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Palaeoenvironmental changes in the Late Triassic (Rhaetian) of the Northern Calcareous Alps: Clues from stable isotopes and microfossils

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ABSTRACT

The Triassic Kössen Formation (Rhaetian) in the Northern Calcareous Alps has been studied with respect to oxygen and carbon isotope ratios of brachiopod shells and whole rocks, together with the stratigraphic range and ecology of ostracod assemblages, in order to detect palaeotemperature changes in the Kössen Formation and determine their significance for environmental and climatic conditions in the Rhaetian sea of the Eiberg Basin (Northern Calcareous Alps). For this purpose 60 $\delta^{18}O$ measurements on 43 articulate brachiopods samples from 8 different horizons were carried out. The results indicate a progressive decrease of ~2.5 °C in seawater bottom temperature in the middle-late Rhaetian. The carbonate microfacies as well as macro- and microfossil assemblages indicate a gradual increase of water depth in the Eiberg Basin, and thereby explain the observed bottom water cooling. The oxygen isotope data further suggest that the palaeobathymetric temperature gradient in the Eiberg Basin was rather low, indicating that almost no deep water exchange with Tethys existed at that time. Carbon isotopes from brachiopod shells and from bulk carbonates show a trend to heavier values from the Hochalm Member up to the lowest unit 3 of the Eiberg Member that parallels oxygen isotopes. This positive $\delta^{13}C$ trend is interrupted by a sudden ~1.5‰ negative excursion in the late Rhaetian (Late Rhaetian Event), a time span when the oxygen isotopes remain heavy.

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1. Introduction

The global mass extinction which started in the Late Triassic and culminated at the Triassic/Jurassic (T/J) boundary has been attributed to various environmental perturbations such as rapid sea level fall, intensive volcanism, strong increase in atmospheric CO_2 concentration, and marine carbonate dissolution (e.g. Hesselbo et al., 2007). For example, a four-fold increase of CO_2 concentration across the T/J boundary was proposed based on a drastic decrease of stomatal frequency of leaf cuticles (McElwain et al., 1999). Recent analysis of stomatal index and density of fossil seedfern leaves from South Germany are suggestive of strongly rising CO_2 levels already during the early and middle Rhaetian (Bonis et al., 2010). Carbon isotope studies on pedogenic carbonate nodules have been used to estimate atmospheric CO_2 concentrations. The data of Tanner et al. (2001) support a distinct carbon dioxide increase during the Rhaetian and Cleveland et al. (2008) proposed two injections during this period. Schaller et al. (2011), in contrast, favour a CO_2 increase in the Hettangian, whilst $\delta^{13}C$ of bulk organics suggest that a CO_2 pulse occurred in the late Rhaetian (Ruhl and Kürschner, 2011). However, it is likely that remarkable atmospheric CO_2 fluctuations affected climate conditions and thus also the palaeotemperature of ancient sea water, particularly in protected shallow marine basins.

The aim of the present study is to detect such palaeotemperature changes during the middle and late Rhaetian interval using $\delta^{18}O$ analysis of brachiopods in the Rhaetian Kössen Formation (Elsler, 2010). Carbon isotopes of brachiopod shells and bulk carbonate rocks were also measured through the section in order to detect the $\delta^{13}C$ evolution and potentially pulses of CO_2. In addition, an analysis of the stratigraphic range and palaeoecology, particularly palaeobathymetry, of ostracod taxa in the Kössen Formation completes the palaeoenvironmental study.

2. Geological setting, stratigraphy, facies and palaeogeography

The studies were conducted at the Eiberg section, which is located in a quarry (SPZ Zementwerk Eiberg GmbH) about 3 km south of Kufstein (North Tyrol) (Fig. 1). At this section the upper part of the Hochalm Member (upper unit 2 to unit 4, sensu Golebiowski, 1989) and the Eiberg Member are exposed (Fig. 3). Based on the conodont faunas and rare ammonoid findings the latter author has correlated the Hochalm Member unit 2 with the Tethyan *Paracochloceras suessi* zone and the Hochalm Member units 3–4 and Eiberg Member unit 1 with the *Vandaites stuerzenbaumi* zone. The Eiberg Member units 2–4 belong to the *Choristoceras marshi* zone. According to the new

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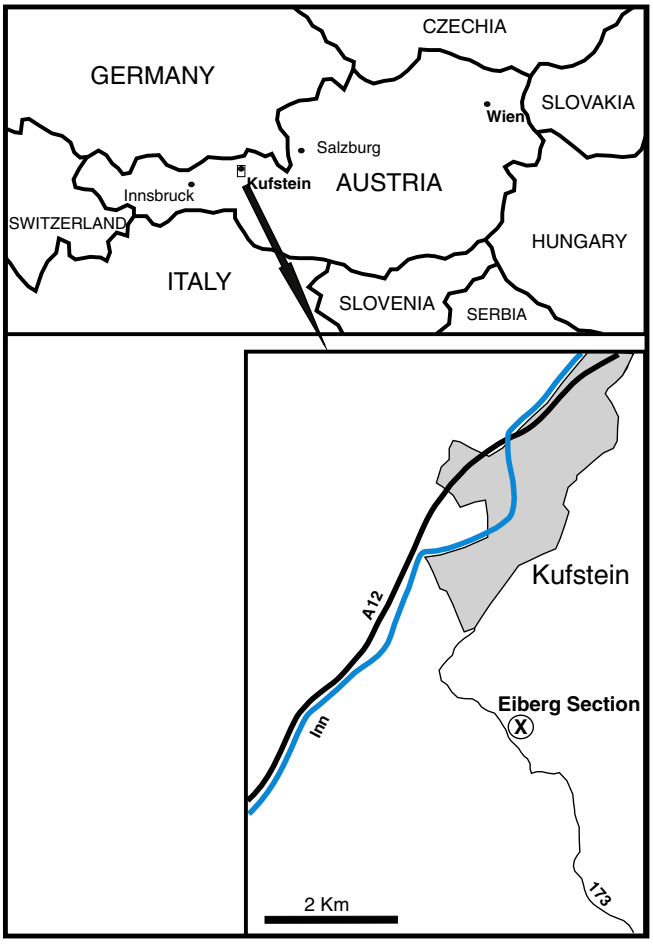

Fig. 1. Locality map of the Eiberg section.

stratigraphic scheme proposed for the Rhaetian Stage (Krystyn et al., 2007; Krystyn, 2008) the Hochalm Member unit 2 and lowermost part of unit 3 can be correlated with the Tethyan Substage Rhaetian 1, Hochalm Member units 3–4 and Eiberg Member unit 1 belong to Rhaetian 2, while the Eiberg Member units 2–4 represent Rhaetian 3. The maximum thickness of the Kössen Formation is 270 m (Golebiowski, 1989). Considering the duration of the Rhaetian Stage of 4.5 Ma as proposed by Kozur and Bachmann (2008), the average sedimentation rate within the Eiberg Basin would be around 0.06 m per 1000 years. At the Eiberg section, the uppermost part of the Kössen Formation (Eiberg Member, unit 4) is separated from the Early Jurassic strata (Allgäu Formation) by a prominent fault (Fig. 4, Supplement).

Palaeogeographically, the Eiberg section is situated in the central part of an extensive east–west trending intraplatform basin at the northwestern margin of Tethys known as "Eiberg Basin" (Fig. 2). Based on its present geographic extent, the size of this basin has been estimated to be at least 40 km wide and 200 km long (Krystyn et al., 2005). The latter authors assumed the presence of at least one deep connection with the open Tethys which allowed the immigration of the pelagic ammonoids and conodonts. Brachiopod oxygen isotopes of this area (Kössen and Hochalm sections), published by Korte et al. (2005a), suggest that no water exchange took place between the Eiberg Basin and Tethys at depths below 80 m. In general, the lithofacies development of the Kössen Formation is indicative of a successive deepening of the depositional environment. This long-term deepening was interrupted by several subordinate shallowing upward events that are clearly documented by the litho- and biofacies and changes of palynomorph associations (Golebiowski, 1989; Holstein, 2004). According to Golebiowski (1989) the carbonate microfacies and biofacies (particularly the composition of the brachiopod and bivalve associations) suggest that the Hochalm Member unit 2 was deposited in a shallow subtidal environment of less than 20 m water depth. A deepening below storm wave base to 30 to 50 m due to maximum transgression was reported by the latter author for the Hochalm Member unit 3. The lower and middle parts of the Eiberg Member (units 1–3) show a further deepening to about 50–100 m followed by a regressive tendency towards the top of the Kössen Formation (unit 4). A maximum water depth of between 170 m and 240 m was estimated for the Eiberg Basin at the Steinplatte carbonate ramp (Stanton and Flügel, 1997). This calculation was based on the width and the presumed inclination of this carbonate ramp at the southern margin of the Eiberg Basin. Later studies also suggest that the Eiberg Basin attained substantially greater water depths during the middle-late Rhaetian. Krystyn et al. (2005) reconstructed similar bathymetries in late Rhaetian times concluding that the water reached maximum depths of 200 m. If the successions are still in their original relative positions, the data of Krystyn et al. (2005) would imply an average water depth of 150 m to 200 m for the middle and upper parts of the Eiberg Member.

3. Stratigraphy of brachiopod horizons

The Kössen Formation at the Eiberg section consists of 8 horizons with abundant well-preserved brachiopods (Fig. 4, and Supplement). The first horizon, comprising a thick-bedded bioclastic packstone with bivalves and the terebratulid brachiopod *Rhaetina pyriformis* (Suess), occurs at the top of the Hochalm Member (unit 4). The second brachiopod horizon is situated in the lower part of the Eiberg Member (middle part of unit 2). The host rock is a bioclastic packstone at the top of a 2 m thick succession of bioclastic limestone reflecting a minor thickening and shallowing upward cycle. The brachiopod fauna consists exclusively

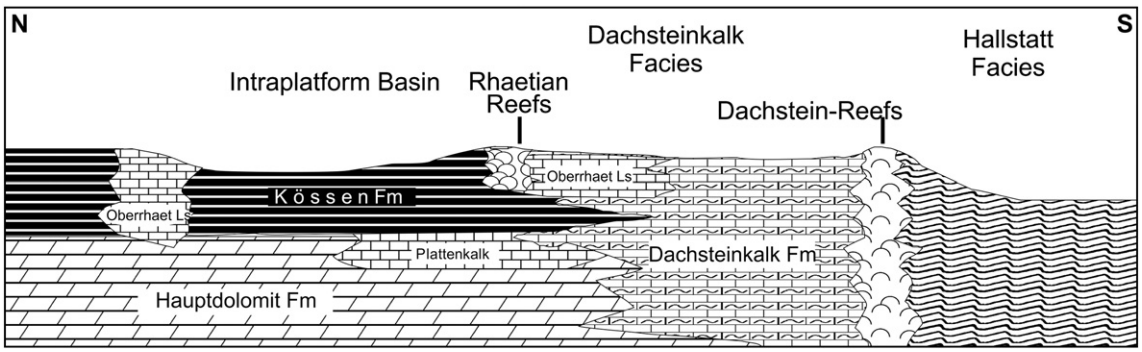

Fig. 2. Palaeogeographical model for the northwestern Tethys margin; not to scale.
Modified after Hüssner et al., 1996 and Krystyn et al., 2005.

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