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Lithostratigraphic definition and depositional model of the Hütteldorf Formation (Upper Albian - Turonian, Rhenodanubian Flysch Zone, Austria)

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KEYWORDS

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Abstract

The type area of the Hütteldorf Formation (Rhenodanubian Flysch Zone), in the western part of Vienna, comprises deep-water claystones and sandstones of a loosely constrained Late Albian-Turonian age. Tectonostratigraphically, the formation lies near the base of the Kahlenberg Nappe, below the Campanian Kahlenberg Formation.

The composite type section of the Hütteldorf Formation consists of two abandoned quarries in the Hütteldorf area in the Rosental valley. Both quarries have been measured and the facies documented. Quarry outcrops mainly display sandstone-rich sections of the Hütteldorf Formation; red claystone intervals between sandstone packages are poorly exposed, although they are conspicuous elsewhere. Three different facies have been recognized: a thick-bedded sandstone facies with massive beds and frequent amalgamation, a thin-bedded sandstone facies with laminations, and a pelitic facies dominated by red claystones.

The Hütteldorf Formation is interpreted as the result of a deep-water turbidite to mass-flow system deposition below the calcite compensation depth. Instead of a classical deep-water fan system, a large-scale basin-axial depositional channel system, developed within red claystones of the basin plain, is proposed as a new sedimentological model for the Hütteldorf Formation.

Das Typusgebiet der Hütteldorf-Formation (Rhenodanubische Flysch Zone) wurde im Westen Wiens, untersucht. Die Hütteldorf-Formation setzt sich aus Tiefwassersedimenten, v.a. Tonsteinen und Sandsteinen zusammen mit einem schlecht definierten Alter von späten Albium bis Turonium. Die tektonostratigraphische Position ist an der Basis der Kahlenberger Decke, unterhalb der Kahlenberg-Formation (Campanium).

Das zusammengesetzte Typusprofil der Hütteldorf-Formation umfasst Profile aus zwei stillgelegten Steinbrüchen im Rosental in Hütteldorf. Beide Profile wurden vermessen und die Fazies der Hütteldorf-Formation dokumentiert. Diese Aufschlüsse zeigen hauptsächlich die sandsteinreiche Fazies der Hütteldorf-Formation; die für die Hütteldorf-Formation charakteristischen roten Tonsteinfolgen sind hier nur untergeordnet vertreten. 3 Faziestypen wurden festgestellt: dickbankige massige Sandsteine mit häufiger Amalgamation, dünnbankige Sandsteine mit Laminationen und eine pelitische Fazies mit vorwiegend roten Tonsteinen.

Die Fazies der Hütteldorf-Formation wird als turbiditisches Tiefwassersystem unterhalb der Calcitkompensationstiefe interpretiert. Als neues Sedimentationsmodell für die Hütteldorf-Formation wird ein großräumiges axiales Rinnensystem innerhalb einer Beckenebenenfazies diskutiert, im Gegensatz zur klassischen Interpretation als klastischer Tiefseefächer.

1. Introduction

West of Vienna, in the Wienerwald, the Rhenodanubian Flysch Zone of the Eastern Alps consists of several thrust slices (nappes). Some of the lithostratigraphic units within these nappes are still loosely defined, although they have been mapped in detail and are shown on recent maps of the Geological Survey of Austria (e.g. Schnabel, 1997). One such formation is the Hütteldorf Formation of the Kahlenberg Nappe. Although this formation covers a relatively large area, especially in the Penzing district in western Vienna, no detailed and valid lithostratigraphic definition exists up to now.

This paper gives a first detailed lithostratigraphic definition of the Hütteldorf Formation, including logged sections of the type profile, and suggests a new sedimentological model for the deposits. Field investigations were made during 2004-2005, as a part of a project granted by the Wiener Hochschuljubiläumsfond.

2 Geological Setting

The Rhenodanubian Flysch Zone (RFZ), presently situated to the north of the Northern Calcareous Alps, comprises one of the major tectonic units of the Alpine fold-and-thrust belt in the Eastern Alps. The RFZ has been included within the Penninic Zone (including North-, Middle and South-Penninic elements; Egger, 1992; Faupl, 1996; Faupl and Wagreich, 2000; Egger and Schwerd, 2007), a part of the Alpine Tethys (Stampfli et al., 2002). This indicates a palaeogeographic position for the RFZ between the European shelf to the north (Helvetic and Ultrahelvetic units) and the Austro-Alpine microplate (Austro-Alpine units with the Northern Calcareous Alps) to the south. Various geodynamic models for the flysch basin(s) of the RFZ have been discussed; for example, Hesse (1982) proposed a dormant deep-sea trench. The onset of thick siliciclastic flysch deposition during mid- to Late Cretaceous times has been interpreted as a consequence of the onset of com-

com-pression and/or subduction in the Liguria-Piemont-Penninic ocean system to the south of the RFZ (Mattern 1999; Wagreich, 2001). Post-depositional thrusting and wrench faulting during the Alpine orogeny have largely destroyed the original basin configuration and its relation to its source areas.

Sedimentation within the RFZ began in an abyssal environment during Early Cretaceous times and continued up to the Eocene. Palaeo-water depths have been estimated at between 3000–5000 m, well below the local calcite compensation depth (Butt, 1981). The successions (Rhenodanubian Group of Egger and Schwerd, 2007) are characterized by a variety of carbonate-dominated and siliciclastic flysch deposits (Schnabel 1992; Mattern 1999; Egger et al., 2002; Wortmann et al. 2004; Egger and Schwerd, 2007). Flysch successions in the Cenomanian to Turonian were characterized by a thick siliciclastic-dominated, sandstone-rich succession of turbidites (Reiselsberg Formation, Mattern 1999; Hütteldorf Formation, Schnabel, 1992, 2002) overlain by carbonate-dominated flysch in the Coniacian to Campanian (Röthenbach Subgroup, Egger and Schwerd, 2007; Kahlenberg Formation, Prey in Plöchinger and Prey, 1993).

The RFZ to the west of Vienna comprises several thrust units, namely, the Nordrandzone (=Tulbinger Kogel Schuppe of Schnabel 1997), the Greifenstein Nappe, the Laab Nappe and the Kahlenberg Nappe (Plöchinger and Prey, 1993; Schnabel, 1997). The Kahlenberg Nappe, including the Hütteldorf Formation, is regarded as the southernmost and structurally highest tectonic unit in this thrust stack (Faupl and Wagreich, 2000; but for a different view see Trautwein et al., 2001a, b, Mattern, 2008), including Mesozoic strata of the St. Veit Klippenzone at the base (Prey, 1973, 1975). The possibility of attributing the Kahlenberg Nappe to the South-Penninic unit, similar to the Ybbsitz Klippenzone (Decker, 1990), is still open (e.g. Faupl and Wagreich 1992, 2000).

Above the contact to the underlying St. Veit Klippenzone, the nature of which (sedimentary or tectonic) is still unclear, the Kahlenberg Nappe consists of a succession of turbiditic units, starting in the Mid-Cretaceous (Aptian/Albian?, Prey, 1973, 1985) with poorly exposed so-called Gault-Flysch (Prey in Plöchinger and Prey, 1993) overlain by the Hütteldorf Formation (Upper Albian-Turonian, Prey, 1973; maybe also ranging up to the Santonian according to Schnabel, 1997, 2002), the Kahlenberg Formation (mainly Campanian, Müller, 1987) and the Sievering Formation (Maastrichtian, Faupl et al., 1970).

3. Lithostratigraphic Definition of the Hütteldorf Formation

3.1 Derivatio nominis and synonyms

The lithostratigraphic term “Hütteldorf Formation” („Hütteldorfer Sandstein“) dates back to Götzinger (1951:230): „*...Der Oberkreidesandstein der Klippenhülle des Tiergartenklippengebietes („Hütteldorfer Sandstein“) welcher durch Führung von bunten Schiefern charakterisiert ist*“. The name itself is derived from the former village of Hütteldorf, now part of the Viennese urbanised district of Penzing, where most of the outcrops of the formation occur. Brix (1972) and Schnabel (1997, 2002) used the term for the lower part of the Upper Cretaceous succession of the Kahlenberg Nappe and the Satzbergzug, a tectonic klippe of this nappe (Prey, 1973, 1979).

In the 19th century, the Hütteldorf Formation was included within the Wiener Sandstein (Viennese Sandstone), which incorporated most of the sandstone-rich units of the RFZ into one term (e.g. Keferstein, 1828, Paul, 1898).

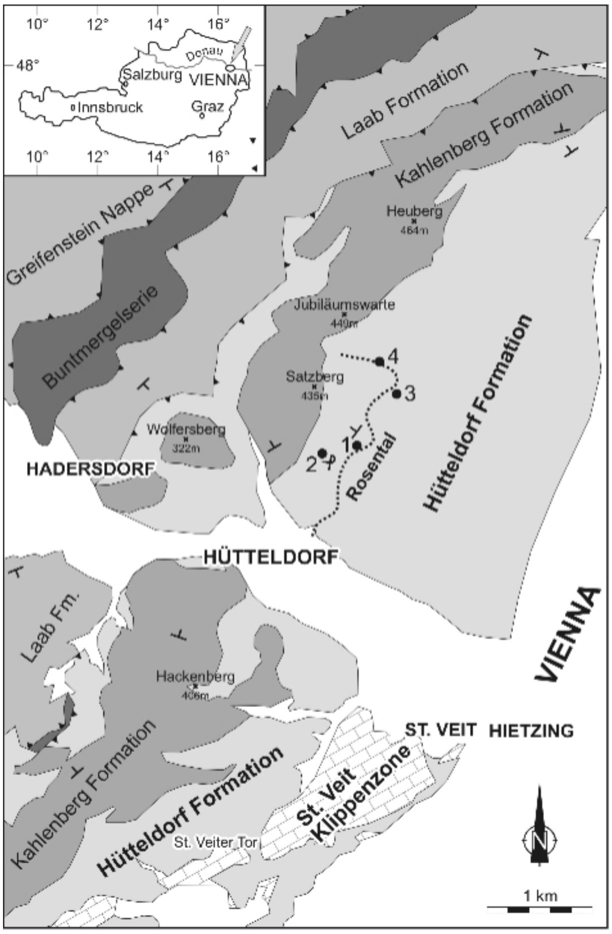

Figure 1: Schematic geological map of the Hütteldorf area (modified from Schnabel, 1997). Outcrops of Hütteldorf Formation mentioned in the text: 1. Rosentalgasse quarry; 2. Silbersee quarry; 3. Kleingartenverein quarry, Rosental; 4. outcrop in Rosental creek. Inset map shows the location of investigated area in Austria.

Janoschek et al. (1956) included the Hütteldorf Formation in their *Klippenhüllflysch der St. Veiter Klippenzone*, indicating the close relationship of the St. Veit Klippenzone to the overlying flysch unit. Later, these turbidite successions were included in the Reiselsberger Sandstein (or Reiselsberg Formation; Prey, 1973; Tollmann, 1985) because of their similar ages and sandstone facies. Grün et al. (1972) termed Albian sandy turbidites in the Halterbachtal, south of Rieglerhütte, as Bartbergschichten (see also Prey in Plöchinger and Prey, 1993:66) that, according to Schnabel (1997), can be regarded as partly synonymous to the Hütteldorf Formation.

3.2 Type area

The type area of the Hütteldorf Formation lies in Hütteldorf, within the urban area of Penzing, in the 14th district of Vienna, with a composite type section in abandoned quarries in the Rosental valley (Prey in Plöchinger and Prey, 1993:63ff). Currently, these outcrops are becoming more overgrown and recultivated, and less and less rock is exposed.

Two quarries and some minor outcrops within the Rosental creek were selected for the composite type section of the formation. The old quarry in Rosentalgasse (WGS84 coord. E 016° 16' 04"; N 48° 12' 35") is regarded as the original type section (Prey in Plöchinger and Prey, 1993), originally exposing a more than 20 m thick section, although the upper part is now almost fully covered by soil and vegetation, and only the lower part could be measured during this study. A longer section has been measured nearby (250 m WSW), in old quarries in the Silbersee recreation area (WGS84 coord. E 016° 15' 51", N 48° 12' 37"). Further small outcrops occur within a small abandoned quarry in the Kleingartenverein Rosental (WGS84 coord. E 016° 16' 21", N 48° 12' 51") and along the banks of the Rosental creek. Note that since only thick sandstone intervals were quarried, the quarry outcrops forming the type section represent a biased selection in which intervening finegrained sediments are poorly exposed or not exposed at all, being covered either by soil and vegetation or by buildings and gardens. Therefore, the quarries may not show the true character of the formation in its most typical development, where variegated thin bedded turbidites prevail (Schnabel, 2002). During this study, the only exposures of red claystones found lay in the Rosental creek, west of the Loiblbrunnen (WGS84 coord. E 84 016° 16' 21", N 48° 13' 00"). Similar red claystones have been described from Hochrotherd (Prey, 1983) and Wolfsgraben, about 14 km to the southwest of Rosental, where slices of the Kahlenberg Nappe are preserved above the Laab Nappe (Schnabel, 1997). Temporary outcrops of the fine-grained strata have been exposed during excavations such as the recent and ongoing railway tunnelling works in western Vienna (Wienerwald tunnel, Lainzer tunnel).

3.3 Lithostratigraphic subdivision, lower and upper boundaries

The Hütteldorf Formation is underlain by dark, quartz-rich sandstones and dark grey claystones of the Rehbreingraben Formation (Albian; Gault-Flysch according to Prey in Plöchinger and Prey, 1993). The boundary between these two formations is currently not exposed, but both the conspicuous red colour of the claystones and the lighter grey colour and brownish weathering of the Hütteldorf Formation is a useful criterion for differentiation.

The Hütteldorf Formation is overlain by the Kahlenberg Formation of Santonian?-Campanian-Early Maastrichtian age (Müller, 1987; Schnabel, 2002). In contrast to the Hütteldorf Formation, this is characterized by high carbonate contents in both pelites (marlstones and limestones) and turbiditic sand-stones. Red claystones are extremely rare in the Kahlenberg Formation.

On the Baden geological map sheet (ÖK 58/Baden), Schnabel (1997) introduced the term Rosental Member, characterized by sandstone-rich turbidite successions, as a lithostratigraphic sub-unit of the Hütteldorf Formation. The here described type section of the Hütteldorf Formation from Rosental might belong to this member, although sandstone-rich intervals could occur several times within the succession. The red claystones of the Hütteldorf Formation were also termed the (Obere) Bunte Schiefer, a subunit known from the RFZ fur-ther to the west (e.g. Egger and Schwerd, 2007) and also as Flysch-Mittelkreide or Mittelkreideflysch (Mid-Cretaceous Flysch; Prey, 1973 1979). However, no further lithostratigraphic definition has been given for the Vienna area.

3.4 Chronostratigraphic age, biostratigraphy and fossils

The biostratigraphy of the Hütteldorf Formation and its chronostratigraphic age is only loosely defined because of the poor microfossil content. Several samples taken for foraminifera analysis yielded no or only a very poor agglutinated fauna. Furthemore, no calcareous nannofossils were found during the present study because of the presence of only carbonate-free claystones and siltstones.

Published data indicate a Late Albian-Cenomanian-Turonian age (e.g. Prey, 1973, 1979, 1985). *Plectorecurvoides alternans*, *Trochammina* (cf.) *globorotaliformis* sensu Prey (1973), *Dorothia filiformis* and more rarely *Uvigerinammina jankoi* are typical elements of foraminiferal assemblages. Prey (1973) found very rare *Rotalipora ticinensis*, indicating a Late Albian age for some parts of the formation, and *Rotalipora* cf. *appenninica* in the Silbersee area, indicating a Cenomanian age (Prey in Plöchinger and Prey, 1993:65). The nannofossils *Eprolithus floralis*, *Eiffellithus turriseiffeli* and *Braarudosphaera africana* are also rarely present in marlstones (Prey, 1973:77) and support this age assignment. Janoschek et al. (1956) reported *Rotalipora appenninica, R.* aff. *reicheli* und *R. globotruncanoides* in the surroundings of the St. Veit Klippenzone (Löfflergasse) that also indicate a Cenomanian age. Double-keeled globotruncanids are rarely present, which point to a Turonian or younger age for parts of the red claystones of the Hütteldorf Formation (Prey, 1979).

The upper age limit of the Hütteldorf Formation is constrained by the age of the overlying Kahlenberg Formation, in which the presence of marlstones and marly limestones allows a more precise age assignment, using calcareous nannofossils. *Arkhangelskiella cymbiformis* and *Broinsonia parca parca* are present in most nannofossil samples from the Kahlenberg Formation (Prey, 1973; Müller, 1987; Wagreich, unpublished), indicating a Campanian age, although parts may reach down into the Santonian. However, as no unequivocal Coniacian-Santonian age indication has been reported for the Kahlenberg Formation, parts of the Hütteldorf Formation may reach up well into the Santonian.

Macrofossils are absent in the Hütteldorf Formation, apart from the discovery of a shark tooth *(Ptychodus*; Götzinger, 1951:245) and the ichnofossil *Chondrites*.

3.5 Lithology

The Hütteldorf Formation comprises a succession of mainly thick-bedded grey, partly coarse-grained sandstones and red, greenish grey and grey claystones and mudstones (Prey, 1973; Schnabel, 2002). The facies of the sandstones is regarded predominantly as a thick-bedded sandstone-turbidite facies (Prey in Plöchinger and Prey, 1993). Detailed facies descriptions are given with the type section.

Several occurrences of volcanic rocks, such as picrites, have been recorded in the Hütteldorf-Formation; for example, in Spiegelgrundgasse in Vienna (Grengg, 1914; Prey in Plöchinger and Prey, 1993: 63f). Similar picrites were cored during the planning phase of construction of the Lainzer Tunnel. These have a chloritic-hematitic groundmass with pseudomorphs after pyroxene, plagioclase and olivine, and carbonate-filled vesicles (Zirkl, in Janoschek et al., 1956; Slapansky, in Hofmann, 1997).

3.6 Description of the type section

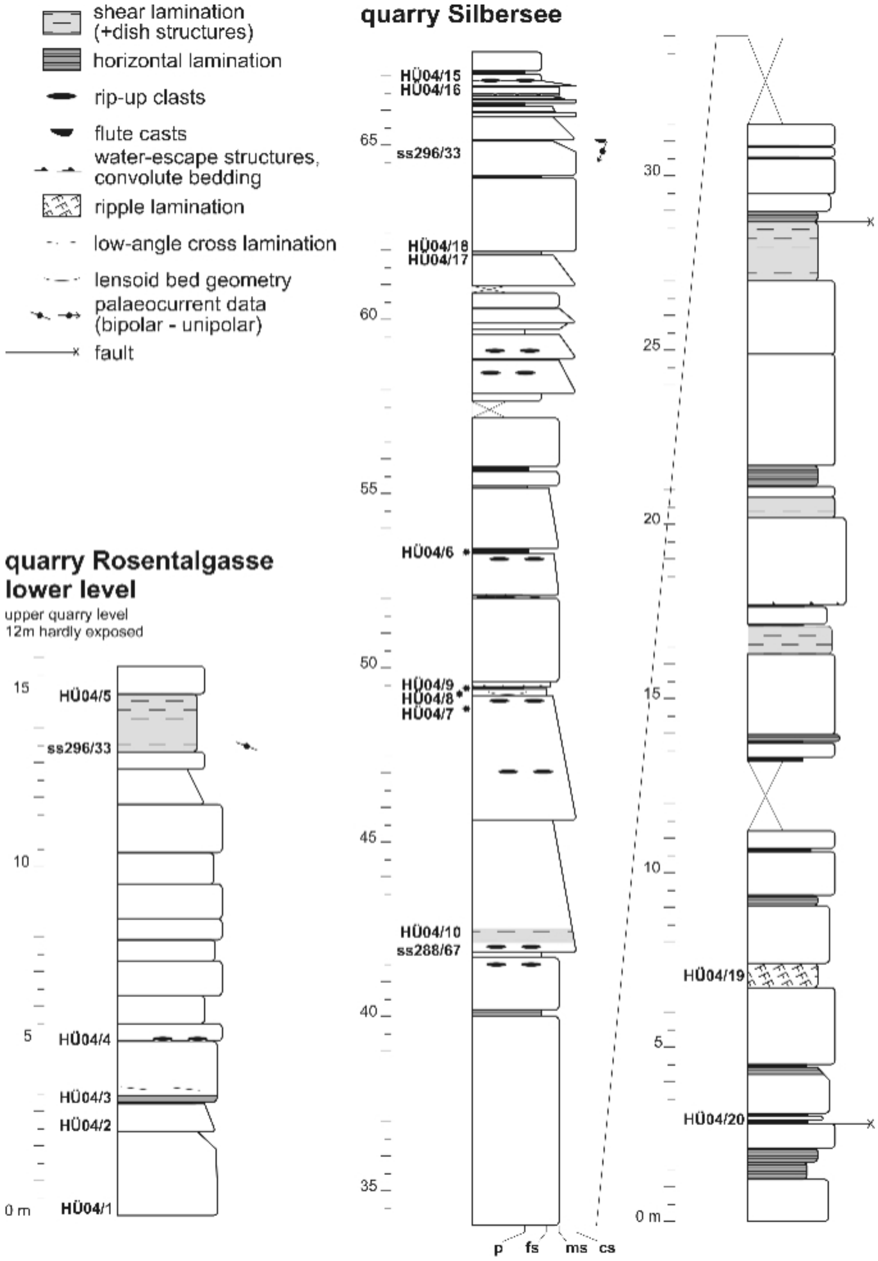

Figure 2: Composite type section of the Hütteldorf Formation from the abandoned Rosentalgasse and Silbersee quarries, Hütteldorf in the 14th district of Vienna.

The type-section (Fig. 2) of the Hütteldorf Formation consists of the sections in the Rosentalgasse and Silbersee quarries. The lower 15 m of the Rosentalgasse quarry is well-exposed whilst the upper part is largely covered by vegetation and is no longer accessible for sedimentological logging. The Silbersee area includes a continuous, 65 m thick section northeast of the Silbersee pond. To the south, the former quarry section is covered by soil and vegetation and only a few sandstone beds are occasionally exposed. Due to the slope-parallel dip of the beds, a single bedding plane is exposed at the eastern bank of the Silbersee pond; this contains spheroidal sandstone concretions up to 50 cm in diameter.

In the Rosentalgasse quarry, normal grading of sandstones indicates a right-way-up bedding orientation (ss 278/32° to 296/33°; all orientations given as dip azimuth and dip angle), whereas in the Silbersee section, rare sole marks and grading indicate an inverted, overturned position (ss 288/67° to 270/56°). This reflects a tight fold in the type area of the Hütteldorf Formation, previously unrecognised due to the poor outcrop. This, in turn, indicates that previous thickness estimates of several 100s of metres are exaggerated. The minimum thickness, here estimated from the Silbersee area, is ca. 150 m.

3.6.1 Thick-bedded turbidite sandstone facies

The sandstone facies of the Hütteldorf Formation is characterised by thick and amalgamated beds, up to a composite thickness of more than 6 m (Fig. 3a). Single graded beds, which probably represent one depositional event, display thicknesses up to 4.80 m. The separation of this facies from the thin-bedded turbidite sandstone facies has been set at ca. 40 cm. Intervening grey silt- and mudstones are up to 10 cm thick. The median thickness of single beds is 144 cm in the Silbersee section (37 beds) and 106 cm in the Rosentalgasse section (15 beds).

Sharp, erosive bases and normal grading of the beds from coarse sandstone, rarely also fine conglomerate with clasts up to 1 cm, to fine-grained sandstone is a common feature. Marked grading is normally restricted to the lower quarter of the beds (Fig. 3g), whereas the rest of the beds show a massive appearance without visible grain-size contrasts. Platy, grey, intraformational mud clasts up to 20 cm in diameter are common in the lower portions of thick beds. Inversely graded bed intervals have very rarely been observed in some basal parts of thick sandstone beds.

Within the thick-bedded turbidite sandstone facies, two bedding types have been distinguished: (i) the dominant type has graded bases without any lamination or with laminations only in the uppermost part of the beds (Fig. 3a); (ii) up to 15% of the beds are medium- to fine-grained bedded to laminated sandstones with a maximum thickness of 2 m. The latter facies type displays horizontal lamination, shear lamination, ripple lamination (Fig. 3c) and dewatering/water escape structures such as dish and flame structures (Fig. 3e).

Interpretation. The thick-bedded sandstone facies shows characteristics of deposits of highly concentrated high-density turbidity currents to sandy debris flows. Both transport types and transitional types may be responsible for the thick massive sandstone beds (see discussions in Shanmugam, 1996; Stow and Johansson 2000; Amy et al., 2005). On the classification of Lowe (1982), these beds are mostly classed as S2/S3-turbidites of highly-concentrated flows. In the classification scheme of Pickering et al. (1989) this facies can be classified into fa-cies B 1.1 (thick-medium bedded, disorganized sands) and B2.1 (parallel-stratified sands) with transitions into A1.4 (disorganized pebbly sands). Stow and Johansson (2000) included such sandstones in their DWMS-facies (deep-water massive sands). Based on the common occurrence of grading at the base of thick beds, the relatively good sorting of the sandstones without conglomerate portions and frequent laminated tops, most of the beds comprise high-concentrated turbidity current deposits rather than sandy debris flows (comp. Lowe, 1982; Amy et al., 2005).

3.6.2 Thin-bedded turbidite sandstone facies

Intercalated within the thick-bedded sandstones, are thin-bedded, 2 to 40 cm thick medium to fine-grained sandstone beds. These beds have sharp bases and show faint normal grading. Incomplete Bouma sequences, with grading and horizontal and ripple lamination, were observed. Beds often display a lensoid geometry (Fig. 3b) and disappear laterally within a few metres. Whereas only one 2 cm bed of this facies type was recognized in the Rostentalgasse quarry, it comprises about 9% of the total measured section in the Silbersee outcrop. Laminations, dewatering structures and convolute bedding (Fig. 3d) are present, as well as transitions to the medium- to fine-grained bedded to laminated sandstones of the thick-bedded facies.

Interpretation. According to the classification of Pickering et al. (1989), these sandstones fall into either the classical turbidite facies C2 (organized sand-mud couplets) or B2.1 (parallelstratified sands). The thin-bedded sandstone facies shows characteristics of transitional deposition from relatively low- to high-concentrated and high-density turbidity currents. Incomplete Bouma sequences argue against sandy debris-flow deposition for most of the beds.

3.6.3 Pelitic facies

Silt- to mudstones within the sandstone intervals make up less than 3% of the measured type section. They display a dark-grey to greenish-grey colour and a maximum thickness of 20 cm. Most of these mudstones are free of carbonate. These beds are interpreted as pelitic portions of highly concentrated turbidites.

Massive, several metres thick red claystones are an important feature of the Hütteldorf Formation (Prey, 1973, 1983), although outcrops are extremely rare. An at least 1.5 m thick carbonate-free red claystone with a few grey laminae is exposed in the Rosental creek west of Loiblbrunnen (Fig. 3h). Temporary outcrops in building pits and trenches (Prey, 1973) and during construction works indicate the presence of rare thin turbidite beds within the red intervals. Homayoun (1995) reported illite as the main clay mineral of the claystones, with mixed layers and minor amounts of kaolinite, chlorite and smectite.

This facies is interpreted as a product of pelagic clay deposition in a deep-water environment below the calcite compensation depth. Thin grey silty layers and thin distal turbidites indicate the distal influence of low density turbidity currents. The red claystones can be classified into facies E1 (disorganized muds and clays) with transitions to G1 (biogenic oozes and muddy oozes) of Pickering et al. (1989).

3.6.4 Sandstone petrography and heavy minerals

Thin-sections of sandstones from the type area indicate a predominance of siliciclastic detritus. Coarse-grained sandstones are dominated by rock fragments of quartzites, chlorite-quartzites, muscovite-chlorite-quartzites and mica schists, sometimes with garnet. Significant amounts of dolostone and limestone fragments are present, as well as feldspar (both plagioclase and alkali feldspars) and basic magmatites, volcanites and polyquartz. Up to 5% clayey matrix is present. The sandstones are classified as lithic arenites.

Heavy mineral assemblages (Prey, 1973; Faupl, 1996) show the dominance of garnet and varying amounts of zircon, tourmaline, rutile and apatite. A low percentage of chrome spinel is present in most of the samples from thick-bedded sandstones.

4. Discussion

The Hütteldorf Formation comprises a deep-water flysch unit

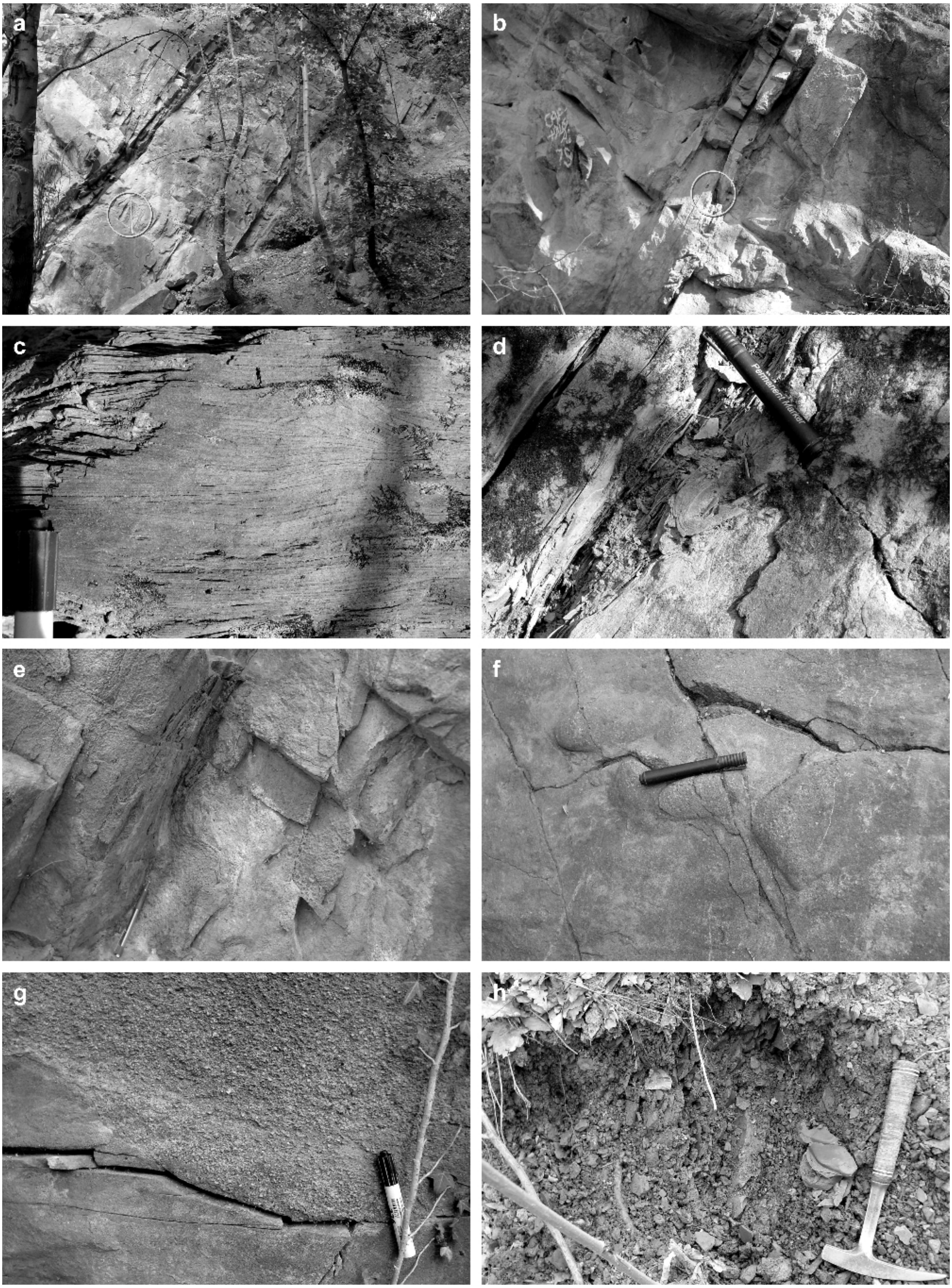

Figure 3: Photographs of sediments of the Hütteldorf Formation. a) thick-bedded sandstone facies (scale = 1 m), Silbersee section (overturned); b) intercalation of thin-bedded sandstone facies with lensoid geometry, Silbersee section (overturned); c) ripple lamination in thin-bedded sandstone facies, Silbersee section (overturned); d) convolute bedding in thin-bedded sandstone facies, Silbersee section (overturned); e) water escape structure (above pencil) in thin-bedded sandstone facies, Silbersee section (overturned); f) flute casts in thin-bedded sandstone facies, Silbersee section (overturned); g) amalgamated beds in thick-bedded sandstone facies, Kleingartenverein quarry, Rosental; h) red claystones exposed along the banks of the Rosental creek.

within the Kahlenberg Nappe. Due to the limited available outcrop and post-depositional deformation, the palaeogeographic significance and the relationship to other coeval deep-water units remain problematic. Although there are strong similarities with the Reiselsberg Formation (Cenomanian-Turonian) of the RFZ further to the west (Mattern, 1999; Egger and Schwerd, 2007), the tectonic position of the Hütteldorf Formation within the Kahlenberg Nappe is different and there is less detrital muscovite in the sandstones and significant amounts of chrome spinel in heavy mineral assemblages of the Hütteldorf Formation (Prey, 1973, Faupl, 1996).

The Ybbsitz Formation (Cenomanian-Turonian) of the Ybbsitz Klippenzone (Homayoun and Faupl, 1992) in western Lower Austria, has significant similarities to the Hütteldorf Formation, although sandstone intervals in the former are thinner, red claystones are only rarely found and the carbonate content of the Ybbsitz Formation sandstones is considerably higher (Homayoun and Faupl, 1992). However, the tectonic position of the Kahlenberg Nappe and Ybbsitz Klippenzone are essentially equivalent (Schnabel, 1992, Faupl and Wagreich, 1992; Faupl, 1996) which, consequently, puts the depositional areas of the Ybbsitz and Hütteldorf formations at a close distance within the same (South-Penninic) oceanic basin, accounting for the similarities between the two formations.

The Upper Cretaceous Kaumberg Formation of the Laab Nappe (Faupl, 1976, 1996) is characterized by similar red claystones and thin distal turbidites as the fine-grained facies of the Hütteldorf Formation, although sandstones in the Kaumberg Formation are generally richer in carbonate, especially calcite. Prey (1973) noted the similarities of the Upper Cretaceous red claystones of both nappes. Using the palaeogeographic framework of Faupl and Wagreich (1992), the Kaumberg Formation may be taken as the distal part of the same basin plain on which the coarser-grained Hütteldorf Formation formed the proximal part.

The relationship of the Hütteldorf Formation and the Kahlenberg Nappe as a whole to the St. Veit Klippenzone still remains unclear, due to the strong deformation of the Klippenzone and uncertainty about its contact with the adjacent flysch. Several authors proposed a continuous sedimentary succession from the St. Veit Klippenzone into the Kahlenberg Nappe and, consequently, attributed the Hütteldorf Formation to the flysch-like cover ("Klippenhüllflysch") of the Mesozoic klippen rocks (e.g. Janoschek et al., 1956; Prey, 1973, 1975; Schnabel, 1992). However, this view is not unanimous and contradicting observations have been reported (e.g. Prey, 1985).

4.1. Turbidite facies associations, cycles and palaeocurrents

Due to the limited outcrop, facies associations and cycles can be only evaluated to a very limited extend. However, two facies associations, probably representing two different architectural elements, have been recognized. The first comprises thick- and thin-bedded sandstone packages with amalgamation and dewatering structures and sometimes conspicuous lensoid geometries. Within the sandstone packages, the Silbersee section displays a crudely developed lower thickening-upward cycle and an upper thinning-upward cycle, especially if maximum bed thicknesses are compared (Fig. 4). Smaller-scale thinning-upward cycles may be present. The second facies association comprises the pelitic packages of red mudstones with minor and thin turbidite sandstone beds, sometimes displaying complete or incomplete Bouma sequences.

Palaeocurrent indicators have only very rarely been observed in the investigated outcrops and do not show a simple distribution. Flute casts (Fig. 3f) have been measured at the base of one bed in the Silbersee section (original palaeocurrent direction NNE-SSW, 020-200°). Another single 10 cm chute (Kleingartenverein quarry) indicates transport from west to east as well as a single ripple lamination (si 095/28°; Rosentalgasse quarry). One parting lineation indicates a bipolar palaeocurrent value of 120-300°.

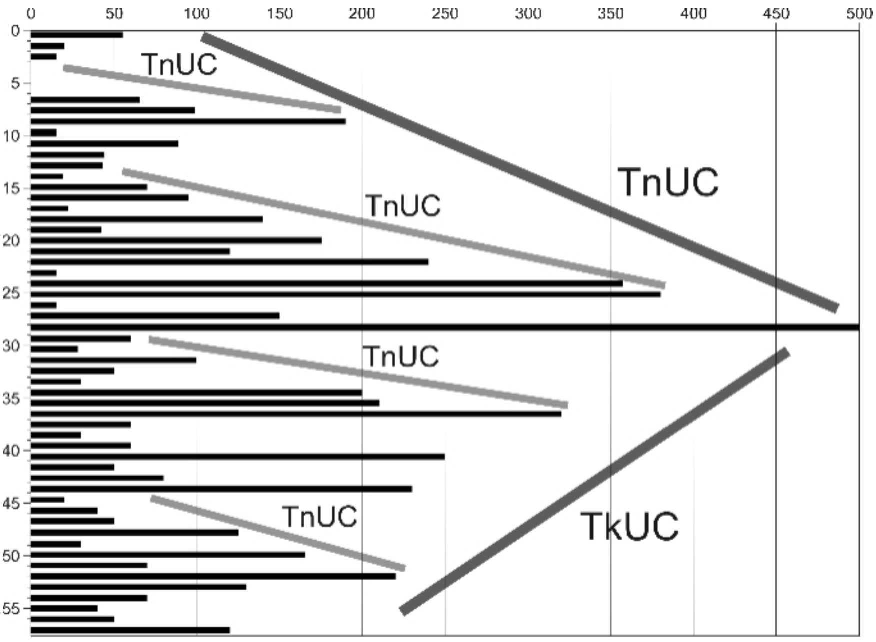

Figure 4: Diagram of sandstone bed thickness versus bed number (1-56). Note lower thickening-upward cycle (TkUC) and upper thinning-upward cycle (TnUC) and presence of smaller scale thinning-upward cycles.

4.2 Interpretation of Facies and Depositional System

In general, the sandstones of the Hütteldorf Formation display clear-cut features of turbidites or sandy debris flows, such as grading, mostly normal but also inverse, amalgamation, sole marks, such as flute casts, horizontal and current ripple lamination, and dewatering/water escape structures. The sandstone facies includes both thick-bedded and thin-bedded high- to low-density turbidite sandstone packages. This facies association, especially features like common amalgamation and lenticular geometries, point to the presence of channels in a deep-water depositional system (Mattern, 2002). The thinning-upward cycles in the Silbersee section support the interpretation of the thick sandstones of the Hütteldorf Formation as a deep-water channel facies (Walker, 1978), although the typical conglomeratic channel facies is missing.

In such a context, the intercalated finer sandstone intervals, with Bouma sequences, climbing ripple laminations and dewatering structures may be interpreted as channel margin or levee facies (Walker, 1978; Beaubouef, 2004; Hubbard et al., 2005). Such an interpretation is also supported by the lack of significant thicker pelitic intervals, which may have been frequently eroded due to coarse sand-rich turbidity currents flowing along the channel axis.

The pelitic facies of the red claystone intervals, with their impoverished deep-water agglutinated foraminifera assemblages and their lack of carbonate, clearly indicate deposition at abyssal depths, below the calcite compensation depth. This facies can be compared to modern deep-sea pelagic red clays. Although outcrops are very poor, literature data (e.g. Prey, 1973) indicate the presence of thin, fine-grained turbidite sandstone beds within this facies that sometimes display typical distal turbidite Bouma sequences. This facies association represents a typical deep-sea basin plain facies, deposited far away from coarse clastic input.

A traditional interpretation of the deep-water depositional system would classify the Hütteldorf Formation as representing parts of a large turbiditic deep-water fan, with channelized areas characterized by sedimentation of thick, amalgamated sandstone packages (e.g. Walker, 1978). In models for ancient fans, such as those of Walker (1978) and Reading and Richards (1994), the sandstone packages would correspond to the channelized mid-fan portion of a low-efficient sand-rich fan (see also Mattern, 2005). Channel dimensions are clearly larger than outcrop sizes; that is, larger than 50 – 100 m. A similar interpretation has been given by Mattern (1999, 2002) for the thick-bedded Reiselsberg (Sandstone) Formation in the Allgäu area of Germany. Following that interpretation, the red claystone intervals in the Hütteldorf Formation would inevitably correspond to an interchannel facies, although the claystones display more similarities to a distal basin plain facies, as noted above. However, no intervening outer fan lobe facies is known from the Hütteldorf Formation; channel and channel margin/levee facies of the mid-fan and the basin plain facies are directly intercalated, without any transitional sand-rich typical turbidite intervals of the outer fan, as expected from the traditional deep-sea fan models.

An alternative explanation, here favoured for the Hütteldorf Formation, comes from more recent models of an axial, longitudinal channelized turbidite deep-water system within a deep-sea basin plain (see also Egger, 1992). Both in recent (Posamentier, 2003; Posamentier and Kolla, 2003) as well as ancient deep-water environments, such systems have been increasingly recognized, especially in tectonically active basins such as foreland basins and trenches (Beaubouef, 2004; Hubbard et al., 2005, 2008; De Ruig and Hubbard, 2006). Such systems are characterized by a large (km to 10s km), single, often meandering, axial channel system, filled by coarse-grained material of a channel/levee facies association (Fig. 5). The channel system cuts into fine-grained facies (clayey basin plain facies) and essentially lacks transitional facies types, apart from levee and overbank complexes.

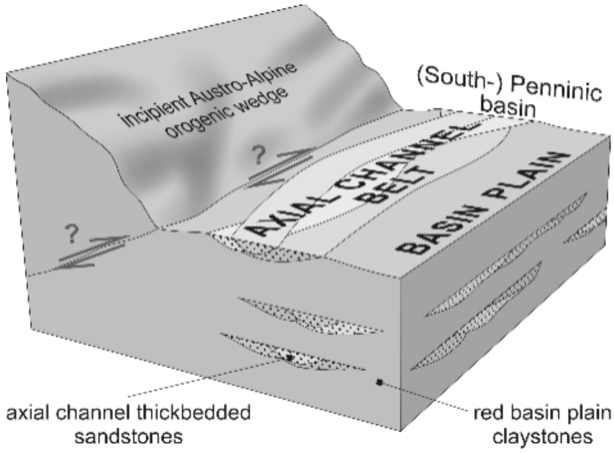

Figure 5: Axial turbidite channel belt model for the Hütteldorf Formation; modified from Beaubouef (2004), Hubbard et al. (2005, 2008) and Crane and Lowe (2007).

Although the large-scale geometry of the Hütteldorf Formation depositional system is not known and cannot be reconstructed from the meagre outcrops investigated, several features suggest such a single channel model instead of a deep-water fan model.

- palaeocurrent directions, although very rare, indicate predominantly a strike-parallel and thus basin-parallel orientation (E-W) rather than a lateral or radial (N-S) fan shape orientation;
- amalgamated, coarse-grained sandstone packages are similar to channel-in-channel successions of large channelized systems that often show vertical aggraded channel deposits (Hubbard et al., 2005, 2008);
- the thin-bedded facies is essentially similar to channel margin/levee facies, especially the lensoid geometries that are a conspicuous feature;
- transitions from channel facies to basin plain facies are sudden, due to migration of the main channel and no transitional outer fan/lobe facies has been recorded.

Such channelized deep-water systems often form in restricted basins, such as foreland basins (Hubbard et al., 2005, 2008; Crane and Lowe, 2007). Basin fills are dominated by thick successions of vertically aggraded channel deposits with channel belts that are a few kilometres wide and up to more than 100 km long. Structureless, normally-graded sandstone beds deposited from high-density turbidity currents (Lowe, 1982) and thinner-bedded turbidites characterized by partial Bouma sequences comprise the distinct channel facies association.

In a larger context, the proposed depositional model of a largescale axial, probably sinuous channel belt complex within a basin plain for the Hütteldorf Formation may also apply to several other flysch sandstone formations for which a submarine fan model is not established and longitudinal transport directions dominate over lateral sediment transport; for example, the mid-Cretaceous flysches (Hesse, 1974) or the Altlengbach Formation (Egger, 1995). Future studies of the largescale geometries of these depositional systems may give evidence for a distinction between deep-water fans and axial channel systems.

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