Paleoenvironmental and diagenetic implications of $\delta^{18}$O and $\delta^{13}$C isotope ratios from the Upper Jurassic Plassen limestone (Northern Calcareous Alps, Austria)

Interprétation du milieu de dépôt et de la diagenèse à partir des proportions isotopiques $\delta^{18}$O et $\delta^{13}$C du calcaire de Plassen (Jurassique supérieur des Alpes calcaires du Nord, Autriche)

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Abstract

The first $\delta^{18}$O and $\delta^{13}$C data from the Upper Jurassic of the Northern Calcareous Alps are presented. The interpretation of stable isotope ratios serves as an approach for paleoenvironmental and diagenetic studies of the Plassen carbonate platform, which cannot be obtained by palaeontological methods and microfacies analyses alone. The studied part of the Plassen limestone is characterized by (1) lithoclast facies, also called ‘intraformational breccia’; the origin of lithoclasts was formerly unknown; (2) peloid facies; (3) bioclastic facies, composed of peloids, porostromate algae, green algae and red algae; and (4) oncoid facies. Two types of fracturing and four cement generations can be distinguished. Isotope ratios of the matrix, oncoids, three cement generations and whole rock samples revealed that (1) the studied section represents an open marine carbonate platform with high water circulation and high input of cool oceanic waters; (2) the platform was not affected by emersion and fresh water influence; normal marine conditions prevailed; (3) carbonate cements were precipitated in a closed diagenetic system, but burial diagenesis was absent; (4) both fabric-selective and non-fabric-selective fracturing occurred in a normal marine environment, affecting the formation of ‘intraformational breccias’. © 2002 Éditions scientifiques et médicales Elsevier SAS. All rights reserved.

Résumé

Nous présentons des données préliminaires d’isotopes stables $\delta^{18}$O et $\delta^{13}$C dans des roches carbonatées du Jurassique Supérieur des Alpes Calcaires du Nord. L’étude avance l’interprétation du milieu diagénétique du plateau carbonaté de Plassen, et donne des résultats que l’on n’obtient pas par l’analyse seule de paléontologie et de microfaciès. Le calcaire de Plassen est caractérisé par (1) des faciès lithoclastique aussi appelée brèche intra-formationnelle dont l’origine était inconnue jusqu’à présent; (2) des faciès peloides; (3) des faciès bioclastiques composées de peloides, d’algues porostromates, d’algues vertes et rouges; et (4) des faciès oncoides. Deux types de fracturation et quatre générations de ciment peuvent être distingués. Les proportions isotopiques de la matière intergranulaire, des oncoides, des ciments de différentes générations ainsi que des échantillons entiers révèlent que (1) la section analysée représente une plate-forme carbonatée marine avec une forte circulation d’eau et grande influence d’eaux marines; (2) la plate-forme n’était affectée ni par émersion ni par d’eaux douces; un milieu plutôt marin normal était dominant; (3) les ciments carbonatés étaient précipités dans un système

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diagonétique clos tandis que une diagenèse d’enterrement était absente; (4) fracturation se passait dans un milieu marin normal en fonction de la fabrique ainsi qu’indépendamment de la fabrique, celui-ci formant les brèches intra-formationnelles. © 2002 Éditions scientifiques et médicales Elsevier SAS. Tous droits réservés.

Keywords: Upper Jurassic; Northern Calcareous Alps; Plassen limestone; δ¹⁸O and δ¹³C Stable isotopes; Palaeoecology; Diagenesis

Mots clés: Jurassique supérieur; Alpes Calcaires du Nord; Calcaire de Plassen; Isotopes stables δ¹⁸O et δ¹³C; Paléoécologie; Diagenèse

1. Introduction

Upper Jurassic carbonates are well known in Middle Europe and cover wide areas. The Late Jurassic was a time of significant carbonate platform and reefal development (Scott, 1988; Leinfelder, 1994; Insalaco et al., 1997; Wood, 1999), which was mainly caused by a general sea-level rise providing suitable habitats (Hallam, 1975; Leinfelder, 1994) and by the equable climate (Frakes et al., 1992; Hallam, 1993).

While Upper Jurassic carbonate platforms and reefs of the epicontinental realm are well studied (Leinfelder, 1994; Leinfelder et al., 1994; Insalaco, 1996; Insalaco et al., 1997), the knowledge on the Alpine region is relatively poor.

The Upper Jurassic to lowermost Cretaceous carbonate platform development in the Northern Calcareous Alps is represented by the Plassen limestone (Tollmann, 1976), which is characterized by steeply bordered isolated platforms surrounded by an oceanic environment (Steiger and Wurm, 1980; Steiger, 1981; Gawlick et al., 1999). The environmental setting represents a tropical, wide, ‘Bahamas-type’ carbonate platform with coral patch reefs, which was probably subject to platform emersions (Fenninger, 1967). The Plassen limestone is a highly pure limestone with a CaCO₃ content of > 99% (Mooshammer and Lobitzer, 2000). Most of these features, as well as the absence of sponge reefs, represent remarkable differences compared to the epicontinental equivalents.

The current paper presents the first stable isotope data from the Late Jurassic of the Northern Calcareous Alps. Isotope studies were used to solve particular paleoenvironmental, diagentic and stratigraphic problems raised from microfacies analysis. After a description of the carbonate facies and the diagentic features, we present the δ¹⁸O and δ¹³C isotope ratios of carbonate particles, micrite, cements, as well as whole rock samples. The discussion focuses on the preservation potential of the primary isotope signal, the problem of vital fractionation in cyanobacteria and micrite formation, the paleotemperature equations, the occurrence of platform emersions, the diagentic history, as well as the potential use of stable isotopes for stratigraphic correlations.

2. Study area and geological setting

The study was conducted at the Plassen near Hallstatt (Salzkammergut), Upper Austria (Fig. 1). The Plassen, which represents the type locality of the Plassen limestone (for review see Tollmann, 1976), is situated in the area of the historical salt mines of Hallstatt. It can be reached via a hiking trail from Hallstatt. The section was measured and sampled at the hiking trail no. 640 (hiking map of Freitag and Berndt 1:50.000, sheet no. WK 281; see also ÖKM a p 1:50.000, no. 96, Bad Ischl) from Salzberg towards the Plassen, at 1225 m above sea level. The Plassen limestone at the type locality is in tectonic contact with Triassic sediments and evaporites of the ‘Haselgebirge’. Jurassic sediments underneath as well as younger units overlying the Plassen limestone are unknown (Mandl, 1999).

The Plassen limestone represents a unique development in the Jurassic to Early Cretaceous of the Northern Calcareous Alps (NCA). During the Upper Triassic and the lowermost Jurassic, the NCA were part of the European shelf. Following the Middle Jurassic spreading in the Alpine Tethys related to the break-up of Pangaea, the NCA and the European Plate became separated by an oceanic basin (Ziegler, 1990; Stampfli and Mosar, 1999).

Fig. 1. Study area showing the locality of the Plassen and the mentioned hiking trails.
3. Materials and methods

We studied a representative, ca. 10 m thick profile. Samples were taken at every facies change; the vertical sampling distance never exceeded 50 cm. Forty 60 × 120 mm thin sections were prepared and analyzed for microfacies studies. Ten 30 × 50 mm thin sections were prepared and analyzed for cathodoluminescence microscopy. Cathodoluminescence studies were conducted with CTLT, Cold Cathode Luminescence 8200 mk3, Cambridge (20 kV, 200–400 μA) equipment at the Institute of Petrology, University of Vienna.

Carbonate nomenclature follows Dunham (1962) and Embry and Khavkin (1972). Due to the low diversity of carbonate particles and facies types, the abundance of carbonate components was estimated in light microscope, following Flügel (1982). The facies were designated according to the estimated relative abundance of components.

Samples for isotope measurements were drilled with a dental driller, which allowed sampling of patches with diameters down to 0.5 mm. We sampled oncoids (two samples), micrite (six samples), three cement generations (18 samples), as well as bulk samples (38 samples) (Table 1). Stable isotope analyses were performed using a Finnigan MAT Kiel II Delta Plus mass-spectrometer operation line at the Institute of Geology and Paleontology, University of Graz. The studied material is stored at the Institute of Geology and Paleontology, University of Graz.

4. Results

4.1. Components and matrix

Peloids are the most prominent components. They do not show any internal structure and most of them probably represent micritized bioclasts. Bioclasts are arenitic to ruditic. They are represented by porostromate cyanobacteria, dasycladalean algae, “stromatoporoids” as well as corals. Oncoids are ellipsoidal with a maximum diameter of 30 mm and show bioclastic nuclei. Mollusc fragments are rare. They are recrystallized and show micritic rims.

The groundmass is dominated by sparite, while only a few samples reveal micrite matrix. Siliciclastic mud was not found. This coincides with the studies of Moshammer and Lobitzer (2000) who found that the Plassen limestone is composed of up to >99% CaCO₃.

Table 1

<table>
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<th>Sample</th>
<th>δ¹⁸O (PDB)</th>
<th>δ¹³C (PDB)</th>
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4.2. Facies

The Plassen limestone at the studied locality is well bedded and shows a grayish weathering surface. Bed thickness varies between 10 and 50 cm, vertical facies changes rarely occur within one bed (Fig. 3). The lateral thickness of beds is usually variable. Micrite content is highly variable; its dominance is restricted to a few beds (2, 4, and 23).

4.2.1. Lithoclast facies

This facies is dominated by lithoclast rudstones with sparry matrix (Fig. 2a). Only bed 19 shows some micrite. This facies frequently occurs in various Plassen limestone occurrences as 'intraformational breccia' (Fenninger, unpublished data). Lithoclastic components are composed of other facies described below. The peloid grainstone facies is most dominant. Lithoclasts are mostly subangular and frequently subrounded. The genesis of this facies is generally not clear. Parts of this facies resembles vadose silt.

4.2.2. Bioclast floatstone facies

Bioclast floatstones with peloid grainstone matrix (Fig. 2b) prevail. Only bed 4 shows a wackestone matrix. Ruditic bioclasts are dominated by “stromatoporoids”, red algae and porostromate algae. The matrix is dominated by peloid grainstones; arenitic bioclasts also occur, mostly consisting of Dasycladales. Most bioclasts show micritic rims. Microbial mats do not occur.

4.2.3. Bioclast–peloid grainstone facies

Bioclast–peloid grainstones (Fig. 2c) are partly stabilized by microbial mats (beds 1 and 3). Bioclasts are dominated by Dasycladales and “stromatoporoid” fragments; they show micrite rims and can serve as nuclei for oncoids. Most probably, the peloids represent micritized bioclasts.

4.2.4. Peloid grainstone facies

Peloid grainstones (Fig. 2d). Beds 7 and 9 show partial stabilization by microbial mats. At least some of the peloids represent micritized bioclasts. This facies is distinguishable from the bioclast–peloid grainstone facies by the low abundance of bioclasts as well as by well sorted and graded peloids.

4.2.5. Oncoid floatstone facies

Oncoid floatstone with peloid grainstone matrix (Fig. 2e). Oncoids are floating in a matrix, which resembles the peloid grainstone facies. Algal mats occur in bed 13.

4.3. Diagenesis

The rocks are well cemented. Non-fabric-selective stylolithes can occur, but grain contacts are not affected by pressure solution. Pseudosparite and microsparite (Flügel,
Fig. 2. Facies and diagenesis of the studied Plassen limestone section at the type locality. Image width = 12 mm. a. Lithoclast facies, showing two clasts, one of them with cement 1. Sample no. pl. 5-2. b. Bioclastic floatstone facies with a peloid grainstone matrix. Sample no. pl. 8. c. Bioclastic grainstone facies. Sample no. pl. 3a. d. Peloid grainstone facies with stabilization by cyanobacterial mats. Sample no. pl. 1. e. Oncoid floatstone facies. Sample no. pl. 11. f. Diagenesis and fractures. A fabric-selective fracture is filled with the marine cements 1 and 2. Non-fabric-selective fractures are filled with fresh water cement 3. Sample no. pl. 6.

Figure 2. Faciès et diagenèse des Calcaires de Plassen de la coupe étudiée dans la localité type. Largeur des images 12 mm. a. Faciès à lithoclastes montrant deux clastes, l’un d’eux avec ciment de type 1. Échantillon no. pl. 5-2. b. Faciès floatstone bioélastique avec une matrice grainstone péloïdale. Échantillon no. pl. 8. c. Faciès grainstone bioélastique. Échantillon no. pl. 3a. d. Faciès grainstone peloidal avec stabilisation par des tapis cyanobactériens. Échantillon no. pl. 1. e. Faciès floatstone à oncoides. Échantillon no. pl. 11. f. Diagenèse et fractures. Remplissage de la fissure sélective par une cimentation marine de type 1 et 2. Les fissures non sélectives renferment un ciment d’eau douce de type 3. Échantillon no. pl. 6.
do not occur. The lithoclast facies can contain a matrix, which resembles ‘vadoze silt’ [Flügel, 1982]. The sediment is affected by two types of fractures (Fig. 2f). The first type is fabric-selective (compare Flügel, 1982), while the second type is non-fabric-selective. Non-fabric-selective fractures can cut the first fracture type. All of the fractures are filled with sparitic cement.

Four cement generations can be distinguished (Fig. 2f). (1) Brownish, fibrous cements form isopachous rims around particles, within primary pores, as well as within fabric-selective fractures. (2) The second cement generation is represented by drusy cements filling the remaining pore space, as well as fractures cutting the first cement type. (3) Blocky cements fill the younger fractures. (4) The fourth cement generation is represented by a blocky cement that occurs in the youngest recognized fractures; these fractures are extremely thin and could only be recognized in cathodoluminescence microscope.

Cathodoluminescence studies reveal relatively low, late diagenetic changes of carbonate components. The limestone generally shows a dull appearance. Only the peloids, cement 3 and cement 4 reveal luminescence. However, while the cements show a distinct orange color, the luminescence of peloids is very low and hardly visible in microscope.

4.4. δ18O and δ13C isotope ratios

Isotope ratios of all analyzed samples fall into a narrow range of δ13C values (1.6–3.6‰), but the δ18O values show a wider distribution (−0.4 to −7.0‰) (Fig. 4; Table 1). The distribution of whole-rock samples revealed no correlations with the particular facies (Fig. 3). Values of δ18O and δ13C range from −2.0 to −4.2‰ and 1.6 to 2.9‰, respectively.

The ratios of the separately analyzed rock components, however, show characteristic distribution patterns: δ18O and δ13C values of micrite (−1.5 to −2.8‰ and 2.0 to 2.8‰, respectively) and oncoids (−2.4 to −2.6‰ and 2.4 to 2.7‰) on the one hand, and those of the 1st cement generation (−1.6 to −3.9‰ and 1.2 to 3.3‰), the 2nd cement generation (−0.4 to −2.6‰ and 2.5 to 3.1‰) and the matrix of the lithoclast facies (−0.5 to −2.4‰ and 2.4 to 2.7‰), on the other, are very close to each other.

In contrast, the ratios of the 3rd cement generation are more depleted in δ18O (−4.9 to −7.1‰). The δ13C (2.3–3.6‰) is, however, comparable to the above-mentioned values.

Finally, the δ18O ratios were used to calculate the paleotemperature using the formula of Anderson and Arthur [1983]. Temperatures based on micrite values fall between 18–24 °C, those based on whole-rock samples 20–31 °C. Due to the equal δ18O values, calculations using the isotopic ratios of oncoids yield results comparable to the micrite values.

5. Discussion

5.1. Diagenetic overprint of the primary isotope signal

δ18O and δ13C isotope ratios in limestones are subject to late diagenetic overprints. The preservation of the primary signal is, however, a prerequisite for the interpretation of isotope data [Hudson, 1977; Allan and Matthews, 1982; Marshall, 1992]. Isotope studies on the Plassen limestones suffer from the problem that fossils with a high preservation potential, such as brachiopods, are particularly rare and could not be found in the studied section.

There are, however, several arguments suggesting that the measured δ18O and δ13C isotope ratios are close to the primary signal. (1) Cathodoluminescence studies revealed that only the peloids show a very low luminescence and thus show very low diagenetic alterations. (2) Organic material in cyanobacteria (e.g., oncoids) is preserved in the form of insoluble kerogen and usually preserves the primary isotope signal with little changes [Schidlowski, 2000]. (3) The measured values are within the range of other Upper Jurassic platform carbonates (e.g., Leinfelder et al., 1993; Simon and Steuber, 1993). (4) The isotope ratios are characteristic for a closed diagenetic system. Otherwise, highly negative δ18O associated with highly negative δ13C isotope ratios would occur [Marshall, 1992]. This indicates low circulation of pore waters and thus low influence of fresh water causing diagenetic alterations. (5) Deep burial diagenesis, which can also overprint the primary isotope signal, is absent as evidenced by the positive δ13C values (e.g., Marshall, 1992).

5.2. Vital fractionation and micrite formation

Photosynthetic organisms preferably take up 13C. This vital fractionation causes a depletion of 13C and therefore highly negative δ13C values (e.g., Wefer and Berger, 1991). As vital fractionation can occur in cyanobacteria and the latter could influence both micrite formation [Reinert and Neuweiler, 1995; Thompson, 2000] and submarine cement precipitation, the measured values do not necessarily reflect the sea water equilibrium.

Similar isotope ratios of micrite, oncoids, and the first cement generation suggest two different interpretations: (1) oncoid-forming cyanobacteria did not cause any vital fractionation and the isotope values thus represent sea water equilibrium; or (2) vital fractionation of cyanobacteria influenced the values of oncoids, micrite and of the first cement generation.

According to Schidlowski (2000), the vital fractionation in cyanobacteria causes distinctly negative δ13C values. As the isotope ratios of oncoids, micrite, and cement 1 revealed positive values and the diagenetic overprint is expected to be very low (see the former chapter), we suggest that no respiratory carbon is incorporated in the measured compo
ments. This allows the conclusion that the presented isotope values reflect the sea water equilibrium.

This conclusion leads to crucial interpretations concerning the micrite formation. Generally, two types of micrite can be separated (for review see Reitner and Neuweiler [1995]; (1) automicrite formed by in situ precipitation, and (2) allomonicrite representing reworked material formed by bioerosion and disintegrated biodetritus. Characteristically, allomonicrite shows lighter carbon isotope values (δ^{13}C +1‰) than automicrite (mean values of δ^{18}O −1‰ and δ^{13}C +3.5‰). This indicates that the studied micrite represents automicrite.

5.3. Paleotemperature

The paleotemperature calculated from micrite (18–24 °C) coincides with the mean Upper Jurassic surface temperature of 20 °C calculated by Valdes and Sellwood [1992], but it seems too low for a tropical, Tethyan platform. According to Tucker and Wright [1990] the present day Bahamas platform, which today is situated at the same latitude as the study area was during the Late Jurassic [Stampfl et al., 1998], shows a temperature variation from 22 to 31 °C. Temperature calculations from whole-rock samples (20–31 °C) seem to be more appropriate; however, whole-rock samples hardly reflect the original isotope composition of the sea water, because they represent a mixture of primary components and secondary cements.

The fact that the paleotemperature corresponds to the mean Upper Jurassic surface temperature suggests that the studied facies was deposited on an open marine platform with a high water circulation and a high input of cool oceanic waters. A low-energy, restricted lagoonal environment can be excluded, because this would result in higher temperatures. This interpretation is supported by the low amount of micrite.

5.4. Platform emersion and salinity

There are some indications for an emersion of the carbonate platform. (1) Fenninger [1967] suggested the occurrence of emergences based on the general platform setting. (2) The origin of the observed fractures is unknown; they could have been formed during periods of platform emersion. (3) Moreover, the formation of the lithoclast facies is unknown; the matrix of the lithoclast facies partly resembles vadose silt, which can be formed by fresh water diagenesis.

Emersion of carbonate platforms causes changes in salinity, which depend on the climatic setting. Arid climates lead to increased salinity due to evaporitization. Humid climates, on the other side, can lead to decreasing salinities due to influx of fresh water. Both of these events should be recognizable by the isotope values. Isotope signatures associated with exposure in humid climates show depleted δ^{18}O values due to fresh water influence, while evaporitation leads to an enrichment of δ^{18}O [Allen and Matthews, 1982; Marshall, 1992].

As discussed above, the isotope ratios of the current study represent typical signals of normal marine Upper Jurassic carbonate platforms. Consequently, there are no indications for platform emersions for the studied section.

5.5. The origin of lithoclasts, fractures and cements

The lithoclast facies is generally abundant in Plassen limestones (Fenninger, unpublished data). As the clasts are composed of sediments associated with this facies, it represents an ‘intraformational breccia’. Comparable breccias can be formed by tectonic activities or by erosion during platform emersion. The latter interpretation is supported by the matrix of the lithoclast facies, which partly resembles vadose silt. Another feature that potentially could be explained by tectonic activities or platform emersion are the fractures filled by different cement generations.

Isotope values of the matrix between the breccia components (δ^{18}O −0.5 to −2.4‰, δ^{13}C 2.4 to 2.7‰) reveal typical marine signatures (see discussions above). This indicates that the formation of intraformational breccias was influenced by marine waters. As subaerial erosion during platform emersion can be excluded, the formation of breccias and fractures was obviously caused by autobrecciation.

The isotope ratios of three cement generations filling two different fracture types reveal that they were formed under different conditions. The first cement generation filling fabric-selective fractures, as well as the second cement generation filling non-fabric-selective fractures, reveal marine isotope signatures. The third cement generation filling the youngest fracture type, however, shows a fresh water signature characterized by a depletion of δ^{18}O. These results allow the following reconstruction of the diagenetic scenario. (1) Autobrecciation caused the submarine formation of the first, fabric-selective, fracture generation in the unconsolidated sediment. The fractures, as well as the primary pore space are coated with the first, submarine cement generation. (2) Later on, the remaining pore space between particles and within the fractures is filled by the second submarine cement generation. (3) After consolidation, another event caused the formation of non-fabric-selective fractures. These fractures, which can cut the first fracture type, are also filled with cement type 2. The fact that isotope signatures of the matrix of the intraformational breccia are comparable to those of cement 2 suggest that the breccia formation is caused by the same event that affected the formation of the second fracture generation. (4) After termination of the marine development, the youngest types of non-fabric-selective fractures were formed within the consolidated rocks. They are filled with the fresh water cements 3 and 4.
5.6. Stratigraphic correlations

The studied type locality is restricted to Late Kimmeridgian to Tithonian age, but the sedimentation of Plassen limestone can generally last until the Berriasian [Fenninger and Hötzl, 1967; Fenninger and Holzer, 1972; Steiger and Warm, 1980; Darga and Schlagintweit, 1991; Schlagintweit und Fbli., 1999]. However, the Jurassic/Cretaceous boundary could not yet be identified with biostratigraphic methods due to provincialism of benthic associations (for review see Darga and Schlagintweit, 1991).

Isotope ratios show remarkable temporal variations during the Phanerozoic [Veizer et al., 1999]. Consequently, these ratios can be used for stratigraphic correlations, even on whole-rock samples (e.g. Davy and Jenkyns, 1999).

Biostratigraphical data of the studied section revealed Late Kimmeridgian to Tithonian age [Fenninger and Hötzl, 1967], which roughly corresponds to the presented δ¹⁸O and δ¹³C isotope ratios (compare Veizer et al., 1999). The isotope curve shows remarkable changes at the Jurassic/Cretaceous boundary [Veizer et al., 1999], which potentially could be recognized elsewhere in the Plassen limestone. This fact, as well as the narrow range of isotope values of whole rock samples, suggests their general applicability for stratigraphic correlations of the Plassen limestone. This will, however, require further studies of longer sections and should be accompanied by biostratigraphical investigations (e.g., locality Trisselwand; Schlagintweit and Fbli., 1999).

6. Conclusions

Analyses of δ¹⁸O and δ¹³C isotope ratios of the Plassen limestone allowed interpretations of paleoenvironmental and diagenetic problems, which are not possible by paleontological methods and microfacies analysis alone.

- Our data suggest that the diagenetic overprint of the primary isotope signal is low to absent and the cyanobacteria did not cause vital fractionation. Consequently, the isotope values of oncocids, micrite and carbonate cements 1 and 2 may be close to sea water equilibrium.
- Isotope signatures of the micrite matrix are characteristic for automicrite.
- The paleotemperature equations suggest that the studied facies represent an open marine carbonate platform with rigorous water circulation and a significant input of cool oceanic waters.
- The carbonate platform was not affected by emersion. All isotope values of carbonate particles and submarine cements indicate a normal marine environment without influence of fresh water or evaporation.
- Carbonate cements were precipitated in a closed diagenetic system; the Plassen limestone was not affected by deep burial diagenesis.
- Submarine, fabric-selective fracturing of the unconsolidated sediment was most probably caused by submarine, autobrecciation, rather than by erosion during emersion events. Non-fabric-selective fracturing of the consolidated sediment led to the formation of intraformational breccias in a marine environment.
- Isotope ratios appear to be generally applicable for stratigraphic correlations, although further studies on longer sections are necessary to prove this.

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References