

TAPHONOMY AND STRATIGRAPHY OF EARLY CRETACEOUS AMMONOID MASS OCCURRENCES (LATE VALANGINIAN; NORTHERN CALCAREOUS ALPS; UPPER AUSTRIA)

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ABSTRACT

Ammonoids of Early Cretaceous age were collected in the Kolowratshöhe section, which is located in the easternmost part of the Staufen- Höllengebirgs Nappe (Tyrolic Unit, Northern Calcareous Alps). The cephalopods, which occur in turbidite sandstones of the Rossfeld Formation, indicate a latest Late Valanginian age (*Criosarasinella furcillata* Zone). The ammonoid fauna (483 specimens) comprises 13 different genera, each represented by 1-2 species. Ammonitina are the most frequent components (65%, represented by *Haploceras*, *Neocomites*, *Criosarasinella*, *Rodighierites*, *Olcostephanus*, *Jeanthieuloyites*), followed by the lycoceratids (17%, *Lytoceras*, *Leptotetragonites*, *Protetragonites*), the phylloceratids (7%, *Phylloceras*, *Phyllopachyceras*) and the ancyloceratids (11%, *Bochianites*, *Crioceratites*, *Himantoceras*). The cephalopod fauna consists only of Mediterranean elements (dominated by *Olcostephanus*, microconchs and macroconchs, 231 specimens). The term '*Olcostephanus densicostatus* abundance zone' is established for these abundance beds. The ammonoid specimens of the Kolowratshöhe are accumulated into 3 different layers within an interval of 30 centimeters of sandstone. The fauna of the Kolowratshöhe section is interpreted as a mixed assemblage, comprising allochthonous elements transported from the shallower shelf and parautochthonous pelagic elements from the open sea.

The presence of abundant glauconite indicates low sedimentation rates in the source area, whereas the final deposition of the sandstones of the Rossfeld Formation took place during conditions of relatively high sedimentation rates but under the influence of turbidites and varying bottom morphology. The allochthonous glauconite points to a shallow shelf environment as the primary source for the sandstones. This source area was interpreted as a land high and a shelf from which the sediments were delivered into basins of the Northern Calcareous Alps (e.g., Tyrolic Unit) to the north of the swell. The basin palaeogeography is interpreted as a submarine, north-directed proximal/distal slope belonging to an uplifted area situated to the south of the basin.

Unter-Kreide Ammoniten wurden bei der Kolowratshöhe, im östlichsten Teil der Staufen-Höllengebirgs Decke (Tirolikum, Nördliche Kalkalpen), aufgesammelt. Die Cephalopoden aus den Turbidit-Sandsteinen der Rossfeld-Formation zeigen oberstes Ober-Valanginium an (*Criosarasinella furcillata* Zone). Die Ammonitenfauna (483 Exemplare) enthält 13 verschiedene Gattungen, wobei jede von 1-2 Arten repräsentiert wird. Die Ammonitina sind die häufigsten Vertreter (65%, repräsentiert durch *Haploceras*, *Neocomites*, *Criosarasinella*, *Rodighierites*, *Olcostephanus*, *Jeanthieuloyites*), gefolgt von den Lycoceratina (17%, *Lytoceras*, *Leptotetragonites*, *Protetragonites*), den Phylloceratina (7%, *Phylloceras*, *Phyllopachyceras*) und den Ancyloceratina (11%, *Bochianites*, *Crioceratites*, *Himantoceras*). Die Cephalopoden-Fauna setzt sich ausschließlich aus mediterranen Elementen zusammen (dominiert von *Olcostephanus*, Mikrokonche und Makrokonche, 231 Exemplare). Der Terminus '*Olcostephanus densicostatus* abundance zone' wird für diese Anreicherungsschichten eingeführt. Die Ammoniten der Kolowratshöhe sind in 3 verschiedenen Lagen innerhalb eines Intervalls von 30 Zentimetern Sandstein angereichert. Die Fauna der Kolowratshöhe wird als Misch-Vergesellschaftung gedeutet. Die Fauna enthält sowohl allochthone Elemente, welche aus flacheren Schelfbereichen transportiert wurden, als auch parautochthone, pelagische Elemente des offenen Meeres.

Das häufige Auftreten von Glaukonit deutet auf geringe Sedimentationsraten im Liefergebiet hin, wogegen die endgültige Ablagerung der Sandsteine der Rossfeld-Formation unter Bedingungen relativ hoher Sedimentationsraten stattfand. Die Ablagerung der Sandsteine wurde von Turbiditen und durch sich verändernde Morphologien des Meeresbodens beeinflusst. Der allochthone Glaukonit deutet auf einen flachen Schelf als Bildungsort und primäres Liefergebiet der Sandsteine hin. Dieses Liefergebiet, von dem aus die Sedimente in die nördlich gelegenen Becken der Nördlichen Kalkalpen (e.g., Tirolikum) transportiert wurde, wird als Festland mit vorgelagertem Schelf interpretiert. Die Paläogeographie des Beckens wird als submariner, nach Norden gerichteter proximal/distaler Hang, der einem im Süden des Beckens emporgehobenen Bereich angehört, gedeutet.

1. INTRODUCTION

Lower Cretaceous pelagic sediments are known to form a major element of the Staufen- Höllengebirgs Nappe of the Northern Calcareous Alps (NCA) of Austria. Valanginian to Hauterivian cephalopod- bearing deposits are represented by

two different facies, the Schrambach Formation and the Rossfeld Formation. The stratigraphy of these formations and their suggested environments were recently summarized by Piller et al. (2004). Upper Valanginian to Hauterivian sediments of the

two different facies, the Schrambach Formation and the Rossfeld Formation. The stratigraphy of these formations and their suggested environments were recently summarized by Piller et al. (2004). Upper Valanginian to Hauterivian sediments of the Schrambach Formation are mainly composed of limestones to marly limestones with rare turbiditic sandstone intercalations, whereas the Rossfeld Formation comprises turbiditic marls and sandstones (Immel, 1987).

The thickness of Lower Cretaceous sediments occurring in the northern tectonical units of the NCA decreases towards the north. Geodynamical processes occurring within the basins involved were reviewed by Faupl and Wagneich (2000). The dominating sandstone deposits within the Tyrolic Unit (e.g., Rossfeld Formation) become less prominent within northern nappes (e.g., Bajuvaric units). Boorová et al. (1999) conducted one of the most recent and detailed lithological and biostratigraphical analyses from the Jurassic Oberalm Formation (uppermost Tithonian) up to the Upper Rossfeld Formation (Upper Valanginian) in the Gutratsberg Quarry (near the Rossfeld type locality).

The area around the Kolowratshöhe southeast of Bad Ischl (Upper Austria, see Fig. 1) was first mentioned by Hauer (1850; Kolowratshöhe) and later by Uhlig (1887; Pernecker Salzberg). The latter locality is most probably the same as the one reported herein. During the 1970s and 1980s, a small fauna of cephalopods was described from the surrounding area (Immel, 1978, 1987). The cephalopod fauna published by this author was collected in sandstones and marly limestones of the Rossfeld and Schrambach formations. Most of the ammonoid material that he presented is housed in private collections and was not collected by the author. Additional ammonoid faunas of surrounding areas were also described by Hauer (1847, 1848), Uhlig (1882) and Fugger (1907). Fugger's ammonoids derive from localities of the Rossfeld, which is the type section for the Rossfeld Formation, but the localities are situated in the neighboring Markt Schellenberg (Bavaria, Germany). From the latter area, a large fauna was collected by Weber (1942) and Pichler (1963) between the Rossfeld and Markt Schellenberg.

The locality studied has been inaccessible for almost 30 years. Until now, only private persons had collected at this locality and no material could be found stored at official places like the Natural History Museum (Vienna), Institute of Palaeontology (University of Vienna), Geological Survey (Vienna) or even in smaller collections of Upper Austria or Salzburg.

New excavations (2002-2004) by the author were extremely successful and yielded a rich and diverse fauna which is presented herein. This was probably the last opportunity to collect fossils at this locality because of excavation circumstances. The collected ammonoid fauna (483 specimens) presented herein is fully integrated in the collection of the Natural History Museum (Vienna). Only a small number (18) of additional specimens is stored in private collections (e.g., collection Maherndl, Bad Ischl).

The present study examines deposits of the Lower Cretaceous Rossfeld Formation, cropping out at the Kolowratshöhe. The aim

of the present work is to detail the ammonoid fauna of the Kolowratshöhe locality, and to analyse the dynamics of the sedimentation for a better understanding of the taphonomy and sedimentology of such Cretaceous pelagic ammonoid beds.

2. GEOGRAPHICAL SETTING

Outcrop. The outcrop is situated in the Staufen-Höllengebirgs Nappe in the southernmost part of Upper Austria, about 3 km southeast of Bad Ischl and 1.5 km east of Perneck (588 m, ÖK 1:50 000, sheet 96 Bad Ischl; Schäffer, 1982) (Fig. 1). The succession comprising the ammonoid-bearing beds, is located at the end of an old, overgrown forest road on the western side of the Kolowratshöhe (1109 m). The sandstone succession is running between the Rettenbach (557 m) to the north and the vicinity of the Salzberg (827 m) to the south. The poor exposure is situated on the left side of the small road. The exact position of the ammonoid site was determined by GPS: N 47°41'24" and E 13°39'24" (Fig. 2). The site can only be accessed with permission from the forest agency, over a steep forest road (approx. 10 km) which has its initial point on the main road from Bad Ischl to Bad Goisern.

3. GEOLOGICAL SETTING AND BIOSTRATIGRAPHIC AGE

3.1 SETTING

The locality is situated in the southernmost part of the Tyrolic Unit, which in this region lies under and/or adjoins the small 'Hallstätter Scholle'. The Tyrolic Unit forms part of the 'Traunalpen

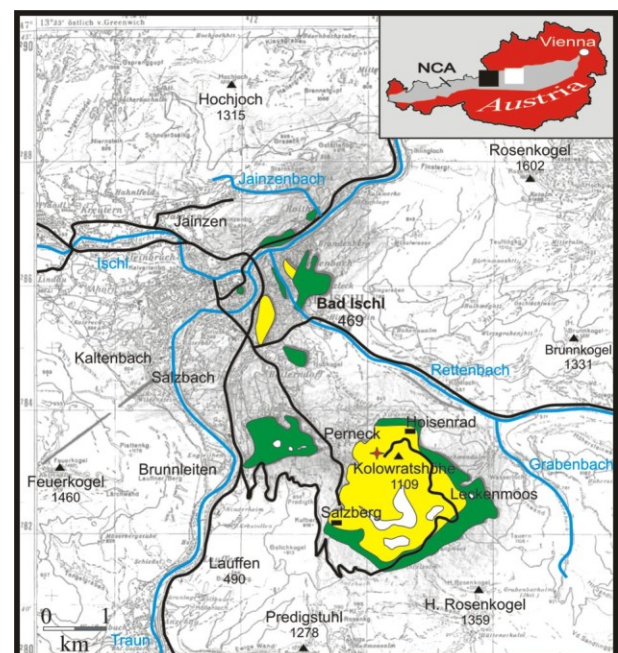


FIGURE 1: Localities map of the investigated area showing the outcrop of Lower Cretaceous sediments around the section within the Staufen-Höllengebirgs Nappe (Tyrolic Unit). Rossfeld Formation – yellow. Schrambach Formation – green. In the right upper corner map of Austria with indicated position of the Kolowratshöhe section (white square) and the type locality from the Rossfeld (black square).

Scholle', which in this region represents the westernmost part of the Staufeu-Höllengebirgs Nappe (Tollmann, 1976).

Lower Cretaceous sediments are represented in the area around the Kolowratshöhe section by two formations, the Rossfeld Formation (approx. 120 m, Upper Valanginian) and the Schrambach Formation (approx. 40 m, Hauterivian) (Fig. 2). The allochthonous slope-trench sediments of the Rossfeld Formation have been divided at the type locality (Decker et al., 1987) into three different depositional settings: 1) lithofacies A, which is characterized by silty grey marls (approx. 175 m); 2) lithofacies B, characterized by thin to thick bedded sandstones (approx. 120 m) and 3) lithofacies C, characterized by coarse clastics (approx. 50 m).

3.2 LITHOLOGY

The Kolowratshöhe section consists of essentially ochreous (weathered surface) to dark grey (fresh surface) calcareous, glauconitic sandstones of the Rossfeld Formation. The sandstones, which are assigned to the lithofacies B type of Decker et al. (1987), are well sorted and show biogenic components (e.g. foraminifera, echinids). Single grains are not well rounded, and the sediment seems to be immature. The sandstone consists mainly of quartz and calcite. Further constituents are glauconite, feldspar (albite to plagioclase), chlorite (clinochlore) and unidentified clay minerals (?illite and ?serpentine). Due to weathering, the green colour of the glauconite has changed into brown and consequently the whole sandstone becomes brownish. Glauconite occurs in two different varieties. The first is greenish, the second dark brown, the latter having probably a higher iron content. The sediment has a heavily burrow-mottled fabric owing to bioturbation by abundant *Chondrites* and *Planolites* and rare *Zoophycos*.

Single beds are of 20-30 cm thickness and show flat lower and upper boundaries. In most cases these beds show an internal layering, displaying different compositions and a fining upward grading. The internal layers have undulating boundaries and are marked by an accumulation of phosphatic grains. Due to bioturbation, the boundaries are sometimes not clearly expressed and components are mixed and protrude into upper or lower beds. Some beds exhibit a fine, more pelitic top up to 1 cm thickness.

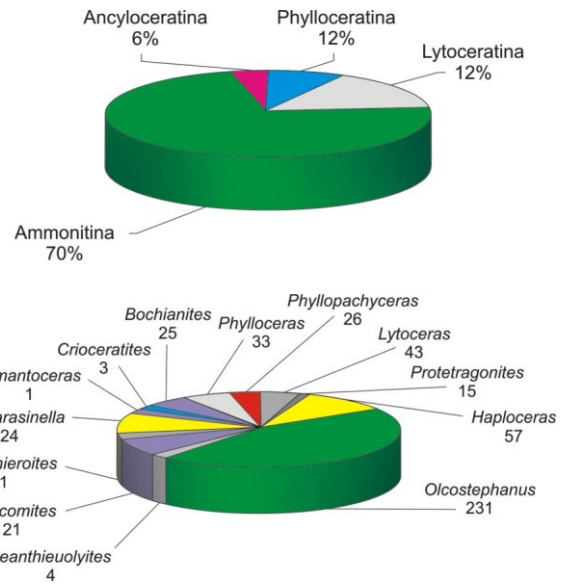


FIGURE 3: Ammonoid assemblage composition from the Kolowratshöhe locality. Note the dominance of the Ammonitina and the abundance of the genus *Olcostephanus*.

3.3 FOSSIL ASSEMBLAGE

The macroinvertebrate fauna consists of ammonoids (483), aptychi (14) and brachiopods (4, *Triangope*). Macrovertebrates are only represented by shark teeth (*Sphenodus*). The order *Coniferales* is represented by *Brachyphyllum*, which is the only identifiable plant remnant in the Kolowratshöhe section.

A small number (14) of aptychi in contrast to the very high (483) number of ammonoid specimens (compared with other Valanginian sediment successions of the NCA; Lukeneder, 2001, 2003b) is observed. Isolation of the cephalopod beaks from the ammonoid shell took place either through transport (and therefore different behaviour in the water column) or through current-induced grain differentiation during accumulation.

The abundant and generally well-preserved cephalopods are dominated by olcostephanids (Fig. 3). Members of Phylloceratina, Lytoceratina, Ammonitina and Ancyloceratina are present. The very abundant Late Valanginian ammonoid assemblage consists of 13 genera: *Phylloceras*, *Phyllopachyceras*, *Lytoceras*,



FIGURE 2: Exposure of the Kolowratshöhe section, which is situated in the Rossfeld Formation. 'Now and then': Left - 1970s. Right - 2004.

Protetragonites, *Haploceras*, *Olcostephanus*, *Neocomites*, *Criosarasinella*, *Rodigheroites*, *Jeanthieuloyites*, *Crioceratites*, *Himantoceras*, and *Bochianites* were collected by the author and by Wolfgang Mahernndl. The ammonoid fauna contains only descendants of the Mediterranean Province.

All the *olcostephanids* have been assigned to one and the same species, i.e. to *Olcostephanus densicostatus*. This contrasts with the idea of Immel (1987), who identified the *olcostephanids* from the same locality and the same level as *Olcostephanus sayni* (Immel, 1987: Pl. 3, Fig. 6) and *Olcostephanus astierianus* (Immel, 1987: Pl. 3, Fig. 8). Immel's figured material forms part of the collection of Wolfgang Mahernndl (Bad Ischl), which was studied by the author. It can be concluded that the locality 'Ischler Salzberg' (Immel, 1987) is in fact the same as the studied locality of the Kolowratshöhe section. Immel's specimens are deformed and therefore morphologically different due to tectonics (different whorl-height against whorl-breadth). Therefore the morphological variation led to misidentification of this species (Fig. 4). Moreover, it has always been difficult to distinguish between juvenile micro- and macroconchs in *olcostephanids*. This difficulty does not exist in

adult specimens (e.g., lappets or collared apertures) (Fig. 5). Finally, *Olcostephanus sayni* is known to occur in the Hauterivian, not in the Valanginian.

3.4 BIOSTRATIGRAPHY

The ammonoid association sampled in the Kolowratshöhe section indicates that the cephalopod-bearing beds of the Rossfeld Formation belong to the *Criosarasinella furcillata* ammonoid Zone (*Criosarasinella furcillata* Subzone) of the latest Late Valanginian (zonation according to Hoedemaeker et al., 2003) (Fig. 6).

The following species were identified: *Phylloceras serum*, *Phyllopachyceras winkleri*, *Lytoceras subfimbriatum*, *Lytoceras sutile*, *Protetragonites* sp., *Haploceras* (*Neolissoceras*) *grasianum*, *Haploceras* (*Neolissoceras*) *desmoceratoides*, *Olcostephanus densicostatus*, *Neocomites praediscus*, *Neocomites subpachydicanus*, ?*Rodigheroites* sp., *Jeanthieuloyites* cf. *quinquestriatus*, *Criosarasinella furcillata*, *Crioceratites* sp., *Himantoceras* sp., *Bochianites oosteri*.

This ammonoid association and the occurrence of *Criosarasinella furcillata* indicate the *Criosarasinella furcillata*

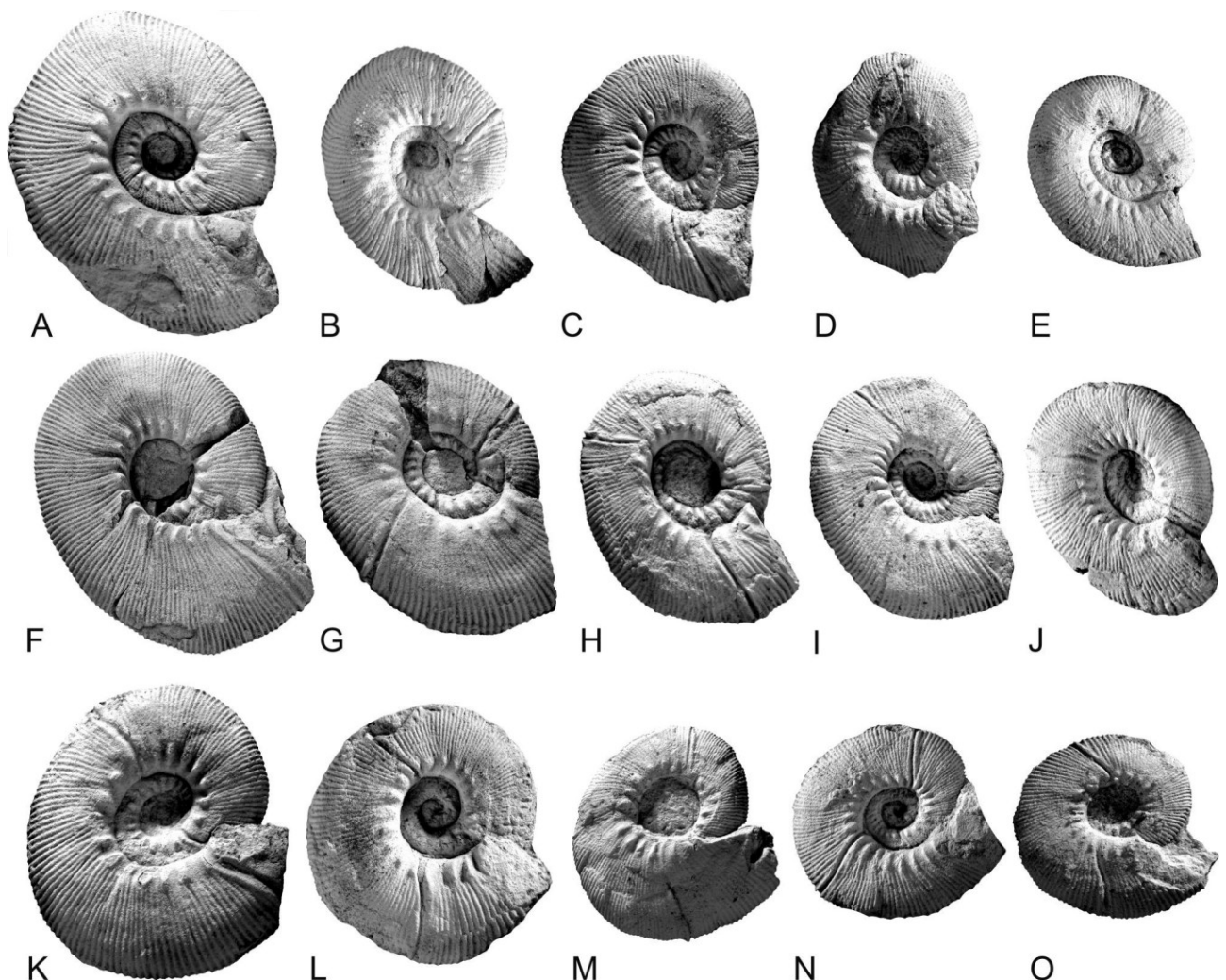


FIGURE 4: Different preservational modes in *Olcostephanus densicostatus*. Top row (A-E; 2005z0233/0050-54) – almost undeformed. Mid row (F-J; 2005z0233/0055-59) – moderate deformation. Bottom row (K-O; 2005z0233/0060-64) – flattening of specimens.

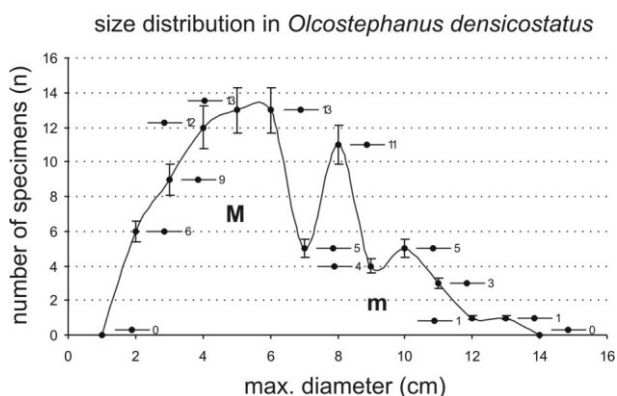


FIGURE 5: Bimodal distribution curves showing adult maximum size in *Olcostephanus densicostatus* (max. diameter against number of specimens). In general the macroconchs (M) are larger than microconchs (m), but the size ranges of the two antidimorphs overlap.

total-range Zone, and particularly the *C. furcillata* Subzone. Additionally, *Neocomites praediscus* is more or less a species restricted to the *C. furcillata* Subzone but was also mentioned to occur in the upper part of the underlying *Olcostephanus nicklesi* Subzone.

Similar ammonoid assemblages from the same biostratigraphic zone were described for example by Bulot and Thieuloy (1995) and, Bulot et al. (1992), Reboulet (1995) in France, by Pérez-Valera and Company (2001) in Spain, and by Wippich (2001, 2003) and Ettachfini (2004) in Morocco.

Based on its abundance, the specimens of the genus *Olcostephanus* are the most valuable constituent for the palaeogeographic and taphonomic interpretation of the fauna. The term '*Olcostephanus densicostatus* abundance zone' is introduced here for these abundance beds. This is meant in the sense that these *Olcostephanus densicostatus* beds are valid for correlating widely separated occurrences of the latter species. It is assumed, at least for Lower Cretaceous sediments of the Northern Calcareous Alps, that high abundances of this species may always indicate the *Criosarasinella furcillata* Zone. This approach has been proven by Lukeneder (2001; 2003a, b; 2004a, b, c, d), who established several correlatable ammonoid abundance zones ('levels', 'horizons') for certain ammonoid species in Alpine Lower Cretaceous sediments. These abun-

dance zones are defined by the high abundance or mass-occurrence of the name-designating taxon (e.g., *Olcostephanus densicostatus* abundance zone). These marker beds apply even if the zonal index fossils are missing. They reflect the acme of such species or genera and not their stratigraphical range. In a few cases only the genus name of the abundant ammonoids could be given because the specimens were not identifiable to the species level (e.g., *Euptychoceras* abundance zone, Lukeneder, 2003b).

4. MATERIAL, PRESERVATION AND METHODS

The material is in general well preserved despite the coarse sandy sediments and their normally poor casting-qualities. The preservation of the ammonoids (mostly moulds without shell) and the lithological character (mottled sandstones) of the Rossfeld Formation makes the sampling difficult. The phragmocones are mostly flattened, while the body chambers are better preserved because of early sediment infilling. The fragmentation is due to preburial transport, sediment compaction and considerable tectonic deformation. The fragmentation hampers the precise determination of most ammonoids. In most cases, faint suture lines are visible, but they are not sufficiently preserved to reproduce them.

All reported and figured specimens in the present paper were collected from the same locality, the Kolowratshöhe section. The material examined is stored in the collection of the Natural History Museum, Vienna, Austria (NHMW). All specimens in Plate 1, 2 and 3 were coated with ammonium chloride before photographing.

The author follows the classification of Cretaceous Ammonoidea by Wright et al. (1996), and the ammonoid systematics was adopted by the following authors: Reboulet (1995), Wippich (2001) and Lukeneder (2004a, b). Concerning the genus *Olcostephanus*, special attention was given to the papers by Bulot (1990, 1992, 1993), Company (1987), Cooper (1981) and Bulot and Company (1990).

In order to obtain pure glauconitic grains, samples were disaggregated with acetic acid in water. Size fractions were obtained by wet sieving with 1000 µm, 500 µm, 250 µm, 125 µm and 63 µm mesh. After ultrasonic treatment, single glauconite grains were dried at 55° C and then selected by hand-picking.

Thin sections and polished sections were made for sedimentological, mineralogical and lithological investigations. Polished surfaces were covered with hydrochloric acid to make differences in matrix visible. The sandstones were subject to X-ray diffraction analysis on a Siemens D5000 X-ray diffractometer. Quantitative chemical analyses were carried out on a JEOL JSM- 6400 scanning electron microscope equipped with a KEVEX energy-dispersive system. All the analyses were carried out in the laboratories of the Department of Geology and Palaeontology at the Natural History Museum (Vienna).

5. DISCUSSION

5.1 TAPHONOMY

The taphonomic investigations of cephalopod assemblages provide insight not only into the autecology of these organisms,

Stages	Zones	Subzones	
VALANGINIAN	Upper	<i>C. furcillata</i>	<i>T. callidiscus</i>
			<i>C. furcillata</i>
		<i>N. peregrinus</i>	<i>O. (O.) nicklesi</i>
			<i>N. peregrinus</i>
	Lower	<i>S. verrucosum</i>	<i>K. pronecostatum</i>
			<i>S. verrucosum</i>
<i>B. campylotoxus</i>		<i>K. biassalense</i>	
		<i>B. campylotoxus</i>	
	<i>T. pertransiens</i>		

FIGURE 6: The stratigraphic position within the uppermost Valanginian (*Criosarasinella furcillata* Zone, *C. furcillata* Subzone) of the Kolowratshöhe fauna (in grey). Table after Hoedemaeker et al. (2003).

but also into their palaeoenvironment and palaeocommunity structure (Bottjer et al., 1995; Brett and Baird, 1986). Taphonomical results based on data obtained from the marine fossil record have been extensively reviewed by Allison and Briggs (1991).

The Lower Cretaceous sediments of the Rossfeld Formation (Staufen-Höllengebirgs Nappe) do not represent the best conditions for excellent preservation of entire ammonoids because of their depositional history (turbidites) and the sandy, rather coarse composition. Interestingly, the ammonoids from the Kolowratshöhe section are well preserved and most of them are entire (approx. 70 %) what hints to no or moderate, non-destructive transport mechanisms and therefore favors a more autochthonous nature of the latter specimens. Judging from the internal structures of the sandstones, we are dealing turbidite beds of a medial position between a proximal (near- source) and a distal depositional development (Einsele, 1991). Hence, transportation of at least some bio-clasts is presumed.

The fragmentation of at least 30 % of the ammonoids provides evidence for post-mortem transport, breakage on the sea floor through current effects, and/or consequences of predation (Lukeneder, 2004a, b). In most cases, breakage probably resulted from the impact of shells with other bioclasts within the turbidity currents, or the shells were ruptured by current-induced transport before embedding. Accumulated small ammonoids and shell fragments in body chambers of adjacent large ammonoids, in combination with cephalopod alignment in single layers suggest also current-effects on deposition (Fig. 9). This applies both to straight shells (e.g., *Bochianites*) as well as coiled shells (e.g., *Lytoceras*, *Haploceras*, *Olcostephanus*). This points to regulation by bottom currents. Erosional features on the upper side of large ammonoids (e.g., macroconchs of *Olcostephanus*) suggest erosion of uncovered shell parts after embedding. The shell transport took place during phases of turbidity flows, as is reflected by their occurrence in several separated ammonoid-layers (up to 10 cm thickness).

The accumulation of the shells which show horizontal alignment in thin, separated layers, is probably due to reworking and current-induced removal of sediment (Figs. 7 and 8). The latter specimens were most probably secondarily re-orientated and so aligned after a first turbiditic sedimentation phase. In contrast, ammonoids are extremely rare or even missing in the sandstone beds between the ammonoid beds (I, II, and III; Figs. 7 and 8).

Encrustation by serpulids on larger smooth shell fragments hint at a longer depositional history for the latter ammonoids. Either they were encrusted during a drifting stage or were colonised while laying on the sea floor long enough for the polychaetes to settle on these special hard substrates or secondary 'hardgrounds' (see Lukeneder and Harzhauser, 2003). Encrustation is missing on ribbed ammonoid shells. Densely ribbed shells of the olcostephanid group are less fragmented than those of the lytoceratids (e.g., *Lytoceras*), phylloceratids (e.g., *Phylloceras*), ammonitids (e.g., *Haploceras*, *Neocomites* and *Criosarasinella*) and ancyloceratids (e.g., *Bochianites* and *Crioceratites*). Because of the fragile, juvenile phragmocone morphology of heteromorphic ammonoids,

Bochianites, *Crioceratites* and *Himantoceras* are generally fragmented; in most cases, only smaller, fractured parts are present. This may reflect different living habitats and therefore different post mortem histories. It may also reflect the more stable shells of the more 'spheroidal' and involute olcostephanids are more resistant to damage than compared other ammonoid shell morphologies.

In accumulated mixed assemblages, such as at the Kolowratshöhe section, the KB1-A outcrop (Lukeneder, 2004b) and the Eibeck section (Lukeneder, 2004a), macroconchs and microconchs are found together. Mixed assemblages are defined by the latter author by comprising allochthonous elements transported from the shallower shelf and autochthonous benthic and parautochthonous pelagic elements (e.g., olcostephanids) from

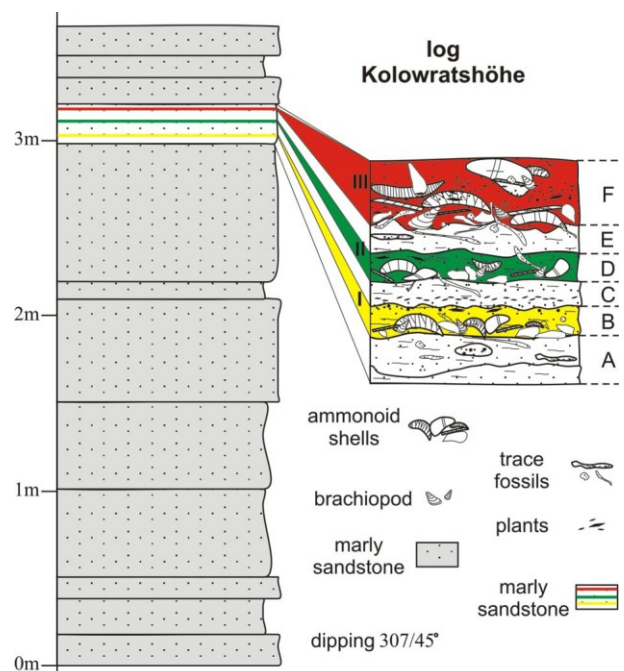


FIGURE 7: Log of the section showing the intercalated ammonoid layers I, II and III (yellow, green and red).

the open sea. Assuming an analogous situation for the Kolowratshöhe section as for the Eibeck section, this would mean that the presence of undamaged macroconchs accompanied by intact microconchs (with lappets) within the same bed points to a similar derivation of the ammonoids from the same source, in this case the pelagic fauna of the sea above.

This interpretation is contrasted by the occurrence of some lytoceratid specimens showing different sediment-infillings of the phragmocones (fine, light-grey material) as compared to the body chambers ('normal' sandstone). Reasons for these differences in sediment infilling remain still unclear. Probably it's due to infilling processes, which separates fine from coarse sediment particles. However the former aspect is evidence that at least a small contingent of ammonoids was allochthonous, i.e. transported from shallow to deeper regions, from shelf to slope.

The cephalopods of the Kolowratshöhe section thus constitute a mixed allochthonous/parautochthonous fauna. This effect is enhanced by the fact that turbidity currents and other submarine mass-flows may already contain a mixed shelf and slope assemblage by picking up bioclasts from different bathymetric zones along their way (Einsele and Seilacher, 1991). The term 'mixed' assemblage is used in the sense of Kidwell and Bosence (1991). The latter described a mixed assemblage as the addition of shells of one assemblage to the members of another assemblage. For classification and reviews on taphonomical processes of marine shelly faunas see also Norris (1986), Kidwell et al. (1986), Kidwell (1991), Kidwell and Bosence (1991), and Speyer and Brett (1991).

5.2 SEDIMENTOLOGICAL AND LITHOLOGICAL IMPLICATIONS

The described fauna was deposited within sediments formed by turbidity currents on the slope (Decker et al., 1987). The sediments were probably reworked and transported in suspension some distance to the north. Originally, the sediments had been deposited on the shelf south of the later embedding place of the ammonoid fauna (Fig. 10). In this southern area, unstable marine sediment accumulations form the prerequisite for the turbidity currents (Einsele, 1991) that built up the Rossfeld Formation. The position of the source area was determined by the work of the present author and others including Faupl (1979), Faupl and Tollmann (1979), Decker et al. (1983), Decker et al.

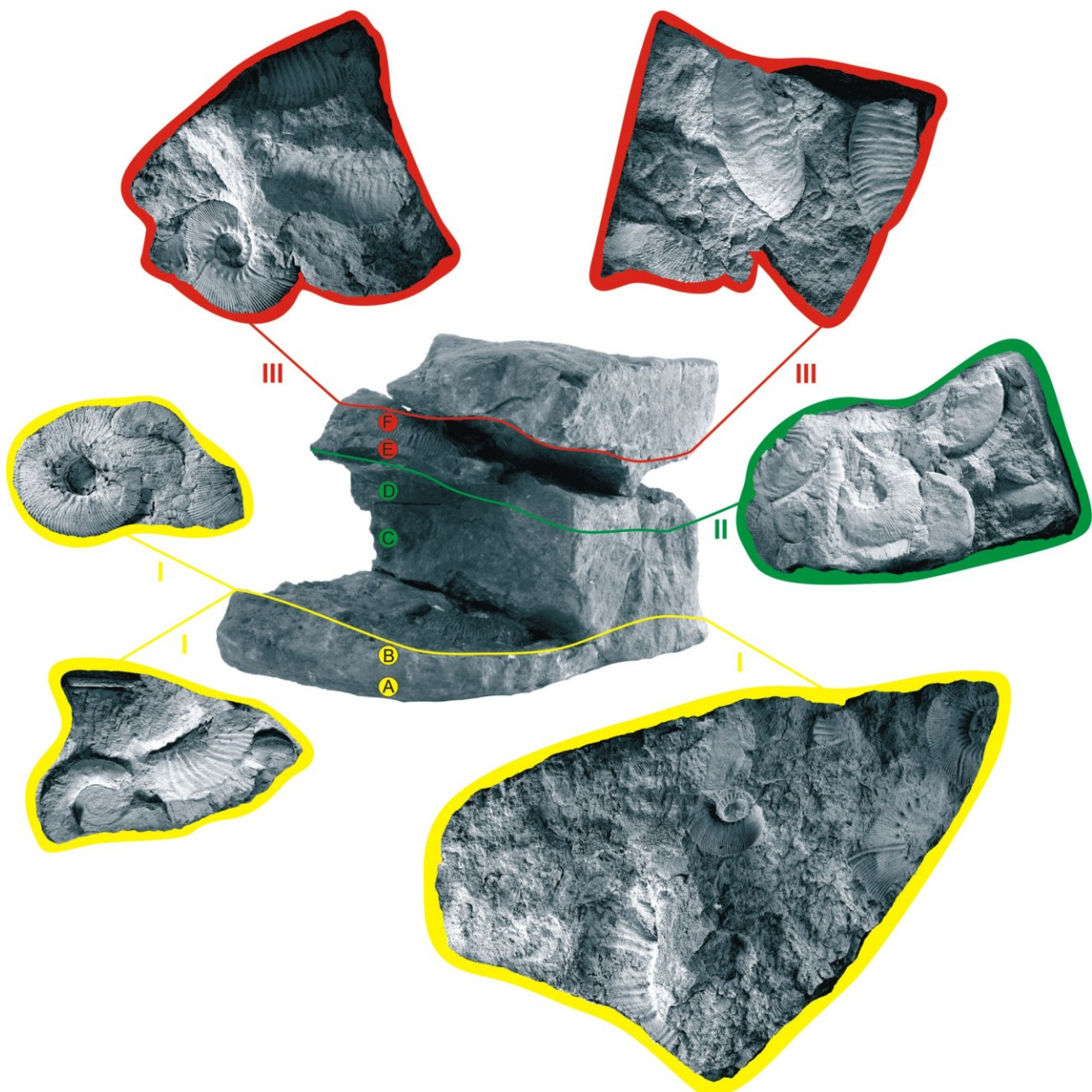


FIGURE 8: Plane surfaces of the corresponding ammonoid layers I (2005z0233/0065a), II (2005z0233/0065b) and III (2005z0233/0065c) indicated in Fig. 7. (yellow, green and red).

(1987), Faupl and Wagneich (1992), Vašíček and Faupl (1996, 1998), and Wagneich et al. (1999). The source area for the siliciclastics was a tectonically active land high (Faupl and Wagneich, 1992, Vašíček and Faupl, 1996, 1998) from which the sediments were delivered into northern basins of the Northern Calcareous Alps (e.g., Tyrolic Unit).

Turbidity currents can either be generated by sediment stirred up by storm waves in more shallow-water (Einsele and Seilacher, 1991) or be the consequence of other physical events (Einsele, 1991) such as 1) earthquakes, 2) tsunamis, and 3) sediment overloading. The causes and features of such rapidly deposited 'event' sediments are extensively reviewed by Einsele et al. (1991a), and the depositional environment of sandy turbidites and other mass flows deposits is summarized by Einsele (1991). The sediment succession investigated herein is interpreted as the result of gravity-induced sediment mass flows (mainly turbidites). The accumulated sediment masses most probably became unstable after 'shock- events' like earthquakes within the extremely unstable, tectonically active area in which nappes were formed during the Early Cretaceous. The described example is therefore attributed to an autocyclic sequence (Einsele et al., 1991b) formed by nonperiodic turbidites (Bouma et al., 1982; Cook et al., 1982; Howell and Normark, 1982; Tucker and Wright, 1990).

Sedimentological analysis applied to the sandy Lower Cretaceous glauconite-rich deposits of the Kolowratshöhe locality, allows to interpret the glauconite grains as being allochthonous. This means that the glauconite grains were removed from their place of origin (inner shelf), and redeposited and concentrated in a somewhat deeper environment within slightly younger deposits. Glauconitic minerals are relatively common authigenic constituents of marine sediments, and, if autochthonous, are good indicators of low sedimentation rates. A palaeodepth range between 60 and 550 m and an open marine environment are considered to be ideal for glauconitisation (Odin and Fullagar, 1988; see also Odin, 1988). Such environmental settings are characterized by low- energy and relatively slow sedimentation. It is probable that glauconite formation is only restricted to zones with low deposition rates and does not demand a specific water depth (Velde, 2003). After their formation, glauconitic grains can be transported and thus redeposited.

Sandy environments of low deposition rates, which appear at the source area (shelf) of the sediments from the Kolowratshöhe section thus constitute the ideal place for glauconitisation (Pasquini et al., 2004). Because of the redeposition of the sediments during 'short' events by turbidity currents, the accumulation rate at the final depositional area is in contrast high. The morphology of these glauconitic grains allows a tentative prognosis as to a reconstruction of the transport history. Accordingly, the more angular (not well-rounded), medium-sorted granular facies points to a moderate transport distance of the sediments at the Kolowratshöhe. The almost green to brownish colour of glauconite minerals (mixed layer minerals, ferric minerals) most likely depends upon the relative abundance of the iron ion valence in the silicate structure (Velde, 2003). Glauconite is not stable during surface weathering. It tends to

oxidize ochre in sandstones and, during surface alteration, to form kaolinite and iron oxide.

6. CONCLUSIONS

The final deposition of the sandstones from the Kolowratshöhe took place during conditions of relatively high sedimentation rates. The sandstones of the Rossfeld Formation in this area consist mainly of turbidites. The source area was a subaerial high and a shelf from which the sediments were delivered into northern basins of the Northern Calcareous Alps. The high has been shown to extend above the sea-level as confirmed by findings of the land plant *Brachyphyllum*. On the whole, the presence of glauconite indicates a low deposition rate in the source area. The lithological and mineralogical diagnostic findings point to an amalgamation of single turbidite beds after a decline or cessation of sedimentation. A cessation is strongly supported by the accumulation of glauconitic grains in single layers that separate single beds of glauconitic sandstones.

The macrofauna of the Kolowratshöhe section is represented especially by ammonoids. The whole section yielded 483 ammonoids. Based on the presence of the index fossil *Criosarasinella furcillata*, the fauna can be assigned to the *Criosarasinella furcillata* ammonoid Zone (*Criosarasinella furcillata* Subzone). The ammonoid fauna contains only descendants of the Mediterranean Province.

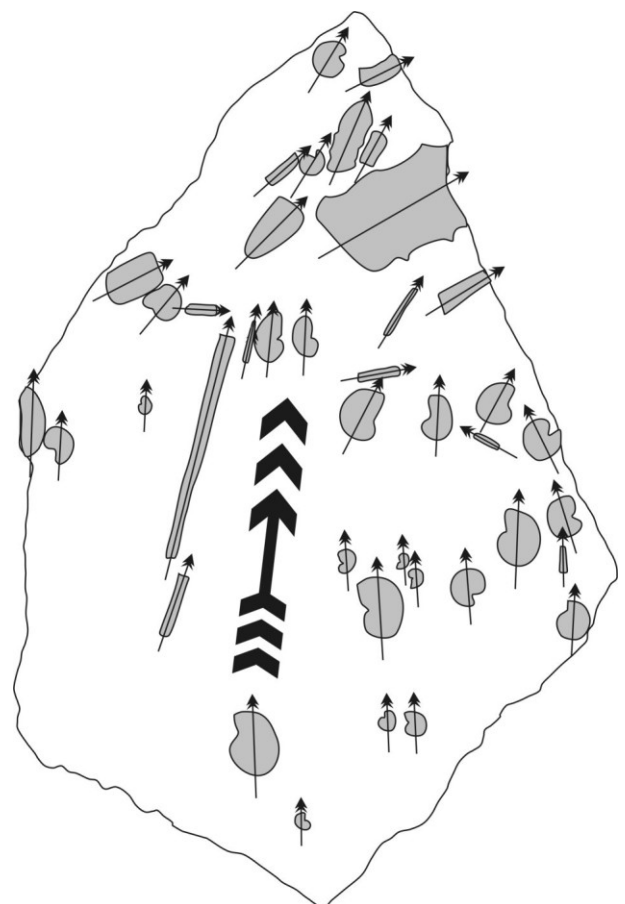


FIGURE 9: Current-induced orientation in ammonoids on a bedding plane I (black arrows indicate current direction).

The invertebrate fauna (e.g., ammonoids and brachiopods) are accumulated in isolated single-layers. The shells are aligned concentrated in particular levels and some show current-induced orientation. This applies both to straight shells (e.g., *Bochianites*) as well as coiled shells (e.g., *Lytoceras*, *Haploceras*, *Olcostephanus*). This points to orientation by currents. Additionally, accumulated small ammonoids and shell fragments in the body chambers of somewhat larger ammonoids supports the assumed effect of agglomeration and scavenging by currents. The accumulation of ammonoid layers indicates either deposition on site at short, favourable 'time-intervals', or to reworked accumulation-layers after turbiditic transport.

At least some of the abundant ammonoid specimens seem to have been redeposited from shallower shelf regions into a slope environment. The encrustation of larger smooth shell fragments by serpulids indicates a somewhat longer depositional history for such shells. This is interpreted as a sign for overgrowth of such secondary 'hardgrounds' uncovered by

sediments, by the benthic organisms during lengthier exposure. Most probably the encrustation took place already at the primary depositional area on the shelf.

The very small number (14) of aptychi contrasts the very high (483) number of ammonoid specimens. Isolation took place either through transport (and therefore different behaviour in the water column) or through current-induced grain differentiation during accumulation. The latter scenario leads to different places of deposition for these two cephalopod elements of the same animal.

Based on all these data, the fauna of the Kolowratshöhe section is interpreted as a mixed assemblage, comprising transported elements from the shallower shelf (allochthonous) along with more parautochthonous pelagic elements (olcostephanids) from the open sea.

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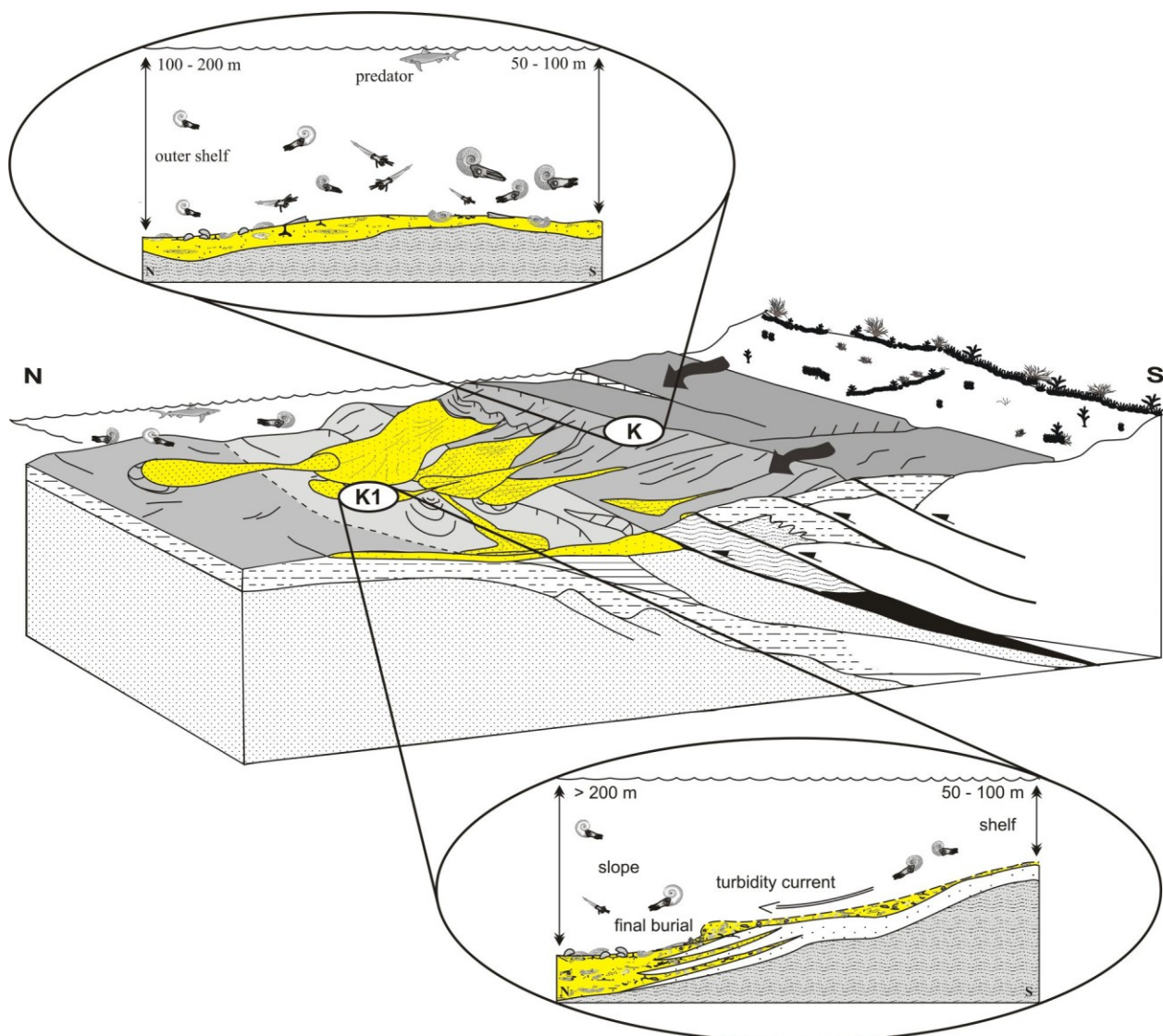


FIGURE 10: Model for the palaeogeographic transect and sedimentary origin of the glauconitic turbidite beds of the Rossfeld Formation at Bad Ischl during the uppermost Valanginian. K – source area of glauconitic sediments and some of the ammonoids. K1 – final deposition after transport.

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PLATE 1:

- FIGURE A:** *Phylloceras serum* (Oppel), x 0.5, 2005z0233/0001.
FIGURE B: *Phylloceras serum* (Oppel), x 0.5, 2005z0233/0002.
FIGURE C: *Lytoceras subfimbriatum* (d'Orbigny), x 0.5, 2005z0233/0003.
FIGURE D: *Lytoceras sutile* Oppel, x 0.5, 2005z0233/0004.
FIGURE E: *Lytoceras sutile* Oppel, x 0.5, 2005z0233/0005.
FIGURE F: *Phyllopachyceras winkleri* (Uhlig), x 0.5, 2005z0233/0006.
FIGURE G: *Protetragonites* cf. *quadrisulcatus* (d'Orbigny), x 0.5, 2005z0233/0007.
FIGURE H: *Phyllopachyceras* cf. *rogersi* (Kitchin), x 0.5, 2005z0233/0008.
FIGURE I: *Phyllopachyceras* cf. *rogersi* (Kitchin), x 0.5, 2005z0233/0009.
FIGURE J: *Phyllopachyceras* cf. *rogersi* (Kitchin), x 0.5, 2005z0233/0010.
FIGURE K: *Phyllopachyceras* cf. *rogersi* (Kitchin), x 0.5, 2005z0233/0011.
FIGURE L: *Haploceras desmoceratoides* Wiedmann, x 0.5, 2005z0233/0012.
FIGURE M: *Haploceras grasianum* (d'Orbigny), x 0.5, 2005z0233/0013.
FIGURE N: *Haploceras grasianum* (d'Orbigny), x 0.5, 2005z0233/0014.
FIGURE O: *Olcostephanus densicostatus* (Wegner), M, x 0.5, 2005z0233/0015.
FIGURE P: *Olcostephanus densicostatus* (Wegner), M, x 0.5, 2005z0233/0016.
FIGURE Q: *Olcostephanus densicostatus* (Wegner), M, x 0.5, 2005z0233/0017.
FIGURE R: *Olcostephanus densicostatus* (Wegner), M, x 0.5, 2005z0233/0018.
FIGURE S: *Olcostephanus densicostatus* (Wegner), m, x 0.5, 2005z0233/0019.
FIGURE T: *Olcostephanus densicostatus* (Wegner), M, x 0.5, 2005z0233/0020.
FIGURE U: *Olcostephanus densicostatus* (Wegner), m, x 0.5, 2005z0233/0021.
FIGURE V: *Olcostephanus densicostatus* (Wegner), M and m, x 0.5, 2005z0233/0022.



PLATE 2:

- FIGURE A:** *Jeanthieuloyites* cf. *quinquestriatus* (Besairie), x 0.5, 2005z0233/0023.
FIGURE B: *Jeanthieuloyites* cf. *quinquestriatus* (Besairie), x 0.5, 2005z0233/0024.
FIGURE C: *Jeanthieuloyites* cf. *quinquestriatus* (Besairie), x 0.5, 2005z0233/0025.
FIGURE D: *Jeanthieuloyites* cf. *quinquestriatus* (Besairie), x 0.5, 2005z0233/0026.
FIGURE E: *Criosarasinella furcillata* Thieuloy, x 0.5, 2005z0233/0027.
FIGURE F: *Criosarasinella furcillata* Thieuloy, x 0.5, 2005z0233/0028.
FIGURE G: *Criosarasinella furcillata* Thieuloy, body chamber, x 0.5, 2005z0233/0029.
FIGURE H: *Criosarasinella furcillata* Thieuloy, body chamber, x 0.5, 2005z0233/0030.
FIGURE I: *Criosarasinella furcillata* Thieuloy, body chamber, x 0.5, 2005z0233/0031.
FIGURE J: *Neocomites subpachydicranus* Reboulet, x 0.5, 2005z0233/0032.
FIGURE K: *Neocomites subpachydicranus* Reboulet, x 0.5, 2005z0233/0033.
FIGURE L: *Neocomites praediscus* Reboulet, x 0.5, 2005z0233/0034.
FIGURE M: *Neocomites praediscus* Reboulet, x 0.5, 2005z0233/0035.
FIGURE N: ?*Rodigheroites* sp., x 0.5, 2005z0233/0036.
FIGURE O: *Himantoceras* sp., x 0.5, 2005z0233/0037.
FIGURE P: *Crioceratites* sp., x 0.5, 2005z0233/0038.
FIGURE Q: *Crioceratites* sp., x 0.5, 2005z0233/0039.
FIGURE R: *Crioceratites* sp., x 0.5, 2005z0233/0040.
FIGURE S: *Bochianites oosteri* (d'Orbigny), x 0.5, 2005z0233/0041.
FIGURE T: *Lamellaptychus* sp., x 0.5, 2005z0233/0042.
FIGURE U: *Lamellaptychus* sp., x 0.5, 2005z0233/0043.
FIGURE V: *Zoophycos*, x 1, 2005z0233/0044.
FIGURE W: *Triangope* sp., x 1, 2005z0233/0045.
FIGURE X: *Sphenodus* sp., shark tooth, x 1, 2005z0233/0046.
FIGURE Y: *Brachyphyllum* sp., Coniferales, x 1, 2005z0233/0047.
FIGURE Z: Accumulated ammonoids on a bedding plane, *Olcostephanus*, *Protetragonites*, *Neocomites*. x 1, 2005z0233/0048.



PLATE 3:

FIGURE A: Current-directed ammonoid shells (*Olcostephanus*, *Protetragonites*, *Haploceras*, *Bochianites*) on a bedding plane (65 specimens). For explanation see Figure 9.
x 0.5, 2005z0233/0049.

