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Upper Cretaceous oceanic red beds (CORB) in the Northern Calcareous Alps (Nierental Formation, Austria): slope topography and clastic input as primary controlling factors

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Abstract

In the Northern Calcareous Alps, Upper Cretaceous oceanic red beds are composed of the Nierental Formation, deposited in bathyal slope basins along the active margin of the Austroalpine microplate. The sedimentation of red shales and marls was highly diachronous, starting in the Late Santonian. Carbonate contents vary between 50 and 90%. Siliciclastic and carbonate-dominated turbidite and mass-flow and slump deposits are common. Planktic foraminifera dominate the foraminiferal assemblages. Sedimentation rates for red (hemi)pelagic intervals are generally in the order of a few mm/ka up to 26 mm/ka. Within the Gosau valley area red (hemi)pelagic intervals a few tens of metres thick are diachronous. This case study suggests that Late Cretaceous oceanic red-bed deposition was not a single event but distributed over a longer time span and can, therefore, be regarded as the normal background sedimentation in deep-sea settings with relatively low sedimentation rates. However, the colour and thus the oxidation state of the (hemi)pelagic as well as turbiditic sediments was controlled by various regional and local factors. Within the morphologically complex orogenic-wedge setting of the slope basins of the Gosau Group, basin topography and local clastic input strongly influenced the occurrence and facies of the oceanic red beds.

Keywords: Upper Cretaceous; Red beds; Nierental Formation; Austria

1. Introduction

The Cretaceous was a time of extreme changes in ocean systems, leading to global anoxic events. In many marine deep-water successions the Late Cretaceous was characterized by a change in sedimentation from organic carbon-rich black shales at the Cenomanian/Turonian boundary to red "oxic" deposits with extremely low amounts of preserved organic carbon. These Upper Cretaceous oceanic red beds (CORB, e.g., Hu and Sarti, 2002; Hu et al., 2005) characterized a majority of deep-marine pelagic and hemipelagic settings in oceanic basins from the early to mid-Turonian onwards with the exception of the equatorial Atlantic (Hofmann et al., 2003). The initiation of CORB seems to have been controlled by the interplay of various palaeoceanographic and climatic factors; a marked diachroneity has been noted by Hu et al., 2005. In addition, in orogenic regions such as the Eastern Alps, CORB sedimentation was influenced by tectonism and synorogenic depositional processes.

This paper describes the occurrence of CORB in the Northern Calcareous Alps (NCA; Fig. 1) of Austria in

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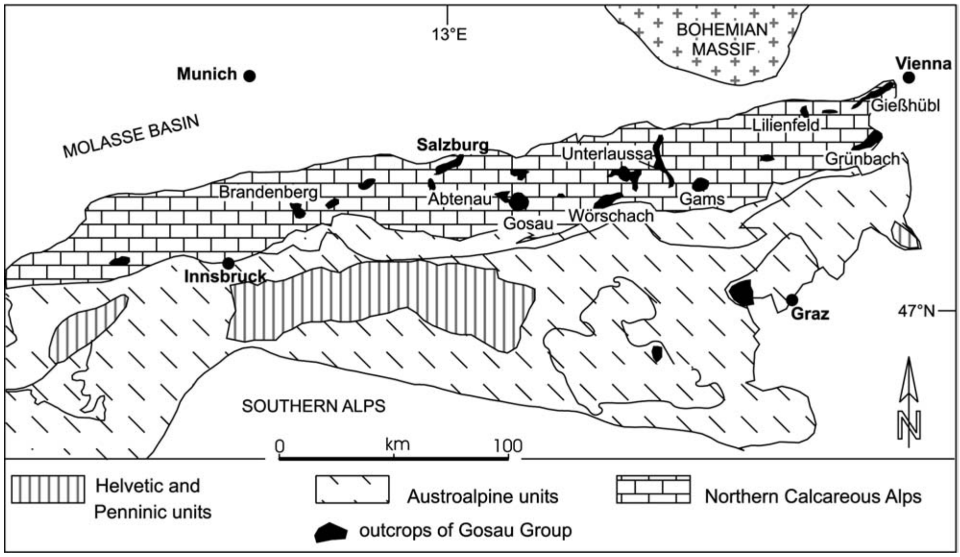

Fig. 1. Localities of the Gosau Group of the Northern Calcareous Alps within the Eastern Alps.

order to investigate the role of several possible controlling factors on the deposition and evolution of deep-marine red beds in the Late Cretaceous. The Gosau Group of the NCA provides an excellent example of tectonically influenced deposition within an active margin-orogenic wedge setting (e.g., Butt, 1981; Wagreich and Faupl, 1994; Sanders, 1998; Wagreich and Decker, 2001).

2. Geological setting

The Eastern Alps underwent a complex evolution of repeated extension and compression owing to the movement and collision of the African plate and several microplates (e.g., Channell et al., 1992). African-European convergence during the Cretaceous (Eo-Alpine orogenic phase; e.g., Faupl and Wagreich, 2000) and again from the Eocene onwards led to the formation of an orogenic wedge to the north of the Adriatic Plate, overriding the European-Penninic Plate (Fig. 2). The complex structural evolution of the NCA, a part of the Eastern Alps fold-and-thrust belt, includes a prominent Early–early Late Cretaceous stage of thrusting and cover nappe stacking, followed by subsidence of the Gosau Group basins from the Late Turonian onwards (Wagreich and Faupl, 1994; Wagreich, 1995; Willingshofer et al., 1999; Wagreich and Decker, 2001). Oblique subduction of the Penninic Ocean north of the Austroalpine microplate resulted in strong dextral shearing and the formation of rapidly subsiding shelf and slope basins along the northern active continental margin of the Austroalpine microplate (Wagreich, 1995; Wagreich and Decker, 2001).

The continental to shallow marine lower Gosau Subgroup (Late Turonian–Campanian) is overlain by the deep-water deposits of the upper Gosau Subgroup (Santonian–Eocene). The two subgroups are separated by an angular unconformity owing to a diachronous synsedimentary tectonic event. Parts of the lower Gosau Subgroup were deformed, uplifted and eroded during this time (Wagreich, 1993, 1995). Strong NCA-wide subsidence during the deposition of the upper Gosau Subgroup has been interpreted as a result of subduction-driven tectonic erosion of parts of the accretionary wedge (Wagreich, 1995) or underthrusting (Willingshofer et al., 1999).

Sedimentation in the Gosau basins was characterized by significant facies and thickness changes within short distances; small, rapidly subsiding depocenters surrounded by stable areas; high local clastic sediment input; the existence of prominent strike-slip faults; and a diachronous deep-water facies development. These basins display considerable similarities to the strike-slip basins of the Californian continental borderland (e.g., Wagreich and Decker, 2001).

3. CORB of the Nierental Formation

The stratigraphic term Nierental Formation (“Kalkmergel des Nierenthale”) was introduced by Gümbel (1861) for grey and red marlstones and marly limestones of the Upper Cretaceous. Following several revisions (e.g., Herm, 1962; Butt, 1981; Wagreich and Krenmayr, 1993), Krenmayr (1999) redefined the lithostratigraphic term and gave an extensive description of the type locality and the neostratotype near Salzburg and Bad Reichenhall. Wagreich and Marschalko (1995) reported that the Nierental Formation continues into the Western Carpathians of the Slovak Republic.

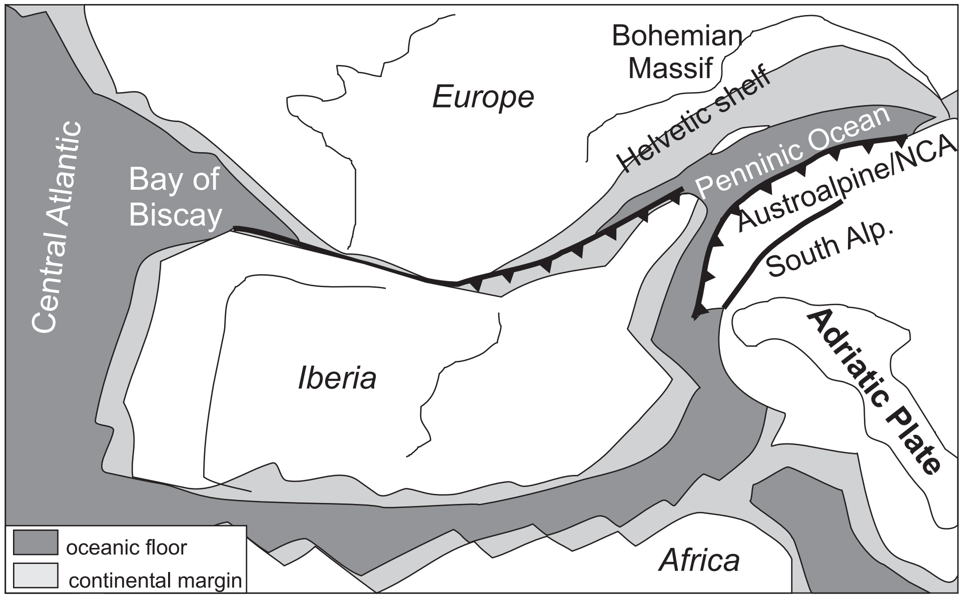

Fig. 2. Simplified palaeogeographic map for the Maastrichtian, based on Stampfli et al. (1998). Austroalpine/NCA, Austroalpine microplate including the Northern Calcareous Alps; South Alp., Southern Alpine Units.

The base of the Nierental Formation may be either gradational from both grey shelf marls and deep-water turbidite successions, or unconformable upon coarse, shallow-water strata of the lower Gosau Subgroup (Wagreich and Faupl, 1994). The upper boundary of the Nierental Formation is generally gradational into turbidite or debrite successions, although unconformities do exist locally (e.g., Lilienfeld; see Fig. 3).

The age of the Nierental Formation shows a significant diachroneity between individual Gosau outcrop areas of the NCA. The oldest parts are mid to Late Santonian, and crop out in the Brandenberg area (nannofossil zones CC 16–17 according to the standard zonal scheme of Perch-Nielsen, 1985; *Dicarinella asymetrica* foraminiferal Zone). In most of the exposures, the Nierental Formation begins within the lower or upper Campanian (CC 17–20), whereas in the southeastern part of the NCA, a Maastrichtian age (CC 24) of the first red hemipelagic/pelagic deposits is recorded (Wagreich and Faupl, 1994). Also, the top of the Nierental Formation is strongly diachronous; e.g., in some areas the formation ends in Campanian deposits, whereas in others, pelagic deposits continue into the Paleogene (see Fig. 2 and Wagreich, 2001).

3.1. Facies description

The Nierental Formation comprises a varying mixture of pelagic/hemipelagic and mass-flow deposits (mainly turbidites, coarse debrites and slump deposits; e.g., Wagreich and Faupl, 1994; Krenmayr, 1996, 1999). All of these are present in most Gosau Group successions of the NCA (Wagreich and Faupl, 1994). The lithostratigraphic definition of the Nierental Formation (Krenmayr, 1999) includes successions with a turbidite sandstone portion of up to 50% of the total thickness, although usually less. Complete Bouma-cycles frequently occur. The fine-grained turbiditic top-portions show strongly varying carbonate contents of between 20 and 70% and their thicknesses range from less than 1 cm up to 5 m. The pelagic/hemipelagic mudstones are characterized by carbonate contents of 60–90% (marlstones to marly limestones) and occur as centimetre- to a few decimetre-thick intervals in mixed turbiditic-hemipelagic facies, but may also form pure (hemi)pelagic successions many tens of metres thick (cf. Fig. 4A).

Red and grey colours of varying intensity can be observed in the pelitic material of both the turbiditic and (hemi)pelagic deposits. Hemipelagic and turbidite mudstones can be differentiated by differing carbonate contents, grain-size distributions, and content of microfossils (Krenmayr, 1996). Pure (hemi)pelagic successions can be red or grey without displaying any significant lithologic differences. This is also true for thin- to medium-bedded mixed (hemi)pelagic/turbiditic successions that may show reddish as well as grey colours. The muddy parts of thick-bedded turbidites sometimes display a red top-portion, independently from the colouration of (hemi)pelagic intervals. In several sections (e.g., at Gosau) it is possible to demonstrate that clastic content decreases continuously towards pure or nearly pure, intensively red-coloured (hemi)pelagic sediment-packages. Up-section, the clastic content increases again simultaneously with a lightening of the red colouration. Several types of complex colour

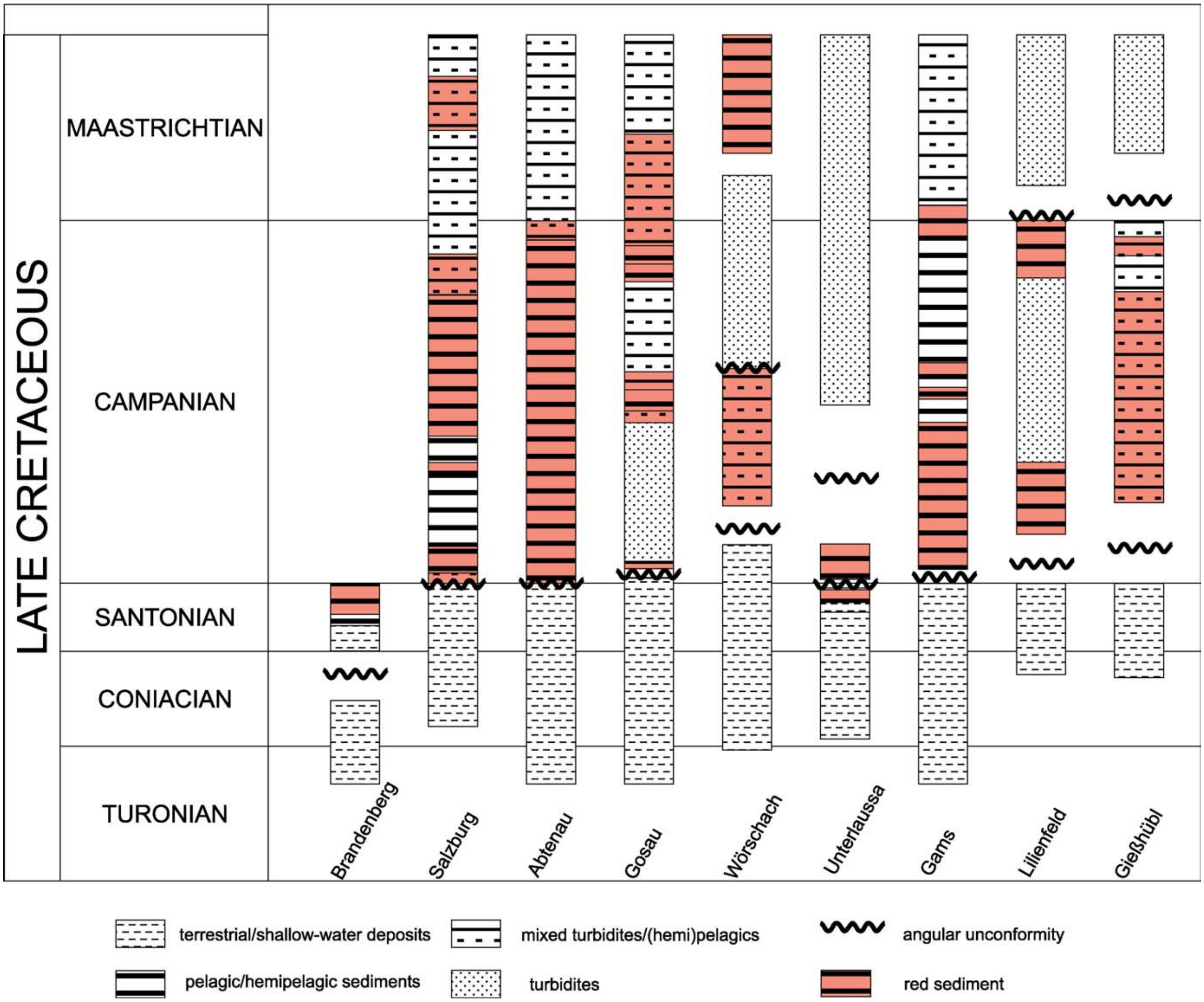

Fig. 3. Sections of the Gosau Group within the NCA, arranged from west to east.

sequences from turbidite to hemipelagic mudstones were described by Faupl and Sauer (1978) and Krenmayr (1996).

Siliciclastic and carbonate-dominated turbidites and mass-flow deposits are interbedded in regionally varying amounts. Slump deposits are also a common feature. Intensive bioturbation of the *Zoophycos* ichnofacies is ubiquitous. The (hemi)pelagic marlstones to marly limestones are mainly composed of coccoliths and planktic foraminifera. The latter contribute up to 10% of the bulk sediment volume. Benthonic foraminifera make up a maximum of 10% of the foraminiferal assemblage. They comprise mainly taxa typical for upper and middle bathyal environments; water depths of about 500–1500 m were estimated by Butt (1981).

A semi-quantitative analysis of the clay mineral composition was carried out for a sample set of 15 (hemi)pelagic and turbiditic mudstones from different exposures of the Nierental Formation. The clay minerals present are smectite, chlorite, illite, kaolinite and occasionally small amounts of mixed-layer minerals (mainly illite-chlorite and illite-smectite). Illite together with smectite generally predominates (up to 95%). Chlorite is present in portions of 4–25% whereas kaolinite varies between zero and 17%; both reflect changing composition of the hinterland. No systematic trends could be observed within turbidite-(hemi)pelagite couplets or between grey and red parts of the Nierental Formation. It is not possible to differentiate between mudstone types by means of clay mineral composition, even at single localities.

3.2. Intrabasinal variations

Intrabasinal variations of the facies development of the Nierental Formation have been recorded from the

Fig. 4. A, succession of red hemipelagic marly limestones with diffuse marlstone–marly limestone cycles along the Postalm road, Retschegg, Abtenau (height of outcrop about 2.5 m). B, red hemipelagic and grey turbidite-hemipelagic successions in the Rotwandgraben near Gosau (height of outcrop about 55 m).

Gosau type area and the Abtenau area (Fig. 5). These successions are about 15 km apart, arranged along a south-east–north-west palaeogeographic transect. Deep-water deposition started in the early part of the Early Campanian, as indicated by nannofossil zone CC 17 (CC 17b of Wagreich, 1992) and the *Dicarinella asymetrica-Globotruncanita elevata* foraminiferal zone. In the south-eastern part of the transect of Gosau valley, a siliciclastic fan succession at least 350 m thick (Ressen Formation) of Early Campanian age overlies reddish hemipelagic layers. Thick (hemi)pelagic sediments of the Nierental Formation begin above the Ressen Formation within the Lower Campanian (CC 19). In contrast, in the Abtenau area, a thick Lower–Upper Campanian (CC 17–22b/23a) succession of (hemi)pelagic red marly limestones is present without any significant turbidite admixture (Krenmayr, 1996). These CORB are arranged in indistinct cycles of darker red and softer marlstones interbedded with lighter red and harder marly limestones (Fig. 4A), which may be an expression of Milankovitch cyclicity.

Even more abrupt facies changes exist within horizontal distances of only a few km in the Upper Campanian of the Gosau valley area. Within the Rotwand- and Elendgraben sections (Wagreich and Krenmayr, 1993), the Nierental Formation is characterized by red, grey and sometimes greenish hemipelagic and turbiditic deposits (Fig. 4B). Sections rich in thin-bedded and minor thick-bedded turbidites are interbedded with nearly pure red hemipelagic intervals a few tens of metres thick. Both sections were dated using nannofossils and some additional planktic foraminifera to the *Globotruncanita calcarata* Zone. The results indicate that even within this short distance, the red hemipelagic intervals were not synchronously deposited and cannot be correlated from the Rotwand section to the Elendgraben section.

3.3. Sedimentation rates

In general, compacted sedimentation rates for the (hemi)pelagic deposits of the Nierental Formation at the type locality and in Gosau-Abtenau are reported to lie between 10 mm/ka in mixed hemipelagic/turbiditic sequences (Krenmayr, 1999) and 26 mm/ka in the pure red hemipelagic deposits of the Abtenau area (Krenmayr, 1996). Sedimentation rates of turbidites (including sandstones) at these localities range from 12 to 23 mm, but higher values (30–60 mm) have been estimated, at Gams for example (Krenmayr, unpublished). Turbidite frequency was calculated to be about one event every 10,000 years at the type locality. For the Cretaceous/Palaeogene boundary interval total sedimentation rates of 14–18 mm/ka were also reported by Lahodynsky (1988).

4. Discussion

The diachronous facies distribution within the Nierental Formation of the NCA gives significant information about the nature and evolution of CORB. Although the primary causes for CORB deposition are still debated, some important conclusions can be drawn from the deposition within the NCA.

The palaeogeographic position of the NCA during the Campanian–Maastrichtian was a northward-deepening slope at the front of an orogenic wedge situated on the northern margin of the Adriatic/Austroalpine Plate. This margin was characterized by relatively small-scale

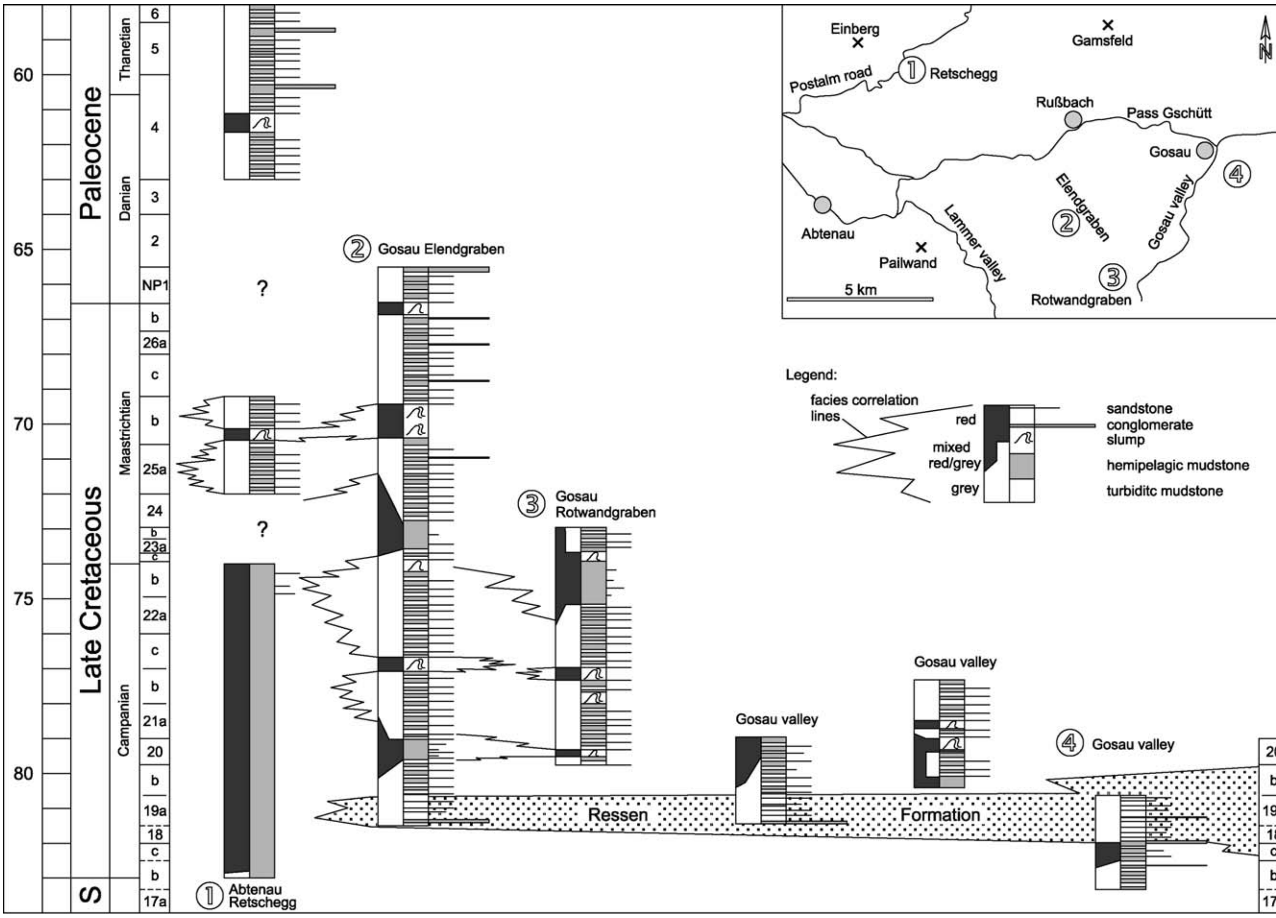

Fig. 5. Chronostratigraphic correlation of sections of the Nierental Formation in the Gosau–Abtenau area. Inset: locality map: 1, Abtenau, Retschegg, section along Postalm road; 2, Rußbach, Elendgraben section; 3, Gosau, Rotwandgraben section; 4, Gosau valley sections at Hofergraben and Feichteckgraben.

slope basins as a result of strike-slip faulting. A general northward-deepening trend and an increasing siliciclastic sediment supply from rising metamorphic complexes to the south can be reconstructed (Butt, 1981; Wagreich and Faupl, 1994). The NCA were situated at a latitude of about 30° North within the tropical to subtropical climatic belt (Wagreich and Faupl, 1994), at the northern margin of the Tethys oceanic realm.

The frequent changes of red and grey colours within successions of otherwise similar lithology suggest that a rather sensitive chemical equilibrium existed that was responsible for sediment colour. The crucial factor that determined the colour of single layers of sediment is whether the bottom water was well oxygenated or not. This in turn depended mainly on the oceanic current system and the morphological features of the sea floor. If a particular sedimentary subenvironment of the Nierental Formation was exposed to oxygenated bottom-water currents then hematite was formed and the sediment turned red. These currents may have changed over time within intervals of several tens to hundreds of thousands of years. Unfortunately, in the case of the Upper Cretaceous Tethys Ocean, the detailed Alpine slope morphology and the pathways of oceanic currents remain just a matter of speculation.

Within the complex active-margin setting of the Gosau Group, thick and intensively red-coloured CORB are present only where siliciclastic sediment is missing or relatively scarce. Because calculation of sedimentation rates was only possible for a very restricted number of sections and also owing to the fact that pure (hemi)pelagic sections rendered relatively high values (up to 26 mm/ka), the occurrence of CORB cannot be linked directly to low sedimentation rates. However, all calculated values of sedimentation rates can be regarded as relatively low when compared to recent pelagic sedimentation rates (Krenmayr, 1999).

The strong intrabasinal variations of lithofacies within short horizontal distances and within the diachronous (hemi)pelagic intervals of the Nierental Formation can be interpreted as (1) a result of syntectonic deposition within small, morphologically complex slope basins and (2) the local input of small, laterally confined turbidite/mass flow systems. The topographic position within or at the margin of the basin or at local topographic highs, and the influence by local (oxidizing) bottom currents, mainly controlled the colouration of single beds. The calculated recurrence time of ca. 10 ka for turbidite events for the Wasserfallgraben section (Krenmayr, 1999) excludes the possibility that the time between turbidite events might have been too short for oxidizing the sediment. In many sections at different Gosau localities, red slumped pelites occur as intercalated packages within grey turbiditic–(hemi)pelagic series. This implies that within the Gosau basins oxidizing and more reducing conditions existed on the sea floor contemporaneously.

This dynamic situation strongly suggests that CORB are not single, relatively short time events as interpreted for Cretaceous oceanic anoxic events (e.g., Jenkyns, 1980), but that their deposition occurred over a longer time span, at least from the Early Turonian onwards. CORB sedimentation in the Late Cretaceous can be regarded as the predominant type of background pelagic and hemipelagic sedimentation in deep-sea settings with relatively low sedimentation rates of the order of a few mm/ka up to about 30 mm/ka. Where significant clastic input was present, as in the case of some of the Gosau slope basins or within flysch-type basins of the Alps and Carpathians (Hu and Sarti, 2002), CORB development is suppressed or masked by turbiditic sequences. Complex morphologies and current situations may be responsible for multiple colour variations between red and grey. The case of the diachronous, red (hemi)pelagic intervals of the Nierental Formation also suggests that if siliciclastic input is mainly controlled by tectonic activity then sea-level changes played a minor role in the development of CORB.

5. Conclusions

During the Late Cretaceous, after the oceanic anoxic event OAE2 at the Cenomanian/Turonian boundary, the state of the oceans changed to a more oxic environment, as recorded by widespread deposition of oceanic red beds (CORB). Several causes of this change to the sedimentation of red pelagic and hemipelagic strata are possible, including palaeoproductivity or palaeogeographic changes. Within active continental margins and orogenic wedges the situation becomes more complicated. The case study in the Nierental Formation of the Northern Calcareous Alps of Austria indicates that CORB sedimentation was highly diachronous within these slope basins. Local clastic input and the complex morphology of the basins exerted the main control, whether CORB were present or grey turbidite and hemipelagic deposits prevailed.

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