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An Outline of the Quaternary Stratigraphy of Austria

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Abstract: An overview of the Quaternary Stratigraphy in Austria is given. The subdivision of the mappable depositional units is based partly on criteria of lithostratigraphy (lithic properties) and allostratigraphy (e.g. unconformities). Traces of glaciations are missing for the Early Pleistocene period (2.58–0.78 Ma). The few and isolated sediment bodies are documenting fluvial accumulation and loess deposition along the rivers. Paleomagnetically correlated loess-paleosol-sequences like the profil at Stranzendorf including the Gauss/Matuyama boundary respectively Neogen/Quaternary are documenting slightly warmer condition than during during the Middle Pleistocene (0.78–0.13 Ma) which is in accordance with the global $\delta^{18}O$ record.
Four major glaciations (Günz, Mindel, Riß, Würm) are proved during Middle and Late Pleistocene. All of these are documented by proglacial sediments topped by basal till, terminal moraines linked with terrace bodies and loess accumulation as well. This allows to recognize the climatic steering of sedimentation in context with advancing glaciers and the dispersion of permafrost and congelifraction as far as into the Alpine foreland.
Both youngest major glaciations (Riß and Würm) are correlated according to geochronological data with the Marine Isotope Stages (MIS) 6 and 2. The simultaneousness of Günz and Mindel with the phases of massive global climatic deterioration during MIS 16 and 12 seems plausible. Phases of less climatic deterioration and consequently glaciations have been found only in loess profiles like Krems Schießstätte so far.

[Ein Abriss der Quartär-Stratigraphie von Österreich]

Kurzfassung: Es wird ein Überblick über die in Österreich verwendete Quartär-Stratigraphie gegeben. Die stratigraphische Gliederung der kartierbaren Sedimenteinheiten basiert teilweise auf Kriterien der Lithostratigraphie (lithologischer Eigenschaften) und jenen der Allostratigraphie (z.B. Diskonitinuitäten).
Für das Altpleistozän (2.58–0.78 Ma) fehlen bis jetzt Spuren einer Vergletscherung. Die wenigen und isolierten Sedimentvorkommen belegen fluviatile Akkumulation und Lössablagerung in der Umgebung der Flüsse. Paläomagnetisch korrelierte Löss-Paläoboden – Sequenzen wie das Profil Stranzendorf mit der Gauss/Matuyama – Grenze bzw. Neogen/Quartär – Grenze dokumentieren in Übereinstimmung mit den globalen $\delta^{18}O$ Werten etwas wärmere Bedingungen als im Mittelpleistozän (0.78–0.13 Ma).
Vier Großvergletscherungen (Günz, Mindel, Riß und Würm) sind für Mittelpleistozän und Jungpleistozän belegt. Diese sind mit Sedimenten aus der Vorstoßphase überlagert von Grundmoräne, Endmoränen im Alpenvorland und damit verknüpfte Terrassenschüttungen sowie Lössakkumulation dokumentiert. Daraus ist die klimagesteuerte Sedimentation im Zusammenhang mit dem Vorstoß der Gletscher, der Ausbreitung des Permafrostes und der Frostschuttbildung bis ins Vorland erkennbar.
Die jüngsten Großvergletscherungen Riß und Würm werden aufgrund geochronologischer Daten mit den Marinen Isotopenstufen (MIS) 6 und 2 korreliert. Für Günz und Mindel scheint eine Gleichzeitigkeit mit den Phasen massiver globaler Klimaverschlechterung während MIS 16 und MIS 12 plausibel. Dokumente für die schwächeren Glaziale wurden bisher nur in Lössprofilen (z.B. Krems Schießstätte) gefunden.

Keywords: *Alps, stratigraphy, Quaternary, Early Pleistocene, Middle Pleistocene, Late Pleistocene, glaciation, glacial deposits, landscape evolution*

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The stratigraphic subdivision of the sedimentary archive of Austria attributed to the Quaternary (the last 2.58 Ma, Gibbard et al. 2009) represents a big challenge for two reasons at least. First, very different former environments (ranging from glacial, fluvio-glacial, to lacustrine and eolian) and facies associations whose sedimentary record is fragmentary and discontinuous, are documented in the Austrian landscape for the Pleistocene (2.58 Ma–0.01 Ma BP). Such a complex setting leads to the second reason for problems in establishing a homogeneous stratigraphic approach. Only few sedimentary units in inneralpine, mostly glacially shaped basins can be classified according to the principles of lithostratigraphy (North American Commission on Stratigraphic Nomenclature [NACSN] 2005) i.e. using lithic characteristics and the Law of Superposition. However, it is evident that fluvio-glacial or fluvial deposits in the Alpine Foreland, having more or less the same lithic content during all Quaternary phases of sedimentation but occurring in different but contiguous terrace levels and documenting different phases of aggradation followed by incision, represent discontinuity-bound units in the sense of allo-stratigraphy (NACSN 2005). As these units cannot be treated according to the lithostratigraphic criteria mentioned above, any stratigraphic subdivision within this setting has to rely on a mixture of different criteria for discriminating sedimentary units mappable at least at the scale of 1:10,000.

The stratigraphy and stratigraphic terminology currently in use is the result of a scientific development beginning in the middle of the 19th century when glacial deposits in the Alps as well as intercalated sediments bearing organic material like the Hötting breccia (see Penck 1921) gained attention. The Eastern Alps and their foreland (including parts of Upper Austria) resemble the type-area for the classical Alpine stratigraphy according to Penck & Brückner

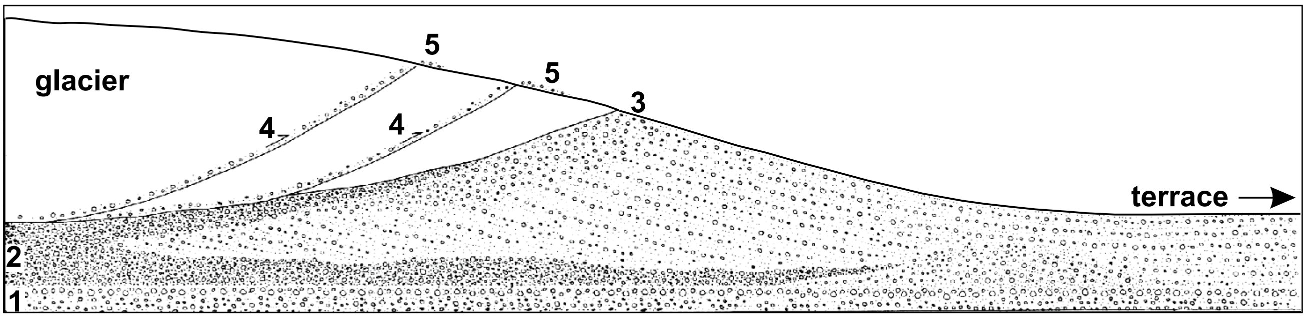

Fig. 1: Schematic sketch showing the principal sedimentary units at the glacier terminus and the transition to a proglacial terrace. 1: proglacial gravel of the glacier advance phase ("Vorstoßschotter", "Vorstoßsedimente") 2: (overconsolidated) basal till 3: terminal moraine 4: thrust with basal debris 5: supraglacial debris transported predominantly by debris flows

Abb. 1: Schematische Skizze mit der Darstellung der prinzipiellen Sedimentkörper am Gletscherende und am Übergang zur Terrasse im Gletschervorfeld. 1: „Vorstoßschotter", „Vorstoßsedimente" 2: (überkonsolidierte) Grundmoräne 3: Endmoräne 4: Scherfläche mit basalem Schutt 5: supraglazialer Schutt überwiegend in Form von Schlammströmen bis Muren transportiert.

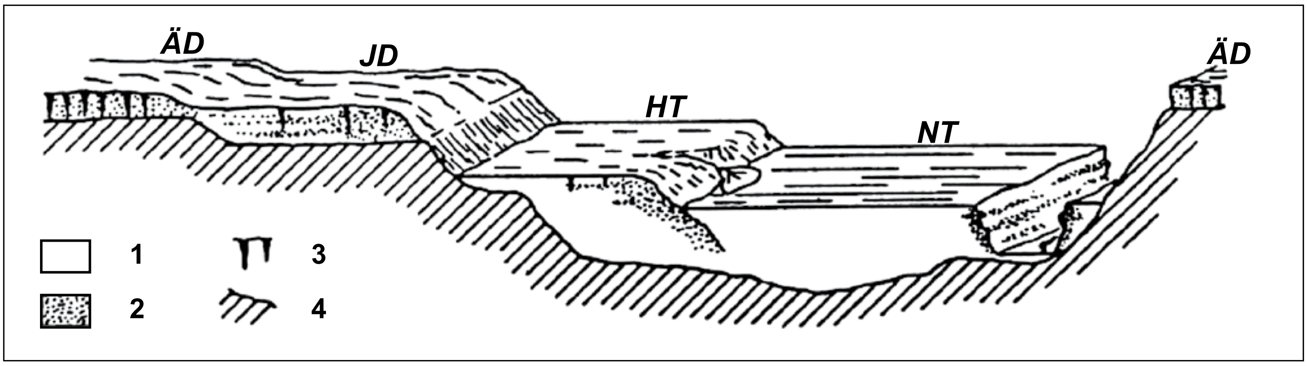

Fig. 2: Schematic sketch of the typical sequence of terraces in the foreland of the Eastern Alps (from van Husen, 1986). 1: unweathered gravel 2: conglomeratic parts 3: Geologische Orgel (pipe-like weathering structure), 4: Pre-Quaternary bedrock. NT: Niederterrasse (Würm), HT: Hochterrasse (Riß); JD Jüngere Deckenschotter (Mindel); ÄD: Ältere Deckenschotter (Günz).

Abb. 2: Schematische Skizze mit der typischen Terrassensequenz im Vorland der Ostalpen. 1: unverwitterte Kiese 2: konglomerierte Bereiche 3: geologische Orgeln 2: präquartärer Untergrund. NT: Niederterrasse (Würm) HT: Hochterrasse (Riß) JD: Jüngere Deckenschotter (Mindel) ÄD: Ältere Deckenschotter (Günz).

(1909) with the *Günz*, *Mindel*, *Riß* and *Würm* glaciations based on the concept of "Glaziale Serie" genetically linking tongue basins with basal till, terminal moraine deposits and terraces consisting of proglacial outwash (compare Fig. 1). Terrace bodies and moraines of the four glaciations differ in the degree of weathering (Fig. 2) and the characteristics of cover beds (e.g. loess/paleosol assemblages). Cases of superposition are rare (e.g. near Munich/Bavaria). In the Austrian part of the Alpine foreland which was affected by tectonic uplift, outwash terraces were correlated based on the criteria mentioned above in the context of their morphological position within the valley, with the oldest ones in the highest position.

This stratigraphic scheme which is reduced by some authors (e.g. Bowen 1978) to include solely the element of morphological correlation, classifying it as morphostratigraphy, has been extended and adapted in the sense of climate-based stratigraphy. However the deposits of most glacials and also some interglacials, stadials and interstadials do not cover geological time without gaps, which would be required for a (regional) chronostratigraphy (Gibbard & West 2000). Thus no regional chronostratigraphic subdivision sensu stricto exists for the Quaternary sediments of Austria, with the exception of the Würm glacial period which was officially classified as a stage by the Subcommission on European Stratigraphy (SEQS; Chaline & Jerz, 1984). It is subdivided into three substages: Lower (Early), Middle and Upper (Late) Würm based on palynological and lithological criteria evident in strato-types. The other glacials and at least the last interglacial (Riss/Würm-Interglacial), which represents the Alpine equivalent of the Eemian (Grüger 1979) are informally used in the sense of stages. The Marine Isotope Stages (MIS; see Gibbard & Cohen 2008, Cohen & Gibbard 2011) provide the chronostratigraphic framework (Fig. 3) within which the climate-based units (e.g. Günz glacial) are correlated (van Husen 2000a) based on the existing geochronological and biostratigraphic constraints, whose quality and precision decreases in most cases with the age of the deposit. In the case of the Middle Pleistocene glaciations Günz and Mindel which fall into the Brunhes epoch (van Husen 2000a) it is inferred that they are concurrent with phases of global excess 100-kyr ice as a result of unusually long intervals of low summer insolation, which are followed by major Terminations as evident in the $\delta^{18}O$ record (Raymo 1997). Such a situation is true based on geochronological data at least for the other major glaciations during Riss (MIS 6) and (Upper / Late) Würm (MIS 2). With the knowledge on the course of these two major climatic deteriorations and their impact on the Alpine sedimentary record, a correlation of the older glaciations with the marine $\delta^{18}O$ stratigraphy seems possible based on the relation between type and magnitude of the global climate signal and the amount of reconstructed sediment production (van Husen & Reitner 2011).

Short Outline of the Stratigraphy as Linked to Landscape Development

The description of the system of Quaternary sedimentary units of the Middle to Late Pleistocene is based on the succession of cold (glacial) and warm (interglacial) periods shown by the $\delta\ ^{18}O$ record (Raymo 1997, van Husen 2000a; see Fig. 3). All these varying global climatic conditions had an impact on processes shaping the landscape of the Alps in relation to the respective magnitude of the climate signal. Thus expansion of permafrost, strong congelifraction and the vegetation cover changed simultaneously with growing and shrinking of the valley glaciers. These changes occurred in higher or lower parts of the Alps or in the foreland depending on the degree of climatic deterioration (van Husen 2000a). Beside the great events (glaciations) resulting in glacier expansion into the foreland, climatic deteriorations are often documented in loess profiles only (e.g. Krems Schießstätte). The corresponding gravel beds, if ever formed and preserved, have not been recognized so far. Periglacial debris production and gravel accumulation prograded successively from the inneralpine areas to the foreland during climatic deterioration, finally forming extended terraces along the rivers (Danube and tributaries) probably only during the four climax periods. The parallelization of separated bodies of terminal moraines of the former network of valley glaciers and transient glaciers was done in consideration of the laws of ice dynamic. Isolated terraces have been correlated according to their surface gradient as well as to their base level in relation to the recent river (Fig. 2). In both cases this is supported by lithology, sedimentary facies, morphology, development of weathering and loess cover (Piller, van Husen & Schnabel 2003).

According to these principal climatically controlled sedimentary and erosional processes it is possible to trace the four terraces (Penck & Brückner 1909) along the Danube and the tributaries down-stream to the Vienna Basin (Figs. 4, 5, 6 & 7) due to a uniform and quite stable tectonic situation. Within the Vienna basin such a tectonic setting seems to be present only in the westernmost part (the city of Vienna). East of the Leopoldsdorfer fault and at the centre of the Vienna Basin recent tectonic subsidence is taking place (Decker, Peresson & Hinsch 2005) influencing the deposits of the two youngest glaciations (Gänserndorfer and Prater Terrasse) north of the river Danube and forming the Mitterndorfer Senke (Mitterndof Basin) south of it. Between these two areas of active subsidence a zone of less tectonic influence runs parallel to the river (Rauchenwarter Platte – Maria Ellender Hügelland – Prellenkirchner Terrasse) where the gravel accumulations of Lower and Middle Pleistocene seem to be in accordance with the terraces west of the Vienna basin (Fuchs 1985a, 1985b, 1985c). Therefore local names (e.g. Fuchs 1964, 1985a, 1985b, 1985c) are not added to the table in Fig. 3 but mentioned here as synonyms.

For the period of the Early Pleistocene no traces of glaciations have been found. However, the succession of cool and warm periods during this time had an effect on landscape evolution especially in the Alpine forelands in the North and Southeast. Thus gravel accumulation along the rivers combined with loess deposition in the surrounding area took place more or less in the same way but under slightly warmer conditions than during the Middle Pleistocene (van Husen 2000a). Some remnants of these sediments belonging to this long period before the major glaciations began, are included in the table (Fig. 3).

Lateglacial deposits like glacial sediments of prominent stadials are not within the scope of this review. Overviews on the stratigraphic terminology of this timespan have been given by van Husen (1997), Reitner (2007), and Ivy-Ochs et al. (2009).

This review aims to present the currently used Quaternary stratigraphic subdivision based on mappable bodies of sediments. In addition, three major long sections (Stranzendorf, Krems Schießstätte and Mitterndorf Basin) and an important area with fossil rich cave sediments are presented which are crucial for the understanding of Quaternary landscape evolution and have the potential to serve as reference sections for future local chronostratigraphic subdivisions.

The chronostratigraphic framework for the Quaternary is given by the major chronostratigraphic subdivisions according to the standards presented by Gibbard et al. (2009) with the Early/Middle Pleistocene boundary at the Matuyama-Brunhes paleomagnetic Chron boundary following the recommendation by Richmond (1996) and Head & Gibbard (2005) and the Middle/Late Pleistocene boundary at the beginning of the Eemian (Gibbard 2003) roughly identical with the base of the MIS 6/5 boundary. In addition the record of the Marine Isotope stages serves as a global chronostratigraphic reference.

The localities of stratigraphic units are displayed in the Figures 4, 5, 6, or 7. It is important to note that the Austrian landscape is subdivided into four elements: the Alps, the Northern Alpine Foreland (representing the predominant part of the Molasse Basin) drained by the river Danube and its southern tributary rivers (Inn, Traun, Enns, Ybbs and Traisen), the Vienna Basin and the Styrian Basin located in the southeast drained by the river Mur and its tributaries. The stratigraphic subdivisions with their interrelationships and the correlations – partly well established, partly inferred – with the chronostratigraphic frame are summarized in the table in Fig. 3.

Early Pleistocene Units

Geiersberg Schotter

This unit is described by Graul (1937) and Rupp (2008). The type locality is situated east of the city of Ried im Innkreis (location see Fig. 5) on ÖK 1:50,000 sheet 47 Ried im Innkreis. The name originates from the small village Geiersberg. The Geiersberg Schotter (in English: Geiersberg gravel) are small remnants of a former gravel accumulation north of the Kobernaußer Wald (Rupp 2008). They unconformably overlay the Neogene deposits of the Molasse Basin.

The gravel deposit is dominated by quartz and quartzite with some crystalline and a few limestone pebbles. The heavily oxidized and weathered gravel shows coarse bedding with thick sand layers and consists of eroded and redeposited material of the Neogene Hausruck Formation.

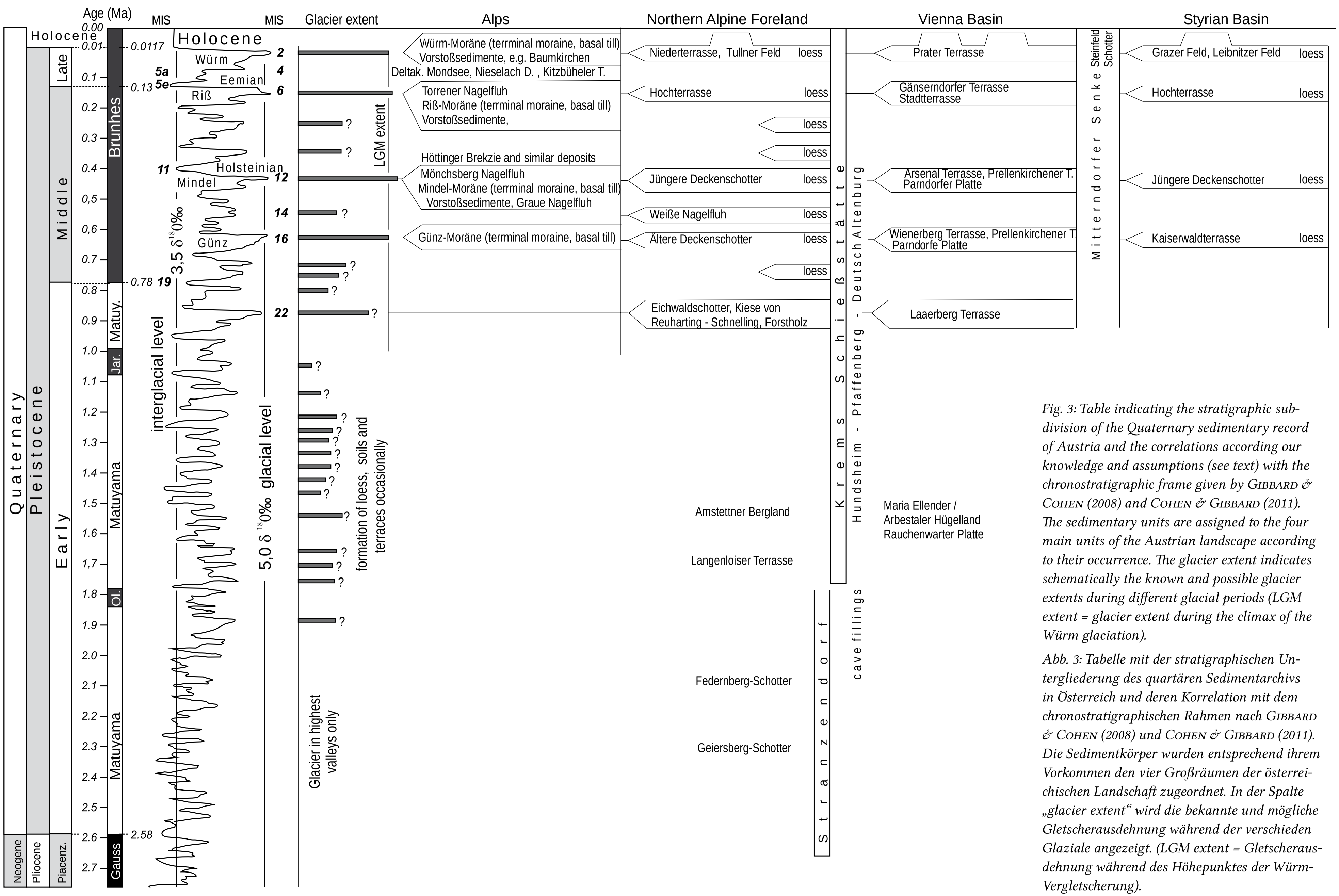

Fig. 3: Table indicating the stratigraphic subdivision of the Quaternary sedimentary record of Austria and the correlations according our knowledge and assumptions (see text) with the chronostratigraphic frame given by GIBBARD & COHEN (2008) and COHEN & GIBBARD (2011). The sedimentary units are assigned to the four main units of the Austrian landscape according to their occurrence. The glacier extent indicates schematically the known and possible glacier extents during different glacial periods (LGM extent = glacier extent during the climax of the Würm glaciation).

Abb. 3: Tabelle mit der stratigraphischen Untergliederung des quartären Sedimentarchivs in Österreich und deren Korrelation mit dem chronostratigraphischen Rahmen nach GIBBARD & COHEN (2008) und COHEN & GIBBARD (2011). Die Sedimentkörper wurden entsprechend ihrem Vorkommen den vier Großräumen der österreichischen Landschaft zugeordnet. In der Spalte „glacier extent" wird die bekannte und mögliche Gletscherausdehnung während der verschieden Glaziale angezeigt. (LGM extent = Gletscherausdehnung während des Höhepunktes der Würm-Vergletscherung).

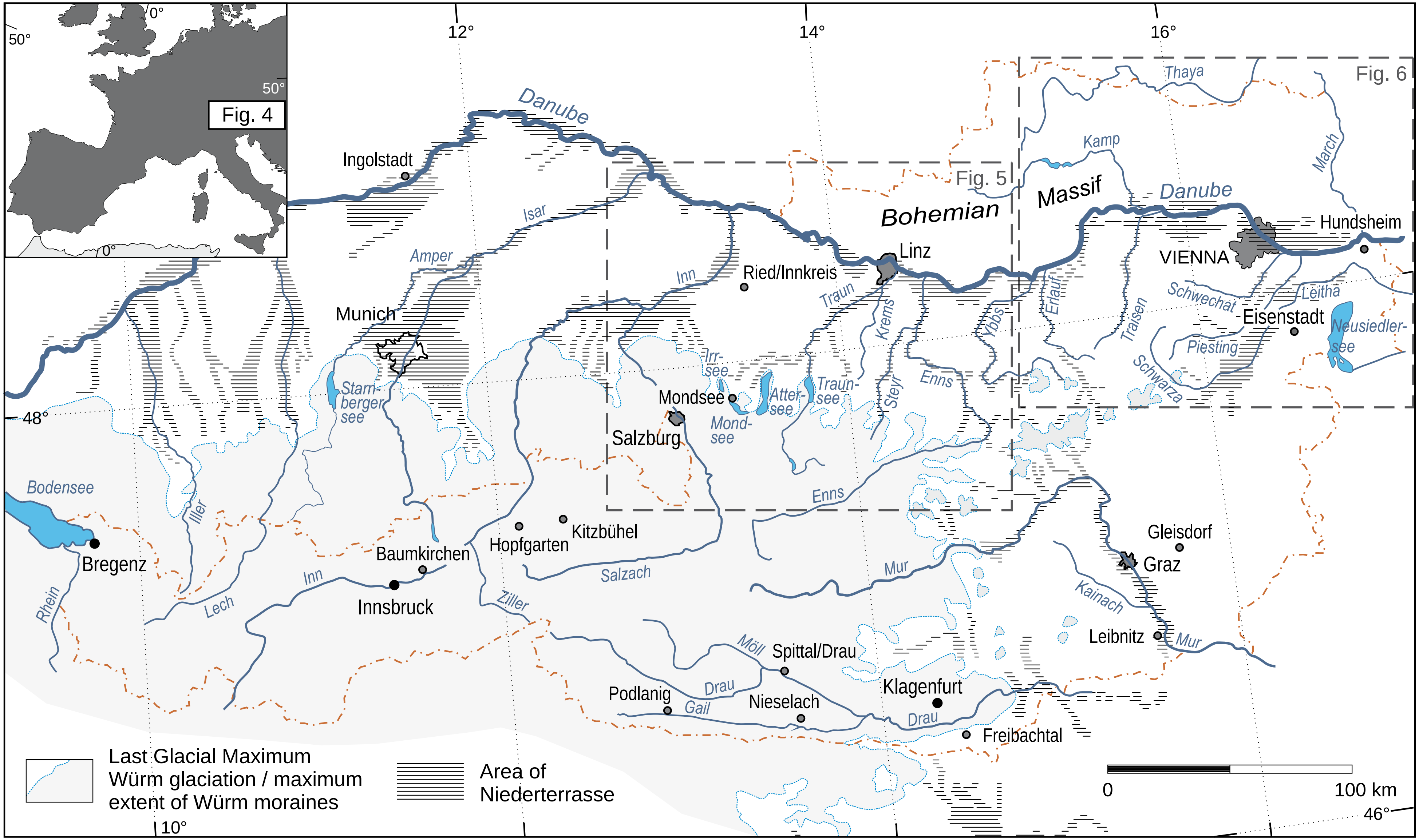

Fig. 4: Key map of the Quaternary landscape of Austria with the limit of the last glaciation (Würm) and its outwash deposits (Niederterrasse) (after VAN HUSEN *2000a). All localities mentioned in the text are shown in this figure or in detailed maps of Figs. 5, 6 & 7.*

Abb. 4: Karte der quartären Landschaft von Österreich mit der Ausdehnung der letzten Vergletscherung (Würm) und deren Schmelzwasserablagerungen (Niederterrasse) (nach VAN HUSEN *2000a). Alle im Text erwähnten Lokalitäten sind in dieser Abbildung oder den Detailkarten (Abb. 5, 6 und 7) zu finden.*

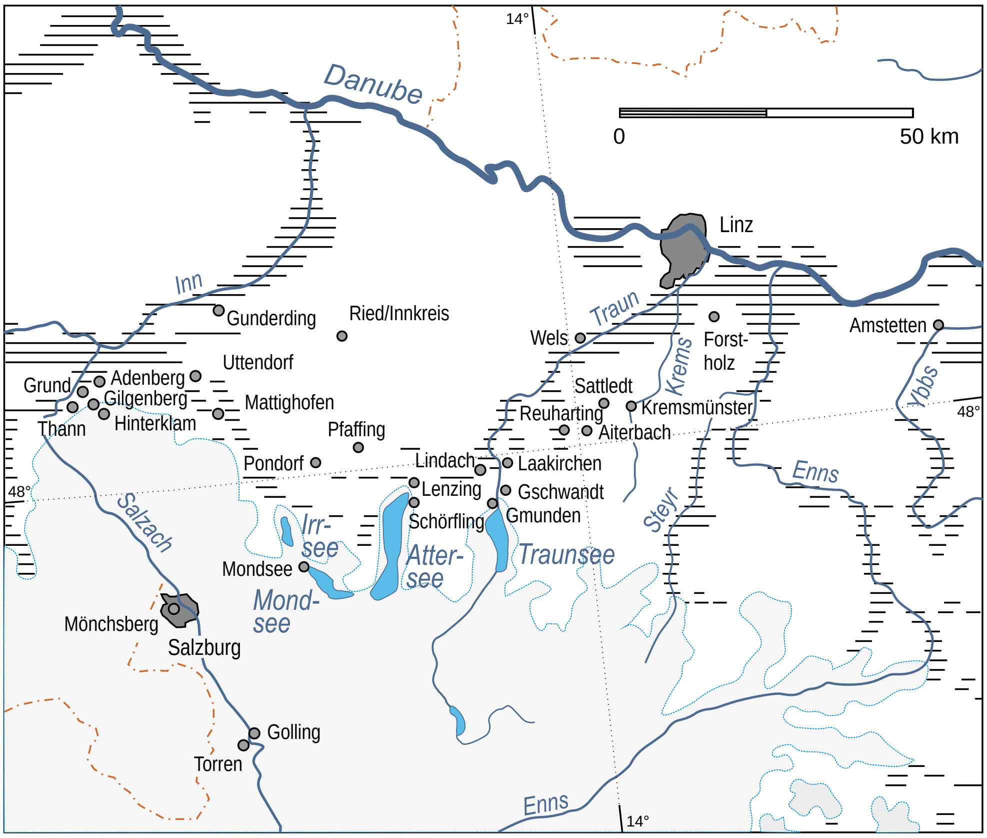

Fig. 5: Detailed map showing all localities between Salzburg and Linz. For legend see Fig. 4.

Abb. 5: Detailkarte aller Lokalitäten zwischen Salzburg und Linz. Für die Legende siehe Abb. 4.

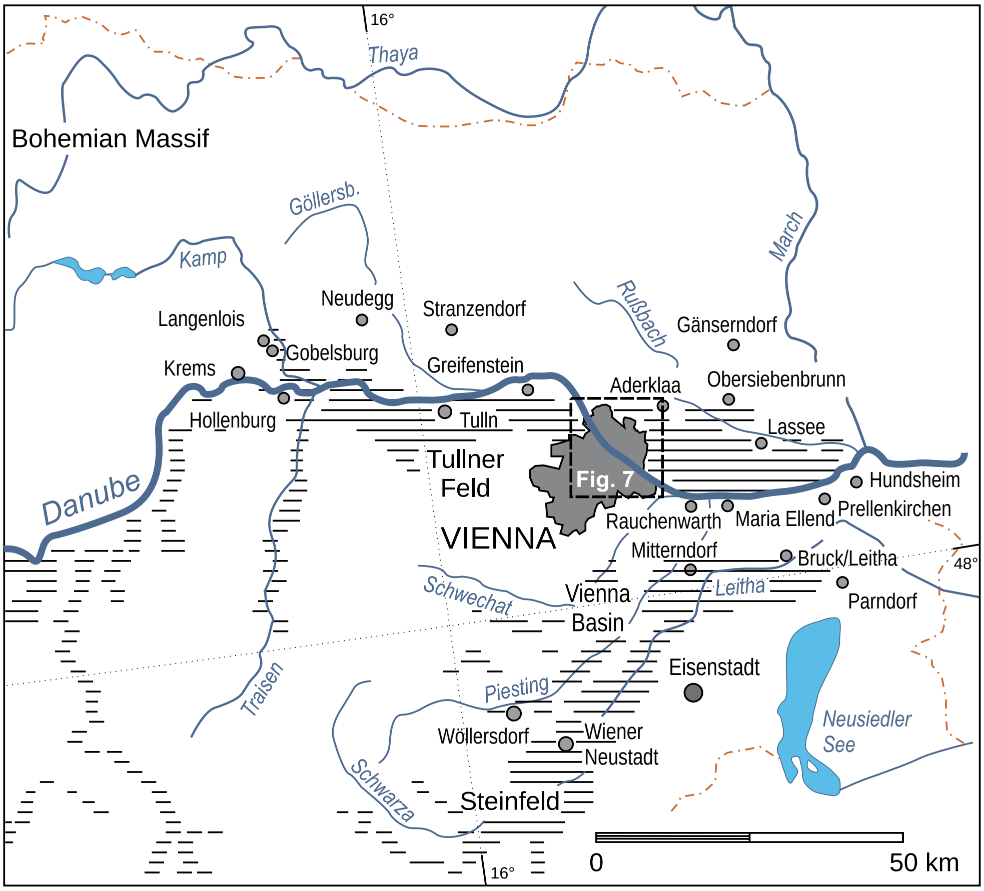

Fig. 6: Detailed map indicating all relevant localities in the NE of Austria close to Vienna. For legend see Fig. 1. The black frame of Fig. 7 is indicated.

Abb. 6: Detailkarte aller relevanten Lokalitäten im Nordosten von Österreich in der Umgebung von Wien. Für die Legende siehe Abb. 4. Der schwarze Rahmen zeigt die Ausdehnung der Detailkarte in Abb. 7.

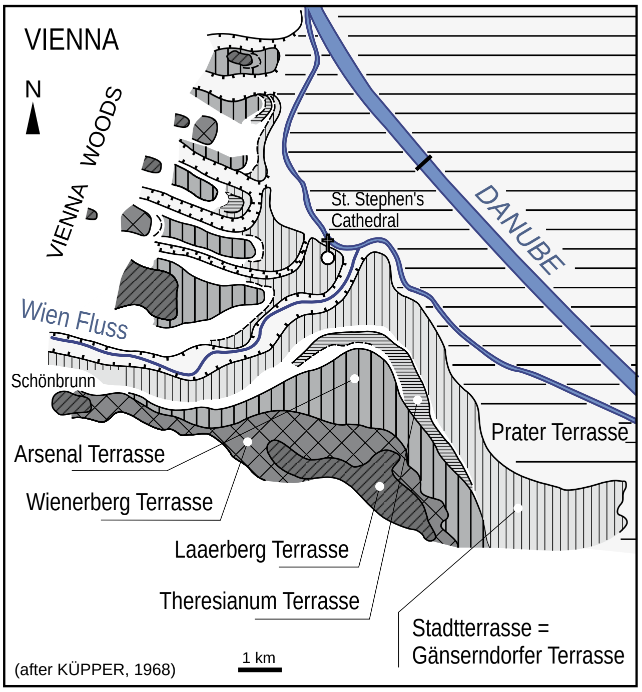

Fig. 7: Detailed map showing the classical terrace system in Vienna.

Abb. 7: Detailkarte mit dem klassischen Terrassensystem im Stadtgebiet von Wien.

The chronostratigraphic age is assumed to correlate with a cold period during Early Pleistocene which is much older than the period when the Federnberg Schotter were formed.

Federnberg Schotter

The description of this unit meaning Federnberg gravel in English is given by Graul (1937) and Rupp (2008). The type area is situated west of the city of Ried im Innkreis (location see Fig. 5) on ÖK 1:50,000 sheet 47 Ried im Innkreis. The name originates from a local ridge named Federnberg. The Federnberg Schotter is a large remnant of extended gravel accumulations along the rivers north of the Kobernaußer Wald (Rupp 2008).

The base of the gravel is marked by an unconformity at the transition to the Neogene deposits of the Molasse Basin.

The deposit consists of predominantly rounded and well-rounded coarse sand-bearing gravel. It is poorly sorted and more or less horizontally bedded with intensive cross bedding which typifies deposition by a braided river. Petrographically the gravel is dominated by quartz and quartzite. Pebbles of crystalline rocks are rare and limestone pebbels are very rare. The material is frequently eroded consitst largely of re-deposited gravel and sand of the Neogene Hausruck Formation. The gravel is weathered and strongly oxidized.

The chronostratigraphic age is thought to correlate with a cold period in the Early Pleistocene, much older than the period when the Eichwald Schotter were formed.

Langenloiser Terrasse

The first description of the Langenlois terrace was given by Fink & Piffl (1976c) for the type area in the southern part of Kremsfeld (location see Fig. 6; ÖK 1:50,000 sheet 38 Krems a.d. Donau). Synonymous is the term Gobelsburger Terrasse (Piffl 1959).

Lithologically the unit consists of coarse sand-bearing gravel with a thickness ranging from 10 to 15 m. The deposits are unconformably underlain by Neogene sediments of the Molasse Basin.

The gravel deposits are strongly weathered and partly covered with loess. They mainly consists of crystalline rocks (c. 70–80%) mixed with limestone and sandstone (30–20%) in the non-weathered parts, typical for fluvial deposits of the Danube. The unit is covered by thick loess deposits interrupted by paleosols.

According to paleomagnetic measurements the gravel accumulation took place in the upper part of the Matuyama chron in the Early Pleistocene.

Eichwaldschotter

The first recognition is from Graul (1937) as 'Aichberg-Geinberg Verschotterung'. The unit is first defined by Weinberger (1955). The type area is situated NE of the city of Mattighofen (location see Fig. 5) on ÖK 1:50,000 sheet 46 Mattighofen. The name (Eichwald gravel in English) originates from a local field name. The gravel unconformably overlies Neogene sediments of the Molasse Basin.

Lithologically the sediment consists predominantly of rounded and well-rounded coarse sand-bearing gravel beds. The lithological composition of the gravel is quite similar to that of the younger terrace gravel along the rivers Inn and Salzach in front of the terminal moraines of the Salzachgletscher. They were formed by braided river as well. The gravel is strongly weathered and covered by loess.

The chronostratigraphic age is assigned to a cold period older than Günz. Based on the similarity in facies and lithology with the typical fluvioglacial sediments of Middle Pleistocene age (e.g. Ältere Deckenschotter of the Günz glaciation) the Eichwaldschotter may represent the beginning of major Alpine glaciations at MIS 22 during the Early-Middle Pleistocene transition, as recorded in the southern Alpine area and foreland (Muttoni et al. 2003, 2007).

Kiese von Reuharting - Schnelling, Forstholz

Publications of Kohl (in: Krenmayr et al. 1997) and Krenmayr et al. (2006) describe the unit (gravel of Reuharting-Schnelling, Forstholz**)** for the type area in the northern part of the Traun-Enns Platte (locations see Fig. 5; ÖK50 sheets 49 Wels, 51 Steyr).

The lithology of the 20 to 30 meter thick unit consists of coarse sand-bearing gravel deposits. The predominantly occurring sub-rounded crystalline rocks are partly mixed with limestone and dolomites. The gravel is deeply weathered and partly covered with a residual clay deposit. According to sediment structures and some sub-angular boulders the accumulation took place during cold periods (Kohl in: Krenmayr et al. 1997).

The chronostratigraphic age is assumed as cold periods older than Günz (Kohl in Krenmayr et al. 1997) and may correlate with MIS 22 according to arguments mentioned for the Eichwaldschotter unit.

Fig. 8: Outcrop of the Federnberg Schotter (location south of Ried/Innkreis, see Fig. 5) showing horizontally bedded and oxidized gravel with rounded clasts consisting predominantly of quartz and quartzite (outcrop height is approximately 2 m). Layers of clast-supported gravel with open-framework are indicative for deposition by braided river.

Abb. 8: Aufschluss mit Federnberg Schotter (Lokalität südlich von Ried/Innkreis, siehe Abb. 5) bestehend aus horizontal geschichtetem und oxidiertem Schotter mit gerundeten Quarz- und Quarzitgeröllen (die Aufschlusshöhe beträgt etwa 2 m). Lagen von korngestützen Kiesen („Rollkiese") sind typisch für die Ablagerung durch „braided river".

Amstettner Bergland

A description is given by Krenmayr & Schnabel (2002) for the type area in the hills between the rivers Enns, Donau and Ybbs (location see Fig. 5; ÖK 1:50,000 sheets 51 Steyr, 52 St.Peter i. d. Au, 53 Amstetten) near the city of Amstetten. Synonyms are Strengberg Schlierriedelland and Ybbs-Erlauf-Melk Schlierriedelland (Fischer 1979).

The lithology of the up to 20 m thick unit consists of fine to coarse sand and clay containing gravel deposits. The gravel is strongly weathered and covered by weathered loess. This gravel deposits is interpreted as the remnant of former terraces accumulations formed by the river Danube. The gravel mainly consists of crystalline rocks, mixed with limestone and sandstone components supplied by the southern tributaries of the Danube. In the highest elevated terrace these materials are mostly weathered while in the lower situated terraces 30 to 40% of the sediment is unweathered.

The chronostratigraphic age is assumed to correlate with Early Pleistocene.

Maria Ellender / Arbesthaler Hügelland

Schnabel et al. (2002) mentioned the unit in the type area which is the hilly area (the meaning of Hügelland in German) south of the river Danube (location see Fig. 6) between Königsberg in the West and Wartberg in the East (ÖK 1:50,000 sheet 60 Bruck a.d. Leitha).

The unit is made up of remnants of former extended gravel deposits. It consists of fine to coarse sand-bearing gravel beds interbedded with up to 20 m thick sand layers. The gravel clasts are mainly rounded to well-rounded and composed of c.80–90% crystalline rocks mixed with limestone and sandstone. The sedimentology indicates a deposition by the river Danube. The chemical weathering of the deposits is very well developed and reaches down to the base of the gravel.

The chronostratigraphic age is correlated with the Early Pleistocene (Fuchs 1985c).

Rauchenwarter Platte

The unit was first described by Küpper (1968). The type area is the hilly area between the Vienna Airport (Katharinenhof) in the north and the villages of Himberg and Ebergassing in the south (ÖK 59 Wien). The name [(gravel) sheet of Rauchenwarth in English] is derived from the village of Rauchenwarth (location see Fig. 6).

Lithologically the unit consists of fine to coarse sand-bearing gravel deposits interbedded with sand layers. The deposit is interpreted as the remnants of former extended gravel deposits. The gravel is mainly rounded to well-rounded and composed of 80–90% crystalline rocks mixed with some limestone and sandstone indicating deposition by the river Danube. The chemical weathering of the deposits is intensive and may reached down to the base of the gravel. North of Rauchenwarth the gravel and Neogene sediments, which make up the base of the gravel, are covered by loess (Fuchs 1985). The thickness of the the unit amounts some 15 m.

The chronostratigraphic age of the deposits are correlated with the Early Pleistocene (Fuchs 1985 d).

Laaerberg Terrasse

This unit (Laaerberg terrace in English) was first defined by Schaffer (1902) and later on described by Fink & Majdan (1954) and Küpper (1968) for the type area in the 10th district of the city of Vienna (see Fig. 7) around the flat hill called Laaerberg (ÖK 1:50,000 sheet 59 Wien) a recreation area.

Lithologically it consists of coarse sand-bearing gravel of crystalline rocks (mostly quartz and quarztite) which was deposited by the river Danube. The unit shows an unconformable contact to underlying Neogene sediments and has a thickness around 3–4 m. The gravel deposits have a reddish matrix as a result of intense weathering and show cryoturbation structures.

The chronostratigraphic age is older than that of the Günz glaciation and is assumed to correspond with cold periods within the Early Pleistocene.

Middle Pleistocene Units

Günz-Moräne (terminal moraine, basal till)

The first description of Günz-Moräne in the sense of terminal moraine was given by Penck & Brückner (1909) for the type area in the Iller-Lech Platte, along the river Günz. Reference sections in Austria are described by Weinberger (1955) and Kohl (2000). In Austria the Günz moraines of the Salzach glacier are well developed at Siedelberg (Weinberger 1955) west of Uttendorf (location see Fig. 5), where also the transition into the gravel of the Ältere Deckenschotter is preserved. Other remnants of these terminal moraines are described from the Traun glacier at Berg SE Lindach and from the Krems glacier around Sattledt (Weinberger 1955, Kohl 2000, Egger & van Husen 2007).

Lithologically the unit consists of diamictons (till) of coarse sand-bearing gravel with boulders. Often a varying content of silt and clay can be noticed. Locally indistinct bedding can be found. The clast composition of the deposits reflects the lithology in the catchment area according to the resistance of the material against glacial abrasion. Only the remnants of basal till on the up-flow side of the terminal moraine are highly consolidated (compare Fig. 1). The till is normally deeply weathered to depths of 5 meter. The thickness of the unit is unknown and probably shows strong variations. The unit is partly covered by loess.

The Günz basal till, consists of an overconsolidated massive, matrix-supported diamicton. It has an unconformable contact to underlaying pre-Quaternary bedrock as well as older Pleistocene sediments.

Genetically, the Günz terminal moraine was deposited (overwhelmingly) as a dump moraine by a stationary glacier. It marks the maximum ice extent of the glacier tongues menitioned above. Generally, the basal till can be classified as a subglacial traction till (Evans et al. 2006).

The chronostratigraphic age is probably correlated with MIS 16 (van Husen 2000a).

Älterer Deckenschotter

This unit was first described by Penck & Brückner (1909) for the type area in the Iller-Lech Platte. The name meaning older sheet of gravel in English originates from the morphologically wide-spread occurrence of the apparently homogenuous gravel deposits north of the Eastern Alps, like in the Traun-Enns Platte. Synonymous are the Terrasse N Hochstraßburg (Fuchs 1964) and the Enns-Ybbs Schotterplatte (Fischer 1979).

The lithology shows coarse sand-bearing gravel typified by a poor sorting and bedding. The lithology of the clasts corresponds to the sources in the catchment areas of the rivers. Along the rivers Traun and at the Traun-Enns Platte (between the rivers Traun and Enns, Fig. 5) the material predominantly derived from the Alps (limestone, dolomite, and flysch sandstones) is mixed with older crystalline-bearing gravel in the lower part of the sequence (Kohl 2000). At Enns-Ybbs Schotterplatte (between the rivers Enns and Ybbs, Fig. 5) the gravel was supplied by the river Enns (Fischer 1979). Distinct gravel layers may show a good cementation.

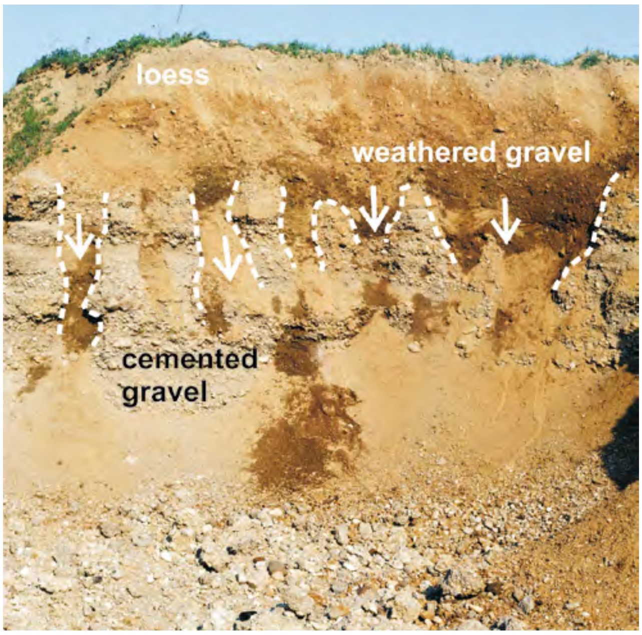

Fig. 9: Outcrop of Ältere Deckenschotter (location east of Kremsmünster) with a cover of younger loess on top (outcrop height approximately 6 m). White arrows and dashed lines indicate the locations of pipe-like weathering structures ("Geologische Orgeln") which occur between "pillars" of cemented gravel (conglomerate).

Abb. 9: Aufschluss mit Älterem Deckenschotter (Lokalität östlich von Kremsmünster), der von einem jüngeren Löss bedeckt ist. Die weißen Pfeile und die strichlierten Linien zeigen die Lage von röhrenförmigen Verwitterungsstrukturen („Geologische Orgeln") zwischen konglomerierten Kiesen an.

Intensive weathering is evident on the top of the gravel below the up to 10 m thick loess cover. Frequently occurring pipe-like weathering features (Geologische Orgeln) exsist throughout the whole sequence (see Figs. 2 & 9). The unit has a variable thickness of 15 to 30 meter due to changing bedrock topography. It consists of fluvial gravel mainly deposited by braided rivers. The unit is connected with terminal moraines in the Salzach glacier at Siedelberg West of Uttendorf (Weinberger 1955), in the Traun-Enns Platte (Kohl 2000), and the Enns-Ybbs Schotterplatte (Fischer 1979). Some remnants occur along the Danube and its southern tributaries (Krenmayr & Schnabel et al. 2006, Schnabel et al. 2002).

The chronostratigraphic age is probably correlated with MIS 16 (van Husen 2000a), but the unit may include older deposits as well.

Wienerberg Terrasse

This unit (in English: Wienerberg terrace) was first described by Fink & Majdan (1954) and Küpper (1968) for the type area in the 10th district of the city of Vienna (see Fig. 7) around Spinnerin am Kreuz (ÖK 1:50,000 sheet 59 Wien). Lithologically it consists of coarse sand-bearing gravel of mainly crystalline rocks which were deposited by the river Danube. The thickness amounts 10 m. In the upper parts subangular flysch gravel (Plattelschotter) frequently occurs. The gravel deposits are weathered in the upper part and covered by loess. Cryoturbations mixed both. Remnants of elephants (El. planifrons) were found by Küpper (1968).

It is supposed that the unit represents the Älteren Deckenschotter in the Vienna Basin. Thus the chronostratigraphic age is assumed to correlate as well to MIS 16.

Prellenkirchner Terrasse

The unit was mentioned by Wessely (2006) as Petronell-Prellenkirchner Terrasse with the type area around the village of Prellenkirchen (ÖK 1:50,000 sheets 61 Hainburg, 79 Neusiedl a. See). The name (in English: Prellenkirchen terrace) derives from the village of Prellenkirchen (location see Fig. 6).

The terrace consists of coarse gravel and sand deposited by the river Danube. The gravel is rounded to well-rounded and consists predominantly of crystalline rocks (c. 80%) mixed with limestone, dolomite and sandstones (c. 20%). It is strongly weathered and partly covered with loess. The gravel deposit is underlain by a basal package of sand and clay. It is situated at about 40 m above the recent levels of the rivers Danube and Leitha. Sediment structures (e.g. cross bedding) indicate deposition by braided rivers. The thickness is about 10 m.

The unit developed during probably two glacial periods (Günz, Mindel, cf. Fuchs 1985b). Thus the chronostratigraphic age might correlate with MIS 12 and MIS 16.

Parndorfer Platte

Descriptions of this unit are from Wessely (1961) and Häusler (2007) for the type area east of Parndorf (ÖK50 sheets 61 Hainburg, 79 Neusiedl a. See). The name meaning (gravel) sheet of Parndorf in English originates from the village of Parndorf (location Fig. 6).

Lithologically the unit consists of fine to coarse sand-bearing gravel deposits of the river Danube. The gravel clasts are rounded to well rounded and predominantly composed of crystalline rocks (c. 90%) mixed with limestone, dolomite and sandstones (c.10%) in the lower situated younger parts. The older, higher situated gravel, which is strongly weathered and partly covered with loess deposits shows intensive cryoturbation (Häusler 2007). Gravel deposits occur tectonically isolated from its surroundings at an about 20 m higher situated base of sand and clay (Fuchs 1985). Sediment structures (e.g. cross bedding) indicate deposition by a braided river. The thickness is about 10 m.

It is assumed that the sediments were deposited during two glacial periods (Günz, Mindel, cf. Fuchs 1985a, b; Häusler 2007). Thus the chronostratigraphic age might correlate with MIS 12 and MIS 16.

Kaiserwaldterrasse

The first descriptions was given by Penck & Brückner (1909). Additional information is provided by Winkler-Hermaden (1955) and Fink (1961). The type area of the Kaiserwald terrace is south of Graz (location see Fig. 4) between the rivers Mur and Kainach (ÖK 1:50,000 sheet 190 Leibnitz).

Lithologically the unit consists of coarse sand-bearing gravel deposits which show intensive cross bedding. The material was deposited by the rivers Mur and Kainach. The base of Kaiserwaldterrasse showing an unconformable contact to Neogene sediments is above the surface level of the Grazer Feld (Niederterrasse) surface. An up to 10 m thick cover of weathered loess is characteristic for this up to 15 m thick gravel unit (Ebner 1983).

The chronostratigraphic age is according to the high baselevel and the loess cover probably correlated with the Günz glaciation (MIS 16) but the unit may include older deposits as well.

Weiße Nagelfluh

The first description was given by Angerer (1909) for the type area in the Traun-Enns Platte (ÖK 1:50,000 sheets 67 Grünau i. Almtal, 68 Kirchdorf) with the type section in the former quarries Lärchwand (N 48°03'20", E 14°07'15") and Wolfgangstein (N 48°04'00", E 14°08'48") both located in the village of Kremsmünster (location see Fig. 5). A reference section is in the quarry of Egenstein (N 47°58'42", E 13°57'35"). The name (in English: white conglomerate) derives from the striking bright colour of the conglomerates. Synonym is the Kremsmünsterer Nagelfluh.

Lithologically the deposit is made up of massive well cemented sand-bearing conglomerates (Figs. 10 & 11). The clasts are predominantly rounded limestone, dolomite and some sandstone (Flysch).

The deposit is 5 to 15 m thick. Angular to sub-angular boulders probably transported by ice floes occur frequently. The sediments are poorly sorted with intensive cross bedding and small foresets (channel fill). The uppermost part shows weathering with layers of reddish clay (Kohl in Krenmayr et al. 1997, Fig. 11). The deposits is well-known as local building stone. The unit was probably deposited by braided river very likely during a cold period. A connection with till deposits is not known.

The chronostratigraphic age is probably correlated with MIS 14 (van Husen 2000a).

Mindel-Moräne (terminal moraine, basal till) and Vorstoßsedimente

The first description of Mindel-Moräne in the sense of terminal moraine was given by Penck & Brückner (1909). In Austria, Weinberger (1955), del Negro (1969) and Kohl (2000) mentioned the unit. Type area is the Iller-Lech Platte, along the river Mindel. Reference sections in Austria are situated only at the northern rim of the Eastern Alps where the glacier termini during the Mindel glacial are well documented like in the area between the Salzach glacier in the West and the Krems glacier in the East (Weinberger 1955; del Negro 1969; Kohl 2000, Egger & van Husen 2003; van Husen 1989; Egger 1996; Egger & van Husen 2007). The ridge of Sperledt between Adenberg and Edt (Weinberger 1955) marks the terminal moraine of the Salzach glacier. The same is true for the Traun glacier at Forstern, Pondorf, Weißenkirchen, Pfaffing, Hehenberg and Laakirchen, Rabesberg (Weinberger 1955, del Negro 1969, Kohl 2000, Egger & van Husen 2007) and for the Krems glacier at Magdalenerberg, Kremsmünster and Schlierbach (Weinberger 1955, Kohl 2000, Egger & van Husen 2007, Fig. 5).

Lithologically the unit consists of diamictons (till) of coarse sand-bearing gravel with boulders. Often a varying content of silt and clay can be noticed. Locally indistinct

Fig. 10: Historical quarry in Kremsmünster to mine the building stone of Weiße Nagelfluh (white conglomerate) (location s. Fig. 5). The superposition of Weiße Nagelfluh(white conglomerate made up predominantly by triassic limestone) by Graue Nagelfluh, a conglomerate representing the proglacial sediments of the advancing Krems-Steyr glacier during the Mindel glaciation and finally by the Mindel basal till is evident.

Abb. 10: Historischer Steinbruch in Kremsmünster (Lage s. Abb. 5) für den Abbau der als Baustein genützten Weißen Nagelfluh. Dieses aus hellen Karbonatgeröllen bestehende Konglomerat wird von Grauer Nagelfluh („Vorstoßschotter" der Mindel-Vergletscherung) und letztlich der Mindel-Grundmoräne überlagert.

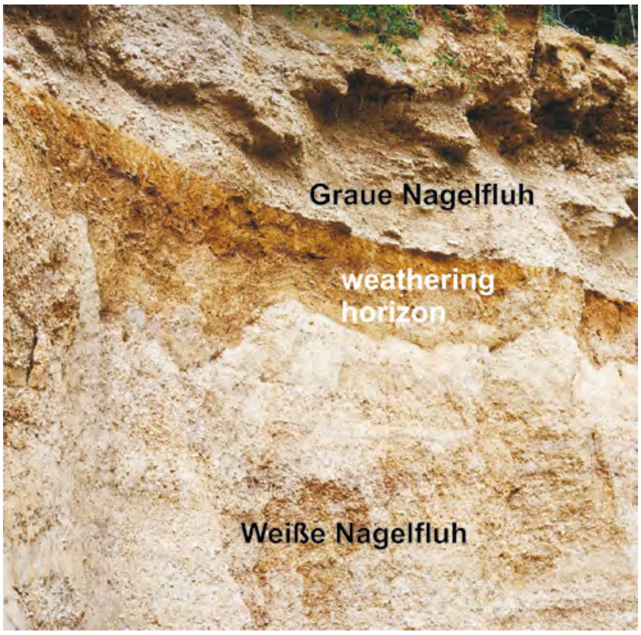

Fig. 11: Weathering horizon on top of Weiße Nagelfluh (white conglomerate) overlain by Graue Nagelfluh (grey conglomerate) indicating a stable surface under supposed interglacial conditions (location: quarry south of Kremsmünster, height of the outcrop approximately 4 m).

Abb. 11: Der Verwitterungshorizont am Top der Weißen Nagelfluh und überlagert von Grauer Nagelfluh dokumentiert vermutlich interglaziale Bedingungen (Lokalität: Steinbruch südlich von Kremsmünster, Aufschlusshöhe ca. 4 m).

bedding can be found. The clast composition of the gravel deposits reflects the lithology in the catchment area according to the resistance of the material against glacial abrasion. Only the remnants of basal till on the up-flow side of the terminal moraine are highly consolidated (see Fig. 1). The till is normally deeply weathered to an average depth of 3–5 meter. The thickness ranges from some meters to 30–40 m. The unit is partly covered by loess.

The Mindel basal till, consisting of massive, matrix-supported diamicton, often covers a few meter thick basal gravel bed which reflects sedimentary transition to the till. These gravel deposits called "Vorstoßschotter" in German were formed in front by fluvial action in of the advancing glacier and covered by till immediately after deposition (Fig. 1 & Fig. 9).

Genetically, the Mindel terminal moraine was (overwhelmingly) deposited as a dump moraine by a stationary glacier. It marks the maximum ice extent of the tongues of Salzach, Traun and Krems glacier (Weinberger 1955, Kohl 2000, van Husen 1977, Egger & van Husen 2007) during the pleniglacial conditions.

Riß basal till (German: Grundmoräne) i.e. overconsolidated massive matrix-supported diamicton with occasional shear planes) occurs on top of pre-Quaternary bedrock as well as on older Pleistocene sediments. The contact is in most cases unconformable. Generally, the basal till can be classified as a subglacial traction till (Evans et al. 2006).

The chronostratigraphic age is probably correlated with MIS 12 (van Husen 2000a).

Graue Nagelfluh

The first description is from Kohl (1977) for the type area around Kremsmünster (ÖK50 sheet 68 Kirchdorf, location see Fig. 6). The the type section is situated in the quarry Lärchwand (N 48°03'20", E 14°07'15"). The name (English meaning: gray conglomerate) originates from the dark greyish colour that results from a high content of Flysch sandstones.

The lithology of the 5–10 m thick unit is described as coarse sand-bearing gravel with a weak bedding. Clasts consist of limestone, dolomite and sandstone and are irregularly cemented. Frequent cross bedding and a transition into the overlying till (Mindel) is evident. The unit was probably deposited by a braided river in front of the advancing glacier (Mindel) in the Krems valley (Upper Austria) around Aiterbach, Rindbach, Kremstal (Kohl 2000). The underlying unit is the weathered Weiße Nagelfluh.

The chronostratigraphic age is probably correlated with MIS 12 (van Husen 2000a).

Jüngerer Deckenschotter

Description was given by Penck & Brückner (1909) especially for the Iller-Lechplatte. The name meaning younger sheet of gravel in English indicates the unit as a morphologically wide-spread gravel deposit which is only slightly incised into the Älterer Deckenschotter (Fig. 2), like in the Traun-Enns Platte (between the rivers Traun and Enns, Fig. 5). Synonymous are the Terrasse von Lehen and respectively the Terrasse S Ordning (Fuchs 1964).

The lithology consists of coarse sand-bearing gravel deposits with weak layering. The material reflects the lithology of the catchment areas of the supplying rivers. In contrast to the Älteren Deckenschotter along the rivers Traun and Enns, all the material of the Jüngerer Deckenschotter originates from the Alps as is demonstrated by the content of limestone, dolomite, and flysch sandstone. In some layers the gravel is well cemented. The gravel deposits are intensively weathered at the top which is covered by loess. Pipe-like weathering features (Geologische Orgeln) occur frequently (s. Fig. 2).

The unit is up to 40 m thick and connected to Mindel Moränen NE of Adenberg (Weinberger 1955), S Lindach (Kohl 2000, Egger & van Husen 2007). Additional remnants Jüngerer Deckenschotter occur along the Danube and its southern tributaries (Krenmayr & Schnabel et al. 2006, Schnabel et al. 2002).

The chronostratigraphic age is probably correlated with MIS 12 (van Husen 2000a).

Mönchsberg Nagelfluh

The first descriptions of the Mönchsberg conglomerate were given by Boué (1830), Morlot (1847), Penck & Brückner (1909), and Götzinger (1936). The type area is the city of Salzburg (location see Fig. 5) and its vicinity (ÖK 1:50,000 sheet 63 Salzburg). The type section is located at the Mönchsberg (N 47°48'00" E 13°02'00") in the city center of Salzburg of which the name of the unit is derived. Synonymous the term Salzburger Nagelfluh is used.

Lithologically the unit consists of coarse sand-bearing gravel deposits which are in part well-cemented to conglomerate. The outcropping thickness reaches 80 m. The gravel composition is similar to that of the modern gravel of the river Salzach. Layers are dipping 20°–30° in west to northeastern directions. Apart from a few layers that consist only of coarse gravel without sand the conglomerates show a predominantly sand matrix. The conglomerates are well-known for its use as building stone (Kieslinger 1964). The unit is supposed to represent foreset-beds of a kame which was formed in small lakes during the initial phase of down-melting of the Salzach glacier at the end of the Mindel glaciation (Termination V).

Thus the unit is probably correlated with MIS 12 (van Husen 2000a).

Arsenal Terrasse

Publications about the unit called Arsenal terrace in English are from Schaffer (1902), Fink & Maydan (1954), and Küpper (1968). The type area is the railway station "Südbahnhof" and the nearby situated former military complex Arsenal (location see Fig. 7; ÖK 1:50,000 sheet 59 Wien).

Lithologically the unit consits of 10–15 m thick coarse sand-bearing gravel deposits. The gravel is mainly composed of crystalline rocks from the river Danube and contains angular boulders (Suess 1862) in the lower parts which were obviously transported by ice floes. In the upper parts layers with subangular flysch gravel (Plattelschotter) are dominant. The gravel deposits are covered by a weathering zone and loess which are intermingled by cryoturbations.

It is supposed that the unit represents the Jüngeren Deckenschotter in the Vienna Basin. Thus the chronostratigraphic age is assumed to correlate as well with MIS 12.

Höttinger Brekzie

The first recognition of the Hötting breccia was made by Escher von der Linth (1845) and Morlot (1847). Modern comprehensive descriptions are given by Penck 1921 and Sanders & Ostermann (2006). The type area is in Innsbruck (Fig. 1) north of the river Inn between Höttinger- (N47°17'00" E 11°22'20") and Mühlauergraben (N 47°18'00" E 11°24'50") (Fig. 1; ÖK 1:50,000 sheet 118 Innsbruck). The name comes from the village of Hötting (now part of Innsbruck) at the mouth of the Höttingergraben. Synonymous are other similar breccias on the southern rim of the Calcareous Alps (van Husen 2000a).

The lithology is a well-cemented breccia containing angular triassic carbonate rocks, silt-sandstone and some associated crystalline erratics. The predominantly coarse talus contains some fine-grained layers. Based on the colour two types of breccias can be recognized: the White Breccia and the Red Breccia in the lower parts of the slope. The colour results from the bedrock colour that influences the matrix (Ampferer 1936). Plant fossils crop out on one spot (Rossfall-Lahner N 47°17'30" E 11°22'40"). The flora is rich in taxa indicating warm interglacial conditions (e.g. Rhododendron, vitis) during deposition (v. Ettingshausen 1885, v. Wettstein 1892, Gams 1936, Denk 2006).

The origin and facies of the unit is a talus formed mostly by debris and mud flows but also by rock fall and grain flow (Sanders, Ostermann & Kramers 2009). The latter formed laminated silt deposits in distal puddles (Sanders & Ostermann 2006). The thickness can amount more than 100 m. The unit is underlain by older till (Mindel) and Triassic bedrock and superimposed by two tills separated by gravel deposits (Ampferer 1936).

The chronostratigraphic age is supposed to Mindel/Riß interglacial (Penck 1921, Ampferer 1936) and can probably cover the full time-span of MIS 11 to MIS 7 (van Husen 2000a). Recently a correlation with MIS 5 is discussed (Sanders & Ostermann 2006). Such a young age is supported by luminescence ages which suggest an Early- to Middle Würm deposition of the Hötting Breccia (Gemmel & Spötl 2009).

Riß-Moräne (terminal moraine, basal till) and "Vorstoßsedimente"

The first description of Riß-Moräne in the sense of a terminal moraine (German: Endmoräne) was given by Penck & Brückner (1909). The type area is located at the eastern rim of the former Rhein glacier around the type locality Biberach a. d. Riß. Reference areas are in the Salzach glacier (Weinberger 1955) and Traun glacier (van Husen 1977) area. The name is derived from the River Riß (Baden Württemberg /Germany).

Only few clear remnants of Riss terminal moraines are known in the Eastern Alps: Salzach glacier (locations see Fig 2) around Thann, Grund, Gilgenberg, Hinterklam (Weinberger 1955) and Kühberg (Egger & van Husen

2003), Traun glacier around the glacier tongues at Irrsee, Attersee and Traunsee (Egger & van Husen 2003, van Husen 1989, Egger 1996, Egger & van Husen 2007), and Krems glacier around Warthberg (Kohl 2000).

Lithologically the unit consists of diamictons (till) of coarse sand-bearing gravel with boulders. Often a varying content of silt and clay can be noticed. Locally indistinct bedding can be found. The clast composition of the gravel deposits reflects the lithology in the catchment area according to the resistance of the material against glacial abrasion. Only the remnants of basal till on the up-flow side of the terminal moraine are highly consolidated (see Fig. 1). The till shows normally advanced weathering, averaging a depth of 1 to 2 m. The thickness ranges from some meters to 30–50 m. The unit is partly covered by loess.

The Riß basal till often covers a few meter thick basal gravel bed which reflects sedimentary transition to the till. These fluvial gravel deposits called "Vorstoßschotter" in German were formed in front of the advancing glacier and covered by till immediately after deposition.

Genetically, the Riß terminal moraine was (predominatly) deposited as a dump moraine by a stationary glacier. It marks the maximum ice extent of the tongues of Salzach, Traun and Krems glacier (Weinberger 1955, Kohl 2000, van Husen 1977, Egger & van Husen 2007) during the penultimate pleniglacial conditions.

Riß basal till (German: Grundmoräne) i.e. overconsolidated matrix-supported massive diamicton with occasional shear planes) occurs on top of pre-Quaternary bedrock as well as on older Pleistocene sediments. The contact is in most cases unconformable. Generally, the basal till can be classified as a subglacial traction till (Evans et al. 2006).

The chronostratigraphic age of the unit is correlated with MIS 6 (van Husen 2000a). Such an assumption is backed by findings at Mondsee (van Husen 2000c; see Mondsee Deltakomplex) where in a continuous sequence Riss basal till is superimposed by Riss/Würm interglacial lake deposits (Drescher-Schneider 2000), correlated with the Eemian; MIS 5e).

Hochterrasse

The term meaning high terrace in English was introduced by Penck during geological mapping in the Bavarian Alpine Foreland (Geologische Karte Ingolstadt). The type area was first around Ingolstadt and later in the Iller-Lech-Platte. Originally the name was connected with the large terrace on the valley flanks that follows the modern river course. Later it was considered to be the melt water accumulation of the penultimate glacial cycle (Penck & Brückner 1909).

In the area of the Vienna Basin (surrounding the city of Vienna, Fig. 6) the Terrasse westlich Seyring (Grill 1951), the Gänserndorfer Terrasse (Fink 1954), the Theresianumterrasse (Küpper 1968), the Stadtterrasse, and the Simmeringer Terrasse (Schaffer 1902) are synonyms.

The terrace deposits consist of coarse, sand-bearing gravel with weak bedding. Gravel composition displays the lithology of the catchment area of the respective rivers. Along the Danube material from the Alps in the south (e. g. limestone, dolomite, flysch, sandstones) is mixed with the gravel from the tributaries originating in the Bohemian Massif. The thickness of the deposits varies between 20 and 50 m. The gravel deposits show only locally weak cementation. Well-developed weathering occurs on the top just below the loess cover. The onset of pipe-like weathering (Geologische Orgeln) can locally be recognized.

The fluvial gravel deposits were mainly accumulated by braided rivers which were directly connected to the Riß terminal moraines of the Salzach glacier at Gilgenberg (Weinberger 1955; Fig. 5) and of the Traun glacier at Lenzing, Schörfling and Gschwandt (Egger 1996, Egger & van Husen 2007). Some remnants of the unit occur in non-glaciated valleys without terminal moraines. Extended units of Hochterrasse are present along the Danube and its southern tributaries (Krenmayr & Schnabel 2006, Schnabel et al. 2002).

The Hochterrasse of the Inn valley at Gunderding has been dated by optically stimulated lumescence (OSL) providing deposition ages between ~200 and 140 ka (Megies 2006). Such a result is supported by an U/Th dating of a calcitic cement from the same gravel pit providing a minimum age of 113.4 ± 4.4 ka (Terhorst, Frechen & Reitner 2003) of the deposit. The chronostratigraphic age is therefore correlated with MIS 6.

Torrener Nagelfluh

The first description of this Torren conglomerate is given by Pippan (1957) and Kieslinger (1964) for the type area in the Salzachtal around Golling (Fig. 5; ÖK 1:50,000 sheet 94 Hallein). The type section is situated in a quarry at Torren (N 47°35'50", E 13°09'10") which is the name-giving village.

The lithology of the unit is typified by partly well-cemented sand-bearing gravel. The deposit is dominated by carbonate pebbles from local sources which are mixed with crystalline clasts. Only a few layers show well-developed cementation, which were used for building stone (Kieslinger 1964). Layers with clay coating of the pebbles are poorly cemented. The lower sediment layers of the sequence show clinoforms with a dip of 30° to the North. The upper part shows horizontal layering with cross bedding. The uppermost part (c. 2 m) is in part intensively weathered. The sequence is probably formed as a delta complex with fore and top sets in a lake between stagnant ice and the slope (kame terrace).

The outcropping part of the unit has a thickness of about 30 m. A conformable transition to lower situated bottom sets consisting of banded clay is assumed.

The chronostratigraphic age assumes an origin during the initial phase of down-melting at the end of the Riß glaciation. Thus it is correlated with Termination II and with MIS 6 (van Husen 2000a).

Stadtterrasse

Descriptions of the unit were given by several authors (Schaffer 1902; Fink & Majdan 1954; Küpper 1968; Fink 1973). The type area is in the center of the city of Vienna (see Fig. 7; old city around St. Stephen's cathedral, today 1st district – ÖK 1:50,000 sheet 59 Wien). The name meaning city terrace is from the old city of Vienna. Simmeringer Terrasse (Schaffer 1902) and Theresianumterrasse (Küpper 1968) are synonymous.

Lithologically the unit consists of coarse gravel deposits with sand and shows weak layering. The gravel is rounded to well-rounded and is composed of c. 80% crystalline rocks, c. 20% pebbles of limestone and flysch sandstone. The material was deposited by the Danube. Angular boulders of 1 m and more in diameter are mainly found in the lower part of the deposit (Küpper 1950). They were transported and deposited by ice floes during glacial climatic conditions. At the mouth of tributaries originating from the Vienna Woods thick layers of predominant subangular flysch material ("Plattelschotter") interdigitate with the Danube terrace deposits (Küpper 1968, Fink 1973). The terrace is covered with loess and was mainly accumulated by braided rivers. The thickness amounts 10 to 15 m.

It is supposed that the unit represents the Hochterrasse in the Vienna Basin south of the Danube. Thus the chronostratigraphic age is assumed to correlate as well with MIS 6.

Gänserndorfer Terrasse

The first description of the Gänserndorf terrace was given by Fink & Majdan (1954). The type area is the Vienna Basin North of the river Danube (ÖK 1:50,000 sheets 41 Deutsch Wagram, 42 Gänserndorf). The name originates from the city of Gänserndorf (location see Fig. 6). The terrace W of Seyring is synonymous.

Lithologically the unit consists of coarse sand-bearing gravel that show weak layering as well as some cross-bedding.

The gravel was deposited by the river Danube. It is made up of rounded to well-rounded clasts which consist of about 80% crystalline rocks and about 20% limestone and flysch-sandstone. The uppermost part of the unit is weathered and shows strong oxidation of iron (hydroxides). The upper 3 to 4 m of the unit was affected by ice wedges and intensive cryoturbation which included also soil and loess material. In part the terrace body is tectonically subsided at Aderklaa, Obersiebenbrunn, and Lassee (Fuchs & Grill 1984, Decker, Peresson & Hinsch 2005). The fluvial gravel is 10 to 15 m thick and was mainly accumulated by braided rivers.

It is supposed that the unit represents the Hochterrasse in the Vienna Basin north of the Danube. Thus the chronostratigraphic age is assumed to correlate as well with MIS 6.

Late Pleistocene Units

Deltakomplex Mondsee

The first description of the 'Mondsee-Interglazial' was given by Klaus (1975, 1987) and Kohl (2000). Detailed investigations were carried out during 1992–1996 (van Husen 2000b). The type area is the slope north of the village of Mondsee (Fig. 5) near the farmhouse Steiner (N 47°51'56" E 13°20'48" – ÖK 1:50,000 sheet 65 Mondsee). The type section is the Steinerbach (N 47°51'54" E 13°20'37") and three drillholes (N 47°51'54", 55", 56" E 13°20'38", 39", 40"). The name denoting complex delta deposits of Mondsee in English originates from the village of Mondsee.

Lithologically the unit superposes an older till (Riß). The sequence starts with laminated clay, silt and lake marls,

Fig. 12: Riß/Würm - Interglacial (Eemian) lacustrine sediments (lake marl and banded clay) at Mondsee. White sheets mark different pollenzones.

Abb. 12: Lakustrine Ablagerungen (Seekreide und Bänderschluff) aus dem Riß/Würm - Interglazial (Eem).

which were deposited during the interglacial period (Eemian). This lower part is overlain by a coarsening upward sequence of clay, silt and sand layers (Krenmayr 2000). The whole package is covered by basal till (Late Würm).The unit is rich in pollen which document the vegetation development from the late glacial period of the Riß (Termination II, MIS 6) to Middle Würm (MIS 3) (Drescher-Schneider 2000). The pollen record is completed by many macro plant macro remains (Oeggl & Unterfrauner 2000). The preserved sequence evolved as a Gilbert type delta with bottom, fore, and top sets deposited in an ancient greater Lake Mondsee with a lake level of about 60 m above the present-day lake-level (van Husen 2000c). The deposits show a thickness of 10–35 m. The chronostratigraphic age of the sequence is correlated with MIS 6 to 3.

Nieselach deposits

The deposits are described by Fritz (1971), van Husen & Draxler (1982), van Husen (2000a). The type area is situated south of St. Stefan in the Gail valley (ÖK 1:50,000 sheet 199 Hermagor, Fig 4). The village Nieselach is name-giving.

The about 1.5–2 m thick lignite (Fig. 13) as a part of the sediment sequence was repeatedly the base of mining activities, Ucik (1973).

The 6–8 m thick sequence consisting of horizontally bedded sandy, silty, occasionally gravelly sediments with lignite in the uppermost part conformably overlays banded clay (lake deposits after Riß deglaciation). The lignite is unconformably overlain by coarse gravel, which is regarded to represent "Vorstoßschotter" i.e. proglacial fluvial sediments deposited during the glacier advance phase of the Late Würm glaciation.

The predominantly coarse sand layers with gravel and silt layers were deposited in a meandering river with a low-en-

Fig. 13: Outcrop at Nieselach showing the lignite overlain by the gravel of the "Vorstoßschotter".

Abb. 13: Aufschluss bei Nieselach mit dem Lignit überlagert von „Vorstoßschotter".

ergy stream regime. Layers of massive or banded clay document sedimentation in oxbow lakes, which finally got filled with wood (willows and other bushes) and peat, the source material of the lignite.

According to paleomagnetic data (presence of the Blake event within the sequence) a chronostratigraphic age of MIS 5e is given. However, a U/Th dating of the lignite (113,000 ± 2000 BP; Geyh, Hennig & Oezen 1997) and the palynological record provide arguments for a correlation with the Eemian (MIS 5e) as well as with the 1st Würm Interstadial (MIS 5c). Deposits with a quite similar pollen content are found in fine-grained lacustrine sediments at Freibachtal (SE of Klagenfurt, Carinthia, Fig. 4, Felber & van Husen 1976, Fritz 1992).

Kitzbüheler Terrasse

The unit Kitzbühel terrace was first described by Unger (1836) and mapped by Ohnesorge (1917). Its type locality is in the town of Kitzbühel (Tyrol, Fig. 4), which is namegiving.

Drilhole data for a tunnel and outcrops show a 40 m thick sequence. It consists of a basal till (attributed to MIS 6) overlain by massive and banded silts with no pollen which show a coarsening-upward into sand-bearing gravel deposits (Reitner & Draxler 2002; Reitner 2005). The gravel is overlain by a laminated organic-bearing clayey silt deposit and a three meter thick lignite (a former peat). The latter unconformably underlies the upper basal till (Late Würm, MIS 2).

The coarsening-upward sequence is regarded to represent a phase of rapid sedimentation during or shortly after deglaciation. From the organic-bearing upper part of this and other locations with wood remnants or lignite within the extensive Kitzbühel terrace it is concluded that during an interstadial phase an elevated valley floor with prograding alluvial fans and swampy intercone deposits existed.

Pollenanalyses (by S. Bortenschlager and I. Draxler) together with an U/Th age of 90±8 ka (Reitner 2005) indicate that the peat was formed during the 1st Early Würm Interstadial (MIS 5c). Thus the valley infill of the Kitzbüheler Terrasse supposedly covers the timespan from end of the Riß glaciation (Termination II, MIS 6) to the Early Würm.

A quite similar situation with sediments of EarlyWürm age consisting of lignites intercalated in up to 100 m thick gravel beds are found in the area of Hopfgarten/Brixental (west of Kitzbühel, Fig. 4). The whole sequence is probably correlated with MIS 5d–5a based on palynological evidence (Reitner 2005, Reitner & Draxler 2002).

Würm-Moräne (terminal moraine, basal till) and "Vorstoßsedimente" (e.g. banded-clay deposit of Baumkirchen

The first description of Würm-Moräne in the sense of a terminal moraine was given by Penck & Brückner (1909). The type area is the Lake Starnberg (German: Starnberger See, former Lake Würm/Würm See) and its outlet the river Würm located SE of Munich (Bavaria/Germany, Fig. 4). Reference area is the Austrian lake Traun See and its surrounding (located near the city of Gmunden, Fig. 5) (van Husen 1977). The name originates from the Lake Würm and river Würm. Deposits of the Würm-Moräne occur in all formerly glaciated valleys of the Eastern Alps. Prominent examples of Würm-Moräne are located in the surrounding of the Salzach Valley N of Salzburg and as well in the Drau valley east of Klagenfurt (see glacier extent in Figs. 4, 5)

Lithologically the Würm terminal moraine unit consists of in general massive diamicton (till), of coarse-grained sand-bearing gravel with boulders and an often varying content of silt and clay. Locally indications of weak bedding can be found. The clast composition of the gravel deposits reflects the lithology in the catchment area according to the resistance of the material against glacial abrasion. Only the remnants of basal till on the up-flow side of the terminal moraine are highly consolidated (Fig. 1). The till is normally slightly weathered to depths ranging between 0.5 and maximum 1 m.

Genetically, the Würm-Endmoräne is a terminal moraine which was (predominantly) deposited as a dump moraine by a stationary glacier (Fig. 1). It marks the maximum ice extent during the last pleniglacial conditions in all valleys originating from formerly glaciated regions.

Within these areas a patchy cover of Würm basal till (German: Grundmoräne) i.e. overconsolidated massive matrix-supported diamicton with occasional shear planes) on top of pre-Quaternary bedrock as well as on older Pleistocene sediments is present. The contact is in most cases unconformable. The thickness of the till varies from some meters to 40 m at drumlins. Generally, the basal till can be classified as a subglacial traction till (Evans et al. 2006).

"Würm-Vorstoßsedimente" is a term used for sediments which are coverd by Würm basal till and whose facies indicates deposition in the proglacial area (sensu lato) of glaciers advancing to their maximum extent during the Würm Pleniglacial. This includes sediments of different facies (fluvial, alluvial, glacio-fluvial, lacustrine and glaciolacustrine). Around the terminal moraines such sediments below basal till are typically gravel beds so called "Vorstoßschotter" (Penck & Brückner 1909) of some meters thickness. Within the Alpine valleys up to 100 m thick sediment sequences of such coarse sand-bearing gravel are preserved (van Husen 2000a) (see Figs. 1 & 14). Prominent examples are found in the lower Inn valley (east of Innsbruck, especially around the village of Baumkirchen), the Drau valley near Spittal/Drau (Schotter von St. Peter in Holz; Schuster, Pestal & Reitner 2006) and in the Gail valley (Schönlaub 1989) (all locations in Fig. 4). Only under special circumstances also thick layers of banded clay occur (e.g. Baumkirchen, E of Innsbruck, Figs. 1, 4 & 15, Fliri et al. 1970, Fliri 1973). All these gravel beds as well as fine grained sediments are showing coarsening upwards sequences and mostly a transition into the overlaying Würm basal till. The banded clay of Baumkirchen contains macro plant remains (branches of pine, alder, buckthorn) with ^{14}C ages of 31–27 ka BP and pollen indicating cold climatic conditions with a shrub tundra surrounding the former lake (Fliri 1973). A branch of Alnus from the deposit at Podlanig (Gail valley, Fig. 1) with a ^{14}C age of 28.3 ± 0.7 ka (van Husen 1989) as well documents ice-free conditions and strong aggradation in the big valleys during that time.

The Würm-Moräne is correlated with the Late Würm (Chaline & Jerz, 1984) and thus with MIS 2, whereas the banded clay of Baumkirchen is correlated with the Middle Würm (Chaline & Jerz, 1984) and with MIS 3. The onset of proglacial gravel on top of the banded clay at Baumkirchen marks the beginning of the Late Würm (MIS 2) after Chaline & Jerz (1984).

Niederterrasse

The term meaning low terrace in English was introduced by Penck during geological mapping in the Bavarian Alpine Foreland (eg. Geol. Karte Ingolstadt). The type area was first around Ingolstadt and later in the Iller-Lech-Platte. Originally the name was connected with the lowest of the extensive valley terraces following the modern river course (Fig. 2). Later it was considered to be the meltwater accumulation of the last glacial cycle (Penck & Brückner 1909).

Fig. 14: "Vorstoßschotter" (gravelly facies of "Vorstoßsedimente") representing proglacial sediments overlain by Würm basal till (gravel pit near Baumkirchen). Note the poor sorting and the large boulders in the gravel.

Abb. 14: „Vorstoßschotter" (kiesige Fazies der „Vorstoßsedimente"), ein typisches Sediment aus dem Gletschervorfeld, überlagert von Würm-Grundmoräne (basal till) (Schottergrube bei Baumkirchen). Die schlechte Sortierung und die Größe der Gerölle im Schotter sind auffallend.

Fig. 15: Outcrop at the abandoned clay pit at Baumkirchen with typical banded clay.

Abb. 15: Aufschluss in der aufgelassenen Tongrube von Baumkirchen mit dem typischen Bänderton bzw. Bänderschluff.

The terrace deposits consist of coarse, sand-bearing gravel with weak bedding. Gravel composition displays the lithology of the catchment area of the respective rivers. Along the Danube material from the Alps in the South (e. g. limestone, dolomite, flysch, sandstones) is mixed with the gravel from the tributaries originating in the Bohemian Massif. The gravel is usually not cemented and the weathering horizon on top of the sequence is relatively thin. A cover of loessic sediments occurs only at the rim to adjacentolder terraces due to re-deposition. The thickness of the terrace deposits varies between 20–100 m. The gravel deposits are unconformable underlain by pre-Quaternary bedrock.

The gravel of the Niederterrasse derive from fluviale accumulation by braided rivers and are widerspread in more or less all glaciated and non glaciated valleys. Based on the model of the 'Glaziale Serie' (Fig. 1) the Niederterrasse is directly connected with Würm-Moränen (terminal moraines) in more or less all the valleys in the Eastern Alps which were affected by former glaciers (s. Figs. 4 & 5), as for example: the Salzach glacier (Weinberger 1955) and Traun glacier (Egger 1996; Egger & van Husen 2007). Many extensive remnants occur along the Danube and its southern tributaries as well as in the South along the rivers Mur and Drau and their tributaries (Krenmayr & Schnabel et al. 2006; Schnabel et al. 2003). Due to climate controlled congelifraction the Niederterrasse are also developed in non-glaciated areas.

Evidence for deposition in a non-glaciated area is found at Neurath (Stainzbach / SW of Graz) where a gyttja interbedded in gravel beds providing ^{14}C ages of 19,720 ± 390 ka BP and 21,270 ± 230 ka BP marks the end of sedimentation under periglacial conditions (Draxler & van Husen 1991). Based on the outlined processes the deposits of the Niederterrasse are correlated with MIS 2 and 3 and thus to Middle and Late Würm.

Tullner Feld

The name of the unit is derived from the city of Tulln and the unit was first described by Piffl (1971). The type area lies between Krems in the West and Greifenstein in the East on the ÖK 1:50,000 sheets 38 Krems an der Donau, 39 Tulln, 40 Stockerau (Fig. 6).

Lithologically, the Tullner Feld deposits consist of sand-bearing coarse gravel. The material is predominantly rounded and well-rounded. It was deposited by the river Danube. In particular a high content of crystalline rocks mixed with limestone, dolomite and sandstone is observed at the debouchment of tributaries in the southern part of the distributional area. The gravel deposits are horizontally layered with cross bedding. Wide-spread layers of sand occur particularly north of the Danube. Weathering is restricted to about the uppermost 50 cm. Gravel deposits south of the Danube display permafrost features like cryoturbation and ice wedges. Large and usually angular boulders of 1 m and more in diameter occur frequently at the base of the gravel deposits near the underlying bedrock .

The thickness of the terrace deposits varies between 10–20 m. An unconformity at the base of the gravel deposits marks the transition to the Neogene deposits of the Molasse Basin.

Sedimentological charateristics of braided river type, permafrost structures, and poor weathering in the area south of the Danube point to accumulation of the deposits during glacial conditions (Piffl 1971). On the contrary, the gravel deposits in the area north of the Danube show sediment structures typical for meandering rivers as a result of complete re-working of the glacial terrace by the river Danube. Such process took place without lowering of the surface and basal erosion level compared to that of the glacial terrace in the sense of the Niederterrasse. This re-working without incision by the river Danube resulted from the large debris load supplied from the tributaries while they eroded their local Niederterrassen deposits (van Husen 2000a).

The chronostratigraphic age of the sediments in the Tullner Feld is correlated with the Late Würm (MIS 2) for the area south of the Danube and with the Early Holocene for the area north of the Danube. The latter is supported by ^{14}C dates of about 9–9.7 ka BP which are obtained from tree trunks of oak, elm, poplar, and willow.

Prater Terrasse

The terrace was first discussed by Schaffer (1902), Fink & Majdan (1954), Küpper (1968) and Fink (1973). The type area of the Prater Terrasse (terrace) is the SE part of the island between Danube and Danube canal in the 2nd district of Vienna (Fig. 7; ÖK 1:50,000 sheet 59 Wien). The name is derived from an extensive and well-know recreation area in Vienna characterized by meadows and forest.

The thickness of the gravel deposits amounts some 10 m and the sediments are unconformable underlain by Neogene deposits of the Vienna Basin.

The deposits of the Prater Terrasse consist of coarse gravel and sand with predominantly rounded and well-rounded components transported by the river Danube. A high content of crystalline rocks mixed with limestone, dolomite and sandstone is observed particularly around the mouths of tributaries. In the Marchfeld north of the Danube the gravel shows horizontal layering and cross bedding while intercalated wide-spread layers of sand occur frequently. At some locations north of the Danube permafrost features like cryoturbations and ice wedges were described (Fink & Majdan 1954). The about uppermost 50 cm of the deposits are affected by weathering. At the base and partly also within the gravel deposits near the bedrock large and mostly angular boulders of 1 m and more in diameter occur frequently (Küpper 1950). These were transported and deposited by ice floes under glacial conditions.

According to braided river sediment structures and permafrost features as well as poor weathering the Prater Terrasse in the northern part of the Marchfeld north of the Danube was considered to represent glacial conditions (Fink & Majdan 1954, Küpper 1968, Fink 1973). In contrast the gravel deposits of the Danube south of this area are partly characterized by sediment structures of meandering rivers. The Danube has only reworked the material of the glacial terrace without lowering the elevation of the surface by erosion. This was due to the debris load the Danube had to carry from the tributaries, eroding their Niederterrassen (van Husen 2000a). Thus the northern parts of the Prater Terrasse are correlated with the Late Würm (Chaline & Jerz, 1984) and with MIS 2. Reworked terrace sediments are considered to be Early Holocene. Tree trunks (oak, elm, poplar, willow) especially in the Marchfeld north of the Danube were dated at about 8500–7000 ^{14}C years BP (Fink 1973).

Leibnitzer Feld, Grazer Feld

The names were introduced by Penck & Brückner (1909) as local expressions of the Niederterrasse. Descriptions were published by Winkler-Hermaden (1955) and Fink (1961). The type area is the Mur valley south of the city of Graz (ÖK 1:50,000 sheet 190 Leibnitz). The names are derived from the cities of Graz and Leibnitz (Fig. 4).

The gravel deposits of the river Mur consists of coarse material mixed with sandy and contain boulders. The sediment shows intensive cross bedding. The thickness is about 15 m. The deposits are unconformably underlain by Neogene sediments.

The gravel was deposited by braided rivers presumably during the Late Würm (MIS 2).

Long sections

Mitterndorfer Senke, Steinfeldschotter

The first description was given by Sueß (1862), Stiny (1932), and Küpper (1950). The type area is in the southern part of the Vienna Basin (location see Fig. 6; ÖK 1:50,000 sheets 59 Wien, 60 Bruck a.d. Leitha, 76 Wiener Neustadt, 105 Neunkirchen, 106 Aspang). The name of the Mitterndorf basin is derrived from the village Mitterndorf whereas that of the Steinfeld gravel originates from a field name SW of Wiener Neustadt. The Wöllersdorfer Schotterfläche (Brix 1988) is a synonym.

The Mitterndorf Basin was filled by two alluvial fans, the Piesting River fan in the north [former Wöllersdorfer Schotterfächer] and the Schwarza River Fan [former Neunkirchner Schotterfächer] in the south. Both alluvial fans show a characteristic alluvial fan cyclic sequence development of up to about 2 m thick fine clastic sequences which are alternating with massive, fine to coarse gravel (Salcher & Wagreich 2010). The uppermost coarse gravel unit of the whole sequence is called Steinfeldschotter. The thickness of the whole sequence is up to 170 m consisting of different units with thicknesses reaching up to ~35 m. It unconformably overlays Neogene sediments of the Vienna Basin.

The fine clastic facies assemblage is recognized in the lithology of a drillhole as brown to red brown loam or sandy loam with a varying gravel content. These loamy sequences are laterally extensive and can be correlated between wells across an area larger than 100 km^2. Such correlations allow the evidence of vertical tectonic movements. Massive, coarse sediments of alluvial fans are sheet flow dominated (bed load sheets). Close to the mountain front they are debris flow dominated. Coarse sediment deposition on the fan surface is supposed to occur during rather cold periods where intenisified periglacial influence leads to an increased sediment supply (Salcher & Wagreich 2010). Analogues from outcrops and a scientific cored drillhole (scientific THER-1) suggest that the loamy sequences represent overbank fines in most cases. Such fine clastic deposits are rich in terrestrial molluscs faunas and point to climatically rather warm periods. (Küpper 1950, Salcher & Wagreich 2010).

Preliminary results from mollusc assemblages of cored overbank fines from the bottom of the basin confirm a Middle to Late Pleistocene age of the sediments in the Mitterndorf Basin (Küpper 1950, Decker, Peresson & Hinsch 2005, Salcher & Wagreich 2010). Based on the characteristics of the sequence and luminescence dating results the infill of this tectonically formed Mitterndorf Basin may have started around MIS 7 (Salcher, personal communication). The youngest coarse gravel unit, the Steinfeldschotter is correlated with the Late Würm and with MIS 2.

Krems Schießstätte

The descriptions were given by Penck (1903), Hoernes (1903), Götzinger (1936) (Kremser Verlehmungszone), and Fink & Piffl (1976 a) for the type area at the eastern slope of Wachtberg North of the city of Krems (location see Fig. 6; ÖK 1:50,000 sheet 38 Krems a.d. Donau). The type section is situated in the local rifle range (German: Schießstätte).

Lithologically it is a 40 m thick loess profile with a sequence of paleosols. Molluscs of warm and cold periods (Ložek 1976) and remnants of tiny mammals (Rabeder 1976) were found. The deposit was formed in a lee position interrupted by weathering horizons (paleosols). According to paleomagnetic investigation (Koci & Kukla 1976) of the section started to develop at the end of the Olduvai event and was continuing through the Brunhes chron (Fink & Kukla 1977).

Stranzendorf

This section was described by Fink & Piffl (1976 b) and Frank & Rabeder (1997 a). The type area is in the southern part of Weinviertel (ÖK 1:50,000 sheet 40 Stockerau). The type section is east of the village of Stranzendorf (location see Fig. 6; N 48°27'10" E 16°05'20").

Lithologically the 40 m thick profile consists of gravel deposited by the Danube with a strong influence of a tributary from the South (Fink & Piffl 1976b, Frank & Rabeder 1997a). The section is overlain by a loess sequence with paleosols (Fink & Piffl 1976, Rabeder & Verginis 1997). A fauna rich in molluscs (Frank & Rabeder 1997a) and vertebrate (Nagel & Rabeder 1991, 1997) was found. According to the fossils the loess sequence was generally deposited under warmer conditions then during the Middle and Late Pleistocene. Changes from cooler and dryer periods (loess sedimentation) to humid and warmer periods with weathering (forest paleosols) occurred frequently (Frank & Rabeder 1997a).

The chronostratigraphic age is correlated with Gelasian and the earliest part of the Early Pleistocene after Frank & Rabeder (1997 a).

Hundsheim-Pfaffenberg-Deutsch Altenberg

Descriptions are given by Toula (1902), Freudenberg (1914), and Ehrenberg (1929). Since 1971 this site hs been intensively investigated by the Institute of Paleontology (University of Vienna). The type area are the Hainburger

Berge around Pfaffenberg (location see Fig. 6; ÖK 1:50,000, sheet 61 Hainburg) with type section in the quarry Hollitzer (Deutsch Altenburg) N 48°08'15", E 16°55'00" and in the Hundsheimer Spalte N 48°08'24", E 16°56'05".

Lithologically the unit consists of cave sediments like talus cemented by sinter, fluvial sand, loess, and transported soil material. A comprehensive and detailed description of the fossils is given by Frank & Rabeder (1997 b, c). The karst caves originating in Triassic carbonates were filled with different sediments due to changing sedimentation conditions over a long timespan. At least 50 spots were described (Frank & Rabeder 1997 b, c).

The chronostratigraphic age is assumed according biostratigraphic data (Frank & Rabeder 1997 b, c) to range from Middle Pliocene to Middle Pleistocene.

Discussion and Conclusions

The stratigraphic framework for the Quaternary of Austria (Fig. 3) summarizes our current knowledge on climatically controlled sedimentation as well as on tectonic processes like uplift or subsidendence. It provides guidelines especially for the classification of terraces of the Alpine foreland which are connected via the Glaziale Serie (Penck & Brückner, 1909) to the glacial sediments of the four well documented glaciations of Middle to Late Pleistocene age. Based on facies, weathering and position along the valleys the stratigraphic positions of separated terrace units can be established. However, such a correlation within the sedimentary inventory of Austria as well as with global archives is very difficult for the isolated and rarely found remnants of Early Pleistocene deposits. The only exception are sediments at Stranzendorf, one of the rare European sites where the Quaternary/Neogene boundary has been pinned down by paleomagnetic evidence. The correlation of lithological units related to the last glaciation (Late Würm) is possible based on well developed facies schemes and on glaciological considerations. However, such an approach has its limitations for sediments below the basal till of the last glaciation. An indisputable stratigraphic correlation of e.g. the "Vorstoßsedimente"/"Vorstoßschotter" is only possible if a continuous sequence including the transition to the basal till is evident like at the type section at Baumkirchen (Chaline & Jerz, 1984) or at similar locations. In the absence of absolute age dates one can never exclude the possibility that an unconformable contact represents a major hiatus and that the sediments above and below are of completely different age. Thus, the examples from both the foreland and the Alpine area illustrate that reliable physical datings by e.g. radiometric methods, luminescence, cosmogenic isotopes or paleomagnetics are strongly needed for deposits older than the last glacial climax and especially for Middle- to Early Pleistocene units to back up stratigraphic correlations.

From the formal stratigraphic point of view the Austrian record of Quaternary sedimentary units resembles a compound stratigraphy including aspects of lithostratigraphy (lithic characteristics) as well as of allostratigraphy (discontinuities/unconformities) for the definition of different units. However, a strict formalization of the terminology as outlined in the North American Stratigraphic Code (NACSN 2005) or by Salvador (1994) only seems to be an exercise in stratigraphy without any added value (compare Piller, van Husen & Schnabel, 2003). Thus at present we do not follow efforts of standardisation which elsewhere result in a plethora of lithostratigraphic subdivisions (e.g., British Isles; Bowen 1999a), which are partly "not amenable to systematic and widespread mapping away from their stratotypes" (Bowen 1999b). A stratigraphy of lithological units which is not applied in geological practise especially in maps is of limited value. In this context it has to be emphasized, that for example the youngest phase of the Quaternary (Würm Lateglacial to Holocene) is documented in geological maps not by stratigraphic units but mostly by lithogenetic unit. In the sense of GeoSciML (Concept Definition Task Group of IUGS CGI Interoperability Working Group 2008, Schiegel et al. 2008) these units such as alluvial fan or ice-marginal deposits are defined by their depositional origin as manifested by material properties. However, there is evidently a need for a critical assessment of the nomenclature especially for units of the Early Pleistocene which are not well described and defined (e.g. Arbesthaler Hügelland, Amstettner Bergland, Rauchenwarter Platte etc.).

In the absence of a regional alternative the MIS stratigraphy serves as a chronostratigraphic frame for correlations with climatic events especially for the Early–Middle Pleistocene. The high resolution record of Greenland ice cores has been applied as a standard for geological time only for some well constrained Late Würm especially Lateglacial sediments (e.g. Boch et al., 2005) and speleothems (e.g., Spötl & Mangini, 2002). The fragmentary sedimentary record in Austria as well as in the northern-alpine foreland, the occurrence of hiatuses and the missing of long records do not promote the development of a regional chronostratigraphy. Long loess sequences like at Stranzendorf and Krems Schießstätte would be candidates for standards, although they also include periods of non-deposition or erosion. The problem of cross-facies correlations and the need for reliable age dates remain within the terrestrial system.

Finally the current knowledge on Quaternary stratigraphy relies on the results of field work covering at most 60 % of the country mapped by modern standards. Hence, further improvements in stratigraphy can be expected from progress in geological mapping as well as from drillholes. New findings, modern re-investigations of type sections and areas as well as better geochronological constraints from modern dating techniques with reference to mapping results, are expected to improve this compound stratigraphy.

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