Paleocene – Eocene paleogeography of the Northern Calcareous Alps (Gosau Group, Austria)

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Abstract: Paleogene deposits of the Gosau Group of the Northern Calcareous Alps (NCA) mainly comprise turbidites (e.g., Zwieselalm Formation, Brunnbach Formation, Gießhübl Formation) and hemipelagites (Nierental Formation). Shallow-water carbonates (Kambühel Formation) are known only from the southeasternmost part of the NCA. Four facies associations of the Paleogene Gosau Group can be distinguished: siliciclastic and mixed siliciclastic-carbonate turbidites, hemipelagites and pelagites, debrites including olistoliths, and shallow-water carbonates. Paleogeographic reconstructions and facies distributions for the Early Paleocene indicate a narrow carbonate shelf in the southeast, a generally north-facing paleoslope with slope basins acting as depocenters, and depositional areas below the local calcite compensation depth in the Weyer Arc and the Gießhübl syncline at the northeastern margin of the NCA. South of the NCA, subaerial exposure of rising metamorphic complexes shed siliciclastic detritus to the north. Sedimentation of the Gosau Group ended during the Late Paleocene (Gießhübl syncline) to Early/Middle Eocene (Gosau–Abtenau, Wörschach, Gams, Windischgarsten) due to compressional tectonics. Only within the Salzburg – Reichenhall area, is marine sedimentation up to the Late Eocene known. For the Paleocene of the Northern Calcareous Alps an active continental margin setting with slope basins influenced by strike-slip faulting is inferred, based on continuing subsidence and deep-water deposition and rapid lateral facies changes. Deep-water sedimentation has been largely controlled by local relief and depocenters formed by synsedimentary faulting. A northward propagating front of deformation and thrusting during Paleocene to Eocene times is indicated by the presence of the youngest Gosau deposits at the northern margin of the Northern Calcareous Alps, near Salzburg.

Zusammenfassung: Paläogene Ablagerungen der Gosau-Gruppe der Kalkalpen umfassen vor allem Turbidite (u.a. die Zwieselalm-Formation, die Brunnbach-Formation und die Gießhübl-Formation) und Hemipelagite (Nierental-Formation). Seichtwasserkarbonate (Kambühel-Formation) sind nur aus dem SE der Kalkalpen bekannt. Innerhalb des Paläogens können vier Faziesassoziationen unterscheiden werden: siliziklastische und gemischt siliziklastisch-karbonatische Turbidite, Hemipelagite und Pelagite, Debrite mit Olistolithen und Seichtwasserkarbonate. Paläogeographische Rekonstruktionen und Faziesverteilungen für das Frühe Paleozän zeigen einen schmalen Karbonatschelf im Südosten, einen generell nach Norden abtiefenden Paläohang mit Sedimentfallen bildenden Hangbecken, und Ablagerungstiefen unterhalb der lokalen Kalzitkompensationstiefe im

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Norden innerhalb der Weyerer Bögen und der Gießhübler Mulde. Im Süden der Kalkalpen bilden aufsteigende metamorphe Komplexe ein subaerisches Liefergebiet für siliziklastischen Detritus. Die Sedimentation der Gosau-Gruppe endete im Späten Paleozän (Gießhübler Mulde) bis Frühen/Mittleren Eozän (Gosau–Abtenau, Wörschach, Windischgarsten, Gams) durch beginnende kompressive Tektonik. Nur im Gebiet von Salzburg-Reichenhall setzt sich die marine Sedimentation bis ins Späte Eozän fort. Ein aktiver Kontinentalrand mit Seitenverschiebungen wird als Sedimentationsraum der Hangbecken der Gosau-Gruppe der Kalkalpen im Paleozän interpretiert, wobei anhaltende Absenkung und starke laterale Faziesunterschiede charakteristisch waren. Die Tiefwassersedimentation wurde weitgehend durch lokale Reliefunterschiede und tektonisch angelegte Becken kontrolliert. Die Sedimentationsgeschichte der paleozänen bis eozänen Gosau-Gruppe legt eine nordwärts propagierende Deformationsfront nahe, mit den jüngsten Ablagerungen der Gosau-Gruppe am Nordrand der Kalkalpen bei Salzburg.

Keywords: Paleogeography, Lithostratigraphy, Paleogene, Northern Calcareous Alps, Gosau Group

Contents

1. INTRODUCTION

Since the work of Kühn (1930) Paleogene strata within the Northern Calcareous Alps (NCA) have been known from several areas of the Gosau Group. Most of these Paleogene deposits are characterized by deep-water facies, including turbidites and hemipelagites (Faupl et al., 1987; Wagreich & Faupl, 1994); shallow-water sediments have been reported only from the southeastern part of the NCA (Tollmann, 1976). Outcrops of the Gosau Group comprise only erosional and tectonic remnants of the widespread Paleogene cover of the Northern Calcareous Alps as evidenced, for example, by the widespread open marine deep-water facies and resedimentation of Paleogene deposits into younger strata (Hagn, 1981; Moussavian, 1984). Paleogene deposits of the Gosau Group record the geodynamic evolution of the Eastern Alpine orogenic wedge from a phase of deep-water sedimentation to renewed thrusting, which culminated in the meso-Alpine orogeny as a consequence of compression between the European and the African-Adriatic plate (e.g., Dewey et al., 1989).

This paper presents an overview of the Paleocene to Eocene paleogeographic evolution of the NCA, including a detailed sketch in the Weyer arc area. The paleotectonic evolution and the paleogeographic relationships to tectonic units to the north and to the south of the NCA such as the Rhenodanubian Flysch Zone and the Southern Alps are briefly discussed.

2. GEOLOGICAL SETTING

The fold-and-thrust belt of the NCA (Fig. 1) originated from the Austroalpine microplate, which was situated between the European Plate to the north and the Adriatic Plate to the south (CHANNEL et al., 1992). Late Cretaceous oblique southward subduction of the Penninic Ocean below the Austroalpine microplate resulted in deformation and thrusting of the NCA, which were situated at the northern leading edge of the Austroalpine upper plate from the Late Cretaceous onwards (Fig. 2).

Deposition of the Gosau Group generally post-dates Cretaceous folding and thrusting in the NCA and was partly coeval with metamorphism and exhumation of Austroalpine basement units to the south of the NCA. Prolonged subsidence, from Late Turonian onwards, led to widespread deep-water conditions during the latest Cretace-

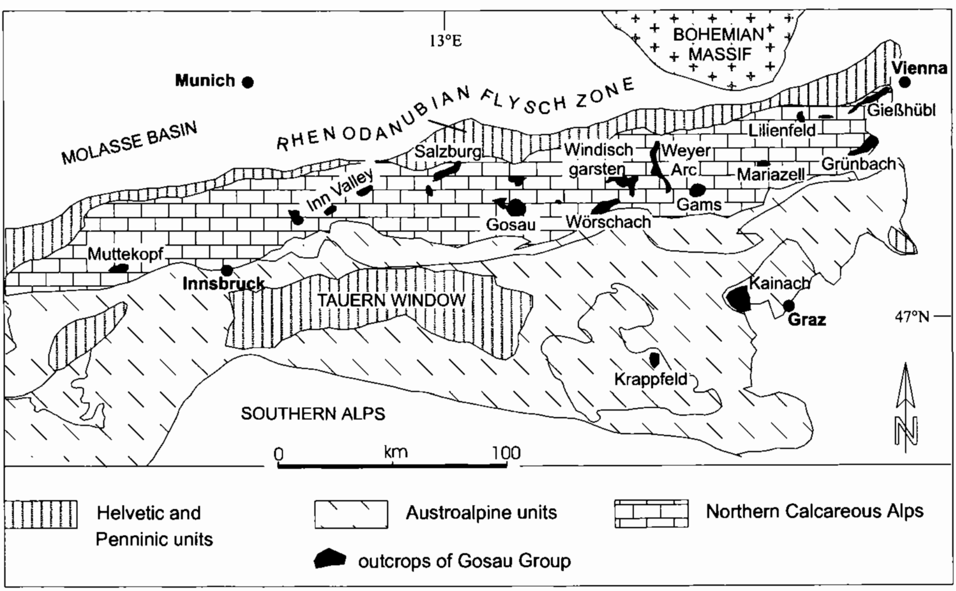

Fig. 1: Schematic map of the Eastern Alps with major outcrops of the Upper Cretaceous to Paleogene Gosau Group.

ous and the Paleogene (WAGREICH, 1991; WAGREICH & FAUPL, 1994). Paleogene deep-water sediments of the Gosau Group are known from the western NCA to the eastern margin of the NCA and its eastward continuation into the Western Carpathians (WAGREICH & MARSCHALKO, 1995; for locations see Fig. 1), e.g. the Muttekopf area (WOPFNER, 1954; ORTNER, 1994), isolated outcrops in the Inn valley (HAGN, 1981), the Untersberg-Salzburg-Lattengebirge area (HERM et al., 1981; HILLEBRANDT, 1962, 1981; MOUSSAVIAN et al., 1990; KRENMAYR, 1999), Gosau-Rußbach-Abtenau (WILLE-JANOSCHEK, 1966; WILLE, 1968), Wörschach-Liezen (JANOSCHEK, 1968; POBER, 1984), Windischgarsten (PREY, 1992), the Weyer Arc (OBERHAUSER, 1963; FAUPL, 1983; PLÖCHINGER, 1987), Gams (KOLLMANN, 1964; WAGREICH, 1994), the Grünbach-Neue Welt area (PLÖCHINGER, 1961; HRADECKÁ et al., 1999; EGGER et al., 2000b) and the Gießhübl syncline and its continuation into the Vienna Basin (WESSELY, 1974; SAUER, 1980; PLÖCHINGER & SALAJ, 1991). Several K/T-boundary sites were described from these sections, including detailed investigations in the Gosau area (Elendgraben and Rotwand-sections, PREISINGER et al., 1986; LAHODYNSKY, 1988; PERYT et al., 1993), in the Gams area (Knappengraben section; LAHODYSNKY, 1988) and in the Lattengebirge near Bad Reichenhall (Wasserfallgraben, HERM et al., 1981; JAFAR, 1994).

Outcrops of shallow-water sediments, mainly shallow-water limestones, are restricted to the southeasternmost part of the NCA, from the Kambühel near Ternitz (TRAGELEHN, 1996) to the Hochschwab area (KEGLER et al., 2000). Shallow -water carbonates are also found as olistoliths in deep water strata (e.g., LEIN, 1982; MOUSSAVIAN, 1984; POBER, 1984; NOWESKI et al., 2000).

3. PALEOGEOGRAPHIC OVERVIEW

The Late Cretaceous orogenic wedge of the Eastern Alps was situated at a paleolatitude of about 30°N, based on paleomagnetic inclinations (MAURITSCH & BECKE, 1987; HAUBOLD et al., 1999). For the depositional area of the NCA, a relatively warm, humid climate can be reconstructed for the Late Cretaceous and mixing of Tethyan and Boreal taxa (e.g., KOLLMANN, 1980) suggests a biogeographical borderland position of the NCA at the northern margin of the Tethys (SANDERS et al., 1997). An eastward continuation of the depositional area of the Gosau Group into the Western Carpathians is proven by detailed facies correlations (WAGREICH & MARSCHALKO, 1995; FAUPL et al., 1997). From the Cretaceous onwards, deep-water turbidite troughs of the Flysch Zones of the Eastern Alps were situated to the north-northwest of the Northern Calcareous Alps (e.g., BUTT, 1981; EGGER, 1992; WAGREICH & FAUPL, 1994). Although the paleogeographic position and paleotectonic setting of the Rhenodanubian Flysch Zone is still under debate (e.g., BUTT, 1981; EGGER, 1992; FAUPL & WAGREICH, 1992; 2000; OBERHAUSER, 1995), an original position within the Penninic oceanic realm can be assumed (Fig. 2). Paleogene clastic sedimentation within the Rhenodanubian Flysch Zone was mainly below the local CCD (e.g., HESSE & BUTT, 1976; BUTT, 1981). To the north of the Penninic oceanic domain, Helvetic/Ultrahelvetic units together with autochthonous Cretaceous strata at the southeastern and southwestern edge of the Bohemian Massif comprise the shelf to upper slope of the southern margin of the European plate (BUTT, 1981; FUCHS & WESSELY, 1996).

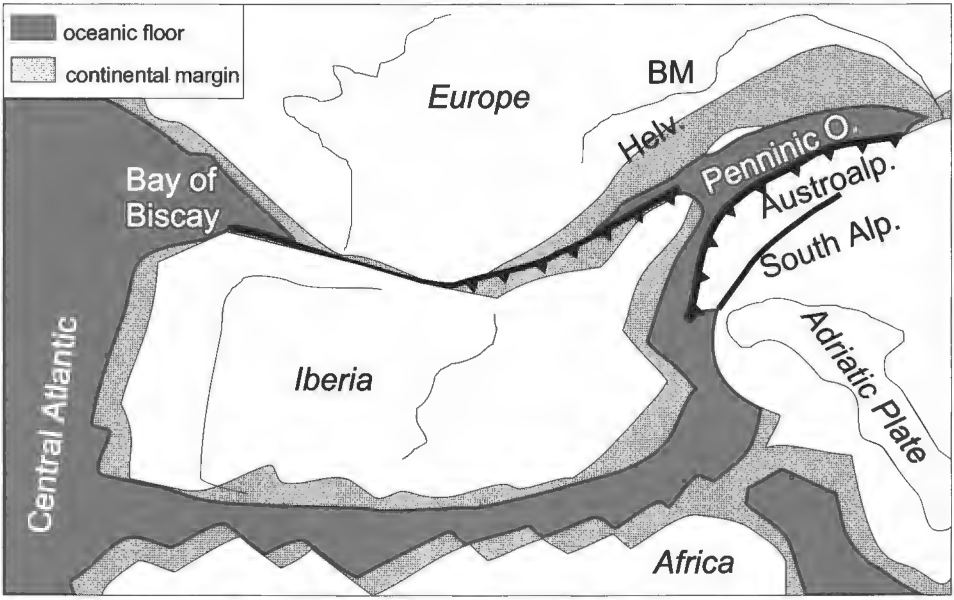

Fig. 2: Schematic palaeogeographic map for the Early Paleocene, strongly simplified from STAMPFLI et al. (1998). BM – Bohemian Massif, Helv. – Helvetic shelf, Austroalp. – Austroalpine microplate, South Alp. – Southern Alpine Units.

To the south of the NCA, exhumation of metamorphic complexes of the Austroalpine basement formed a rising source area for Paleogene siliciclastics (WOLETZ, 1963; FAUPL et al., 1987). This rising hinterland separated the depositional area of the Gosau Group of the NCA from southern, "Central-Alpine" basins such as Krappfeld and Kainach (FAUPL & WAGREICH, 1994; NEUBAUER et al., 1995; WAGREICH & SIEGL-FARKAS, 1999). Whereas no Paleogene deposits have been reported from Kainach, an Upper Paleocene/Lower Eocene terrestrial to shallow-water succession is known from Krappfeld (WILKENS, 1989; RASSER, 1994). Pebbles of Paleogene shallow-water limestones in Miocene conglomerates in the eastern part of the Eastern Alps (e.g., JANOSCHEK, 1968) record a more widespread cover of parts of the Austroalpine basement by shallow-marine strata during the Paleocene-Eocene than is suggested by present outcrops. Paleogene deposition within the "Central-Alpine" area can be interpreted as a continuation of the "Central Carpathian Paleogene" deep-water trough from Slovakia (e.g., MARSCHALKO, 1968) into the Eastern Alps. Farther to the south, a marine seaway from the "Central Alpine" Gosau basin of Krappfeld into the Southern Alps can be assumed, due to the occurrence of Paleocene-Eocene deep-water strata, in, for example, the Lombardian basin in northern Italy, where an Early Paleocene hiatus is followed by deposition of turbidites and marlstones of Paleocene – Middle Eocene age (BERSEZIO et al., 1993).

4. LITHOSTRATIGRAPHY, BIOSTRATIGRAPHY AND CHRONOSTRATIGRAPHIC CORRELATIONS

The lithostratigraphy of Paleogene deposits of the Gosau Group is still poorly developed. Detailed lithostratigraphic investigations are often missing or exist only as unpublished results in several doctoral theses (e.g., SAUER, 1980; POBER, 1984; TRAGELEHN, 1996). This overview therefore gives a state-of-the-art review of commonly used lithostratigraphic terms, rather than referring to established lithostratigraphic subdivisions (Fig. 3). Several deep-water siliciclastic formations such as the Wörschachberg Formation of the Wörschach-Liezen area (POBER, 1984) or the Rotkopf Formation of the Muttekopf (ORTNER, 1993) may be included in the future into a single formation.

Well defined lithostratigraphic subdivisions of Paleogene deposits have been established in the Gosau area based on WEIGEL (1937) and KOLLMANN (in PLÖCHINGER, 1982: Nierental Formation, Zwieselalm Formation), in the Gießhübl syncline (PLÖCHINGER, 1964: Gießhübl Formation; WESSELY, 1974; SAUER, 1980) and in the Grünbach-Neue Welt area (PLÖCHINGER, 1961: Zweiersdorf Formation). Paleocene shallow-water carbonates of the Kambühel Formation, as defined by TOLLMANN (1976) were recently investigated by TRAGELEHN (1996) who distinguished two members (St. Lorenzen Member, Ragglitz Member).

Biostratigraphic data for the deep-water successions are mainly based on planktic foraminifera and calcareous nannoplankton. Most of the biostratigraphical data on planktic foraminifera come from several papers, published in the 1960's, e.g., HILLEBRANDT (1962), WILLE-JANOSCHEK (1966), WILLE (1968), KOLLMANN (1963, 1964), OBERHAUSER (1963), OBERHAUSER in PLÖCHINGER (1964). Calcareous nannofossils (STRADNER, 1961; WAGREICH & KRENMAYR, 1993; JAFAR, 1994; HRADECKÁ et al., 1999) comprise additional, but scattered biostratigraphic data. Standard zonations for planktic foraminifera (P-zones of BERGGREN et al., 1995) and calcareous nannoplankton (NP-zones, MARTINI, 1971; PERCH-NIELSEN, 1985) are used in this paper (Fig. 3). Chronostratigraphic correlations of the shallow-water deposits in the Kambühel Formation are mainly based on the biostratigraphical ranges of calcareous algae, e.g., MOUSSAVIAN (1984) and TRAGELEHN (1996). Chronostratigraphic correlations and absolute age assignments have been taken from BERGGREN et al. (1995).

5. FACIES ASSOCIATIONS

Four generalized facies associations have been distinguished within the Paleogene part of the Gosau Group: siliciclastic and mixed siliciclastic-carbonate turbidites, hemipelagites and pelagites, debrites, and shallow-water carbonates of reef, lagoonal and fore-reef facies.

5.1. Siliciclastic and hybrid turbidites

Paleogene turbiditic successions, such as the Gießhübl Formation in the eastern NCA, attain a thickness up to 1000 m (WESSELY, 1974; SAUER, 1980). Different types of turbidites and deep-water mass-flow deposits were described, such as classical "proxi-

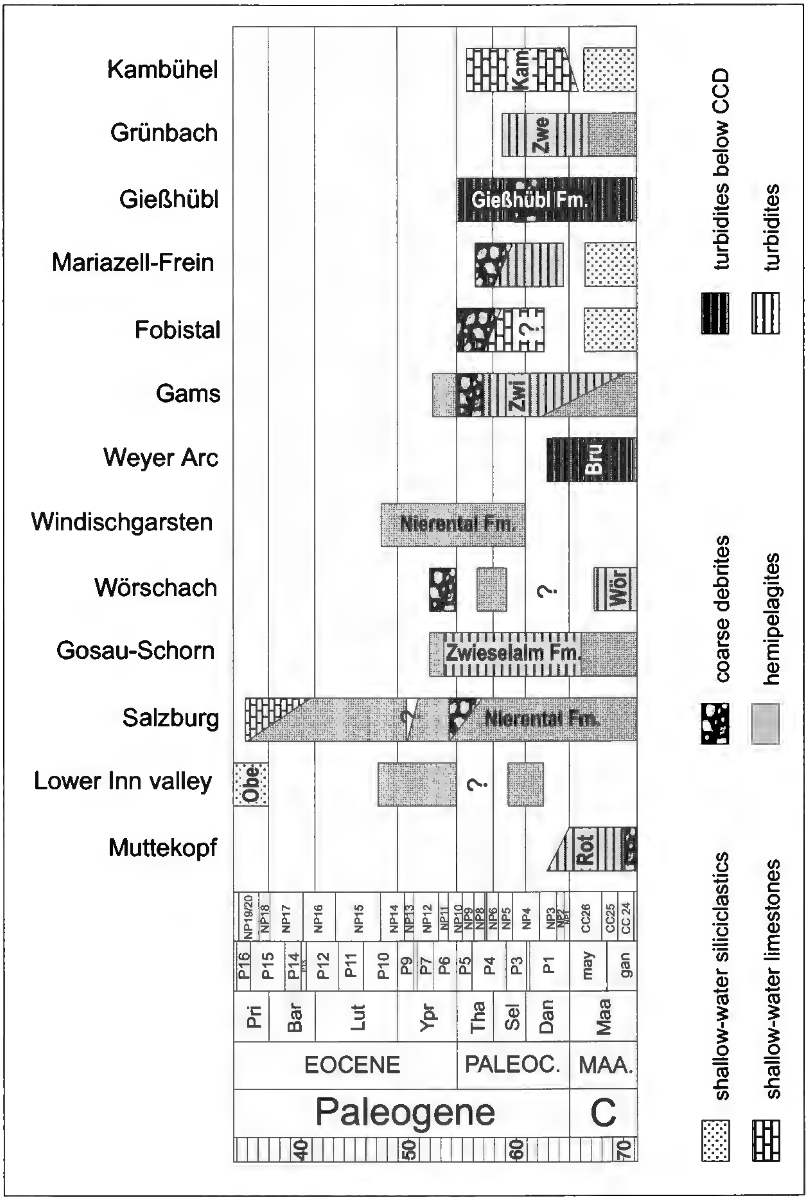

Fig. 3: Lithofacies, lithostratigraphy and chronostratigraphic correlation of main successions of Paleogene sediments of the Gosau Group. Chronostratigraphic framework and planktic foraminiferal P-zones after BERGGREN et al. (1995), calcareous nannoplankton NP-zones after MARTINI (1971) and PERCH-NIELSEN (1985). Abbreviations: Rot – Rotkopf Formation, Obe – Oberaudorf Formation, Zwi – Zwieselalm Formation, Wör – Wörschachberg Formation, Bru – Brunnbach Formation, Zwe – Zweiersdorf Formation, Kam – Kambühel Formation.

mal" and "distal" sandy turbidites, modified sandy grain flow deposits and debris flow conglomerates, from, for example, the Weyer Arc (FAUPL, 1983) and the Gießhübl syncline (SAUER, 1980). Submarine channel-fill fining- and thinning-upward cycles attain thicknesses of up to 25 m (FAUPL, 1983; WAGREICH, 1986). Several meters thick turbiditic marls (BOUMA Te-intervals) point to ponding of turbidity currents. Non-turbiditic intercalations comprise either calcareous marlstones (KRENMAYR, 1999) or shales devoid of carbonate (FAUPL & SAUER, 1978); the latter indicate deposition below the CCD, for example for the Gießhübl Formation and the Brunnbach Formation. The gravity flow dominated facies association points to deposition on small submarine fans. Proximal fan areas are characterized by channels filled with conglomerates and pebbly sandstones, whereas classical turbidites indicate interchannel and distal fan depositional environments. Paleocurrent indicators record either transport from the south (FAUPL, 1983; LAHODYNSKY, 1988) or basin-parallel E-W flows (SAUER, 1980).

Turbiditic sandstones can be classified as lithic arenites and display mixing of siliciclastic and carbonate debris. Carbonate clasts include both extraclasts, such as limestones and dolomites from the underlying succession of the NCA, and bioclasts from a contemporaneous carbonate shelf. Resedimentation of Cretaceous deposits of the Gosau Group has also been commonly observed. The siliciclastic fraction comprises mainly low- to medium grade metamorphic clasts, such as polycrystalline quartz, phyllites, quartzites, and mica schists. Heavy mineral assemblages are generally rich in garnet (WOLETZ, 1963; SAUER, 1980; FAUPL et al., 1987), but show a considerable variety from one succession to the other and even within one outcrop area (FAUPL, 1983; KRENMAYR, 1999), indicating different source areas. Ar/Ar dating of micas from pebbles suggests significant erosion of pre-Alpine, Permian metamorphic crystalline units of the Austroalpine basement to the south (FRANK et al., 1998).

5.2. Hemipelagites and pelagites

Hemipelagites (terrigenous component with >40% silt, cf. STOW & PIPER, 1984) and pelagites (pelagic marly limestones and pelagic shales) occur either as several tens to hundreds of meters thick packages or as a few meters thin intervals within turbidite-dominated successions. Red and grey thin to medium bedded marly limestones, marls and shales with a generally high degree of bioturbation of the *Zoophycus*-ichnofacies predominate. Intercalations of thin sandstone and debrite beds or slump deposits are common. The position of the basin in regard of the local calcite compensation depth and the input of fine-grained siliclastics controls the ratio of clay minerals versus carbonate minerals (KRENMAYR, 1996). Basins below the CCD contain non-carbonatic hemipelagic clays (HESSE & BUTT, 1976; FAUPL, 1983). Variable carbonate contents are reported from hemipelagites of Gams, Gosau and the Lattengebirge, where Paleogene pelagic sediments mainly comprise marly limestones or calcareous marlstones (Nierental Formation; KRENMAYR, 1996, 1999). The carbonate content consists mainly of calcareous nannoplankton and planktic foraminifera. The foraminiferal assemblages indicate upper to middle bathyal depths of deposition (BUTT, 1981). Deposition within a slope environment is suggested by the presence of slump deposits, low sedimentation rates (ca. 1cm/1000a) and irregular facies organisation (KRENMAYR, 1999).

5.3. Debrites

The debrites facies association consists mainly of coarse mass flow and slump deposits. Based on the composition of components, both carbonate-rich debrites (mainly carbonate breccias with low to very low matrix contents) and polymict (mixed siliciclastic-carbonate debrites with generally higher matrix contents) can be distinguished. The occurrence of olistostromes (debrites with high proportions of fine-grained matrix and olistoliths up to 50 m in diameter) was reported from several Gosau areas, such as Wörschach (JANOSCHEK, 1968; POBER, 1984), Lattengebirge (MOUSSAVIAN et al., 1990), Gams (NOWESKI et al., 2000) and Mariazell-Frein (LEIN, 1982). The matrix of the debrites commonly consists of (hemi)pelagic sediments with variable proportions of broken carbonate fragments. Slumped masses of fine-grained hemipelagites and turbidites are often associated with debrite successions. Carbonate-rich debrites consist mainly of resedimented shallow-water limestones of the Kambühel Formation, including olistoliths up to several tens of meters in diameter such as those in the Upper Thanetian of the Gams area (NOWESKI et al., 2000). Mixed debrites include components of the Kambühel Formation, marly limestones and marlstones of the Nierental Formation, various components of the underlying NCA-succession and the Austroalpine basement, e.g., at Wörschach (POBER, 1984) and Salzburg-Lattengebirge (MOUSSAVIAN et al, 1990). The middle part of the Gießhübl Formation (Lower Thanetian) is characterized by fine-grained breccias rich in red algae (WESSELY, 1974, 1988, 1989). Source areas for carbonate-rich debrites are mainly local carbonate platforms and slopes of the Kambühel Formation. Polymict debrites indicate considerably larger source areas, including siliciclastic material from the southern hinterland, which was transported through the carbonate-dominated shelf.

5.4. Shallow-water carbonates

Various types of white to creamy red shallow-water carbonates are known from the Paleogene Gosau Group. TRAGELEHN (1996) argued that lagoonal, reef and fore-reef talus facies of Danian to Middle Thanetian age can be distinguished, although most of them are redeposited into deeper water strata. In situ carbonates are very rare, but occur in the type locality, the Kambühel near Ternitz (Fig. 1; TRAGELEHN, 1996, 2000) at the southeastern margin of the NCA, and probably also in parts of the Kambühel Formation in the Hochschwab area (WAGREICH, 1994). In both areas, these limestones overly Maastrichtian siliciclastics ("Orbitoidenschichten", TRAGELEHN, 1996; comp. Fig. 3). Paleocene reef carbonates comprise bafflestones/boundstones/rudstones with abundant corallinacean and dasycladacean algae and corals. Fore-reef facies includes packstones rich in corallinacean algae. Coral bafflestones and floatstones are interpreted as lagoonal facies (TRAGELEHN, 1996). Third-order transgression-regression cycles, marked by emersion horizons, have been reported by TRAGELEHN (1996) from the Kambühel. Olistoliths of fore-reef facies, and from reef and restricted lagoonal facies (peloidal grainstones) occur in the Hochschwab area (KEGLER et al., 2000). Reef growth stopped during the Middle Thanetian, probably due to a sea-level fall and tectonism (TRAGELEHN, 1996).

6. PALEOGEOGRAPHY AND PALEOBATHYMETRY OF THE GOSAU GROUP DURING THE PALEOGENE

The paleogeographic evolution of the NCA during the Paleocene-Eocene is summarized using facies maps and published paleocurrent data. For simplicity, no tectonic restorations for post-Gosau tectonic deformations (e.g., LINZER et al., 1995; PERESSON & DECKER, 1997) were included. In general, this deformation, mainly along strike-slip faults, is in the range of several kilometers (PERESSON & DECKER, 1997) and does not significantly distort the general facies patterns.

6.1. Early Paleocene (Danian, NP1–NP4)

During the Early Paleocene turbidites and hemipelagites dominated the deposits of the Gosau Group of the NCA, from the Tyrol in the west (Muttekopf area, OBERHAUSER, 1963; ORTNER, 1993) to the Gießhübl syncline in the east (SAUER, 1980) (Figs. 3,4). Several localities (Gosau, Gams, Lattengebirge, Gießhübl syncline) display a conformable succession of Maastrichtian to Paleocene deep-water sediments, without major facies changes around the K/T-boundary (LAHODYNSKY, 1988; KRENMAYR, 1999). Several hundred of meters thick turbiditic successions are known from Gosau, Gams and the Gießhübl syncline, whereas the sedimentary record had already ended during the Early Paleocene in the Muttekopf and the Weyer Arc area. Paleocurrent data point to southern source areas for the turbidites (FAUPL, 1983), although basin-parallel, E-W trending flows are also recorded.

For the Paleocene, a reconstruction of the slope can be inferred along a NNW-SSE section from the Weyer Arc to the Hochschwab, based on the information provided by the sedimentary facies and the microfaunas (Fig. 5). Within the Weyer Arc segment, carbonate-free red and green hemipelagic clays within the turbiditic succession of the Brunnbach Formation record deposition below the local CCD (FAUPL, 1983). This deep-water basin received material from two sources, building a sand-rich and a sand-poor submarine fan (FAUPL, 1983). The depth of the CCD in this tectonically active continental margin setting is hard to assess; a minimum depth of 3500 m is assumed here. Deposits of the Brunnbach Formation are known from the Weyer Arc southward to St. Gallen/ Spitzenbach (PLÖCHINGER, 1987). South to southeast of this deep basin, the Gosau Group of Gams records deposition in bathyal depths above the CCD, since hemipelagic intervals display carbonate contents above 40% (WAGREICH & KRENMAYR, 1993; KRENMAYR, 1996). During the Paleocene, both the hemipelagic and the turbiditic pelites became successively poorer in carbonate material, probably indicating a general deepening trend of this basin. South of Gams, the Gosau Group of the Fobistal at the Hochschwab (WAGREICH, 1994) includes shallow-water carbonates and limestone olistoliths (NOWESKI et al., 2000).

A slope basin – trench-slope basin setting (UNDERWOOD & BACHMANN, 1982; MACDONALD, 1993) is inferred for the Gams area, based on bathyal foraminiferal assemblages of hemipelagites, sudden thickness and facies changes of deep-water deposits within a few kilometers, from W to E and along the southern basin margin, where a 400 meter thick basinal turbidite succession is replaced by a few meters of pelagic marly limestones (WAGREICH, 1994; NOWESKI et al., 2000). Submarine fan deposition and the distribution of turbidites was largely controlled by coarse clastic input from the south and the E-W

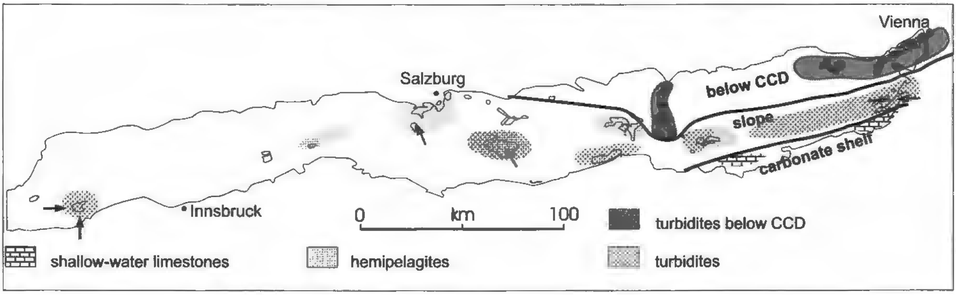

Fig. 4: Paleogeographic sketch map for the Early Paleocene of the NCA (NP1–4). Arrows indicate paleocurrent directions.

elongated basin shape. The Weyer Arc and the Gams basin display considerable similarities to slope basins within an accretionary wedge, such as small depocenters filled by turbidites, intervening structural highs with relatively thin (hemi)pelagic deposits, multiple source areas, including local sources, ponding of turbidites, frequent slumping and large mass flows, including olistolithic blocks, and synsedimentary active faults. The deep-marine basins of the Californian Continental Borderland serve as close analogues to such a setting (Krenmayr, 1999), where an active continental margin is dissected by strike-slip faulting forming several deep basins and intervening highs (comp. Teng & Gorsline, 1989; Normark et al.,1998).

A paleo-water depth reconstruction, based on contouring of estimates of depositional depths for the eastern part of the NCA, is shown in Fig. 6. This reconstruction gives only a rough estimate, because of non-restoration of post-Gosau deformation and the

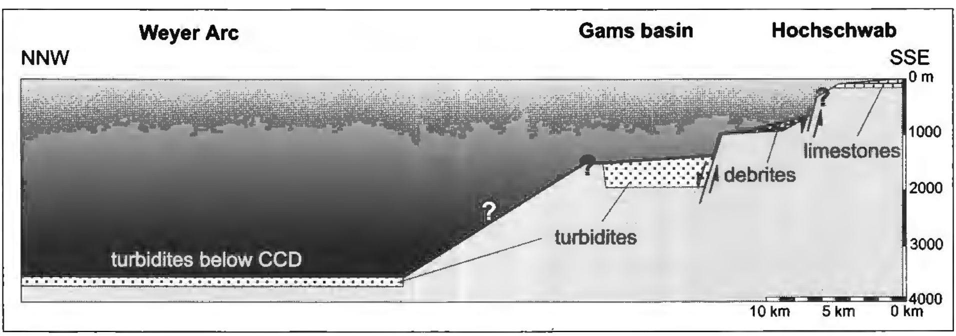

Fig. 5: Sketch illustrating Paleocene depositional waterdepths and facies along a NNW-SSE composite section through the eastern NCA from the Weyer Arc to Hochschwab. A northward deepening slope was segmented into depocenters and highs by synsedimentary faults. The Gams slope basin is filled by a 400 m thick turbidite succession of Paleocene age. Vertical exaggeration 4x.

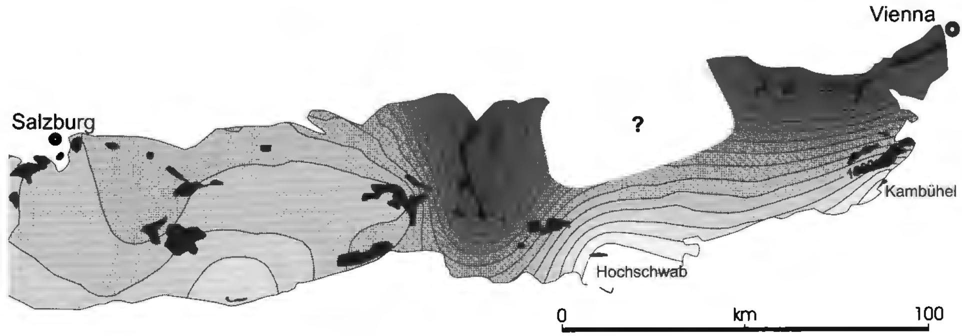

Fig. 6: Paleo-waterdepth estimates for the eastern part of the NCA during the Late Paleocene, based on facies distribution and foraminiferal assemblages (Contouring method: programme Surfer 6.0, Kriging algorithm, Octant search method). For simplicity no restoration of the NCA to the Paleocene position of tectonic units was performed. Note shallow water areas in the SE, from Kambühel to Hochschwab/Fobistal and a deep basin in the north of the NCA.

lack of data in some parts of the NCA, especially to the east of the Weyer Arc. However, water depths below the CCD prevailed in the northeast, the Gießhübl syncline and its continuation up to Hainfeld (WESSELY, 1989; PLÖCHINGER & SALAJ, 1991), and the Weyer Arc area (FAUPL, 1983). Bathyal depths characterized by the deposition of hemipelagites and turbidites, are found to the south and the west. To the west of the Weyer Arc, the slope gradients were smaller than to the east. In the southeasternmost part of the NCA, the distribution of shallow-water carbonates of the Kambühel Formation indicates shallowing and a possible coastline near the southern margin of the NCA. A narrow shelf along the southern margin of the NCA can be reconstructed based on the common erosion of NCA strata and the poor rounding of clasts (KRENMAYR, 1999).

6.2. Middle/Late Paleocene (Selandian-Thanetian, NP5–NP9)

The several hundred meter thick, Middle/Upper Paleocene turbidite succession of the Gießhübl Formation is known from the area of Lilienfeld, the Gießhübl syncline and its continuation below the Vienna Basin (WESSELY, 1974; SAUER, 1980). Sandy turbidite intervals predominated also in the successions in Gosau-Abtenau, Gams and Grünbach, whereas (hemi)pelagic marl deposition, with minor turbidites, has been reported from the Salzburg-Lattengebirge area (KRENMAYR, 1999). Turbidite sandstones display high amounts of reworked Upper Cretaceous material, indicating considerable erosion of Upper Cretaceous strata. Ponding of turbidites, the highly diachronous onset of turbidite sedimentation in Gams and diachronous red hemipelagic intervals in the Gosau area (WAGREICH & KRENMAYR, 1993) point to a considerable local relief within the slope basins.

Coarse debrites, including olistoliths of Paleocene shallow-water carbonates, are widespread in the NCA, especially during the Thanetian to Lower Ypresian (Fig. 3). They occur either as several meter thick debrite layers associated with mixed siliciclastic-carbonate turbiditic successions, as seen in the middle Gießhübl Formation of the

Gießhübl syncline (Sauer, 1980), in Frein near Mariazell (zones P4, NP5; Lein, 1982), and in Gams (Noweski et al., 2000), or as isolated breccias including olistoliths up to 50 m in diameter overlying Maastrichtian sandstones in the southeasternmost parts of the NCA, as in the Hochschwab area (Kegler et al., 2000). It is likely that these olistoliths were derived from a line source rather than from a point source, because they occur over a minimum length of about 100 km, from the eastern margin of the NCA (Tragelehn, 1996) to Gams. Olistostromes including metamorphic clasts were reported from the lower "Ilerdian" (P5) of the Salzburg-Reichenhall area and the Kaisergebirge/Tyrol (Moussavian et al., 1990). The southern carbonate platform was probably dissected by canyons, enabling the siliciclastics to bypass the carbonate environment, similar to present-day depositional settings around several Caribbean islands (Heubeck, 1992).

The occurrence of bentonites originating from tuffs of airfall derivation in the Upper Paleocene (NP10) of Salzburg (Untersberg area, Egger et al., 1996) point to a close connection of the depositional areas of the Gosau Group and parts of the Rhenodanubian Flysch, where similar bentonites of basaltic composition are known (Egger et al., 2000a). According to Hesse & Butt (1976) and Wagreich & Faupl (1994), the slope deposits of the Gosau Group formed the southern margin of the closing oceanic basin of the Rhenodanubian Flysch.

6.3. Eocene

Eocene deposits of the Gosau Group are known from Gams (Kollmann, 1963, 1964; Wagreich, 1994; Egger & Wagreich, this volume), Windischgarsten (Prey, 1992), the Schorn area near Gosau and Abtenau (Wille, 1968), the area of Salzburg-Untersberg (Hillebrandt, 1962, 1981), and small outcrops in the lower Inn valley near Sebi (Hagn, 1981; see Fig. 7). In Gams and Schorn, the successions are characterized by the dominance of pelites and only rare turbiditic sandstone beds. An Early Eocene age is also reported for the olistostrome in the Wörschach area (Janoschek, 1968), which includes components of metamorphic rocks and shallow-water carbonates.

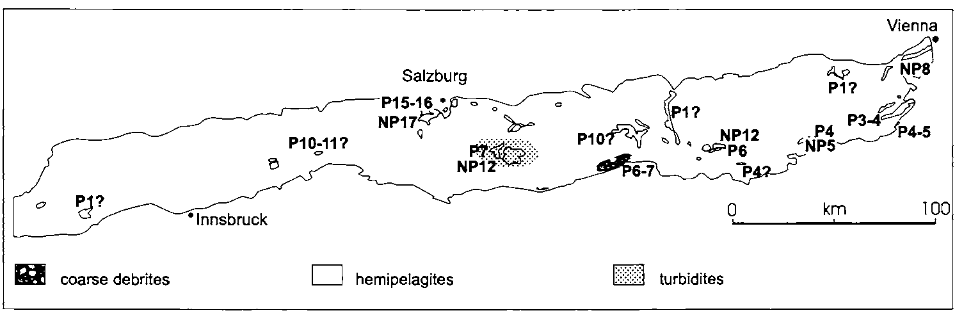

Fig. 7: Paleogeographic sketch map for the Early Eocene of the NCA (NP10–13), including biostratigraphic datings of the end of sedimentation for mentioned successions of the Gosau Group. P and NP numbers indicate the youngest verified foraminiferal or nannoplankton zones for each succession.

An Early to Middle Eocene age (NP12–NP15) for the end of sedimentation has been reported from most of these areas; only the succession in the Salzburg-Untersberg area displays a significantly younger interval up to the Late Eocene (P15–16, NP19). However, an Early Eocene hiatus (HILLEBRANDT, 1962, 1981) and renewed transgression of Middle/Upper Eocene shallow-water carbonates (DARGA, 1990) have been proven in this area. This unusually high stratigraphic range may be explained by a transition from the Gosau Group sedimentary cycle to the Late Eocene/Oligocene sedimentary cycle of the "lower Inn valley Tertiary" (ORTNER & SACHSENHOFER, 1996; ORTNER & STINGL, this volume), a complex pull-apart – piggyback basin which was connected to the foreland Molasse Basin. Due to renewed northward thrusting during the Middle/Late Eocene, the southern parts of the NCA were subaerially exposed and marine sedimentation ended in most of the Gosau basins. At only the tip of the NCA wedge, marine sedimentation continued within piggyback basins, which subsided during ongoing thrusting of the NCA onto the Rhenodanubian Flysch Zone and Helvetic Units. The position of the lower Inn valley basin was controlled by sinistral strike-slip faulting along the Inntal fault (ORTNER & SACHSENHOFER, 1996), which forms a segment of the Innsbruck–Salzburg–Amstetten fault system (EGGER & PERESSON, 1998). Early movements along this fault system during the Middle(?) to Late Eocene may have controlled both the sedimentation of the Oberaudorf Formation of the lower Inn valley basin and the basin subsidence and renewed marine transgression in the Salzburg area. Based on pebbles from Molasse deposits, sedimentation in the Salzburg area continued into the Early Oligocene (HAGN, 1983), similar to the situation in the lower Inn valley.

7. DISCUSSION AND CONCLUSIONS

Paleogene deposits of the Gosau Group of the NCA record deep-water sedimentation on top of the early orogenic wedge of the Eastern Alps, which evolved during Early to early Late Cretaceous, eo-Alpine deformation (FAUPL & WAGREICH, 2000). Paleogeographic reconstructions indicate a generally northward deepening slope, dissected by depocenters and structural highs forming slope basins along an active continental margin. Deposition of turbidites and hemipelagites below the CCD in the Weyer Arc area and the Gießhübl syncline indicate the deepest depocenter in the north of the NCA. In the southeasternmost parts, shallow-water carbonates of the Kambühel Formation give evidence for a narrow carbonate shelf with bypass of silicilcastics, which were shed into the deep-water basins from rising low- to medium grade metamorphic Austroalpine basement complexes to the south. Garnet-dominated heavy mineral assemblages characterize Paleogene turbidites filling the slope basins. Mica schist clasts and detrital mica Ar/Ar ages of Permian metamorphic age give evidence for erosion of higher structural units of the southern Austroalpine basement, such as equivalents of the Innsbruck quartzphyllites, which were not affected by eo-Alpine metamorphism (FRANK et al., 1998). Northward of the orogenic wedge, within the Penninic domain, the depositional area of the Rhenodanubian Flysch was situated. According to HESSE & BUTT (1976) and WAGREICH & FAUPL (1994), the slope deposits of the Gosau Group formed the southern margin of the closing oceanic basin of the Rhenodanubian Flysch. Flysch troughs and slope basins of the Gosau formed a trench-slope basin complex (UNDERWOOD & BACH-

MANN, 1982) during the Paleocene. The occurrence of bentonites, both in the Gosau Group and the Rhenodanubian Flysch (EGGER et al., 1996), gives further evidence for a close connection of these deep-water depositional areas.

Basin subsidence and northward tilting of the NCA during the latest Cretaceous to Paleocene was interpreted as a result of tectonic erosion of parts of an accretionary wedge to the north of the NCA (WAGREICH, 1993; 1995). Tectonic subsidence curves show decreased subsidence rates during the Paleocene to Early Eocene, although no indications for an infilling of the basins have yet been found. The complex arrangement of basins and highs may have been a result of an active continental margin setting with oblique subduction and strike-slip faulting, similar to the Californian continental borderland (cf. TENG & GORSLINE, 1989). Deep-water sedimentation, for example the interplay of turbiditic versus hemipelagic sedimentation, seemed to have been largely controlled by local subsidence and sediment supply and not by eustatic sea-level changes.

The sedimentary evolution during the Paleogene and the timing of the end of sedimentation seem to indicate a northward propagating deformation and thrusting front during Paleocene to Eocene times. Frequent resedimentation of shallow-water carbonates from the southeastern parts of the NCA began during the Middle Paleocene (e.g., WESSELY, 1974; MOUSSAVIAN et al., 1990), indicating the onset of deformation in the hinterland and tectonic instability of the narrow carbonate shelf at the southern margin of the NCA. Sedimentation of the carbonates of the Kambühel Formation had already ended during the Early Thanetian (TRAGELEHN, 1996), followed by resedimentation of large blocks by olistostromes into deeper water areas to the north, e.g., in Gams (Late Thanetian) and Wörschach (Ypresian). Sedimentation in most outcrop areas of the Gosau Group ended during the Early to Middle Eocene. Only in the area around Salzburg did sedimentation probably continue in a piggyback basin above the moving thrust stack of the NCA, which overthrust the Rhenodanubian Flysch during the Middle/Late Eocene (FAUPL & WAGREICH, 2000). This indicates a transition from the Gosau basins to the strike-slip/piggyback basin formation in the lower Inn Valley area.

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