



STRATIGRAPHY
AND DEPOSITIONAL ENVIRONMENTS
OF THE CRINOIDAL LIMESTONE
OF HOCHGERN, BAVARIAN ALPS
(CHIEMGAU)

by
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SUMMARY

The Hochgern Crinoidal Limestone is of Lower to Middle Jurassic age. The deposit consists of low energy sediments, reflecting the environments of the transitional area between shelf and basin. They are considered to have accumulated at a level upslope of the other time-equivalent but unlike carbonate unit (Hochlerch Limestone) of the area. This unit also shows characteristics of deposition under quiet water environments.

INTRODUCTION

Considerable research has been done till now on the geology of the Alps. The main emphasis has so far lain on tectonics and stratigraphy. Very few studies have been made on the depositional environments. The author believes that in one

particular instance a reconstruction of the depositional environments helps better to understand the occurrence of time-equivalent but unlike carbonate units in the area. Lithologic differences of these carbonate units result from their formation in relatively different position on a depositional slope.

GEOLOGICAL SETTING

Jurassic crinoidal limestone outcrops form a group of precipitous rocks about 200 meters below and on the western slope of Hochgern peak (1744 meters). Two minor outcrops are located in the neighbourhood of the major one. The top beds of this Hochgern Crinoidal Limestone unit are pink in colour whereas the lower beds are white.

About 50 meters north of the Hochgern Crinoidal Limestone is the outcrop of Hochlerch Limestone beds (previously termed by Mathur, 1974, as Massive Red Limestone unit). This unit builds the mountain chain of Hochlerch, Zwölferspitz and Silleck (Fig. 1). The two rock units are separated from each other by a narrow strip of Rhaetic Limestone outcrop (Triassic, Rhaetian). The northern flank of the Hochlerch-Silleck mountain chain is formed as a vertical face about 300 meters high. The southern flank is developed into gradual undulating slopes which are covered with grass and are used as pasture land. The slopes extend much further beyond the crinoidal limestone rocks and encompass several different rock units.

The area under study is a part of the Alpine geosyncline. Distribution of different rock types of the area is shown on the geological map (Fig. 2). Structurally, two synclines, parallel to each other and both extending in an east-west direction, have been formed here. The northern one, the Hochlerch-Silleck syncline, is composed mainly of Hochlerch Limestone (Lower to Middle Jurassic) and younger units. The syncline is asymmetrical. In the north the Hochlerch Limestone unit lies

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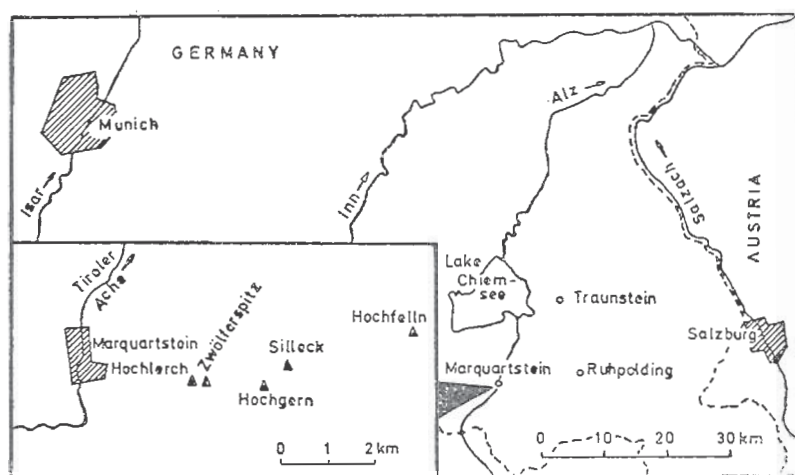


Fig. 1—Avinash C. Mathur, Stratigraphy and depositional environments of the Crinoidal Limestone of Hochgern, Bavarian Alps (Chiemgau).

on Hauptdolomit (Triassic, Norian). The contact is structural. Basal Limestone unit (Lower Jurassic underlies the Hochlerch Limestone in the southern limb. The lower beds of the Basal Limestone unit consists of the several different lithologies (Mathur 1973).

Pink crinoidal limestone beds form the youngest unit of the southern syncline. These, together with the white crinoidal limestones lie on the Basal Limestone unit which has a stratigraphic contact with the older Rhaetic Limestone beds.

The contact between the synclines is taken to be structural and is due to a low angle thrust. Lack of suitable exposures prevents an examination of the structural contact line. It is taken to be along the line of contact between the Basal Limestone unit of the Hochlerch-Silleck syncline and the Rhaetic Limestone beds. The contact becomes indistinct at several places, especially in the western part where the Rhaetic Limestone does not crop out but is covered with the Basal Limestone beds.

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The stratigraphy and the depositional environments of the rock units of the Hochlerch-Silleck syncline have been examined earlier (Mathur 1973, 1974, 1975). The present study deals with the stratigraphy of the Hochgern Crinoidal Limestones of the southern syncline together with their underlying unit.

STRATIGRAPHY

In the southern syncline the Basal Limestone unit underlies the Hochgern Crinoidal Limestone unit. The following is standard succession for the area :

- Pink crinoidal limestone
- 2. Hochgern Crinoidal Limestone
 - White crinoidal limestone
 - 1. Basal Limestone

Basal Limestone : The underlying unit to the crinoidal limestone is the Basal Limestone which lies here on the Rhaetic Limestone unit. The Basal Limestone is predominantly a grey to bluish grey silicified limestone. Similar to the Basal Limestone outcrops of the Hochlerch-Silleck syncline, the lowermost beds here contain some Me/Mn concretions in a dark grey micritic limestone which contains abundant chert. Crinoidal fossil debris is extensively present in these beds. A few, small sized brachiopods are also to be found. Other fossils are rare. At several places weathered out siliceous monoxic sponge spicules are observable.

Chert nodules are profusely present in the beds higher up. The nodules consist of dark brown to black isotropic opaline chert and are full of desiccation cracks. The bedding of the strata upwards becomes more distinct because the thin shale

partings separating these beds get easily weathered out. Further up, although the chert content remains high, there are dark spots present in these beds.

The size and frequency of chert nodules and the mottling of limestone decreases appreciably to the vanishing point in the uppermost beds. The lithology of the unit changes from dark to bluish grey micritic limestone with abundant chert in the lower beds to lighter grey micritic limestone in the uppermost beds. The total thickness of the unit is 86 meters.

The fossils located in this unit were :

- « Rhynchonella » latifrons STUR
- « Rhynchonella » sp.
- « Terebratula » sp.
- Schlotheimia (Schlotheimia) hypolepta (LANGE)
- « Belemnite » sp.
- Pentacrinites sp.

As the lower beds of the overlying crinoidal limestone unit represent the Pliensbachian stage and because of the presence of ammonite Schlotheimia the age of the Basal Limestone unit is considered to be from Hettangian to Sinemurian stages (Lower Jurassic). Thus, this unit, which is restricted to the Hettangian stage in the Hochlerch-Silleck syncline extends in the southern syncline upto Sinemurian.

Hochgern Crinoidal Limestone : This unit consists of two members. The lower member is composed of white crinoidal limestone. Pink crinoidal limestone constitutes second overlying member which lies on the first one.

White crinoidal limestone : The lower beds of this member are light grey but pure white upwards. The uppermost beds are buff to yellowish. The individual beds can be upto 15 centimeters thick, the total thickness of member being less than 40 meters. The rock when weathered is crumbly.

Chert nodules are very frequent in some of the lower beds. Other beds are free of them. The nodules on the lowermost

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beds show shrinkage cracking. Higher up, the nodules found in certain beds do not show any signs of shrinkage or syneresis. The outer surface of these nodules is smooth and free of any wrinkles. The nodules are composed of yellowish to dark brown opaline silica which is isotropic in thin section. In some cases fossil remains such as belemnite rostra act as the core of the nodules. Other nuclei are apparently free of fossils. In individual cases the core is not completely silicified. A few nodules also occur in the upper beds. In one of the upper beds of white crinoidal limestone the outer surface of the silica deposit looks porcellaneous and contains small pores and holes.

These sections show the rock to be crinoidal lime grainstone. All the varieties of poorly sorted to well sorted and washed grains are present in the facies.

Crinoidal columnals, mostly of the genus *Pentacrinites* are the main constituents of these beds. One to two centimeters long pluricolumnals also occur rarely. Brachiopods are encountered throughout these beds, whereas belemnites are more common in the lower beds and are rarer in the upper ones. A piece of a bivalve shell (*Parvamusium* ? sp.) and a sea-urchin were also found.

The fossils found were :

- « *Rhynchonella* » sp.
- Lobothyris punctata* (SOWERBY)
- « *Terebratula* » sp.
- Passaloteuthis zietenii* (WERNER)
- Passaloteuthis* cf. *apicicurvata* (DU BLAINVILLE)
- Nannobelus engeli* (WERNER)
- Nannobelus* cf. *alveolatus* (WERNER)
- Nannobelus* cf. *armatus* (DUMORTIER)
- Salpigoteuthis* cf. *lagenaeformis* (ZIETEN)
- Hastites* cf. *clavatus* (STAHL)
- « *Belemnites* » sp.
- Holactypus* sp.
- Pentacrinites* sp.

The belemnite *Nannobelus engeli* (WERNER) from the lower beds gives their age as Uppermost Sinemurian to Pliensbachian stage. The other fossils also indicate an Early Jurassic age. The upper limit is fixed by the overlying pink crinoidal limestone, the lower beds of which represent the Toarcian age (Lower Jurassic).

Pink crinoidal limestone : Overlying the buff or yellow coloured crinoidal limestone is the pink crinoidal limestone. The change on colour is due to hematite rich lime mud present as matrix. The weathered rock is crumbly. In thin section the rock is seen to be crinoidal lime grainstone. The upper beds tend to be crinoidal lime packstone with considerable amount of mud content. Chert nodules are absent in these beds. In certain upper beds, where there is locally a concentration of mud there are a few greenish spots. In these places, which are rare and are less than two centimeters across, the crinoidal content is less than fifty percent the rest being lime mud.

The total thickness of these beds is 13 meters, some of the beds being as much as 1.5 meters thick. Apart from Pentacrinites columnals, brachiopods and belemnites were also found in these beds.

The fossils identified are :

- « *Rhynchonella* » *mutans* ROTHPLETZ
- « *Rhynchonella* » *aschaviensis* FINKELSTEIN
- Stroudithyris infraolithica* (DESLOONGCHAMPS)
- Zeilleria waltoni* (DAVIDSON)
- Acrocoelites* cf. *subspinaeformis* KOLB
- Hastites* cf. *toarcensis* (OPPEL)
- Hastites* cf. *forthensis* KOLB
- « *Belemnite* » sp.
- Pentacrinites* sp.

On the westernmost outcrop and just above the buff coloured crinoidal limestone is a particular rust to dark brown coloured horizon discernible as part of the lowest pink crinoidal limestone

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bed. It is 15 centimeters thick at this place but is reduced in thickness laterally to only 2.5 centimeters and vanishes completely farther east. The rock is not homogenous in composition or colour. Hand specimens and thin sections show Fe/Mn concretions, crusts and organic remains of yellow and dark brown colours in pink crinoidal limestone matrix. Several brachiopods, ammonites, belemnites and crinoids were found here. The fossils (ammonites) are corroded partially or on one side, depending upon how they were imbedded. The fossils collected are :

- « Rhynchonella » sp.
- « Terebratula » sp.
- Harpoceras sp.
- Hildoceras bifrons (BRUGIÈRE)
- Hildoceras cf. caterinii MERLA
- Hildoceras cf. semipolitum BUCKMAN
- Hildoceras sublevisoni FUCINI
- Hildoceras sp.
- Brodieia cf. retrograda MERLA
- Acrocoelites striolatus (PHILIPPS)
- « Belemnites » sp.
- Pentacrinites sp.

The ammonites found here are of the Toarcian stage (Lower Jurassic). The belemnites and brachiopods of the pink crinoidal limestone indicate a Lower (Toarcian) to Lower Middle Jurassic age. This means that the white crinoidal limestone extends from Upper Sinemurian to Pliensbachian stage.

THE DEPOSITAL ENVIRONMENTS — A DISCUSSION

The live crinoids appear to grow in relatively quiet waters on a soft muddy bottom. Studies on recent crinoids have also shown that the disintegration of their skeleton after death is very rapid. Cain (1963) observes that within two days of death specimens of *Antedon bifida* had completely collapsed, even under static sea water conditions. Preservation of large pluricolumnals of 10 centimeters or more in length therefore implies burial in situ under very quiet environments. Perfectly preserved crinoid specimens are possible only under very special conditions of burial such as a sinking of the animals into layers of soft mud, free of scavengers and under very quiet environments. Completely disarticulated skeletons being the usual occurrence, the presence of pluricolumnals would thus indicate entombment near to their place of growth and also quiet water conditions.

Crinoids are not only found embedded in sediments, the crinoidal stems can also trap finer sediments. After a study of Borden crinoidal limestones Carozzi and Soderman (1962) conclude that in case of vigorous growth of crinoids their stems act as a screen. Clastic particles whether brought in by suspension or by traction are trapped here. Also, the metabolism of the crinoids leads to a continuous production of CO_2 . This induces phytoplankton proliferation in the clear waters above the crinoidal colony. Within a few crinoid generations much fine sediment can be trapped here. This in its turn leads to the death of the crinoidal colony. Development of crinoidal beds in accordance with this model should show a succession of lithologies from well washed crinoids below to mud-supported calcarenites, micrites with scattered crinoid fragments and even pure micrite on the top. A few escaping crinoid larvae start the cycle again. The Hochgern Crinoidal Limestone would thus

represent one such complete cycle or stage 1 and 2 of Carozzi and Soderman (1962). The different ratios of mud to crinoidal fragments implies in these cycles only different stages in trapping of sediments under the same energy conditions, namely under quiet water environments.

The above type of lithologic sequences can also be observed in other localities in the Alps, especially in Allgäu and Chiemgau regions. For instance the profusely described « Hierlatz » limestone might in some cases very well represent the upper members of such sequences. An environmental interpretation of these has not been done as far.

The conclusions of Carozzi and Soderman (1962) are also substantiated by the results of Rac and Mann (1970). While undertaking a quantitative environmental analysis of St. Genievieve Limestone they found that for assessments of energy parameters elasticity measurements are considerably more important than elasticity and frequency taken together, which would mean in the present case that the size of the crinoidal columnals seen in thin sections has a greater bearing on energy interpretation than the ratio of crinoids to mud fraction.

Quiet water environments imply no flow or very low velocities. While experimenting on flow velocities required for erosion and transport of sediments Hjulström (1936) observed that the critical velocity becomes smaller as the particle size decreases, but after a certain minimum the flow velocity needed for erosion increases for consolidated fine sediments. Working further in this problem Sundborg (1956, p. 178) finds that loose and unconsolidated clay or silt may be swept away by quite a small change in the flow velocity and that Hjulström's results are based on material of uniform grain size and bottom bed with no inclination. Heterogeneous mixture of different types of grain would be selectively eroded and transported. The conditions for these are as yet incompletely known. However, Cain (1968) in his experiments on crinoidal sediments concludes that a certain water velocity is required to remove the mud from the crinoidal debris in deposits of mud supported crinoidal

limestones. His model can be modified by two important factors : the state of consolidation of mud on the bottom and the gradient of the bed there. If the mud has settled down then it would require some energy to throw it up again. On the other hand if mud is more or less, still in suspension, very low bottom currents would be sufficient to winnow the crinoids. In case of bed gradient, any mud present, it shall be easily carried downslope and away from the crinoidal debris. Thus very low (bottom) currents should be sufficient to produce washed and sorted crinoidal deposits in areas of gradient.

Rate of sedimentation is another important factor in depositional environmental interpretations. In general, geosynclines are associated with thick deposits of sediments. However, the Hochgern Crinoidal Limestone shows a very low rate of deposition, namely only about 2-3 millimeters per thousand years, which would indicate either a starved basin or an area of deposition beyond the shelf. Apart from the thickness of the deposits certain conclusions can also be drawn from the organic activity evident in the sediments. In areas of rapid sedimentation fauna is abundantly present, chiefly represented by deposit feeders. Filter feeders play a subordinate role there. In case of slow sedimentation and less suspended organic matter the faunas are sparse, but where suspended organic matter is abundant, filter feeders particularly crinoids are dominant (Sokolova 1959).

Thus the presence of crinoids in areas of slow sedimentation would imply abundant suspended organic matter. The slow rate of sedimentation would also explain the pink colour of the upper crinoidal beds. Fischer (in Mesolella et al 1974) suggests that if the rate of sedimentation is very slow the oxygen present might just be sufficient to oxidise thoroughly iron compounds, thus giving the red colour to the sediments.

In such a case parts of the suspended organic matter should also be oxidised depending on the supply of oxygen. Thus slow sedimentation would result in lack of burial of organic matter in the substrate, no reduction of the ferric oxides and hence

preservation of the red colour. If however the supply of suspended matter increases suddenly this might overthrow the precarious balance. This would explain the presence of the thin layer of dark coloured Fe/Mn rich deposits present in the lowest bed of the pink crinoidal limestone.

The reason for the corrosion of the ammonites in those beds lies perhaps in subsolution. Hollmann (1964) found that due to subsolution the upper surfaces of the ammonites of *Calcare Ammonitico Rosso* in Italy studied by him were corroded. According to him this takes place under conditions of low water currents in places which are relatively deep. The idea of greater depth for these deposits is in agreement with the concepts of Carozzi and Soderman (1962) on crinoidal sediments. According to them, for the establishment of a crinoidal colony an undisturbed substratum is required and hence the crinoids grow in depressions which lie below the wave-base.

According to Carozzi and Soderman (1962) the presence of chert in crinoidal accumulation would also represent a quiet physical environment for its deposition. Rapson (1962) found that chert nodules which do not show any synereis and shrinkage ruptures are penecontemporary to deposition. Rapson concludes further that in case of absence of currents, silica solutions are not able to penetrate the interstitial pores of the already formed chert nodules. In these cases complete replacement through silica does not take place. The cores of this type of nodules do not show any silification but retain their original lithologies.

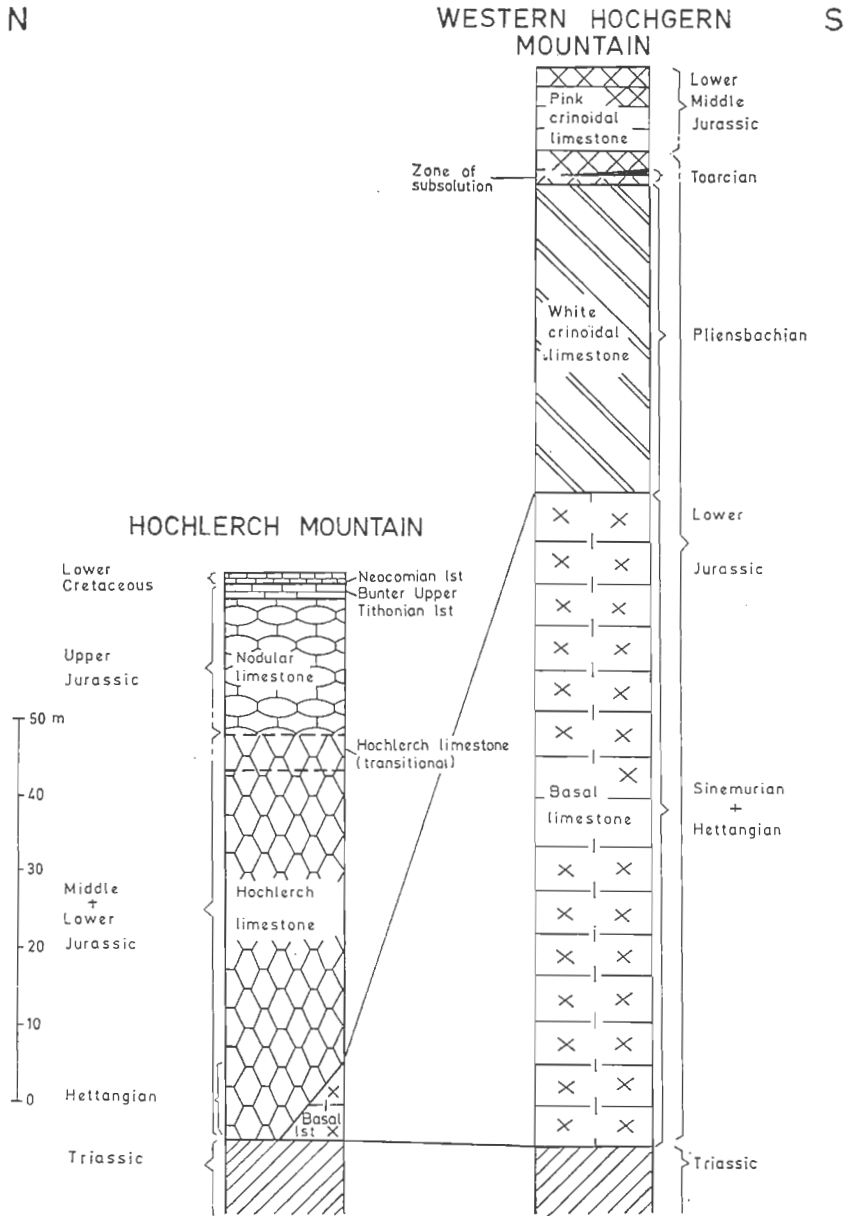
Great importance is generally attached to the presence of lime mud in interpreting depositional environments. Lime mud is indicative of quiet water conditions. Heavy accumulation of lime mud is found either in the open seas in areas of slopes and basins or else in shallow bar-sheltered areas. On the other hand, sheltered areas may contain considerable amount of terrigenous detritus. Coogan (1969) considers planktonic mud to be slope and basinal. Basinal sediments are usually laminated or thin bedded and darker in colour. In contrast, the

bedding of these crinoidal limestones is very pronounced. Individual beds are upto 1.5 meters thick. The crinoidal limestones would thus represent the slope or the transitional area between the shelf and the basin. Bissell (1970) gives the increase in numbers and thickness of encrinal limestones as a significant characteristic of the area transitional from the shelf to basin.

Another point of consideration in interpreting the depositional milieu is the environmental compatibility of associated strata, both vertically and laterally. Brachiopod fragments, crinoidal columnals and siliceous sponge spicules are abundantly present in Basal Limestones, the underlying beds to the crinoidal limestones. Generally these are also found in shelf sediments but their occurrence with poorer sorting and the presence of mud would indicate environments lower than the shelf. The darker colour of these beds is due to the presence of ferrous oxide which indicates that only limited supply of oxygen was available. These limestones, just like the Hochgern Crinoidal Limestone indicate low energy or quiet water deposition which implies deposition below the wave base.

The other deposit in the area, time-equivalent to the hochgern Crinoidal Limestone is the Hochlerch Limestone (Fig. 3). Structurally, this unit forms a part of the Hochlerch-Silleck syncline. The unit consists of massive pink coloured limestones. Individual beds are upto 5 meters thick. The upper beds of this unit are thinner and also contain some nodules. There is no sharp contact which divides them from the overlying nodular limestone unit. These upper beds have been therefore termed transitional beds. The total thickness of the Hochlerch Limestone is 40 meters. Rock thin sections show it to be lime mudstone. The fauna is sparse and consists mainly of ammonites and brachiopods with some sponge spicules and crinoids. The fauna indicates an age of Lower to Middle Jurassic (Mathur 1974). The polished rock surface shows mottling. Stromatactis is also present. This deposit has been identified as a deeper-water mud mound (Mathur 1975) which was deposited under quiet water conditions which exist below the wave-

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base. This type of mud mound develops on the lower parts of slopes (Wilson 1969, 1975). Both the Hochlerch Limestone unit and the Hochgern Crinoidal Limestone unit have as their common underlying base the Basal Limestone. If the mud mound is considered to have been deposited downslope of the crinoidal limestone the presence of some crinoids and sponge spicules in the Hochlerch Limestone is easily explained.

The average sediment accumulation rates for both these units are very low, less than 1 millimeter per thousand years for the Hochlerch Limestone and 2 to 3 millimeters per thousand years for the Hochgern Crinoidal Limestone. This also might well indicate their positions relative to each other, Hochgern Crinoidal Limestone accumulation being upslope of the Hochlerch Limestone. Accumulation rates for both the units are about the same as those for present deep-sea deposits. As both the rock units represent quiet water conditions below the wave-base they would be indicative of the transitional area between the shelf and the basin for their deposition.

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FIGURE CAPTIONS

Fig. 1 — Index map.

Fig. 2 — Geological map of the area (adapted from Dhein, 1944). Quaternary deposits are shown white.

Fig. 3 — Schematic diagram showing stratigraphic relation of Hochlerch Limestone to Hochgern Crinoidal Limestone.