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Biostratigraphy and lithostratigraphy of the Krimpenbach Formation (Upper Santonian – Campanian), Gosau Group of Gams (Austria)

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(With 5 text-figures)

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Abstract

The Krimpenbach Formation of the Gosau basin of Gams comprises a new sedimentary cycle deposited during the change from terrestrial and shallow-water to deep-water environments. The following lithologies are present: a basal interval of grey alluvial conglomerates, characterized by abundant "exotic" clasts such as quartz porphyries, including minor coal layers; shallow-water coarse to medium-grained sandstones and marls; calcarenites with detritus of rudists, oysters, red algae, benthic foraminifera; fine-grained sandstones and siltstones with inoceramids and rare ammonites. The successions record subaerial exposure during the Santonian followed by a short interval of alluvial fan- and fan-delta sedimentation during transgression in the Late Santonian to Early Campanian, and shallow-marine nearshore to pelagic sedimentation during Early to Late Campanian. Biostratigraphic data, mainly planktic foraminifera and nannofossils, indicate Late Santonian to Late Campanian ages: the *asymetrica-elevata*-Zone, the *elevata*-Zone and the *ventricosa*-Zone and nannofossil standard zones CC17 to CC21/22a. Heavy mineral assemblages are characterized by stable minerals, epidote, garnet and varying amounts of chrome spinel.

Zusammenfassung

Die Krimpenbach-Formation des Gosaubeckens von Gams stellt einen eigenständigen Sedimentationszyklus dar, der während der Umstellung von terrestrisch-seichtmarinen zu tiefmarinen Sedimentationsbedingungen abgelagert wurde. Folgende Lithofaziestypen können unterschieden werden: ein basaler Abschnitt von grauen Konglomeraten, zumeist mit hohen Anteilen an "exotischen" Komponenten, etwa Quarzporphyre, und wenigen Kohlelagen; seichtmarine grob- bis mittelkörnige Sandsteine und Mergel; Kalkarenite mit Bruchstücken von Rudisten, Austern, Rotalgen und benthischen Foraminiferen; feinkörnige Sandsteine und Siltsteine mit Inoceramen und seltenen Ammoniten. Diese Abfolge belegt subaerische Exposition während des Santoniums, gefolgt von einem kurzen Intervall von Sedimentation auf alluvialen Schwemmfächern und Fan-Deltas während der Transgression im Obersantonium bis Untercampanium. Im Unter- bis Obercampanium folgt eine Entwicklung von seichtmarinen, küstennahen zu pelagischen Ablagerungsbedingungen. Biostratigraphische Daten, vor allem planktische Foraminiferen und Nannofossilien, belegen ein Alter von Spätem Santonium bis Spätem Campanium: *asymetrica-elevata*-Zone, *elevata*-Zone und *ventricosa*-Zone, sowie die Nannofossilstandardzonen CC17 bis CC21/22a. Schwermineraluntersuchungen zeigen vorherrschend stabile Minerale, Epidot, Granat und unterschiedliche Gehalte an Chromspinell.

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1. Introduction

The Gosau Group of the Eastern Alps comprises mainly Upper Cretaceous to Paleogene clastic sediments deposited after Early Cretaceous to Cenomanian thrusting. Within the Northern Calcareous Alps the Gosau Group unconformably overlies folded and faulted Triassic to Lower Cretaceous strata. After a phase of widespread subaerial exposure and erosion during the Turonian, deposition of terrestrial to shallow marine clastics prevailed from the Late Turonian onwards, followed by deep-water sedimentation during Campanian to Eocene (e.g. WAGREICH & FAUPL 1994). The evolution from shallow-marine to deep-marine depositional systems comprises a complex phase of the basin evolution, including uplift, faulting and erosion followed by rapid deepening to bathyal depths, e.g. at the type locality in the Gosau area (WAGREICH 1993, 1995).

This paper describes the Krimpenbach Formation in the Gams area (Styria), which was deposited during the time interval, when the change from terrestrial and shallow-water to deep-water sedimentation took place (SUMMESBERGER et al. 1999). Based on sedimentological and biostratigraphic investigations, the evolution of the Gams area during this time interval is also discussed.

2. Geological setting and lithostratigraphic overview of the Gosau Group of Gams

The Gosau Group of Gams comprises deposits of Late Turonian to Eocene age (e.g. WICHER 1956; KOLLMANN 1963, 1964; KOLLMANN & SUMMESBERGER 1982; SUMMESBERGER & KENNEDY 1996; EGGER & WAGREICH 2001), unconformably overlying Permian to Upper Jurassic strata of the Göller nappe system of the Northern Calcareous Alps. In the western outcrop area around the villages Mooslandl and Gams, up to 1000 m of terrestrial to shallow-marine strata of the lower Gosau Subgroup (Upper Turonian - Santonian: Kreuzgraben Formation, Noth Formation, Schönleiten Formation, Grabenbach Formation) can be found (KOLLMANN & SUMMESBERGER 1982; SUMMESBERGER & KENNEDY 1996; SIEGL-FARKAS & WAGREICH 1997, KOLLMANN & SACHSENHOFER 1998). In the eastern outcrop area around Gamsforst, Krautgraben and Krimpenbach (Fig. 1), deep-water sediments of the Nierental Formation (upper Gosau Subgroup) rest unconformably upon a relatively thin Santonian/Campanian succession, which was mainly attributed to the Krimpenbach Formation by SUMMESBERGER et al. (1999) and EGGER et al. (2000). Whereas the upper Gosau Subgroup comprises mainly turbiditic and hemipelagic strata of Campanian to Early Eocene age (KOLLMANN 1964; LAHODYNSKY 1988, EGGER & WAGREICH 2001), the Krimpenbach Formation displays a large variety of lithologies as a consequence of a complex depositional setting and significant synsedimentary deformation within the basin.

Due to the great thickness of the Gosau Group (about 1800 m according to KOLLMANN 1964), polyphase post-Cretaceous tectonism and extensive Quaternary cover most outcrops display only parts of the succession and several sections had to be measured and sampled in detail to get a more complete view on the Krimpenbach Formation.

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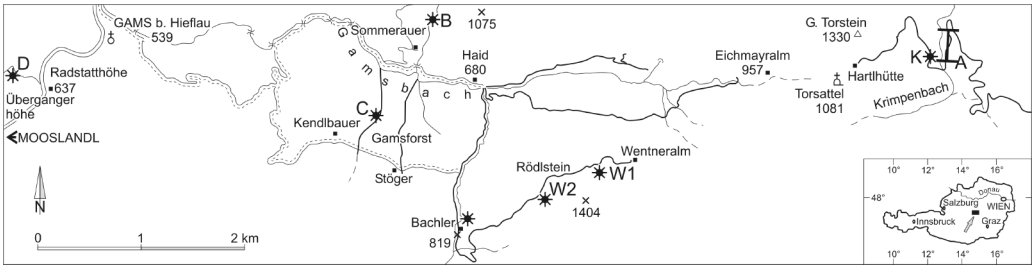

Fig. 1: Map of investigated outcrops and sections of the Krimpenbach Formation in the area of Mooslandl, Gams and Krimpenbach. A - type section of the Krimpenbach Formation along the forest road in the Krimpenbach valley; B - olistoliths in the Schweinbach creek east of farm house Sommerauer; C - outcrops in the creek northeast of farm house Kendlbauer; D - outcrops at Radstatthöhe and Überganger Höhe; K, W1, W2 - fossil sites of SUMMESBERGER et al. (1999).

3. The Krimpenbach Formation

The Krimpenbach Formation consists of a maximum 80 m thick succession of conglomerates, siliciclastic sandstones, calcarenites, red and grey marly siltstones, shales and marlstones. Minor lithologies include coal seams and thin layers of rudist limestones. The Krimpenbach Formation comprises large parts of the "Tieferer Mergelkomplex" and the "Kalke des Campans" of KOLLMANN (1964) and includes the limestones of the Krimpenbach section mentioned by WICHER (1956). The upper part of the Krimpenbach Formation is contemporaneous to the deep-water deposits of the Nierental Formation in the depocenter of the "Gams basin" (KOLLMANN 1964: 97ff, WAGREICH & KRENMAYR 1993: 72f).

3.1. Lithostratigraphic definition

The type section is situated in the Krimpenbach valley, at a forest road southeast of Großer Torstein (section from coordinates BMN re644810/ho282000 to re644725/ho281680), east of the stream Krimpenbach (Fig. 1), from which the name of the formation was taken. The type section comprises the easternmost outcrop area of the Krimpenbach Formation in the Gams area (WAGREICH 1994). Additional sections were investigated westward from the type section: between the Torsattel and the Hartlhütte (BMN re643356/ho281501 to re644166/ho282051); at the forest road from Bachler to the Wentneralm (BMN re638525/ho279465 to re640225/ho280480; see also SUMMESBERGER et al. 1999); at a road cut directly north of the farm house Bachler (re 638359/ ho 279731); at a small hill south of the farm house Stöger (re 637451/ ho 280406); within a small creek north of farm house Kendlbauer (re 561923/ho 281438 to re 562122/ ho 281205); at the western end of the Gosau Group outcrops west of Radstatthöhe (BMN re558130/ho281525) and at a new forest road within the creek between Radstatthöhe and Übergangerhöhe north of Mooslandl (BMN re557670/ho281240).

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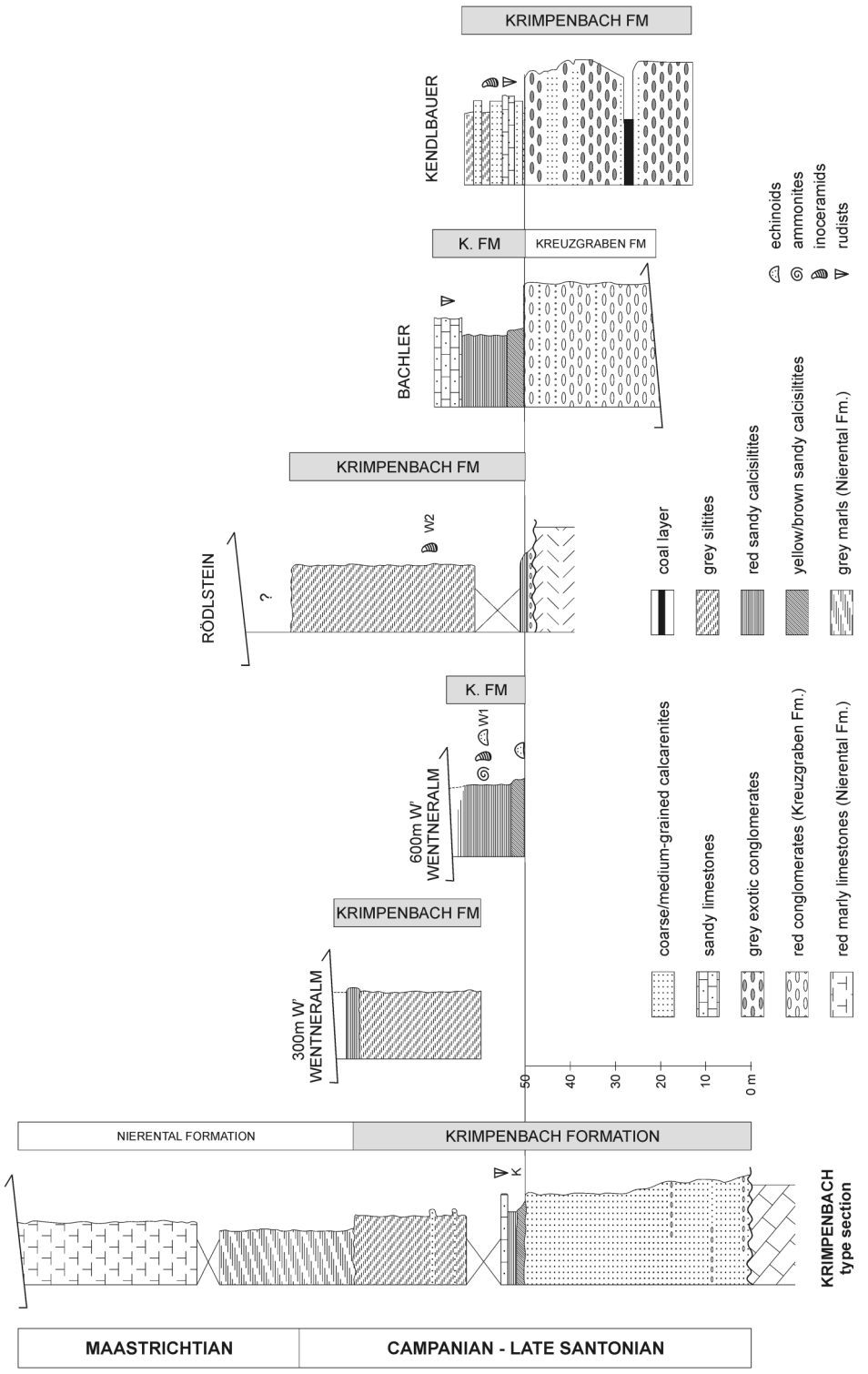

Fig. 2: Sections of the Krimpenbach Formation in the Gams area. K, W1, W2 indicate stratigraphic position of fossil sites of SUMMESBERGER et al. (1999). Correlation line is drawn at the first biostratigraphically dated, Upper Santonian/lower Lower Campanian horizon.

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A peculiar situation occurs in the Schweinbach creek north of the farm house Sommerauer (BMN re638055/ho282850) and in small creeks of the Gamsforst (BMN re637370/ho280500). Here, large olistoliths of various lithologies of the Krimpenbach Formation are intercalated in Campanian to Maastrichtian deep-water marls of the Nierental Formation.

The lower boundary of the Krimpenbach Formation is defined by the change from red conglomerates of the Kreuzgraben Formation to either grey conglomerates or grey finer clastic sediments (Fig. 2). In the Rödlstein area west of the Wentneralm, red calcarenites and calcareous siltstones of the Krimpenbach Formation directly overly Triassic dolomites.

The upper boundary of the Krimpenbach Formation is only preserved in the eastern outcrop areas, as overlying sediments were removed in the western part due to erosion. In the type region of the Krimpenbach and Torsattel area, grey silty marlstones of the Krimpenbach Formation are overlain by darker grey, soft marls of the Nierental Formation.

3.2. Description of sections

Krimpenbach type section

The Upper Cretaceous succession in the Krimpenbach area (Fig. 2) starts either with a few meter thick conglomerates of local origin (Kreuzgraben Formation) or the Krimpenbach Formation directly overlies Triassic or Jurassic limestones. The following lithologies are present in the Krimpenbach type section along the forest road east of the Krimpenbach:

Coarse to medium–grained calcarenites: The 35 - 50 m thick calcarenites (Fig. 2, 3) contain abundant marine bioclasts (bivalves including rudist and oyster debris, red algae, rare benthic foraminifera) and carbonate lithoclasts from the surrounding limestones and dolomites. Locally, thin pebble and coarse sandstone layers are intercalated, including well-rounded quartz porphyry and quartzite clasts. The calcarenites are strongly bioturbated and primary structures are rarely preserved. Large wave ripples of a shoreface environment were found within these coarse sandstones along the forest road to the west of the Krimpenbach, near Hartlhütte (Fig. 3). These bioclastic calcarenites show similarities to fine-grained varieties of the Untersberg Formation southwest of Salzburg. Based on the marine bioclasts and the bioturbation they are interpreted as a shallow neritic nearshore facies below or within the fair weather base. Coarse-grained intervals probably indicate the presence of small fan-deltas, a common feature of the marginal marine environments of the Gosau Group (e.g. WAGREICH 1989, 1998). The large wave ripples were probably formed during storm events. No biostratigraphic information is known from this succession.

Grey calcareous siltstones, marlstones and fine sandstones: The coarse sandstones grade into 15 to 30 m thick light to medium grey calcareous siltstones, marlstones and fine sandstones (Figs. 2, 3). The fossil locality Krimpenbach of SUMMESBERGER et al. (1999) is situated within the transitional interval from coarse to fine-grained grey sandstones at the western bank of the Krimpenbach.

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These strongly bioturbated fine sandstones and siltstones are interpreted as a neritic shelf facies further offshore in comparison- to the underlying calcarenites, deposited below fair weather wave base, but above storm wave base. The high carbonate content results from a mixture of variable amounts of broken bioclasts (mostly red algae, echinodermal debris, benthic foraminifers and bryozoa) and a significant terrigenous component, transported into the basin by storm-induced shelf currents. Primary stratification was largely destroyed by bioturbation, but some sandy layers display horizontal and low-angle wavy lamination, which suggests deposition as tempestites.

Wentneralm Road, Rödlstein and Bachler

Although the sections in this area are more intensively deformed than in the Krimpenbach due to overthrusting and strike-slip faulting along the southern margin of the Gams basin, a continuous section can be reconstructed, starting with a several tens of meters thick interval of red conglomerates of the Kreuzgraben Formation. These conglomerates grade into grey conglomerate and sandstones along the road to the Wentneralm or directly into brown calcarenites or grey sandy siltstones near farm house Bachler (Fig. 2). Rudist debris is intercalated here within one layer, which may be an equivalent to thicker rudist limestones further to the south, in the Bergstein area (KOLLMANN 1964: 101).

The overlying grey siltstones to fine grained sandstones with inoceramids crop out along the Wentneralm forest road. Red coloured siltstones can be found both at the base and at the top of this interval. The ammonites, inoceramids and echinoids of locality Wentneralm I of SUMMESBERGER et al. (1999) were collected from such a red interval. Shell layers of inoceramids are present, including fossil locality Wentneralm II of SUMMESBERGER et al. (1999). The microfauna is characterized by large agglutinated foraminifera, *Lenticulina*, *Gavelinella,* and rare planktic foraminifera. Nannoplankton samples from this interval are poor. The ichnofauna consists of burrows of *Thalassinoides* and rare large *Zoophycus*. The foraminiferal assemblages with significant amounts of planktic foraminifera indicate an outer neritic depositional environment above storm wave base.

At the Rödlstein conglomerates and coarse sandstones at the base are missing and a few meter thick interval of red coarse calcarenites to rudites lie directly above Triassic dolomites. The calcarenites display a silty to marly reddish matrix and angular dolomite clasts. The matrix contains benthic and scarce planktic foraminifera and grades into the grey siltstones described above.

Gamsforst - Kendlbauer

In the Gamsforst area distinctly different facies types are present in the Krimpenbach Formation. In the creek north of farm house Kendlbauer grey conglomerates (Figs. 2, 3) overly unconformably strongly deformed Lower to Mid-Triassic siltstones and carbonates ("Aufbruchszone" of KOLLMANN 1964). The conglomerates are characterized by more than 80% of rounded quartz porphyry and quartzite clasts in a grey to greenish grey sandstone matrix. Thin sandstone layers and two coal seams are present in the lower part of these up to 30 m thick conglomerates. Imbrications of long axis of elongated clasts could be observed frequently. The conglomerates are interpreted as deposits of small alluvial fans. Coal layers indicate the presence of swamps.

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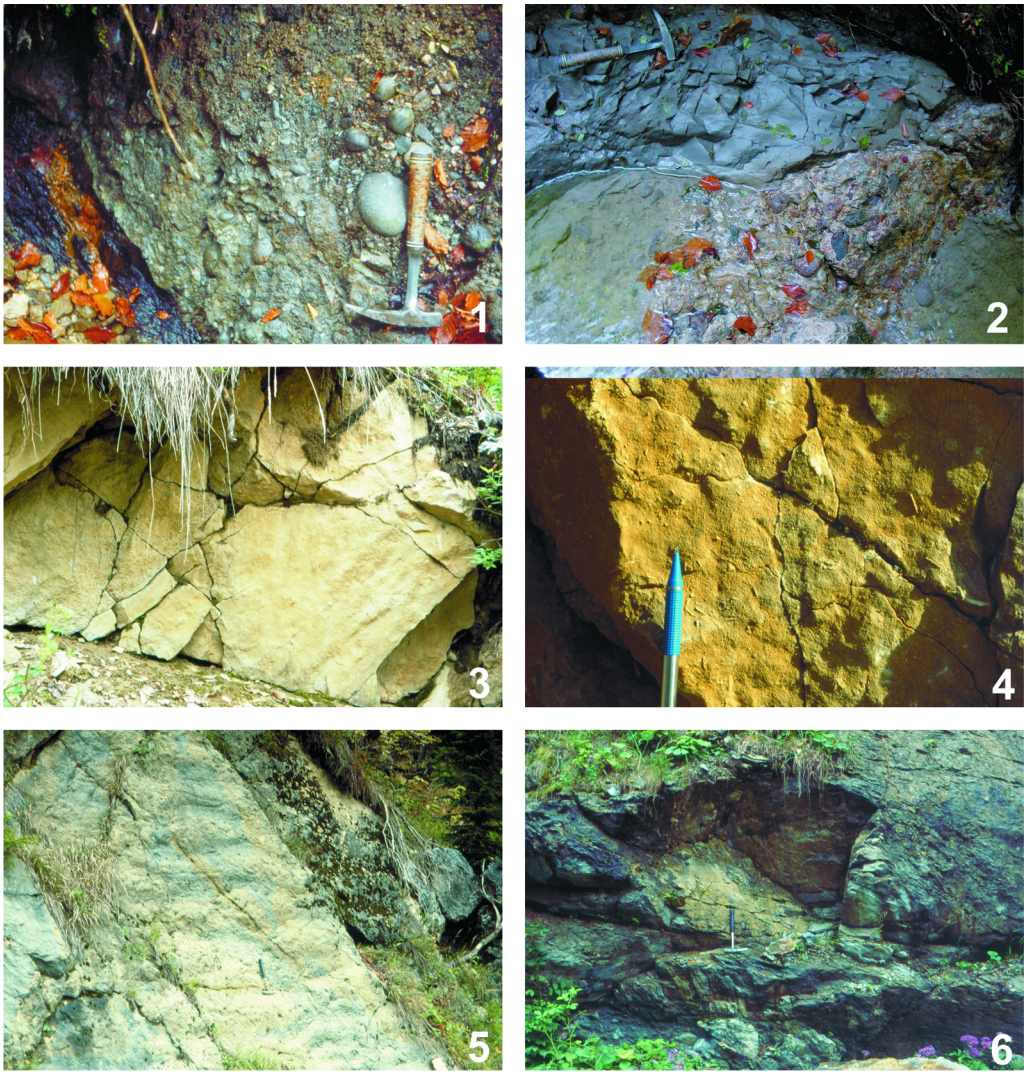

Fig. 3: Outcrop photographs of characteristic lithologies of the Krimpenbach Formation in the Gams area: 1) quartz porphyry- and quartzite-rich conglomerate overlying shaly coal (left corner), Kendlbauer section; 2) quartz porphyry- and quartzite-rich, bioclast-bearing conglomerate overlain by grey marine marls, Kendlbauer section; 3) medium-grained, thick-bedded calcarenites, type section of the Krimpenbach Formation; 4) Bioclastic calcarenites, type section of the Krimpenbach Formation; 5) Large-scale wave ripples on top of coarse-grained sandstone bed, forest road near Hartlhütte east of Torsattel; 6) grey siltstones to fine-grained sandstones, forest road to the Wentneralm.

In the top of this interval, a conglomerate layer with a grey marl matrix and some minor mollusc fragments indicates the transition from terrestrial to marine environments, probably in a small fan delta system. The overlying 10 m of the succession consist of coarse to fine, sometimes pebbly sandstones and minor marls, calcarenites and mollusc

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shell beds. Some rudist fragments and shallow-marine benthic foraminifera such as *Quinqueloculina* were found. The marl intercalations already contain significant amounts of planktic foraminifera, indicating a rapid deepening to outer neritic depths within the section.

R a d s t a t t h ö h e - Ü b e r g a n g e r h ö h e

In the area of Radstatthöhe a several tens of meters thick succession of grey conglomerates with significant amounts of exotic clasts and intercalated red silty to sandy clays overly unconformably Coniacian to Santonian neritic marls of the Grabenbach Formation. Clasts include limestones, dolomites, cherts and red siltstones from Triassic rocks, quartz porphyries and quartzites, and significant amounts of reworked sandstones from the underlying formation. The matrix of the conglomerates is sandy, similar to the conglomerates of the Gamsforst area. Coarse normal grading and imbrications of larger clasts is a common feature of the conglomerates. The up to 2 m thick red sandy to silty clay beds within the conglomerates display thin sandstone intercalations. No marine fossils could be found in the red clays. This succession is overlain by a marine sandstone-marl interval.

This conglomerate - red clay succession is interpreted as a coarse braided stream system, probably with transitions to alluvial fans, including channel fills and fine-grained interchannel flood plain deposits. This non-marine succession overlying marine Coniacian-Santonian marls thus records a break in the sedimentation, subaerial exposure and erosion during the middle to Late Santonian.

O l i s t o l i t h s of the K r i m p e n b a c h F o r m a t i o n
within the Nierental Formation (Schweinbach section)

Olistoliths of characteristic lithologies of the Krimpenbach Formation can be found within several meter thick olisthostroms of the Nierental Formation. The best outcrop was already described and sampled by KRISTAN-TOLLMANN & TOLLMANN (1978) in the Schweinbach section near farm house Sommerauer (Fig. 1). Here, large olistoliths of quartz porphyry-rich conglomerates, grey sandstones and grey marls similar to outcrops of the Krimpenbach Formation in the Gamsforst area are dispersed in a marly matrix, which yielded a foraminiferal assemblage of the Late Campanian *calcarata* Zone. A similar situation was found in a small creek in the Gamsforst, where blocks of conglomerates are intercalated in red and dark grey marls of the Nierental Formation.

The olistoliths of the the Krimpenbach Formation give evidence for a considerable larger depositional area of these sediments as indicated by today's outcrops. As transport directions in the Nierental Formation are generally from the south to the north, the depositional area of the Krimpenbach Formation extended southward of the present-day Gams basin.

3.3. Biostratigraphy

Biostratigraphic data for the Krimpenbach Formation were already reported by KOLLMANN (1964), who assigned a Campanian age to the calcarenites and conglomerates of this formation. New biostratigraphic data are mainly based on ammonites and inoceramids (SUMMESBERGER et al. 1999). Additional data from calcareous nannofossils and

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foraminifera are presented in the following section. A test for palynomorphs in grey marls of the creek north of Kendlbauer was unsuccessful.

The oldest parts of the Krimpenbach Formation comprise terrestrial, coal-bearing conglomerates and red sandy clays underlying marine grey marls in the small creek north of farm house Kendlbauer. A Late Santonian age is probable for these parts of the section, as these conglomerates overly unconformably Coniacian to Lower Santonian grey marine marls of the Grabenbach Formation at Radstatthöhe, and are overlain by latest Santonian to Early Campanian marine sediments.

Planktic foraminifera from samples of the uppermost conglomerate layers (BMN re562175/ho281262) indicate the *asymetrica-elevata* foraminiferal Zone (e.g. WAGREICH 1992). Sample GAM200 from the marly matrix of an exotic conglomerate bed included a nannofossil assemblage typical for standard zone CC17 of PERCH-NIELSEN (1985) and CC17a of WAGREICH (1992). The following marker species are present:

Bipodorhabdus cf. *brooksi* (BUKRY 1969) CRUX 1982
Calculites obscurus (DEFLANDRE 1959) PRINS & SISSINGH 1977
Lucianorhabdus cayeuxii DEFLANDRE 1959
*Marthasterites furcatus (*DEFLANDRE IN DEFLANDRE & Fert 1954) DEFLANDRE 1959
Micula decussata VEKSHINA 1959
*Reinhardtites anthophorus (*DEFLANDRE 1959) PERCH-NIELSEN (1968)

Sample GAM97 from a marly layer in the uppermost part of the conglomerates included:

Bipodorhabdus brooksi (BUKRY 1969) CRUX 1982
Calculites obscurus (DEFLANDRE 1959) PRINS & SISSINGH 1977
Lithastrinus grillii STRADNER 1962
Lucianorhabdus cayeuxii DEFLANDRE 1959, including curved morphotypes
*Marthasterites furcatus (*DEFLANDRE IN DEFLANDRE & Fert 1954) DEFLANDRE 1959
Micula decussata VEKSHINA 1959
*Reinhardtites anthophorus (*DEFLANDRE 1959) PERCH-NIELSEN (1968)

This assemblage gives evidence for standard zone CC17b of WAGREICH (1992) due to the presence of *Calculites obscurus* and curved *Lucianorhabdus cayeuxii*, which ranges from the latest Santonian to the lowermost Campanian according to macrofossil correlations in the Gosau area (WAGREICH 1992). Foraminifera from the same sample included the marker species

Bolivinoides strigillatus (CHAPMAN)
Dicarinella asymetrica (SIGAL)
Globotruncanita elevata (BROTZEN)
Globotruncanita stuartiformis (DALBIEZ)
Sigalia deflaensis (SIGAL)
Sigalia decoratissima (DE KLASZ)

These marker species indicate the *asymetrica-elevata* Zone of the uppermost Santonian to lowermost Campanian based on the presence of *Dicarinella asymetrica* and *Globotruncanita elevata*. The presence of species of the genus *Sigalia* point to a position in the lower part of the *asymetrica-elevata* Zone as compared to the zonation in the Gosau type area (WAGREICH 1992). The plankton : benthos+plankton ratio of the sample is about 60, indicating already an offshore environment of deposition.

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A similar plankton assemblage was encountered in a marly block within the olistostrom of the Schweinbach section (sample GAM89)

Nannofossil marker:

Calculites obscurus (DEFLANDRE 1959) PRINS & SISSINGH 1977
Lithastrinus grillii STRADNER 1962
Lucianorhabdus cayeuxii DEFLANDRE 1959; including curved morphotypes of WAGREICH 1992
Marthasterites furcatus (DEFLANDRE in DEFLANDRE & FERT 1954) DEFLANDRE 1959
Micula decussata VEKSHINA 1959
Reinhardtites anthophorus (DEFLANDRE 1959) PERCH-NIELSEN (1968)

Foraminifera:

Bolivinoides strigillatus (CHAPMAN)
Dicarinella asymetrica (SIGAL)
Globotruncanita elevata (BROTZEN)
Globotruncanita stuartiformis (DALBIEZ)

The facies of the grey and partly red marly siltstones and silty to sandy marls in the Wentneralm and the Krimpenbach areas yielded several macrofossil horizons, which indicate a time span from Late Santonian to Late Campanian (SUMMESBERGER et al. 1999). The oldest horizon included, among others, *Selenoceramus* cf. *inflexus* (BEYENBURG), indicating a latest Santonian to earliest Campanian age, which is in accordance with the nannofossil assemblages of standard zone CC17b (SUMMESBERGER et al. 1999).

The red siltstones at the road to the Wentneralm (Wentneralm I of SUMMESBERGER et al., 1999) yielded *Hauericeras* cf. *pseudogardeni* (SCHLÜTER), *Pachydiscus (P.) launayi* und *Selenoceramus inflexus* (BEYENBURG). This indicates an Early Campanian age (*bidorsatum*-ammonite-zone, SUMMESBERGER et al. 1999).

The uppermost macrofossil horizon (Wentneralm II of SUMMESBERGER et al., 1999) is characterized by *Inoceramus cf. bosenbergensis Walaszczyk, Inoceramus planus* (MÜNSTER), *Inoceramus aff. borilensis* JOLKI?EV, *Cataceramus balticus* cf. *haldemensis* (GIERS), *Pachydiscus (P.) tweenianus* (STOLICKA) und *Pachydiscus (P.) haldemsis* SCHLÜTER), which prove a Late Campanian age of the *phaleratum* - *polyplocum*-ammonite Zone (SUMMESBERGER et al. 1999).

The youngest ages of the Krimpenbach Formation can be found in the type section, within the topmost layers of the Krimpenbach Formation. Here, a late Late Campanian age of the overlying soft marls of the Nierental Formation has been proven due to the presence of a nannofossil assemblage of zone CC22b, parts of which can be correlated to the *calcarata* foraminiferal Zone (e.g. WAGREICH & KRENMAYR 1993). This indicates still a level in the Late Campanian and gives clear evidence against a range into the Maastrichtian.

The integration of macro- and microfossil biostratigrapic data defines a Late Santonian to Late Campanian age for the Krimpenbach Formation. Nannofossil zones CC17 to CC21/22a can be proven, and planktic foraminifera indicate the *asymetrica-elevata*-Zone, the *elevata*-Zone and the *ventricosa*-Zone.

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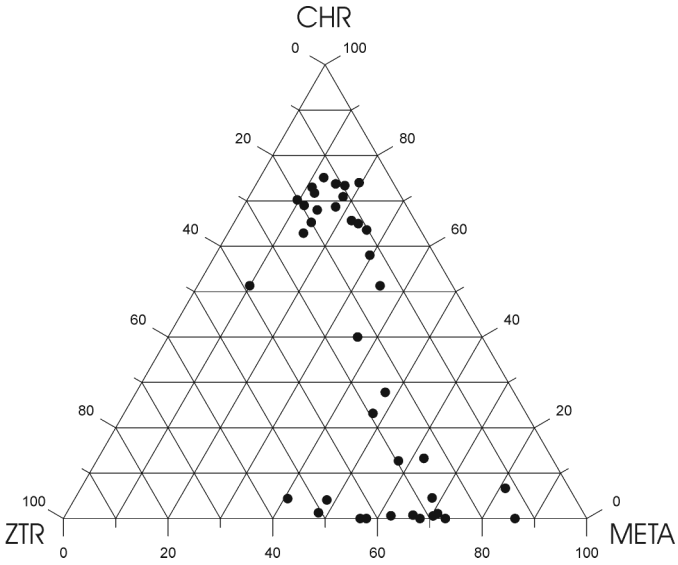

Fig. 4: Heavy mineral assemblages of the Krimpenbach Formation. Triangle displaying stable minerals (ZTR - zircon, tourmaline, rutile), metamorphic minerals (META - garnet, staurolite, chloritoid, epidote-zoisite-minerals, blue amphiboles and green hornblende) and chrome spinel.

3.4. Petrography of sandstones and conglomerates

A distinct petrographic feature of the coarse-grained deposits of the Krimpenbach Formation is the significant amount of "exotic" material. Conglomerates are rich in quartz porphyry and quartzite clasts, especially in the Kendlbauer section, where these lithologies make up more than 80 % of the clasts (Fig. 3). In the Radstatthöhe area, these lithologies vary between 10 and 50 % of the clast assemblages. In the eastern outcrop areas quartz porphyries are relatively rare (1 – 5 %) and clasts from the surrounding Mesozoic limestones and dolomites dominate the assemblages. Quartz porphyries and quartzites show a considerable rounding, which indicates possible reworking from older sediments, as the transport distances of these pebbles within the Upper Cretaceous alluvial-fluvial depositional systems may have been insufficient to produce such a rounding of these durable clast lithologies. Thin section analysis of the quartz porphyries indicates a non-metamorphic texture with only slight recristallization of the volcanic matrix and alteration of rare feldspar crystals.

3.5. Heavy mineral assemblages

Heavy mineral assemblages from the Gosau Group of Gams were reported by WOLETZ (in KOLLMANN 1964), although samples of the Krimpenbach Formation were not included in this study. Heavy mineral assemblages of the Krimpenbach Formation indicate a high amount of exotic material similar to the petrography of conglomerates. 3 types of assemblages were encountered (comp. Tab. 1 and Fig. 4).

The first assemblage type displays minor amounts of or lack of chrome spinel (0 – 37 %). Garnet (16 – 38 %) and minerals of the epidote group (3 – 40%) prevail besides stable minerals like zircon and tourmaline, and apatite. These assemblages appear mainly in the

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Tab. 1: Heavy mineral data from the Krimpenbach Formation and the Kreuzgraben Formation from the eastern part of the Gams basin. Heavy minerals separated by tetrabromethan, sieve fraction 0.063 - 0.4 mm, by point counting method. Percentages below 1 are displayed as 0,5.

	sample no.	ZIR	TUR	RUT	APA	GRA	CHL	STA	EPI	CHR	AMP	HOR	SON
Kreuzgraben Fm., Wentneralm	GAM124B	3	13	1	25	4	0	0	51	0	3	0	0
	GAM141B	10	20	8	23	20	0	1	16	0	0	0	1
	GAM142B	11	42	3	31	8	2	0	1	2	0,5	0	0
Grey conglomerates, base of	GAM125K	16	8	7	16	8	0,5	0,5	35	0,5	8	0	0
Krimpenbach Fm., Wentneralm	GAM128K	20	8	7	26	8	0,5	2	12	3	13	0	1
Conglomerates, Kendlbauer section	GAM95Q	3	10	0,5	2	7	9	0	14	50	3	1	1
	GAM98Q	6	5	1	1	13	5	0	3	65	0,5	0,5	0,5
	GAM198	3	3	0,5	1	11	6	0	1	74	0,5	1	0
	GAM165	4	5	1	3	12	7	0,5	5	62	0	1	0
Olistoliths of Krimpenbach Fm.	GAM91o	3	7	0,5	5	7	9	0	0,5	67	0,5	0	0,5
in the Sommerauer area	GAM93o	4	6	1	1	12	6	0,5	4	64	1	0	1
	GAM191o	4	7	1	4	9	14	0	4	56	1	0,5	0
	GAM196Ko	5	4	0,5	1	9	6	0	1	73	0,5	0,5	0
Marine sandstones,	GAM161Q	4	5	3	14	0,5	75	0	0	0	0	0	0
Kendlbauer section	GAM163Q	5	5	1	10	5	46	0	19	6	3	0	0
Calcarenites and sandstones,	GAM239A	8	9	0,5	0,5	8	3	0	1	68	0,5	2	1
Gamsforst	GAM239B	6	6	0,5	0,5	9	1	0	1	74	0	1	1
	GAM240	5	8	0,5	1	10	2	0,5	2	68	1	2	1
	GAM241	7	12	0,5	1	8	1	0,5	1	69	0	1	0,5
Sandstones and calcarenites,	GAM227Kr	16	6	6	34	20	0	0,5	13	0	4	1	0
Torsattel	GAM226Kr	13	7	2	33	16	0,5	0	23	0,5	5	0	0
	GAM254KF	21	17	4	4	27	0	3	15	0	9	1	0
	GAM230Rö	4	16	3	4	34	0,5	0,5	7	26	0,5	2	0,5
	GAM76T	9	15	2	8	28	1	0	29	1	8	0	0
	GAM78T	8	11	6	14	33	0,5	0	12	0,5	14	1	0,5
	GAM185T	9	8	7	11	33	0	1	22	4	4	0	1
Calcarenites, type section,	GAM260A	16	10	3	5	38	0	0	23	0	1	0	4
Krimpenbach	GAM260B	11	23	6	19	30	0	0	6	1	2	0	2
	GAM260A	11	9	4	4	18	0	0	40	13	2	1	0
	GAM260B	5	15	2	9	23	0,5	1	6	37	2	1	0
	GAM261	8	9	3	24	29	0	0	16	0	9	0	2
	GAM262	11	10	7	1	35	0	0,5	13	12	6	0	5
Siltstones and marlstones,	GAM264In	16	29	5	3	21	1	1	3	4	10	1	6
type section, Krimpenbach	GAM220I	12	12	0	16	17	5	0	10	19	5	2	2
	GAM265	5	13	1	5	5	6	0	0,5	62	0,5	2	1
Siltstones and marlstones,	GAM114Ig	6	9	1	2	3	5	0	0	71	0	4	1
Wentneralm	GAM182Ig	5	10	1	0,5	5	3	0	0	73	0	3	0
	GAM122Ig	3	7	1	1	6	5	0	0,5	73	0,5	3	0
	GAM180ge	6	10	3	6	7	0	0	1	66	1	0	0,5
	GAM181Ige	12	23	2	5	8	0,5	1	0	49	0	0	0
	GAM120Ir	7	13	2	4	10	0	0	4	61	0	0	0

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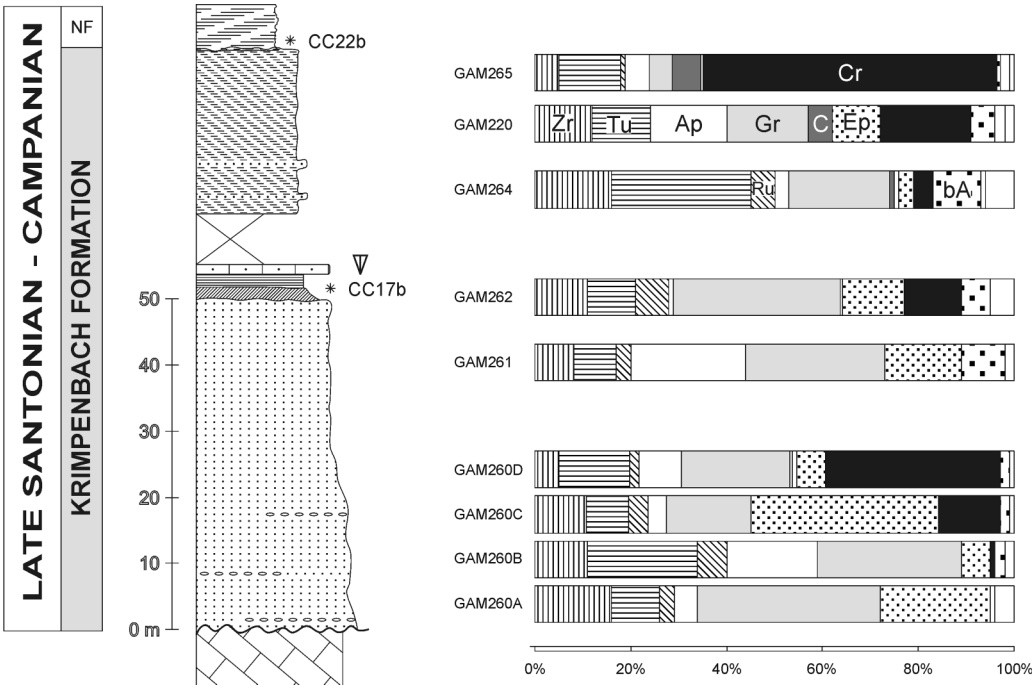

Fig. 5: Heavy mineral distribution in the type section of the Krimpenbach Formation, including nannofossil data. NF – Nierental Formation; Zr – zircon, Tu – tourmaline, Ru – rutile, Ap – apatite, Gr – garnet, C – chloritoid, Ep – epidote group, Cr – chrome spinel, bA – blue amphiboles; other minerals normally below 2% include staurolite, hornblende and brookite; CC – nannofossil standard zones (PERCH-NIELSEN 1985).

eastern lower part of the Krimpenbach Formation, e.g. in the calcarenites of the Krimpenbach- and Torsattel areas and in the grey conglomerates along the Wentneralm forest road. The high epidote content is very similar to those reported from Upper Campanian-Maastrichtian turbiditic sandstones of the Nierental Formation (KRENMAYR 1999).

Chrome spinel dominates the second type of assemblages with percentages between 49 and 74%. These assemblages occur mainly in the western outcrop areas, e.g. within the conglomerates of the Kendlbauer creek and within the siltstones in the Wentneralm area. In their high chrome spinel content these assembalges are similar to those from the Turonian - Coniacian sandstones near Gams (comp. WOLETZ in KOLLMANN 1964).

The third assemblage type is characterized by high amounts of chloritoid (46 - 75%) together with minor stable minerals, apatite, garnet and some chrome spinel. This assemblage type occurs within the marine sandstone above the exotic conglomerates of the Kendlbauer section.

Within the type section a gradual change from epidote-dominated to chrome spinel-dominated assemblages can be recognized (Fig. 5). The lower part of the calcarenites is characterized by the absence or minor amounts of chrome spinel and thus may represent more local source areas than the overlying siltstones and marls, which have significant amounts of chrome spinel up to 62%.

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In comparison to the underlying Turonian to Lower Santonian sandstones (e.g. WOLETZ in KOLLMANN 1964) the Krimpenbach Formation displays significant differences, especially in a higher content of metamorphic minerals, mainly garnet, chloritoid and minor amounts of minerals of the epidote group, and in lower contents of blue amphiboles. Thus, some changes of source areas from the Turonian-Coniacian to the Late Santonian-Campanian can be inferred. Ultrabasic source areas are still present; the importance of metamorphic source areas seems to increase gradually although ultrabasic rocks are still ubiquitous as indicated by the high amounts of chrome spinel.

4. Discussion

The Krimpenbach Formation records a time of significant changes during the deposition of the Gosau Group of the Gams area. Biostratigraphic data indicate that the deposition of the Krimpenbach Formation started during the Late Santonian to Early Campanian. Unconformable contacts of alluvial to fluvial conglomerates both onto Triassic carbonate substratum as well as on Coniacian to lower Santonian neritic deposits of the Gosau Group indicate a significant phase of uplift, subaerial exposure and erosion during the Lower to Middle Santonian, before the deposition of the Krimpenbach Formation. This phase seems to be accompanied also by faulting as suggested by angular unconformities, comparable to several other Gosau localities of the Northern Calcareous Alps (e.g. WAGREICH & FAUPL 1994; WAGREICH & DECKER 2001). After this deformation coarse terrestrial sedimentation started in small basins with the deposition of alluvial-fluvial conglomerates. Distal areas are characterized by pelitic sedimentation or small swamps. This facies association can be interpreted as a lowstand systems tract deposited during a relative sea level lowstand. The petrography of the sandstones and conglomerates and the heavy mineral data indicate both more local source areas rich in sedimentary and epimetamorphic rocks as well as "exotic" source areas with ultrabasic material.

The following shallow marine fan delta to shallow neritic conglomerates, coarse sandstones, calcarenites and marls record a fast transgression and/or strong subsidence, as suggested by the high plankton content of marls immediately above the conglomerates. The contrasting facies types, e.g. coarse siliciclastic conglomerates vs. neritic bioclastic calcarenites, indicate a transgression onto a complex topography with the development of local sediment transport systems and small fans. This transgressive systems tract is of Early Campanian age. Transgression was probably from northwest to southeast, as indicated by the contemporaneous bathyal facies of the Nierental Formation northwest of the depositional area of the Krimpenbach Formation.

Depositional water depths increased further upsection and the transition from coarse sandstones and calcarenites to marly siltstones with inoceramids and ammonites records maximum flooding and the transition into the highstand systems tract which consists of outer neritic hemipelagic marls. These highstand deposits cover the former complex topography and grade basinward into the pelagic bathyal marls to marly limestones of the Nierental Formation. An Early to Late Campanian age can be proven by ammonites, inoceramids, planktic foraminifera and nannofossils.

Source areas indicate a general change from more local sources to more regional sources, including chrome spinel and a significant amount of garnet and also chloritoid. This source area evolution is very similar to other Gosau basins, where the establish-

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ment of fully marine shelf conditions results in a change from local to more regional source areas with chrome spinel and finally to the predominance of an epi- to meso-metamorphic hinterland (e.g. WAGREICH 1988).

The transition from the neritic Krimpenbach Formation to the overlying bathyal Nierental Formation in the Krimpenbach section is interpreted to record a pulse of tectonic subsidence during the Late Campanian (CC 22ab), when the former marginal, south eastern parts of the Gams basin subsided into bathyal depths. Subsidence may be interpreted as a consequence of ongoing tectonic erosion as suggested for this diachronous subsidence event in the Northern Calcareous Alps (WAGREICH 1993, 1995).

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