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Age and significance of Lower Cretaceous mass flows: Ischl Breccia revisited (Rossfeld Formation, Northern Calcareous Alps, Austria)

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Abstract

New investigations on Lower Cretaceous sedimentary rocks southeast of Bad Ischl (Upper Austria) focused especially on outcrops of the Ischl Breccia. The local term "Ischler Brekzie" describes mass flows of the Rossfeld Formation of Late Valanginian depositional age at Salzberg and Kolowratshöhe and of Late Hauterivian to Early Barremian depositional age in the Perneck valley. The polymictic component spectrum contains ophiolitic and siliciclastic material, derived from an ophiolitic nappe stack (Neotethyan Belt). Mixed siliciclastic-calcareous rock fragments and biogenic components originated from the Early Cretaceous shelf area. In addition, Upper Jurassic and Lower Cretaceous Oberalm and Schrambach formations occur as components. Upper Juvavic platform carbonates or Lower Juvavic hemipelagic rocks do not occur in the mass flows of the Rossfeld Formation. The evolution of the Rossfeld Formation was triggered by sea-level fluctuations and only minor tectonic activity. The alleged uniform, laterally continous Lower Cretaceous basin sequence of Bad Ischl in fact belongs to three blocks of different palaeogeographic position: The Reinfalzalm-Mitterberg Unit (distal Trattberg Rise), the Gschwandtalm-Perneck Unit (proximal Tauglboden Basin) and the Reiterndorf-Hubkogel Unit (distal Tauglboden Basin). The Alpine Haselgebirge Mélange of the Bad Ischl salt deposit was resedimented within the Oberalm Formation in the Late Tithonian corresponding to the well documented Gartenau and Weitenau occurrences. Today´s structural position and exposure of the Bad Ischl salt deposit was successively formed from mid-Cretaceous to Quaternary by both tectonism and erosion.

Neue Untersuchungen der Unterkreide-Abfolge südöstlich von Bad Ischl (Oberösterreich) fokussierten sich vor allem auf die Vorkommen der sogenannten Ischler Brekzie. Diese lokale Gesteinsbezeichnung beschreibt olistostromatische Ablagerungen der Roßfeld-Formation. Diese zeigen im Bereich Salzberg und Kolowratshöhe ein spätvalangines, im Perneck Graben hingegen ein späthauterives bis frühbarremes Sedimentationsalter. Der gemischte Komponentenbestand beinhaltet ophiolithische und siliziklastische Resedimente eines ehemaligen ophiolitischen Deckenstapels (Neotethyan Belt). Gesteinsfragmente aus gemischt siliziklastischem-karbonatischem Ursprung sowie Reste von Organismen stammen aus dem ehemaligen unterkretazischen Schelfbereich. Resedimentierte Ober-Jura und Unter-Kreide Gesteine der Oberalm- und Schrambach-Formation stammen aus tieferliegenden erodierten Bereichen. Es treten weder hochjuvavische Plattformkarbonate noch tiefjuvavische, hemipelagische Gesteinsfragmente auf. Die Entwicklung der Roßfeld-Formation wurde durch Meeresspiegelschwankungen und geringe beziehungsweise abnehmende tektonische Aktivität beeinflusst. Die früher als einheitliche Beckensequenz dargestellte Unter-Kreide Schichtfolge von Bad Ischl kann drei Blöcken unterschiedlichen paläogeographischen Ursprungs zugeordnet werden: Der Reinfalzalm-Mitterberg Einheit (distale Trattberg-Schwelle), der Gschwandtalm-Perneck Einheit (proximales Tauglboden-Becken) und der Reiterndorf-Hubkogel Einheit (distales Tauglboden-Becken). Die Alpine Haselgebirge Mélange der Salzlagerstätte von Bad Ischl wurde, analog zu den Vorkommen von Gartenau und Weitenau, innerhalb der Oberalm Formation im Ober-Tithonium resedimentiert. Die heutige Form und Lage des Vorkommens wurde durch tektonische und erosive Vorgänge zwischen der mittleren Kreide und dem Quartär geprägt.

1. Introduction

The throughout widely accepted reconstruction of the Early Cretaceous geodynamic history of the Northern Calcareous Alps is inferred to be characterised by a convergent tectonic regime reflected in a coarsening upward trend in the Upper Valanginian to Aptian Rossfeld and Lackbach formations (Medwenitsch, 1958; Del-Negro, 1960; Pichler, 1963; Plöchinger, 1968; Faupl, 1978; Faupl and Tollmann, 1979; Decker et al., 1987; Schweigl and Neubauer, 1997a, 1997b; Darga and Weidich, 1986; Tollmann 1985; von Eynatten and Gaupp, 1999). The Rossfeld sedimentary cycle presumably ended in Aptian times with the final thrust emplacement of the Juvavic and Haselgebirge Nappes above the Tirolic Nappe (Medwenitsch, 1949, 1958; Plöchinger, 1968; Tollmann 1985; Faupl and Wagreich, 1992; Schweigl and Neubauer, 1997a, 1997b; Faupl and Wagreich, 2000; Schorn and Neubauer, 2011). The contemporaneously eroded ophiolitic material is interpreted to have been mixed with the Juvavic components, and deposited together with this carbonate clastic material as conglomerates, breccias, sandstones and olistoliths within a 'syntectonic' coarsening upward cycle (e.g., Decker et al., 1987; Schweigl and Neubauer, 1997a, 1997b). These rocks summarized as Rossfeld Formation are interpreted to represent the Early Alpine orogenic cycle in the Early Cretaceous.

A different tectonic model was introduced into the discussion by Gawlick et al. (2008) who interpreted the Rossfeld Formation as deposits of the molasse stage within an underfilled foreland basin (Tauglboden/Oberalm Basin) in front of the Neotethyan Belt (Missoni and Gawlick, 2011a). In this alternative scenario, the process of nappe-emplacement started already in the Middle Jurassic and continued at least until the early Late Jurassic. Decreasing tectonic activity with the evolution of shallow-water carbonate platforms in the latest Jurassic and the earliest Cretaceous (e.g., Gawlick et al., 2009, 2012) was followed by an increase of siliciclastic input from the Late Berriasian onwards (Gawlick and Schlagintweit, 2006; Missoni and Gawlick, 2011b). Tectonic activity in the Early Cretaceous influenced the Jurassic ophiolitic nappe-stack as well as the foreland (e.g., Northern Calcareous Alps) only locally

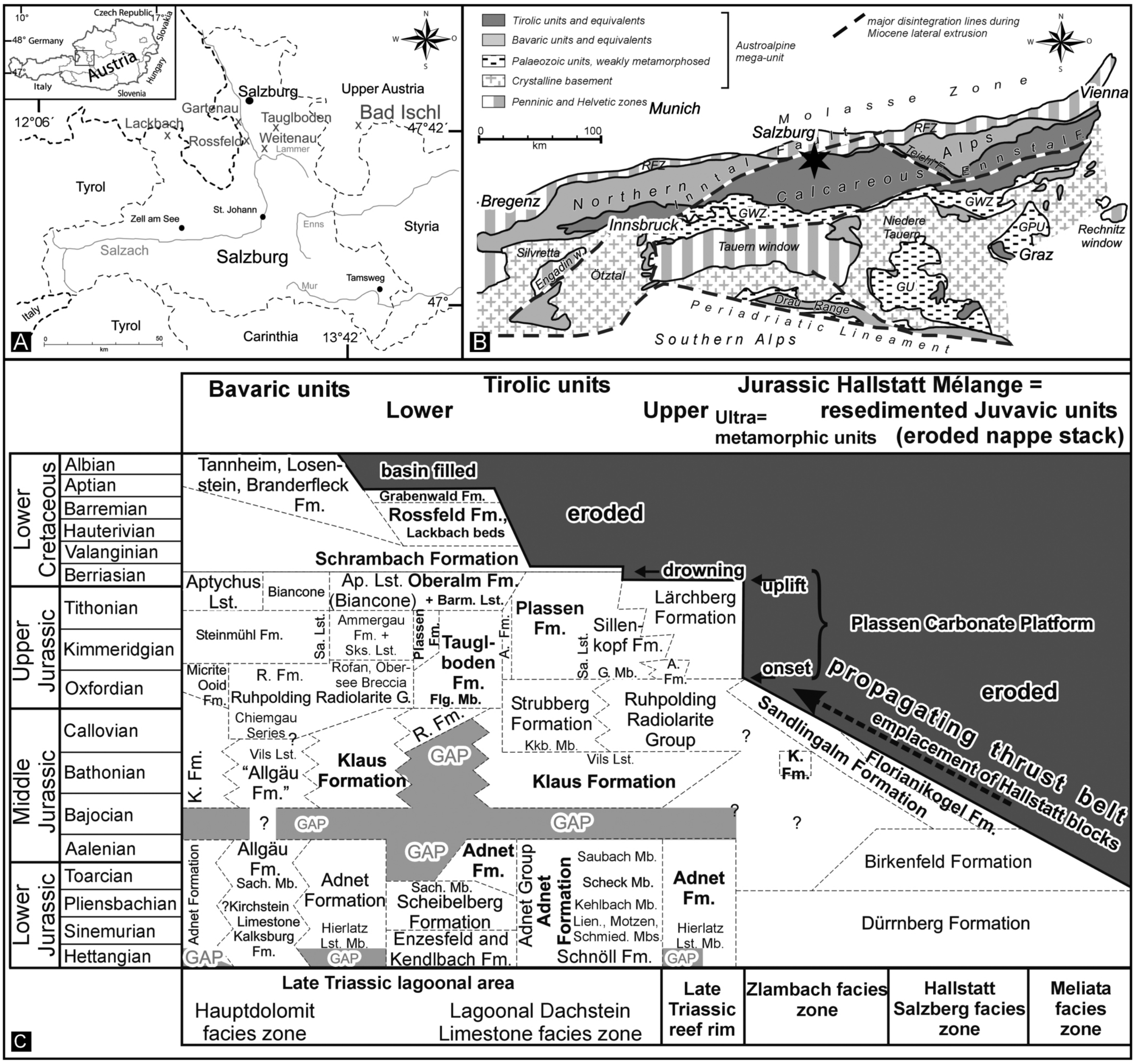


Figure 1: A: Geographic overview of Upper Austria, Bad Ischl and other localities mentioned in the text. B: Geological overview of the Eastern Alps (modified after Frisch and Gawlick, 2003). The described locality Bad Ischl is situated within the central part of the Northern Calcareous Alps (indicated by a star). Abbreviations: GP – Graz Paleozoic unit, GU – Gurktal unit, GWZ – Greywacke zone, RFZ – Rhenodanubian Flysch zone. C: Stratigraphy of the Northern Calcareous Alps with an overview of the common formation names according to Gawlick et al. (2009), compare Piller et al. (2004). Upper Jurassic and Lower Cretaceous formation names used in the text are written in bold letters. Modified after Missoni and Gawlick (2011a, 2011b). Abbreviations: A. Fm – Agatha Formation, Ap. Lst. – Aptychus Limestone, Barm. Lst. – Barmstein Limestone, Flg. Mb – Fludergraben Member, G. Mb – Gotzen Member, K. Fm – Klaus Formation, Kkb. Mb – Klauskogelbach Member, Lien. Mb – Lienbach Member, R. Fm – Ruhpolding Formation, Sa. Lst. – Saccocoma Limestone, Sach. Mb – Sachrang Member, Schmied. Mb – Schmiedwirt Member, Sks. Lst. – Seekarspitz Limestone.

(e.g., Schlagintweit et al., 2008, 2012). The sedimentological evolution of the contemporaneous Lower Cretaceous Rossfeld and Lackbach formations was triggered by sea-level fluctuations and minor/decreasing tectonic activity (Krische, 2012; Krische et al., 2014).

Towards a better knowledge on the geodynamic history of the Northern Calcareous Alps in the Early Cretaceous, the investigation of the oligo- to polymictic conglomerates, coarse-grained breccias and arenitic turbidite beds (e.g., Berriasian turbidites: Krische and Gawlick, 2010) seems to be a good tool to shed new light in this still controversial debate (Krische et al., 2014).

Studying of the Lower Cretaceous sedimentary rocks, summarized as Rossfeld Formation, started with the beginning of modern geological field work at the end of the 19th century and has continued to modern times. Alongside provenance or sedimentological investigations, only minor effort has been spent on component spectrum analyses of the coarse-grained conglomerate and breccia beds. Several detailed microfacies component analyses of these mass flow deposits are, however, today available from some localities of the Northern Calcareous Alps of Salzburg (Lackbach: Darga and Weidich, 1986; Rossfeld: Missoni and Gawlick, 2011b; compiled in Krische, 2012; Krische et al., 2014: Gutratberg quarry) (Fig.1). Mixed siliciclastic, magmatic (ophiolite suite and contemporaneous volcanic clasts), metamorphic, radiolaritic and carbonate lithoclasts as well as carbonate bioclasts constitute these polymictic Lower Cretaceous deposits (e.g., Kühnel, 1929; Weber, 1942; Medwenitsch, 1949, 1958; Del-Negro, 1949, 1983; Pichler, 1963; Faupl and Pober, 1991; Schweigl and Neubauer, 1997a; Missoni and Gawlick, 2011b; Krische, 2012; Krische et al., 2014). Krische (2012) compiled sedimentologic, macroscopic, microfacies and biostratigraphic data from the Lower Cretaceous mass flow deposits from Salzburg and Upper Austria (Fig. 1). These new results from various mass flow deposits of the Rossfeld Formation clearly show the need for a reinvestigation of the different Rossfeld Formation mass flows in the Bad Ischl area. There, the latter is described as 'Ischler Breccia' (Medwenitsch, 1958).

The intention of this paper is to present some new data from the Lower Cretaceous sedimentary successions outcropping southeast of Bad Ischl. Of special interest are the components of the coarse-grained Rossfeld-type mass flows of the Ischl Breccia (Medwenitsch, 1958). One of the main targets is to show the similarities and differences of the Ischl Breccia in comparison with the Rossfeld conglomerates and breccia beds of va-

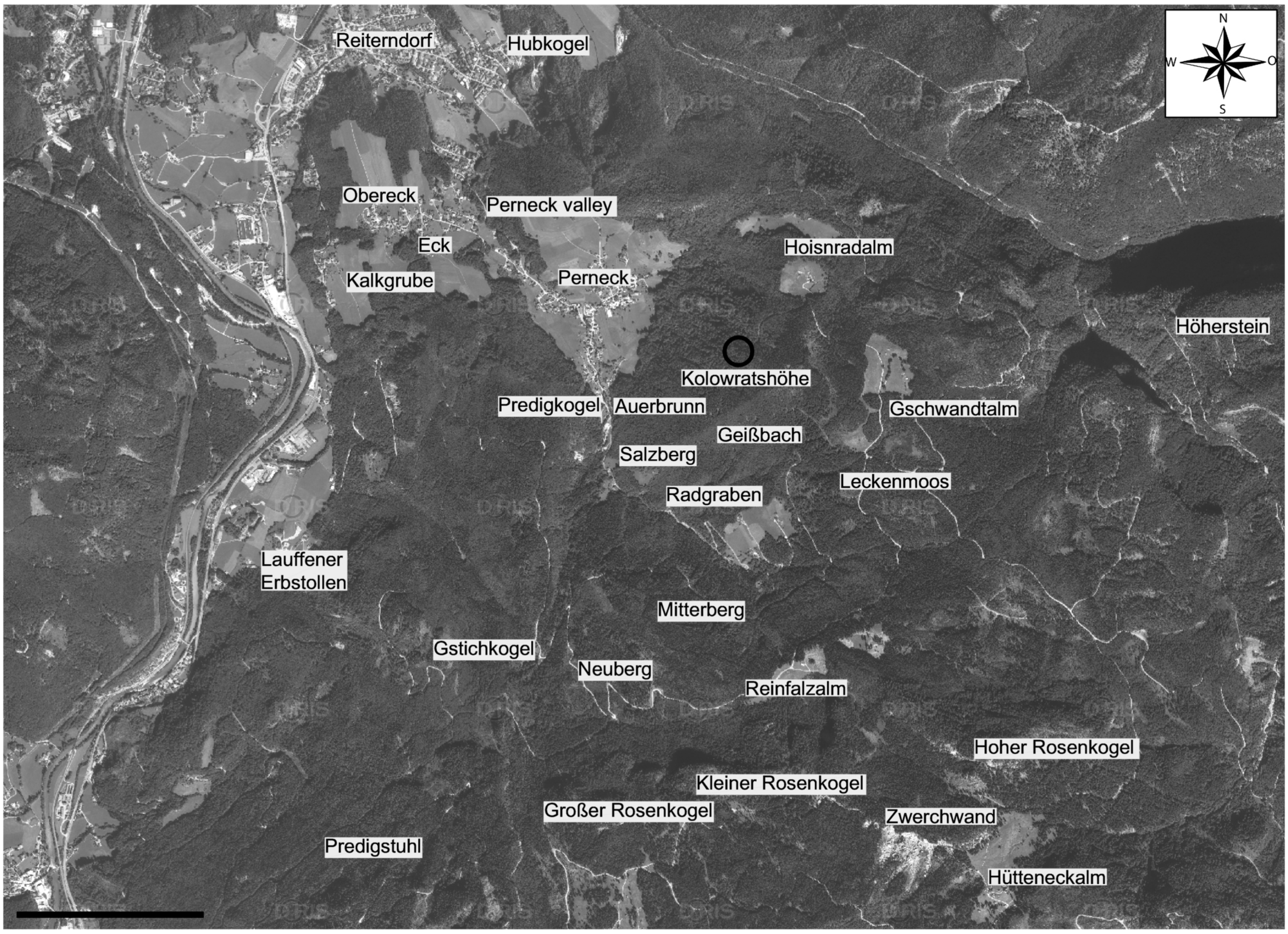


Figure 2: Bad Ischl in detail. Orthofoto (http://doris.ooe.gv.at/) with indications of the investigated sample and field localities mentioned in the text. The black circle indicates the sample location of Lukeneder (2005) at the slope of the forest road on the western Kolowratshöhe. Scale bar 1000 m.

rious occurrences in the Salzburg area (Gutratberg quarry, Rossfeld type-locality, Weitenau area: see Krische, 2012). Varying data about the component spectra and diverging interpretations of the evolution as, e.g., 'wildflysch' deposits (compare Faupl and Tollmann, 1979) were published until now and compiled herein. Of special interest is the occurrence in and nearby the salt mine of Bad Ischl. The emplacement and the actual structural position of the Alpine Haselgebirge Mélange in relationship to the Lower Cretaceous sedimentary strata is of high importance. The link between the evolution of the Ischl Breccia and the Bad Ischl salt deposit is carved out and presented within this study.

2. Ischl Breccia: history and open questions

The Tirolic sedimentary succession of Bad Ischl is part of the Staufen-Höllengebirgs-Nappe according to Tollmann (1985). The former nappe-structure is today differentiated into block pieces, separated by faults and fault zones of Cenozoic age (Frisch and Gawlick, 2003). These individual block pieces can be assigned either to the Lower Tirolic Nappe or to the Upper Tirolic Nappe according to Frisch and Gawlick (2003).

The uppermost Jurassic and Lower Cretaceous sedimentary rocks south of Bad Ischl were introduced by Medwenitsch (1949) as Oberalm and Rossfeld formations. The age range of the Rossfeld Formation is predominantly considered to be Late Valanginian to Late Hauterivian, but hints on a Barremian age also exist (Spengler, 1924; Medwenitsch, 1958; Schäffer and Steiger, 1986; Immel, 1987; compare Mandl et al. 2012: Late Valanginian to Late Hauterivian). Mandl (1999) attributed the Schrambach Formation in between the Oberalm and the Rossfeld formations a Late Berriasian to Early Valanginian age (see also Schäffer and Steiger, 1986; Mandl et al., 2012: latest Berriasian to ?Valanginian) (Fig. 1). Outcrops of the Ischl Breccia were described from the Lauffener Erbstollen, from the Salzberg and the Reinfalzalm (Medwenitsch, 1949, 1958; Lobitzer et al., 2006) (Fig. 2).

2.1 Sedimentation age

The most important macrofossil groups for biostratigraphic dating of the Lower Cretaceous of Bad Ischl are ammonites. Most of them were collected at different localities on the Hubkogel, in the Radgraben and on the Kolowratshöhe (von Hauer, 1850; Uhlig, 1882, 1888; Schäffer, 1973; Immel, 1987; Lukeneder, 2005). The exact positions of the majority of these ammonite bearing outcrops are not known in detail today. In general, the outcropping rocks at the Hubkogel were dated as Late Valanginian to Early Barremian by Immel (1987) (see also Mandl et al., 2012: Hauterivian ammonites from the Hubkogel, det. Alexander Lukeneder). Ammonite investigations along the forest-road on the western Kolowratshöhe by Lukeneder (2005) prove a Late Valanginian age (lower *Criosarasinella furcillata* Zone) for this occurrence (Fig. 2). Nannoplankton and foraminifera were determined by Schmid (1975, 1976, 1977) in different sections of marly rocks at the Hubkogel, on the Hoisenradalm and on the Reinfalzalm (Fig. 2). These age data gave some additional knowledge on the overall Early Cretaceous age of these marly rocks. From the underground mine of Bad Ischl (main gallery: Kaiser Franz-Josef Erbstollen, Lauffener Erbstollen) and from the Radgraben, Lobitzer et al. (2006) recorded foraminifera, calcareous nannoplankton, palynoflora (dinoflagellates, palynomorphes and sporomorphes) from marlstones. The determined microfauna constrained a Valanginian to Middle Albian age range for these rocks (Lobitzer et al., 2006). Dating of the clayey-marly matrix of the Ischl Breccia suggested a Late Hauterivian sedimentation age (Lobitzer et al., 2007). The grey, sandy marlstones sampled along the forest road slope near the Maria Theresia main gallery, still below the Ischl Breccia, yielded a badly preserved calcareous nannoplankton assemblage and rare foraminifera (Mandl et al., 2012), which are in accordance with a Late Hauterivian age of these rocks. According to Medwenitsch (1958) the deposition age of these breccia beds should be Aptian to "Gaultian" (= Albian, uppermost Lower Cretaceous).

2.2 Component spectra

The components of the mass flow deposits and breccia beds have yet only been investigated macroscopically (Medwenitsch, 1949, 1958; Lobitzer et al., 2006) (Table 1). Schäffer and

Medwenitsch, 1949, 1958	black schist from the Haselgebirge (Glanzschiefer) red Werfen schist (Lower Triassic) Hallstatt Limestone (Triassic) red Jurassic limestone marlstone (Liassic) crinoid-rich limestone (Liassic) red, grey and yellow radiolarite Plassen Limestone (uppermost Jurassic) Tressenstein Limestone (uppermost Jurassic) Oberalm Formation (uppermost Jurassic) melayphr quartz
Schäffer and Steiger, 1986	Hallstatt Limestone (Triassic) quartz, feldspar, chlorite amphiboles, kaersutite chromium spinel
Lobitzer et al., 2006	Werfen Formation (Lower Triassic) Barmstein Limestone (Upper Tithonian to Berriasian) Oberalm Formation (Upper Tithonian to Berriasian) Upper Rossfeld Formation (Lower Cretaceous)

Table 1: Clastic components of the mass flow deposits of the Ischl Breccia identified in the Lauffener (Kaiser-Franz-Josef) Erbstollen (Medwenitsch, 1949, 1958; Lobitzer et al., 2006) and outcrops near Reinfalzalm and Salzberg (Medwenitsch, 1949, 1958).

Steiger (1986) showed some results on the light and heavy mineral content of the Ischl Breccia and accompanying rocks (Table 1).

2.3 Model for origin and evolution

Likewise the Rossfeld Formation in the Salzburg region, the Ischl Breccia should reflect a similar depositional history in a similar geological setting. Thrust emplacement of the Lower and Upper Hallstatt Nappes (both belonging to the Lower Juvavic Nappe complex) as well as the Upper Juvavic Nappes (e. g., Dachstein Nappe) onto the Tirolic Nappe complex (Staufen-Höllengebirgs-Nappe) in the latest Early Cretaceous is still a widely accepted model for both the central Salzkammergut region (Medwenitsch, 1949, 1958; Mandl, 1999; Mandl et al., 2012) and the Salzburg Calcareous Alps (e.g., Decker et al., 1987; Tollmann, 1985; Schweigl and Neubauer, 1997a, 1997b; Faupl and Wagreich, 2000; Schorn and Neubauer, 2011). On top of the Tirolic Nappe or in front of the Lower Juvavic Hallstatt Nappes, respectively, coarse-grained, mixed siliciclastic resediments were deposited and interpreted as wildflysch (Medwenitsch, 1949, 1958). The components of the resediments should have been eroded from these advancing nappes and contemporaneously resedimented within the Lower Cretaceous marls of the Tirolic Nappe.

The Haselgebirge should be primarily situated in the footwall of the Juvavic Nappes and due to the tectonic convergence it was partly sheared off and as well as the other eroded rocks accumulated in front of the advancing Hallstatt Nappes as components of the Ischle Breccia. A general coarsening upward trend within the breccia beds with the deposition of big olistolithes and mega-slides should have culminated with the emplacement of the Alpine Haselgebirge slide on top of the Ischl Breccia. According to Medwenitsch (1958) the actual position of the salt deposit of Bad Ischl should be just above the Tirolic sedimentary succession which ended with the deposition of the Ischl Breccia. The Alpine Haselgebirge below the Juvavic Nappes should document the end of the resedimentation phase and the final overthrusting tectonic movements in the latest Early Cretaceous. The sedimentary bed dip of the Rossfeld Formation below the Triassic dolomites (Juvavic Nappe) of the Predigkogel (Medwenitsch, 1949; Schäffer, 1982) and the tectonic contact of the Alpine Haselgebirge to the Ischl Breccia in the Lauffener Erbstollen (Lobitzer et al., 2006) should confirm this interpretation at Bad Ischl respectively in the whole Salzkammergut area (see details below).

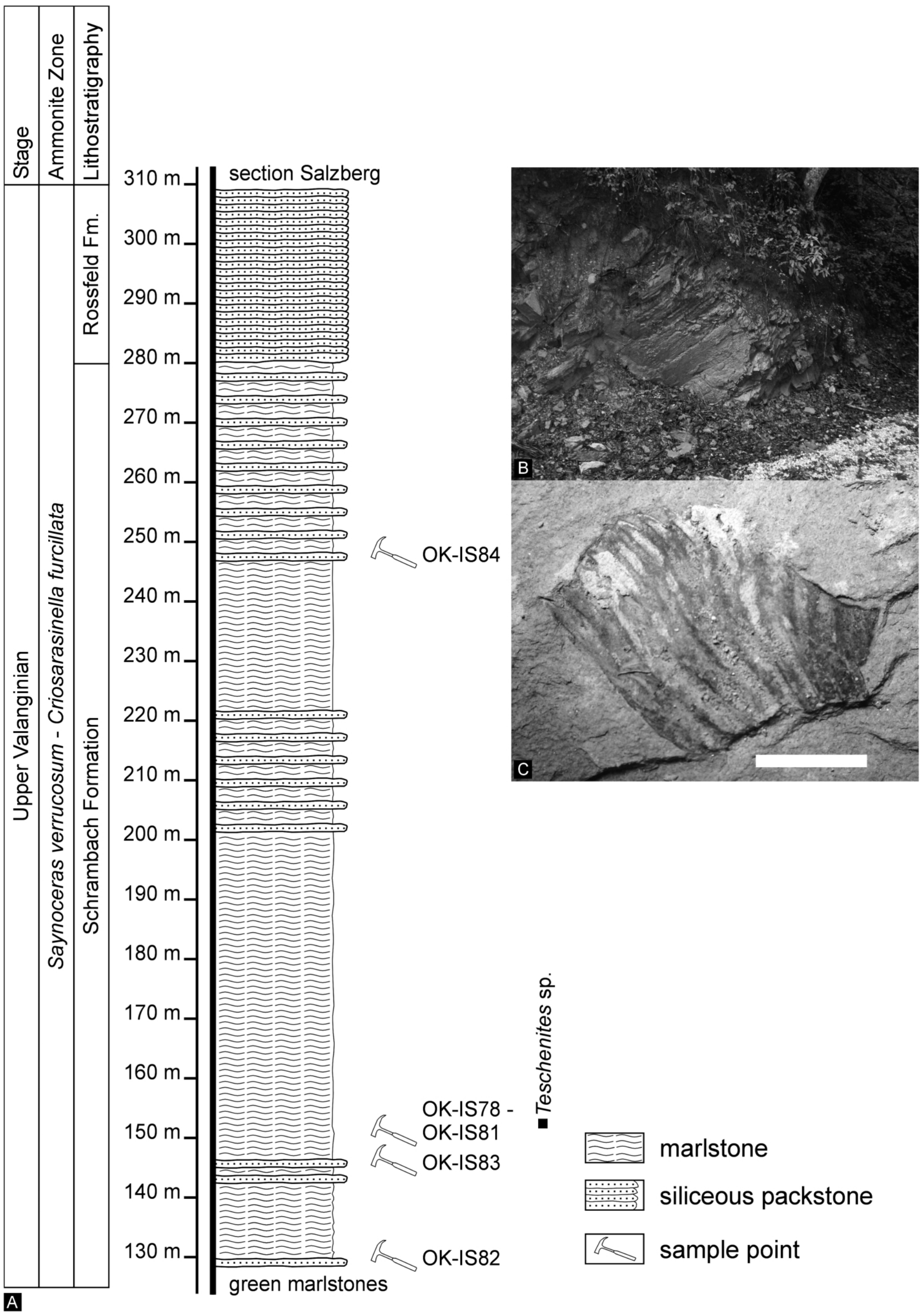


Figure 3: A: Green marlstones and intercalated siliceous packstone beds of the Schrambach Formation exposed in the Radgraben. B: Marlstone outcrop near the forest road. Scale of foto approximately 6 m. C: Ammonite fragment Teschenites sp. (Schrambach Formation). Scale bar 10 mm.

3. Study area

The studied area extends from the western Höhersteinplateau in the east up to the Kolowratshöhe and down to Perneck. The northernmost part of the investigated area is placed around the Hubkogel. To the south the mapped area reaches up to the Reinfalzalm. The east-west running Sulzbach north of Mount Zwerchwand, Großer and Kleiner Rosenkogel marks the southern boundary. Additionally, the most western parts Kalkgrube, Obereck and Eck complete the investigated area (Fig 2.).

Medwentisch (1958), Leischner (1959), Pistotnik (1973/1974), Schäffer (1976, 1983), Lukeneder (2005), Winterleitner (2009), and Mandl et al. (2012) summarized the overall geological situation of the whole area. The official Geological Map of Austria, Sheet Nr. 96 Bad Ischl was prepared by Schäffer (1982). Detailed local results from surface and underground mapping were published by Medwenitsch (1949, 1958), Schadler (1949), Mayrhofer (1953), Leischner (1959), Lichtenegger (1960), Pistotnik (1972), Schöllnberger (1972), Schäffer (1973), Lobitzer et al. (2006, 2007), Winterleitner (2009) and Mandl et al. (2012).

4. Material and methods

The area was investigated in detail by field mapping, lithostratigraphic rock description, ammonite sampling, and structural analyses. Different outcrop sections of Lower Cretaceous sedimentary rocks were studied, mapped in detail and interpreted due to their sedimentary evolution, depositional age, and their possible correlation and palaeogeographic settings. A detailed summary of the common formations of the Northern Calcareous Alps (according to Gawlick et al., 2009) is given in Fig. 1C (modified after Missoni and Gawlick, 2011a, 2011b). From all selected rock-samples thin sections were produced and analysed. The zonation of Reboulet et al. (2014) for ammonite biostratigraphy was used for biostratigraphic dating. Thin sections are stored at the Montanuniversität Leoben, Austria, whereas the ammonite fragments are preserved in the Palaeontological Museum, Eötvös University (1/C Pázmány Péter sétány, H-1111, Budapest, Hungary).

5. Results

5.1 Radgraben

Along the Radgraben a more or less complete section of marly rocks was studied along the forest-road and in the stream ‚bed of the Radgraben (Fig. 3). The typical appearances of the brownish, higher in the section greenish marlstones are thin or thick bedded, flat-platy or wavy bedded varieties. The microfacies shows quartz-bearing wackestones with crinoidal remnants, radiolarians, shell fragments, sparite remnants, micrite clasts, plant debris and detrital grains within a brown matrix. From section metre 130, intercalations of blackish-

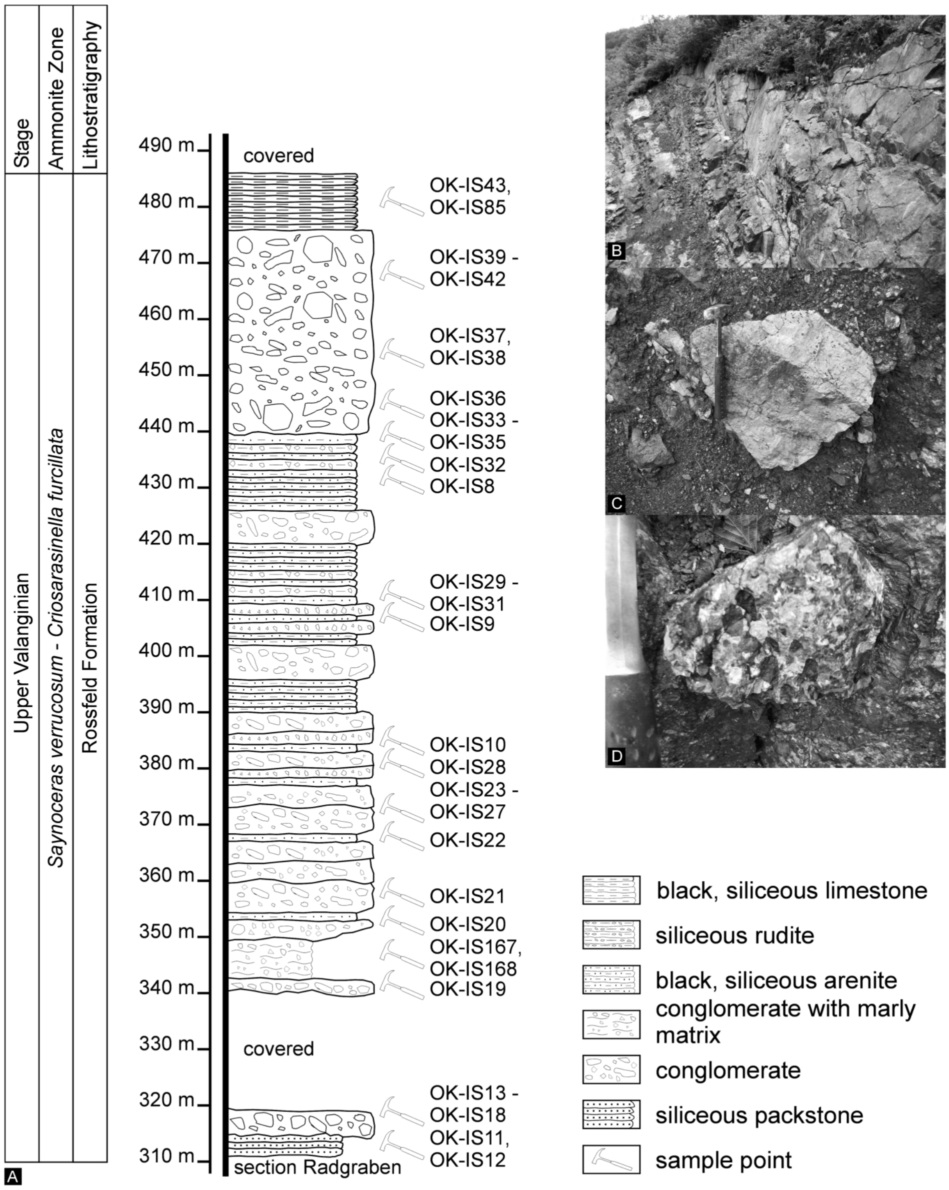
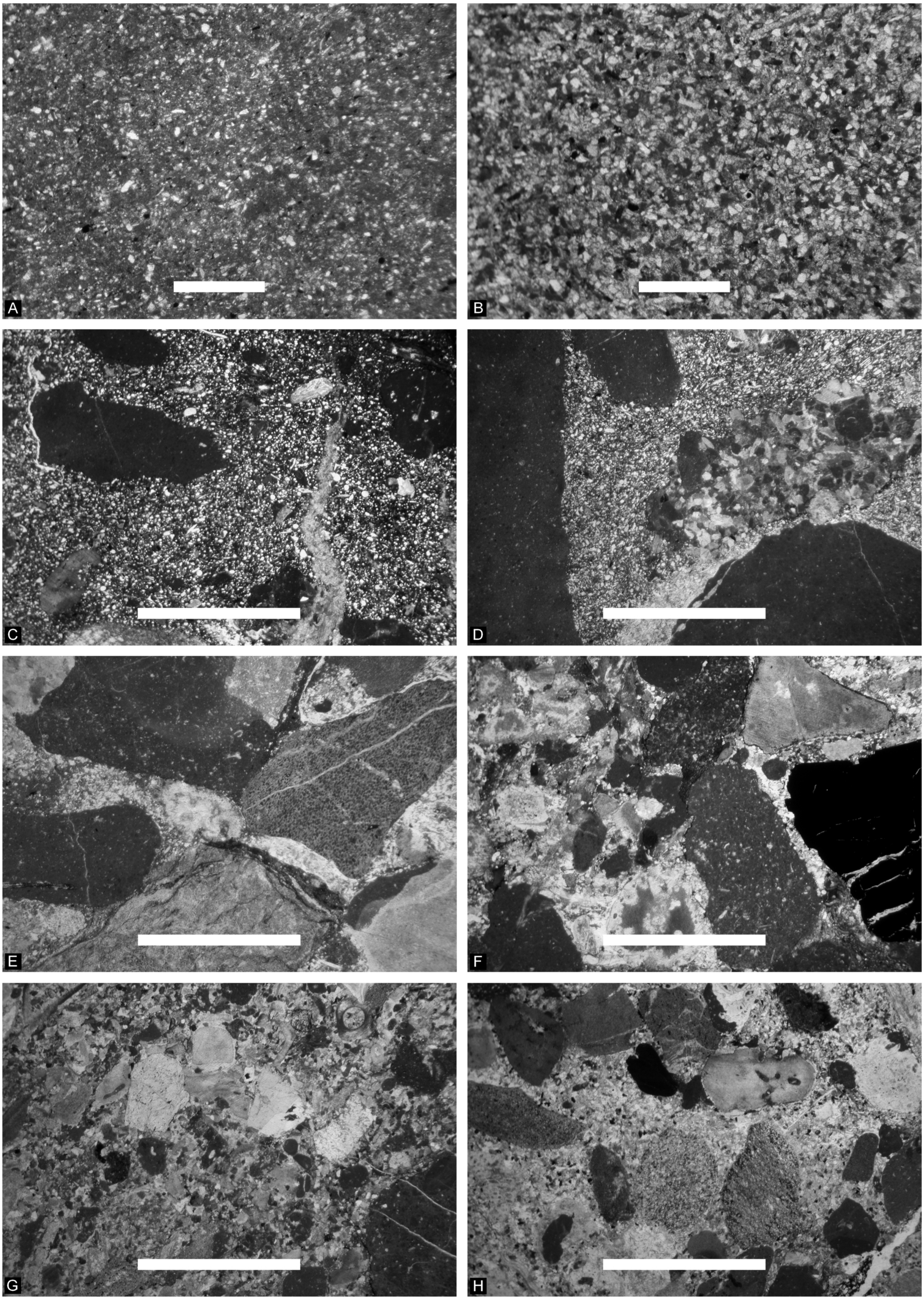


Figure 4: A: Outcrop section of the Rossfeld Formation at the forest road near the Bad Ischl Salzberg. B: Mass flows, siliceous arenites and marl-rich conglomerate layers, tilted by younger tectonic forces. Scale of foto approximately 9 m. C: Single shallow-water carbonate clast within a marl layer. Scale hammer shaft. D: Polymictic breccia clast surrounded by marly rocks. Scale hammer shaft.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brown, 10 to 20 cm bedded, siliceous limestone are observed. They occur in cyclic intervals between section metres 130-150, 200-220 and 250-280, and can be described as packstones with shell fragments, sponge spicula, radiolarians, sparite remnants, micrite clasts and detrital grains. The components are quite similar to those of the marls, but they are packed more densely. Additionally, calpionellid fragments are present. At section metre 150 ammonite fragments like *Teschenites* sp. (det. László Bujtor, Pécs) were found. This sample point indicates a Late Valanginian age of the marlstones (*Saynoceras verrucosum* Zone). According to the lithology, the microfacies (Fig 5) and the general sedimentation age these marly rocks can be defined as Schrambach Formation. Above section metre 280, bedded blackish-brown siliceous, siliciclastic-influenced packstones replace the marlstones completely. Upsection these are bedded in a 10 to 40 cm range and show a significantly greater amount of quartz and detrital grains whilst radiolarians and sponge spicula are getting less and less. In addition to quartz, chromite, serpentine, garnet, amphiboles and micas occur. According to the lithology and the microfacies (Fig 5) this part of the succession corresponds to the Rossfeld Formation.

5.2 Salzberg

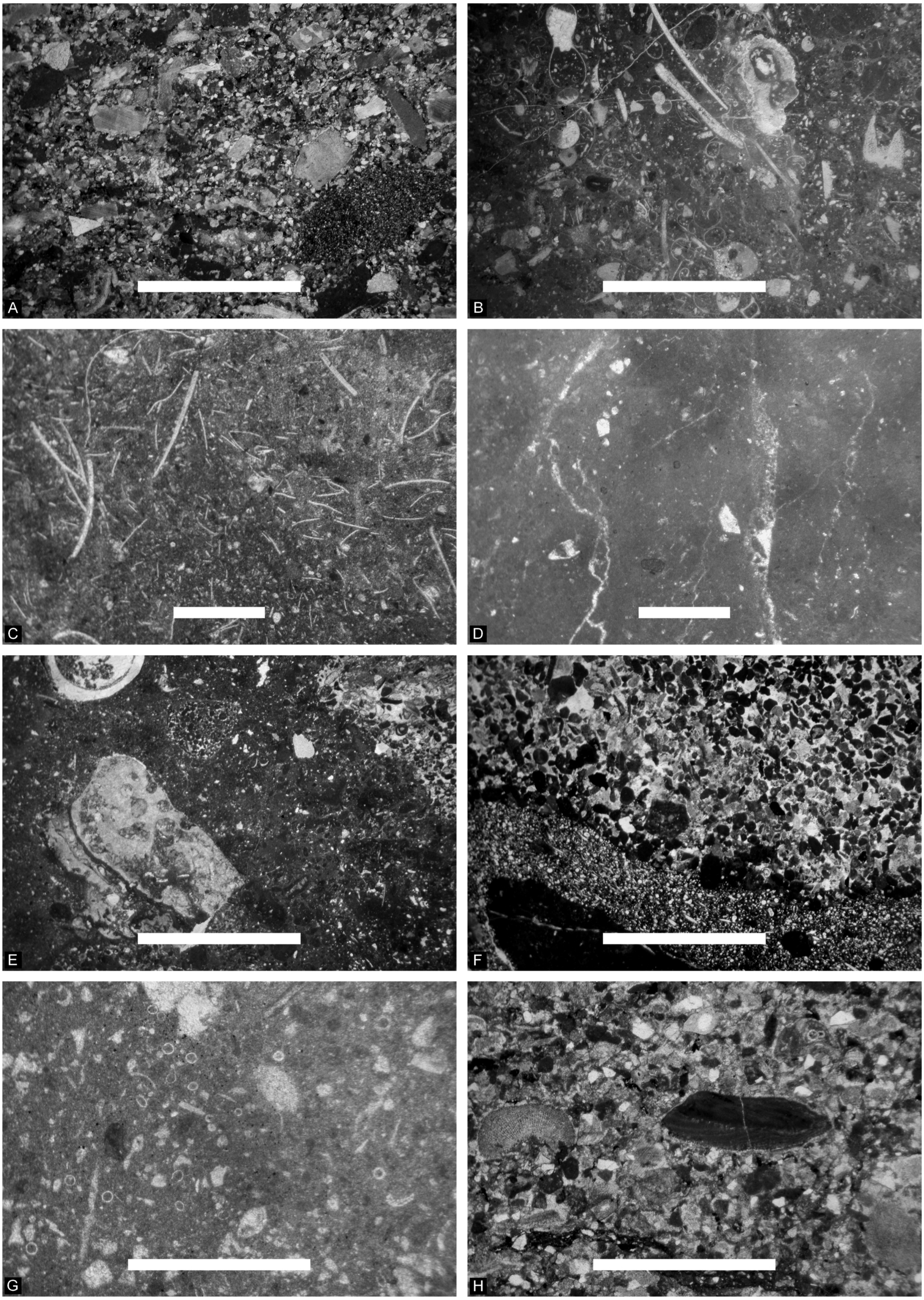
The Salzberg section (Fig. 4) outcrops along the forest-road below the main house of the ancient salt mine down to the Auerbrunn, at the beginning of that road (Fig. 2). It is the direct continuation of the Schrambach Formation of the Radgraben section. On the forest-road slope bedded, blackish-brown siliceous limestones are erosively truncated by coarse-grained breccia beds. This sharp contact defines the substitution of the marlstones and the siliceous limestones sedimentation of the Schrambach Formation by the coarse mass flow deposition of the Rossfeld Formation. The unsorted, subangular, up to half-metre sized components document an abrupt change of the sedimentation pattern. Along the road slope, sedimentologically different types of breccias and conglomerates are exposed. Mixed matrix- and clast-supported conglomerates occur together with carbonate cemented, bedded rudites. The coarse clastics can be described as cohesive to ductile mass flows or non-cohesive mass flows (Walker, 1978; Pickering et al., 1989; Mutti et al., 2009). These coarse, cobble- and boulder-sized clastic rocks are overlain by graded cycles of rudites, siliceous arenites, crinoidal-rich packstones, poorly cemented, glauconite-rich sandy arenites and blackish-brown siliceous limestones (Figs. 4, 5, 6, Table 2). As documented in the profile, the amount of coarse-grained mass flows decreases upwards the section and siliceous limestones and siliceous arenites with scarce ruditic beds become more common. Above the topmost conglomerate beds follow syn-sedimentary folded to bedded, grey, chert-nodule bearing siliceous limestones and thin bedded, grey, siliceous marls. The limestones occur in the form of packstones with sparitic and micritic clasts, crinoidal remnants, radiolarians, texulariids, sponge spicula and detrital grains. Detrital grains from crinoidal-rich packstones, glauconite-rich arenites and siliceous marls comprise quartz, apatite, chromite, zinc-chromite, ilmenite, titanite, serpentine, garnet, mica, feldspar, pyroxens and amphiboles. The Salzberg section follows stratigraphically above the Radgraben section. The maximum sedimentation age of the mass flows is therefore Late Valanginian.

Figure 5: Characteristic microfacies of the Schrambach (A, B) and the Rossfeld formations (C-H) from the Radgraben and the Salzberg sections (Upper Valanginian). A: Quartz-bearing, marly wackestone with crinoidal remnants, radiolarians, shell fragments, sparite clasts, micrite clasts, plant remnants and colourful detrital grains; OK-IS52. B: Siliceous packstone with sparite remnants, micrite clasts, quartz, detrital grains, crinoid and shell remnants; OK-IS84. C: Matrix-supported, lithoclastic conglomerate with different wackestone lithoclasts and crinoids. The matrix is formed by marly radiolarian-sponge spicula packstones with crinoidal remnants; OK-IS19. D: Matrix-supported, lithoclastic conglomerate with hemipelagic radiolarian wackestones and coarse-grained crinoidal packstones (slope facies); OK-IS20. E: Clast-supported, lithoclastic conglomerate with hemipelagic wackestones, lagoonal wackestones, filament-rich limestones and oolithic limestones; OK-IS21. F: Clast supported conglomerate with siliceous limestones, wackestones rich in sponge spicula, packstones with *Tubiphytes* sp., blackish volcanic glass and crinoids; OK-IS21. G: Siliceous, crinoidal turbidite with carbonate lithoclasts and microcrystalline, siliceous rock fragments; OK-IS31. H: Lithoclastic breccia (micrites, siltstones) with crinoids and quartz-rich matrix; OK-IS39. Scale bars: 1 mm for A and B; 5 mm for C to H.

5.3 Lauffener Erbstollen

Reinvestigations in the Lauffener Erbstollen led to completely different results in comparison to earlier descriptions of some of the exposed sections (Medwenitsch, 1958; Lobitzer et al., 2006). The sedimentary contact between the Alpine Haselgebirge and coarse-grained breccia beds (around section metre 3000) was later slightly overprinted by younger tectonics. Grey, siliceous limestone samples from section metre 2950, still in depositional contact above the Alpine Haselgebirge, contain a small, poorly preserved radiolarian fauna including *Zhamoidellum ovum* Dumitrica (Callovian to Early Tithonian). Upsection, from metre 2950 to metre 1860, the basal breccia beds above the Alpine Haselgebirge are followed by successions of biomicritic cherty limestones with calpionellids, resedimented shallow-water material from the Plassen Carbonate Platform and intercalated mass flow deposits with reworked Alpine Haselgebirge clasts and blocks from the Plassen Carbonate Platform. The lithological content of these rocks was in parts described by Medwenitsch (1958). The succession shows typical characteristics of the Late Tithonian Oberalm Formation and Barmstein Limestone (Gawlick et al., 2009) and "Tonflatschenbrekzien" (Plöchinger, 1974, 1977) as known from the Salzburg area (Gutratberg, Leube quarry). Here, the Alpine Haselgebirge is intercalated within the Late Tithonian Oberalm Formation (Plöchinger, 1974, 1977; compare Krische, 2012; Krische et al., 2013a).

That Late Tithonian sedimentary succession is overlain by well bedded red radiolaritic limestones in the hanging wall of a bedding-parallel thrust fault. The red radiolaritic limestone, outcropping between gallery metres 1860 and 1840, yielded a Callovian to Oxfordian age, dated by means of the following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radiolarians (Fig. 7):

Sample EL 38 (metre 1860): *Zhamoidellum ovum* Dumitrica, *Eucyrtidiellum* cf. *unumaense pustulatum* Baumgartner, *Archaeodictyomitra* cf. *mitra* Dumitrica, *Archaeodictyomitra rigida* Pessagno, *Williriedellum* sp., *Zhamoidellum* sp., *Eucyrtidiellum* sp.

Sample EL 39 (metre 1840): *Archaeodictyomitra* sp., *Eucyrtidiellum ptyctum* Riedel and Sanfilippo.

From gallery metre 1840 to 1100 rocks are generally covered by protection structures, for which reason the succession overlying this radiolarite equivalent is not visible. Only a few damages in the protection give insights on the covered rocks. One of these damages near gallery metre 1560 allowed sampling greenish cherty marls which yielded beside sponge spicula a minor, poorly preserved radiolarian fauna (EL 41; Fig. 8): *Archaeodictyomitra mitra* Dumitrica, *Hiscocapsa uterculus* Parona, *Stichomitra altiforamina* Tumanda and *Loopus suyarii* Dumitrica. The radiolarian association indicates a depositional age around the Valanginian/Hauterivian boundary for this sample compared to radiolarian associations published by Goričan (1994), Jud (1994), Baumgartner et al. (1995), and Dumitrica et al. (1997).

Lithologically similar sedimentary rocks occur between gallery metres 1560 and 1100. From gallery metre 1100 to 1030 a series of different mass flows intercalations within marly sediments is visible, lithologically similar to the Ischl Breccia at surface outcrops near to the salt mine. A sparse radiolarian fauna was isolated from the marly matrix of the mass flows. The sample (EL 44, Fig. 9) contains the following species: *Dictyomitra* sp., *Thanarla brouweri* Tan, *Thanarla pulchra* Squinabol, *Wrangellium husei* Pessagno and Whalen and *Xitus gifuensis* Mizutani. The age of this sample is Late Valanginian/Hauterivian using zonations and radiolarian assemblages by Baumgartner et al. (1995) and Dumitrica et al. (1997). However, the age range of *Wrangellium husei* Pessagno and Whalen has to be investigated further. No information at all is available from gallery metre 1030 to 0 due to wall protection without any severe damages.

5.4 Kolowratshöhe west

The sedimentary succession of the Radgraben and the Salzberg sections is exposed in several outcrops from the Auerbrunn along the hillside-toe of the Kolowratshöhe in northwestern direction (Fig. 2). The grey, siliceous limestones show platy to wavy bedding in a 20 to 40 cm range. According to their microfacies they can be described as packstones with crinoidal remnants, radiolarians, sponge spicula, micrite clasts, sparite remnants, quartz, detrital grains and brown, marly clasts. Within the partly siliciclastic influenced siliceous limestones some coarse-sandy to fine-gravel sized conglomerate beds occur. They can be grouped as siliceous, lithoclastic, crinoidal-rich resediments and matrix-supported fine-grained, immature conglomerates with coarse-sandy to coarse-silty

Figure 6: Typical microfacies of crinoid-rich beds (A, F, H) and selected lithoclasts of mass flow deposits (B-E, G) of the Rossfeld Formation (Upper Valanginian) from the Salzberg section. A: Crinoid-rich turbidite with micrite clasts, sparite remnants, quartz-bearing siltstone lithoclasts, quartz and detrital grains; OK-IS9. B: Ammonoid-rich packstone with crinoids; OK-IS27. C: Filament-rich wackestone with radiolarians; OK-IS13. D: Wackestone of the tidal flat with fenestral fabrics and intraformational micro breccias; OK-IS171. E: Slope facies, floatstone with microbial incrusted calcareous sponges, gastropods, crinoids and wave-washed packstone lithoclasts resedimented from platform areas with higher wave energy; OK-IS18. F: Crinoid-rich, siliciclastics-bearing packstone; OK-IS15. G: Wackestone with sparite remnants, lenticuliniids, crinoids and *Calpionella alpina* Lorenz; OK-IS120. H: Quartz- and crinoid-rich packstone with sparite remnants, micritic clasts and *Sporolithon rude* Lemoine; OK-IS22. Scale bars: 1 mm for C, D, G, H; 5 mm for A, B, E, F.

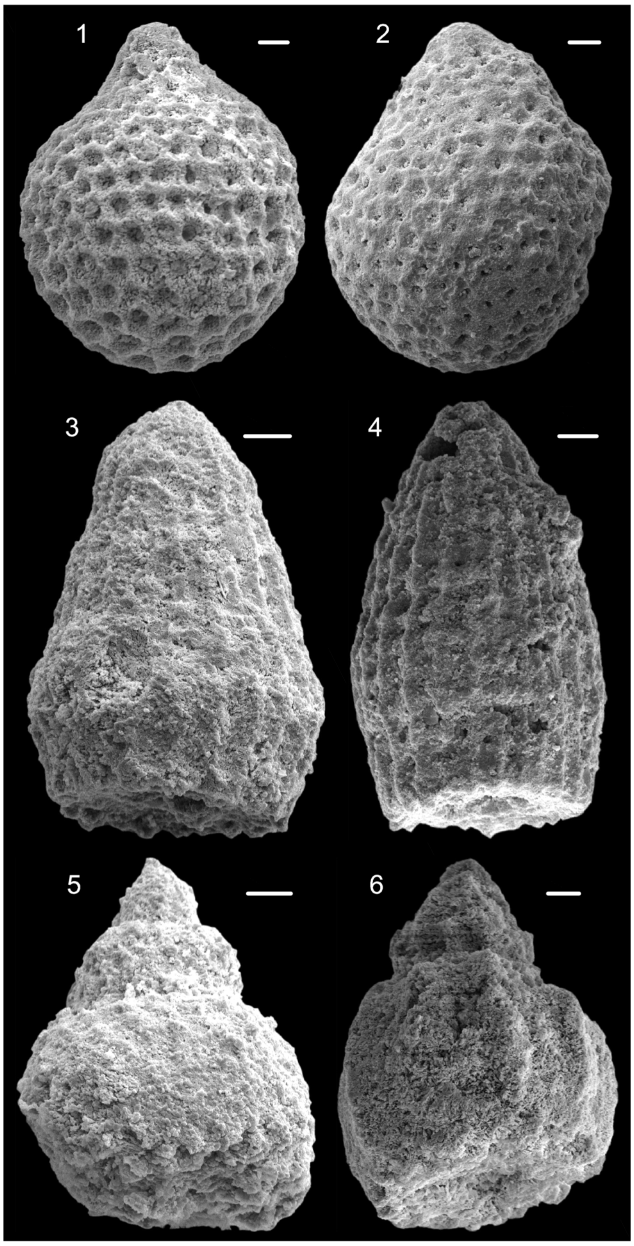


Figure 7: Characteristic radiolarian fauna of Middle to Upper Jurassic rock samples (Ruhpolding Radiolarite Group) of the Lauffener Erbstollen. 1, 2: *Zhamoidellum ovum* Dumitrica, EL38. 3: *Archaeodictyomitra* cf. *mitra* Dumitrica, EL38. 4: *Archaeodictyomitra rigida* Pessagno, EL38. 5: *Eucyrtidiellum* cf. *unumaense pustulatum* Baumgartner, EL38. 6: *Eucyrtidiellum ptyctum* Riedel and Sanfilippo, EL39. Scale bar 10 µm for 1 to 6.

sized components. The pore space between the coarser components is filled up with coarse-silty bioclasts (e.g., crinoids, radiolarians, sponge spicula, textulariids), sparite remnants, micrite clasts, quartz and detrital grains. These rocks are also assigned to the Rossfeld Formation. The conglomerate beds are followed upsection by grey, siliceous limestones, brown, turbiditic, sandy, siliceous limestones and siliceous marls. The sedimentary succession reaches down to the grassland area north of Perneck where the geological documentation ends due to the lack of outcrops.

5.5 Kolowratshöhe forest-road

A section comparable to those of the Radgraben, the Salzberg and the hillside-toe of the Kolowratshöhe outcrops around the top of the Kolowratshöhe and is best exposed along the forest-road on the western and northern side of the mountain (Fig. 2). From the Gschwandtalm to the west, in the valley of the Geißbach and on the hiking path into direction Leckenmoos, marly rocks crop out. The turbiditic marlstones with intercalations of siliceous packstone beds resemble the situation in the Radgraben (Schrambach Formation). Due to intensive erosion along the forest-road-slopes the basal conglomerate beds of the Rossfeld Formation are not exposed on the northern Kolowratshöhe. The continuation of the section can be studied on the western flank of the mountain along the last 200 m of the forest-road. The wavy-bedded siliceous limestones are best described as quartz-bearing, marly packstones and marls (Fig. 10, Table 2). Both radiolarian- and sponge spicula-rich packstones show similarities to the rocks outcropping at the hillside-toe, equally coarse-sandy and gravel sized conglomerate beds and siliceous crinoidal-rich packstones are intercalated (Fig. 10, Table 2). Both facies-types and the bio- and lithoclastic component spectrum are similar to the ones described from the slope base of the Kolowratshöhe (see chapter 5.4).

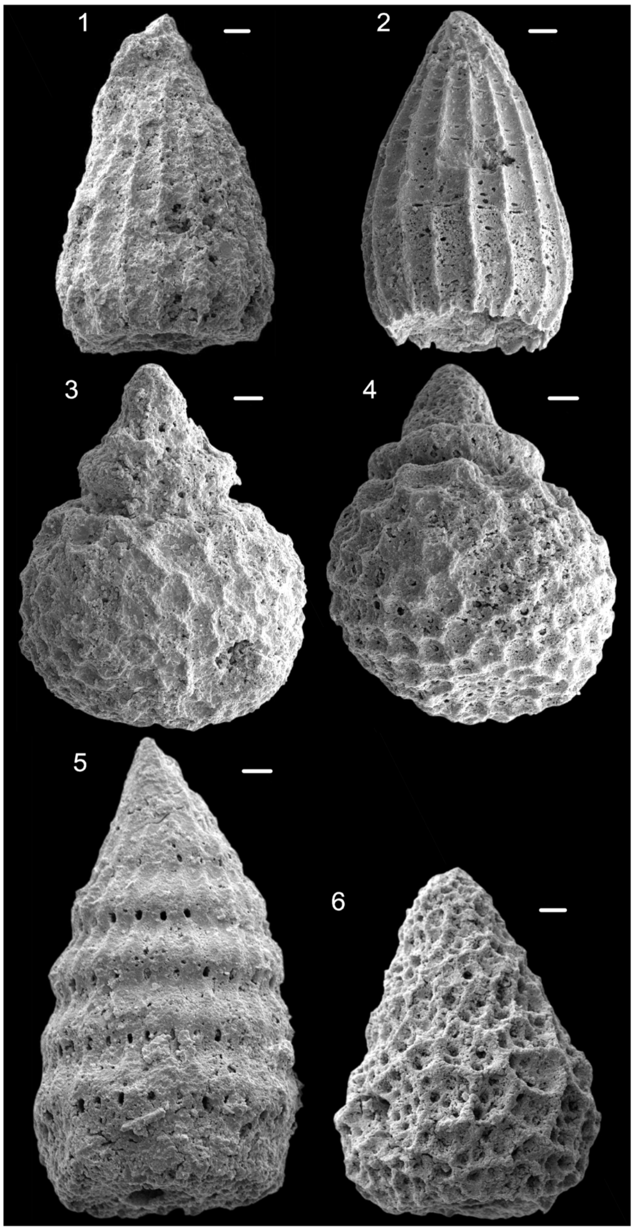


Figure 8: Characteristic radiolarian fauna of the Lower Cretaceous Schrambach Formation of the Lauffener Erbstollen, extracted from sample EL41. 1, 2: *Archaeodictyomitra mitra* Dumitrica. 3, 4: *Hisocapsa uterculus* Parona. 5: *Loopus suyarii* Dumitrica. 6: *Stichomitra altiforamina* Tumanda. Scale bar 10 µm for 1 to 6.

5.6 Perneck valley

Down in the Perneck valley west of the main water-fall, wavy- to flat-bedded siliceous limestones with beds in a 5 cm to 10 cm range are exposed. Intercalated in the upper part of the section occur lithoclast-rich, crinoidal-bearing resediments, brown siliceous arenites and ruditic conglomerate beds (Fig. 11, Table 2). The components can be grouped into bioclasts and lithoclasts (Fig. 12). The matrix is formed by marly packstones with coarse, silt-sized quartz, heavy minerals, detrital grains, crinoids, radiolarians, sponge spicula and sparite remnants. Above the conglomerate beds follow siliceous bedded to turbiditic, black limestones and stretch until the current end of the outcrop. These rocks can also be assigned to the Rossfeld Formation.

6. Discussion

6.1 Ischl Breccia/Rossfeld Formation

The investigated Lower Cretaceous outcrops and sections presented herein show clearly the situation of the Rossfeld Formation on top of marly rocks of the Schrambach Formation. Deposition of the Rossfeld Formation started abruptly with a basal conglomerate and breccia sequence. From the bottom to the top of this basal cycle the clastic rocks become finer and coarse beds remain seldom. These mass flows were termed "Ischler Brekzie" by Medwenitsch (1958).

6.2 Sedimentation age

Based on new biostratigraphical results which are in line with literature data (Lukeneder, 2005) and the correlation of the Radgraben, Salzberg and Kolowratshöhe and Lauffener Erbstollen sections, the sedimentation age of the mass flows can be determined more precisely. Supported by ammonite findings (Teschenites sp., Krische, 2012) in the Schrambach Formation of the Radgraben still below the coarse mass flows, the lower age limit is Late Valanginian (see Ogg et al., 2008; Gradstein et al., 2012) (*Saynoceras verrucosum* Zone). The upper boundary is set by the definition of Late Valanginian (lower *Criosarasinella furcillata* Zone: Lukeneder, 2005) or the Valanginian/Hauterivian boundary above the conglomerate beds on the Kolowratshöhe. By the occurrence of *Teschenites* sp. below the basal mass flows and the definition of the lower *Criosarasinella furcillata* Zone above the conglomerate beds (Lukeneder, 2005), the age of the Rossfeld Formation of the Salzberg and Kolowratshöhe is exactly defined as Late Valanginian. The radiolarian fauna from the cherty marls below the Ischl Breccia in the Lauffener Erbstollen fits also with the Late Valanginian ammonite data. Interestingly, the reported Valanginian/Hauterivian age data from the Lauffener Erbstollen (Lobitzer et al., 2006) fit in general with the radiolarian and ammonite age data. An Aptian to Albian age (Medwenitsch, 1949, 1958) or the assumed long depositional range from Valanginian to Middle Albian (Lobitzer et al., 2006) can be definitely excluded. The proposed Late Hauterivian age from the clayey-marly matrix of the mass flows (Lobitzer et al., 2007) cannot be confirmed for the Salzberg and Kolowratshöhe sections. The marlstones in the Radgraben described by Mandl et al. (2012) are also of Late Valanginian age.

For the Perneck valley section a Late Valanginian depositional age of the mass flows is improbable. The underlying rocks of the Oberalm and Schrambach formations differ with regard to their lithology, microfacies and thickness from those below the Salzberg and the Kolowratshöhe sections (Krische, 2012). The sedimentary evolution of the Reiterndorf, Hubkogel and Perneck valley area is still different to that from the Gschwandtalm and Perneck site. The overall age of this blackish-brown, siliceous limestones and intercalated sandy arenites and accompanying mass flow levels is dated by ammonites as Late Valanginian to Early Barremian (Immel, 1987). Due to similar profiles in the Salzburg area for the sandy arenites and the coarser breccia and conglomerate beds of this second cycle, a Late Hauterivian to Early Barremian depositional age is most likely (see Krische, 2012).

6.3 Component spectra

The component analysis of the mass flow deposits allows a differentiation of the component spectra into the following main constituents (Table 2).

6.3.1 Triassic carbonate clasts

Lower and lower Middle Triassic carbonate material is present even though in only subordinate percentage at the investigated outcrops. These components are also described from the mass flows of the Rossfeld Formation in the Salzburg Calcareous Alps, e.g. in Gartenau and in the Weitenau area (Krische, 2012; Krische et al., 2014). The microfacies of these oolitic-limestones and densely packed shell-rich limestones ("Lumachellenkalk") are best assigned to the uppermost Werfen and the basal Gutenstein formations. Triassic carbonate clasts from shallow-water (e.g., the former Dachstein Nappe: see also Frisch and Gawlick, 2003; Missoni and Gawlick, 2011a, 2011b) or from deep-water (e.g., Lower Juvavic Nappe = Hallstatt Mélange) "Juvavic" origin, as commonly interpreted on the base of clast-colours and without microfacies analyses (Kühnel, 1929; Weber, 1942; Medwenitsch, 1949, 1958; Del-Negro, 1949, 1983; Plöchinger, 1955, 1968, 1974, 1990; Pichler, 1963), are missing at all investigated localities of the Bad Ischl area. Clasts of this origin are generally absent in all investigated mass flow deposits of the Rossfeld Formation of the Salzburg area (Missoni and Gawlick, 2011b; Krische, 2012; Krische et al., 2014).

6.3.2 Uppermost Jurassic and lowermost Cretaceous shallow-water carbonate clasts (e.g. Plassen Formation) and slope-to-basinal carbonate pebbles (Oberalm Formation + Barmstein Limestone)

This group of clasts is very common in the Lower Cretaceous

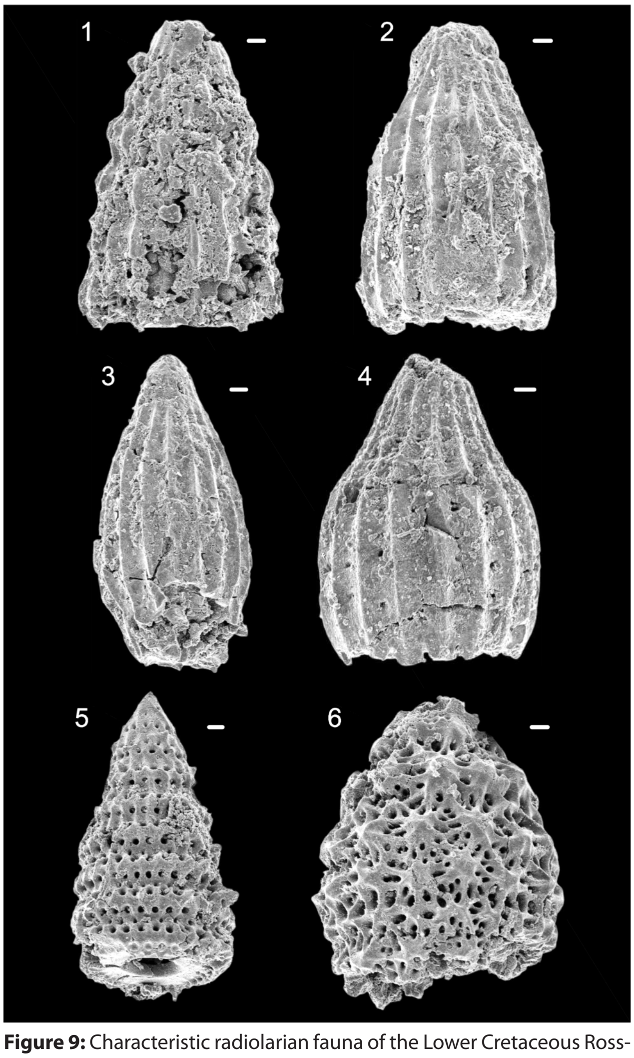


Figure 9: Characteristic radiolarian fauna of the Lower Cretaceous Rossfeld Formation of the Lauffener Erbstollen, extracted from sample EL44. 1: *Dictyomitra* sp. 2, 3: *Thanarla brouweri* Tan. 4: *Thanarla pulchra* Squinabol. 5: *Wrangellium hsuei* Pessagno & Whalen. 6: *Xitus gifuensis* Mizutani. Scale bar 10 µm for 1 to 6.

		section Salzberg	section Kolowratshöhe	section Perneck valley
Bioclasts	Lower Cretaceous	calcareous sponges, corals, serpulids *Coscinophragma* sp. micritic encrusted calcareous algae *Steinmanniporella svilajensis* Sokač and Velić, *Sporolithon rude* Lemoine Bacinella-Lithocodium nodules, oncoids crinoid remnants, brachiopods, bryozoans	*Sporolithon rude* Lemoine brachiopod shells, bryozoans, shell remnants corals, calcareous framework building organisms	different calcareous framework building organisms, e.g., sponges agglutinating lituoliid foraminifera, textularians crinoids, bryozoes, brachiopods, shell remnants
Lithoclasts	carbonates (Upper Jurassic to Middle Berriasian)	Lagoonal facies, Plassen Formation: • dolomitised micrites and wackestones, grey microsparites, micrites with fenestral texture, foraminiferal-rich wackestones, wackstones with dasycladacean remnants, Clypeina-wackestones with *Clypeina parasolkani* Farinacci and Radoičič, wackestones with *Clypeina jurassica* Favre Back-reef facies, higher energy platform area, Plassen Formation: • wave-cleaned packstones with dasycladacean algae like *Salpingoporella annulata* Dragastan and Bucur, calcareous sponges, gastropods, foraminifera like *Redmondoides* sp., ooidal-grainstones Back-reef facies, fore-reef facies, Plassen Formation: • bindstones with microbial incrusting organisms Proximal reef-slope, Plassen Formation: • bioclastic float- to packstones with framework-building organisms, crinoids, *Crescentiella* sp, lituoliid foraminifera • packstones with brachiopods, *Crescentiella* sp., calcareous sponges	Lagoonal facies, Plassen Formation: • packstones with dasycladacean remnants, e.g, clypeiniids • Clypeina wackestones with *Clypeina jurassica* Favre Higher energy platform area, Plassen Formation: • wave-cleaned packstones • ooid-rich packstones Slope facies • coarse and fine-grained packstones with crinoidal remnants and micritic clasts • glauconitic packstones Distal slope/basinal facies, Oberalm Formation: • calpionellid wackestones	Lagoonal facies, Plassen Formation: • wave-cleaned packstones with micritic clasts, foraminifera, dasycladacean remnants Back-reef facies, Plassen Formation: • wave-cleaned ooid-rich packstones with crinoids Platform margin, Plassen Formation: • bindstones with microbial incrusted organism remnants Slope facies, Plassen Formation: • coarse and fine grained crinoidal-pellets packstones Distal slope/basinal facies, Oberalm Formation: • calpionellid wackestones • radiolarian wackestones • wackestones with aptychi, calpionellids, sparite remnants, crinoids • dense, marly wackestones with radiolarian, sponge spicula
	carbonates (Upper Jurassic to Middle Berriasian)	Slope facies, Plassen Formation: • crinoidal-rich packstones with lenticuliniids • packstones with *Mohlerina* sp., *Nautiloculina oolithica* Mohler, other lituoliid foraminifera, *Crescentiella morronensis* Crescenti Distal slope/basin facies: • micrites with mm-thin resedimented layers with sparite and micrite clasts and crinoidal remnants • Calpionellid limestones with *Calpionella alpina* Lorenz and *Crassicollaria intermedia* Durand-Delga (Oberalm Formation) • pack- and wackestones with *Calpionella alpina* Lorenz, aptychi, radiolaria, crinoidal remnants, sponge spicula (Oberalm Formation) • grey filament-rich limestones • sponge spicula-rich resp. radiolaria-rich wackestones	no occurrence	no occurrence
		Breccias (“Oberalmer Basiskonglomerat”, Upper Tithonian): • grain-supported breccias with angular carbonate clasts like lagoonal Dachstein Limestone, Upper Jurassic hemipelagic limestones	no occurrence	no occurrence
	carbonates (Triassic)	oolithic limestones (uppermost Werfen to basal Gutenstein Formations)	no occurrence	no occurrence

		section Salzberg	section Kolowratshöhe	section Perneck valley
Lithoclasts	mixed calcareous-siliciclastic rocks	quartz-bearing, siliceous packstones, siliceous marlstones (Schrambach Formation) marly wackestones quartz-siltstones rich in crinoidal-remants	marly wackestones calcareous-siliciclastic packstones black wackestones with radiolaria, shell fragments, foraminifera, sparite remnants, quartz crinoidal-quartz packstones marly packstones (slope facies) with crinoids, calcareous framework building organisms, sparite remnants, micritic clasts, quartz, detrital grains	brown marly wackestones with sparite remnants, micritic clasts, crinoids, foraminifera, shell remnants brown, quartz-rich wackestones quartz-rich packstones with micritic clasts
	siliceous rocks	light, microcrystalline recrystallised radiolarites	light, microcrystalline recrystallised radiolarites	light, microcrystalline recrystallised laminated radiolarites orange to yellow, siliceous deep-sea clays
	magmatic rocks	volcanites: black, volcanic glass	altered/weathered volcanites	volcanites
	metamorphic rocks		serpentinites, partly altered/weathered	serpentinites
	siliciclastic rocks	green siltstones brown, quartz-bearing siltstones brown, pedogenetic clasts	brown fine-grained siltstones brown claystones	mica-bearing quartz sandstones brown, quartz-bearing siltstones
	diagenetic origin	cherts	cherts	cherts

mass flows of the Bad Ischl area which are comparable to the deposits of the Weitenau area, of the Gartenau quarry and on the Rossfeld (Krische, 2012). The subangular carbonate material was eroded nearby the final depositional area of the breccia and conglomerate beds.

6.3.3 Breccias, „Oberalmer Basiskonglomerat" (Lower Tithonian/Upper Tithonian)

Breccia clasts of the so called "Oberalmer Basiskonglomerat" occur seldom within the conglomerate and breccia beds of the Rossfeld Formation. Reworked breccia components of the Triassic Dachstein Limestone occur exclusively in the form of pebbles as constituents of redeposited "Oberalmer Basiskonglomerat" components.

6.3.4 Radiolarite clasts and other siliceous pebbles

They are quite seldom in the breccia and conglomerate beds of Bad Ischl, on the Rossfeld and in the Weitenau area. A very high percentage of radiolarite pebbles in the basal mass flows of the Rossfeld Formation is only typical for the Gartenau section (Krische, 2012; Krische et al., 2014) and, to a less extent, also for the type locality Rossfeld (Missoni and Gawlick, 2011a).

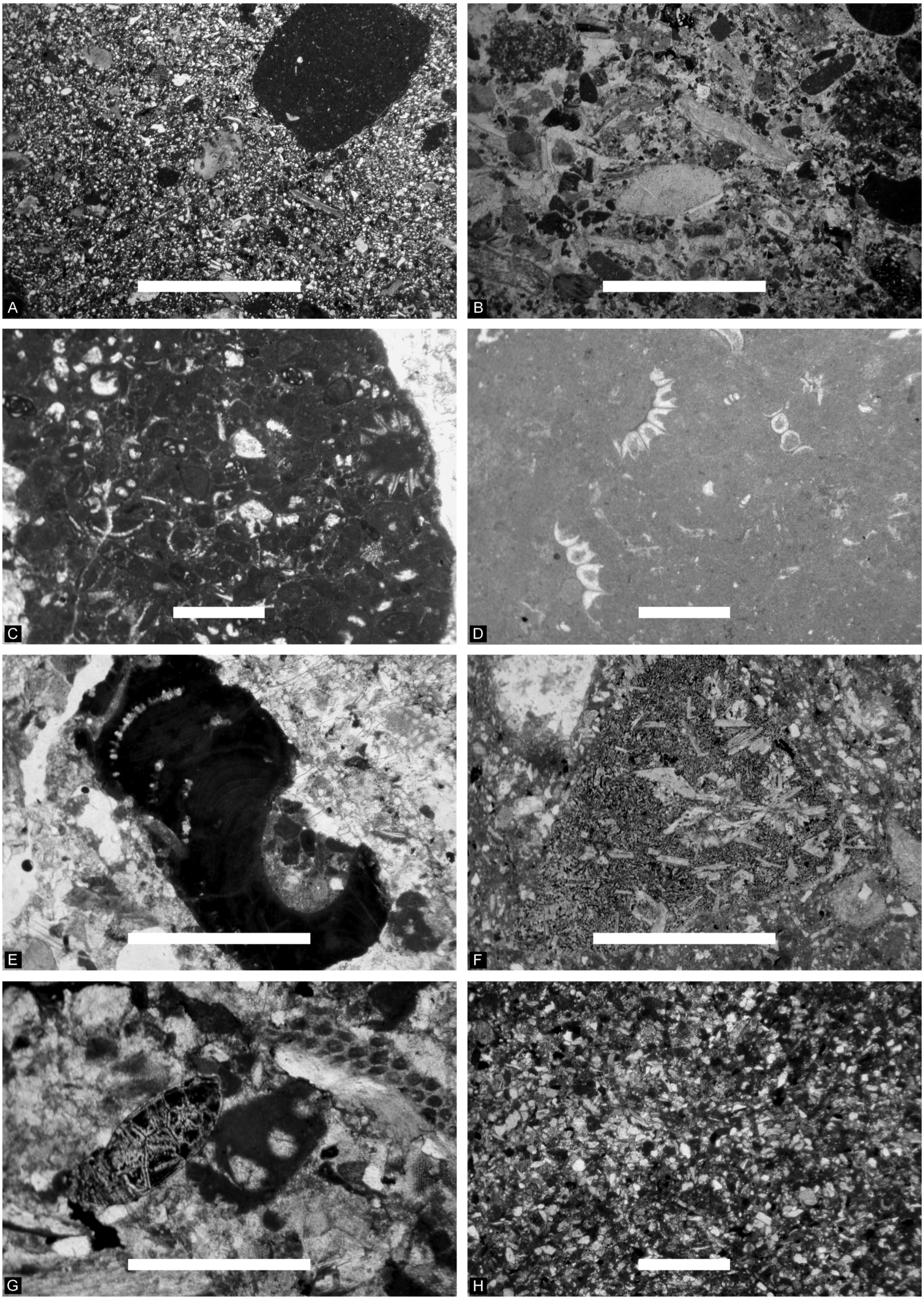
6.3.5 Volcanites, ophiolitic suite, serpentinites

Both magmatic rocks like volcanites and volcanic glass and metamorphic rocks like serpentinites are occuring rarely in the mass flows of the Bad Ischl area and the Weitenau area. In comparison, the mass flows of the Gutratberg quarry show significantly higher amounts of these rocks in their basal parts.

6.3.6 Mixed calcareous-siliciclastic rock clasts

In this group different sedimentary rocks derived from the Lower Cretaceous shelf-area are compiled. Due to the absence of biostratigraphical clearly assignable organisms or typical microfacies characteristics no exact age determination is possible.

Table 2: Microfacies of the Ischl Breccia mass flow deposits of the Salzberg, Kolowratshöhe and Perneck valley sections.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Identical clasts occur, however, in the Salzburg area (Krische, 2012; Krische et al., 2014) in huge amounts beside clearly datable clasts.

6.3.7 Siliciclastic rock clasts, detrital grains, heavy minerals

Siltstones and pedogenetic clasts are generally seldom. In the sandy parts of the arenitic rocks quartz and different, coloured detrital grains like chrome spinel, zinc-rich spinel, illmenite, titanite, serpentine, garnet, apatite, feldspar and different micas occur frequently. This spectrum is quite typical for the Rossfeld Formation at all investigated localities (Gutratberg, Weitenau, Rossfeld: Krische, 2012).

6.3.8 Bioclasts

The existence of contemporaneous shallow-water carbonate areas during deposition of the Rossfeld Formation was more or less unknown previously but is clearly proven by carbonate litho- and bioclasts (corals, calcareous sponges, calcareous algae, *Sporolithon rude* Lemoine). Such components occur frequently in the sandy and coarse-silty grained rock series at all of the investigated localities.

In general the mixture of the components from the Ischl Breccia is identical with the mass flow deposits from the Rossfeld, the Weitenau area and the Gutratberg quarry (Krische, 2012). The two different depositional ages are not reflected in the general composition. The source area for the different component groups is similar for all occurrences. The erosion of an ophiolithic nappe-stack, contemporaneous mixed carbonatic-siliciclastic or siliciclastic shelf-sediments and an older, eroded carbonate platform resulted in deposition of the polymictic mass flow sediments of the Rossfeld Formation. Additionally, the bioclasts show the influence of a Lower Cretaceous shallow-water shelf-area in the Northern Calcareous Alps at that time.

6.4 Evolution of the Rossfeld Formation

Based on their sedimentary characteristics, the Rossfeld Formation mass flows are best interpreted as local boulder-fans with angular to subangular rounded components of carbonate material of significantly older age (e.g., Plassen Formation, Oberalm Formation + Barmstein Limestone, Lower/Upper Tithonian breccias). Subrounded to rounded exotic material like volcanites, serpentinites and detrital grains were delivered by fluvial currents from an eroding ophiolitic nappe-stack (e.g., Krische et al., 2014; compare Missoni and Gawlick, 2011a, 2011b; Stern and Wagreich, 2013) as today preserved, e.g., in the Dinaridic-Albanide-Hellenide mountain belt (Gawlick et al, 2008; Schmid et al., 2008) (Fig. 13). The mass flows can be interpreted as central channel fillings at the distal fan within a meandering and branching channel-system (Darga and Weidich, 1986; compare Faupl and Tollmann, 1979).

The sedimentary successions observed in the field exposures (Bad Ischl, Weitenau, Gartenau, Rossfeld) show two general fining upward cycles. The first one starts with the coarse-grained mass flows of the basal Rossfeld Formation (Late Valanginian) and reaches upward to fine-grained siliceous marls and siliceous limestones. A second mass flow cycle took place in the Late Hauterivian to Early Barremian, again resulting in a fining upward sequence (Rossfeld, Perneck valley). A constant increase in grain-size beginning during deposition of the Schrambach Formation and continuing during the Rossfeld Formation as formerly assumed from the Rossfeld type locality (e.g., Weber, 1942; Pichler, 1963; compare Krische, 2012) is not supported by our field data. A reverse trend, however, is indicated from the Late Barremian onward by orbitolinid-bearing sandstones and arenites of the Grabenwald Member (Schlagintweit et al., 2012; see Krische, 2012).

The current component analyses of the mass flows of the Rossfeld Formation of Bad Ischl do not support the former interpretation of an Early Cretaceous Juvavic nappe movement and nappe emplacement. It seems more reasonable that the mass flows occurred in a setting of only minor or decreasing tectonic activity. Sea-level fluctuations seem to be the most important cause for the erosion and deposition of the mass flows. According to Gradstein et al. (2012) the main sea-level lowstand is located between the *Neocomites neocomiensiformis* up to the *Saynoceras verrucosum* ammonite zones (latest Early Valanginian to earliest Late Valanginian, Reboulet et al., 2014; see also Rasser et al., 2003). At the beginning of the following transgressive cycle the basal coarse-grained mass flows were deposited during the transgressive phase of the Lowstand System Tract (for definition see Coe, 2003).

6.5 Rossfeld Formation evolution and the Alpine Haselgebirge

Based on the results from Bad Ischl and with the additional knowledge from the Gartenau, Weitenau and Rossfeld sections it can be interpreted that the Alpine Haselgebirge Mélange was neither overthrusted as basal sliver of the Juvavic Nappe system nor resedimented on top of the Tirolic Nappe in front of the Juvavic Nappes. The revised interpretation of the former Juvavic Unit together with the new results (Krische, 2012; Krische et al., 2013b, 2014) indicate that the Alpine Haselgebirge Mélange was resedimented in the Late Tithonian into the Oberalm Formation. This interpretation is particularly

Figure 10: Typical microfacies of conglomerate beds and crinoid-rich turbidites from the Kolowratshöhe, Rossfeld Formation (Upper Valanginian). A: Matrix-supported fine-grained conglomerate with wackestone lithoclasts and crinoids as components. The matrix can be described as radiolarian, sponge spicula packstone with sparite remnants, micrite clasts, crinoids, lenticuliniids, quartz and detrital grains; OK-IS120. B: Siliceous crinoid-rich turbidite with different wacke- and packstone lithoclasts; OK-IS170. C: Lagoonal packstone with micrite clasts, foraminifera and *Clypeina jurassica* Favre; OK-IS170. D: Wackestone of the closed lagoon, rich in *Clypeina jurassica* Favre; OK-IS171. E: *Sporolithon rude* Lemoine as bioclast in siliceous crinoid-rich turbidite; OK-IS170. F: Subangular, alterated volcanite with feldspar crystals; OK-IS171. G: Siliceous crinoid-rich turbidite with different carbonate lithoclasts, bioclasts and rounded serpentinite clast; OK-IS121. H: Typical siliceous limestone, radiolarian, sponge spicula packstone with crinoids, micrite clasts, sparite remnants, quartz and detrital grains; OK-IS122. Scale bars: 1 mm for C to H; 5 mm for A and B.

based on the results from Gartenau where the Upper Tithonian Oberalm Formation was drilled below the Alpine Haselgebirge Mélange (Plöchinger, 1977). The Oberalm Formation on top rests primarily with sedimentary contact on the Alpine Haselgebirge Mélange (see Plöchinger, 1976, 1977; Krische, 2012). In the Hochreith Unit of the Weitenau area grey Oberalm-type limestones were drilled below the gypsum deposit of Grubach (Petraschek, 1947). Above the Alpine Haselgebirge Mélange follows the characteristic Upper Tithonian Oberalm Formation with Barmstein Limestone and "Tonflatschenbrekzien" beds (see discussion in Krische, 2012; Krische et al., 2013b). Equivalent successions like the ones outcropping at the Gutratberg and the Weitenau area are exposed in the Lauffener Erbstollen, as described above. In the Bad Ischl salt deposit a drill-hole reached Upper Jurassic limestones below the Alpine Haselgebirge Mélange (Schauberger, 1979). Medwenitsch (1958) described in the Lauffener Erbstollen breccia limestones with green clay components (= "Tonflatschenbrekzie" according to Plöchinger, 1974; Tressenstein Limestone according to Medwenitsch, 1958) above the Alpine Haselgebirge Mélange. This outcrop situation is also confirmed by the authors herein. Schäffer and Steiger (1986) extracted Upper Permian spores from the "Tonflatschenbrekzie". "Tonflatschenbrekzien"-type rocks were also described by Mandl (1982) from the base of the Zwerchwand (Gawlick et al., 2010). Within these rocks occur exclusive witnesses of the resedimentation of the Alpine Haselgebirge Mélange. The basal strata of the overlying Oberalm Formation and Barmstein Limestones and "Tonflatschenbrekzien" are Late Tithonian in age (Krische, 2012; see also Winterleitner, 2009). During the latest Jurassic and the Early Cretaceous the Alpine Haselgebirge Mélange was covered by the Oberalm, Schrambach and Rossfeld formations.

6.6 Palaeogeographic reconstruction

The new investigations contradict the existence of a single uniform Upper Jurassic to Lower Cretaceous basin fill around Bad Ischl. The results, based on section analyses as well as lithological and microfacies investigations show clearly at least three palaeogeographically different units (Krische, 2012; Krische et al., 2012), separated by faults.

In Late Jurassic to Early Cretaceous time the Reinfalzalm-Mitterberg Unit was part of the proximal Trattberg Rise whilst the Gschwandtalm-Perneck Unit was situated in the proximal Tauglboden Basin. The northernmost Reiterndorf-Hubkogel Unit represents the evolution in a distal Tauglboden Basin setting. The processes and forces which have led to a juxtaposition of these different tectonic blocks with in-

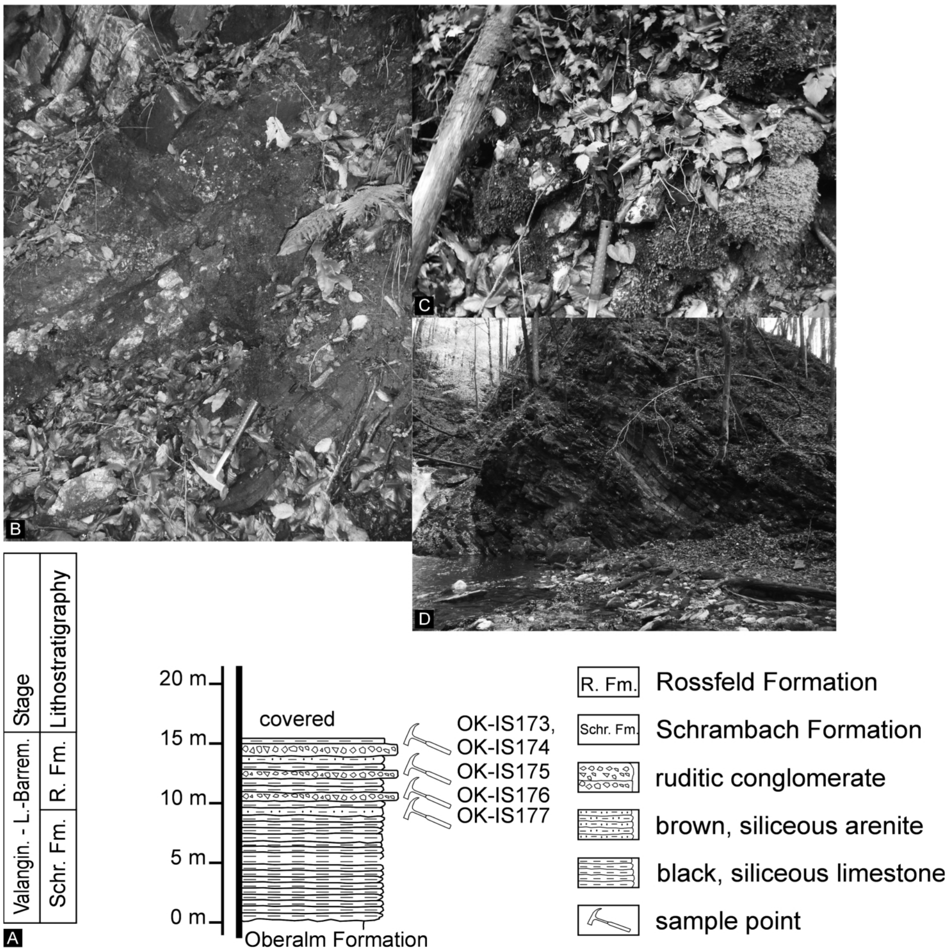
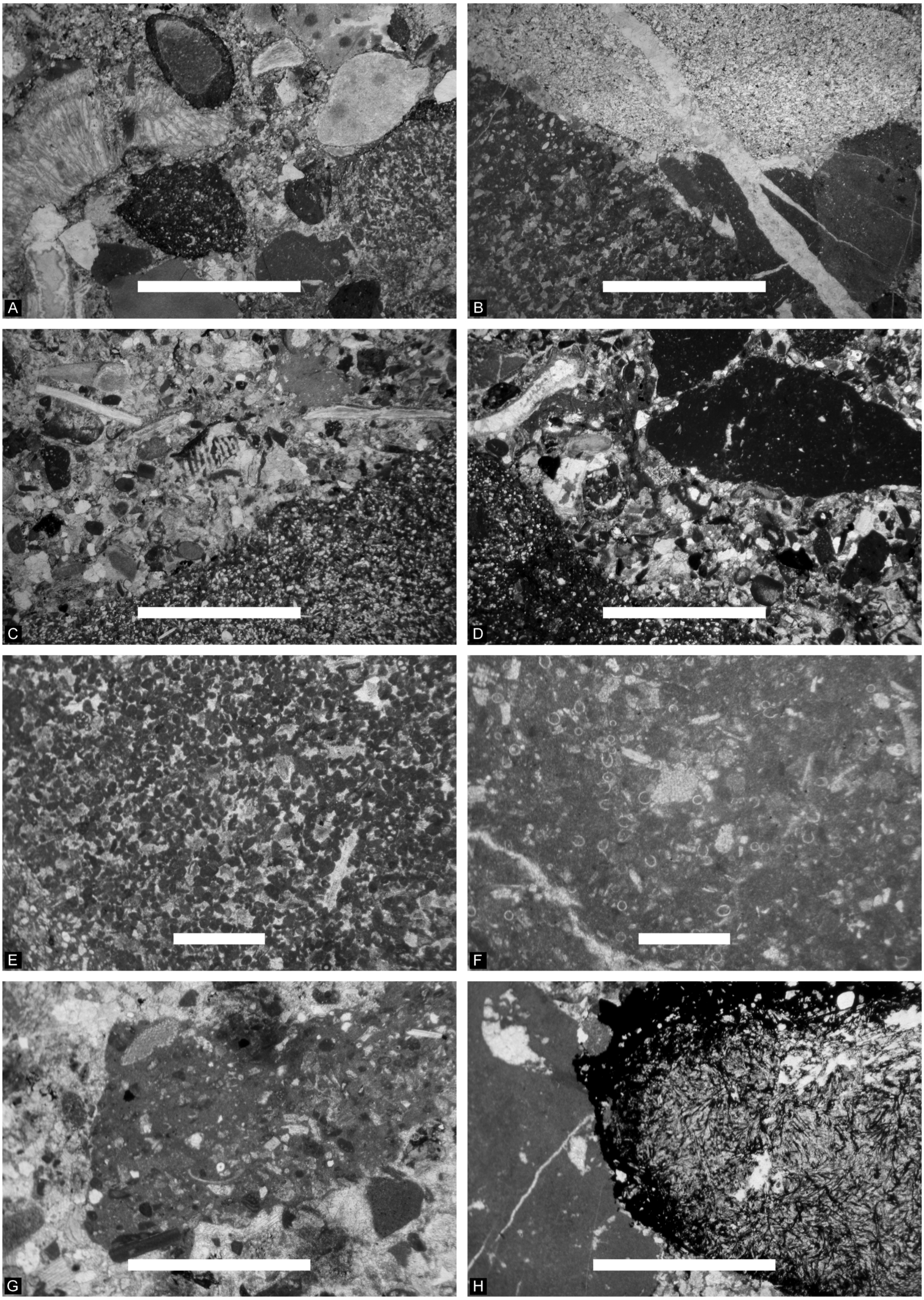


Figure 11: A: Outcrop section of the Schrambach and Rossfeld formations along the Perneck valley. B: Conglomerate and breccia layers within siliceous and arenitic, bedded limestones. Scale hammer shaft. C: Coarse breccia layer, partly covered with leaves. Scale hammer shaft. D: Outcrop situation along the left side of the creek. Scale of foto approximately 15 m.

Figure 12: Perneck valley section: Microfacies of the Rossfeld Formation (Upper Hauterivian to Lower Barremian). A: Clast supported conglomerate with gravel-sized bioclasts (bryozoans) and lithoclasts (micrites, slope facies, siliceous rocks) and sand-sized material like crinoids and quartz, filling the pore space; OK-IS173. B: Clast supported conglomerate with fine-grained quartzsandstones, micrites and packstones with crinoidal remnants and micrite clasts of a slope facies; OK-IS175. C: Erosive basal contact between siliceous radiolarian sponge spicula packstone and coarse-sand grained sediment layer rich in crinoid detritus; OK-IS176. D: Bimodal clast distribution of conglomerates with gravel-sized lithoclasts (slope facies) and sandsized crinoids, agglutinating foraminifera, shell fragments, micrite clasts and quartz; OK-IS176. E: Slope facies, packstone with pellets, crinoids and foraminifera; OK-IS175. F: Calpionellid wackestone (Upper Tithonian Oberalm Formation); OK-IS175. G: Marly wackestone with shell fragments, foraminifera, crinoids and quartz; OK-IS176. H: Altered vulcanite; OK-IS173. Scale bars: 5 mm for A to D; 1 mm for E to H.



A
B
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dividual depositional evolution are poorly understood. Most likely this tectonic re-arrangement occurred in the time-range between the end of the Rossfeld Formation sedimentation and before deposition of the Gosau Group rocks (see Krische et al., 2012). Today´s block-puzzle around Bad Ischl has been formed since that time under variably oriented stress fields which affected and steered the Northern Calcareous Alps evolution from mid-/Late Cretaceous to Late Miocene/Quaternary (compare Schorn and Neubauer, 2011; Leitner and Neubauer, 2011).

7. Conclusions

The following overall results/conclusions can be drawn:

A) Nomenclature

The so-called Ischl Breccia is a local term for coarse-grained mass flow deposits of the Rossfeld Formation.

B) Sedimentation age

The Rossfeld Formation mass flows of the localities Radgraben, Salzberg and Kolowratshöhe were deposited mainly in the Late Valanginian (*Saynoceras verrucosum* Zone up to lower *Criosarasinella furcillata* Zone). Radiolarian data from the Lauffener Erbstollen support this deposition age.

The mass flow deposits in the Perneck valley were though to have an age-range from Valanginian to Early Barremian. Due to lithological correlations with the Rossfeld and the Weitenau area and on the basis of sequence-stratigraphic constraints an overall Late Hauterivian to Early Barremian age of deposition seems most reasonable.

C) Components/Sedimentology

The components of the mass flows can be correlated with several outcrops (Rossfeld, Gartenau, Weitenau) of the Rossfeld Formation in the Northern Calcareous Alps of Salzburg. Ophiolitic and siliciclastic material was eroded from an ophiolitic nappe stack (Neotethyan Belt). Mixed siliciclastic and biogenic components represent the former shelf area. Rocks of the Upper Jurassic and Lower Cretaceous Oberalm (Barmstein Limestone, "Oberalmer Basiskonglomerat") and Schrambach formations were eroded due to sea-level fluctuation and the exposure of the shelf area. Neither clasts from Upper Juvavic platform carbonates (e.g., Berchtesgaden and Dachstein Nappes) nor clasts from the Lower Juvavic Triassic hemipelagic shelf-area (Lower and Upper Hallstatt Nappes) are present in the mass flows.

D) Block configuration

The Cretaceous succession of the Bad Ischl area was formerly interpreted as uniform and laterally continuous. Based on significant lithological differences of the occurring formations, however, the region has to be subdivided into three blocks with individual sedimentary evolutions. The succession of the Reinfalzalm-Mitterberg Unit shows the characteristics of the distal Trattberg Rise, the Gschwandtalm-Perneck Unit that of the proximal Tauglboden Basin and the Reiterndorf-Hubkogel Unit that of the distal Tauglboden Basin. Mass flows of the Rossfeld Formation are only observed in the Gschwandtalm-Perneck and Reiterndorf-Hubkogel Units. The described Rossfeld-like resediments of the Reinfalzalm

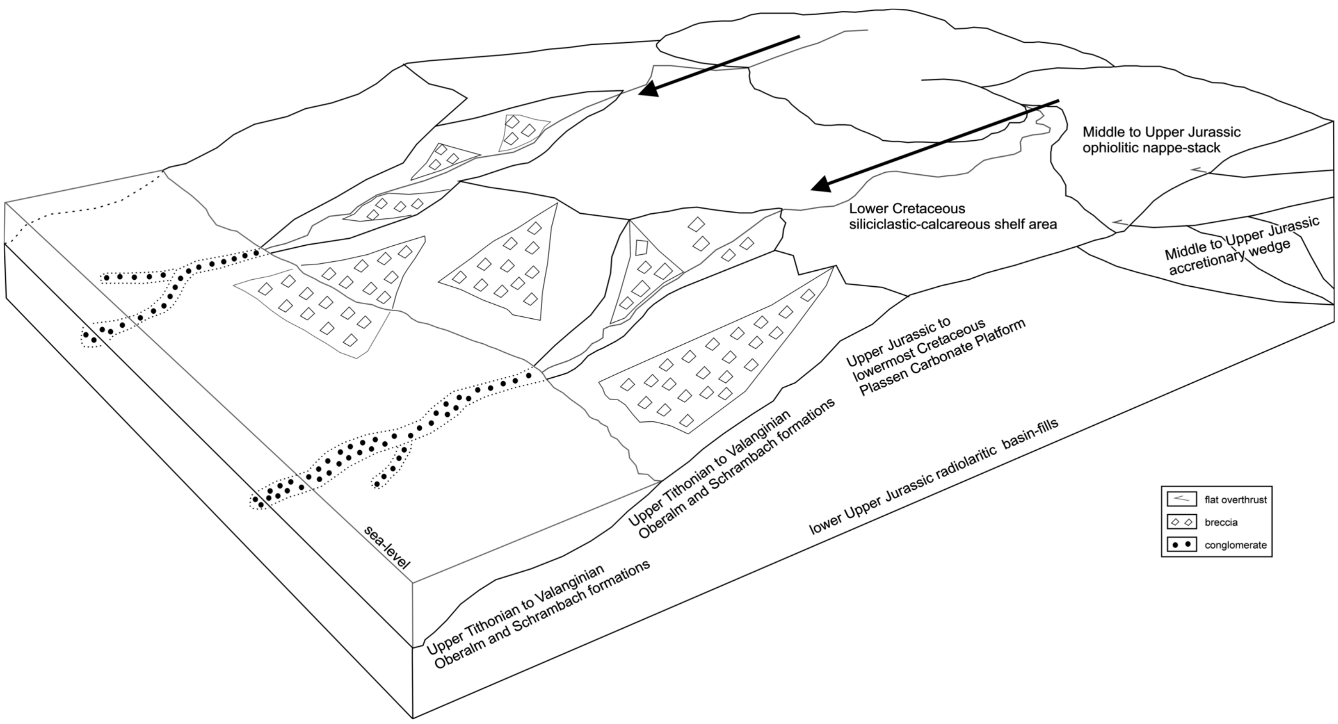

Figure 13: Evolution of the basal conglomerates of the Rossfeld Formation of Bad Ischl (Ischl Breccia) as a simplified scetch. After the main sea-level lowstand in the late Early Valanginian the conglomerates were brought by fluvial systems from the exposed hinterland and shelf area to the deeper parts of the basin. Local material from breccia fans was also incorporated in the conglomerates. During the sea-level rise in the Late Valanginian the typical fining-upward sequences of the Rossfeld Formation were deposited, today clearly visible at several outcrops in Bad Ischl, in Gartenau, in the Weitenau area and on the Rossfeld.

are in fact Berriasian resediments of the Schrambach Formation, comparable to the rocks of the Gartenau section.

E) Alpine Haselgebirge Mélange

The salt deposit of Bad Ischl achieved its current position in Late Tithonian time by means of synsedimentary emplacement into the Oberalm Formation. The overall shape of the salt body was created by mid-Cretaceous to Quaternary tectonic and erosional forces.

F) Sedimentology

A general fining-upward trend in each of the two sedimentary cycles of the Rossfeld Formation is ascertained. In comparison, we find no indications for a coarsening upward trend, resedimentation of olistolithic blocks and nappe emplacement processes during the Early Cretaceous.

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