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Slope angle and basin depth of the Triassic platform-basin transition at the Gosaukamm, Austria

Jeroen A.M. KENTER[1)] & Wolfgang SCHLAGER[2)*)]

[1)] Chevron Energy Technology Company, San Ramon, CA, USA; jeroenkenter@chevron.com

[2)] Vrije Univ. Amsterdam/Earth & Life Sci., De Boelelaan 1085, 1081HV Amsterdam, Netherlands

[*)] Corresponding author, schlager@planet.nl

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Abstract

Large-scale, steep and straight bedding is present in exposures of the Triassic Dachstein carbonate platform slope at the Gosaukamm, Austria. Field observations revealed high and planar clinoforms with declivities of ca. 30° and bedding thicknesses varying between 1 and 100 m. The sediment is mainly composed of poorly sorted mixtures of carbonate sand and gravel, almost devoid of mud. Measurements of geopetal fabrics and the flat stratigraphic boundary of clinoforms and underlying cherty basin limestones (Gosauseekalk) both indicate that the clinoforms are dipping more or less at their original depositional angle of 30°. Tracing of clinoforms yields a minimum estimate of the platform-basin relief of 300 m, while depositional relief exceeding 500 m is most likely. Even the most conservative estimate of water depth puts the basin floor below the neritic realm, supporting the deep-basin model of the Hallstatt zones. However, moderate uplift of the basins relative to the platforms during deposition is probable. The clinoforms at the Gosaukamm confirm the recently documented pattern that granular carbonate sediments, low in mud, are able to build straight, planar clinoforms with depositional angles over 25°.

Steile, geradlinige Riesenbankung kennzeichnet die Aufschlüsse des Abhangs der triasischen Dachsteinkalkplattform im Gosaukamm, Österreich. Geländebeobachtungen weisen auf hohe, ebenflächige Klinoformen mit ca. 30° Neigung und Bankdicke von 1 bis 100 m. Das Sediment besteht aus schlecht sortiertem Kalksand und Kalkschutt, fast ohne Feinmaterial. Geopetalgefüge und die flache Untergrenze der Klinoformen gegen die kieseligen Beckenkalke (Gosauseekalk) weisen aus, dass die Hangschichten ihre ursprüngliche Neigung von etwa 30° weitgehend bewahrt haben.Verfolgung ungestörter Klinoformen im Gelände ergibt eine minimale Beckentiefe von 300 m; sehr wahrscheinlich war das Becken aber über 500 m tief. Auch die vorsichtigste Schätzung ergibt eine Beckentiefe deutlich unter der neritischen Zone und stützt damit die Tiefwasser-Interpretation der Hallstätter Zonen. Eine gewisses Mass an synsedimentärer Hebung des Beckenbodens gegenüber den Plattformen ist aber wahrscheinlich. Die Klinoformen des Gosaukammes bestätigen den vor kurzem erkannten Trend, dass Schlamm-armer Kalkschutt ebenflächige Hangschichten von über 25° Neigung bilden kann.

1. Introduction

The stratigraphy of the Northern Calcareous Alps (NCA) includes carbonate platforms, up to 1500 m thick, in the Middle Triassic, and another generation of platforms, of similar thickness, in the Late Triassic (e.g. Schlager & Schollnberger, 1975; Mandl, 2000). Sedimentary textures and structures, including fossils, are rather well preserved in the platform deposits but their large-scale architecture, in particular the platform-basin transitions, have been severely deformed or dismembered during Alpine orogeny.

Two contrasting models have been proposed for the platform-basin transitions in the NCA. Both were originally formulated by Schwarzacher (1948, p.46) and are shown on Fig. 1. The deep-basin model assumes starved basins of bathyal depths and steep flanks. Maximum water depth according to this model is approximately equal to the maximum difference in thickness between the platforms and the coeval basin sediments, i.e. 800-1200 m for the Late-Triassic platforms and basins in the NCA. The shallow-basin model calls for neritic basins of 50-200 m water depth and more gentle slopes. It invokes differential movements at the platform-basin transition to compensate for the difference in thickness between platform and basin

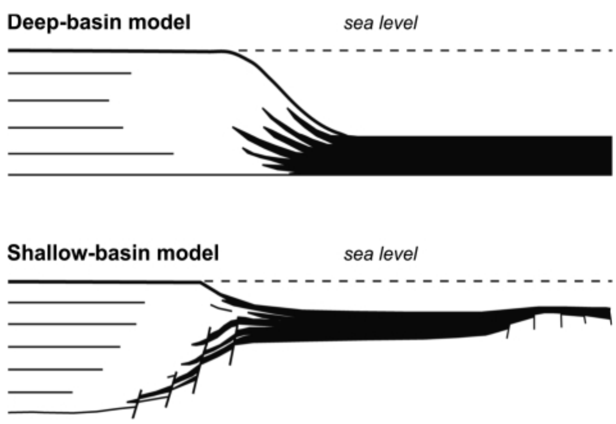

Figure 1: Contrasting models of platform-basin transitions in the Triassic of the Northern Calcareous Alps. The deep basin model assumes that, at any stage of platform growth, water depth in the basin amounts to the difference in thickness between platform succession and basinal succession because the substrate is not deformed by the different sediment loads. The shallow-basin model assumes that the water depth in the basins was only few hundred meters because the substrate was deformed by the load of the growing platforms such that the basin floor rose relative to the platform. Top drawings after Fischer (1964, Fig. 1), bottom drawing after Schlager & Schollnberger (1975, Fig. 1), both modified.

deposits. The deep-basin model is supported by the comparison with the Triassic of the Dolomites where Ladinian and Carnian platforms and basins with steep flanks and relief of 800-1500 m are preserved (Mojsisovics, 1879; Bosellini, 1984). Arguments in favor of the shallow-basin model are (1) The occasional indications for neritic conditions in the basin sediments (e.g. Flügel, 1963 for the Zlambach Fm.; Wendt, 1969 for the Hallstatt Lst.); (2) the repeated observation that the Carnian Raibl Fm. is only about 100-150 m thicker where it overlies the Middle Triassic basin sediments than over the coeval platforms (Jerz, 1965; Schuler, 1968); (3) the presence of salt in the underlying Permian formations and circumstantial evidence for Triassic diapirism in the basinal Hallstatt zones (Lein, 1981; Mandl, 2000, p.65). Salt movement offers a possible mechanism for the differential movement of platforms and basins required by the shallow-basin model.

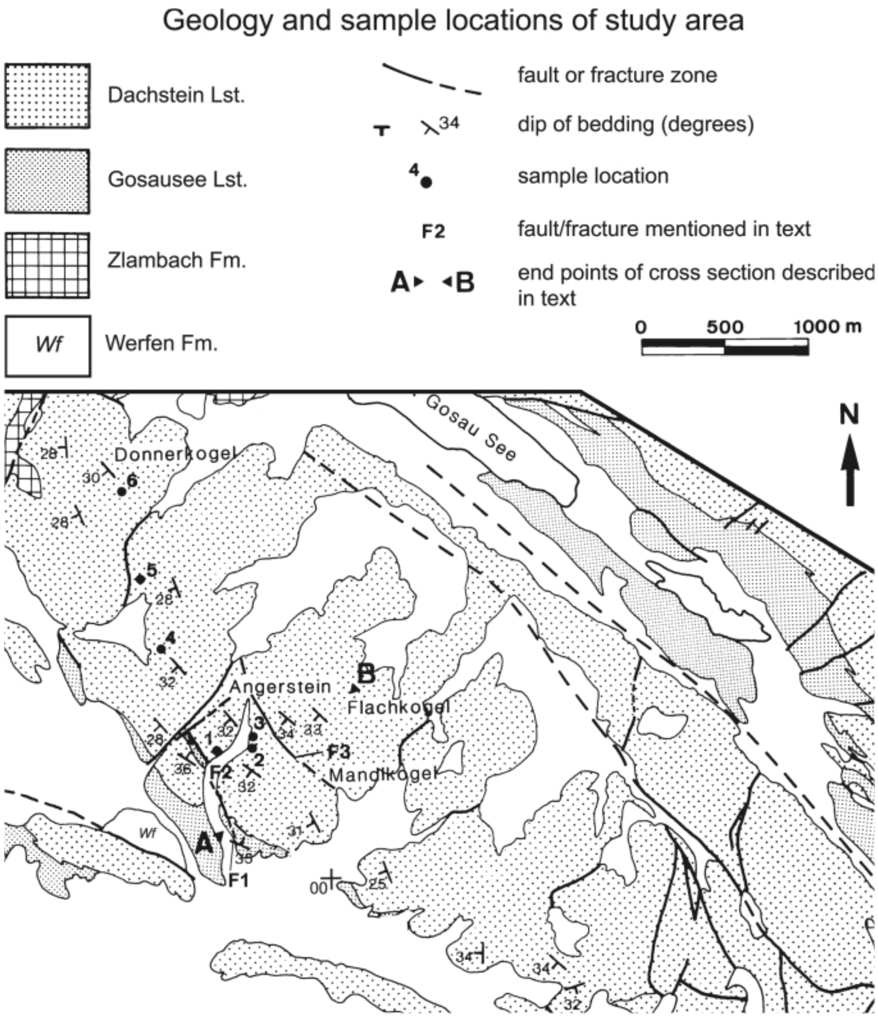

Figure 2: Simplified geological map of the Gosaukamm area showing sample locations, dip of bedding, major fracture zones and location of cross section discussed in text. Geology after Schlager (1967), modified.

The deep-basin model has been invoked by Fischer (1964) for the Late-Triassic Dachsteinkalk platforms and the coeval Hallstatt Basin. The shallow-basin model with differential movement between platforms and basins has been invoked for the Middle-Triassic by Schneider (1964), Sarnthein (1967), Schlager & Schollnberger (1975) and for the Late-Triassic platforms such as the Gosaukamm by Schwarzacher (1948), Schlager & Schollnberger (1975) and Tollmann (1976).

The Gosaukamm is the westernmost part of the Dachstein block – a stratigraphic ensemble dominated by thick Triassic carbonate platforms and bounded by thrust planes or strike-slip faults on all sides. The Dachstein block is considered a nappe by most authors. We prefer the neutral term “Dachstein block” because its boundaries and position in the nappe stack of the NCA remain a matter of debate (see overviews in Mandl, 1999; 2000). The Gosaukamm was severed from the main part of the Dachstein block in the E by a dextral fault; another system of strike-slip faults separates the Gosaukamm in the W from the Hallstatt Zone of the Lammertal (Mandl, 2000).

The stratigraphy of the Dachstein block is dominated by the Middle and Late Triassic platforms mentioned above. Besides extensive outcrops of platform-interior deposits, the Dachstein block also shows platform-margin reef belts and, in fragmented form, parts of the platform basin transition (Mandl, 1999).

The Gosaukamm is one of the areas where parts of the platform margin, the adjacent slope, here referred to as “clinoforms”, and the basin floor have been preserved (Ganss et al., 1954; Zapfe, 1960; Schlager, 1967; Wurm, 1982; Mandl, 1984).

This report adds a new facet to the ongoing discussion on platform-basin transitions in the NCA by combining new observations on the platforms slopes of the Gosaukamm with insights from the Ladinian/Carnian platforms of the Dolomites in the Southern Alps and steep platform slopes elsewhere in the world (Kenter, 1990; Kenter & Campbell, 1991; Kenter et al., 2005). One important result is an estimate of the water depth of the adjacent Hallstatt Basin in the Late Triassic.

2. Field observations at the Gosaukamm

The overall architecture of the Dachsteinkalk and the simplified geology of the Gosaukamm are shown in Figs 2-4. Key observations on the shape and declivity of clinoforms, important fracture zones, samples with geopetal fabrics as well as geographic reference points are indicated.

That the bedding in these large exposures of Dachsteinkalk approximately represented the depositional slope had been

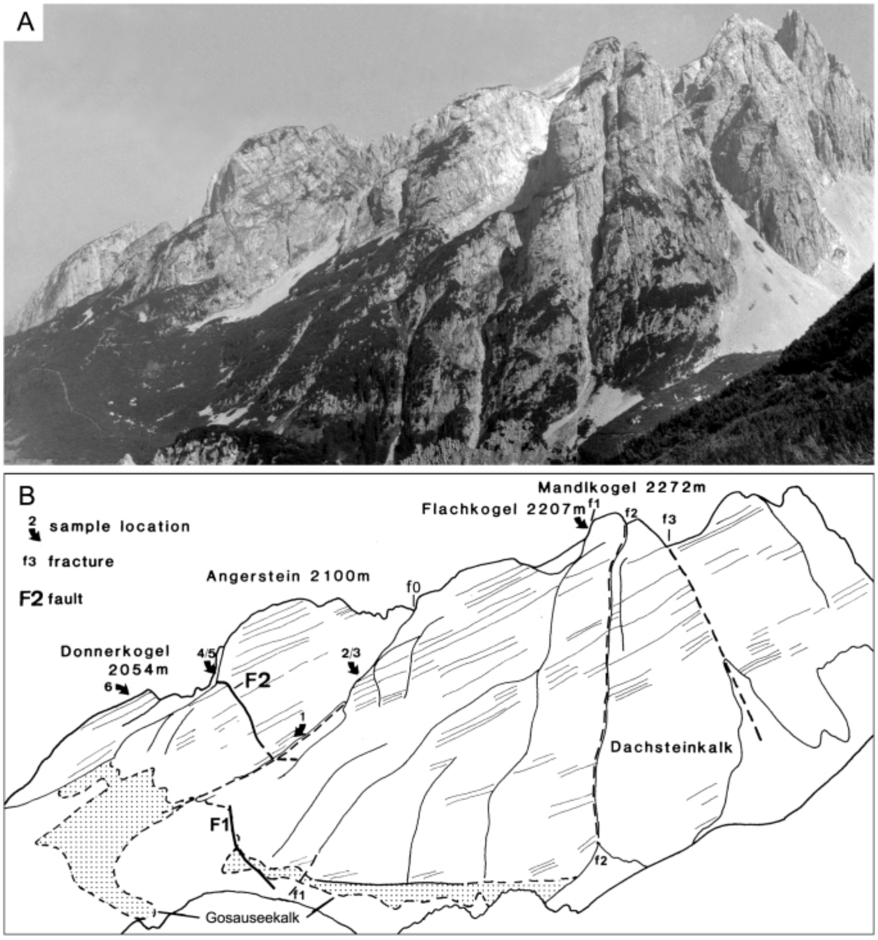

FIGURE 3: Photograph and line drawing of Angerstein-Mandlkogel group of the Gosaukamm, viewed from SE. Note SW-dipping clinoform bedding in Dachsteinkalk and flat lying boundary between basinal Gosauseekalk and Dachsteinkalk in the foreground.

suspected by Rosenberg (in Ganss et al., 1954), Zapfe (1960) and Schlager (1967, p.238). In a detailed study of microfacies and biota, Wurm (1982) confirms the detrital nature of the Dachsteinkalk of the Gosaukamm, but argues for a rather gentle slope. This report provides quantitative data on slope angle, the length of undisturbed clinoforms and the implications for the water depth in the basin.

Figures 3 and 4 show photographs and schematic drawings of the structures present in the SW-facing cliffs. Distinct bedding surfaces of the clinoforms are spaced at 10-100 m but indistinct banding in outcrop shows a spacing of 1-10 m. The bedding in the Dachsteinkalk dips SW or W at angles of ca. 30°, whereas the bedding in the immediately underlying deep-water limestones (Gosauseekalk) is about horizontal or gently NE dipping. With increasing distance from the Dachsteinkalk, dip and structural deformation the Gosauseekalk increase significantly, probably an effect of the western boundary faults of the Gosaukamm (Schlager, 1967, Pl.17).

In the area considered here, the Dachsteinkalk is dissected by numerous fractures. Dominant elements are (1) a system of NW-SE striking fractures, approximately parallel to the strike of the clinoforms and (2) a more irregular set of NE-SW striking fractures that are largely responsible for the segmentation of the Gosaukamm range into a chain of picturesque peaks (see Schlager, 1967, p.259). Most of the fractures show little offset. Fracture zones with demonstrable or probable offset that are relevant for the present reconstruction have been labeled and are shown on Figs 2 - 5. The NW-SE striking fractures are labeled as F1, F2 and F3, the NE-SW fractures as f0….f4. On the panoramic views of Figs 3 and 4, major bedding planes and bundles of thin-bedded, recessive rocks have been indicated. It turns out that the master bedding surfaces can be traced across the cliffs over a distance of about 1000 m without substantial displacement at the fracture zones f1, f2, f3 and f4. The NW-SE fracture zone F1 shows evidence of drag and vertical offset but the amount is not relevant as F1 forms the downslope boundary of the block of Dachsteinkalk used for the slope reconstruction. F2 shows both evidence of drag in the fault and offset; displacement of the marker surface "a" in Fig. 4B indicates that the SW block is upthrown by 40-60 m. The offset on F3 is unknown but there is no indication that it is more than tens of meters as observed on the other faults.

An important objective of this study was to restore the original depositional dip by determining the amount of tectonic tilt. To this end, cobble-size, oriented samples were taken at selected locations and subsequently slabbed and examined for geopetal fabrics. Six samples contained numerous cavities floored with fine-grained, marine sediment. Thin-sections of these geopetal fabrics show that deposition of the internal sediment alternated with the growth of marine radiaxial fibrous calcite cements, confirming the syndepositional origin of these structures (Fig. 5). Furthermore, only very fine-grained cavity fills with well-developed planar surfaces were considered in order to

Location in map	Altitude (m)	Dip in outcrop (degrees)	Number of geopetals	Restored dip (degrees)
1	1760	32	2	39
2	1800	30	1	34
3	1800	32	10	29
4	1755	32	11	30
5	1850	28	5	25
6	2080	31	5	29

TABLE 1: Observations on geopetal fabrics. "Dip in outcrop" indicates present dip of bedding, "Restored dip" indicates dip of bedding after rotating geopetal structures to horizontal. Mean dip in outcrop is 30.6°, mean restored dip 31°. For sample locations see Fig. 2.

minimize the danger of measuring sediment fills that are cone-shaped and thus have a dipping surface.

Original angle and orientation of the depositional layering have been determined in the following way:

(1) Dip angle and azimuth of the depositional bedding was estimated in the field from the intersection of the present rock surface and the depositional layers of debris of different grain size and composition.

(2) Azimuth and dip angle of depositional layering were marked on the sample.

(3) In the laboratory, the sample was cut parallel to depositional dip.

(4) On the cut surfaces, dip angles of the well-developed geopetal fabrics were measured.

(5) Assuming that the surfaces of the selected geopetals originally were horizontal and had been tectonically rotated along a approximately horizontal axis, the sample was rotated to restore the horizontal surfaces of the geopetals and determine the corrected angle of depositional dip.

Results of steps 1 – 5 are plotted in Table 1. The mean dip of outcrop bedding is 30.6°. The mean restored dip, obtainedby rotating geopetal fabrics to horizontal, yielded a mean of 31°. The close similarity of the two values strongly suggests that the structural deformation of the clinoform bedding in the Angerstein-Mandlkogel part of the Gosaukamm is minor.

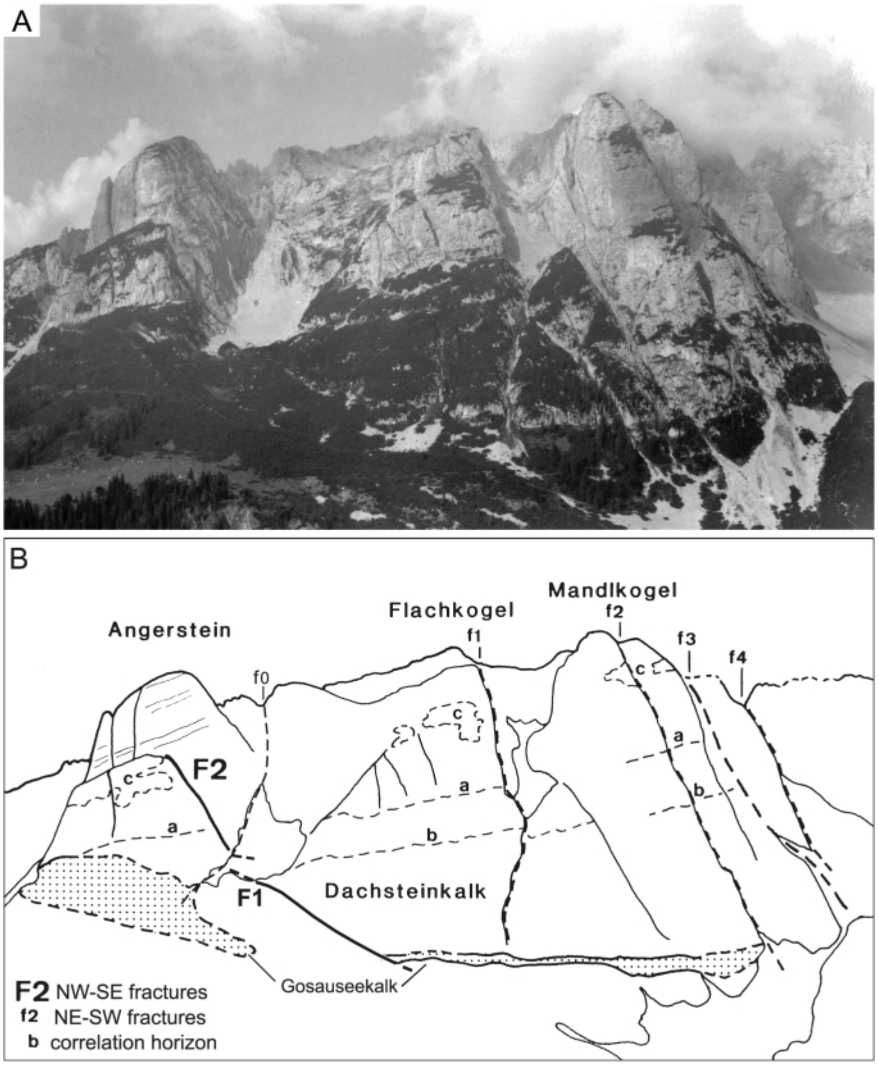

Figure 4: Photograph and schematic drawing of Angerstein-Mandlkogel group viewed from SW. Traceable bundles of recessive beds are labeled (a, b). They indicate only small vertical displacements along fracture zones. Boundary of Gosauseekalk and Dachsteinkalk also shows only minor displacements at fracture zones. Cliffs on the right are about 600 m high.

3. Geometric reconstruction of the clinoforms

The field observations on the clinoforms, geopetal fabrics and fractures were projected into cross-section A-B of Fig. 2, extending in the dip direction of the paleoslope (Fig. 6A). The paleorelief can be estimated by tracing beds along this section since geopetal fabrics within the Dachsteinkalk as well as the horizontal layering of the underlying basinal Gosaueekalk confirm the essentially undisturbed depositional angle of the clinoforms in this part of the Gosaukamm. Fig. 6B presents an imaginary, straight, planar clinoform drawn along the cross-section A-B and dipping at an angle of 30°. The estimated effect of faults F1, F2 and F3 on the reconstructed profile is as follows: F1 represents the downdip boundary fault of the studied stratigraphic interval. F2 has an estimated offset of 40-60 m (see above) but there is no field evidence that it extends to profile A-B; it may be offset by f0 and merge with F1. The fracture zone F3 cuts the profile with unknown offset. Fracture zones f0 through f4 do not intersect the line of section. Moreover, these fractures can be shown to offset stratigraphic markers by few tens of meters at the most.

For each segment the calculated relief is indicated in Fig. 6A. The minimum water depth indicated by the clinoforms is 300 m. This is the depth range covered by the clinoform in the interval between F1 and F3. The water depth estimate increases to 500 m if one assumes that the vertical offset along fault F3 is negligibly small such that the entire section may be considered one undisturbed clinoform. The depth estimate of 500 m still is conservative for two reasons. (1) We have no indication that the upslope end of the section in the Mandlkogel reaches in-situ platform margin deposits. Consequently, the clinoforms must have extended further upward by an unknown amount. (2) If F3 has the same sense of vertical motion as F2, the height of the clinoform in Fig. 6A would

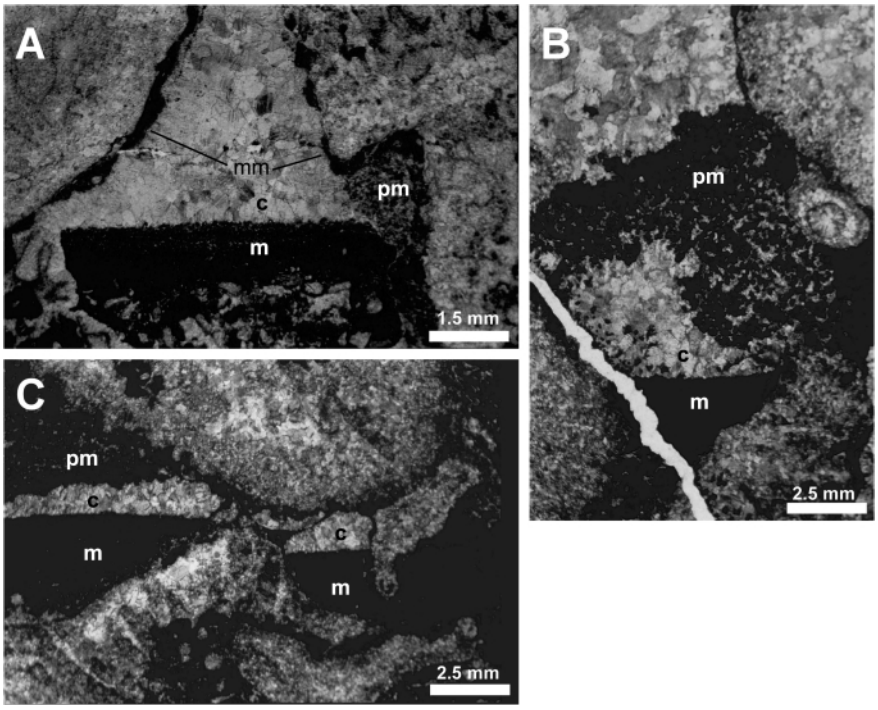

Figure 5: Geopetal fabrics in debris layers of Dachsteinkalk clinoforms. Depositional fabric is "rudstone" or "floatstone", components are skeletal fragments or lithoclasts. All photographs show large fragments enclosing cavities that were partly filled by mud (m), overlain by calcite cement (c). Note difference between homogenous mud fillings (m) used for this study, and coatings of microbial micrite (mm) as well as erosional remnants of earlier cavity fills of pelleted micrite (pm), probably also of microbial origin (see Chafetz, 1985). Pelleted micrite and micrite coatings were already lithified during deposition of the slope rubble and did not form geopetal fabrics relevant for the reconstruction of the slope angle.

have to be extended further. Stronger compaction of the basin sediments could distort our estimate in the other direction. We think that this effect, if present, is insignificant. The clay content of the basin succession up to the level of the Gosauseekalk is very small. Based on Mandl (2000, p. 70) we estimate that marl and shale constitute less than 10% of the stratigraphic column. Pressure solution, on the other hand, seems to have affected platform and basin formations in similar fashion.

Steep platform slopes dipping to 500 m depth immediately adjacent to the platform margin seemingly contradict earlier reports from the Dachsteinkalk. At the Gosaukamm, Wurm (1982) gives no specific slope angle but his model (p. 249) shows a very gentle slope that remains almost entirely with the range of sea-level fluctuations as indicated by evidence of pervasive vadose diagenesis. However, at the present state of knowledge, Wurm's (1982) criteria for vadose diagenesis seem undiagnostic: "vadose crystal silt" is common in the vadose zone but also has been observed in molds of ammonite shells of bathyal deposits that never experienced anything but deep-sea and burial diagenesis (e.g. Schlager, 1974, p. 59). Similarly, overgrowth cement on echinoderms has been found in meteoric, marine and burial settings (Flügel, 2004, p. 300-301). Very influential for the gentle-slope model of Dachsteinkalk plat-forms was the pioneering work of Zankl (1969) at the Hohe Göll, 30 km W of the Gosaukamm. Zankl (1969, p. 76) discovered lenses of red Hallstatt Limestone with pelagic fauna intercalated in fore-reef rubble adjacent to the in-situ reef. He concluded that occurrence of pelagic basin facies in this position is only understandable if one assumes a gently rising basin floor that extends right to the high-turbulence zone of the reef. Again, more recent observations indicate otherwise. In the clinoforms of the Gosaukamm, thin stratigraphic intercalations of fine-grained, reddish limestones with conodonts have been observed and led to a stratigraphic subdivision of the clinoforms (Schauer, 1983; Krystyn et al. 2009, this volume). Similarly, Blendinger (2001) observed lenses and fracture fillings of "pink lime mudstone with thin-shelled bivalves and ammonoids" in the 30°-clinoforms of the Middle-Triassic Marmolada platform and one of us (W.S.) noticed similar intercalations ca. 150 m below the platform margin on the 35°-slope of the Carnian Sella platform margin on the 35°-slope of the Carnian Sella platform in the Dolomites.

4. Discussion

The observations on the Dachsteinkalk clinoforms at the Gosaukamm are important for the reconstruction of the Hallstatt Zones of the Northern Calcareous Alps. Hallstatt Zones are tectonically highly deformed and dismembered elements in the nappe stack of the NCA because their lithologic succession is dominated by thick Early-Triassic evaporites and relatively thin, partly argillaceous, deepwater sediments of the Middle and Late Triassic. The deepwater deposits are coeval with Mid-Triassic and Late Triassic carbonate platforms (Wettersteinkalk and Dachsteinkalk respectively), but platform-basin transitions are poorly preserved or missing altogether.

The outcrops of the Gosaukamm show that planar clinoforms of 30° rose at least 300 m, probably more than 500 m from the bottom of the Hallstatt Basin in the Norian. Geometry and lithology of the slopes of the Gosaukamm are remarkably similar to the slopes of the much better preserved Ladinian and Carnian slopes of the Dolomites area of the Southern Alps. This similarity, already noticed by G. Rosenberg (quoted in Ganss et al., 1954, p. 29), lends credence to using the slopes of the Dolomite platforms as a model for the reconstruction of the tectonically disturbed slopes of the Dachsteinkalk platforms of the NCA.

Our observations tip the balance in favor of the deep-basin model for the Hallstatt Zones. However, this statement is not without qualifications. (1) The basin depth indicated by preserved clinoforms, 300-500 m, still is only half of the difference in thickness between the Dachsteinkalk platforms and the coeval part of the basinal Hallstatt succession. (2) There is evidence that the sediments of the Hallstatt Basins were locally deformed and reworked already in Triassic time (e.g. Lein, 1981). This deformation may, at least in part, be related to salt diapirs rising from the Early Triassic evaporites of the Hallstatt Zones. Differential movements between platforms and basins, - an important characteristic of the shallow-basin model -, therefore seem probable. (3) Our observations represent just one spot estimate of basin depth. It is likely that the depth of the Hallstatt Basin varied significantly in space and time. Basin depth probably increased during the early growth stage of the Dachsteinkalk platforms. It may have decreased again with the terrigenous input in the Hallstatt basin during the Rhaetian (Zlambach Fm.). The Zlambach event may be similar to the basin filling by the terrigenous Cassian Fm. in the Dolomites during the Early Carnian when the Cassian Basins between the platforms shoaled to photic depths and locally supported patch reefs (Fürsich & Wendt, 1977; Rudolph et al., 1989; Russo et al., 1991). Reef patches in the Zlambach domain adjacent to the Gosaukamm have been postulated by Flügel (1963). Interfingering of Zlambach Fm. and Dachstein Reef Lst. was observed by Schollnberger (1973) at the Totes Gebirge, 40 km E of the Gosaukamm. An important difference between Zlambach Fm. and Cassian Fm. is that the observed stratigraphic thickness of the latter is much greater. However, the Zlambach Fm. usually is highly deformed and poorly exposed. It is quite possible that its true thickness is being underestimated and that the Hallstatt basins became significantly shallower during deposition of the Zlambach Fm.

Finally, we draw attention to the vastly different slope profiles observed at the Gosaukamm and the Triassic platforms of the Dolomites on the one hand and the leeward slopes of the extant Bahama Banks on the other. The Triassic slopes are steep, straight and, at their lower end, bend sharply into the flat basin floor. This geometry agrees with the composition of the slope deposits. They consist mainly of sand, rubble and lenses of automicrite, i.e. micrite that was firm or hard upon formation and was precipitated on the slope under the influence of microbes (Kenter, 1990; Keim & Schlager, 2001). The Bahama slopes in the lee of the trade winds are distinctly concave with steep angles only in the top 120-150 m, i.e. in the range of Quaternary sea-level fluctuations. The remaining slope dips at few degrees only and is prone to creep and slumping, in agreement with the high mud content of the sediment. Detailed analyses have shown that most of this mud was exported from the platforms by the continuous action of the easterly trade winds (Pilkey & Rucker, 1966; Droxler et al., 1983; Eberli & Ginsburg, 1988). See Schlager & Reijmer (2009, this volume) for a more detailed analysis of this topic.

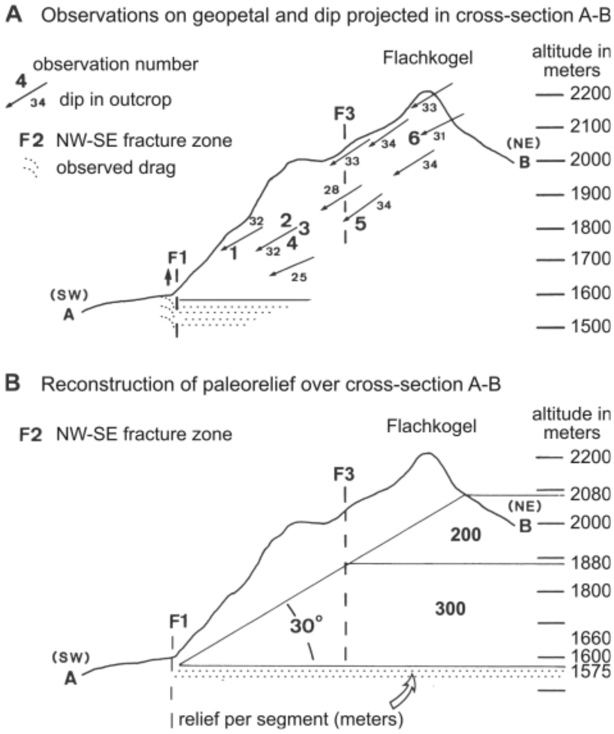

Figure 6: (A) Summary of observations on geopetal fabrics, fracture zones and dip of bedding projected in cross section A-B of Fig. 2. The line of section closely approximates a dip line of the clinoforms. (B) Reconstruction of paleorelief based on information in (A). The most conservative estimate of water depth that can be derived from our observations is 300 m if one considers only the lower segment of the transect. If one assumes that the vertical displacement on fracture zone F3 is negligible and lower and upper segment are still in their original position, the water depth at the lower end of the clinoforms was at least 500 m.

5. Conclusions

Detailed study of the clinoform geometry, sediment composition and geopetal fabrics in the Triassic Dachstein carbonate platform margin in the Gosaukamm shows that the clinoforms are dipping at their original, depositional angle of ca. 30°. A conservative estimate of the platform-basin relief by tracing the clinoforms is 300 m, a value exceeding 500 m is very probable.

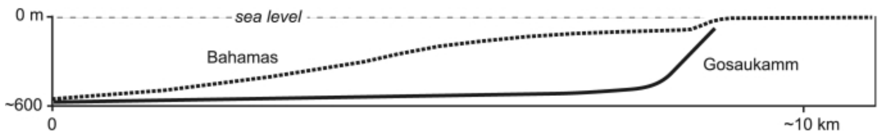

Figure 7: Comparison of slope profiles of the Gosaukamm and the extant Bahama platform. Bold line, slope profile of Gosaukamm as reconstruced from observations reported here. Dotted line, profile of western slope of Great Bahama Bank as documented by bottom surveys, seismic profiles and drill holes (Eberli et al. 2004, Fig.20). Basin depth is similar but slope angles are very different. Except for the upper 100 m, the Bahama slope is much more gentle and dominated by muddy sediment, most of it shed from the platform. Steep slope at Gosaukamm is dominated by rubble and sand with very little mud. Vertical exaggeration 2x.

The existence of steep and high clinoforms in the Gosaukamm and a minimum water depth of 300 m puts the basin floor below the neritic realm, thus supporting the deep-basin model of the Hallstatt zones. However, the demonstrable water depth is considerably less than the difference in thickness between platform and basin successions. Thus, syndepositional differential movements between platforms and basins are probable.

Gosaukamm clinoforms confirm the widely observed tendency of granular carbonate sediments with low mud content to build straight clinoforms with depositional angles exceeding 25°.

Acknowledgments

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Jeroen A.M. KENTER[1)] & Wolfgang SCHLAGER[2)*)]

[1)] Chevron Energy Technology Company, San Ramon, CA, USA; jeroenkenter@chevron.com

[2)] Vrije Univ. Amsterdam/Earth & Life Sci., De Boelelaan 1085, 1081HV Amsterdam, Netherlands

[*)] Corresponding author, schlager@planet.nl