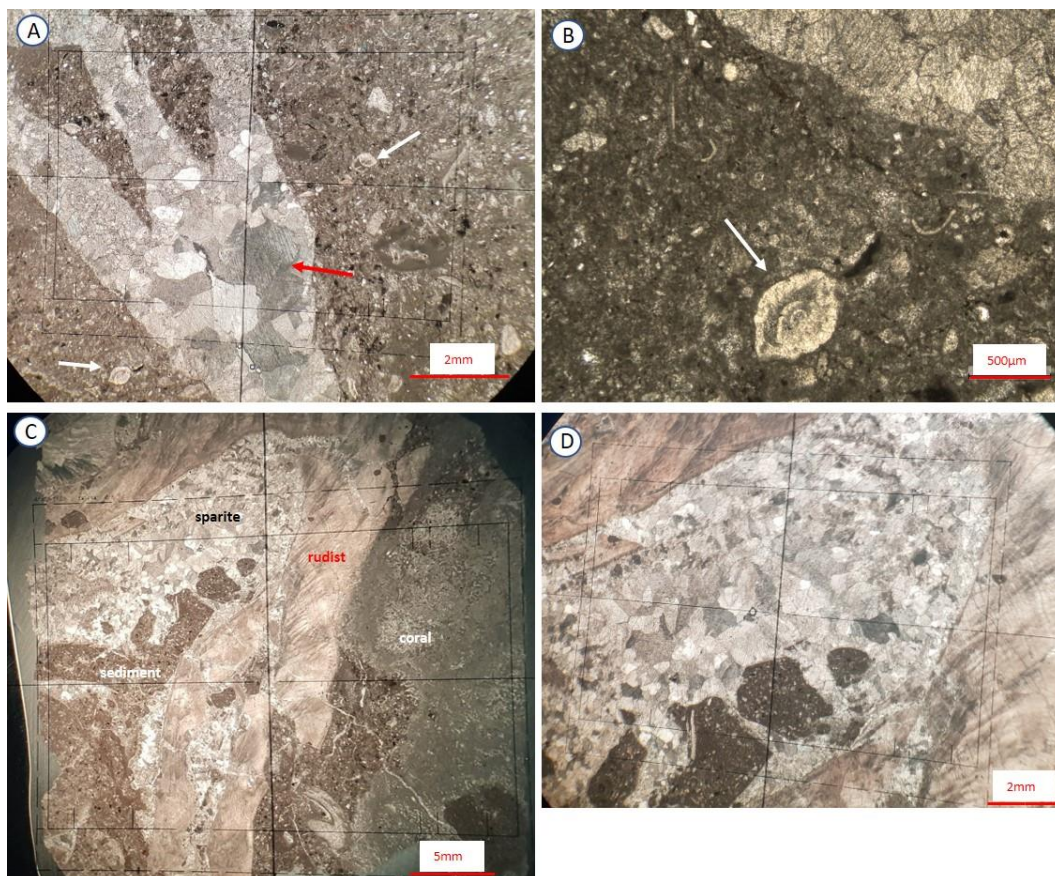


Fig. 38: A (C1) – from bed 1, sparite crystals (red arrow) intruding in bioclastic matrix, foraminifera visible (white arrows) in matrix, as well as other bivalve and echinoid fragments. B (C1) – from bed 1, *Nummofallotia cretacea*; generally, profile C had more foraminifera than either Profile B or A. C (C2) – from bed 2, coral encrusting on rudist fragment filled with sparite crystals and brown bioclastic sediment. D (C2) – from bed 2, close-up of rudist fragment with sparite filling.

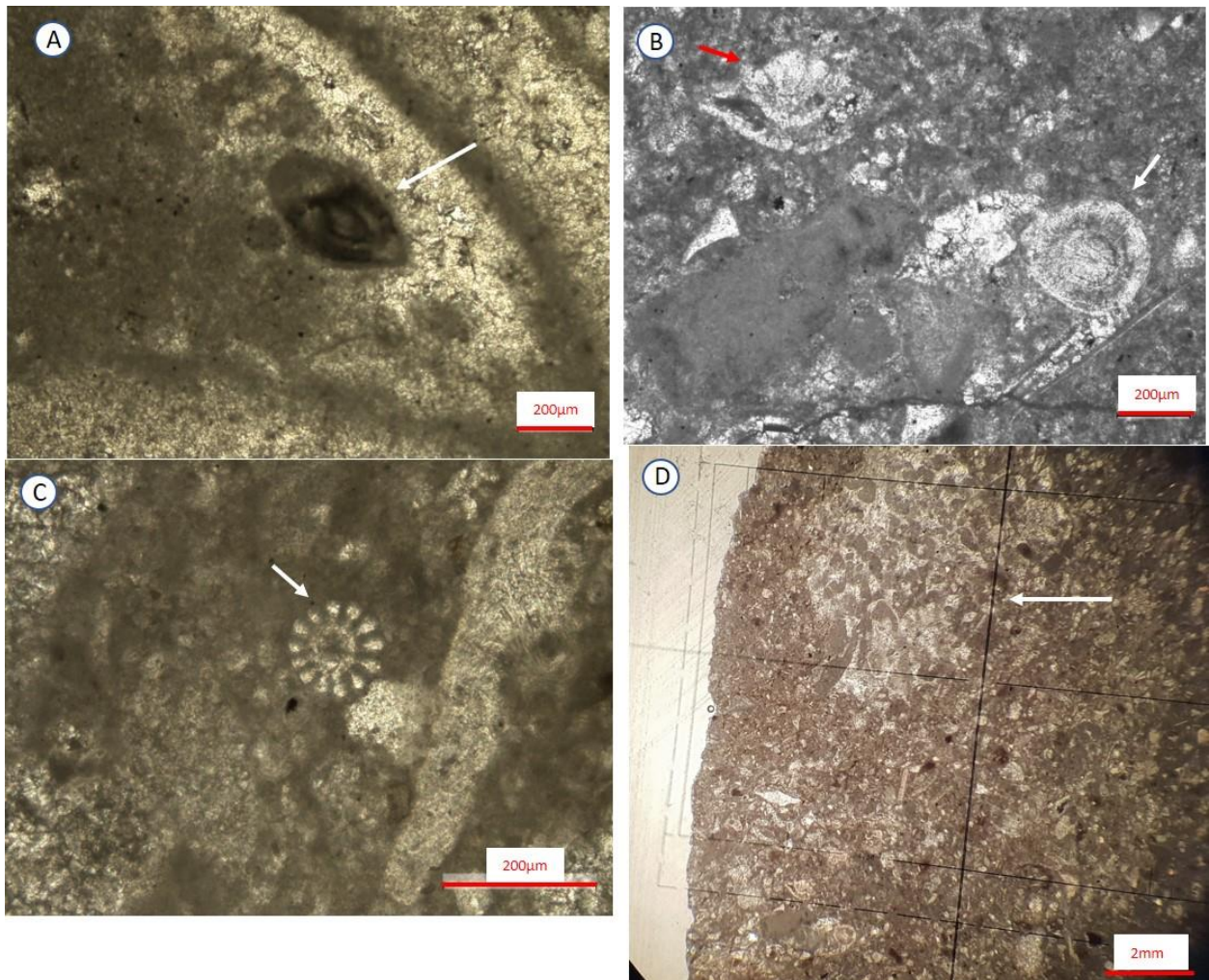


Fig. 39: A (C2) – from bed 2, *Quinqueloculina* sp. (white arrow) embedded in micrite. B (C3.3, BW) – from bed 3, *Nummofallotia cretacea* (red arrow) next to another foraminifera (white arrow, genus unidentifiable). C (C3.1) – from bed 3, sea urchin spine (white arrow). D (C3.1) – from bed 3, coral fragment (genus unidentifiable) in packstone matrix, foraminifera from image B visible in lower left-hand corner.

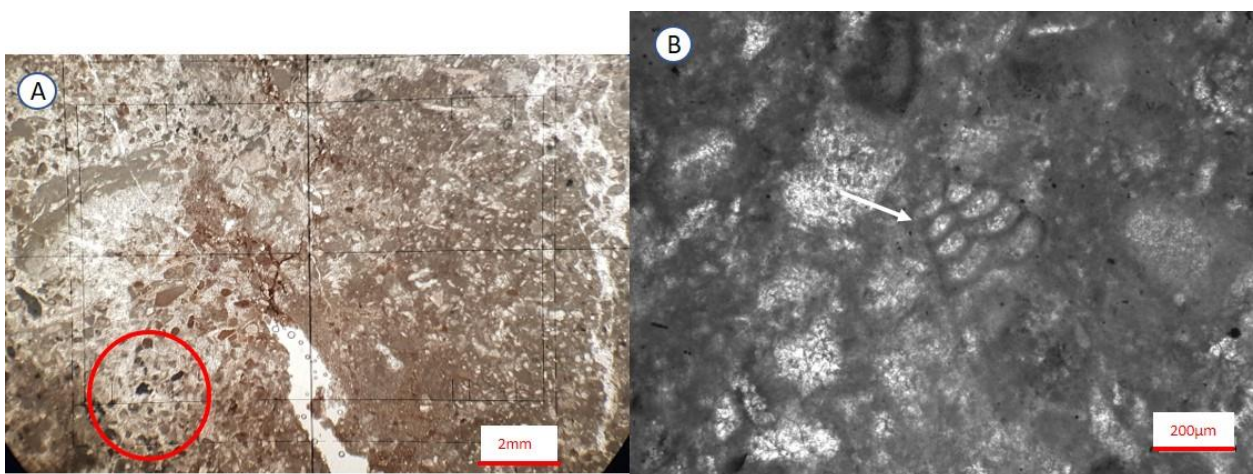


Fig. 40: A (C4.1) – from bed 4, packstone matrix with individual clasts and micrite intrusions, angular peloid components (red circle). B (C4.1, BW) – from bed 4, biserial foraminifera (*Textularina*).

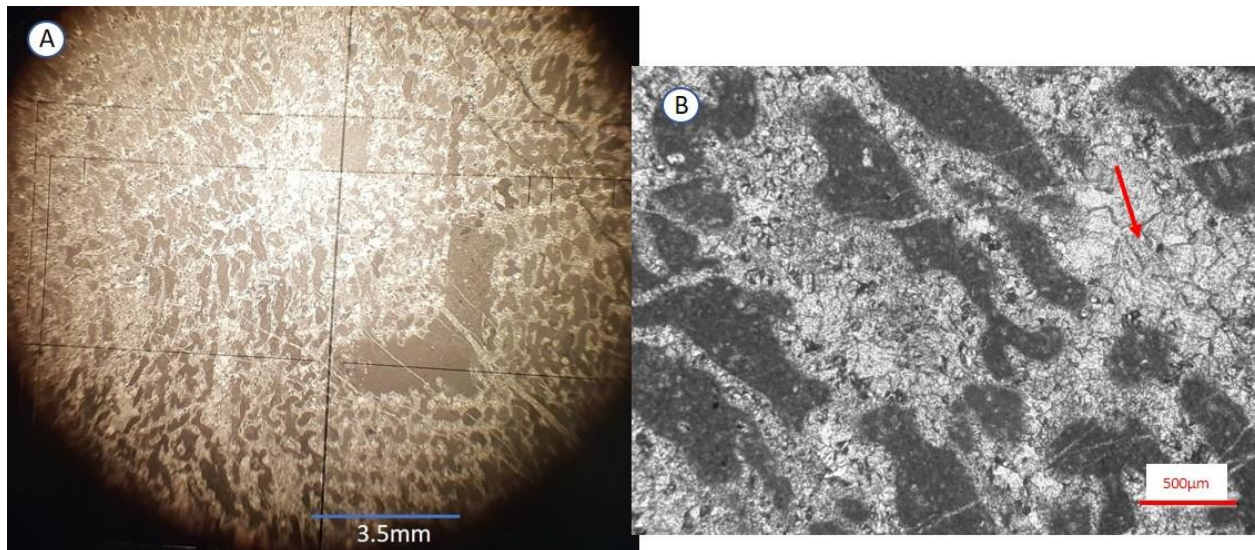


Fig. 41: A (C5) – from bed 5, large coral fragment (genus unidentifiable) with micrite filling in the pores. B (C5, BW) – from bed 5, close-up of micrite crystals (red arrow) in hollow chambers of coral.

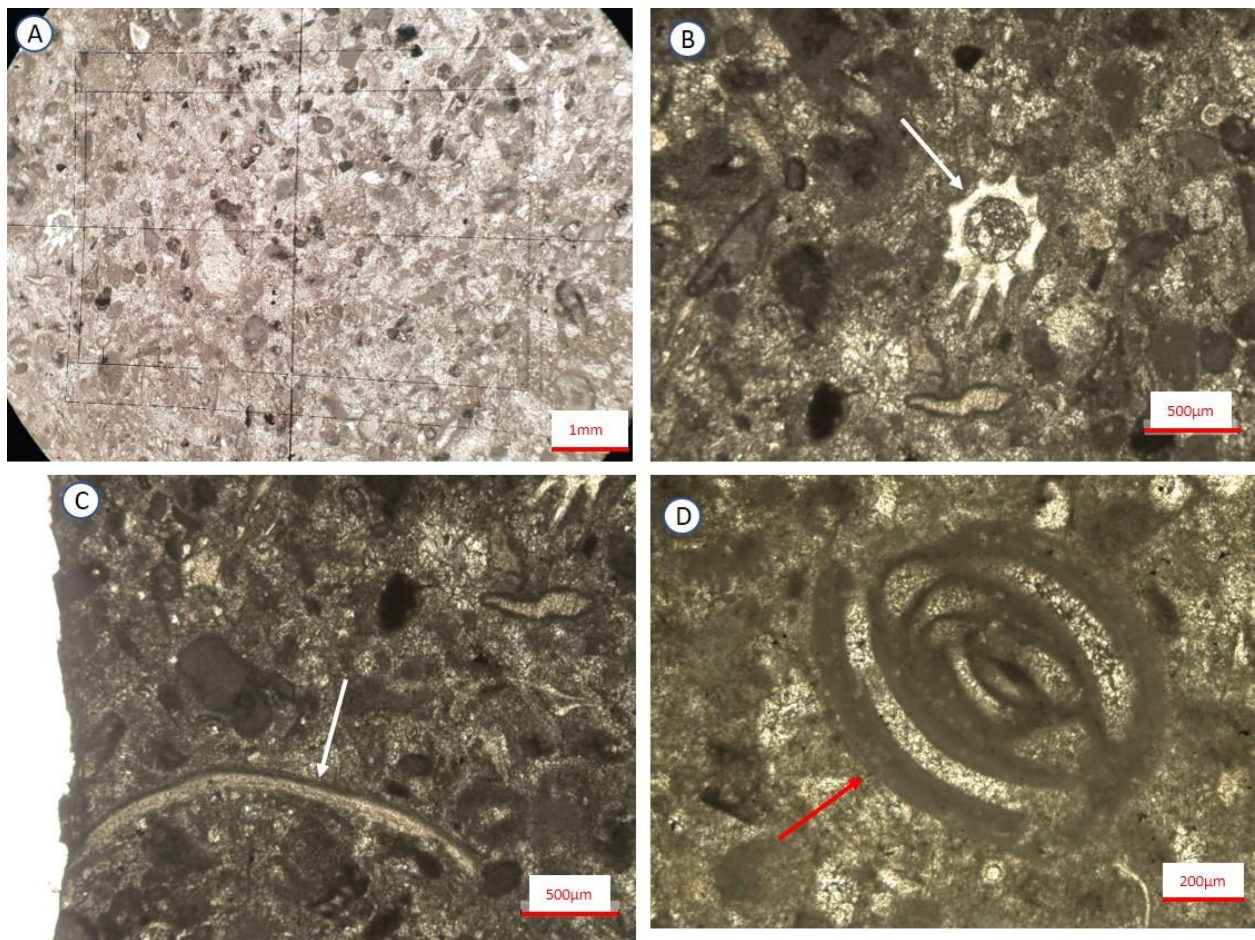


Fig. 42: A (C6) – from bed 6, packstone matrix with micrite cement, peloid components visible, some bioclastic components. B (C6) – from bed 6, sea urchin spine (white arrow) cut obliquely, other bioclastic fragments visible. C (C6) – from bed 6, bivalve fragment (white arrow). D (C6) – from bed 6, *Quinqueloculina* sp. (red arrow), one of many miliolid specimens.

4.1.4 Area Between and Above Profiles A and C

Area Between A and C:

Although not subject to a detailed survey due to its deformed character, the 87m long outcrop between profiles A and C was investigated to determine lithology, fossil content and structure. The most northerly part of this outcrop consists of the core of the anticline, which was discussed above. In this chapter, the outcrop south of the anticline and just north of profile C will be treated. Figure 43 below shows a large-scale overview of this section of the study area:

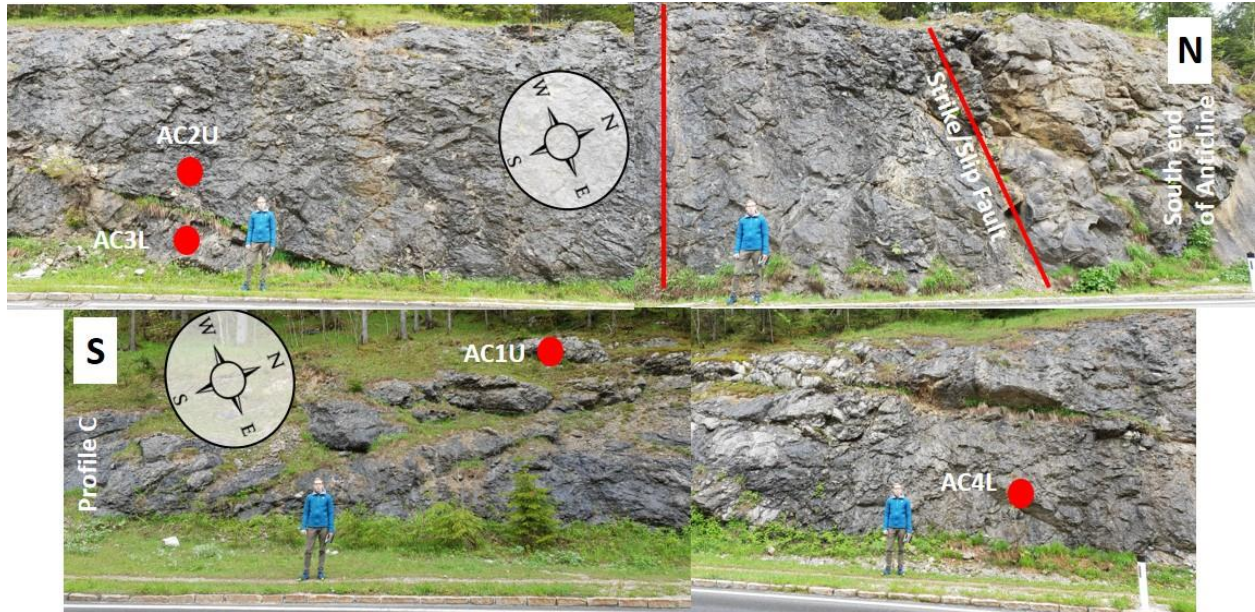


Fig. 43: Outcrop between the anticline in the north and profile C in the south. The red dots indicate positions from which samples were extracted for thin sections.

Starting at the north end of the overview, the portion between the concrete fortification and the strike-slip fault (discussed in 4.1.1 above) consists of sandy, clastic carbonates similar to the first beds in profile A and represents the southern outer limbs of the anticline. The clastic carbonates (sometimes including lithoclasts, sometimes only sand) continue another 8-9m to the end of the fault zone further south (vertical red line, to be discussed in section 4.2 below), followed by dark to medium gray peloid limestone all the way to profile C at the extreme south end of the overview.

A total of 15 samples were taken from the outcrop to investigate the lithology, which is largely packstone to grainstone (except when conglomerate components are present, then rudstone or floatstone). There are no visible macrofossils present (similar to profile A), but the thin sections taken from samples at the red dots in Figure 50 reveal some marine microfossils, though in very limited quantity. On the whole, the lithology is very comparable to the upper beds of profile A, with a large preponderance of peloid limestone, as suspected for this part of the anticline.

Due to the strong faulting, it is nearly impossible to derive useful stratigraphic data from the central part of this outcrop. Structurally, the bedding is difficult to discern; but where it can be identified,

the dip angles are very high near the visible fault and the anticline ($80^{\circ}+$), becoming more moderate in dip the further south the measurements are taken, reaching levels of 30° near the beginning of profile C.

A total of 12 compass measurements were taken in the outcrop between profiles A and C. As mentioned, these had a predictably S/SE dip direction with angles ranging from 33° to over 60° . The unusually steep beds near the fault zone were excluded. Below (Figure 44) is the stereographic projection for this part of the study area:

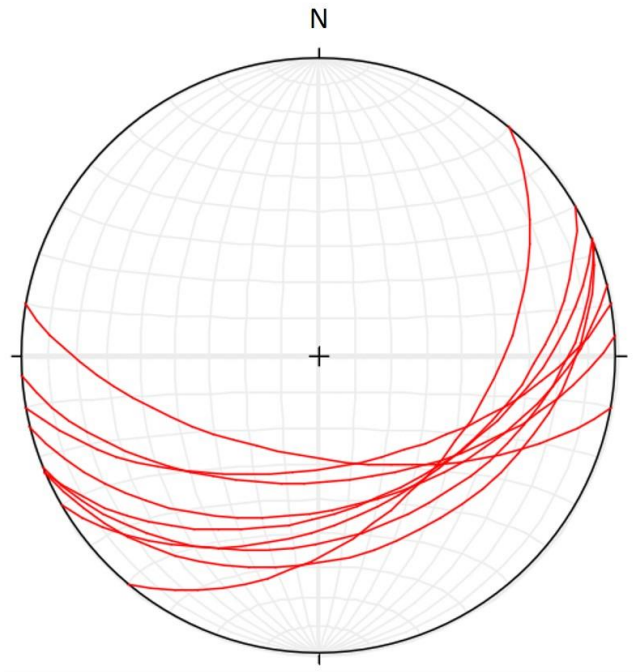


Fig. 44: Stereographic projection of compass measurements for area AC in Schmidt diagram.

Microfacies analysis of the thin sections reveals significant differences to profiles B and C, while exhibiting some similarities to profile A: the clasts of Dachstein limestone, which are totally absent from profile B and only appear as very small components at the top of profile C, are present in this part of the study area, indicating inflow of terrestrial material and a reworking of the substrate. Microfossils, by contrast, are rare and appear only as individual foraminifera or as small fragments of larger marine organisms. Figures 45-47 below show some images from the thin sections produced from samples taken between profiles A and C. Though these images highlight individual features in the thin sections, it should be noted that the packstone/grainstone matrix is dominant and very homogeneous.

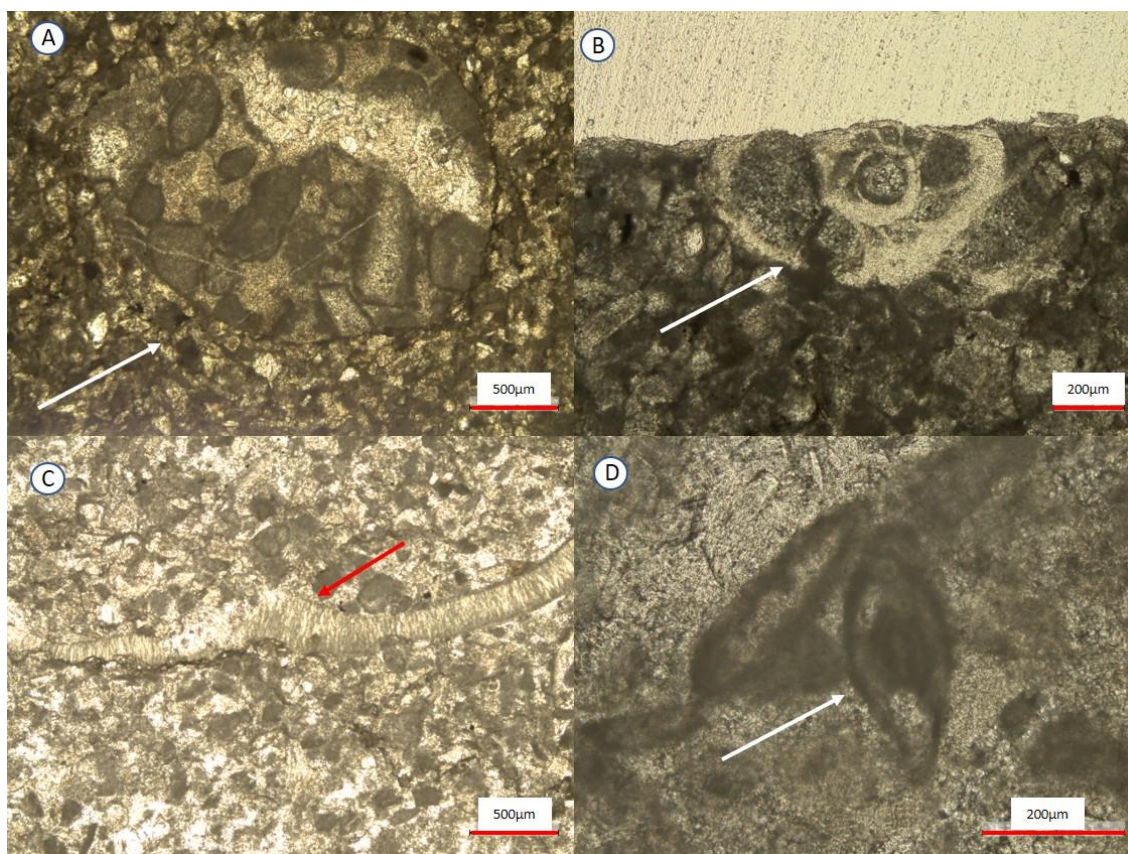


Fig. 45: A (ACL4) – from sample AC1U, Dachstein limestone clast (white arrow) in peloid limestone matrix. B (ACL4) – from sample AC1U, planispiral foraminifera (genus unidentifiable, white arrow). C (AC2U) – from sample AC2U, bivalve fragment (red arrow) in peloid limestone matrix. D (AC2U) – from sample AC2U, *Quinqueloculina* sp. (white arrow) surrounded by micrite.

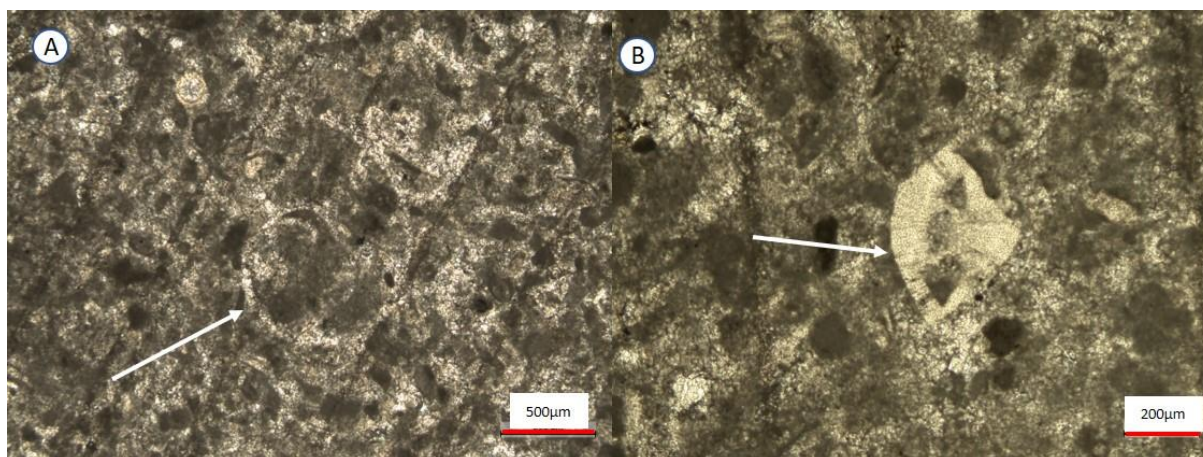


Fig. 46: A (AC3L) – from sample AC3L, dissolved gastropod (white arrow). B (AC3L) – from sample AC3L, *Nummofallotia cretacea* (white arrow).

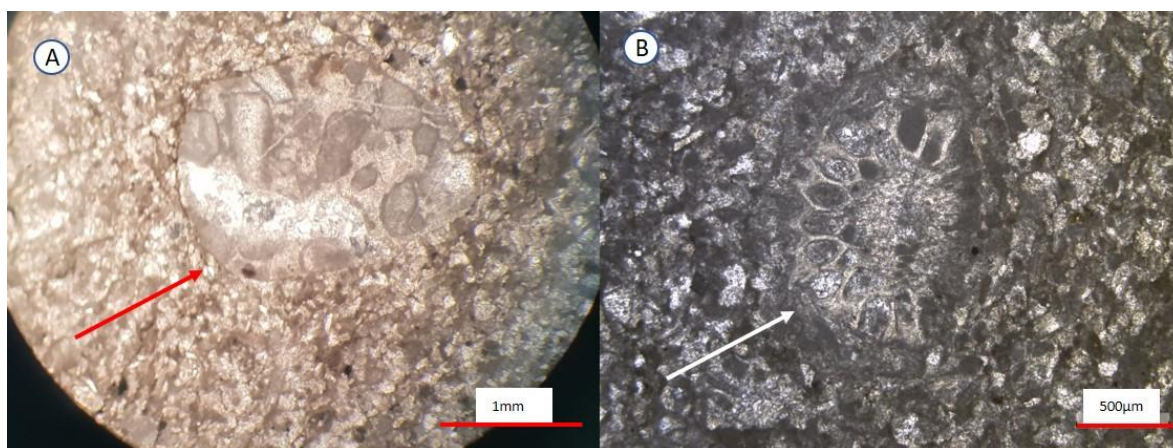


Fig. 47: A (ACL4) – from sample AC1U, clast of Dachstein limestone (red arrow) in peloid limestone matrix. B (ACL4) – from sample AC1U, unidentifiable fossil fragment, possibly shell fragment of radiolite (white arrow).

Area Above Profiles A and C

There are numerous and, in some cases, extensive outcrops above profiles A and C in the forest and up the ridge to the top. To understand the overall context of the profiles formally surveyed in this work, it was decided that representative outcrops extending as far as the boundary with the Bibereck Formation should be sampled, measured and, in some cases, analyzed on a microfacies level. The greatest emphasis was given to outcrops on either side of and up along the ridge of the hill behind profiles A and C, as this was seen as an extension of the anticline and hence a key feature in the study area. In total, 32 separate outcrops were investigated in the forest area above profiles A and C, and a total of 13 thin sections were made from the 34 samples taken from this area. Figure 48 below presents a map of the area, with each star denoting an outcrop investigated in the course of the field work. The circled stars are outcrops from which thin sections were produced.

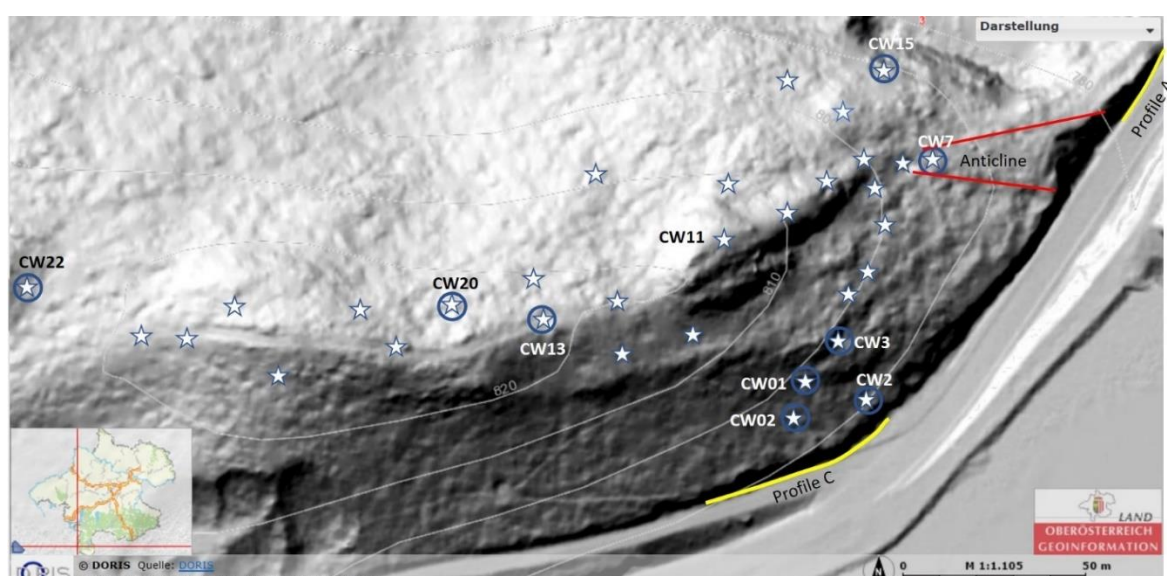


Fig. 48: overview of the west side of study area. White stars indicate outcrops investigated. Circled stars indicate thin section analysis. From Digitales Oberösterreichisches Raum-Informationssystem [DORIS], accessed on 09 October 2019.

The morphology of the hill and ridge behind profile C and the orientation of the beds in profile C indicate that the strata in profile C have a logical continuation at higher elevations. This is clearly the case, as the outcrops investigated just above profile C (CW2, CW3, CW01, CW02) have much the same orientation (S/SE) and the same lithology and fossil content. One clear difference, however, was the lighter color (medium gray, lower marl/clay content, more peloid content) of samples taken from these outcrops. Also, the Dachstein limestone clasts in the thin sections were larger, indicating more terrigenous inflow; but none of these outcrops showed visible evidence of these clasts in the field. Similar to bed 6 in profile C, there was fossil content, but limited to individual foraminifera and fragments (corals, echinoid, inoceramid). Fossil content continued to decline moving up the hill and into the forest.

A very marked change occurred at outcrop CW7 (795m, N: 47.550039, E: 13.514152) at the top of the anticline and the base of the ridge going up the hill: this was at an outcrop exposed due to an uprooted tree, a phenomenon that was very common along the ridge going up the hill. The top soil along the steepest grade of the area is very thin, causing the roots of the local conifers to have only minimal substrate and rendering them vulnerable to toppling as they grow larger and are exposed to storms. At least 20 such toppled trees could be seen along the ridge, which made navigating the terrain challenging at times. Figure 49 below shows an example of such an outcrop at the base of a toppled tree, as well as an image of the outcrop CW7.



Fig. 49: image left shows an outcrop at the base of an uprooted tree; image right shows the outcrop CW7 with evident clasts of Dachstein limestone (red arrows), confirmed through thin section analysis

Such visible evidence of carbonate lithoclasts could be found in several other outcrops in the vicinity, but there were a number of outcrops (CW10, CW11) further up the ridge that had none and reverted back to a peloid limestone lithology of packstone to grainstone. That said, the carbonate lithoclasts (Dachstein limestone) could well have been present on a microfacies level, as was shown in numerous other outcrops from which thin sections were produced.

Further up the ridge at an altitude of around 825m (N: 47.549617, E:13.512763), outcrop CW13 showed the first evidence of a carbonate conglomerate with a clayey-silty matrix, replacing the peloid limestone lithology; and the clasts (carbonate lithoclasts, chert, quartz) increased in size up to the very top of the ridge (CW14) at 831m (N: 47.549584, E: 13.511963), decreasing again at lower elevations on the path leading west. At outcrop CW20 about 15 meters down the ridge

to the north (824m, N: 47.549662, E: 13.512372), there is a bed that appears to contain the actual boundary between the limestone with carbonate lithoclasts and the carbonate conglomerate with clayey-muddy matrix. This can be seen in Figure 50 below:



Fig. 50: At site CW20. The red line denotes the facies change between the limestone with carbonate lithoclasts and the carbonate conglomerate with clayey-muddy matrix (red arrow).

Figure 51 below provides some images of carbonate conglomerates. Sample extraction from one outcrop at the top of the ridge produced visible sparks, as the hammer came into contact with a massive chert clast extruding from the rock.



Fig. 51: Examples of carbonate conglomerate outcrops at the top of the ridge behind profiles A and C. The yellow arrow (left) shows a large carbonate lithoclast, while the red arrow (right) points to a large chert clast.

Roughly 75m from the forest road at 820m elevation (N: 47.549548, E: 13.511078), the carbonate conglomerate lithology reverts back to limestone with no visible clasts. Directly next to the forest

road at CW22, the outcrop there again looked very much like the pure limestone beds in profile A.

Structurally, all outcrops on the north side of the ridge showed N/NE dipping orientations, while all outcrops on the south side of the ridge dipped S/SE. This will be shown in an overview map of the entire study area in a subsequent section. In addition, there will be a separate section (4.3) summarizing the facies distribution in the study area.

Figures 52 and 53 below show a selection of thin section images from this part of the study area.

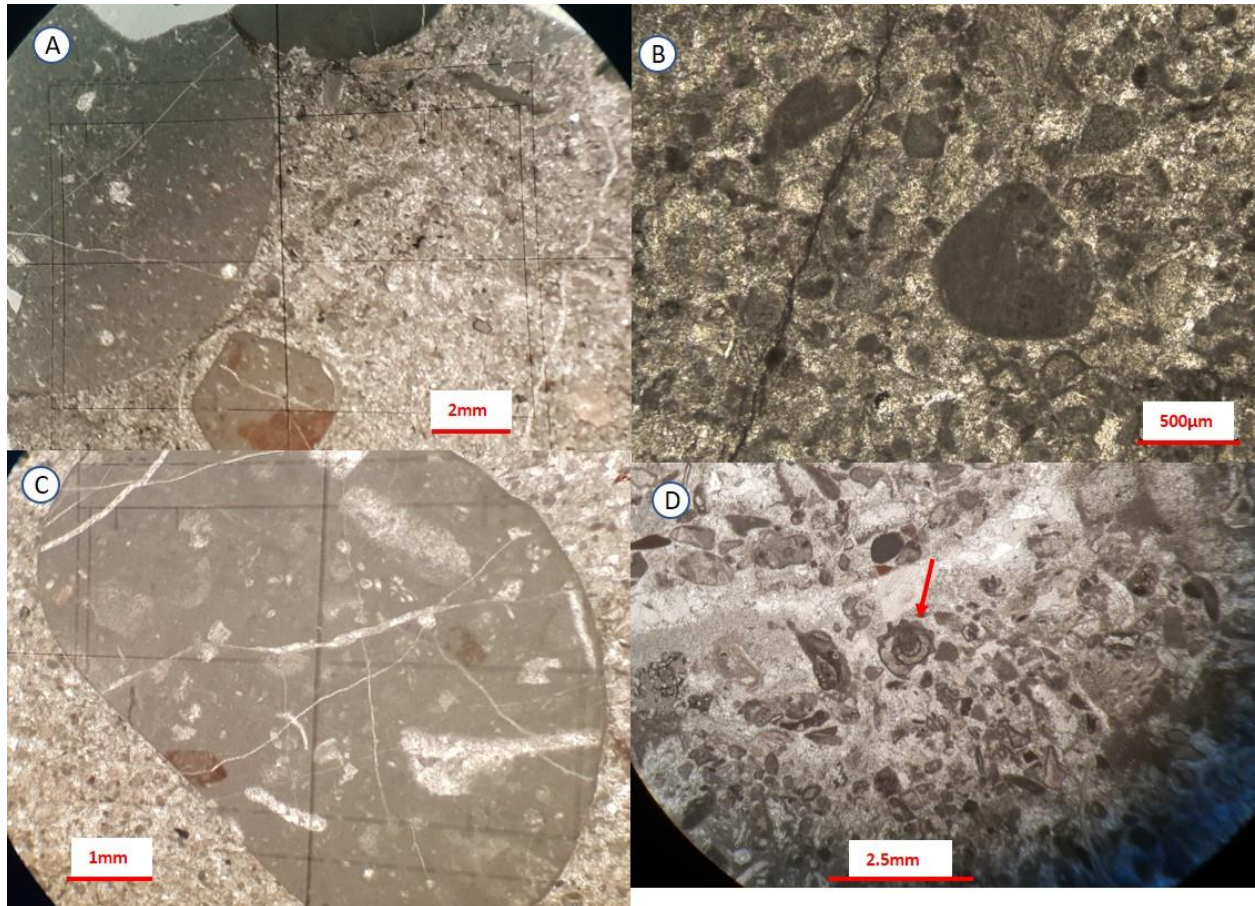


Fig. 52: A (M1) – from outcrop CW01, large carbonate lithoclasts in packstone matrix, low fossil content. B (20MAC) – from outcrop CW2, clast of small Dachstein limestone in packstone matrix, some coral and bivalve fragments. C (CW7) – from outcrop CW7, large clast of Dachstein limestone containing Triassic fossils (*Textularina*, among others). D (40MRC) – from outcrop CW3, wackestone with bioclasts and peloids in micrite matrix, planspiral foraminifera (red arrow).

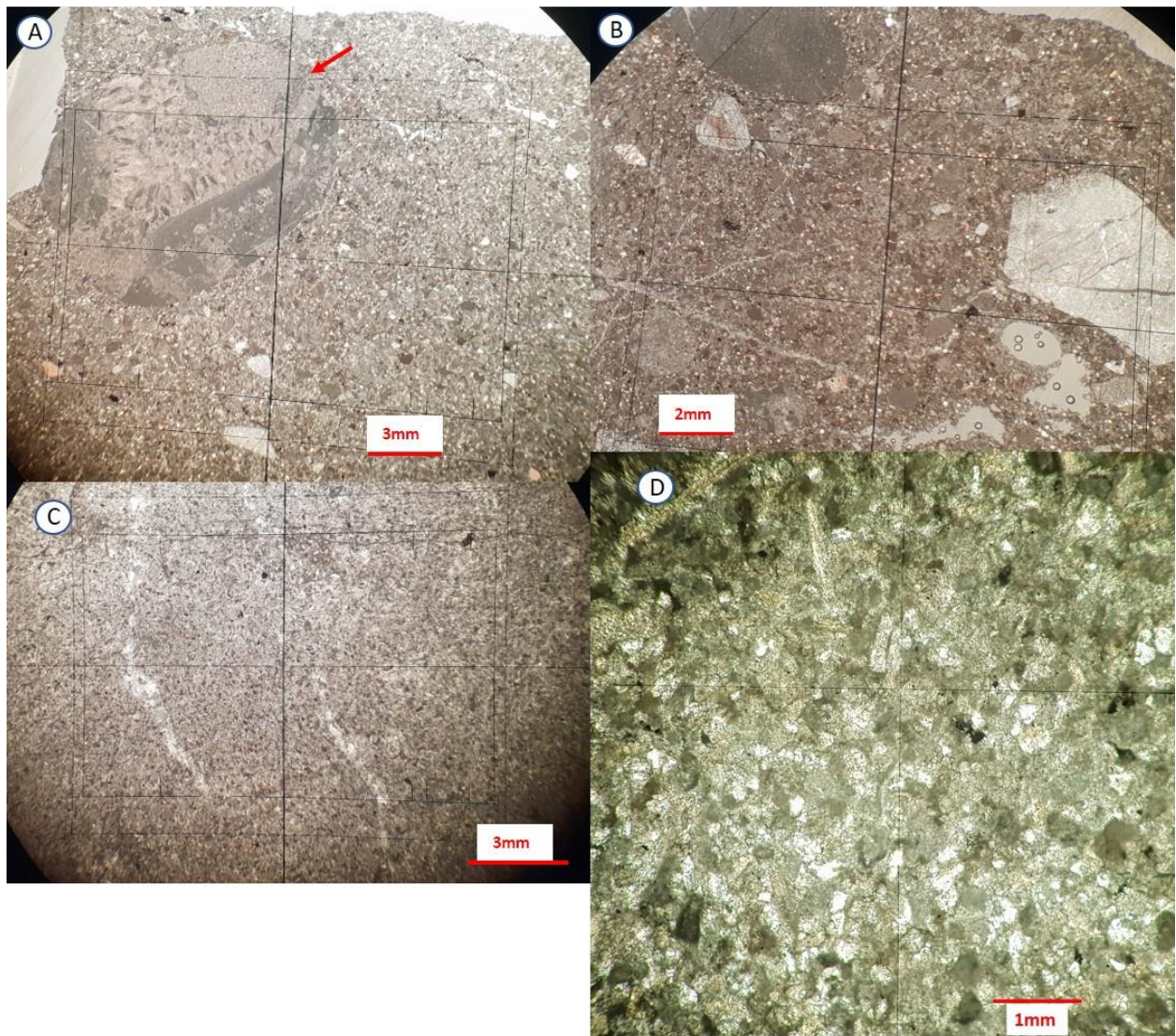


Fig. 53: A (CW13.1) – from outcrop CW13, packstone with terrigenous clasts of varying size, rudist fragments, Triassic coral fragment in large Dachstein clast (red arrow). B (CW13.2) – from outcrop CW13, packstone with terrigenous clasts, including chert, quartz and carbonate lithoclasts. C (XX) – from outcrop CW15, packstone of peloid limestone, low fossil content, similar to lithology near top of profile A. D (D12.13) – from outcrop CW22, very similar to CW15: peloid limestone, packstone, some fossil fragments, near end of ridge trail at forest road.

4.1.5 Profile B

On the west side of the study area, Profile B was selected for a thorough and detailed survey. This outcrop (N 47.549107, E 13.516171) is the most extensive in the study area and, owing to its fossil richness, constitutes an important stop on the Geotrail (or Georundweg) constructed by the municipality of Gosau. It is located on land belonging to the Austrian Federal Forestry Department; and, accordingly, an official permit for the field work had to be obtained from the owners before any work on the outcrop was undertaken. Figure 54 below shows an overview of the outcrop.



Fig. 54: The top picture is a photo of outcrop B taken with maximum zoom from the west side of the reservoir. The picture at bottom left shows beds 3 and 4 from the Geotrail. The picture at bottom right shows the signpost on the Geotrail.

Profile B is part of a small, but distinct carbonate plate structure (roughly 1800 m² in area) situated on the south side of a larger, flatter elevation of carbonate sediments in the west of the study area (see Figure 13 above). It consists of 10 thick beds of detrital rudist limestone with a total thickness of 15.4m running from the Geotrail at 798m altitude up to about 815m at the top and has a lateral extent of about 31m. The sediments in this profile continue past the top of bed 10, but gaps in the stratigraphic succession continue increasing, and thorough correlation of the beds becomes more arduous. For the sake of carbon and oxygen isotope analysis, the extension of this outcrop up to the top of the topographic platform structure was recorded and samples taken to construct more extensive $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves. This will be discussed in a subsequent section.

Profile B has a pseudo-bedding (E/SE at 60°) that, upon closer inspection, turns out to be orthogonal to the actual bedding direction (W/NW at 30°), which is unambiguously indicated by the orientation of fossils in the outcrop. This can be seen in Figure 55 below.

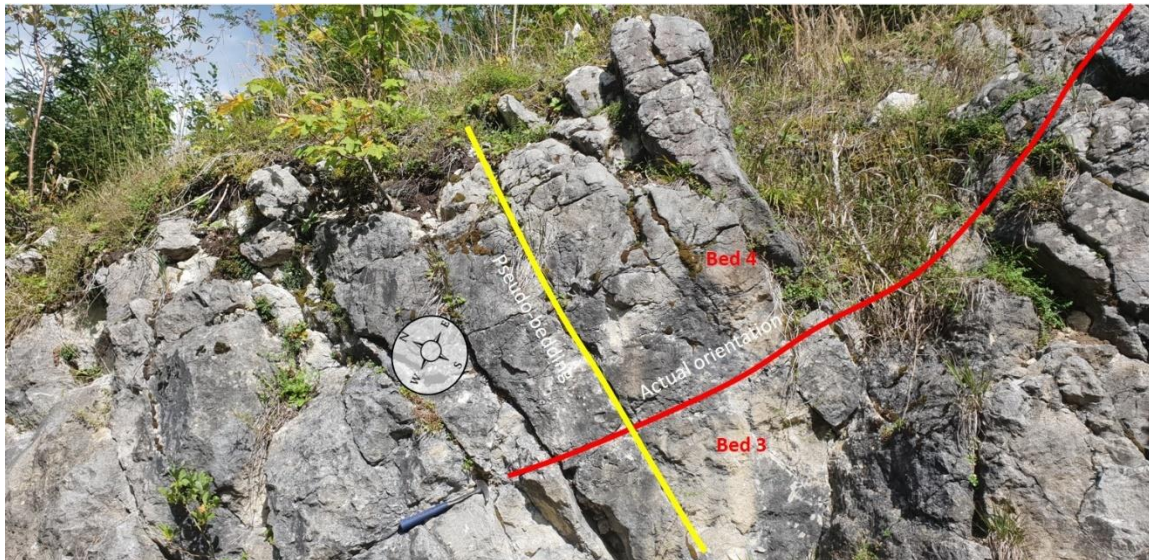


Fig. 55: Profile B near the Geotrail. The picture shows the (pseudo-bedding) orientation of joints running orthogonally to the actual bedding orientation (W/NW at 30°).

This pseudo-bedding could be attributable to tectonic forces acting upon a sedimentary body on a geographically-limited scale, resulting in uniform cracking and jointing of once homogeneous beds. A further significant feature of profile B is the extensive exposure of a few beds and very limited exposure of other bedding planes. For example, beds 1 and 2 are exposed at the Geotrail, but submerge beneath the soil after only about 8-12m extension up the ridge. Bed 4, by contrast, runs nearly the entire length of the outcrop for roughly 25m. At the very top, beds 6-10 have a lateral extension of about 10m each. Beds 3 and 5 extend for 15m to 18m, respectively.

A total of 12 separate compass measurements were taken throughout the surveying work on the outcrop and resulted in the Schmidt diagram depicted in Figure 56 below with consistent W/NW values. The orientation of the outcrop is a downslope toward the brook and is opposite to the N/NE orientation of profile A and the S/SE orientation of profile C.

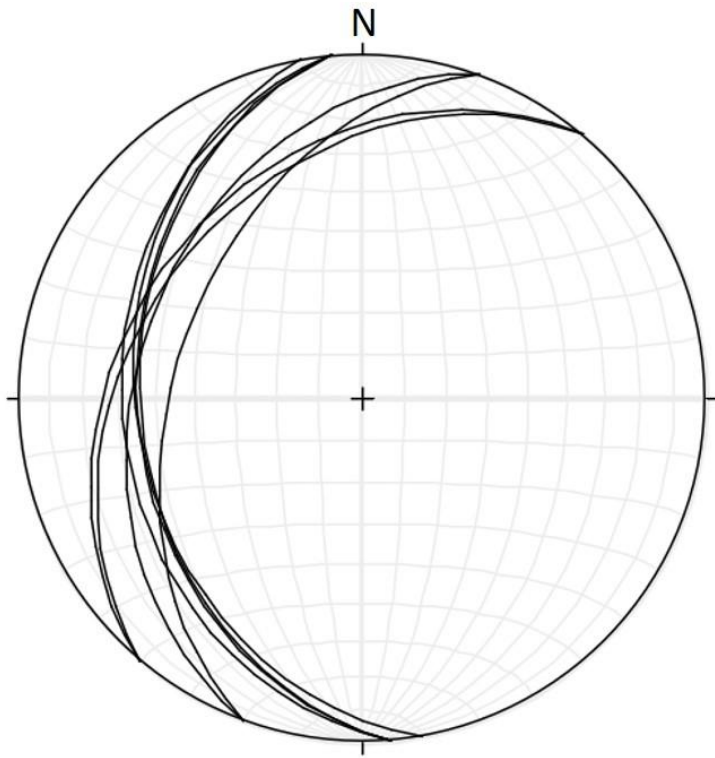


Fig. 56: Stereographic projection of Profile B compass measurements in the Schmidt diagram

The lithology is light-gray rudist limestone, and the beds dip W/NW at angles between 30° and 40°.



Fig. 57: Photos of macrofossils in profile B. Upper left shows the markings of a coral fossil weathering out of bed 4. Upper right shows the cross sections of hippuritid fossils in bed 3. Lower left shows hippuritid fossils in growth position at the bottom of bed 4. Lower right shows a prominent rudist (hippurite) biostrome at the top of bed 4.

Fossils are abundant throughout profile B, and macrofossils are visible as specimens weathering out of the rock or as markings on the face of the rock. There are also a number of rudist biostromes at various positions in the outcrop in beds 3 and 4. Figure 57 on the preceding page shows several instances of macrofossils visible in the outcrop.

There is a uniformity to the lithology of profile B: the samples show a much lighter color than profile A, and this is due primarily to the presence of rudist fragments, micrite cement and significant sparite infillings in the hollow chambers of fossil organisms. Even more common, though, is the dark brown bioclastic sediment that is pervasive throughout the samples, due primarily to high marl content. The only true exception to the otherwise uniformity of the facies consists of the isolated instances of radiolitid and hippuritid biostromes, which can be found in specific sections of beds 3 and 4. That said, beds 3 and 4 are the most extensive beds in the profile; and since the other beds are not as well-exposed, it cannot be concluded that such biostromes are not elsewhere in this part of the study area and simply not exposed. There is one exposure gap of roughly 1m between beds 8 and 9. The images below (Figures 58-60) provide an overview of the ten beds of profile B rising up from the Geotrail.



Fig. 58: This image shows beds 1-4 taken from the south side of the outcrop on the Geotrail. Beds 1 and 2 extend 8-12 m up the hill, then are no longer exposed, while bed 3 continues for 15 m and bed 4 attains a lateral extension of 25 m.



Fig 59: This photo depicts beds 4 and 5 roughly 20-25 m up the hillside from the Geotrail. The red oval shows the position of the rudist biostrome with fossils in growth position.

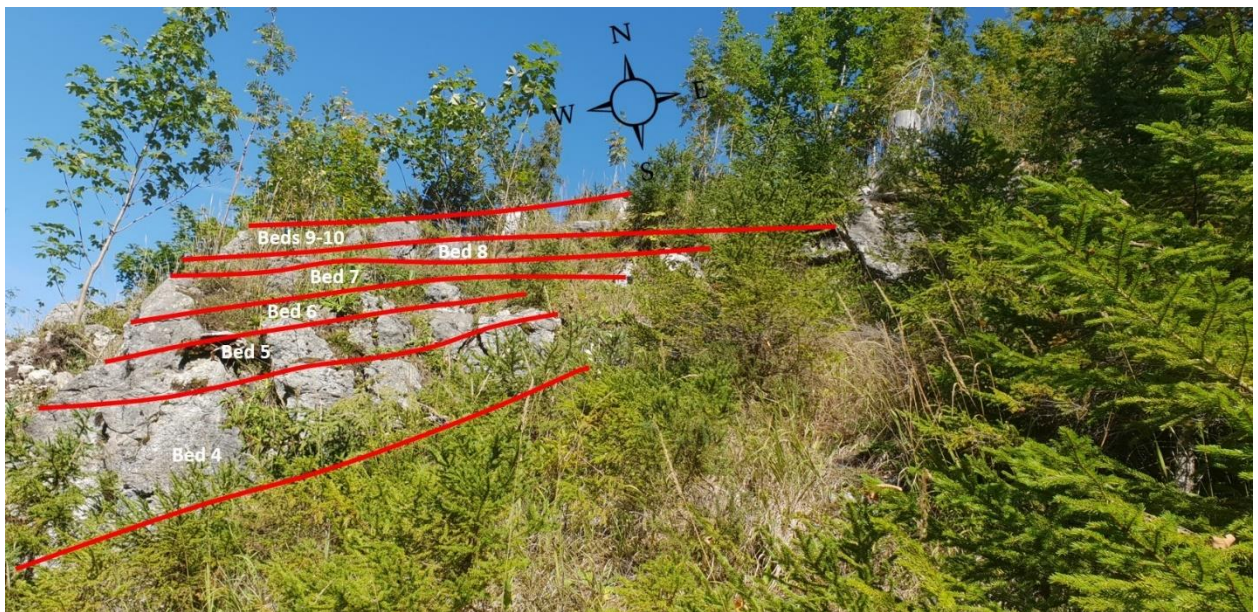


Fig. 60: This photo depicts beds 4-10 of the outcrop from around 30 m up the hill from the Geotrail. The outcrop becomes sparser and less well-exposed beyond bed 10.

The stratigraphic column of all ten beds in profile B is depicted below in Figure 61.

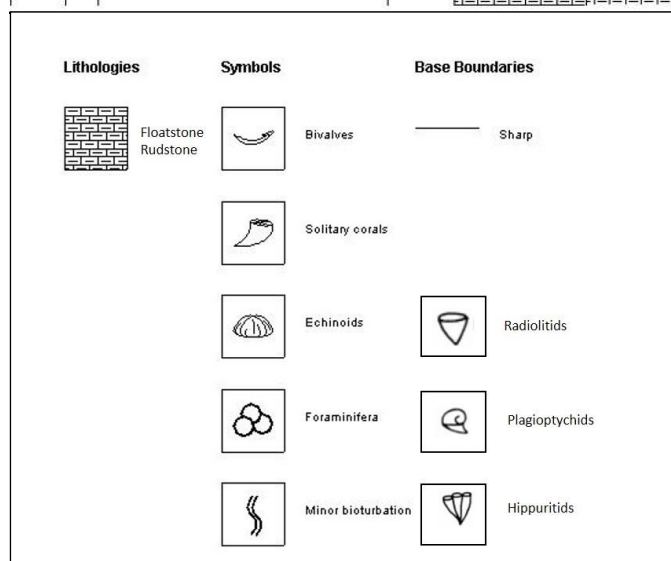
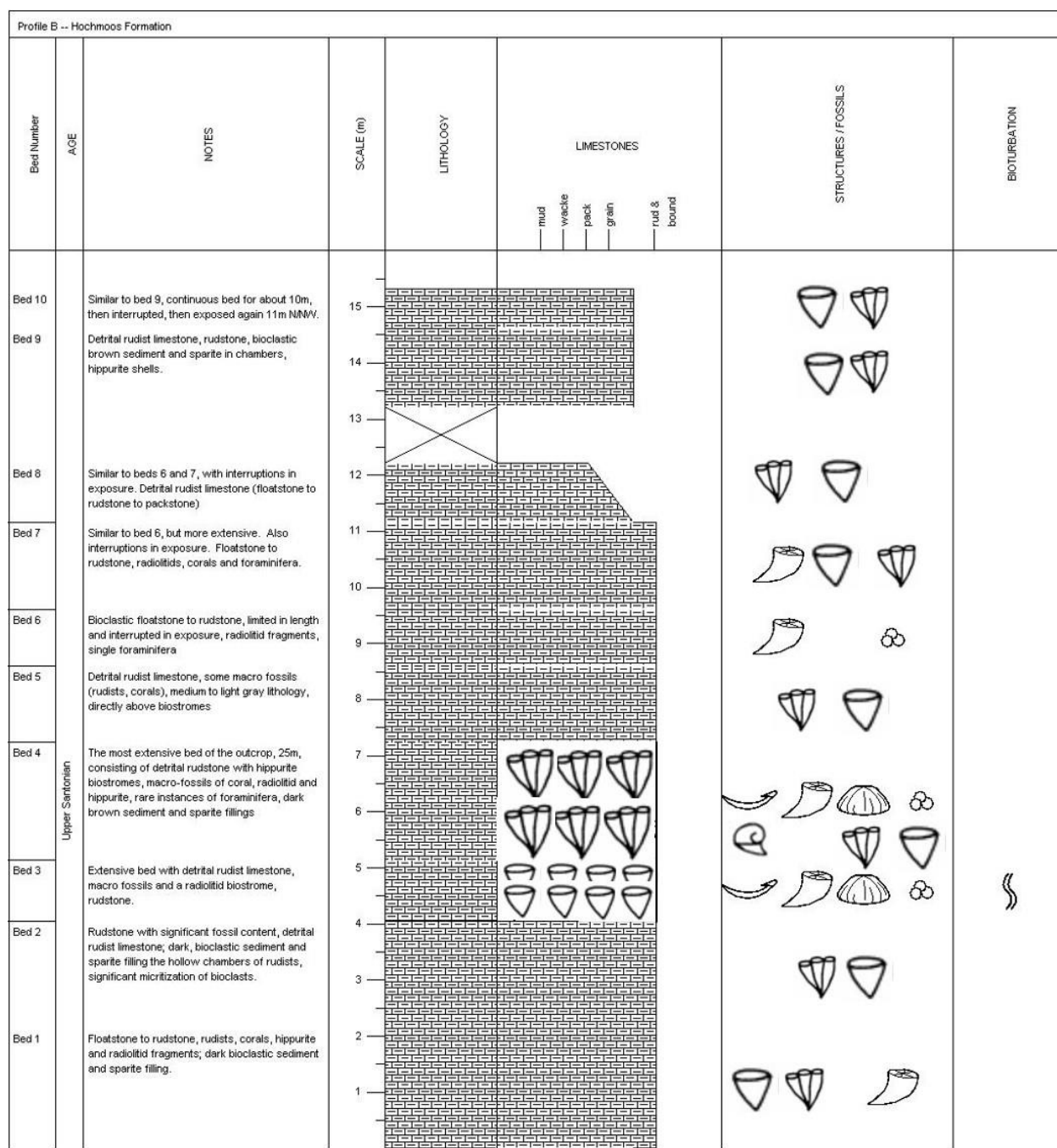


Fig. 61: Stratigraphic column of profile B with indication of radiolitid and hippuritid biostromes in beds 3 and 4. Legend of lithologies and fossils in the box at the left.

Microfacies Analysis – Profile B

Together with the lower beds of profile C, profile B evidences the greatest fossil abundance in the study area, though the variety of fossils is limited and primarily dominated by parautochthonous radiolitid and hippuritid shell detritus. Plagioptychids appear, but only sporadically. Corals are frequently found in the fabric cohabiting with the rudists, often encrusting upon them. Foraminifera occur in isolated instances (miliolina, textularina), as do echinoids (primarily remains of sea urchins). No calcareous green algae fossils were identified in the 57 thin sections created from profile B samples. The non-biogenic components consist of some peloids, but the vast majority of the matrix is composed of micrite, while sparite and a bioclastic dark brown sediment with marl content is commonly found in the hollow chambers of biogenic components. The hippuritid and radiolitid shells, in some instances, have been thoroughly or partially micritized, or fully replaced with sparite. In a few cases, sediment infillings were encased by sparite or micrite left over from shells that had been fully diagenetically leached. In many cases, however, the original shell was intact with its primary calcite make-up. The outcrop can be subdivided into three sections: 1) beds 1-2, which are only 8 and 12m in length, respectively, and consist mainly of detrital rudist limestone, 2) beds 3-4, which in some places are indistinguishable from each other and harbor the only biostromes identified in the outcrop, 3) beds 5-10, which are unexposed in some places and are not nearly as extensive as beds 3 and 4; they also have no exposed biostromes. Figures 62-64 below show characteristic images of the thin sections from beds 1 and 2.

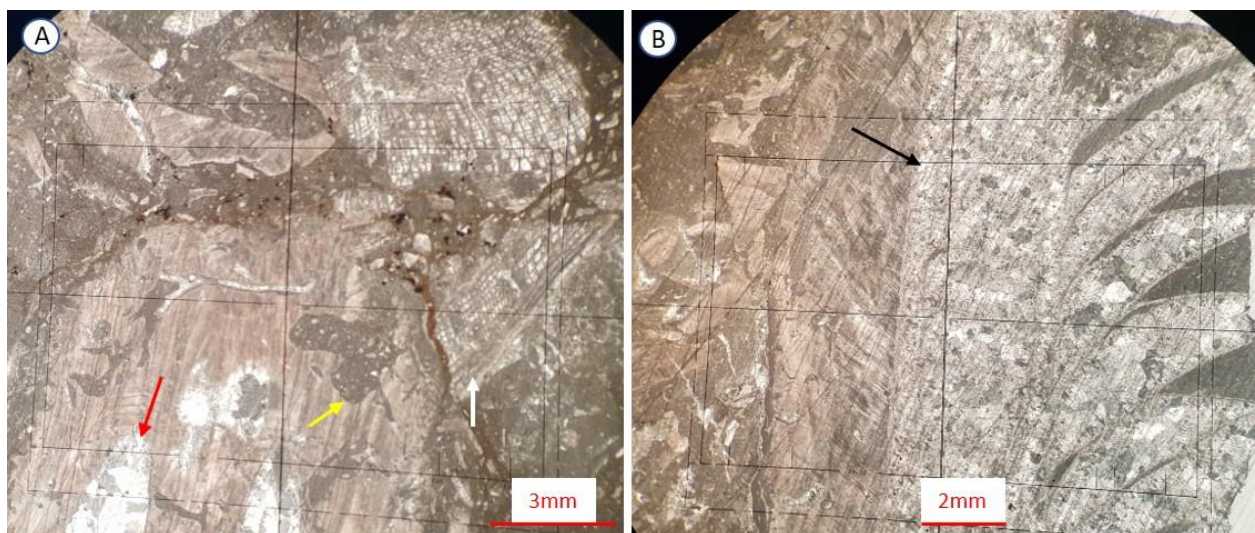


Fig. 62: A (B1.1N) – from bed 1, large rudist shell with bore holes filled with sediment (yellow arrow), hollow chamber filled with sparite (red arrow), radiolitid fragments on the right side (white arrow). B (B2.1N) – from bed 2, fully micritized/sparitized rudist shell (black arrow) with sediment in the hollow chambers; the sediment filled first, then the shell was dissolved later.

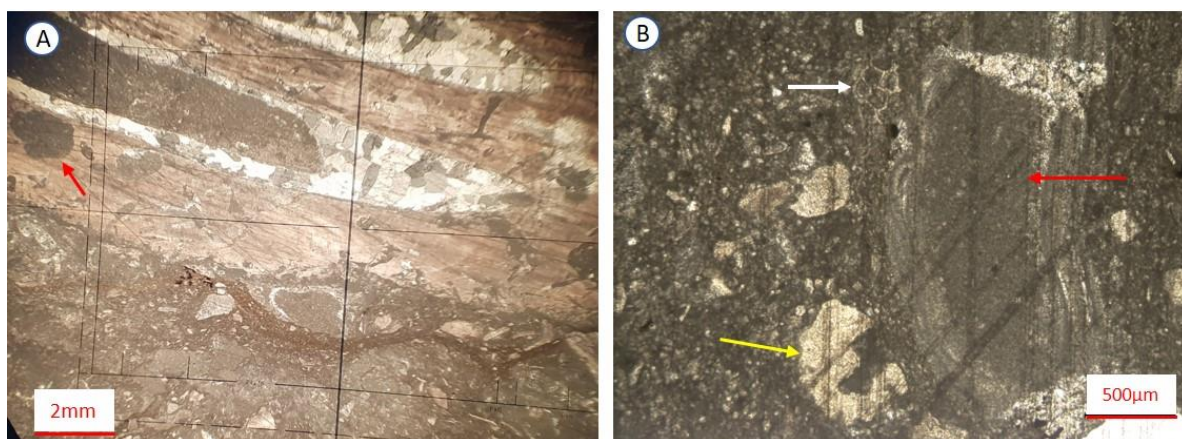


Fig. 63: A (B1.1N) – from bed 1, rudist shell with holes (red arrow) from boring sponges; aragonite inner layer sparitized. B (B2.1N) – from bed 2, example of fragment filled with sediment, then micritized around the edges (red arrow); echinoderm fragments (yellow arrow).

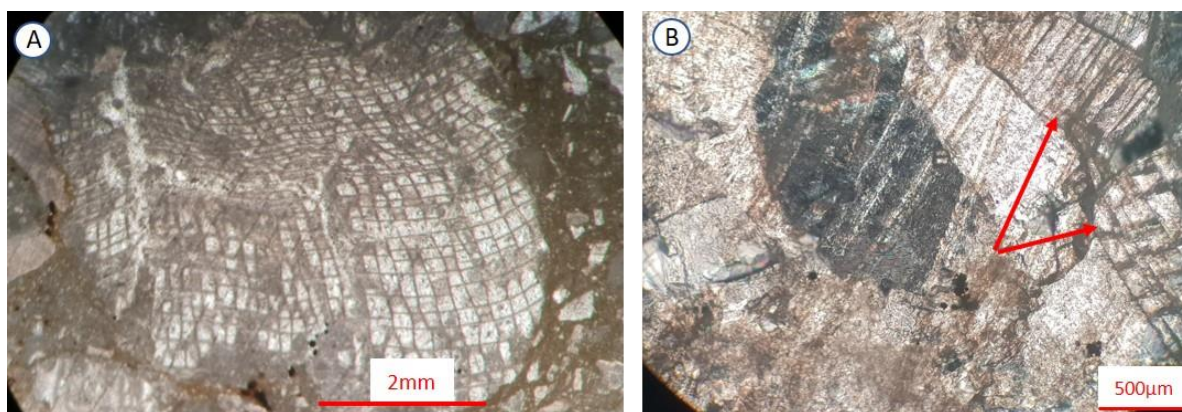


Fig. 64: A (B1.1N) – from bed 1, radiolitid fragment with micrite filling. B (B2.1N) – from bed 2, close-up of sparite crystals with lamination of calcite visible in x-nicols polarization (red arrows).

The bulk of the microfacies work and paleontological analysis was undertaken in beds 3 and 4, as these are most extensive in length and harbored the greatest abundance of both micro- and macrofossils. The following 6 Figures (65-70) provide images of the thin sections taken from these two beds.

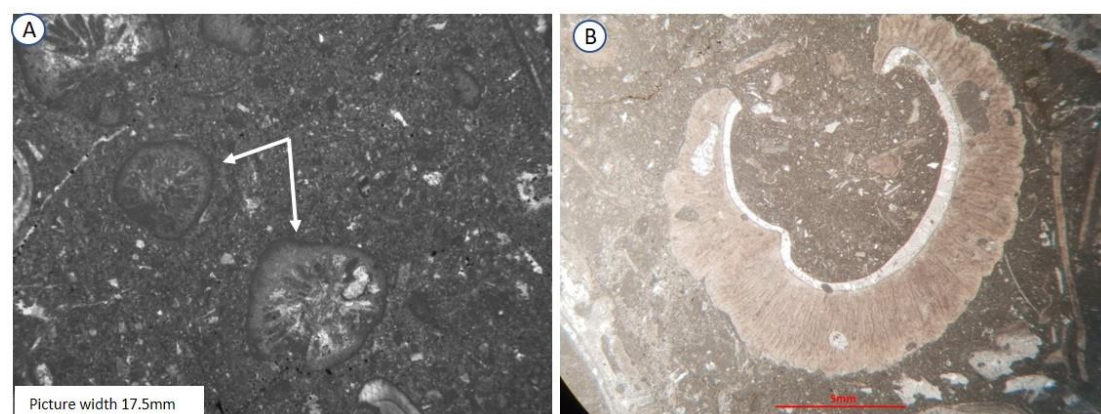


Fig. 65: A (7.1, BW) – from bed 4, images of coral *Cladocora gracilis* (white arrows, d'Orbigny, 1850) in bioclastic matrix with numerous rudist fragments. B (1.15) – from bed 4, rudist cross-section with micritized inner aragonite layer, sediment filling, *Vaccinites* sp.

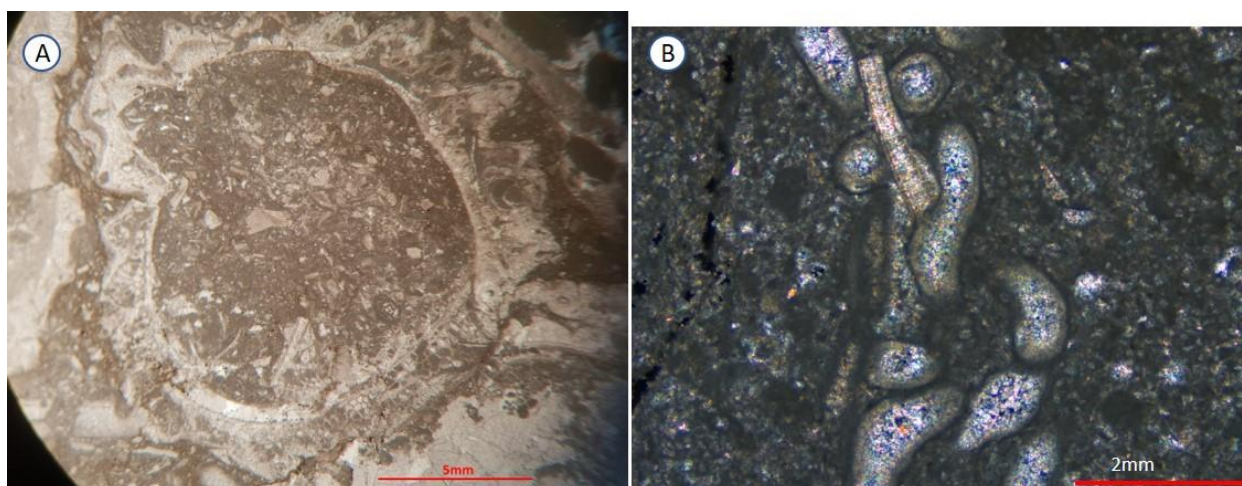


Fig. 66: A (2.1B) – from bed 4, cross-section of a radiolitid, shell highly micritized, sparite crystals in voids. B (7.1) – from bed 4, tubes created by serpulid worms (personal communication, Felix Schlagintweit, October, 2019).

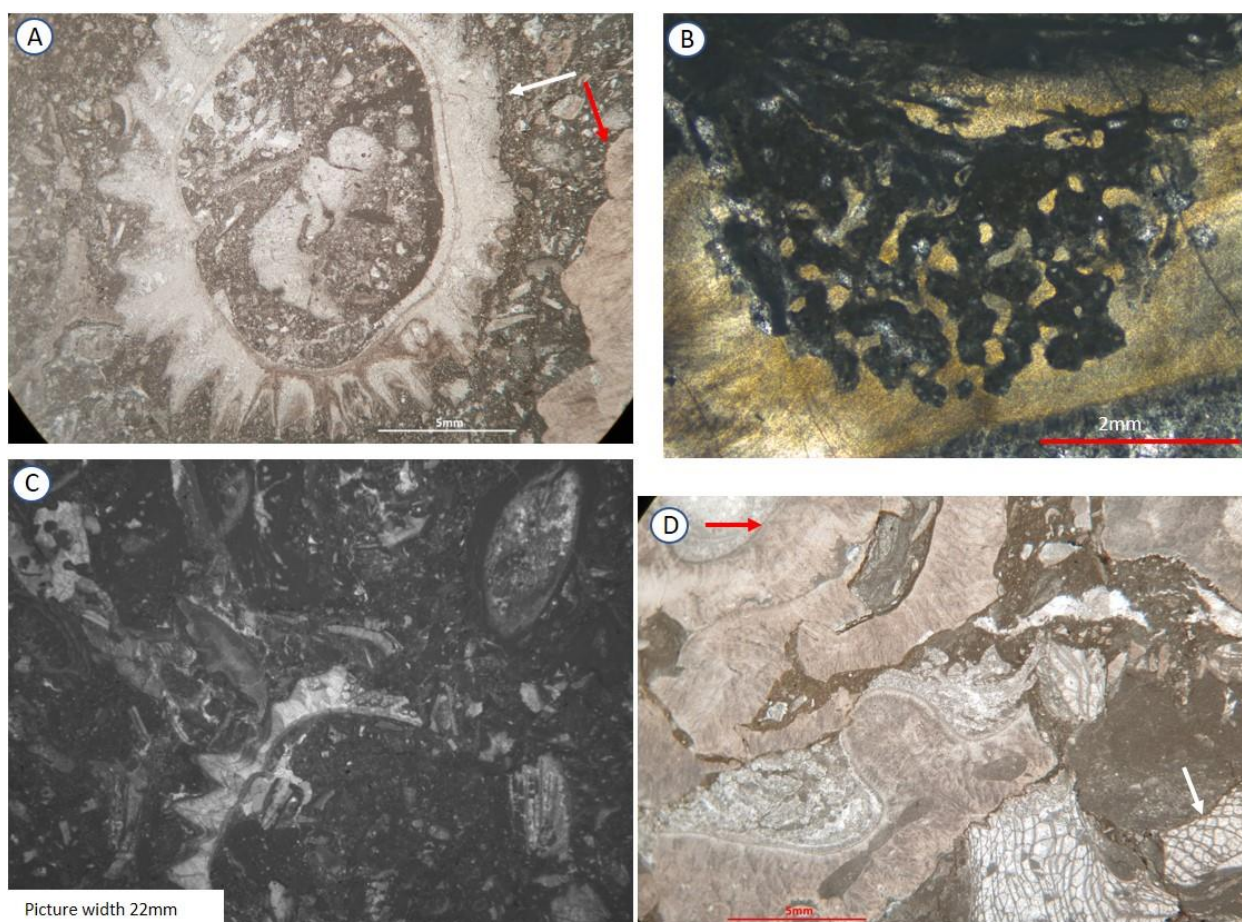


Fig. 67: A (27.1) – from bed 3, micritized cross-section of radiolitid (white arrow) next to (red arrow) preserved calcite shell of hippuritid (*Vaccinites* sp.). B (32.2) – from bed 3, growth of unspecified organism from rudist shell (potentially clinoid boring sponge). C (11.1, BW) – from bed 4, rudist-clastic floatstone with *Procladocora* coral fragments. D (13.1) – from bed 4, hippuritid (red arrow) and radiolitid (white arrow) clastic rudstone.

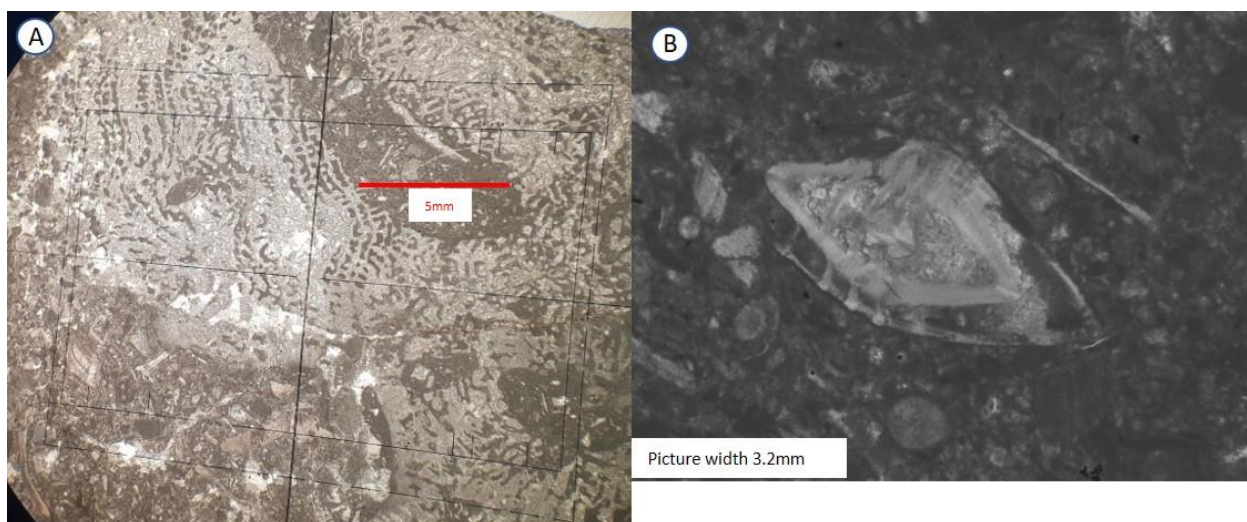


Fig. 68: A (53.2) – from bed 4, coral fragment from *Bosnopsammia* sp. B (9.1.8, BW) – from bed 4, one of very few foraminifera identified in profile B, *Nummofallotia cretacea* in rudist-coral clastic floatstone.

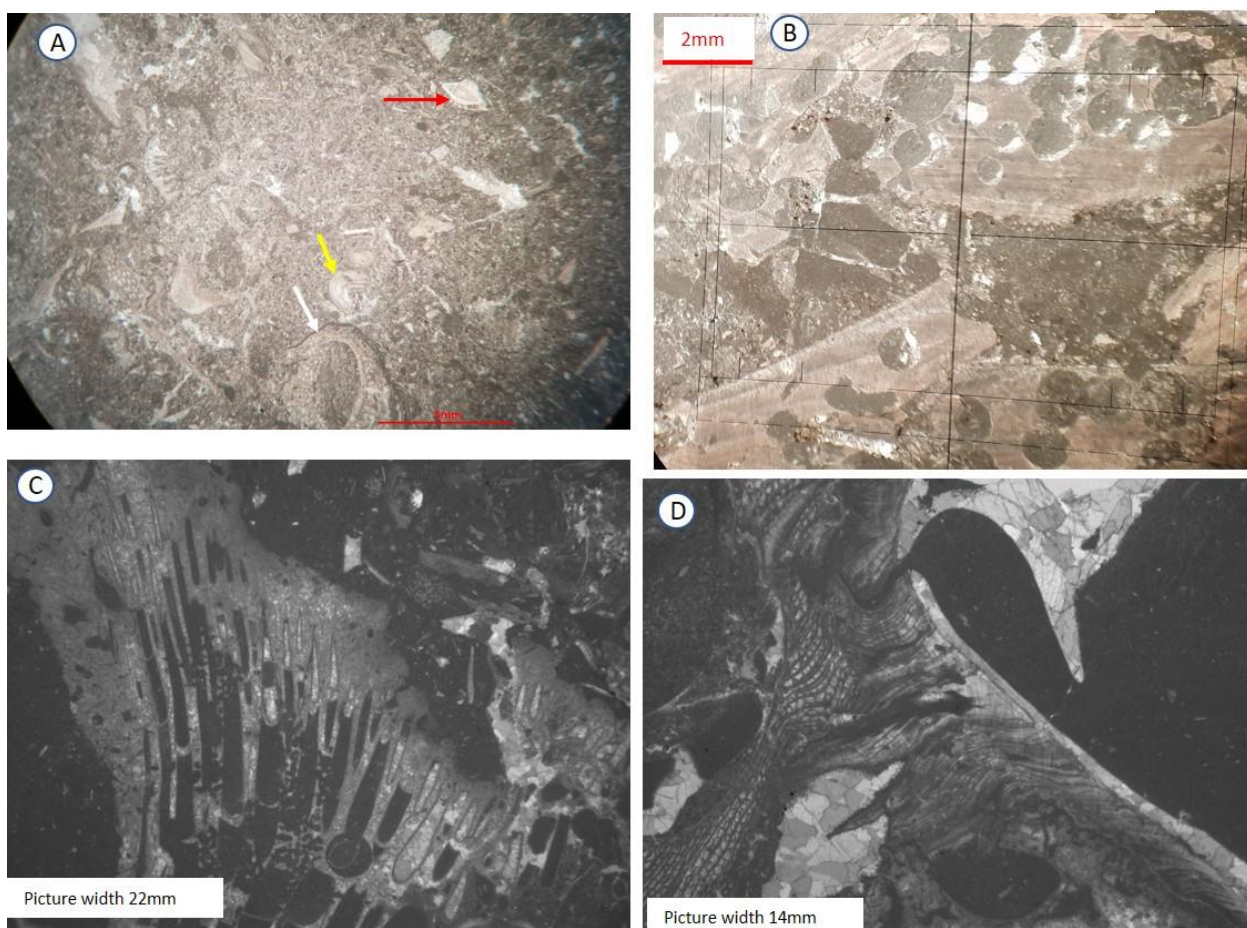


Fig. 69: A (9.1.8) – from bed 4, rudist-coral clastic floatstone: *Nummofallotia cretacea* (red arrow), radiolitid fragment (white arrow), echinoid fragment (yellow arrow). B (44.1) – from bed 4, clinoid-bored hippuritid shell. C (37.2L, BW) – from bed 3, free valve of *Plagioptychus*. D (33.4, BW) – from bed 3, radiolitid preserved with upper valve, early dissolution of aragonite layer of radiolitid, bafflestone.

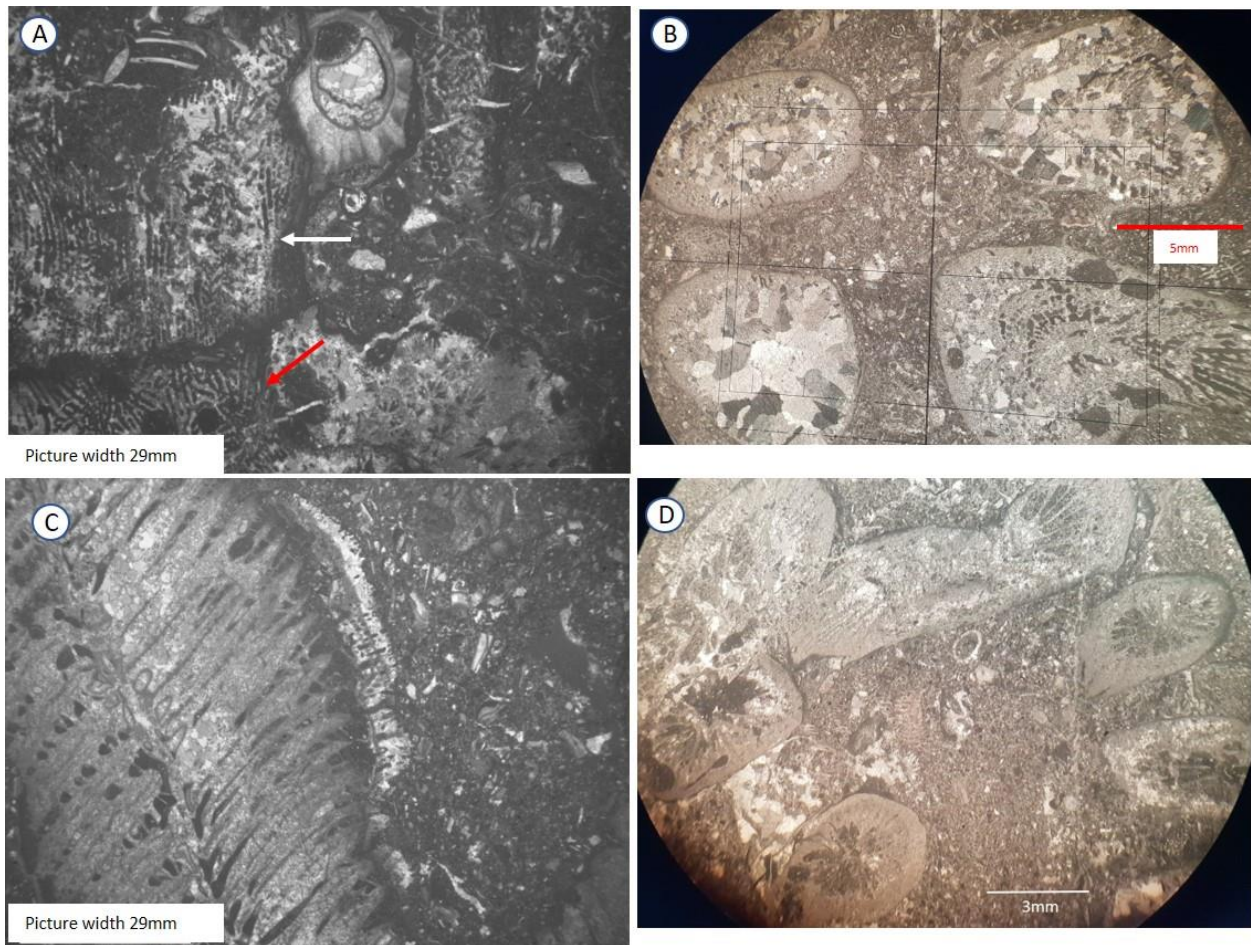


Fig. 70: A (49.1, BW) -- from bed 3, boundstone with two different coral taxa, red arrow → *Parasynastraea tignaria* (Oppenheim, 1930), white arrow → *Columactinastreaea* cf. *Formosa* (Goldfuss, 1829), cross section of young radiolitid (upper middle) with sparite filling. B (52.3) – from bed 4, *Dermosmiliopsis* cf. *tenuicosta* (Reuss, 1854), branching coral. C (54.2, BW) – from bed 3, *Placosmilia* sp. coral with encrusting bryozoans. D (54.1) – from bed 3, coral, *Nefophyllia angusta* (Reuss, 1854) in bioclastic matrix (coral taxa identified by Rosemarie Baron-Szabo, personal communication, November 2019).

Beds 5-10 in profile B account for a bit more than half of the total stratigraphic column, but they are not as extensive or as well-exposed as beds 3 and 4, hence the microfacies analysis was more limited. As mentioned, no biostromes could be identified in these beds: the lithology (floatstone to rudstone) and fossil content are very similar to beds 1 and 2 at the base of the outcrop and beds 3 and 4 between the biostromes. Figures 71 and 72 below provide an overview of images from beds 5-10.

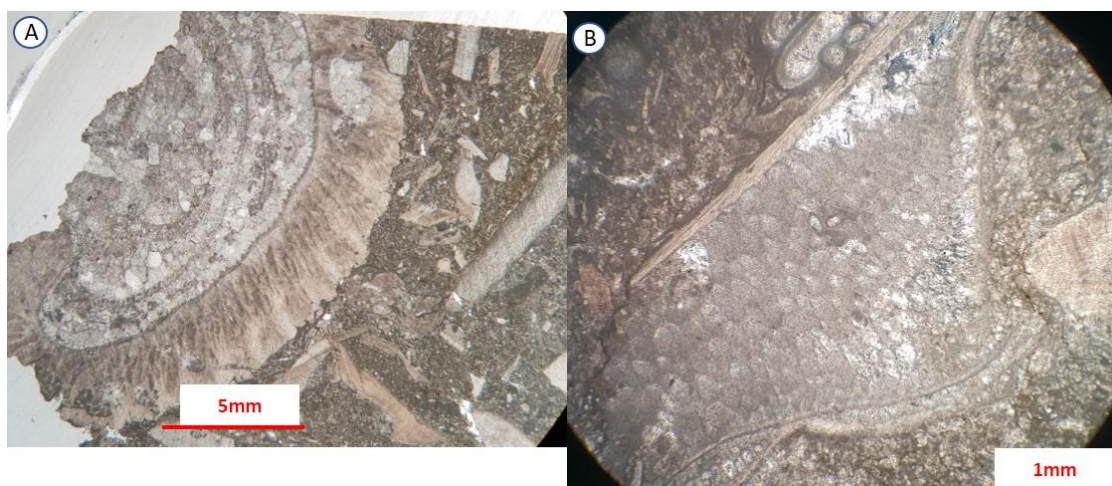


Fig. 71: A (B10.1N) – from bed 10, hippuritid fossil in clastic floatstone, infilling sparite crystals deposited in concentric layers. B (B10.1N) – from bed 10, detail showing micritized radiolite fragment.



Fig. 72: A (41.2) – from bed 5, floatstone with nearly fully-micritized radiolite cross section and radiolite fragments. B (56.2, BW) – from bed 7, radiolite floatstone. C (56.1) – from bed 7, large radiolite fragment with chambers filled with micrite and sparite. D (57.1) – from bed 7, floatstone to rudstone with large radiolite fragment and bioclastic matrix.

4.1.6 Area Surrounding Profile B

Profile B and Surrounding Topographic Platform

As indicated, profile B represents the south edge of a carbonate plate structure (1800 m²) composed of detrital rudist limestone. During the initial field trips, this raised structure was investigated to determine whether it contained additional outcrops similar or different to B. The laserscan map (Figure 13 above) shows a raised topographic platform structure that appears to comprise a single geological entity, perhaps a small reef. In the course of three separate excursions through this area, multiple outcrops were identified and investigated, including some beds that appear to be a continuation of profile B and were used as an extension to measure $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values. In this section, the focus will be on six different areas/outcrops that are representative of the entire plate-like morphological structure.

Samples extracted and measurements taken showed that this structure should be seen as a single geological entity. Figure 73 below provides a laserscan map highlighting this area.

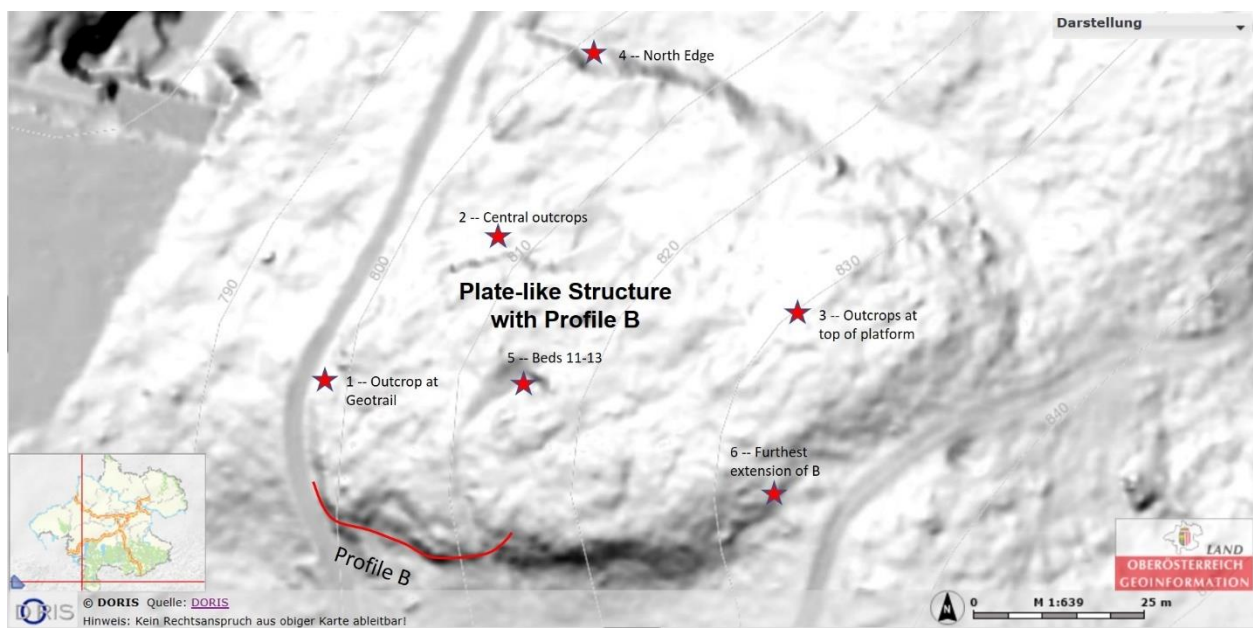


Fig. 73: Plate-like structure with profile B and the outcrops investigated (red stars). From Digitales Oberösterreichisches Raum-Informations-System [DORIS], accessed on 22 January 2020.

Along the Geotrail about 20 meters before the beginning of profile B, there is a large outcrop of Gosau limestone (point 1 in Figure 60) up behind a retaining structure put in place to keep earth and stones from falling onto the path. This outcrop is over two meters high, consists of light rudist limestone and shows no apparent bedding. In its appearance and size, it bears a certain resemblance to the large structure in profile B containing the hippurite biostrome. However, closer inspection revealed only sparse macrofossil content, and the stone was very hard and smooth, which made collecting samples nearly impossible. A look around the corner to the northeast

showed that this outcrop was just the first of a series of similar, massive limestone “walls” leading up the hill. Figure 74 below shows three of these outcrops (point 2 in Figure 73):



Fig. 74: three images of point 2 in Figure 73: large Gosau limestone outcrops with minimal bedding and only sparse fossil content. Grainstone to packstone lithology.

These massive outcrops were interspersed with smaller, less prominent beds of rudist limestone with more macrofossils. Near the top of the topographic platform to the east (at point 3 in Figure 73), the outcrops resembled the majority of profile B: more modest in thickness, but with considerably more fossil content. Figure 75 below is an example of such an outcrop.



Fig. 75: (left) small outcrop of rudist limestone with evident macrofossil content, coral marks (red arrow), rudist shells (yellow arrows). (Right) Large rudist fossil fragment from outcrop at left.

The laserscan map (Figure 73) clearly indicates that the north edge of the plate structure is just as pronounced as the south edge and should have important outcrops. This proved to be the case, but these outcrops were far less accessible. Along this edge of the platform, a small drainage trough has been incorporated into the power station's system of water run-off pipes. This renders the terrain wet and soggy; and there is also significant undergrowth that makes climbing this part of the hill very difficult. Nonetheless, the outcrops near the Geotrail were accessible and could be inspected. One of these massive outcrops measured around 4m from base to top. Like some of the outcrops seen in the central area (point 2), there was minimal to no bedding. But inspection of the weathered face of the outcrop revealed that fossil content was high. Figure 76 below provides two images of this outcrop.



Fig. 76: (Left) Massive wall of rudist limestone at north edge of platform B (point 4 in Fig. 73). For scale, see hammer in lower left corner of picture. (Right) Macrofossil content clearly evident in the face of the outcrop: classic detrital rudist limestone.

Finally, in the course of correcting initial surveying errors of profile B, a possible extension of this profile was identified, shown as point 5 (beds 11-13) in Figure 73. Along a small path about 15-20m from the end of beds 9 and 10, a large outcrop of 4.5 m height juts out of the hillside and possesses a lithology very similar to the outcrops investigated at point 2 (central outcrops) in Figure 73. Further assessment indicated that these beds are potentially a lateral extension of the outcrop at profile B, but that a gap of at least two meters existed between the presumed edge of bed 10 (not clear due to interruptions in exposure) and the base of bed 11. Still, a general

morphological connection could be ascertained; hence, samples were taken from this outcrop and others up the hill for the carbon and oxygen isotope measurements. A picture of beds 11-13 (informally, additional beds in profile B) can be seen in Figure 77 below. Orientation was NW, similar to other outcrops observed on the plate-like structure with profile B.

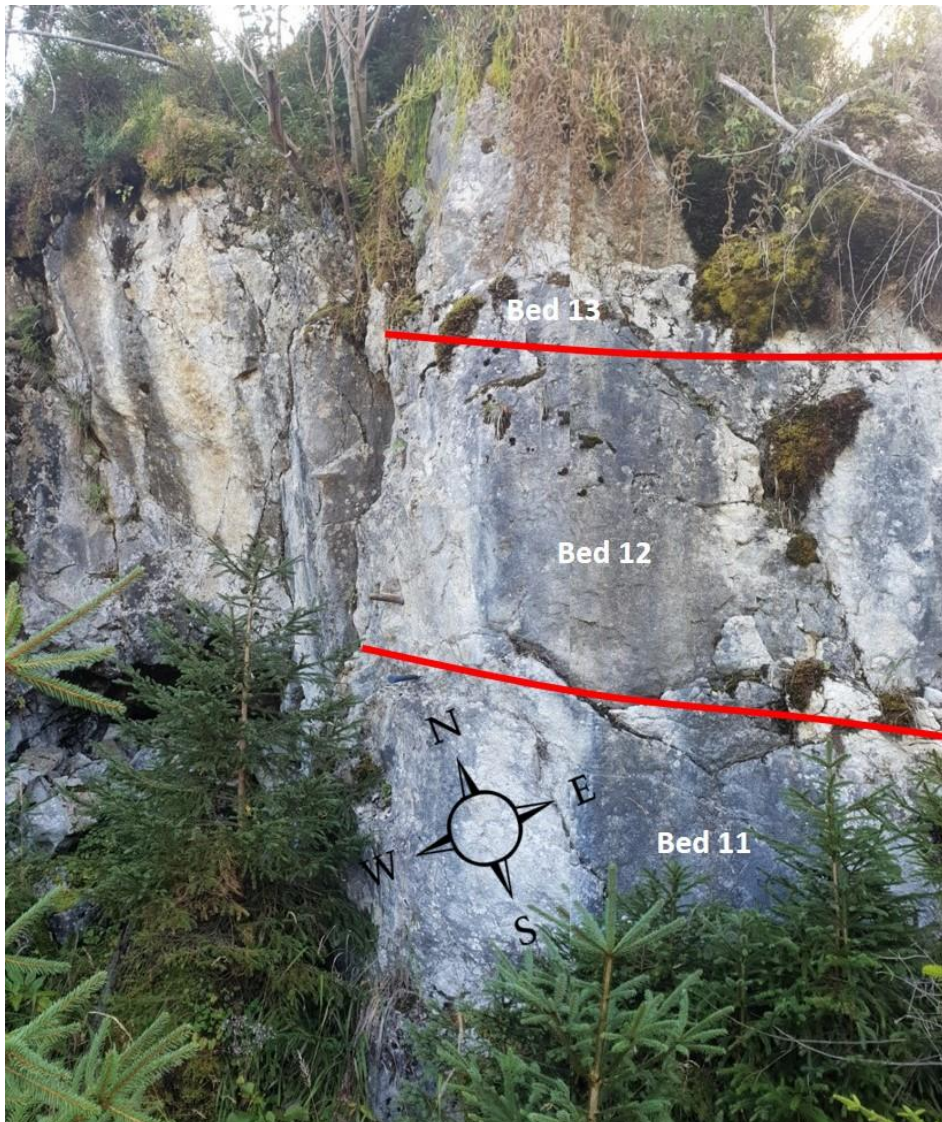


Fig. 77: Massive outcrop to the north of the end of profile B. Height 4.5 m. Lithology: Gosau limestone (grainstone to packstone) and similar to the outcrops at point 2 in Figure 73.

The furthest extension of profile B could be found at the trail at the top of the ridge near the Quaternary sediments between the Hochmoos Formation and the Dachstein Limestone. This was investigated again more thoroughly on a subsequent trip (14 October 2019).

Area North of Profile B and the Topographic Platform Structure

After thorough investigation of topographic platform B (with profile B situated on its southern edge) attention was turned to the greater area surrounding this structure and comprising the most easterly extent of the Hochmoos Formation in Gosauschmied. To this end, on 14 October 2019, a total of 12 outcrops were investigated to the immediate north of B, with the aim of determining lithology, fossil content and orientation. Figure 78 below provides an overview of these twelve outcrops and their locations.

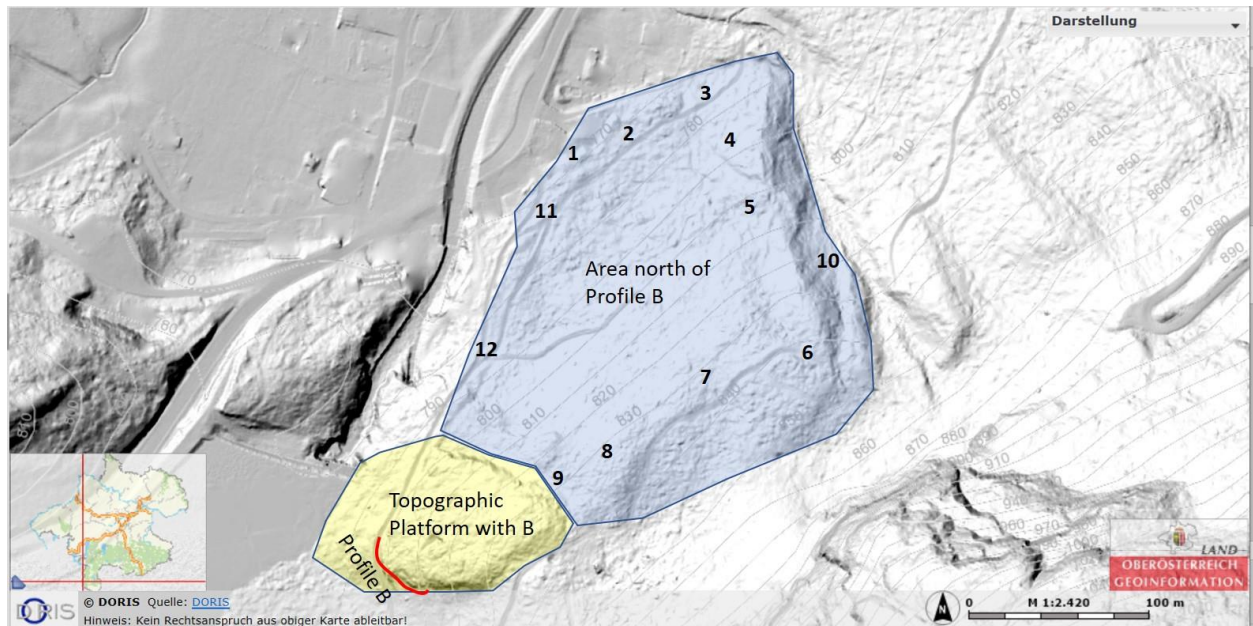


Fig. 78: Depiction of the area north of profile B and its topographic platform. The numbers identify the location of outcrops studied in this area. From Digitales Österreichisches Raum-Informationssystem [DORIS], accessed on 15 October 2019.

This area ranges from the lowest point near the brook at 767m to nearly 850 meters at the top. There are several paths traversing it, including the large trail at the top leading over to the climbing area at Rabenkogel. At the east edge of the area, a brook from underground springs flows down and into the larger Gosau brook in the valley.

The lithology of all twelve outcrops was very similar and showed a clear continuation of the lithology of profile B and its immediate surroundings: medium to light gray detrital rudist limestone. Macrofossils could be seen in all but two outcrops (1 & 2). Figure 79 (next page) shows some images of the outcrops from this area.

A key measure to assess structural cohesion with the topographic platform B is the orientation of the outcrops. Figure 80 (next page) shows the stereographic plot of all measurements taken in the area. The N/NW orientation, though slightly tilted further north than profile B and its topographic platform, clearly indicates a common dip toward the prevailing NW direction of the east half of the study area.

Ultimately, the final assessment is that the area to the north of profile B is lithologically, structurally and stratigraphically connected to profile B and its topographic platform. The facies in this area forms a continuum with the facies in profile B and surroundings, but scarce and discontinuous outcrops do not permit further detailed survey work. Investigations down to the reservoir from the Geotrail were also conducted: the very few in situ outcrops in this part of the study area showed a further continuation of this macrofossil-bearing facies to at least the edge of the water, where obviously further investigation was no longer possible.



Fig. 79: 1) (left) image of brook on the east edge of the area. Despite the topography and a steep drop off in the terrain, no exposed outcrops could be found. 2) (middle) image of a sample near outcrop 4: macrofossils weathering out of the surface with clear indication of detrital rudist shells. 3) (right) image of outcrop 3 with macrofossils in the rudist limestone surface.

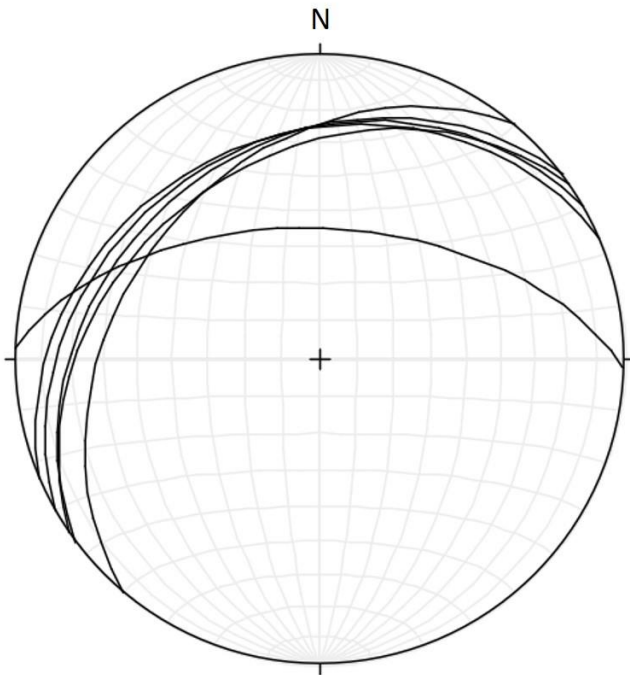


Fig. 80: Stereographic projection in Schmidt diagram of compass measurements of selected outcrops in the area surrounding topographic platform B. A consistent N/NW orientation could be established.

4.1.7 Gosau Brook and Hydroelectric Power Station

The west and east sides of the study area are divided by the Gosau brook and the water reservoir behind the hydroelectric power station. The power station was built in 1968 and, with respect to size and capacity (2,730 MWh/year), is one of the smallest in Upper Austria. The front edge of the dam is at an altitude of 780-781m and GPS coordinates N: 47.549580, E: 13.515881. The exit of the dam is about 10m lower at 770m. Access to this area is naturally prohibited to the general public; but a request to the manager of the power station at Gosauschmied, Ing. Georg Gamsjäger, was approved, making it possible to spend roughly four hours at the base of the dam and along the brook to inspect the outcrops there. Figure 81a shows a picture of the base of the dam taken from the bridge at the top.



Fig. 81a: Photo showing the bottom of the dam and the outcrop on the west side of the brook.

In the course of the afternoon investigating this area, samples and compass measurements were taken of both sides, including outcrops further downstream in the brook to a distance of about 40m from the base of the dam. The goal was to determine whether there was a lithological or structural change from one side to the other and to see how these outcrops correlated with profiles A, B and C.

The outcrops on the east side of the brook proved particularly difficult to access, especially near the base of the dam. There was a constant flow of water over the stones in this area, and extracting samples was laborious. As can also be seen from Figure 81a above, the bedding of the outcrops on the west side was difficult to discern, which may have been the result of a fault zone in the area extending to these formations. This will be discussed in more detail in the section on structure, faults and tectonics (section 4.2 below). In any case, consistent compass measurements were very difficult to attain. Further down the brook on the west side (>50m from the base of the dam), the outcrops and the bedding were more regular and gave consistent

measurements, which were aligned with the N/NE orientation of profile A north of the anticline. On the east side of the dam, compass measurements at the top above the brook were aligned with the W/NW orientation of profile B. Due to limited accessibility, the only compass measurement taken of the east wall near the base of the dam gave a measurement of 270/51, which is due west and is also in line with profile B.

A representative collection of samples was taken, which can be seen exhibited in Figure 81b below.

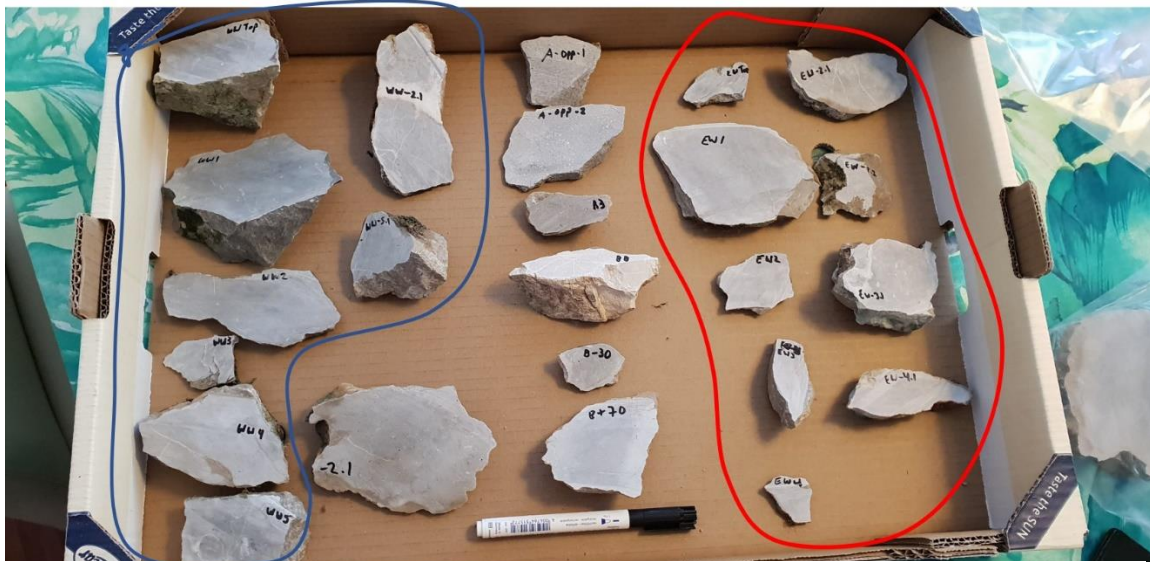


Fig. 81b: Samples from the outcrops near the dam and down the brook (<40m distance from the dam). The samples ringed in blue are from the west wall, while those ringed in red are from the east wall.

None of the samples possessed macrofossil content: no obvious rudist shells or coral fragments weathered out of the surface. No thin sections were created from these samples, but analysis with a magnifying glass showed fragments of fossils in the cut open surface areas. Regarding lithology, all the samples were packstone to grainstone, with a higher percentage of grainstone on the west side of the brook than on the east side. The character of the limestone was very similar to the samples at profile A (peloid limestone), though the general color was lighter and grew lighter from the west side to the east side.

The area from the Geotrail down to the top of the dam was also studied: it was interesting to note that the macrofossils typical of profile B continued in these outcrops, but then disappeared at a point roughly five meters from the top of the dam. This is a clear facies boundary between the detrital rudist limestone characteristic of profile B and the peloid limestone characteristic of profile A and the area around the Gosau brook.

Further study was undertaken downstream on the west side of the brook (>50m from the dam), which revealed the beds comprising the last exposed portion of the core of the anticline and also limestone outcrops with orientation aligned to profile A (N/NE). No corresponding outcrops on the

east side of the brook could be identified. In terms of understanding both sides of the study area and their possible connections, the dam and the reservoir posed significant limits on possible field work. This will be touched upon later in the discussion.

4.1.8 Lithostratigraphic Boundary Bibereck/Hochmoos Formations

In the course of the field work, it was frequently noted that the prevailing geological map from the Geologische Bundesanstalt (095 St. Wolfgang im Salzkammergut 1:50,000) contained some inaccuracies regarding the facies and the formation boundaries in the study area. Most obviously, the map denotes the entire Hochmoos Formation in Gosauschmied as facies type 45, which is classified as “clay slate with sandstone and conglomerate layers” (Tonschiefer mit Sandstein- und Konglomeratlagen). Since the vast majority of outcrops in the study area are variations of limestone (peloid limestone, marly limestone, rudist limestone) and other carbonates (dolomite, calcarenite, carbonate conglomerates), this designation of type 45 is incorrect, except for the core of the anticline. That said, there does not appear to be a designation in the geological map that fits the collection of facies types in this occurrence of the Hochmoos Formation. Type 44 (Hofergraben marls with rudist limestone) is closer, but not truly accurate; and the same applies to Type 51 (fine to medium-grained breccia with rudist limestone). At least these two types include rudist limestone, while Type 45 does not. Type 50 “Rudist reef limestone and detrital limestone” (Rudistenriffkalk und -trümmerkalk), only used outside the Gosau basin, may fit the lithologies at Gosauschmied best.

The other prominent inaccuracy is the extent of both the Hochmoos and the Bibereck Formations and the boundary between them. These are the only two officially-recognized LGS formations in the Gosauschmied area (not considering, for the moment, the extensive Untersberg Formation to the south of Gosauschmied). First, the Hochmoos Formation extends further on the east side of the brook than indicated in the geological map. Just as crucially, the Bibereck Formation extends further south than the map shows. Figure 82 below provides a comparison of the geological map with the extent of the formation and the boundaries determined during the field work.

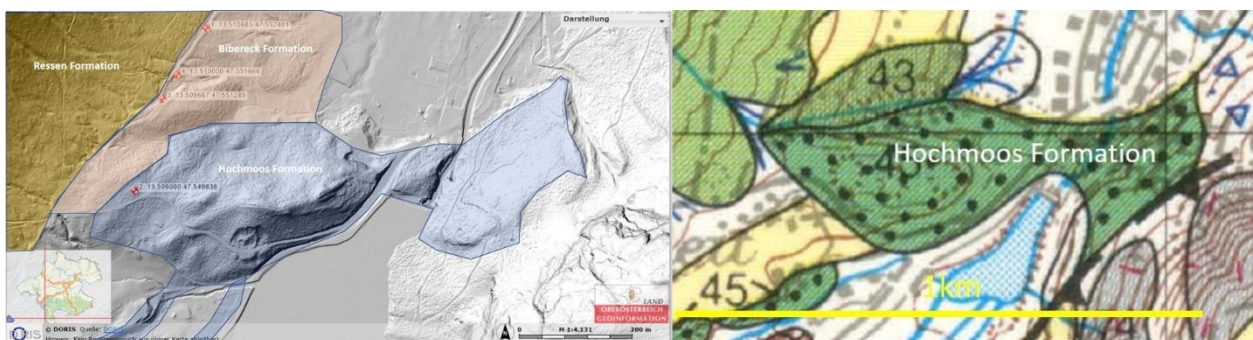


Fig. 82: Comparison of the formation depiction in the 1982 geological map from 095 St. Wolfgang im Salzkammergut (at right; Plöchinger, 1982) with the formation extent and boundaries established during the field work. Type 45 is formally the Hochmoos Formation, while Type 43 is the Bibereck Formation. Left map from Digitales Oberösterreichisches Raum-Informations-System [DORIS], accessed on 05 November 2019; right map from 095 St. Wolfgang im Salzkammergut 1982.

The map on the left in Figure 82 shows that the Hochmoos Formation also extends along the Gosausee highway and includes terrain all the way down to the reservoir on the east side of the study area. By contrast, the Bibereck Formation extends further south along the forest road (doubling as Geotrail) in the west side of the study area. Key outcrops were tested at the GPS points indicated in the map: the limestones of the Hochmoos Formation are first seen further south and to the east of what the geological map indicates. The actual facies change from neritic/bathyal marls (Bibereck Formation) to shallow water limestones (Hochmoos Formation) was noted on the forest road at N: 47.549838, E: 13.509000. The border of the Ressen Formation with the two LGS formations appears to be accurate.

4.1.9 Macrofossil Samples

In the course of the field work, a number of macrofossil samples were collected that had weathered out of the outcrops and hence were not directly in situ. Nonetheless, their position proximate to the outcrops studied clearly indicated their source and rendered them important for understanding additional aspects of the environment in which the outcrops formed.

In bed 3 of profile B, an impressive sample with numerous radiolitid fossils was trapped by the root structure of a small tree, but had otherwise weathered out of the face of the outcrop. Closer inspection together with Diethard Sanders showed that this large assemblage of radiolitids was an example of a radiolitid biostrome: these are, in contrast to hippuritid biostromes, less orderly in their growth patterns, with the colony having a more heterogeneous structure. This sample can be seen below in Figure 83.



Fig. 83: (Left) Entire sample weathered out of bed 3 in profile B. (Right) Cross-section of sample after being cut open. Genus of radiolitid was not identifiable. The sample shows some hippuritid cohabitation.

A very large fossil sample of a portion of a hippuritid biostrome was found at the base of bed 4 in profile B (Figure 84 below). A second somewhat smaller sample was also identified. As with the biostromes seen in situ in bed 4 of profile B, the hippuritid fossils in this sample are packed densely together as a colony, which is how they would have grown in the substrate as part of a reef. This sample was cut at the juncture where the upper and lower halves of the hippurite shells

are joined so as to help identify the genus and, if possible, the species. Together with cross-sections identified in the thin sections, this particular organism was classified as *Vaccinites* sp., with the species indeterminate (potentially *sulcatus* or *alpinus*).



Fig. 84: (Left) Fragment of hippuritid biostrome from the base of bed 4. (Right) Cross-section at joint of upper and lower shells. Genus: *Vaccinites* sp. (discussion Diethard Sanders, August 2019).

Also near the base of bed 4 in profile B, a large radiolitid fossil was identified, though to date no genus could be assigned to it. Its identification as a radiolitid could be determined due to the so-called celluloprismatic mesostructure (Skelton 2013) typical of the family Radiolitidae and so prominently preserved in the thin sections of radiolitid rudists. The sample depicted in Figure 85 shows the entire fossil as found (left) and a cross section (right). It could be a *Durania* sp., but positive identification is still pending: width is 11cm, while height is about 8cm.



Fig. 85: (Left) Radiolitid fossil with celluloprismatic mesostructure (Skelton 2013) typical of the family Radiolitidae. (Right) Cross section showing laminated structure around the core. The fossil is largely preserved primary calcite.

A large fossil sample was identified in the area between the Geotrail and the reservoir below profile B. What was initially presumed to be a coral actually turned out to be an example of a helioporid, which, based upon the thin sections analyzed in the study area, was not a major component in reef structures of the Hochmoos Formation at Gosauschmied. Figure 86 below shows a picture of the fossil sample and an overview of the thin section created from it.



Fig. 86: (Left) Example of a helioporid near profile B. (Right) Thin section (BB1) created from the sample showing the cross section of the individual polyps in the helioporid (personal communication, Rosemarie Baron-Szabo, November 2019).

A large fossil sample was found at site CW20 near the top of the ridge above profile C (see Figure 48 above). Since this sample was not in situ, it was not included in the discussion of this area, but a thin section created from this fossil was identified as *Lamellofungia* sp., a coral genus from the Upper Cretaceous with type locality in the upper Santonian of France (Les Corbières, Aude). The macrofossil portion, by contrast, proved to be *Placosmilia* sp. (Figure 87)

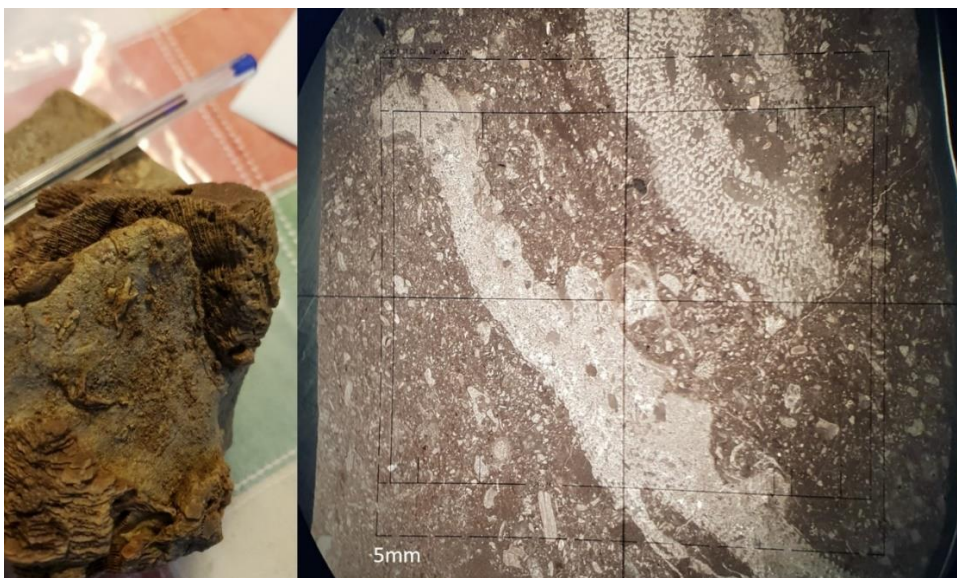


Fig. 87: (Left) Sample with coral *Placosmilia* sp. encrusting on Gosau limestone. (Right) Thin section (KK1) from bottom of fossil sample at left identified as *Lamellofungia* sp. (personal communication, Rosemarie Baron-Szabo, November 2019 and January 2020).

4.2 Structure, Faults and Tectonics

The collective structural data presented in section 4.1 above can be depicted in an overview map of the study area, showing strike and dip values on a large scale for the Hochmoos Formation in Gosauschmied. Figure 88 below shows a structural overview of the study area and key geological features, including the positions of the three profiles studied in-depth.

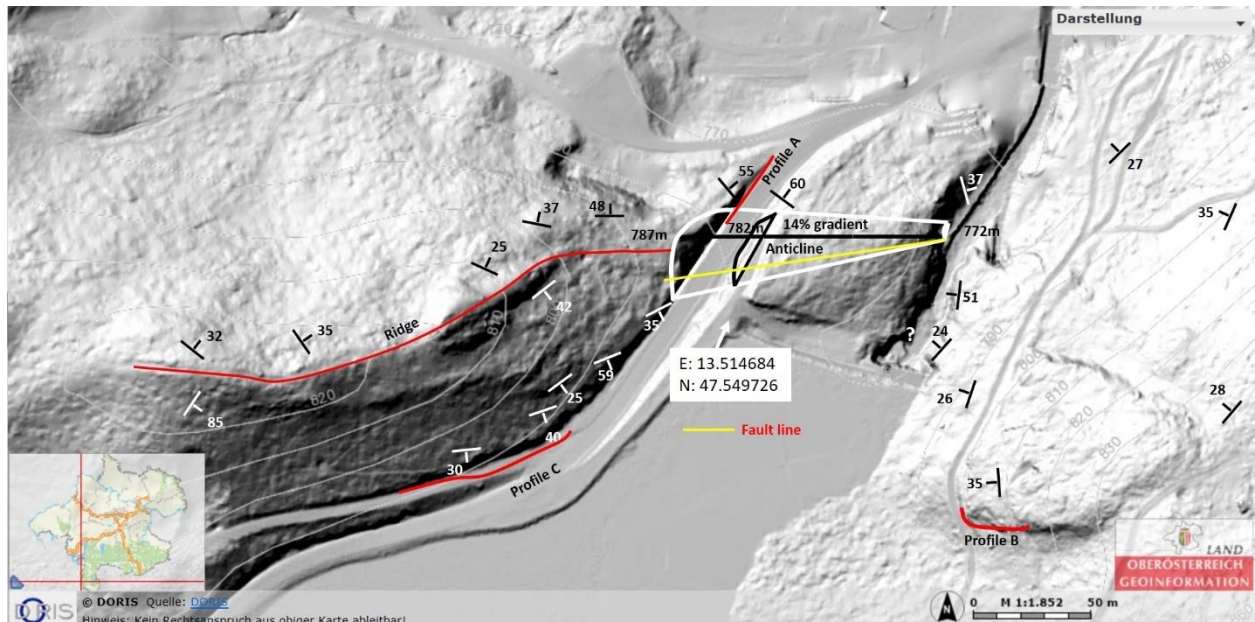


Fig. 88: Structural overview of study area with strike-dip measurements denoted. From Digitales Oberösterreichisches Raum-Informationssystem [DORIS], accessed on 05 November 2019.

This summarizes the overall orientation of the outcrops. As has been noted, outcrops on the east side of the study area show a W/NW orientation toward the valley floor and the brook, while outcrops on the west side of the study area have either a S/SE orientation (south of the anticline/ridge) or a N/NE orientation (north of the anticline/ridge), hence dipping also toward the valley floor and the brook.

The general tectonic setting for the Gosau Group sediments is unconformable deposition on thrust and strike-slip fault contacts between Triassic to Jurassic strata of the Dachstein and Hallstatt Nappe (Wagreich and Decker, 2001). This can be seen in Figure 89 below. Collection of structural data shows that the major features of the basin follow major faults of both Cretaceous and post-Eocene age. In their 2001 paper, Wagreich and Decker explored multiple faults of Cretaceous age in the Gosau basin. A particular fault, designated 95-28 in their paper, refers to a strike-slip fault in the study area at Gosauschmied. Data for this fault was collected by Decker on 16 July 1992 and archived for use in Wagreich and Decker, 2001. The fault planes recorded at this site can be seen in Figure 90 below.

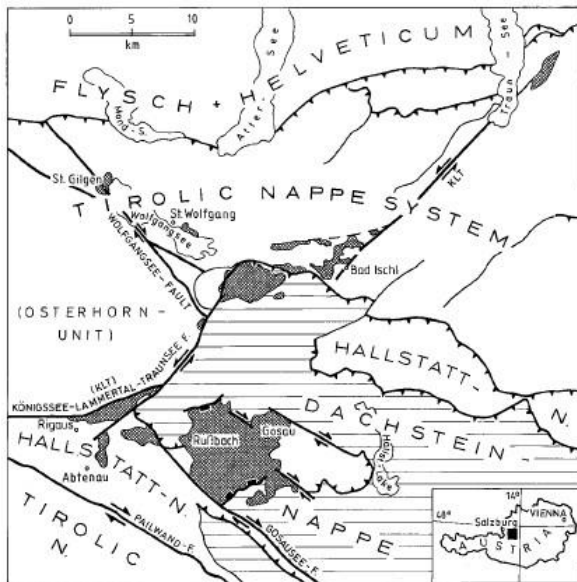


Fig. 89: Tectonic setting of Gosau Group formations (depicted as cross-hatched sediments) in the Gosau basin (Wagreich and Decker, 2001).

95-28-1.cor
Datasets: 21

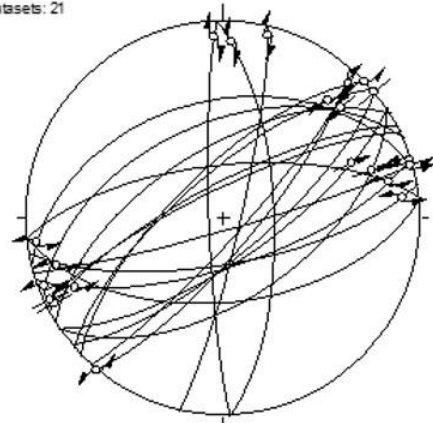


Fig. 90: Data archived 16 July 1992 by Decker. E-NE extending sinistral strike-slip fault with R and R' and a minor normal fault component (Wagreich and Decker, 2001).

This fault zone extends from the west side of the Gosausee highway (see Figure 88 above) and through the outcrops on the opposite side of the road and down to the brook. On the west side of the brook, the fault is seen very markedly next to the area where the anticline was identified. At this juncture, the power station authorities have used bricks and concrete to fortify the outcrop to prevent loose rocks from tumbling into the area near the basin of the dam. This fault could conceivably be responsible for the disrupted bedding identified on the west wall near the dam. Figure 91 below shows some images of the fault zone (95-28) at various places in the study area.



Fig. 91: (left) Fault 95-28 from Wagreich and Decker, 2001, west side of highway (N:47.549872, E:13.514605). (Middle top) Fault 95-28 east side of highway. (Middle bottom) Karstification conglomerate from fault on west side of highway. (Right top) Red arrow indicating Riedel shear areas on the foot wall of fault zone. (Right bottom) Image of Riedel shear structure (red arrow) in fault 95-28.

The north side of fault 95-28 on the west side of the highway was filled with karstification conglomerate and marl detritus. A sample is pictured in Figure 91 above (middle bottom) showing the internal structure: the individual clasts are all carbonate lithoclasts (primarily limestone). Riedel shear areas were identified on the east side of the highway on the south side of fault 95-28.

The most prominent fault in the area is just above the topographic platform structure containing profile B: a dramatic overthrust fault of post-Gosau age has resulted in a Dachstein limestone cliff of roughly 270m height rising out of Quaternary sediments between the Hochmoos Formation and the Dachstein limestone facies (see geological map in Figure 10 above). This fault plane extends SW-NE and runs roughly parallel to the Gosau brook. One question that arose in the course of the field work was whether a secondary fault plane developed along the valley floor and the bed of the brook. This question could not be definitively answered; and in discussions with Kurt Decker (20.11.2019), there was no data to indicate the existence of such a parallel fault plane along the base of the brook; but its existence cannot be positively ruled out, either.

The synsedimentary active normal faults in the Gosau Basin are discussed in detail in Wagreich and Decker (2001). A comparison between different Gosau Group profiles in the Gosau basin will be presented in the discussion section (section 5.3), showing the effects of this synsedimentary tectonic activity on the overall thickness of Hochmoos Formation outcrops across a WNW-ESE transect.

4.3 Facies Distribution in the Study Area

The stratigraphic survey work, sample collection and microfacies analysis in the Hochmoos Formation at Gosauschmied have led to the definition of six main facies types. These are as follows:

Type A: peloid limestone, packstone to grainstone lithology with limited to no fossil content, very hard with very dense texture and a medium-gray color. Calcite veins and stylolites are often found, as well. This facies is typified by the beds 14-24 in profile A.

Type B: bioclastic limestone, rudstone to floatstone to packstone lithology with high macrofossil content consisting mainly of detrital rudist and coral fragments, high amounts of micrite, sparite and bioclastic sediment, less dense than Type A, but still competent with a medium to light gray color. This facies is found in profile B and the area surrounding it.

Type AK: sandy, clastic carbonates, rudstone to packstone lithology with low fossil content and small to medium-sized terrigenous clasts (carbonate lithoclasts, quartz, chert), less competent than either B or A with medium gray/brown color. This facies is typical of the core of the anticline (beds 1-7 in profile A). For the sake of simplicity, the singular marl beds will be considered part of AK, since they occur only in conjunction with this facies.

Type AC: Very similar to Type A, packstone to grainstone with high peloid content, but with increasing terrigenous clasts (visible on a macro or micro level), most prominently carbonate lithoclasts (Dachstein limestone), quartz and chert; varying fossil content that decreases in younger beds; very competent with medium to dark gray color.

Type C: This facies is unique due to the higher marl/clay content, but actually represents a transitional facies between Type B and Type AC: in profile C, the initial two beds contain significant macro- and microfossil content, large amounts of micrite as primary matrix component, sparite infillings and bioclastic sediment with rudstone to floatstone lithology, showing a connection to Type B. In the younger beds higher up, the fossil content decreases, the samples contain more peloid components and gradually lose the marl content and hence become lighter. Lithoclasts also increase in number as the facies transitions to AC.

Type K: This facies consists of carbonate conglomerates with rudstone to floatstone lithology and small to very large rounded lithoclasts (Dachstein limestone, quartz, chert) in a muddy (micritic) carbonate matrix. Type K samples are brown to gray and the least competent lithology in the Hochmoos Formation at Gosauschmied. Fossil content is limited, while the peloid components are very numerous.

Figure 92 below provides an overview of these six facies types and where they are distributed in the study area. It bears repeating that the Grabenbach Formation, which is stratigraphically antecedent to the Hochmoos Formation in the Gosau Group, does not occur at all in

Gosauschmied, while the Bibereck Formation, which follows stratigraphically, is exposed in two different places and has one significant occurrence to the west and north of the Hochmoos Formation. This will be revisited in the discussion section.

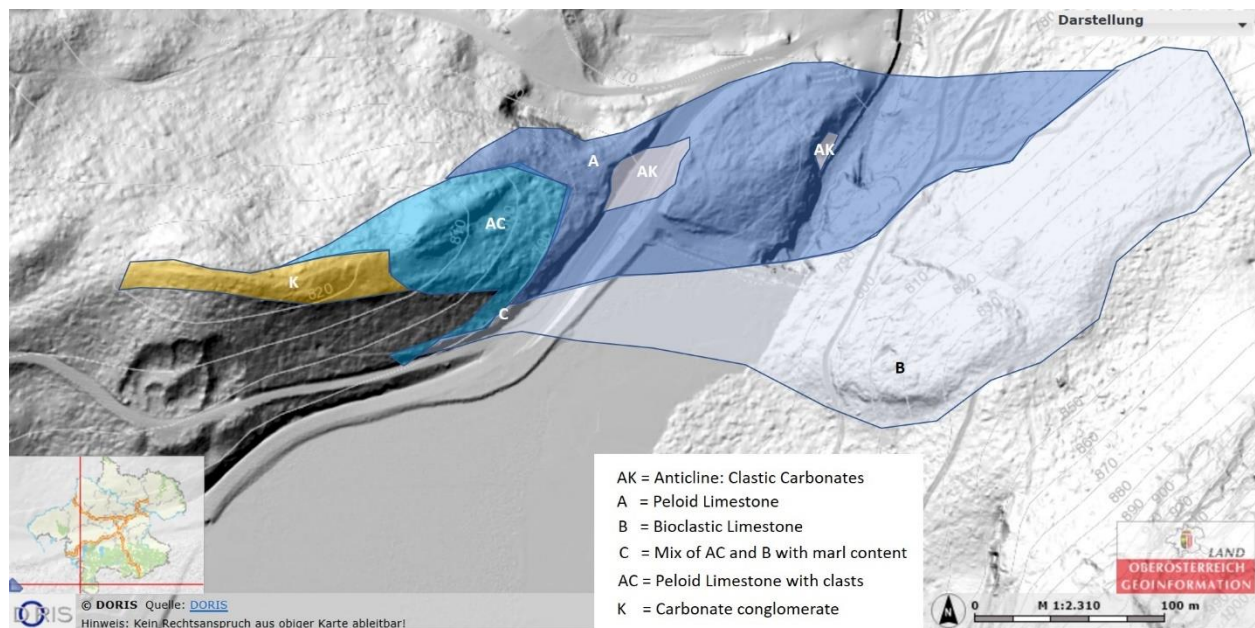


Fig. 92: map of the study area with the distribution of the 6 different facies types. The boundaries between the facies types are not sharp, but gradual, though there are a number of outcrops that appear to show the exact point of transition. From Digitales Österreichisches Raum-Informationssystem [DORIS], accessed on 24 January 2020.

Stratigraphically, the individual facies types transition from AK, the oldest, through A, then B and C, followed by AC and finally K, which comprises the youngest preserved sediments of the Hochmoos Formation in the study area. In the map above, some liberties were taken in assessing facies continuity across areas that, logically, could not be investigated. Nonetheless, the reservoir and the road, both manmade structures, clearly interrupt outcrops that were previously continuous; and the facies similarity of the outcrops on either side of these manmade structures justifies presuming such a continuity. Technically, there could be even a different facies in between, particularly in the reservoir area, but that is outside the realm of possible field work. This will be revisited later in the discussion section when considering possible deposition scenarios.

Figure 93 on the following page provides thin section examples characteristic of each facies type. Two examples have been included for Facies Type C, as this facies is transitional between B and AC with higher marl content.

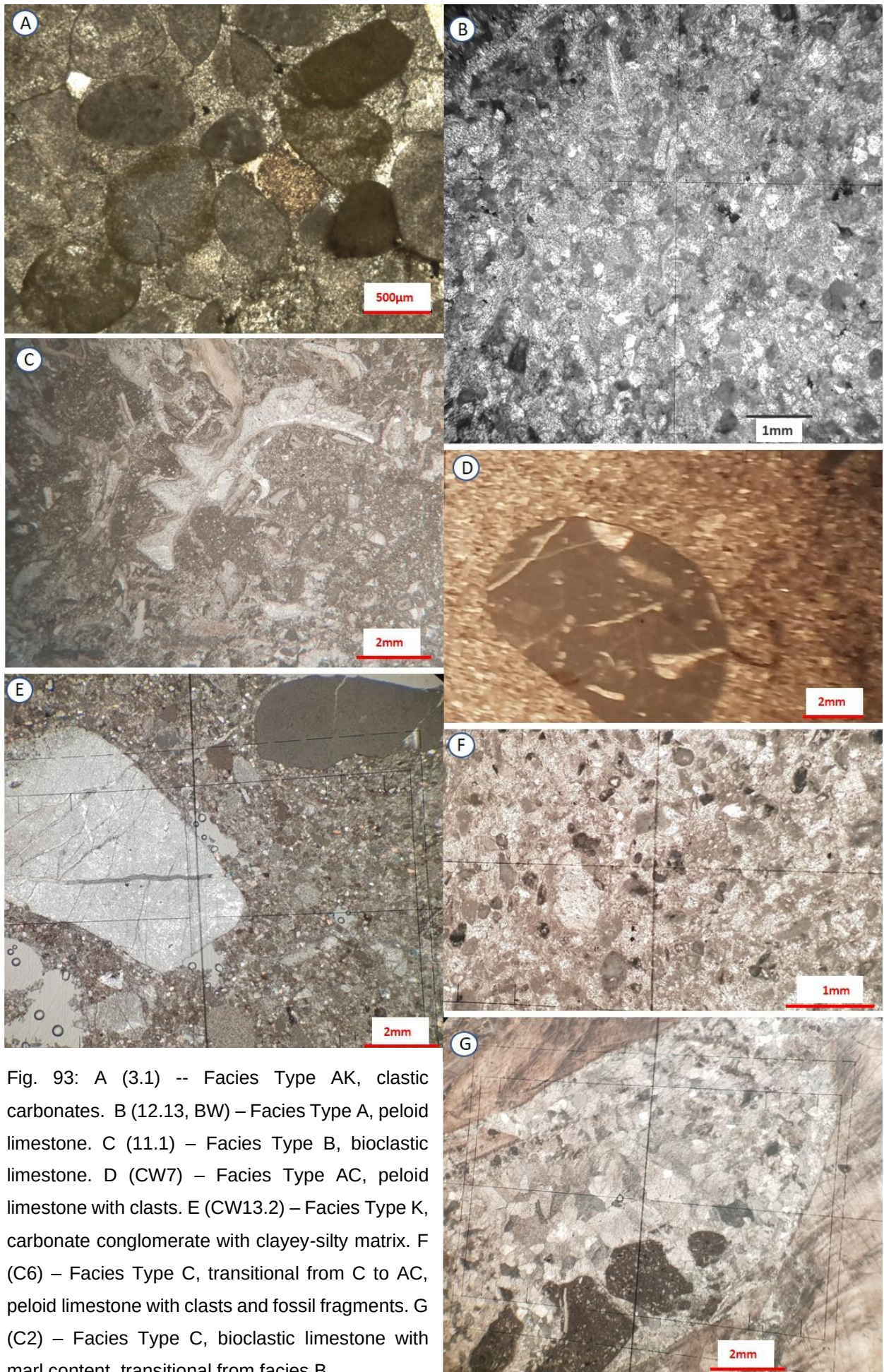


Fig. 93: A (3.1) -- Facies Type AK, clastic carbonates. B (12.13, BW) – Facies Type A, peloid limestone. C (11.1) – Facies Type B, bioclastic limestone. D (CW7) – Facies Type AC, peloid limestone with clasts. E (CW13.2) – Facies Type K, carbonate conglomerate with clayey-silty matrix. F (C6) – Facies Type C, transitional from C to AC, peloid limestone with clasts and fossil fragments. G (C2) – Facies Type C, bioclastic limestone with marl content, transitional from facies B.

4.4 Isotope Measurements

4.4.1 Strontium Ratios

The five separate measurements of strontium ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) were taken at the places indicated in the map in Figure 94. These include three samples from profile B using rudist shell material (bed 4), one sample from profile C using the *Durania* specimen from bed 1 and one sample from site CW11 on the ridge above profile C using a limestone sample.

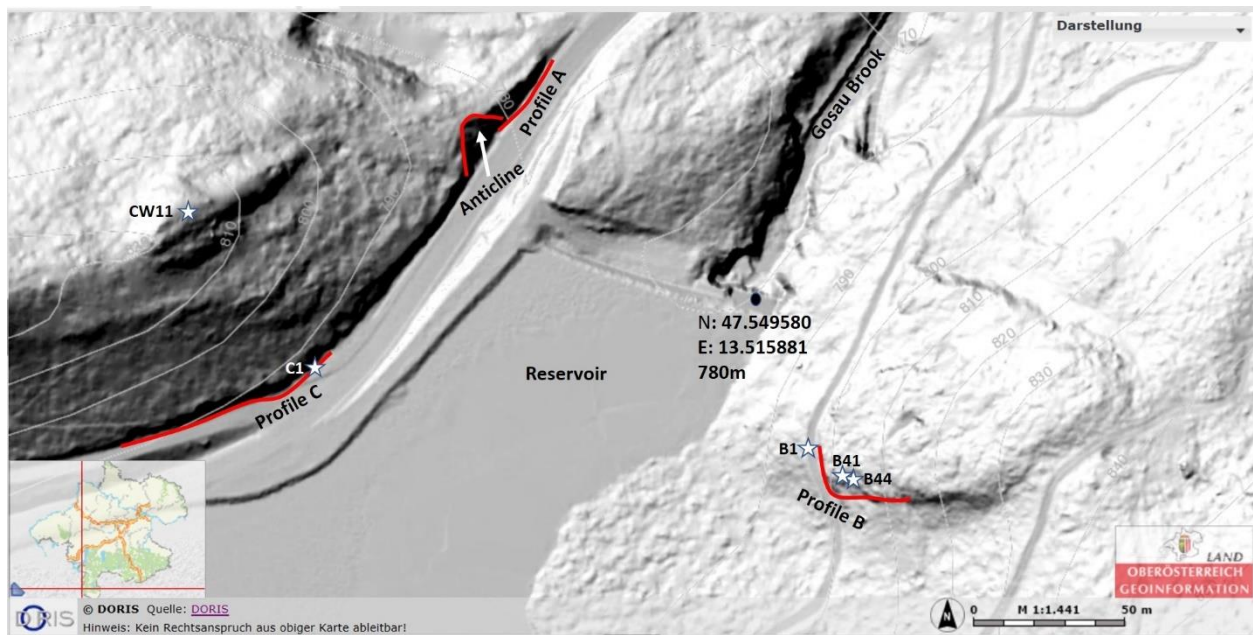


Fig. 94: Strontium isotope measurements were taken from samples extracted at the places indicated in the map (denoted by white stars). Map From Digitales Oberösterreichisches Raum-Informationssystem [DORIS], accessed on 24 January 2020.

The measurements can be seen in Table 1 below. The mean value taken from Wolfgring and Wagreich (2018) at the Postalm is included as a reference for the Santonian/Campanian boundary applicable to Upper Cretaceous marine carbonate sediments of Tethys provenience.

Sample	$^{87}\text{Sr}/^{86}\text{Sr}$	+/-2sm	Latitude	Longitude
C1	0.707515	0.000004	47.549332	13.513960
CW11	0.707549	0.000004	47.549807	13.513452
B1	0.707485	0.000004	47.549107	13.516171
B41	0.707508	0.000008	47.548980	13.516506
B44	0.707514	0.000007	47.548973	13.516511
Wolfgring 2018	0.707534	mean value	47.610500	13.385417

Table 1: Strontium isotope measurements from Gosauschmied compared to the mean value at the Postalm from Wolfgring and Wagreich (2018).

4.4.2 Carbon and Oxygen Isotopes

Figure 95 below shows the plots of the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotope values for profile A and profile B. In the case of profile A, the samples were extracted from the last 10.9 meters of the outcrop, which contained the marl layer and the pure limestone beds. Mean sample resolution was 64cm. The samples from profile B included 10 from the formally described outcrop and another 8 taken from outcrops that could be correlated to B and extended up the ridge to the boundary with the quaternary sediments. Mean sample resolution for these measurements was 500cm. The actual values can be found in appendix E. In some instances, two values were provided for a single sample, which were averaged to provide a single value for the stratigraphic position.

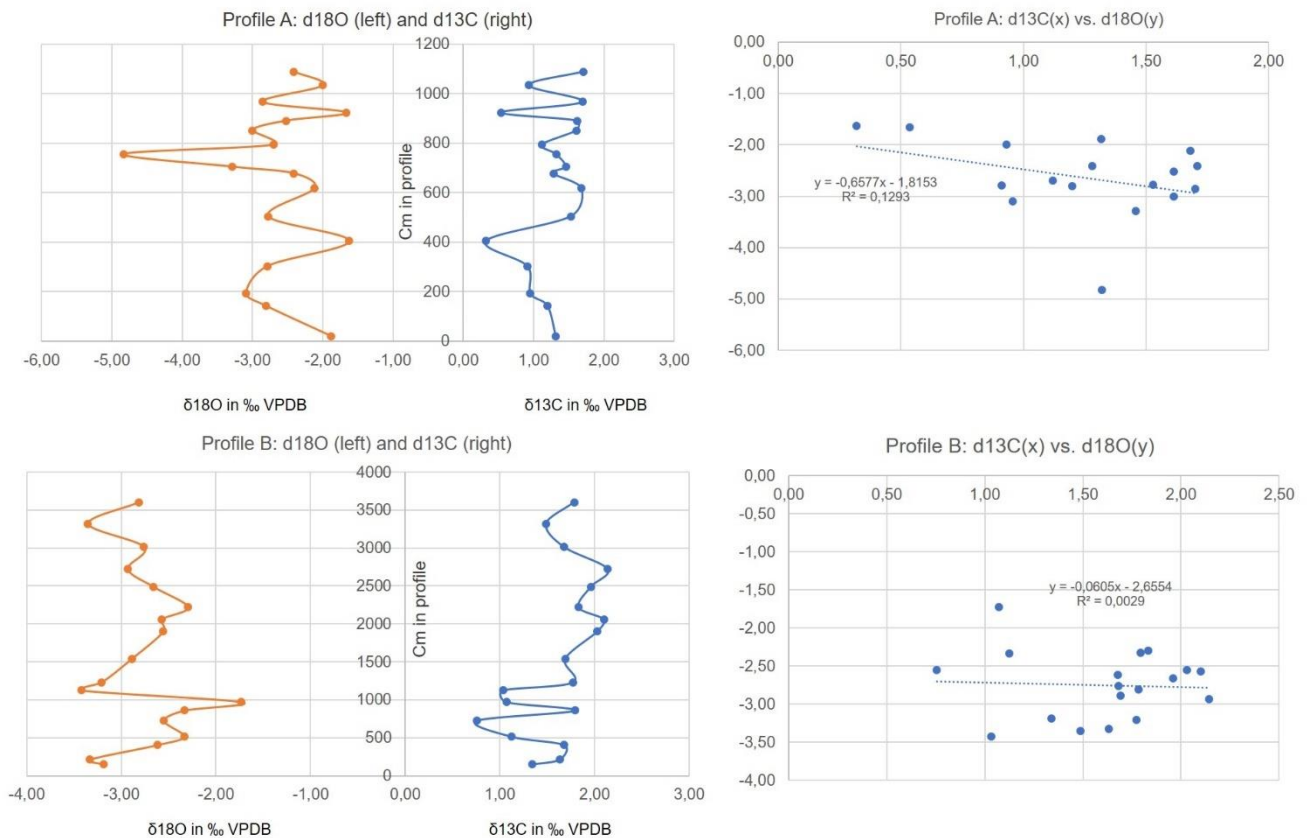


Fig. 95: (Top left) $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ curves for profile A. Height in the profile sampled is given on the Y-axis. (Top right) $\delta^{13}\text{C}$ (x) plotted vs. $\delta^{18}\text{O}$ (y) values. Best fit line and correlation (R^2) for the plot is included. (Bottom left) $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ curves for profile B. Height in the profile sampled is given on the Y-axis. (Bottom right) $\delta^{13}\text{C}$ (x) plotted vs. $\delta^{18}\text{O}$ (y) values. Best fit and correlation (R^2) for the plot is included. Isotope measurements are expressed in ‰ vs. the VPDB standard (Vienna Pee Dee Belemnite).

Values were also obtained for profile C, but the sample number (6) and resolution (110cm) did not produce a meaningful individual curve. These values are also included in appendix E for the sake of completeness.

A composite curve using data from all three profiles was constructed under the assumption that A is at the base, followed by B and then C. These values were taken as a stratigraphic continuum from bed 8 in profile A to bed 6 in profile C. This naturally assumes that profile C is stratigraphically above profile B, and B directly above profile A. This curve can be seen in Figure 96 as a three-point rolling average. Key $\delta^{13}\text{C}$ excursion events from Jarvis et al. (2006) have been correlated to the data and will be addressed in the discussion section that follows.

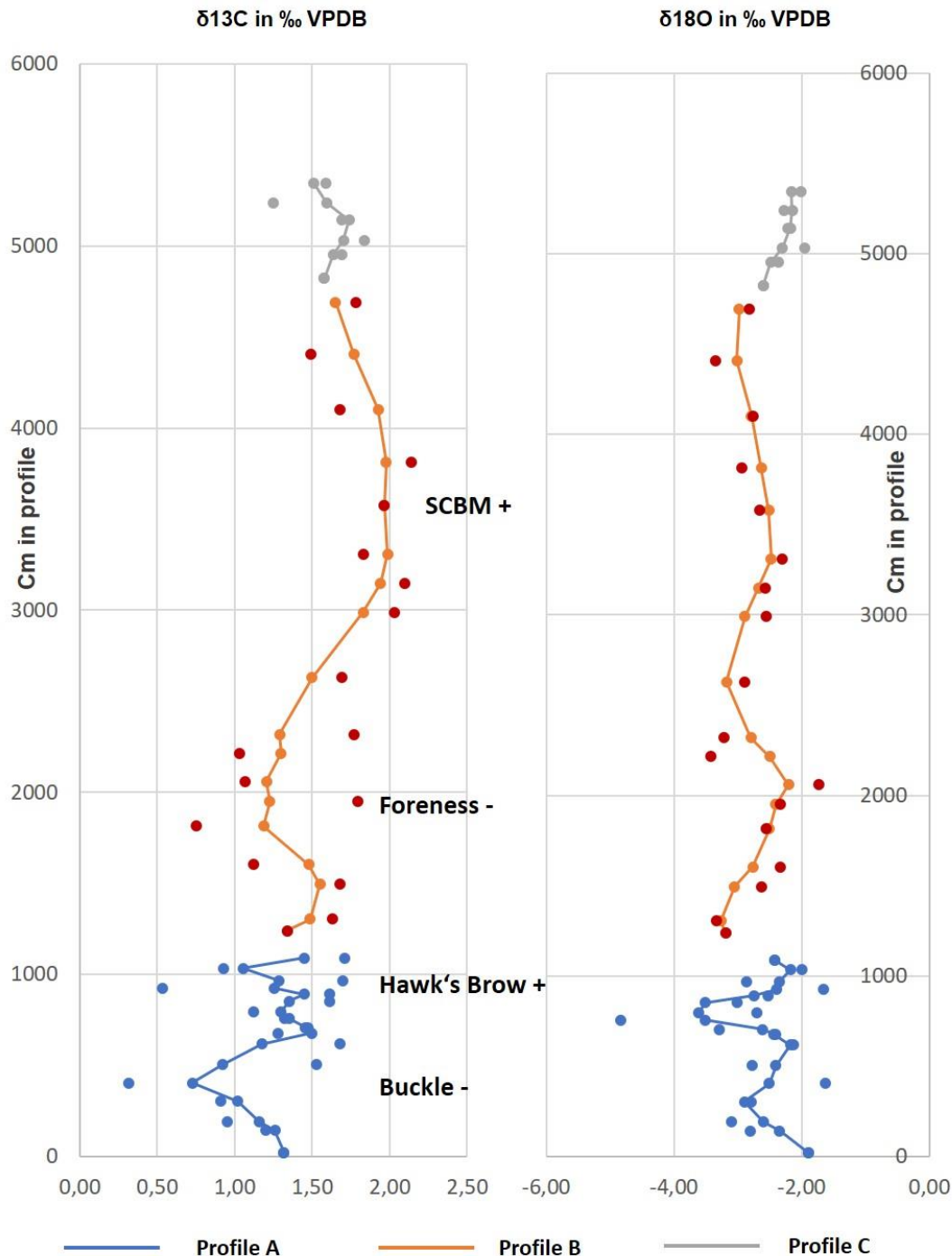


Fig. 96: Composite $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves for the three profiles A, B and C using a three-point rolling average. The original data points are included as a scatter plot. Key $\delta^{13}\text{C}$ excursion events from Jarvis et al. (2006) are correlated to the data.

5 Discussion and Interpretation

5.1 Chronostratigraphy

Based upon prior work in the Gosau basin and the official geological map from the Austrian GBA (095 St. Wolfgang im Salzkammergut 1:50 000), the working hypothesis at the outset of this thesis was that the outcrops in the study area classified as Hochmoos Formation are of late Santonian age with some potential cross-over into early Campanian in the youngest strata. The $^{87}\text{Sr}/^{86}\text{Sr}$ measurements taken in key areas of the Hochmoos Formation at Gosauschmied confirm this hypothesis and provide a strong correlation between the two separate parts of the area (west and east). In addition, 2 nannofossil samples were taken in profile A (bed 8) and from the basal outcrop of the Bibereck Formation (N:47.551289, E:13.509667). According to Wagreich (personal communication, 2019), the sample from profile A contained only a few nannofossils that were not biostratigraphically significant; however, they did not contradict the hypothesis of a late Santonian age. The sample from the Bibereck Formation showed the typical assemblage of the late Santonian to earliest Campanian nannofossil zone CC17b, including *Calculites obscurus* and curved *Lucianorhabdus cayeuxii* without *Broinsonia parca parca*, thus denoting the Santonian-Campanian transition, as already known from the upper Santonian at Schattau (Wagreich et al., 2010) and Postalm (Wolfgring and Wagreich, 2018).

As discussed in the preceding section, Wolfgring and Wagreich (2018) at the Gosau locality of Postalm used a combination of strontium isotope measurements, index fossils and paleomagnetic data to establish a reliable $^{87}\text{Sr}/^{86}\text{Sr}$ ratio at the paleomagnetically-defined Santonian/Campanian boundary for sediments of Tethys provenience. This ratio was a mean of four values and was established at 0.707534. For this period in paleohistory, values greater than this represent a younger (Campanian) age, while values lower than this are of Santonian (or older) age. Four of the five ratios derived from samples in Gosauschmied (3 in profile B and 1 in profile C) all evidence values lower than the reference ratio at the Santonian/Campanian boundary at the Postalm and are hence in the late Santonian. Further, two of the values from profile B and the one from the lower part of profile C show excellent overall correlation (0.707508 B41, 0.707514 B44 and 0.707515 C1), indicating a roughly similar time of deposition. The one outlier among the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios is from the sample taken at site CW11 (823m) along the ridge: the value here is 0.707549 and thus, assuming no diagenetic contamination of the sample, in the Campanian. Naturally, this is only one sample and would need to be corroborated by further measurements. Nonetheless, (1) stratigraphically, this is the highest sample taken for Sr isotope stratigraphy, and therefore a younger age compared to all others at Gosauschmied is in accordance with this stratigraphic position on top of the anticline ridge, and (2) according to Trenkwalder (1999, p.133), the LGS occurrences at the SE edge of the Gosau basin, particularly the Hochmoos Formation, have a

much higher relative stratigraphic position (partially due to reduced thickness) than comparable occurrences at the basin center; and this appears to cause a relative descent of the Santonian-Campanian boundary along a NW-SE gradient compared to the uppermost Santonian lithostratigraphic boundary of the Hochmoos Formation in the basin center (e.g., Wagreich et al., 2010), potentially resulting in an earliest Campanian age for the youngest sediments in the Hochmoos Formation in localities such as Gosauschmied and others (Schmiedsippel, Katzhofgraben) at the SE basin rim. Comparisons between different occurrences of the Hochmoos Formation in the Gosau basin will be discussed in section 5.3 below.

The results from the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ measurements provide a lower degree of chronostratigraphic certainty, primarily due to the missing section continuity and the low resolution of samples taken from profiles A, B and C. With a mean sample resolution of 64cm for profile A and only 17 measurements covering 10.9m, the resulting curve on its own cannot be reliably correlated with any standard (e.g. Jarvis et al., 2006). With respect to profile B, the 36m range in the outcrop is more significant, but the sample resolution (avg. 500cm due to missing section continuity) is quite low for such an extensive profile. Nonetheless, the $\delta^{13}\text{C}$ curve resulting from the 18 samples for profile B implies a negative peak at the beginning followed by a double positive peak probably correlative to the Santonian/Campanian boundary event (SCBE) (Wolfgring and Wagreich, 2018; Jarvis et al., 2002, 2006). However, as of current writing, the position of the Santonian/Campanian boundary in relation to first and last appearances of planktonic markers and the carbon and strontium isotope stratigraphies is not confirmed, as a GSSP definition of the base of the Campanian has not yet been established (see lengthy discussion in Wolfgring and Wagreich, 2018).

When combining profiles A, B and C in a composite curve using a three-point rolling average of the data (Figure 96), a number of further correlations emerge from the $\delta^{13}\text{C}$ results. First, it should be noted that the position of profile C at the top of the column composed by profiles A, B and C is questionable: 1) the $^{87}\text{Sr}/^{86}\text{Sr}$ data discussed above positions the lower beds of profile C in the lower middle strata of profile B and 2) there is no obvious stratigraphic continuation from the top of the sampled area in profile B (and the area above) to the lower beds of profile C. Most likely, profile C is stratigraphically positioned somewhere between beds 3-8 in profile B. However, the position of profile B above profile A is more certain, as the outcrops immediately above profile A continue across the Gosausee highway and over to and beyond the brook, connecting with the base of the facies underlying profile B. What remains quantitatively unresolved is the magnitude of the gap between the two profiles (ca. 1-10m based upon relative elevation and structural data).

Using the composite $\delta^{13}\text{C}$ curve of profile A and B (Figure 96), a number of key excursion events can be identified and, with some caution, correlated to the reference curve in Jarvis et al. (2006). These events (Buckle, Hawk's Brow, Foreness and the SCBE) represent prominent positive and negative excursions documented in marine carbonates sampled from the upper Santonian to the

boundary with the Campanian (Jarvis et al., 2006; Wolfgring and Wägreich, 2018). This provides further support for an uppermost Santonian age for the Hochmoos Formation in Gosauschmied. Furthermore, when correlating this excursion data to absolute timespans as documented in Thibault et al. (2016), an approximate sedimentation rate can be calculated. The total sampled extent of profiles A + B results in a thickness of roughly 47m (depending upon the stratigraphic gap between A and B). Data from Thibault et al. (2016) indicate that the $\delta^{13}\text{C}$ excursion events recorded in the composite curve for profiles A and B span 800 to 1200 ka, with a mean of 1000 ka. This results in an estimated sedimentation rate of 47mm/ka, or 0.047mm/a, which is significantly more than pelagic sedimentation rates (19.9mm/ka) calculated at the Gosau locality of Postalm by Wägreich et al. (2012), but modest for shallow marine carbonate settings.

The plot of the $\delta^{18}\text{O}$ vs. the $\delta^{13}\text{C}$ values for both profile A and profile B shows no statistically significant correlation, hence there does not appear to be significant diagenetic impact on the results.

Summing up, in the absence of diagnostic biostratigraphic macrofossil data, a late Santonian age is confirmed for the greater part of the studied Hochmoos Formation rocks in Gosauschmied based on the following reasoning: (1) The benthic foraminifera *Nummofallotia cretacea* is present in several of the carbonates and rudist-bearing beds and was determined to be typical for the late Santonian of the Schattau area (Wägreich et al., 2010); (2) scarce calcareous nannofossil data at Gosauschmied indicate the late Santonian to earliest Campanian CC17b of Wägreich (1992) up to the base of the Bibereck Formation; (3) Strontium isotope stratigraphy shows a late Santonian age for 4 of the 5 samples, with only the uppermost sample showing a value in the Campanian age range, which accordingly may indicate that the Santonian/Campanian boundary is located within the upper part of the Gosauschmied carbonate succession; (4) carbon isotope values show a negative peak at the base of profile B, followed by a positive double peak, which may correlate to the SCBE and hence infer an even lower position of the Santonian/Campanian boundary within profile B. Thus, the lower part of the studied succession is of (late) late Santonian age; the base of the Campanian may be within profiles B or C or within the overlying Bibereck Formation. The position cannot be ascertained due to the lack of a reliable GSSP marker definition and GSSP description (Wolfgring and Wägreich, 2018).

5.2 Deposition Scenarios and Sequence Stratigraphy

5.2.1 General Considerations

As stated in the background section, the sediments of the Hochmoos Formation in the Gosau basin represent coastal and shallow-marine deposits and structures, including small reefs that primarily consisted of rudists, corals and combinations of these. According to Sanders and Pons (1999), varying depositional settings are, in general, responsible for the wide range of facies found in the LGS, particularly with respect to the development of rudist colonies similar to those found

in the Hochmoos Formation of Gosauschmied. Sanders and Pons (1999) distinguish between three types of siliciclastic-dominated cycles and three types of carbonate-dominated cycles. Specifically, the type B carbonate-dominated cycle in their work is ascribed to rudist formations found in the LGS of the Gosau basin, which are mainly stratigraphically positioned in the Hochmoos Formation. One of the most notable locations with rudist biostromes in Gosau is the Brunftloch at Wegscheidgraben near the Pass Gschütt (Kollmann and Summesberger, 1982; Höfling, 1985; Wagreich, 1988). This outcrop has a thickness of roughly 11 meters, contains two rudist biostromes and is stratigraphically positioned in the upper Hochmoos Formation (Wagreich 1988). However, in contrast to the lithology found in Gosauschmied, the outcrop at Brunftloch contains a much higher quantity of clastic carbonates with significant beds of calcarenite and conglomerates, indicating a depositional milieu with more clastic inflow. A further notable example of a rudist-dominated outcrop in the Gosau basin can be found in the so-called “Reef of Unterbrein” near Russbach, which is stratigraphically positioned in the lower Hochmoos Formation (Wille-Janoschek, 1966; Höfling, 1985) according to Wagreich (1988). In this case, a patch reef of *Hippurites sulcatus* composes the actual barrier reef between a lagoonal milieu and the higher-energy fore reef environment consisting of detrital bioclastic limestone.

Other, much older occurrences of rudist-dominated depositional environments have been studied in the Lattengebirge, Germany, (Höfling, 1985), Brandenberg, Austria (Tyrol) (Sanders, 1997), Haidach, Austria (Tyrol) (Sanders and Baron-Szabo, 1998), Weisswasser, Austria (Lower Austria) (Sanders and Pons, 1999) and Gams, Austria (Styria) (Sanders and Pons, 1999). A commonality to all of these rudist-dominated occurrences of the LGS is a depositional environment from shoreface to inner shelf, with frequently a reef complex (biogenic or bioclastic) creating a lagoonal environment in the tidal to subtidal depths (often with radiolitid colonies) and mixed hippuritid, coral and radiolitid colonies beyond this area and extending to the inner open shelf. Depths do not attain neritic levels, and depositional morphology is flat to medium and most commonly some grade of carbonate ramp or shelf. Hydrodynamic levels can vary greatly and have a substantial impact on the quantity and accumulation of bioclastic limestone and detrital rudist limestone and also on the preservation of rudist biostromes in actual growth position.

5.2.2 Stratigraphic Column of the Hochmoos Formation in Gosauschmied

Based upon the accumulated stratigraphic data and the overall facies distribution in the Hochmoos Formation at Gosauschmied together with the extent of each facies and the relevant structural data, the following consolidated stratigraphic column can be constructed (see Figure 97 next page).

Stratigraphic Column Gosauschmied Hochmoos Formation – Upper Santonian

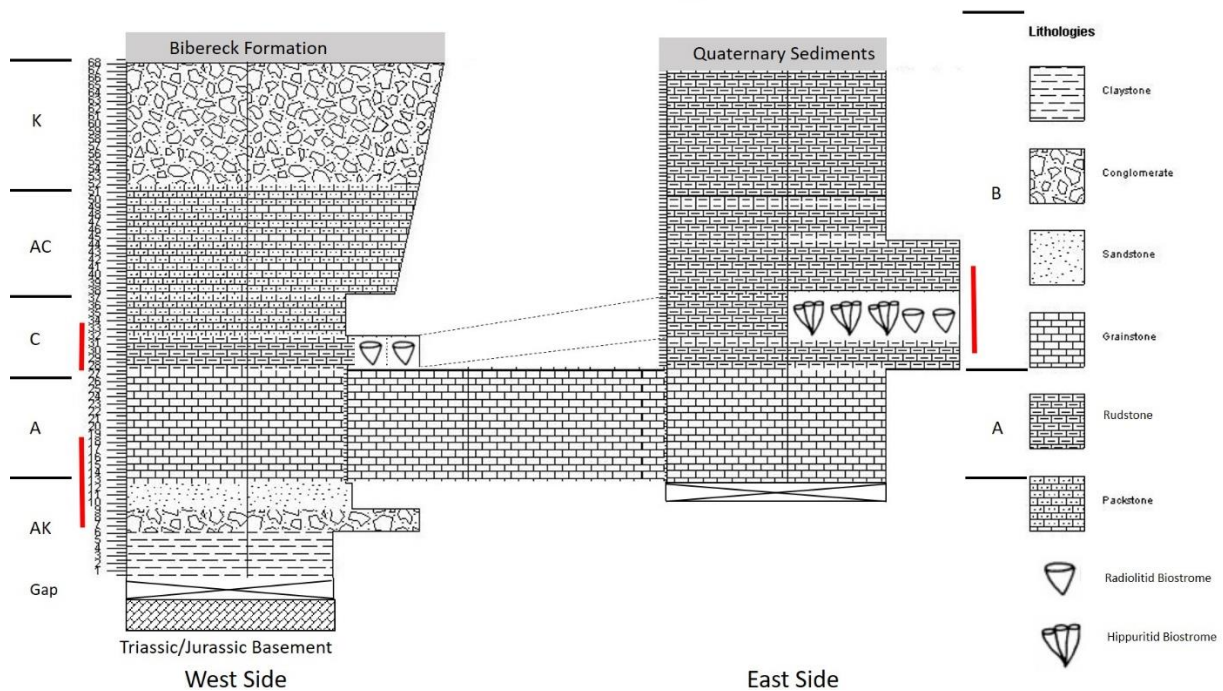


Fig. 97: Consolidated stratigraphic column for the Hochmoos Formation at Gosauschmied. The red lines represent the profiles studied in-depth (A and C on the west side, B on the east side).

This stratigraphic structure and the facies distribution allow for the development of deposition scenarios for the Hochmoos Formation in Gosauschmied, which follows in the next two sections (5.2.3 and 5.2.4).

5.2.3 Depositional Environment in Gosauschmied

Based upon the preceding analysis and discussion, the sedimentary evolution in Gosauschmied points towards a single 2nd order transgression/regression cycle on a medium-grade carbonate ramp or shelf setting exposed intermittently to high levels of hydrodynamic energy.

The relative sea-level variation is interpreted following the facies and microfacies evolution and the general interpretation of the environment. The succession starts (in the core of the anticline) with a siliciclastic marly to sandy succession, including clastic conglomerates and indications for brackish to marginal marine environments (Wagreich, 1988) at a relative sea-level lowstand. Above this, profile A provides evidence of a transgression up to profile B and profile C and a first relative highstand, at which point a parasequence in the area of the rudist biostromes is recorded, entailing a drop in relative sea-level to a range of several meters up to a maximum of 10m. This is then followed by a renewed transgression in which the marly carbonate facies of upper profile C indicates a relative sea-level highstand and a second MFS. Above this, the growing clastic influence up to conglomerates on top of the carbonate ridge points toward a regressive half cycle to a relative lowstand below the uniform transgression of the marly, deeper neritic Bibereck

Formation. This succession, together with relative sea level variation, can be seen in Figure 98 with the example of the west side of the Hochmoos Formation in Gosauschmied.

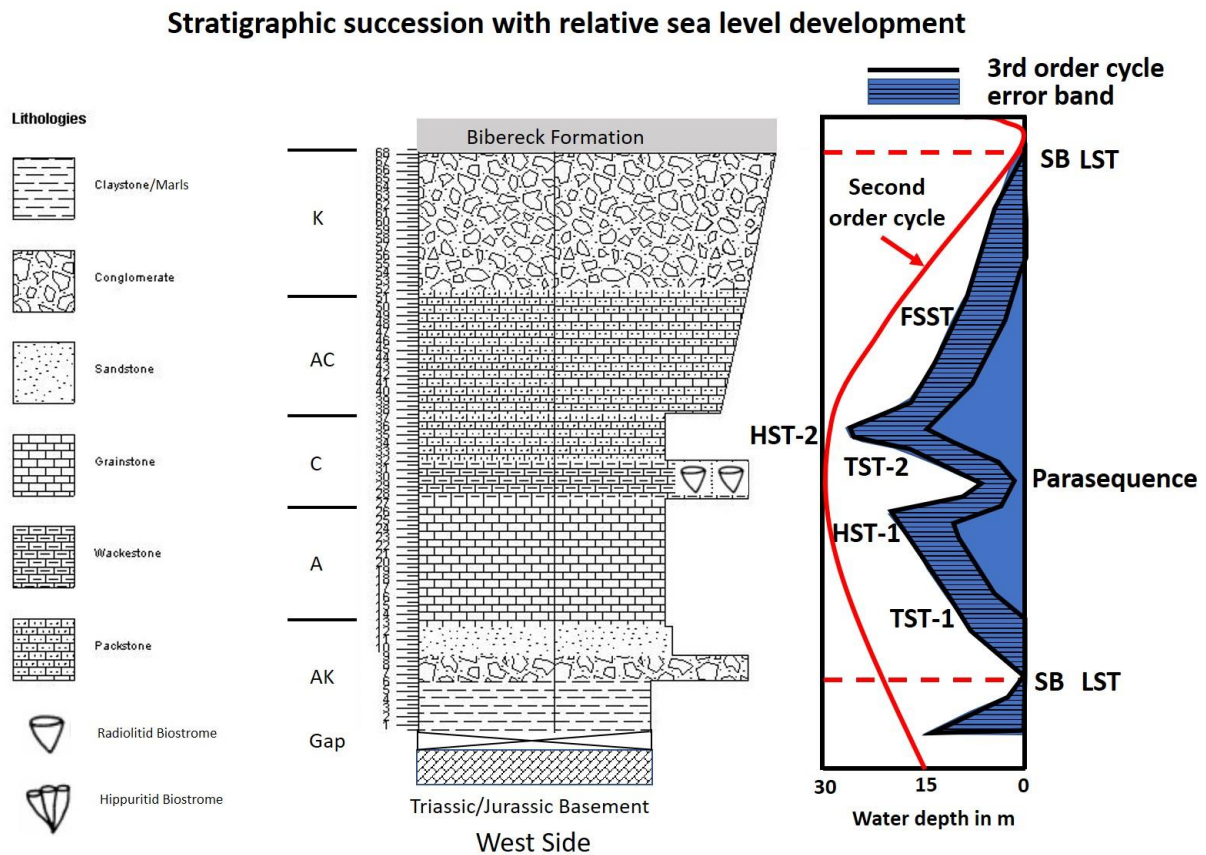


Fig. 98: Stratigraphic succession vs. relative sea level development in a single transgression-regression cycle (red curve, 2nd order) for the Hochmoos Formation at Gosauschmied. The black curve shows the 3rd order relative sea-level variation within the 2nd order cycle in the shelf area with an attendant error band to document potential sea-level range during the transgression-regression.

Further, the syndepositional tectonic activity of the Gosau basin (Wagreich and Decker, 2001) impacted significantly the succession and thickness of the sediments in this SE corner of the region, introducing also tectonically-enhanced subsidence and thus water-depth variations. This will be discussed in a subsequent section (5.3) comparing the Gosauschmied outcrops to other occurrences of the Hochmoos Formation in the Gosau basin.

Sanders and Pons (1999, p.253, Fig. 3) provide a model for an idealized carbonate platform in an LGS shore-to-shelf environment. For the transgressive-regressive processes in Gosauschmied, this model has been slightly adapted to account for the facies succession in this particular area. As discussed, the oldest stratigraphic beds in Gosauschmied show evidence of fluvial/terrestrial activity, hence the beginning of the transgression occurs in an environment with an interplay of fluvial and marine (estuarine) sedimentation developing from a relative sea-level lowstand. This can be depicted in the image below in Figure 99.

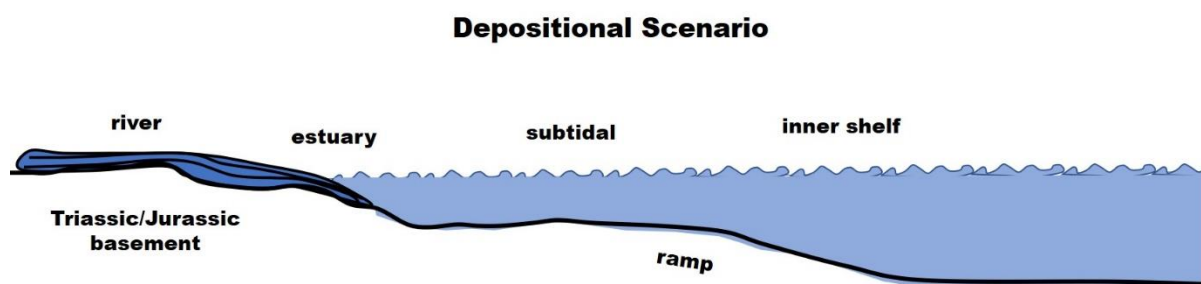


Fig. 99: Inception of the Transgressive Systems Tract (TST) in an estuarine environment with a medium-grade ramp from shore to inner shelf at a relative sea-level lowstand.

5.2.4 Sequence Stratigraphy

The environment depicted above serves as the basis for the sequence stratigraphic processes that occurred during the presumed single 2nd order transgressive-regressive cycle in the Gosauschmied area. As discussed in the section on facies distribution in the study area, the stratigraphic succession can be reconstructed using Facies AK, Facies A, Facies B and C, Facies AC and finally Facies K.

Facies AK

Stratigraphically, the Facies AK sediments in the anticline represent the oldest in the Hochmoos Formation at Gosauschmied. The marl deposits at the center of the anticline contain high carbonate content, mollusc debris, a significant quantity of calcareous tests and scarce marine microfossils (foraminifera and ostracods). It is thus very probable that these marl sediments were deposited in a brackish estuarine milieu and represented the fluvially-dominated, coarse-grained lowstand deposits and an incipient transgression onto the Triassic-Jurassic basement of the NCA (see Figure 100 below).

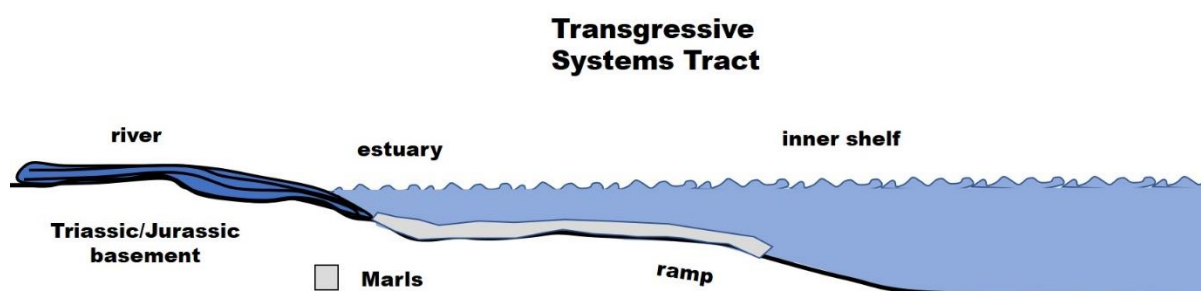


Fig. 100: Transgressive Systems Tract (TST): bioclastic carbonate marls are laid down in an estuarine environment with significant fluvial inflow.

When considering the clastic carbonates that follow these marl sediments, there is an upward shoaling combined with an intermediate drop in relative sea-level: the carbonate lithoclasts of Dachstein limestone in the initial beds of profile A indicate that they arose from reworking of the substrate in a fluvial/marine environment similar to a fan delta. These particles contain Triassic

marine fossils such as involutinida and textularida; otherwise, in the oldest beds of profile A, there are only very limited fragments of Upper Cretaceous fossils. The high level of siliciclastic content further shows significant inflow of terrigenous material (detrital silica, reworked chert).

The clastic carbonates from beds 1-7 in profile A provide a record of the transgression as it proceeded through the initial stages of a fan delta toward, ultimately, a first maximum flooding surface (MFS) in the upper beds of the profile. Terrigenous clasts (sand, dolostones, pelsparite, carbonate lithoclasts) are intermixed with fragments of marine fossils and isolated foraminifera (miliolids, textularida). The dolomitization beginning in bed 3 and complete in bed 4 most likely represents the result of evaporative processes in a marginal coastal and possibly intertidal area with intermittent flooding and receding waters at a relative lowstand. As the sea level rises again, calcarenite beds follow the carbonate conglomerates and contain chert, mono-crystalline quartz and carbonate sands, ultimately leading to a thin marl layer and the cessation of siliciclastic flow into the marine environment. Figure 101 below depicts this transgressive scenario.

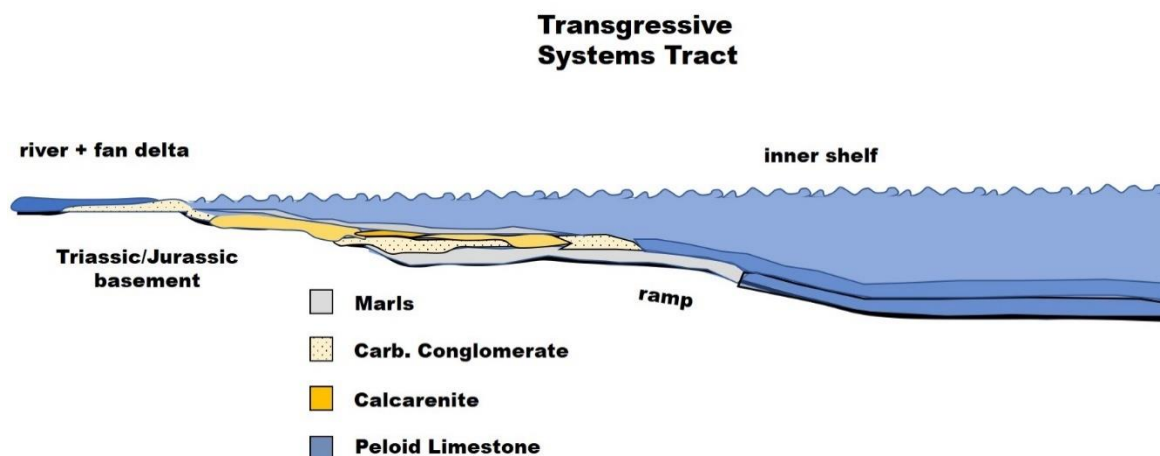


Fig. 101: Transgressive Systems Tract (TST): clastic carbonates (calcarenite, carbonate conglomerates) accumulate in the proximal environment, while distal carbonates are laid down in the inner shelf environment.

Facies A

The upper beds in profile A (9-24) represent a gradual transition to a fully marine environment with increasing peloid content and decreasing marl content. This facies constitutes an extensive and foundational stratigraphic section in the Hochmoos Formation at Gosauschmied and is the result of distal carbonate beds being laid down in a coastal environment onto a ramp-like morphology, ultimately leading to lagoonal and open shelf environments with reef structures in between.

Facies A, with subtle variations, rises beyond profile A and into the forest up the ridge, makes up most of the exposed outcrops between the highway and the brook (together with the clastic carbonates in the anticline) and is to be found from top to bottom on both sides of the brook near

the outlet of the dam. This is also the facies most prevalent on the surface throughout the study area and represents the hardest, most competent lithology (packstone to grainstone): a wide range of outcrops consist of this basic and undifferentiated peloid limestone facies. In the stratigraphic column, facies A has an overall thickness ranging from 12 to 20m, with an average of 15-16m depending upon extent of exposure. It underlies both profiles B and C and is hence older than both.

In profile A, the fossil content in the first limestone beds appears to be of allochthonous origin, while the matrix itself gives evidence of bioturbation and firm-ground burrows. As of bed 14, there is barely any fossil content, and the matrix is unperturbed peloid limestone. Figure 102 below shows the carbonate sedimentation occurring during this Transgressive Systems Tract (TST).

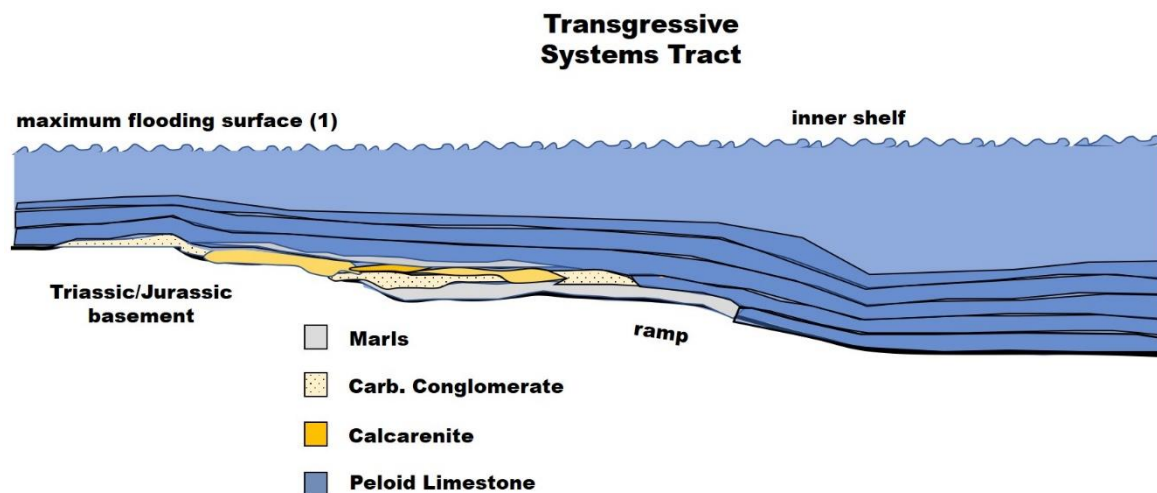


Fig. 102: Transgressive Systems Tract (TST): peloid limestone beds are laid down in a fully marine environment in progradational stacking patterns. Fossil content is low to non-existent in uniform packstone to grainstone lithologies. A first relative MFS is reached.

Facies B and C

The facies in profile B represents a transition to a marine milieu with significant biogenic and bioclastic content. During this phase of the transgressive/regressive cycle, there is progradation of carbonate sediments and upward shoaling combined with a drop in sea-level to produce a relative lowstand after the first MFS. During this phase, rudist and coral-rudist colonies develop in self-protected to partially-protected environments, most likely in an inner shelf environment (Diethard Sanders, personal correspondence 25.09.2019). The vast majority of sediments comprising facies B are bioclastic limestone (detrital rudist limestone) that, with few notable exceptions, result from high energy events regularly destroying the established rudist and rudist-coral bio-assemblages and transporting the detritus in a parautochthonous manner into extensive skeletal mounds and beds. The existence of very prominent outcrops with only minimal macrofossil content, minimal bedding and an extremely dense and competent limestone lithology to the west and north of profile B appear to represent bioclastic sand bodies at the edge of a lagoonal environment (Diethard Sanders, personal correspondence 25.09.2019). The

occurrence of sporadic rudist biostromes in beds 3 and 4 indicate that, at times, the environment was less exposed to storm events and allowed for a minimal preservation of some individual rudist colonies in growth position.

Facies B, as mentioned, has strong similarities to the first two beds of profile C: the fossil content is dominated by rudist and coral fragments that are heavily micritized; sparite fillings are common; and a brownish bioclastic marl sediment is frequently found in the chambers of the fossil fragments. One clear difference is that there are generally more benthic foraminifera in profile C. Plus, *Durania* sp. (?*austensis*) are found in profile C; and generally, radiolitid fragments are more numerous on this side of the study area. Due to these similarities, a clear connection between facies B and this portion of profile C is observed. In fact, these lower beds of profile C appear to be an extension of the depositional activity observed in profile B and most probably represent radiolitid colonies together with singular corals and benthic foraminifera in a partially-protected proximal lagoon environment shielded by the bioclastic sand bodies discussed above. The higher marl content in these lower beds of profile C would also indicate a less turbulent environment than in profile B. In addition, radiolitid biostromes are more often observed in lagoonal environments, while hippuritid biostromes (often together with radiolitids) and corals are more commonly found in an open inner shelf milieu (Diethard Sanders, personal correspondence, 16.01.2020). Figure 103 below depicts this relative lowstand in the HST of the 2nd order transgressive-regressive cycle.

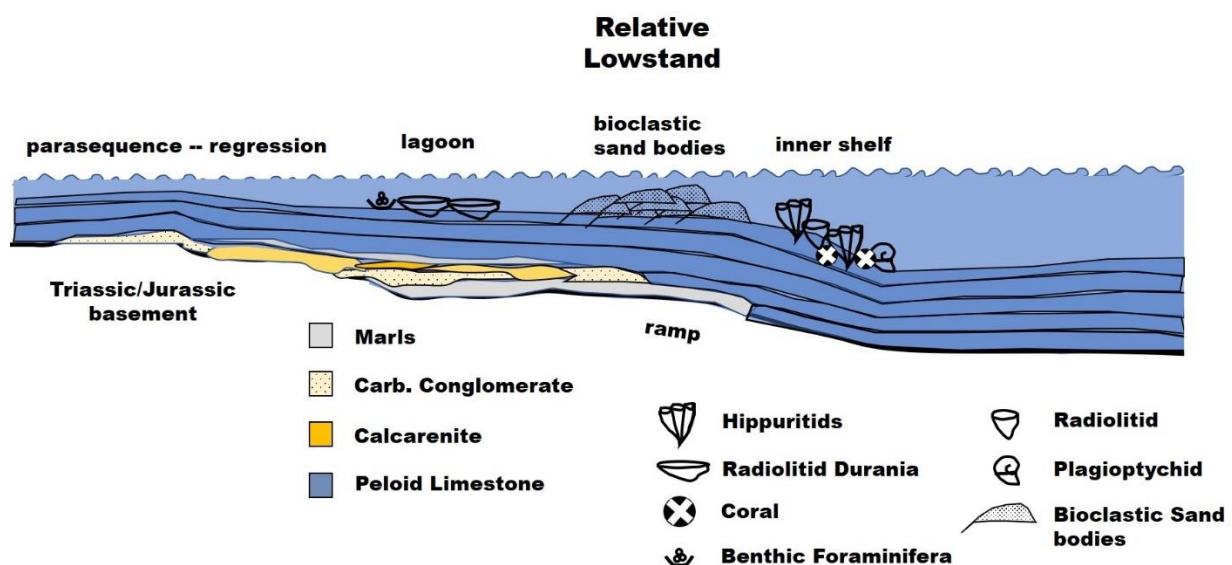


Fig. 103: Relative lowstand: periodically calmer conditions allow for establishment of rudist colonies on both sides of the lagoonal barrier. Facies B sediments are on the open inner shelf, while Facies C sediments (beds 1 & 2) are in the lagoon.

The lithology on both sides of the barrier in between indicates, however, that this environment was subjected to repeated high-energy events, producing the dominant detrital rudist limestone of these two outcrops. Beyond bed 4 in profile B and bed 1 in profile C, there are no further biostromes and only rarely entire rudist fossils preserved in the outcrops.

Pursuant to this relative lowstand, there is a renewed transgression leading to the upper sections of facies C with marly limestones and low fossil content, while also producing significant beds of bioclastic limestone in facies B, as hydrodynamic energy levels increase. This second transgression and HST is depicted in Figure 104.

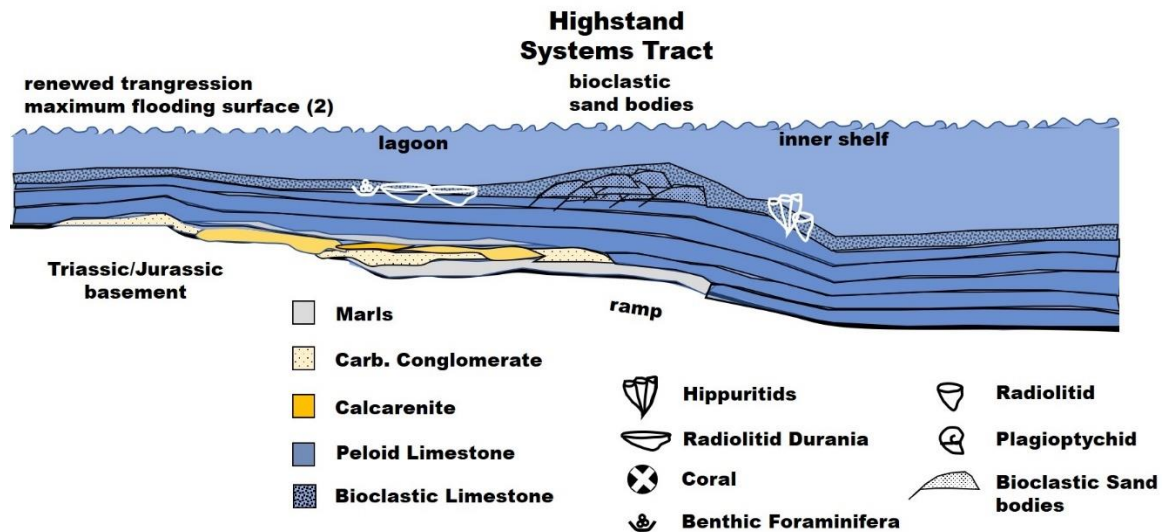


Fig. 104: Highstand Systems Tract: renewed regression. In facies C, marl content persists, while fossil content decreases. In facies B on the inner shelf, by contrast, significant beds of bioclastic limestone are deposited.

Facies AC

Figure 105 below depicts the development of Facies AC as part of the incipient Falling Stage Systems Tract (FSST) in the transgressive/regressive cycle. There is an increased inflow of terrestrial material in the proximal area from reworking of the shoreface as the waters recede, initially with only modest terrigenous clasts, while detrital rudist limestone continues to be deposited on the inner shelf.

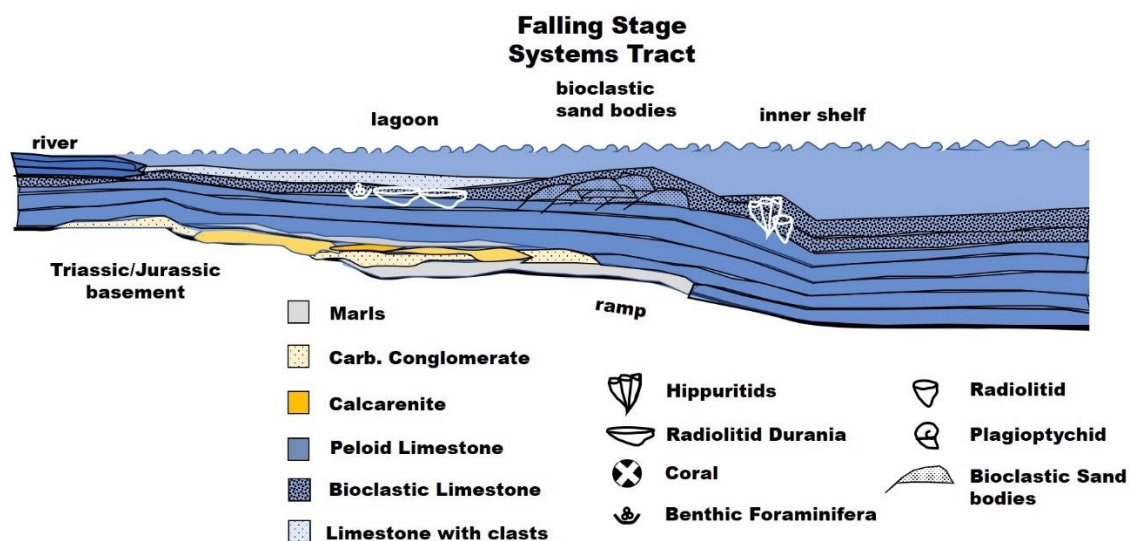


Fig. 105: Falling Stage Systems Tract (FSST): higher energy events lead to the accumulation of bioclastic sediments in the inner shelf (distal), while the proximal reworking of the shoreface leads to an inflow of terrigenous clasts in the lagoonal environment.

Facies K

The final stage in the deposition of the Hochmoos Formation in Gosauschmied is the return of carbonate conglomerates in a fan delta environment as the FSST progresses toward the final Lowstand Systems Tract (LST) of the 2nd order cycle. In the proximal domain, this results in ever larger terrigenous clasts in a marly-muddy carbonate matrix, while in the deeper distal realms, bioclastic, detrital limestone continues to accumulate. In Figure 106 below, this final depositional stage is depicted, with red bars indicating the approximate positions of the three profiles surveyed in this study. A possible synsedimentary or post-depositional fault structure is also included separating the west from the east side of the study area. This will be discussed in more detail in the subsequent section.

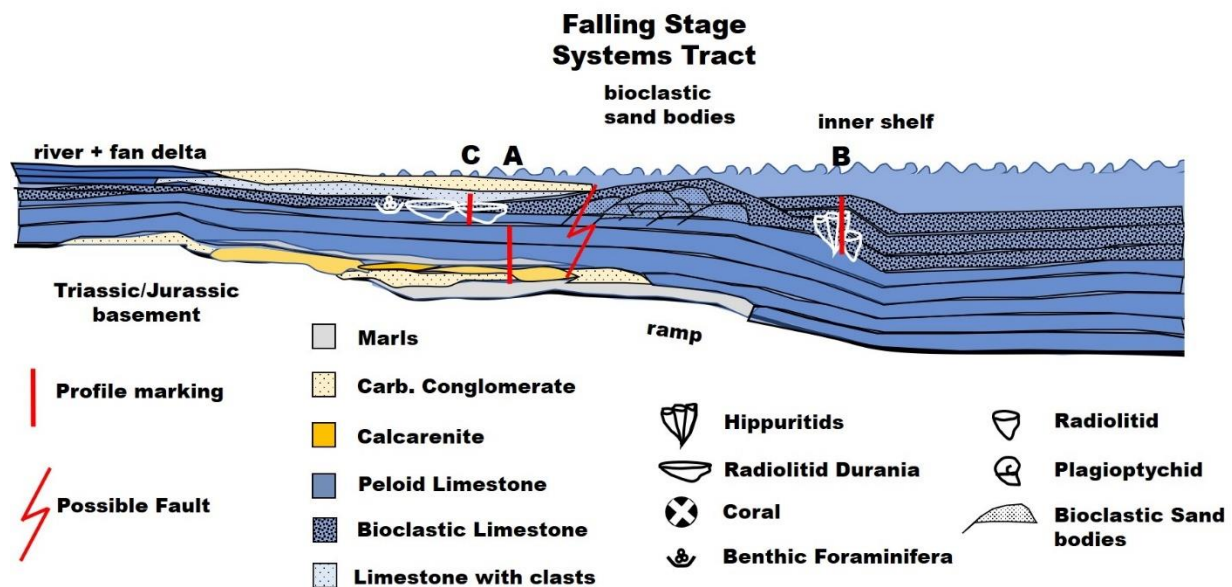


Fig. 106: Falling Stage Systems Tract (FSST): a return to high terrestrial/fluvial input in a fan delta environment in the proximal realm, while deeper areas continue to accumulate bioclastic detrital limestone. The positions of profiles A, B and C are marked in red. A synsedimentary or post-depositional fault structure is added as a possible division between the west and east sides of the study area.

At the termination of this cycle, sediments of the Hochmoos Formation are concluded: on the east side of the study area, the bioclastic limestone at 840m is covered by Quaternary sediments, which abut onto the face of the Dachstein limestone cliff to the SE at the major overthrust fault discussed in section 4.2 above. On the west side of the study area, the neritic marls of the Bibereck Formation to the W and N overlie the Hochmoos Formation. It is presumed that the Bibereck sediments were lain down upon the entire Hochmoos Formation in the area, but that erosive activity sheared away the less competent marl lithology from the underlying carbonates. This will be explored in the next section.

5.2.5 Structural Evolution of the Study Area

In Gosauschmied, the Bibereck Formation is relegated to a relatively flat, low-lying area bordering the valley floor (see Figure 82) and is not found at the higher elevations that make up the Hochmoos Formation. Further, the carbonate conglomerates, which are also much less competent than the peloid limestones, can only be found at the very top of the ridge and not on the steep flanks. The formation of the anticline and ridge that represent a tectonic fold on the west side of the study area certainly postdates the sedimentation process and probably occurred in the Eocene to Miocene timespan (Wagreich, personal correspondence, 27.01.2020). Assuming that the sedimentation in this area was relatively uniform during the late Santonian/early Campanian, the following scenario (Figures 107a-c below) can be postulated to explain why the Bibereck and Hochmoos Formations are not found together in a single outcrop and why the carbonate conglomerates are only found on the top of the ridge and nowhere on the flanks. This, ultimately, has to do with the susceptibility to erosion of the Bibereck marls and the carbonate conglomerates in the hanging wall of the Hochmoos Formation.

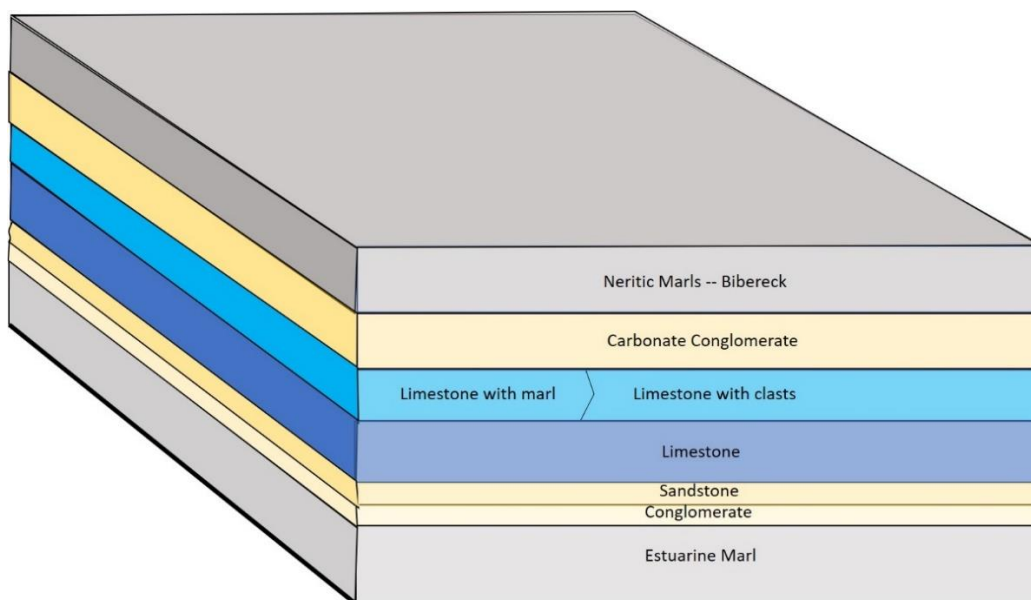


Fig. 107a: Schematic sediment stack of lithologies on the west side of the study area immediately post-deposition, including the Hochmoos Formation and the Bibereck Formation at the very top.

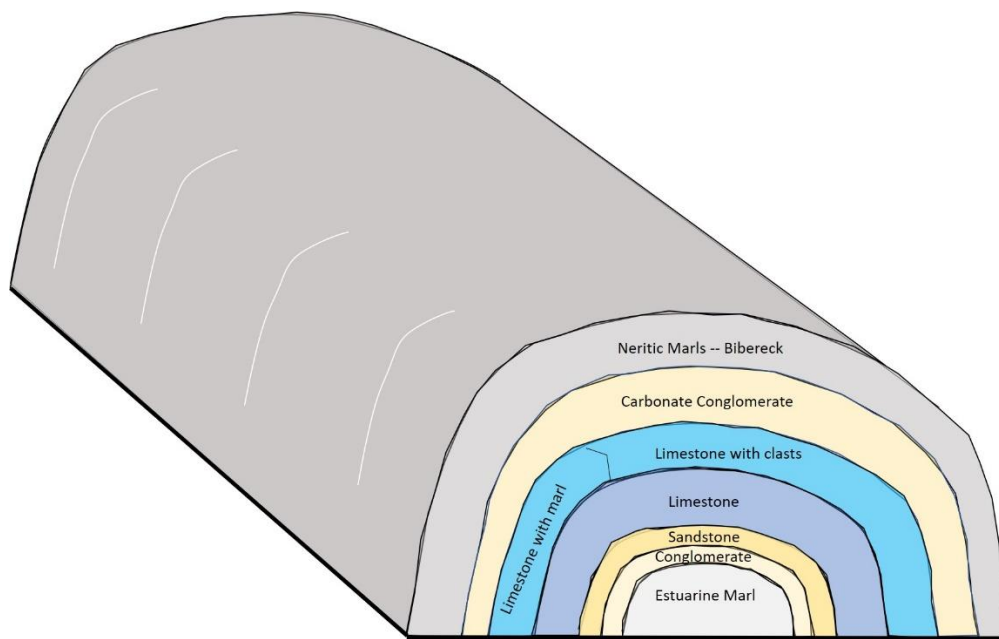


Fig. 107b: Paleogene to Neogene tectonic activity folded the sediments into an anticline in the image above.

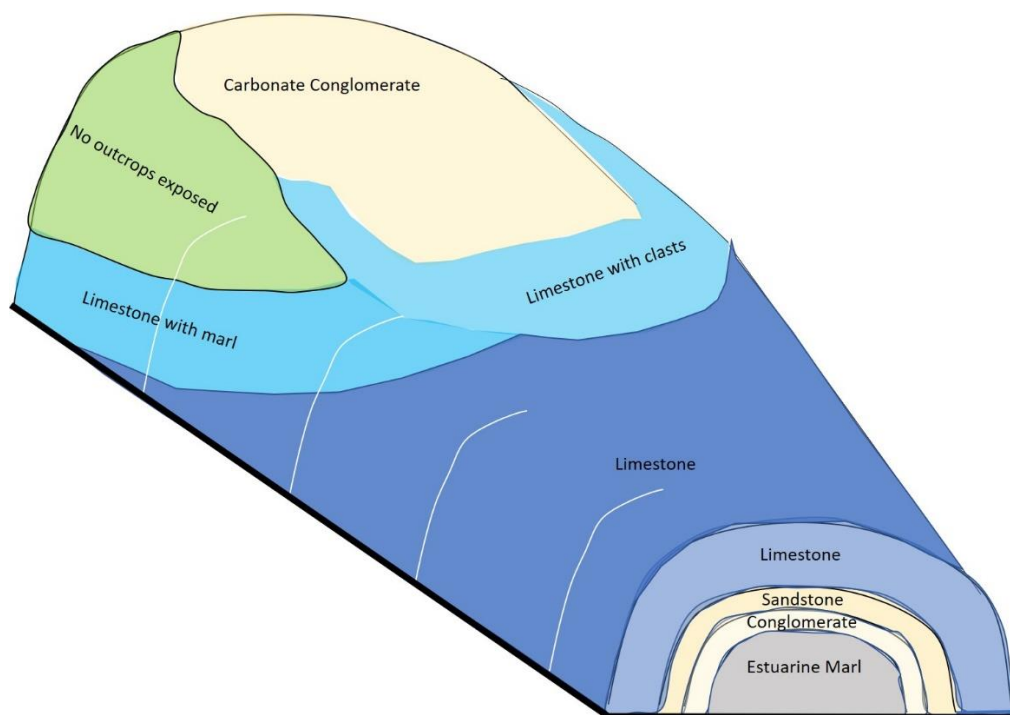


Fig. 107c: The least competent lithologies were eroded away by subaerial erosive activity, including rain, wind and glacial forces. The Bibereck marls are absent, while the carbonate conglomerates with their marly, muddy matrix can only be found on the flat top of the ridge and nowhere on the flanks.

This could also explain why no Bibereck marls are found on the east side of the study area on the elevated and W-NW inclining rudist limestone outcrops of profile B and surroundings.

5.2.6 Summary: Depositional Scenarios

During the process of accumulating the data for this study, the question concerning possible links between the east and west sides of the study area became central to the topic of deposition and stratigraphy. Was this a single area with a single depositional history or two separate areas proximate today, but with separate depositional histories? As a combination of both scenarios, the study area could have a single depositional history, but a synsedimentary fault or post-sedimentary thrust between the two sides making any direct link difficult to establish

There are a number of key arguments that speak for a single depositional history and support the stratigraphic column presented above in Figure 97 (without any synsedimentary fault or post-sedimentary thrust in the center):

- 1) The $^{87}\text{Sr}/^{86}\text{Sr}$ data shows a strong chronostratigraphic link between profiles C and B.
- 2) Thin section analysis indicates that, with the exception of the increased marl content, the first two beds of profile C share many characteristics with the rudist limestone of profile B.
- 3) Both profile B and profile C contain in situ rudist biostromes with similar macrofossil assemblages (radiolitids and hippuritids).
- 4) Further, the profile B and C outcrops rest stratigraphically on similar peloid limestones of facies A, which are clearly temporally antecedent to both.
- 5) Finally, the anticline shows unambiguously that the west side of the study area has a general eastward dip toward the valley basin and the brook. In turn, the outcrops on the east side of the study area tilt W-NW toward the valley floor and the brook. This makes the possibility of a syncline between the two sides very likely, with the beds of B and C conjoined beneath the inaccessible area under the reservoir.

Naturally, there are also arguments to support two separate depositional histories divided by a fault:

- 1) With the exception of the first two beds in profile C, the lithology of profile B and the east side of the study area is completely different from the lithology of the outcrops on the west side. Though peloid limestone underlies both sides, there is no obvious connection between these bases except at the Gosau brook and the power station.
- 2) If there is no syncline between the two sides, then there is no explaining the structurally opposite orientations of the outcrops (W-NW on the east side vs. S-SE and N-NE on the west side).
- 3) The vast extent of the rudist limestone on the east side (profile B and surroundings) does not appear to fit stratigraphically into the succession of lithologies on the west side, which are more cohesive and dominated by peloid limestone (with or without terrigenous clasts).
- 4) There is no instance of the Bibereck Formation on the east side of the study area (other than much further south and at higher altitudes above the Untersberg Formation).

- 5) Finally, the outcrops on the east side have a greater affinity with the Untersberg Formation to the SE (fine to medium-grained breccias with detrital rudist limestone) than with the neighboring outcrops directly to the west.

There is also the possibility that the two sides had a single depositional history, but have since been separated by a post-depositional fault structure along the Gosau brook and are hence not immediately correlatable in their present proximity.

Absolute certainty in resolving these questions is currently impossible due to the presence of the reservoir and the dam covering the connecting terrain. The absence, however, of a clearly proven fault structure separating the two sides provides greater support for a single depositional history with their differences stemming from proximal vs. distal depositional milieus during the transgression-regression cycle illustrated above. Figure 108 below depicts the facies distribution at Gosauschmied with the addition of the possible syncline running from either side to the base of the valley, and the flow of the Gosau brook added to highlight the original state of the study area prior to the erection of the dam and the ensuing reservoir.

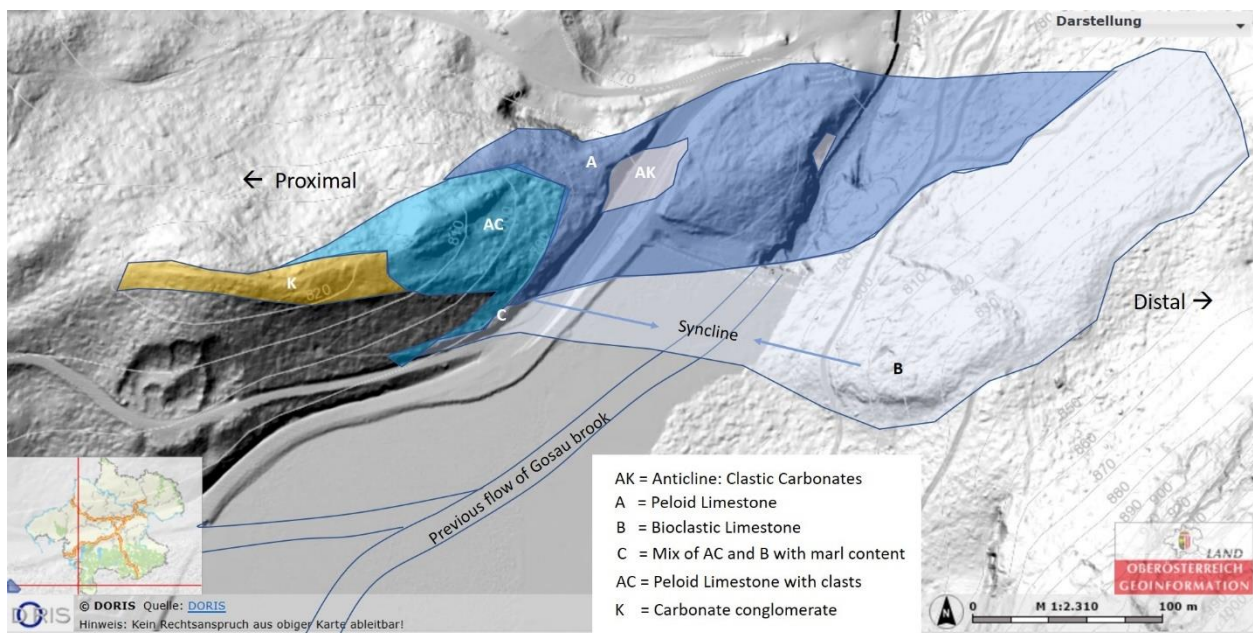


Fig. 108: map of the study area with the distribution of the 6 different facies types resulting from the transgression/regression cycle. The presumed syncline running from either side of the study area to the valley floor is included. From Digitales Oberösterreichisches Raum-Informations-System [DORIS], accessed on 24 January 2020.

Although the working hypothesis is that the two sides of the study area (east and west) have a single depositional history, further comparisons will treat the two sides separately to illuminate their different characters and stratigraphic composition.

5.3 Comparison with Other Occurrences of the Hochmoos Formation

The Gosau Basin is known for its synsedimentary tectonic activity leading to varying thicknesses of sediments from the center of the basin to the edges (Wagreich and Decker, 2001). In light of this, six occurrences of the Hochmoos Formation were selected to compare the overall thicknesses of the outcrops in relation to their position in the basin center or at the edges. Figure 109 below shows the locations of these six separate profiles of the Hochmoos Formation in the Gosau Basin area. These are positioned upon a WNW-ESE transect. Although presumed to have a single depositional history, Gosauschmied West and Gosauschmied East are shown separately.

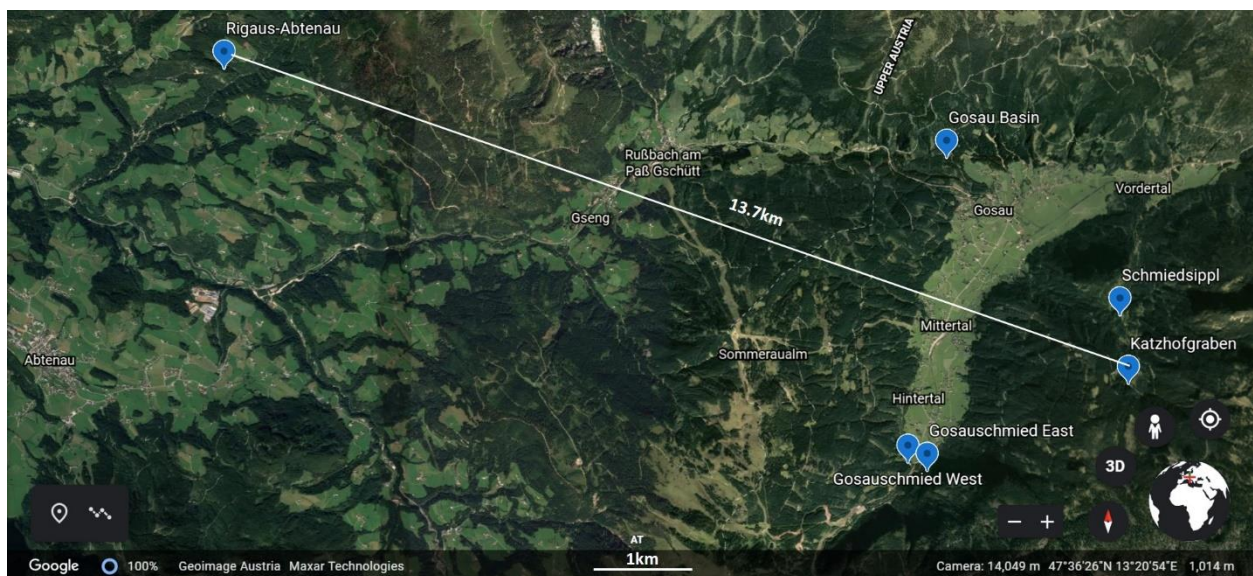


Fig. 109: A selection of occurrences of the Hochmoos Formation in the Gosau Basin. Source: Google Earth, accessed on 10 February 2020.

Figure 110 (next page) shows the sedimentary columns of the six profiles of the Hochmoos Formation, indicating total thickness and basic lithology, including key biostromes if present. The data for this comparison was collected from the following prior studies: **Rigaus-Abtenau**, Jarnik, 1994; **Gosau Basin**, Wagreich, 1988; Wagreich and Decker, 2001; **Schmiedsippel**, Wagreich and Neuhuber, 2005; **Katzhofgraben**, Trenkwalder, 1999. The data for **Gosauschmied West** and **Gosauschmied East** were collected in the course of this study. The distance from the far WNW edge at Rigaus-Abtenau to the far ESE edge at Katzhofgraben is approximately 13.7km, a minimum extent for the Upper Cretaceous Gosau basin of the LGS (Wagreich and Decker, 2001).

Lithostratigraphic Sections of the Hochmoos Formation in the Gosau Basin

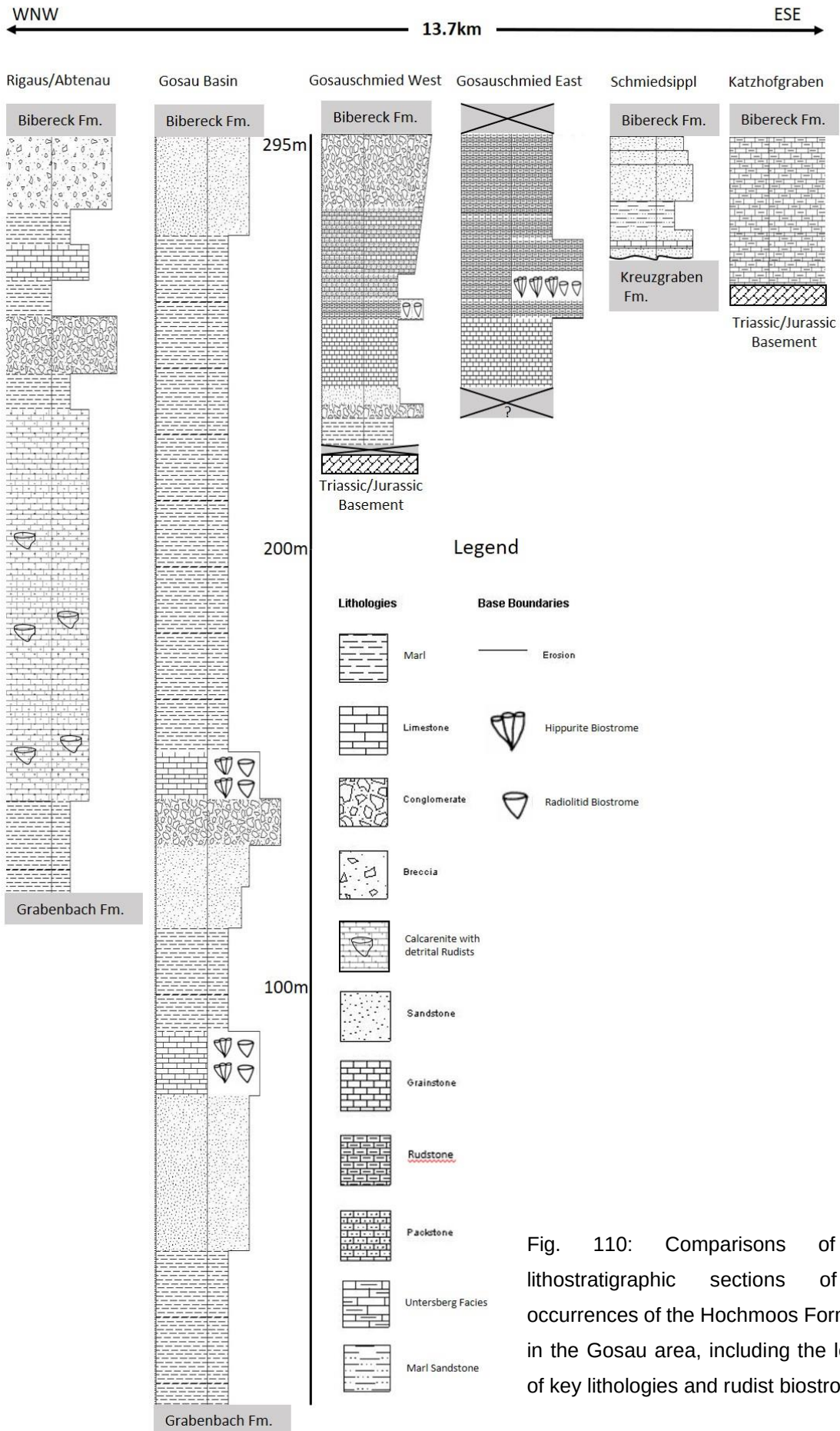


Fig. 110: Comparisons of the lithostratigraphic sections of six occurrences of the Hochmoos Formation in the Gosau area, including the legend of key lithologies and rudist biostromes.

As is evident from the thicknesses of the six different columns, there is quite some variation in the extent of each occurrence of the Hochmoos Formation in the Gosau basin, and this cannot be exclusively explained by water depth over such a limited distance. Wagreich and Decker (2001) show the effects of syntectonic activity in the Gosau area, delineating the effects of normal faults acting to create a pull-apart basin and effecting much higher sedimentation at the basin center and much more modest sedimentation at the basin edges. Figure 111 below (adapted from Wagreich and Decker, 2001) provides a schematic representation of the synsedimentary tectonic forces acting on the basin and the approximate positions of the outcrops included in this comparison. The image on the left depicts the position and degree of the normal faults, showing that the accommodation space for sedimentation increases dramatically toward the basin center and decreases toward the basin edges, particularly in the ESE corner of the basin, which includes Katzhofgraben, Schmiedsippl and Gosauschmied (West and East). This is, naturally, reflected in the more modest sedimentation thickness of these outcrops compared to the major occurrence of the Hochmoos Formation at the basin center (295m). The occurrence at Rigaus-Abtenau attains a thickness intermediate between those at the E-SE edge and Gosau Basin at the center.

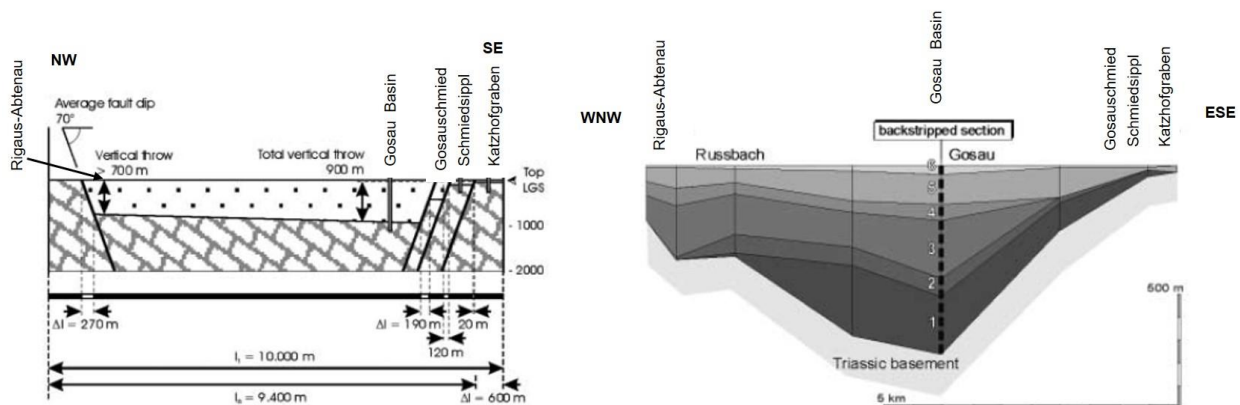


Fig. 111: (left) Schematic representation of synsedimentary normal fault activity and the approximate positions of the Hochmoos Formation outcrops compared in Fig. 109. (right) Result of backstripping through the use of six discrete lithological units indicated by numbers. This shows the extent of tectonic subsidence from the WNW edge to the ESE edge of the Gosau Basin including approximate positions of the outcrops in Fig. 109 (adapted from Wagreich and Decker, 2001)

It is also important to note that these occurrences of the Hochmoos Formation are not only quite different in extent, but also were laid down in different stratigraphic milieus. Only Rigaus-Abtenau and the Gosau Basin are underlain by the Grabenbach Formation, while both Gosauschmied West and Katzhofgraben are presumed to be onlapping directly onto the Triassic-Jurassic basement (as carbonate lithoclasts of Dachstein limestone and other terrigenous clasts attest). The base of Gosauschmied East is less certain (as it lacks the Triassic/Jurassic terrigenous clasts), but is most likely also transgressing onto the Triassic-Jurassic basement. The Hochmoos Formation at Schmiedsippl, by contrast, was deposited (with an erosive surface) directly onto the

Kreuzgraben Formation: it is presumed that either no sedimentation of the Grabenbach and Streiteck Formations occurred or deposits from these two formations were subsequently fully eroded before the Hochmoos Formation sediments were deposited.

The Hochmoos Formation at Gosauschmied is further presumed to be an occurrence of the upper Hochmoos Formation (as delineated by Wagreich, 1988). The modest thickness, position at the SE edge of the basin and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios all point to a temporal position in the uppermost Santonian directly at the boundary with the Campanian and potentially even crossing over into the Campanian in the youngest sediments (top of Gosauschmied West and East).

Marls of the Bibereck formation overlie each of the six occurrences except Gosauschmied East, which is covered by Quaternary sediments at its highest (youngest) extent and most likely abuts onto the overthrust fault with the Dachstein limestone beneath the Quaternary cover.

A final, crucial question regarding the transgression-regression cycle in the Hochmoos Formation in Gosauschmied relates to its cause and the interplay between eustatic sea-level rise and tectonic subsidence. As discussed above, synsedimentary tectonic activity in the Gosau basin is responsible for dramatically varying thicknesses of the LGS occurrences, in general, and of the Hochmoos Formation, in particular, hence tectonic subsidence clearly had a major impact on the magnitude of the accommodation space and the resulting sedimentary thickness. The succession of sediments in Gosauschmied, however, also points toward a general eustatic sea-level cycle (2nd and 3rd orders) occurring in tandem with the tectonic subsidence: the sequence of fluvial-marine clastic carbonates (AK) followed by fully marine peloid limestones (A) and bioclastic limestones (B and lower C), ultimately leading to limestones with terrigenous clasts (upper C and AC) and carbonate conglomerates (K) in the final stage, provides clear evidence of a relative eustatic sea-level rise and fall. Hence, the one process (eustatic sea-level rise and fall) overlies the more general and long-term process of tectonic subsidence occurring simultaneously, resulting in a tectonically-enhanced eustatic transgression-regression cycle. Considering that the eustatic sea-level cycle probably had a magnitude of approximately 30-40m during the transgression-regression process in the shallow costal shelf environment of the late Santonian, the attendant tectonic subsidence must have been in the range of 40-50m to produce the overall thickness of 68m in the Hochmoos Formation at Gosauschmied (accounting also for compaction and subsequent subaerial erosion of the sediments). The neritic marls of the Bibereck Formation which follow the Hochmoos Formation are, by contrast, almost exclusively the result of tectonic subsidence, as the Gosau basin rapidly descended through neritic to bathyal and abyssal depths in the Campanian.

6 Conclusion

Investigations into the Hochmoos Formation at Gosauschmied have identified six distinct facies types as the result of an upper Santonian transgression-regression cycle that possibly also extended into the lowest Campanian (based upon $^{87}\text{Sr}/^{86}\text{Sr}$ values in representative sections from the west and east sides of the study area). The sediments cycle from marls, calcarenite and carbonate conglomerates in estuarine and fan-delta milieus through peloid and bioclastic limestones in fully marine environments to, finally, limestones with terrigenous clasts and carbonate conglomerates as the prior fan-delta milieu resumes in regressing sea waters. The preponderance of bioclastic (detrital rudist) limestone on the east side of the study area and the sparse preservation of in situ rudist biostromes indicate that the depositional milieu was repeatedly subjected to high-energy events (storms, tsunamis, vigorous wave action) that regularly destroyed the extant bioherms and transported them in a parautochthonous fashion as detritus into skeletal mounds along the inner shelf. Only rarely was the environment sufficiently calm for the preservation of rudists in growth position, as evidenced in singular sections of profile B and profile C.

Although the outcrops on the two sides of the study area (west and east) proved at times difficult to correlate, the likely existence of a syncline in the valley floor, under the reservoir and along the bed of the Gosau brook makes a single depositional history for both sides the most probable scenario. The existence of the syncline is supported by structural data (compass measurements) and, above all, by the eastward dipping gradient of the anticline. Further, the microfacies similarities between profile B and the first beds of profile C establish a clear connection between the two sides. Until conclusive proof of a fault between the two halves of the study area can be demonstrated, the prevailing model will be a unified depositional history for Gosauschmied West and Gosauschmied East, with differences issuing from their respective positions vs. the shoreface during the transgressive-regressive cycle (proximal vs. distal).

The maximum overall thickness of the Hochmoos Formation in Gosauschmied at 68m renders it similar to other occurrences of the Hochmoos Formation at the ESE edge of the Gosau basin (Schmiedsippel, Katzhofgraben) and considerably less than the nearly 300m near the basin center and the 170m at Rigaus-Abtenau at the WNW basin rim. This confirms prior work (Wagreich and Decker, 2001) that shows how synsedimentary normal faulting and tectonic subsidence along a WNW-ESE transect have produced a vertical throw of nearly 900m at the center, but merely 20-30m at the ESE basin rim. This explains the significant variation in thickness across an otherwise short distance that cannot be attributed solely to differences in water depth. Therefore, synsedimentary tectonics strongly controlled facies distribution and facies successions also at Gosauschmied; however, the recorded relative sea-level cycle in the upper part of the Hochmoos

Formation is present in most of the recorded sections and thus most probably relates to a tectonically-enhanced eustatic sea-level cycle.

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7.2 Internet

Digitales Oberösterreichisches Raum-Informations-System [DORIS],

<https://doris.ooe.gv.at/default.aspx>

Google Earth web: <https://earth.google.com/web/>

GPS Visualizer: <https://www.gpsvisualizer.com/elevation>

Wikipedia: <https://de.wikipedia.org/wiki/Wikipedia:Hauptseite>

7.3 Software

Google Earth Pro, © Google 2019

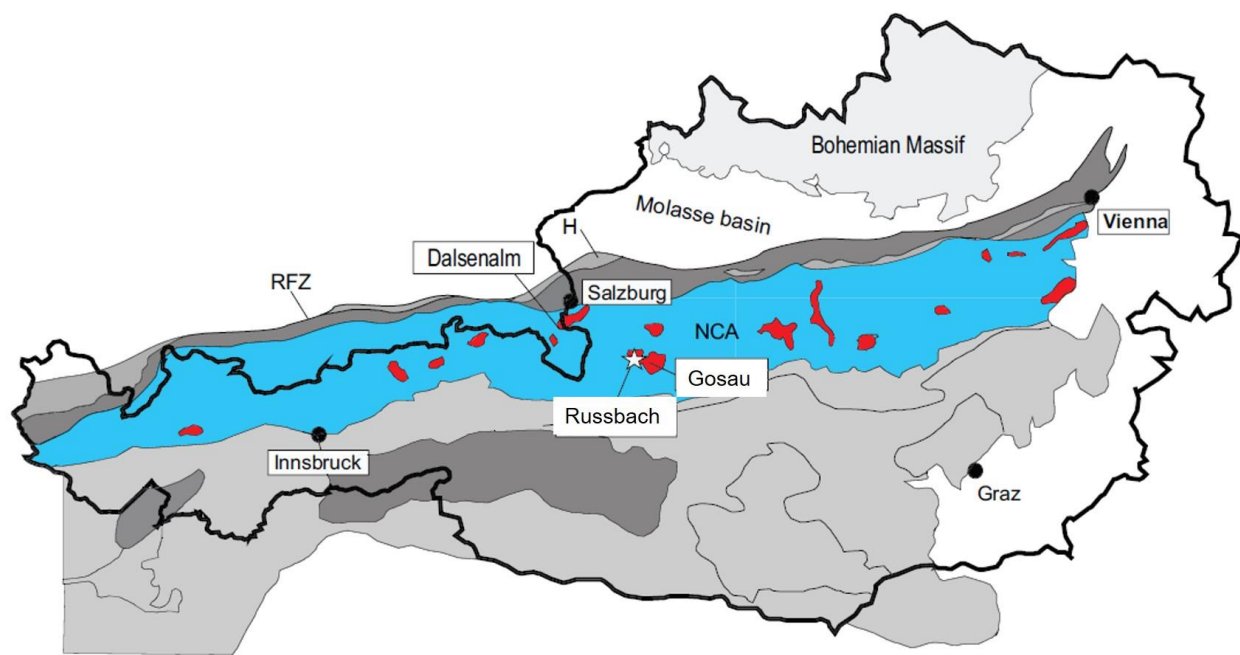
SedLog Version 3.1, <http://www.sedlog.com>, copyright © Dimitrios Zervas, Robert Hall, Fionn Murtagh, Gary Nichols, Peter Burgess, all rights reserved

Stereonet, Version 10.2.9, © Richard W. Almendinger, 2010-2019

8 Appendices

8.1 Appendix A – Gosau Group Locations in the NCA

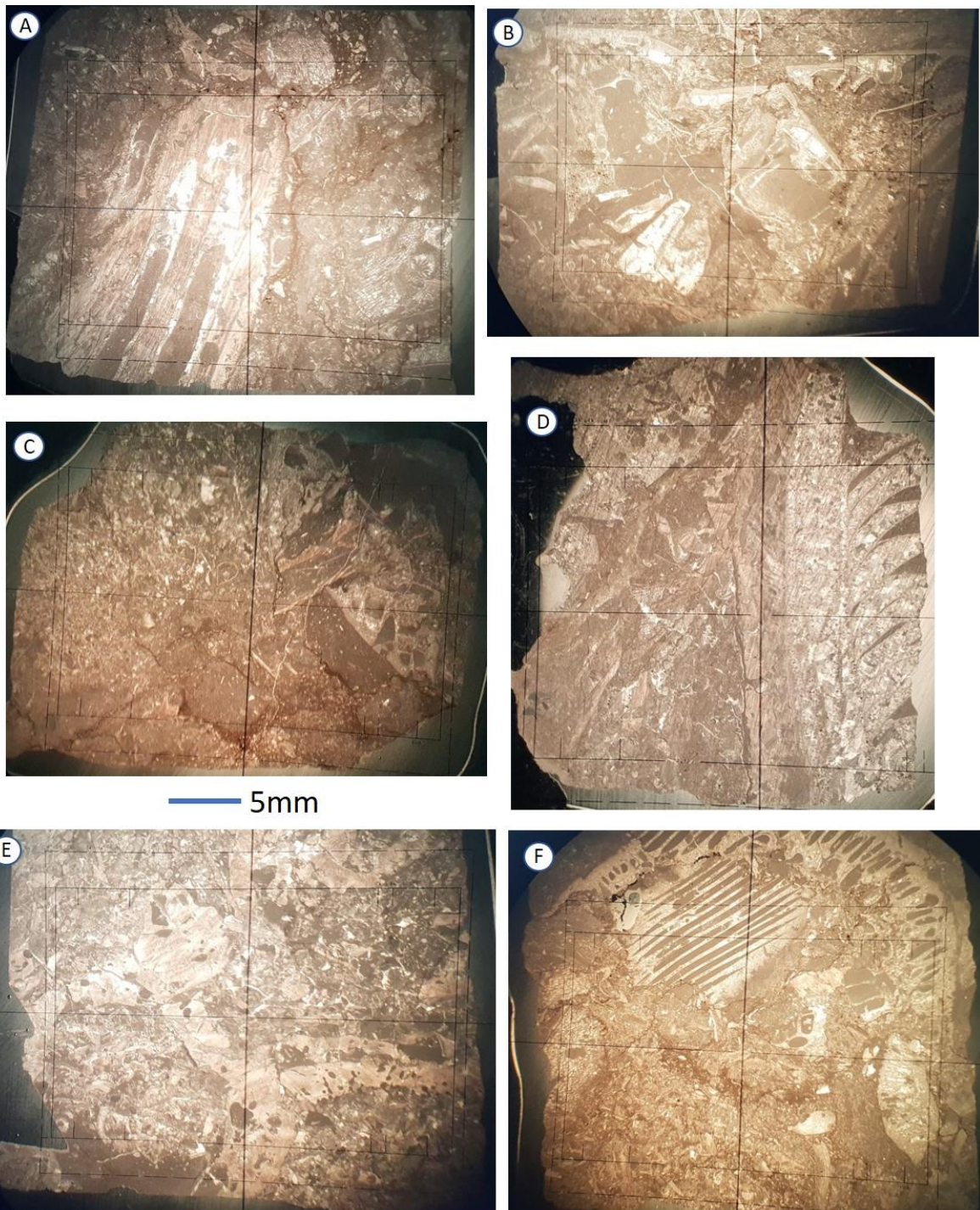
Gosau Group locations in the Northern Calcareous Alps of Austria (Modified from Wolfgring and Wagreich, 2018)



Geological sketch map of the Eastern Alps including Gosau Group successions (red) and the position of Gosau and Russbach in the Gosau Basin; the Northern Calcareous Alps (NCA, blue). Dark grey = Penninic Units (including RFZ = Rhenodanubian Flysch Zone); medium gray = other Austroalpine units; white = Cenozoic basins; H = Helvetic/Ultrahelvetic Units.

8.2 Appendix B – Thin Section Overview

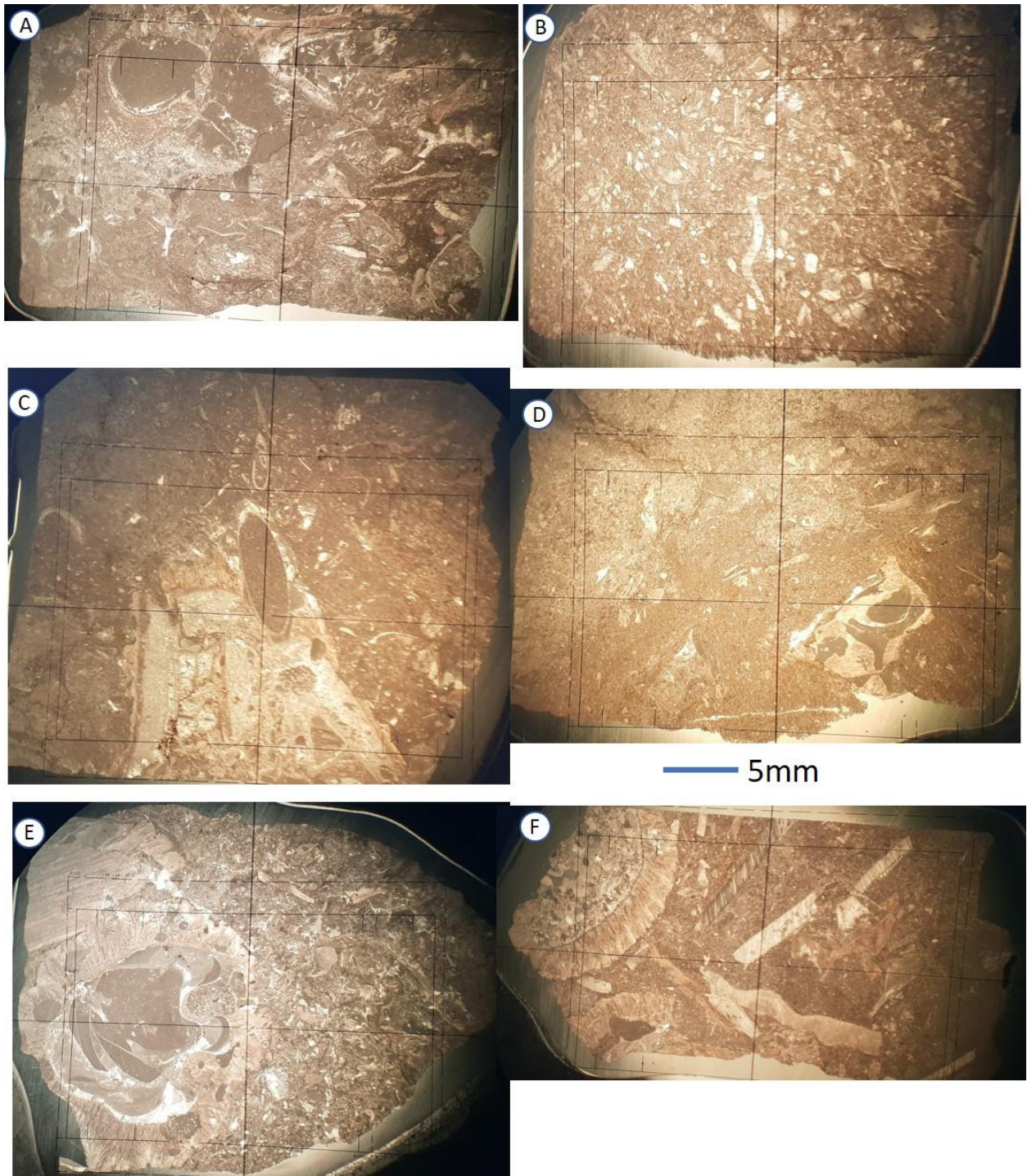
Thin Section Overview – Plate 1



In this and subsequent plates, the thin section name is correlated to a profile bed or outcrop in the legend at the bottom.

A: B1.1N → B1	B: B1A → B4
C: B1B → B4	D: B2.1N → B2
E: B2 → B4	F: B3 → B4

Thin Section Overview – Plate 2



A: B4 → B4

C: B6.1N → B6

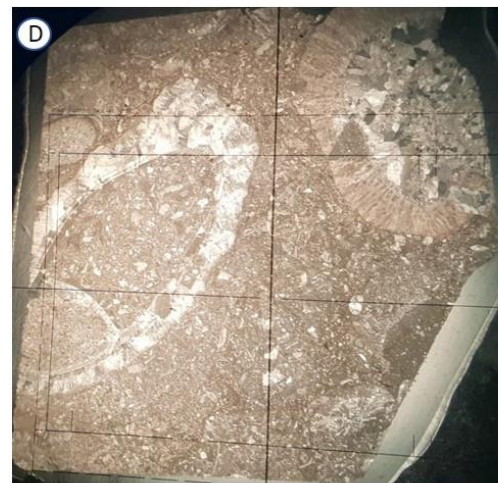
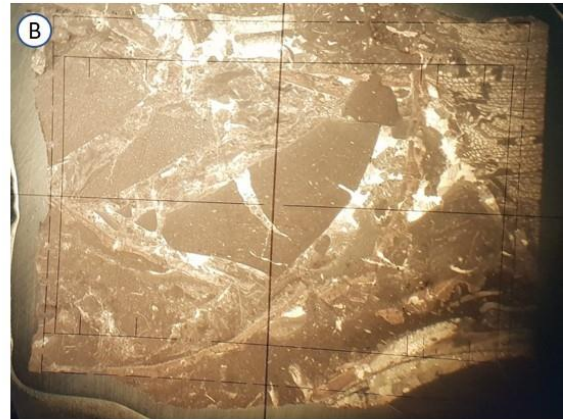
E: B6B → B4

B: B5 → B4

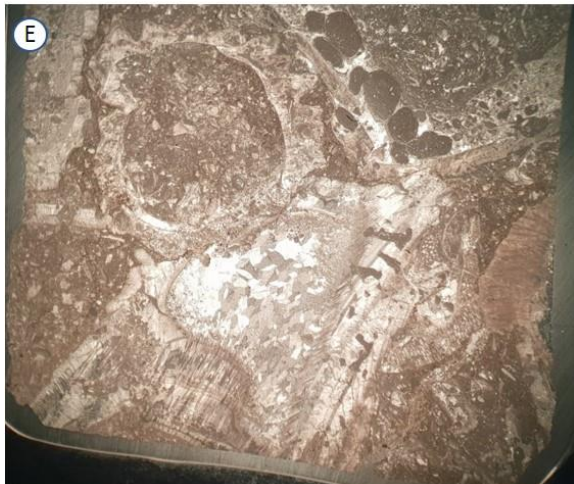
D: B6A → B4

F: B10.1N → B10

Thin Section Overview – Plate 3



— 5mm



A: BB.1 → BB.1

C: 1.15 → B4

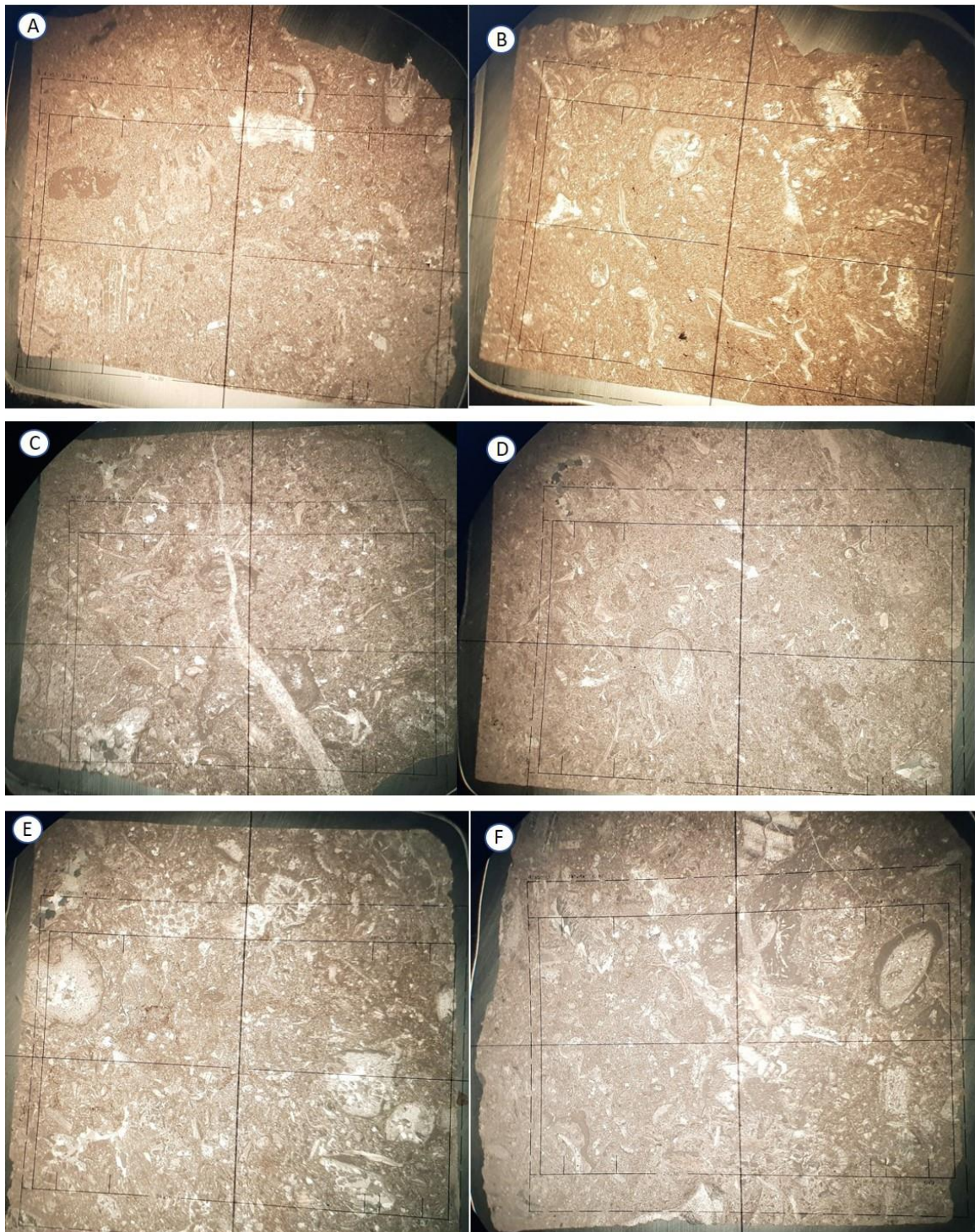
E: 2.1B → B4

B: 1.1 → B4

D: 2.1A → B4

F: 2.3A → B4

Thin Section Overview – Plate 4



— 5mm

A: 5.1 → B4

C: 8.1 → B4

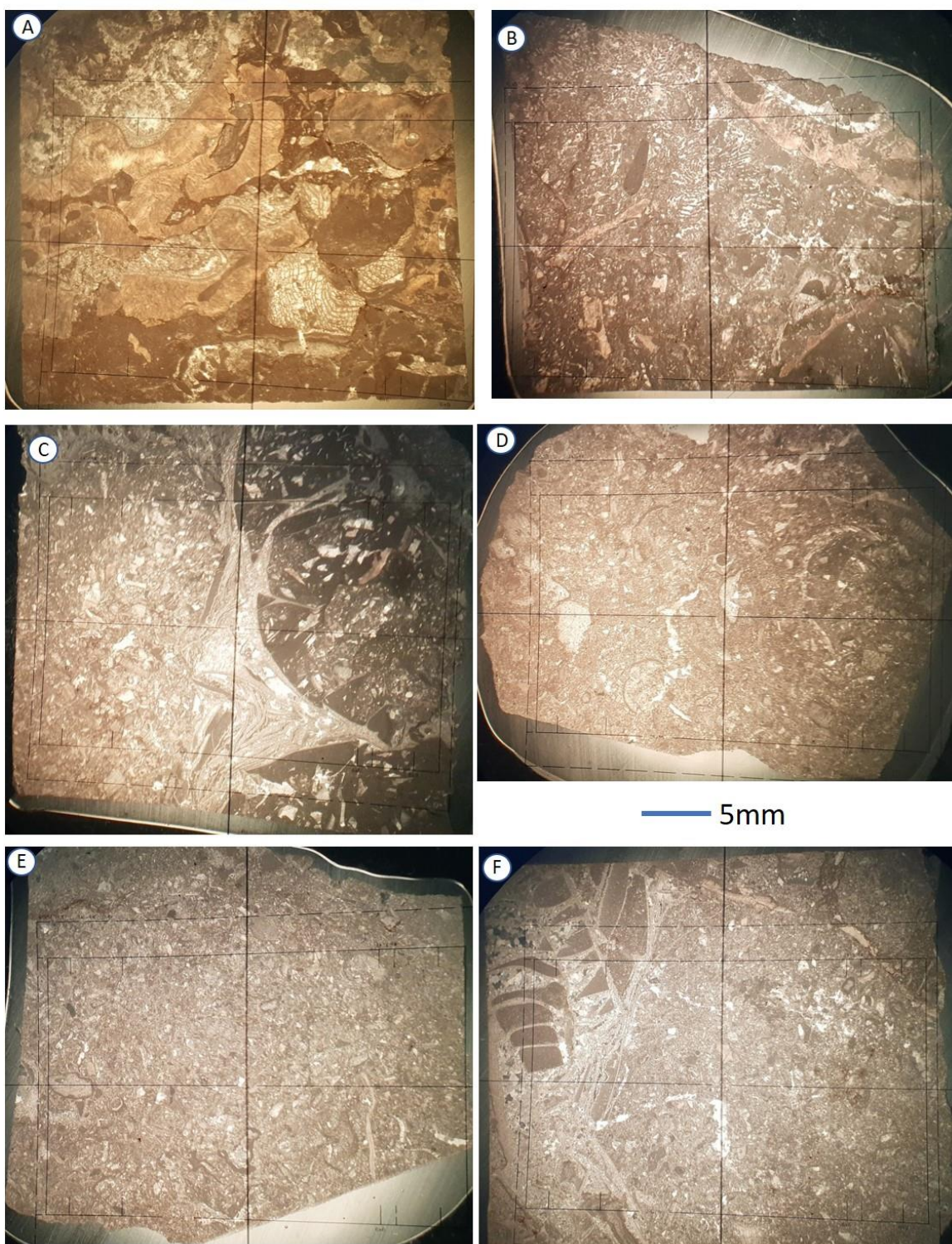
E: 10.1 → B4

B: 7.1 → B4

D: 9.1.8 → B2

F: 11.1 → B4

Thin Section Overview – Plate 5



A: 13.1 → B4

C: 18.1 → B3

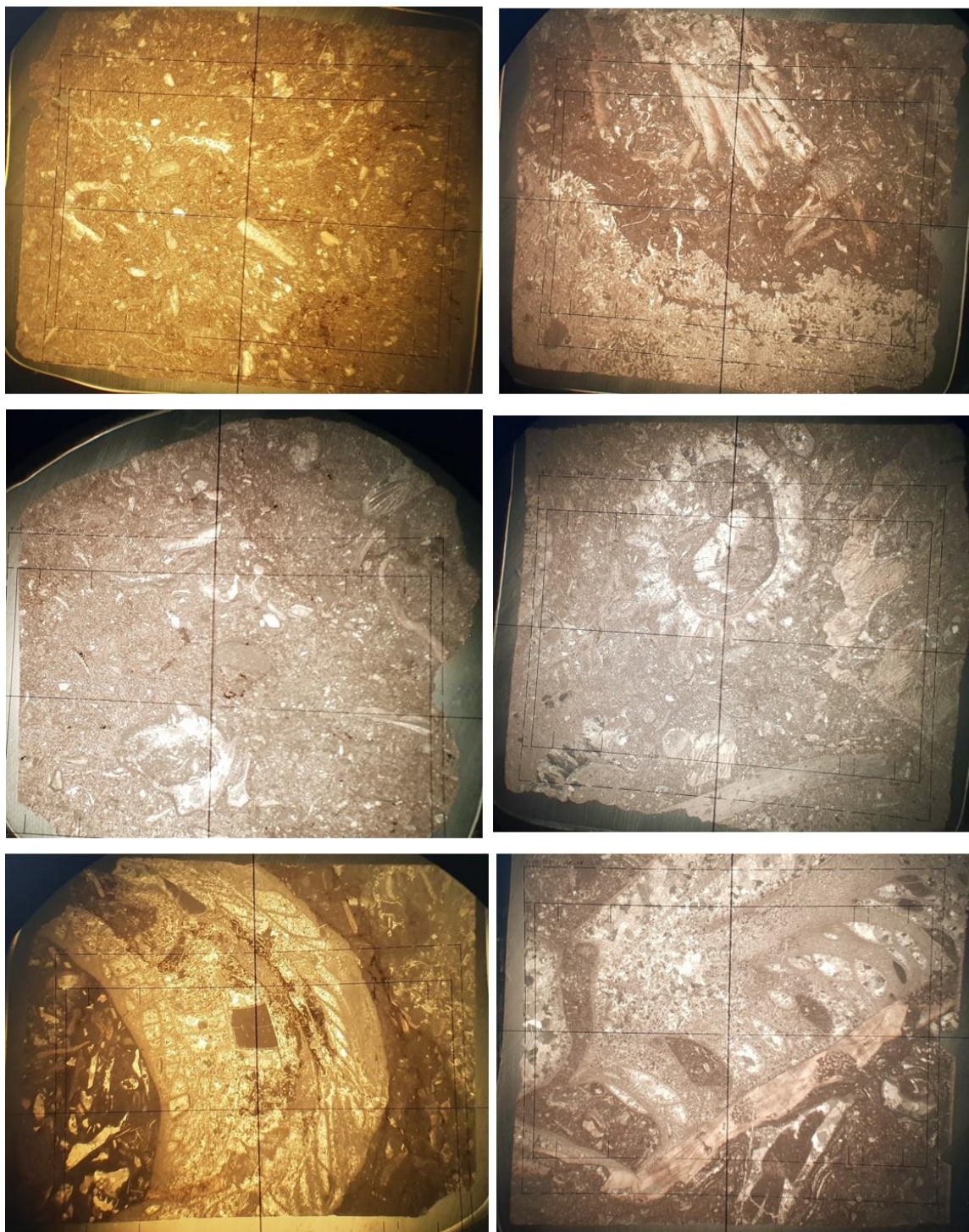
E: 23.1 → B4

B: 16 → B3

D: 21.1 → B3

F: 23.1B → B4

Thin Section Overview – Plate 6



— 5mm

A: 24.1 → B4

C: 26.1B → B4

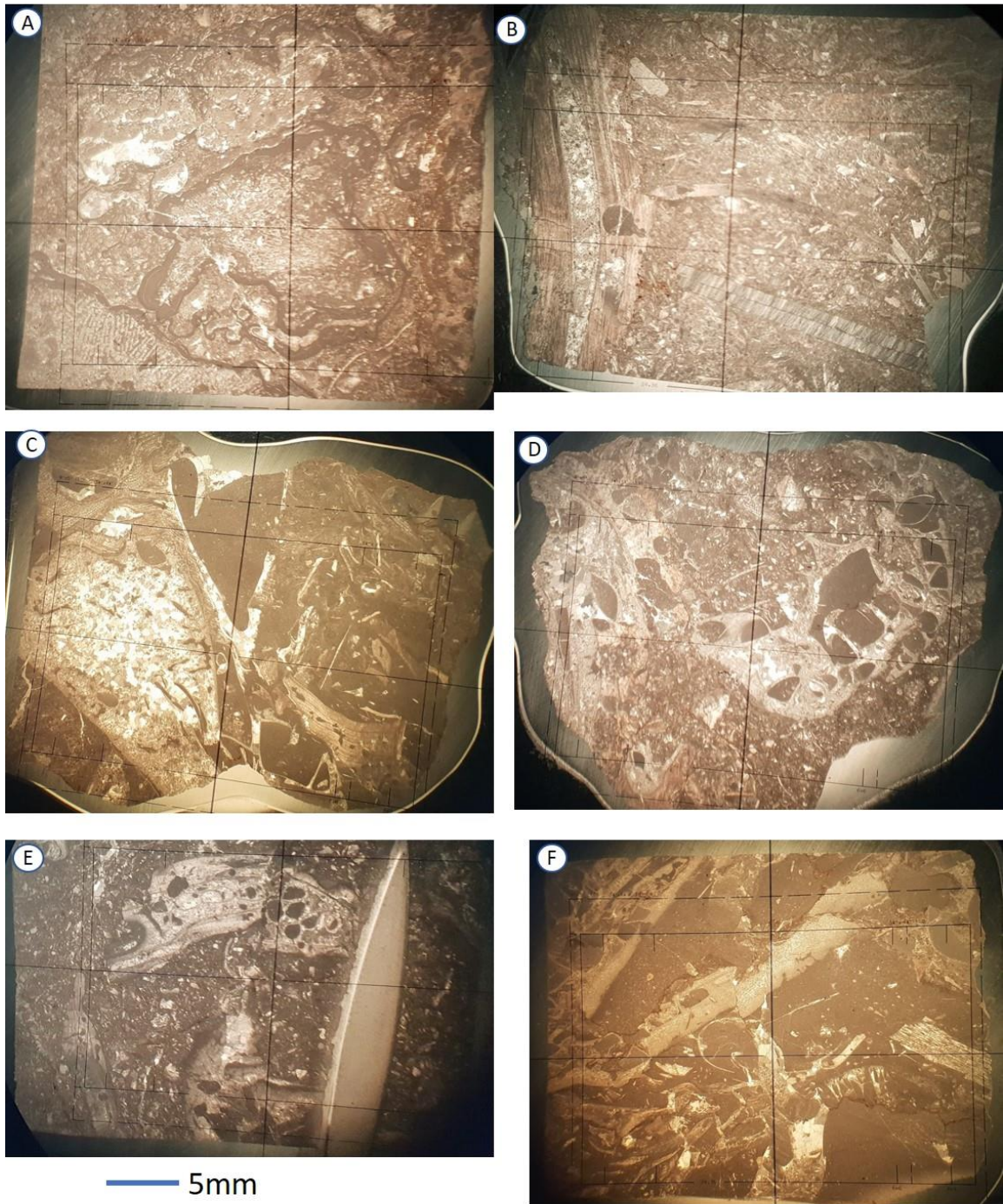
E: 31.1 → B3

B: 25.1 → B4

D: 27.1 → B3

F: 32.2 → B3

Thin Section Overview – Plate 7



A: 33.1 → B3

C: 33.4 → B3

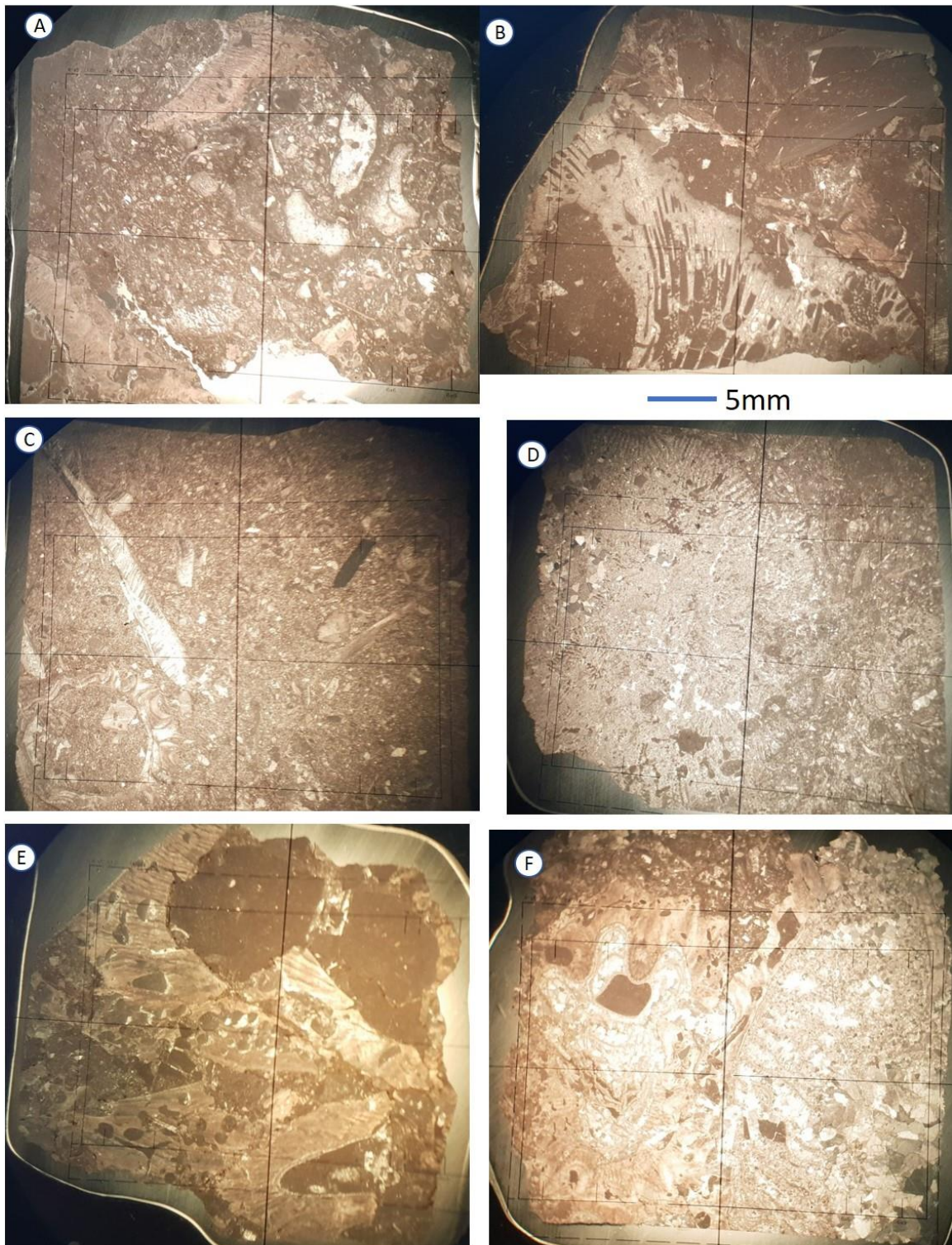
E: 36.1U → B4

B: 33.2 → B3

D: 35.1 → B3

F: 36.12 → B3

Thin Section Overview – Plate 8



A: 37.2 → B3

C: 41.2 → B5

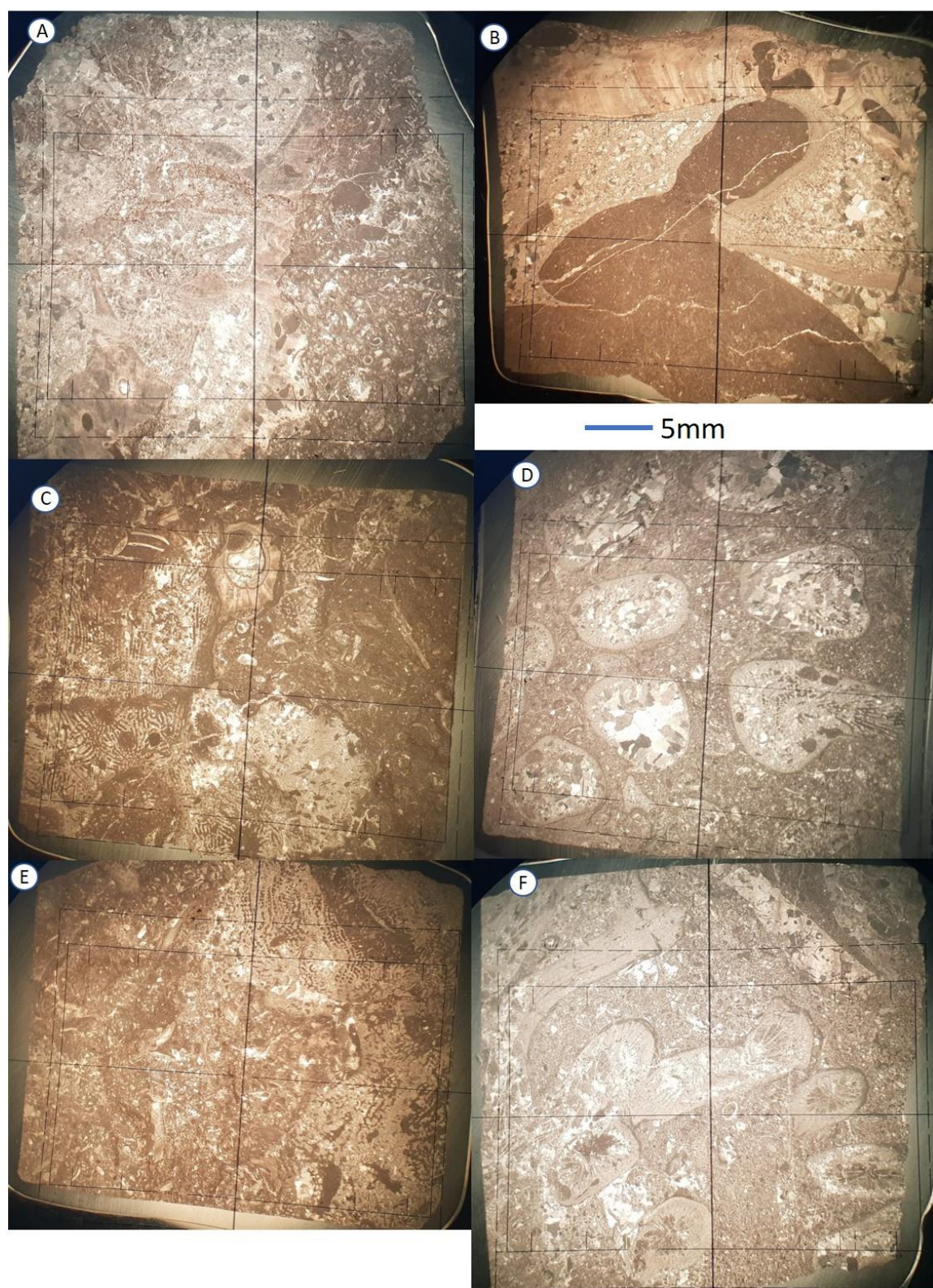
E: 44.1 → B4

B: 37.2L → B3

D: 43.1 → B4

F: 45.1 → B4

Thin Section Overview – Plate 9



A: 47.2 → B4

C: 49.1 → B4

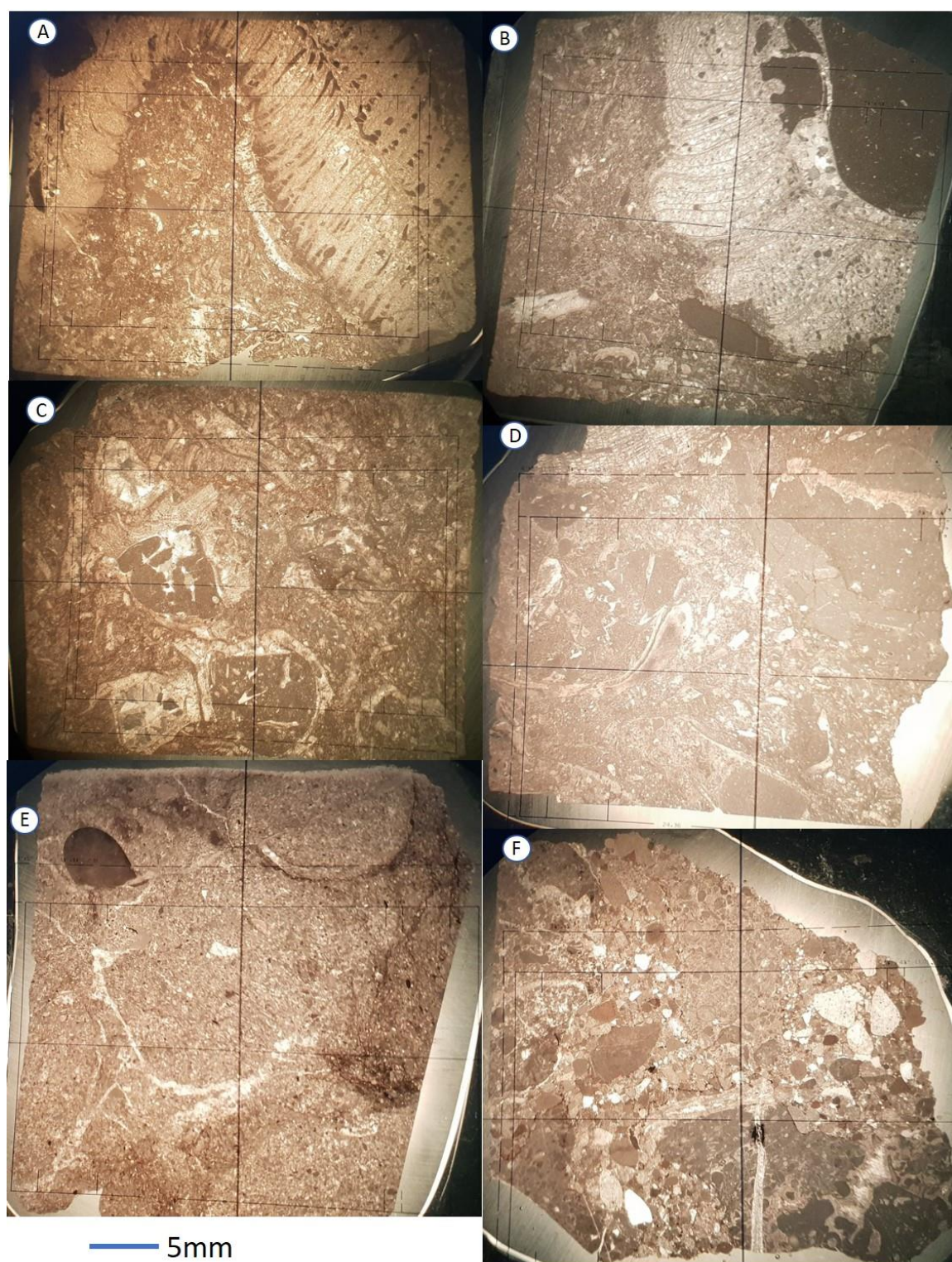
E: 53.2 → B4

B: 48.1B → B4

D: 52.3 → B4

F: 54.1 → B3

Thin Section Overview – Plate 10



A: 54.2L → B3

C: 56.2 → B7

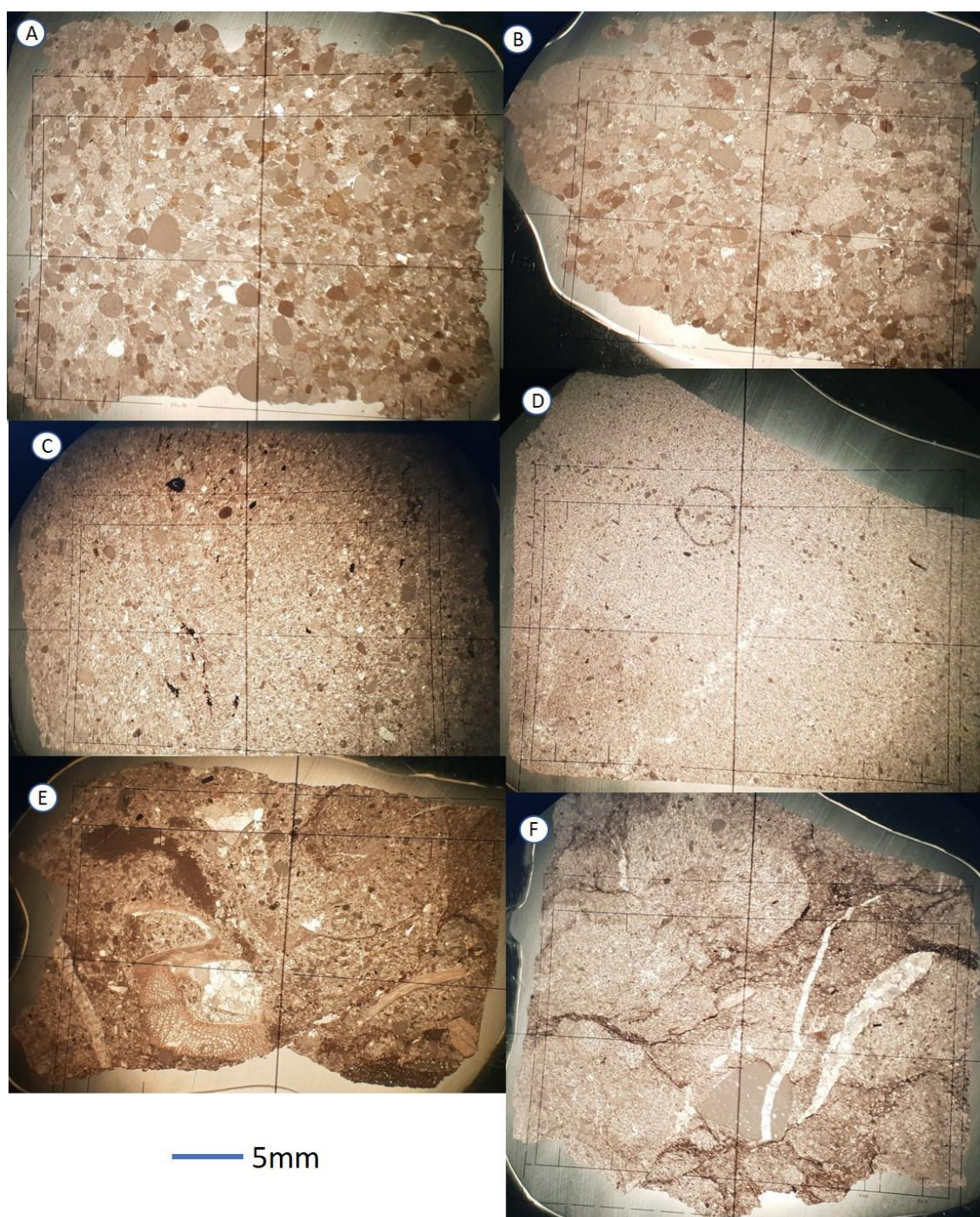
E: A1.1

B: 56.1 → B7

D: B7 → B7

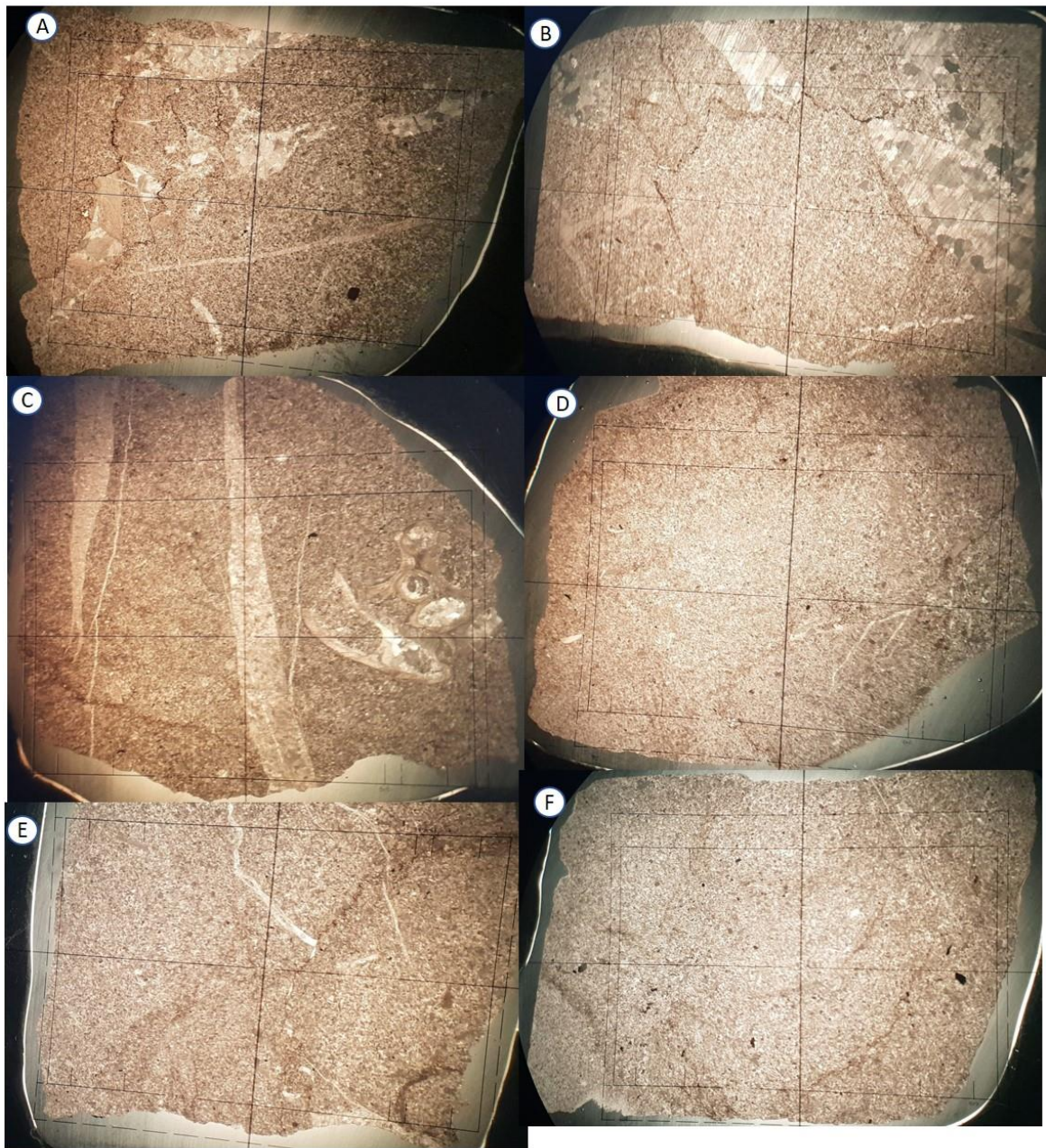
F: A1

Thin Section Overview – Plate 11



A: A3.1	B: A4
C: A5	D: A7.1
E: A10.1	F: A10.2

Thin Section Overview – Plate 12



A: A12.1

C: A13

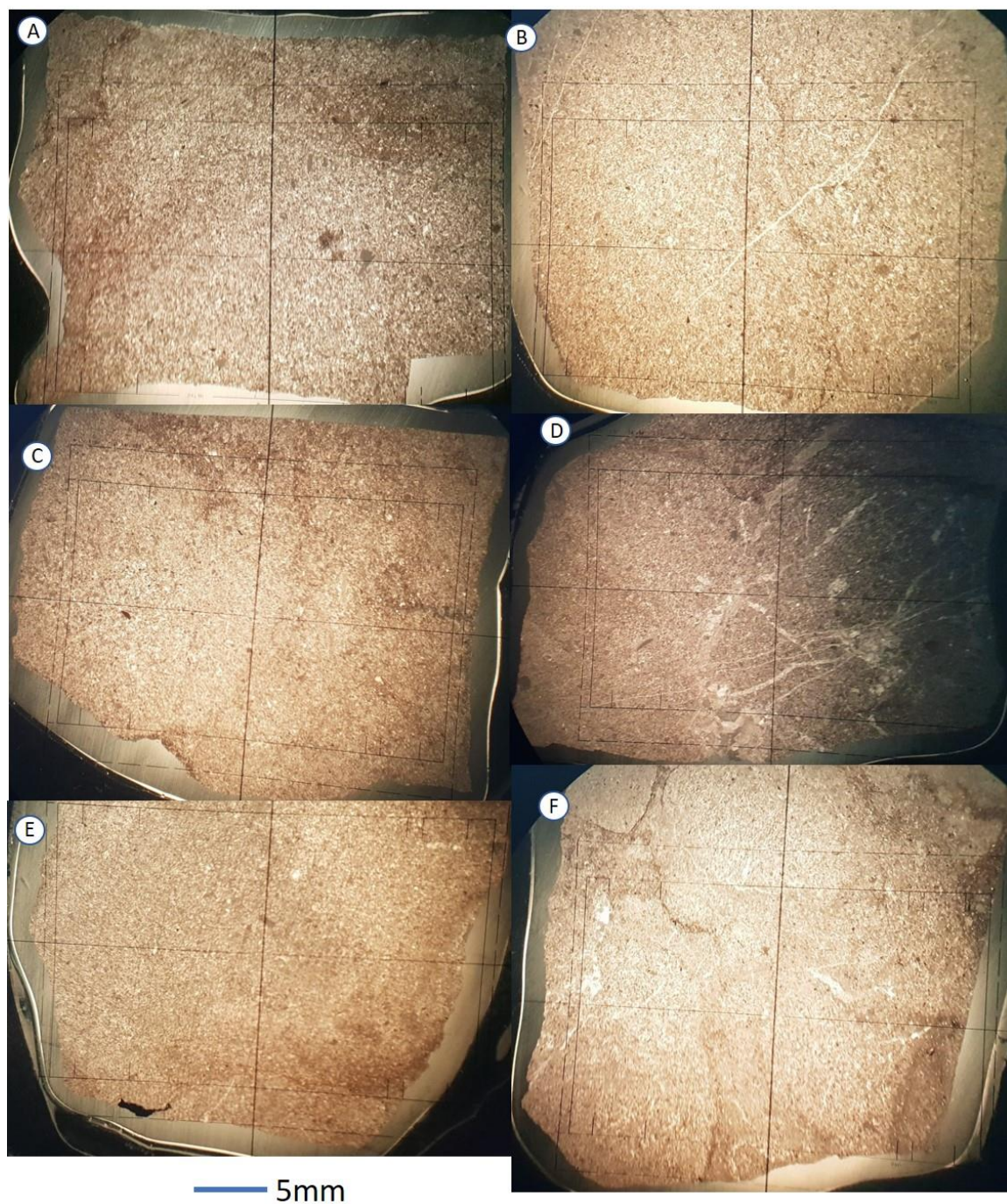
E: A17

B: A12.2

D: A14.1

F: A19.1

Thin Section Overview – Plate 13



A: A20

C: A24

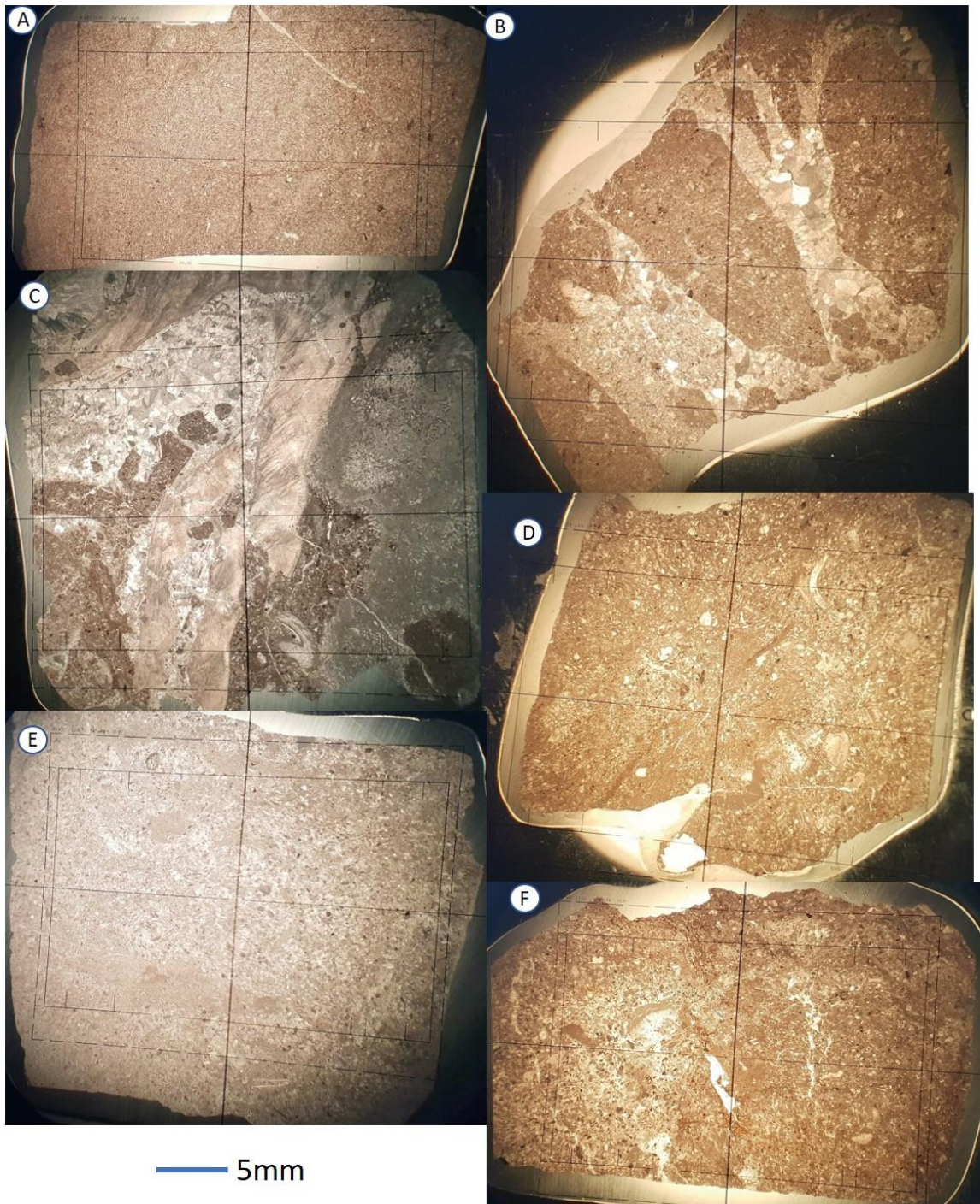
E: AC3L

B: A21

D: AC2U

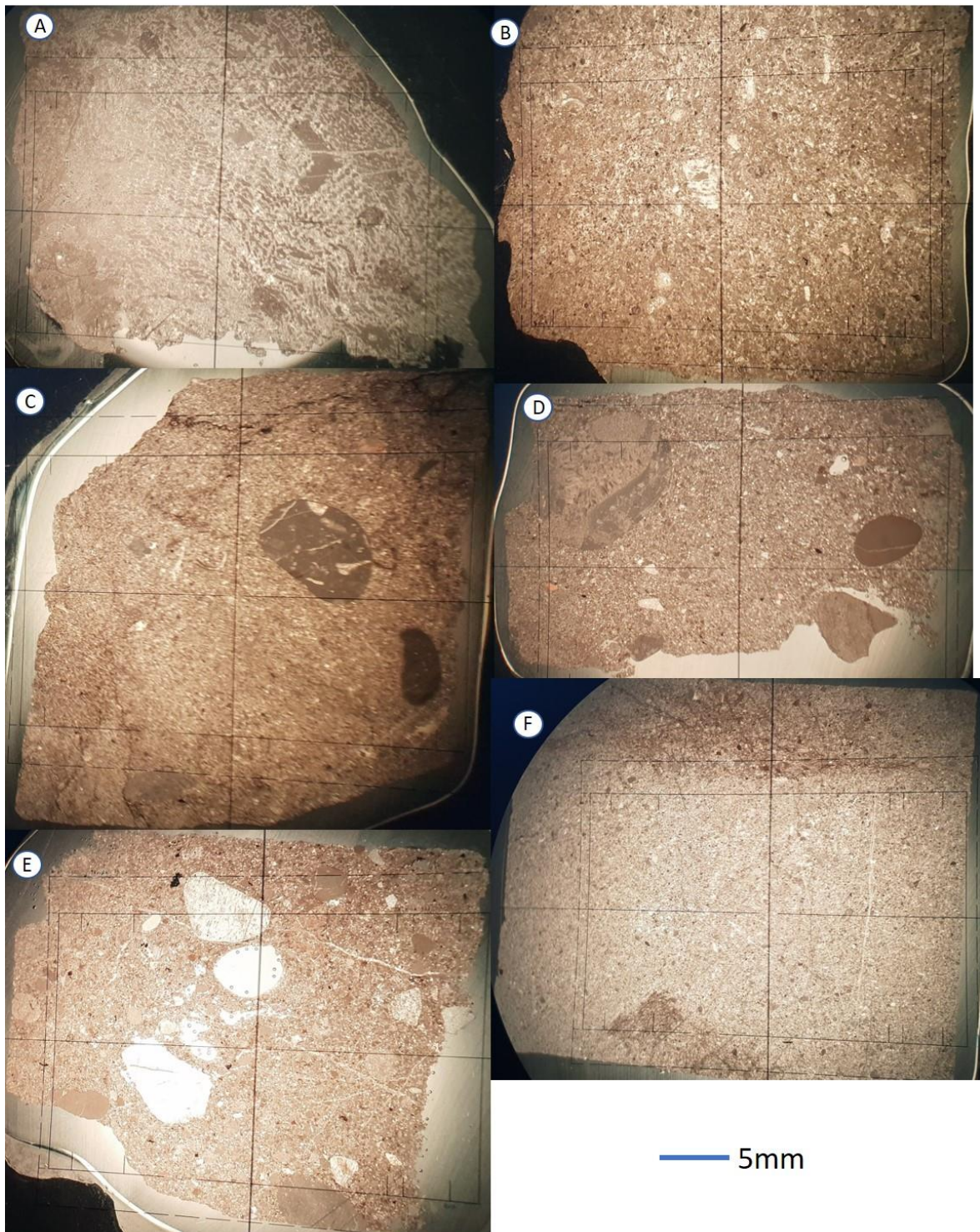
F: ACL4 → AC1U

Thin Section Overview – Plate 14



A: AC14 → AC4L	B: C1.3
C: C2	D: C3.1
E: C3.3	F: C4.1

Thin Section Overview – Plate 15



A: C5

C: CW7

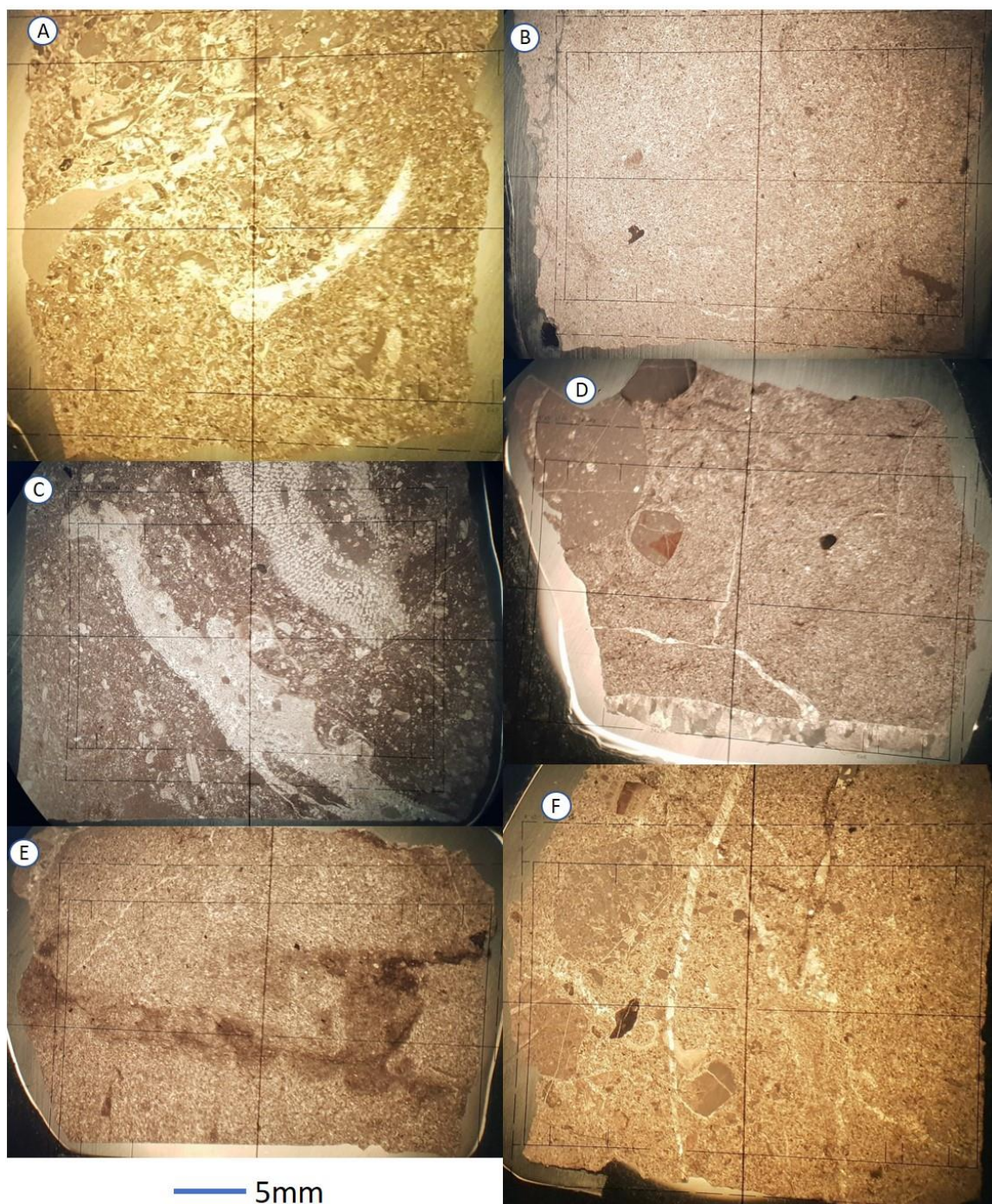
E: CW 13.2

B: C6

D: CW 13.1

F: 20MAC → CW2

Thin Section Overview – Plate 16



A: 40MRC → CW3

C: KK1 → CW20

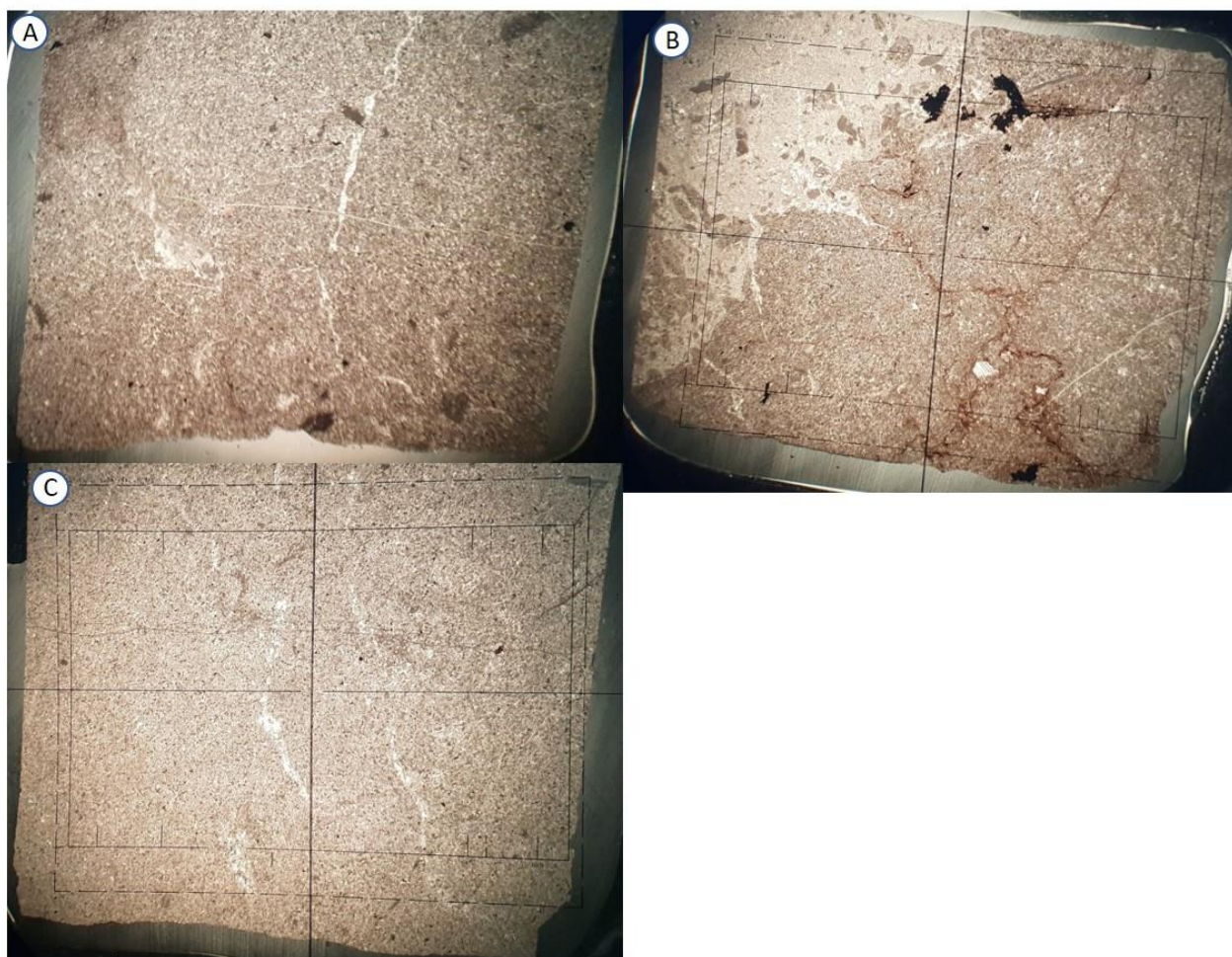
E: M2 → CW02

B: 12.13 → CW22

D: M1 → CW02

F: W2.1 → CW7

Thin Section Overview – Plate 17



— 5mm

A: WL1 → CW01

B: WU1 → CW02

C: XX → CW15

8.3 Appendix C – List of Figures

Figure 1: Extent of study area enclosed in the blue frame. Base map obtained from Digitales Oberösterreichisches Raum-Informations-System [DORIS], accessed on 15 January 2020.

Figure 2: a) Schematic geological map of the Eastern Alps; b) Overview map of position of Gosauschmied in the Gosau Basin (adapted from Wagreich et al., 2010, p. 182)

Figure 3: Geographical setting of the Gosau basin with Gosauschmied in the south. Image from Google Earth, accessed 11 January 2020.

Figure 4: Schematic 3D rendering of Gosauschmied and the alpine backdrop to the south. <https://earth.google.com/web/@47.53816981,13.49613851,867.34032652a,2553.50727216d,35y,58.53871085h,60.01145333t,Or> , accessed on 11 January 2020.

Figure 5: Overview of the study area in Gosauschmied. The light blue highlighted area constitutes the extent of the Hochmoos Formation with the Bibereck Formation to the north and west. Base map obtained from Digitales Oberösterreichisches Raum-Informations-System [DORIS], accessed on 15 October 2019. Extent of formations established during field work.

Figure 6: A) Large scale overview of the Tethys in the Late Cretaceous. B) Palaeotectonic position of the NCA within the Eoalpine deformational belt in the Alpine Tethys/Penninic Ocean (adapted from Neuhuber et al., 2016). The position of Gosau is indicated on the front edge of the accretionary wedge.

Figure 7: Curves showing tectonic subsidence of three separate occurrences of Gosau Group sediments. The procedure for backstripping was based upon Bond and Kominz (1984) and Wildi et al., (1989). The inverted pyramids mark an instance of significant uplift and subaerial erosion, followed by rapid subsidence into bathyal depths. The two subsidence cycles correspond to sedimentation of the Lower and Upper Gosau subgroups (from Wagreich and Faupl, 1994, p. 247).

Figure 8: Schematic plate-tectonic development depicting the subsidence of the Gosau basin to bathyal and abyssal depths through tectonic erosion and the subduction of the Penninic Ocean beneath the Austroalpine microplate (modified from Wagreich 1993, 1995, 2003).

Figure 9: Idealized stratigraphic representation of the eight Gosau Group formations in the Gosau basin (adapted from Summesberger et al., 2017, p.155) with the Kreuzgraben Formation at the bottom in the upper Turonian.

Figure 10: Excerpt from geological map 095 St. Wolfgang im Salzkammergut (GBA, Plöchinger, 1982)

Figure 11: Overview of west and east sides of study area with key structures, places, topography and elevation indicated. Morphologically and structurally, the two sides of the area dip toward the

brook running N-NW through the valley and northward toward the Gosau Basin. The reservoir is at around 781m. (Digitales Oberösterreichisches Raum-Informationssystem [DORIS] – accessed on 15 Jan. 2020.)

Figure 12: Dachstein Limestone boulder near climbing area – Photo taken 02 September 2019

Figure 13: Overview of the study area (zoom in on Fig. 11) showing the positions of the outcrops studied in-depth. The anticline next to profile A is a prominent feature in the study area and will be analyzed in more detail later in this paper. (Digitales Oberösterreichisches Raum-Informationssystem [DORIS] – accessed on 15 Jan. 2020.)

Figure 14: composite photo of the anticline in the study area.

Figure 15: Composite photo of the anticline on the east side of the Gosausee highway (the red line marks the extent of sandy, clastic carbonates. The two yellow lines mark a fault zone to be discussed in a subsequent section)

Figure 16: Projection of the anticline through the study area. From Digitales Oberösterreichisches Raum-Informationssystem [DORIS], accessed on 06 September 2019

Figure 17: Single microfossils in the marl bed. Lower left is a foraminifera (genus unidentifiable, but appears to be a miliolid), the other three are ostracods.

Figure 18: Initial section of profile A. Red lines indicate first eight beds.

Figure 19: Compass measurements from profile A range from dip direction of N/NE to a more N direction in beds 20-24. Dip angles range from 33 to 62.

Figure 20: A – base of bed 5 where sample was extracted, red arrows point toward visible conglomerate components in the surface, chisel 30cm long. B – bed 15, peloid limestone with no visible terrigenous content, packstone. C – panorama view of profile A with line showing transition from clastic carbonate sediments to limestone. The concrete fortification of the anticline is visible in the left of the picture. The top of the anticline at 787m is indicated in the upper left-hand corner.

Figure 21: Stratigraphic column of profile A (preceding page) with legend of lithologies and symbols to the left.

Figure 22: A (A1) – bed 1, *textularida* (white arrow) from a lithoclast of Dachstein limestone. B (A1.1) –bed 1 showing a bivalve fragment (white arrow). C (A1) – bed 1, Triassic fossil fragments inside Dachstein limestone. D (A3.1)– bed 3, various terrigenous components in fine-grained conglomerate, including chert (white arrow), quartz, dolostones, indicative of transgression in a fan-delta milieu.

Figure 23a: A (A3.1, BW) – bed 3, large clasts of quartz (white arrow). B (A4, BW) – bed 4, large dolostone clast with irregular components (white arrow). BW = Black-and-White thin section photograph

Figure 23b: C (A3.1, BW) – bed 3, ostracod fossil (white arrow). D (A4, BW) – bed 4, dolostone clasts within dolomite matrix (rhomboid crystals, black arrow).

Figure 24: A (A1) – bed 1, overview of rock fabric with large chert clast in upper left corner (red arrow). B (A1.1) – bed 1, close-up of Dachstein limestone clast showing *involutinida* foraminifera of Triassic provenience (white arrows). C (A3.1) -- bed 3, overview of fabric with various terrigenous clasts (siliciclastic and carbonate lithoclastic content with pelsparite and dolomite in the interstitial spaces). D (A5) -- bed 5, overview of fabric, very little cement, grainstone, carbonate-lithic arenite with clasts of chert, carbonate sand, chert and mono-crystalline quartz (silt-sized).

Figure 25: A (A7) – bed 7, overview of lithology, visible sand, chert and lithoclasts in a clear line of sedimentation, *Nummofallotia cretacea* (Schlumberger 1900) (red arrow) next to clast of chert (Felix Schlagintweit, personal communication, October 2019). B (A7) – bed 7, close-up of circle in image A showing *Nummofallotia cretacea* (inside red circle), crossed nicols polarization showing interstitial micrite. C (A10.1) – bed 10, micrite-filled radiolitid fragment (red arrow) with sparite crystals at center. D (A10.1) – bed 10, close-up of radiolitid fragment from image C with infilling sparite crystals (red arrow).

Figure 26: A (A10, BW) – bed 10, coral fragment (*Cladacora* sp., white arrow). B (A10, BW) – bed 10, dissolved gastropod (white arrow). C (A12.2, BW) – bed 12, *Nummofallotia cretacea* (white arrow). D (A10) – bed 10, clast of Dachstein limestone (white arrow) with secondary calcite vein (yellow arrow), small radiolitid fragment (red arrow) and multiple stylolites (green arrow).

Figure 27: A (A12.1) -- bed 12, overview of fabric with fine-grained, but irregular peloid components and calcite/sparite crystals. B (A13) – bed 13, ostracod (red arrow).

Figure 28: A (A13) – bed 13, radiolitid fragments (white arrows) filled with sparite crystals in fine-grained peloid limestone. B (A12.2) -- bed 12, fine-grained peloid limestone with irregular components (red arrow) and sparite infilling with large calcite crystals exhibiting clear lamination (yellow arrow).

Figure 29: A (A14) – bed 14, echinoid fragment in limestone of irregularly-shaped peloid components. B (A14) – bed 14, planspiral foraminifera (white arrow) and micrite cement (red arrow) in packstone matrix.

Figure 30: A (A19.1) – bed 19, fine-grained packstone lithology pointing to deposition in open shelf environment, small chert clasts, micrite cement. B (A20) – bed 20, planspiral foraminifera (white arrow) in packstone of peloid limestone (red arrow indicates individual peloid component).

Figure 31: A (A20) – bed 20, *Quinqueloculina* sp. (miliolid, hyaline foraminifera – white arrow). B (A20) – bed 20, sea urchin spine (white arrow). C (A20) – bed 20, echinoid fragment (yellow

arrow). D (A24) – bed 24, overview of peloid limestone lithology, with packstone to grainstone fabric, micrite matrix and fine-grained peloids and small clasts.

Figure 32: Photo of profile C at N 47.549332, E 13.513960 along the Gosausee highway

Figure 33: Panorama view of profile C where the forest road branches off from the Gosausee highway.

Figure 34: Stereographic projection of profile C compass measurements in Schmidt diagram

Figure 35: A – Photo by Diethard Sanders in summer of 1997, in situ *Durania* sp. near the base of profile C. B – photo of *Durania* fragment extracted from bed 1 on 23 May 2019. C – *Durania* fragment identified at the base of beds 1 and 2 (not in situ).

Figure 36: Large-scale overview of Profile C: the picture at the top right shows the beginning of the outcrop, while the picture at bottom left shows the end of the outcrop. The orientation of the outcrop changes as it bends around the forest road to the west.

Figure 37: Stratigraphic column of profile C showing transition from bioclastic rudstone and floatstone lithology to packstone lithology and increasing content of peloid limestone. Legend for the symbols is at the left.

Figure 38: A (C1) – from bed 1, sparite crystals (red arrow) intruding in bioclastic matrix, foraminifera visible (white arrows) in matrix, as well as other bivalve and echinoid fragments. B (C1) – from bed 1, *Nummofallotia cretacea*; generally, profile C had more foraminifera than either Profile B or A. C (C2) – from bed 2, coral encrusting on rudist fragment filled with sparite crystals and brown bioclastic sediment. D (C2) – from bed 2, close-up of rudist fragment with sparite filling.

Figure 39: A (C2) – from bed 2, *Quinqueloculina* sp. (white arrow) embedded in micrite. B (C3.3, BW) – from bed 3, *Nummofallotia cretacea* (red arrow) next to another foraminifera (white arrow, genus unidentifiable). C (C3.1) – from bed 3, sea urchin spine (white arrow). D (C3.1) – from bed 3, coral fragment (genus unidentifiable) in packstone matrix, foraminifera from image B visible in lower left-hand corner.

Figure 40: A (C4.1) – from bed 4, packstone matrix with individual clasts and micrite intrusions, angular peloid components (red circle). B (C4.1, BW) – from bed 4, biserial foraminifera (*Textularina*).

Figure 41: A (C5) – from bed 5, large coral fragment (genus unidentifiable) with micrite filling in the pores. B (C5, BW) – from bed 5, close-up of micrite crystals (red arrow) in hollow chambers of coral.

Figure 42: A (C6) – from bed 6, packstone matrix with micrite cement, peloid components visible, some bioclastic components. B (C6) – from bed 6, sea urchin spine (white arrow) cut obliquely,

other bioclastic fragments visible. C (C6) – from bed 6, bivalve fragment (white arrow). D (C6) – from bed 6, *Quinqueloculina* sp. (red arrow), one of many miliolid specimens.

Figure 43: Outcrop between the anticline in the north and profile C in the south. The red dots indicate positions from which samples were extracted for thin sections.

Figure 44: Stereographic projection of compass measurements for area AC in Schmidt diagram.

Figure 45: A (ACL4) – from sample AC1U, Dachstein limestone clast (white arrow) in peloid limestone matrix. B (ACL4) – from sample AC1U, planspiral foraminifera (genus unidentifiable, white arrow). C (AC2U) – from sample AC2U, bivalve fragment (red arrow) in peloid limestone matrix. D (AC2U) – from sample AC2U, *Quinqueloculina* sp. (white arrow) surrounded by micrite.

Figure 46: A (AC3L) – from sample AC3L, dissolved gastropod (white arrow). B (AC3L) – from sample AC3L, *Nummofallotia cretacea* (white arrow).

Figure 47: A (AC14) – from sample AC4L, clast of Dachstein limestone (red arrow) in peloid limestone matrix. B (ACL4) – from sample AC1U, unidentifiable fossil fragment, possibly shell fragment of radiolitid (white arrow).

Figure 48: overview of the west side of study area. White stars indicate outcrops investigated. Circled stars indicate thin section analysis. From Digitales Oberösterreichisches Raum-Informations-System [DORIS], accessed on 09 October 2019.

Figure 49: image left shows an outcrop at the base of an uprooted tree; image right shows the outcrop CW7 with evident clasts of Dachstein limestone (red arrows), confirmed through thin section analysis

Figure 50: At site CW20. The red line denotes the facies change between the limestone with carbonate lithoclasts and the carbonate conglomerate with clayey/muddy matrix (red arrow).

Figure 51: Examples of carbonate conglomerate outcrops at the top of the ridge behind profiles A and C. The yellow arrow (left) shows a large carbonate lithoclast, while the red arrow (right) points to a large chert clast.

Figure 52: A (M1) – from outcrop CW01, large carbonate lithoclasts in packstone matrix, low fossil content. B (20MAC) – from outcrop CW2, clast of small Dachstein limestone in packstone matrix, some coral and bivalve fragments. C (CW7) – from outcrop CW7, large clast of Dachstein limestone containing Triassic fossils (*Textularina*, among others). D (40MRC) – from outcrop CW3, wackestone with bioclasts and peloids in micrite matrix, planspiral foraminifera (red arrow).

Figure 53: A (CW13.1) – from outcrop CW13, packstone with terrigenous clasts of varying size, rudist fragments, Triassic coral fragment in large Dachstein clast (red arrow). B (CW13.2) – from outcrop CW13, packstone with terrigenous clasts, including chert, quartz and carbonate lithoclasts. C (XX) – from outcrop CW15, packstone of peloid limestone, low fossil content, similar

to lithology near top of profile A. D (D12.13) – from outcrop CW22, very similar to CW5: peloid limestone, packstone, some fossil fragments, near end of ridge trail at forest road.

Figure 54: The top picture is a photo of outcrop B taken with maximum zoom from the west side of the reservoir. The picture at bottom left shows beds 3 and 4 from the Geotrail. The picture at bottom right shows the signpost on the Geotrail.

Figure 55: Profile B near the Geotrail. The picture shows the (pseudo-bedding) orientation of joints running orthogonally to the actual bedding orientation (W/NW at 30°).

Figure 56: Stereographic projection of Profile B compass measurements in the Schmidt diagram

Figure 57: Photos of macrofossils in profile B. Upper left shows the markings of a coral fossil weathering out of bed 4. Upper right shows the cross sections of hippuritid fossils in bed 3. Lower left shows hippuritid fossils in growth position at the bottom of bed 4. Lower right shows a prominent rudist (hippurite) biostrome at the top of bed 4.

Figure 58: This image shows beds 1-4 taken from the south side of the outcrop on the Geotrail. Beds 1 and 2 extend 8-12 m up the hill, then are no longer exposed, while bed 3 continues for 15 m and bed 4 attains a lateral extension of 25 m.

Figure 59: This photo depicts beds 4 and 5 roughly 20-25 m up the hillside from the Geotrail. The red oval shows the position of the rudist biostrome with fossils in growth position.

Figure 60: This photo depicts beds 4-10 of the outcrop from around 30 m up the hill from the Geotrail. The outcrop becomes sparser and less well-exposed beyond bed 10.

Figure 61: Stratigraphic column of profile B with indication of radiolitid and hippuritid biostromes in beds 3 and 4. Legend of lithologies and fossils in the box at the left.

Figure 62: A (B1.1N) – from bed 1, large rudist shell with bore holes filled with sediment (yellow arrow), hollow chamber filled with sparite (red arrow), radiolitid fragments on the right side (white arrow). B (B2.1N) – from bed 2, fully micritized/sparitized rudist shell (black arrow) with sediment in the hollow chambers; the sediment filled first, then the shell was dissolved later.

Figure 63: A (B1.1N) – from bed 1, rudist shell with holes (red arrow) from boring sponges; aragonite inner layer sparitized. B (B2.1N) – from bed 2, example of fragment filled with sediment, then micritized around the edges (red arrow); echinoderm fragments (yellow arrow).

Figure 64: A (B1.1N) – from bed 1, radiolitid fragment with micrite filling. B (B2.1N) – from bed 2, close-up of sparite crystals with lamination of calcite visible in x-nicols polarization (red arrows).

Figure 65: A (7.1, BW) – from bed 4, images of coral *Cladocora gracilis* (white arrows, d'Orbigny, 1850) in bioclastic matrix with numerous rudist fragments. B (1.15) – from bed 4, rudist cross-section with micritized inner aragonite layer, sediment filling, *Vaccinites* sp.

Figure 66: A (2.1B) – from bed 4, cross-section of a radiolitid, shell highly micritized, sparite crystals in voids. B (7.1) – from bed 4, tubes created by serpulid worms (personal communication, Felix Schlagintweit, October, 2019).

Figure 67: A (27.1) – from bed 3, micritized cross-section of radiolitid (white arrow) next to (red arrow) preserved calcite shell of hippuritid (*Vaccinites* sp.). B (32.2) – from bed 3, growth of unspecified organism from rudist shell (potentially clinoid boring sponge). C (11.1, BW) – from bed 4, rudist-clastic floatstone with *Procladocora* coral fragments. D (13.1) – from bed 4, hippuritid (red arrow) and radiolitid (white arrow) clastic rudstone.

Figure 68: A (53.2) – from bed 4, coral fragment from *Bosnopsammia* sp. B (9.1.8, BW) – from bed 4, one of very few foraminifera identified in profile B, *Nummofallotia cretacea* in rudist-coral clastic floatstone.

Figure 69: A (9.1B) – from bed 4, rudist-coral clastic floatstone: *Nummofallotia cretacea* (red arrow), radiolitid fragment (white arrow), echinoid fragment (yellow arrow). B (44.1) – from bed 4, clinoid-bored hippuritid shell. C (37.2L, BW) – from bed 3, free valve of *Plagioptychus*. D (33.4, BW) – from bed 3, radiolitid preserved with upper valve, early dissolution of aragonite layer of radiolitid, bafflestone.

Figure 70: A (49.1, BW) -- from bed 3, boundstone with two different coral taxa, red arrow → *Parasynastraea tignaria* (Oppenheim, 1930), white arrow → *Columactinastreaea* cf. *Formosa* (Goldfuss, 1829), cross section of young radiolitid (upper middle) with sparite filling. B (52.3) – from bed 4, *Dermosmiliopsis* cf. *tenuicosta* (Reuss, 1854), branching coral. C (54.2, BW) – from bed 3, *Placosmilia* sp. coral with encrusting bryozoans. D (54.1) – from bed 3, coral, *Nefophyllia angusta* (Reuss, 1854) in bioclastic matrix (coral taxa identified by Rosemarie Baron-Szabo, personal communication, November 2019).

Figure 71: A (B10.1N) – from bed 10, hippuritid fossil in clastic floatstone, infilling sparite crystals deposited in concentric layers. B (B10.1N) – from bed 10, detail showing micritized radiolitid fragment.

Figure 72: A (41.2) – from bed 5, floatstone with nearly fully-micritized radiolitid cross section and radiolitid fragments. B (56.2, BW) – from bed 7, radiolitid floatstone. C (56.1) – from bed 7, large radiolitid fragment with chambers filled with micrite and sparite. D (57.1) – from bed 7, floatstone to rudstone with large radiolitid fragment and bioclastic matrix.

Figure 73: Plate-like structure with profile B and the outcrops investigated (red stars). From Digitales Oberösterreichisches Raum-Informationssystem [DORIS], accessed on 22 January 2020.

Figure 74: three images of point 2 in Figure 73: large Gosau limestone outcrops with minimal bedding and only sparse fossil content. Grainstone to packstone lithology.

Figure 75: (left) small outcrop of rudist limestone with evident macrofossil content, coral marks (red arrow), rudist shells (yellow arrows). (Right) Large rudist fossil fragment from outcrop at left.

Figure 76: (Left) massive wall of rudist limestone at north edge of platform B (point 4 in Fig. 73). For scale, see hammer in lower left corner of picture. (Right) Macrofossil content clearly evident in the face of the outcrop: classic detrital rudist limestone.

Figure 77: Massive outcrop to the north of the end of profile B. Height 4.5 m. Lithology: Gosau limestone (grainstone to packstone) and similar to the outcrops at point 2 in Figure 73.

Figure 78: Depiction of the area north of profile B and its topographic platform. The numbers identify the location of outcrops studied in this area. From Digitales Oberösterreichisches Raum-Informationen-System [DORIS], accessed on 15 October 2019.

Figure 79: 1) (left) image of brook on the east edge of the area. Despite the topography and a steep drop off in the terrain, no exposed outcrops could be found. 2) (middle) image of a sample near outcrop 4: macrofossils weathering out of the surface with clear indication of detrital rudist shells. 3) (right) image of outcrop 3 with macrofossils in the rudist limestone surface.

Figure 80: Stereographic projection in Schmidt diagram of compass measurements of selected outcrops in the area surrounding platform B. A consistent N/NW orientation could be established.

Figure 81a: Photo showing the bottom of the dam and the outcrop on the west side of the brook.

Figure 81b: Samples from the outcrops near the dam and down the brook (<40m distance from the dam). The samples ringed in blue are from the west wall, while those ringed in red are from the east wall.

Figure 82: Comparison of the formation depiction in the 1982 geological map from 095 St. Wolfgang im Salzkammergut (at right; Plöchinger 1982) with the formation extent and boundaries established during the field work. Type 45 is formally the Hochmoos Formation, while Type 43 is the Bibereck Formation. Left map from Digitales Oberösterreichisches Raum-Informationen-System [DORIS], accessed on 05 November 2019; right map from 095 St. Wolfgang im Salzkammergut 1982.

Figure 83: (Left) Entire sample weathered out of bed 3 in profile B. (Right) Cross-section of sample after being cut open. Genus of radiolitid was not identifiable. The sample shows some hippuritid cohabitation.

Figure 84: (Left) Fragment of hippuritid biostrome from the base of bed 4. (Right) Cross-section at joint of upper and lower shells. Genus: *Vaccinites* sp. (discussion Diethard Sanders, August 2019).

Figure 85: (Left) Radiolitid fossil with celluloprismatic mesostructure (Skelton 2013) typical of the family Radiolitidae. (Right) Cross section showing laminated structure around the core. The fossil is largely preserved primary calcite.

Figure 86: (Left) Example of a helioporid near profile B. (Right) Thin section (BB1) created from the sample showing the cross section of the individual polyps in the helioporid (personal communication, Rosemarie Baron-Szabo, November 2019).

Figure 87: (Left) Sample with coral *Placosmilia* sp. encrusting on Gosau limestone. (Right) Thin section (KK1) from bottom of fossil sample at left identified as *Lamellofungia* sp. (personal communication, Rosemarie Baron-Szabo, November 2019 and January 2020).

Figure 88: Structural overview of study area with strike-dip measurements denoted. From Digitales Oberösterreichisches Raum-Informations-System [DORIS], accessed on 05 November 2019.

Figure 89: Tectonic setting of Gosau Group formations (depicted as cross-hatched sediments) in the Gosau basin (Wagreich and Decker 2001).

Figure 90: Data archived 16 July 1992 by Decker. E-NE extending sinistral strike-slip fault with R and R' and a minor normal fault component (Wagreich and Decker 2001).

Figure 91: (left) Fault 95-28 from Wagreich and Decker, 2001, west side of highway (47.549872, 13.514605). (Middle top) Fault 95-28 east side of highway. (Middle bottom) Karstification conglomerate from fault on west side of highway. (Right top) Red arrow indicating Riedel shear areas on the foot wall of fault zone. (Right bottom) Image of Riedel shear structure (red arrow) in fault 95-28.

Figure 92: map of the study area with the distribution of the 6 different facies types. The boundaries between the facies types are not sharp, but gradual, though there are a number of outcrops that appear to show the exact point of transition. From Digitales Oberösterreichisches Raum-Informations-System [DORIS], accessed on 24 January 2020.

Figure 93: A (3.1) -- Facies Type AK, clastic carbonates. B (12.13, BW) – Facies Type A, peloid limestone. C (11.1) – Facies Type B, bioclastic limestone. D (CW7) – Facies Type AC, peloid limestone with clasts. E (CW13.2) – Facies Type K, carbonate conglomerate with clayey-silty matrix. F (C6) – Facies Type C, transitional from C to AC, peloid limestone with clasts and fossil fragments. G (C2) – Facies Type C, bioclastic limestone with marl content, transitional from facies B.

Figure 94: Strontium isotope measurements were taken from samples extracted at the places indicated in the map (denoted by white stars). Map From Digitales Oberösterreichisches Raum-Informations-System [DORIS], accessed on 24 January 2020.

Figure 95: (Top left) $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ curves for profile A. Height in the profile sampled is given on the Y-axis. (Top right) $\delta^{13}\text{C}$ (x) plotted vs. $\delta^{18}\text{O}$ (y) values. Best fit line and correlation (R^2) for the plot is included. (Bottom left) $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ curves for profile B. Height in the profile sampled is given on the Y-axis. (Bottom right) $\delta^{13}\text{C}$ (x) plotted vs. $\delta^{18}\text{O}$ (y) values. Best fit and correlation

(R^2) for the plot is included. Isotope measurements are expressed in ‰ vs. the VPDB standard (Vienna Pee Dee Belemnite).

Figure 96: Composite $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves for the three profiles A, B and C using a three-point rolling average. The original data points are included as a scatter plot. Key $\delta^{13}\text{C}$ excursion events from Jarvis et al. (2006) are correlated to the data.

Figure 97: Consolidated stratigraphic column for the Hochmoos Formation at Gosauschmied. The red lines represent the profiles studied in-depth (A and C on the west side, B on the east side).

Figure 98: Stratigraphic succession vs. relative sea level development in a single transgression-regression cycle (red curve, 2nd order) for the Hochmoos Formation at Gosauschmied. The black curve shows the 3rd order relative sea-level variation within the 2nd order cycle in the shelf area with an attendant error band to document potential sea-level range during the transgression-regression.

Figure 99: Inception of the Transgressive Systems Tract (TST) in an estuarine environment with a medium-grade ramp from shore to inner shelf at a relative sea-level lowstand.

Figure 100: Transgressive Systems Tract (TST): bioclastic carbonate marls are laid down in an estuarine environment with significant fluvial inflow.

Figure 101: Transgressive Systems Tract (TST): clastic carbonates (calcarenite, carbonate conglomerates) accumulate in the proximal environment, while distal carbonates are laid down in the inner shelf environment.

Figure 102: Transgressive Systems Tract (TST): peloid limestone beds are laid down in a fully marine environment in progradational stacking patterns. Fossil content is low to non-existent in uniform packstone to grainstone lithologies. A first relative MFS is reached.

Figure 103: Relative lowstand: periodically calmer conditions allow for establishment of rudist colonies on both sides of the lagoonal barrier. Facies B sediments are on the open inner shelf, while Facies C sediments (beds 1 & 2) are in the lagoon.

Figure 104: Highstand Systems Tract: renewed regression. In facies C, marl content persists, while fossil content decreases. In facies B on the inner shelf, by contrast, significant beds of bioclastic limestone are deposited.

Figure 105: Falling Stage Systems Tract (FSST): higher energy events lead to the accumulation of bioclastic sediments in the inner shelf and lagoon, followed by proximal reworking of the shoreface and inflow of terrestrial clasts in the receding waters.

Figure 106: Falling Stage Systems Tract (FSST): a return to high terrestrial/fluvial input in a fan delta environment in the proximal realm, while deeper areas continue to accumulate bioclastic detrital limestone. The positions of profiles A, B and C are marked in red. A synsedimentary or post-depositional fault structure is added as a possible division between the west and east sides of the study area.

Figure 107a: Schematic sediment stack of lithologies on the west side of the study area immediately post-deposition, including the Hochmoos Formation and the Bibereck Formation at the very top.

Figure 107b: Paleogene to Neogene tectonic activity folded the sediments into an anticline in the image above.

Figure 107c: The least competent lithologies were eroded away by subaerial erosive activity, including rain, wind and glacial forces. The Bibereck marls are absent, while the carbonate conglomerates with their marly, muddy matrix can only be found on the flat top of the ridge and nowhere on the flanks.

Figure 108: map of the study area with the distribution of the 6 different facies types resulting from the transgression/regression cycle. The presumed syncline running from either side of the study area to the valley floor is included. From Digitales Oberösterreichisches Raum-Informationen-System [DORIS], accessed on 24 January 2020.

Figure 109: A selection of occurrences of the Hochmoos Formation in the Gosau Basin. Source: Google Earth, accessed on 10 February 2020.

Figure 110: Comparisons of the lithostratigraphic sections of six occurrences of the Hochmoos Formation in the Gosau area, including the legend of key lithologies and rudist biostromes.

Figure 111: (left) Schematic representation of synsedimentary normal fault activity and the approximate positions of the Hochmoos Formation outcrops compared in Fig. 109. (right) Result of backstripping through the use of six discrete lithological units indicated by numbers. This shows the extent of tectonic subsidence from the WNW edge to the ESE edge of the Gosau Basin including approximate positions of the outcrops in Fig. 109 (adapted from Wagreich and Decker, 2001)

8.4 Appendix D – List of Tables

Table 1: Strontium isotope measurements from Gosauschmied compared to the mean value at the Postalm from Wolfgring and Wagreich 2018.

8.5 Appendix E – $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values

		Profile B	
	$\delta^{13}\text{C}$	$\delta^{18}\text{O}$	height cm
B1A Avg.	1.34	-3.19	150
B 1 B	1.63	-3.33	215
B 2	1.68	-2.62	405
B 3	1.12	-2.33	515
B 4	0.75	-2.55	725
B 5	1.80	-2.33	860
B6 Avg.	1.07	-1.73	970
B 7	1.03	-3.42	1125
B 8	1.77	-3.21	1230
B 10	1.69	-2.89	1540
B 11	2.03	-2.56	1900
B12 Avg.	2.10	-2.57	2060
B 13	1.83	-2.30	2220
B 14	1.96	-2.66	2488
B 15	2.14	-2.93	2723
B16 Avg.	1.68	-2.76	3013
B 17	1.49	-3.35	3318
B 18 End B	1.78	-2.81	3603
		Profile A	
A 8	1.32	-1.88	20
A 9	1.20	-2.81	142
A 10	0.95	-3.09	192
A11 Avg.	0.91	-2.79	303
A 12	0.32	-1.63	404
A 13	1.53	-2.78	504
A14 Avg.	1.68	-2.12	617.5
A15 Avg.	1.28	-2.41	677.5
A 16	1.46	-3.29	704.5
A17 Avg.	1.32	-4.83	755.5
A18 Avg.	1.12	-2.70	793.5
A 19	1.61	-3.01	851.5
A 20	1.61	-2.52	890.5
A 21	0.54	-1.66	923.5
A22 Avg.	1.70	-2.86	966.5
A23 Avg.	0.93	-2.00	1033.5
A 24 End A	1.71	-2.41	1088.5
		Profile C	
C 1	1.58	-2.60	130
C 2 Avg.	1.69	-2.36	260
C 3	1.84	-1.94	340
C 4	1.69	-2.21	450
C 5 Avg.	1.25	-2.27	545.5
C 6 End C	1.59	-2.00	652