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The Pleistocene in Eastern Austria

JULIUS FINK
Hochschule für Bodenkultur, Vienna, Austria

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JULIUS FINK
Hochschule für Bodenkultur, Vienna, Austria

Abstract

Periglacial conditions were prevalent in eastern Austria during the Pleistocene; therefore, investigations have dealt mainly with terrace and loess features. In this area it is possible to compile a stratigraphy of the complete Pleistocene. The Pleistocene period consists of the "classic" Diluvium in the sense of Penck and Brückner and also of the pre-Günz times. Pre-Günz times lasted probably as long as the "classic" Diluvium: several terraces, accumulated in cold times, are preserved from this period. Large-scale down-cutting occurred in the "great" interglacial (Mindel-Riss) when, for the last time, intensive weathering took place. The Würm Glaciation is distinguished by many loess deposits with well-defined paleosols, originating from several paleoclimatic provinces. In spite of earlier opinions, a bipartition of the Würm must be assumed, with the Paudorf interstadial separating the two sections. The fossil soil of Göttweig was formed in the Riss-Würm Interglacial.

Zusammenfassung. Während des Pleistozäns lag das östliche Österreich zum grössten Teil im Bereich des periglazialen Klimas. Deshalb haben sich die Forschungen vor allem mit den Terrassen und Lössen beschäftigt. In diesem Raum besteht es die Möglichkeit eine Stratigraphie des gesamten Pleistozäns aufzustellen. Das Pleistozän umfasst das "klassische" Diluvium im Sinne von Penck und Brückner und einen wahrscheinlich ebenso langen Zeitraum vor dem Günz, von welchem mehrere, kaltzeitlich akkumulierte Terrassen erhalten sind. Eine wichtige Zäsur stellt das "Grosse" Interglazial (Mindel-Riss) dar, in welchem zum letzten Mal eine intensive Verwitterung vorhanden war. Die Würmeiszeit kann durch viele Lössprofile mit erkennbaren fossilen Böden aus verschiedenen Paläoklimaräumen klar gegliedert werden. Entgegen früheren Auffassungen muss eine Zweigliederung angenommen werden, wobei das Paudorfer Interstadial die beiden Abschnitte trennt. Die Göttweiger Bodenbildung entstand im Riss-Würm Interglazial.

Résumé. Pendant le pleistocène la plus grande partie de l'Autriche orientale se trouvait dans le domaine du climat périglacial. Pour cette raison les recherches ont porté principalement sur les terrasses et les loess.

Il existe la possibilité d'executer dans ces régions une stratigraphie de tout le pleistocène.

Le pleistocène renferme tout le Diluvium "classique" dans le sens de Penck et de Brückner et probablement un temps aussi long avant le Günz dont il y a plusieurs terrasses, qui furent accumulées pendant des temps froids.

Une interruption importante est représentée par Mindel/Riss, pendant laquelle il y avait une érosion intense (argile rouge) pour la dernière fois.

Grâce à beaucoup de profiles de loess la periode de Würm peut-être classée dans des différentes zones paléoclimatiques.

Contrairement à d'autres opinions, on doit subdiviser le Würm en deux parties. Le sol de Paudorf marque la séparation. Le sol de Göttweig s'est formé dans le Riss/Würm.

Contents

Introduction

The western and central part of Austria consists of high mountain ranges (western and central regions of the Alps), which during the Pleistocene were covered by large glaciers. In the western section of the country the glaciers advanced far into the foothills, forming big ice-tongue basins. In the central area, however, the glaciers of Enns valley did not reach the foothills, so that humidity must have been less toward the east. The glaciers advanced different distances during the various glacial epochs. Investigations by A. Kohl and L. Weinberger (unpub. ms.) show that within Austria the "Günz" glaciation had the same extent as "Mindel."[1] Riss and Würm moraines were formed one after another inside the Mindel moraines. This can be studied along the Enns valley glacier, where Würm terminal moraines reach into the transverse

[1] In Austria the "alpine" terminology by Penck and Brückner (1909) is still used:

younger Pleistocene	Würm	"Niederterrasse" (lower terrace)
middle Pleistocene	Riss	"Hochterrasse" (high terrace)
older Pleistocene	Mindel	"Jüngerer Deckenschotter" (younger nappe-like gravels)
	Günz	"Alterer Deckenschotter" (older nappe-like gravels)

The stratigraphic sequence of the Pleistocene is shown in Figure 2 and in Fink (1960).

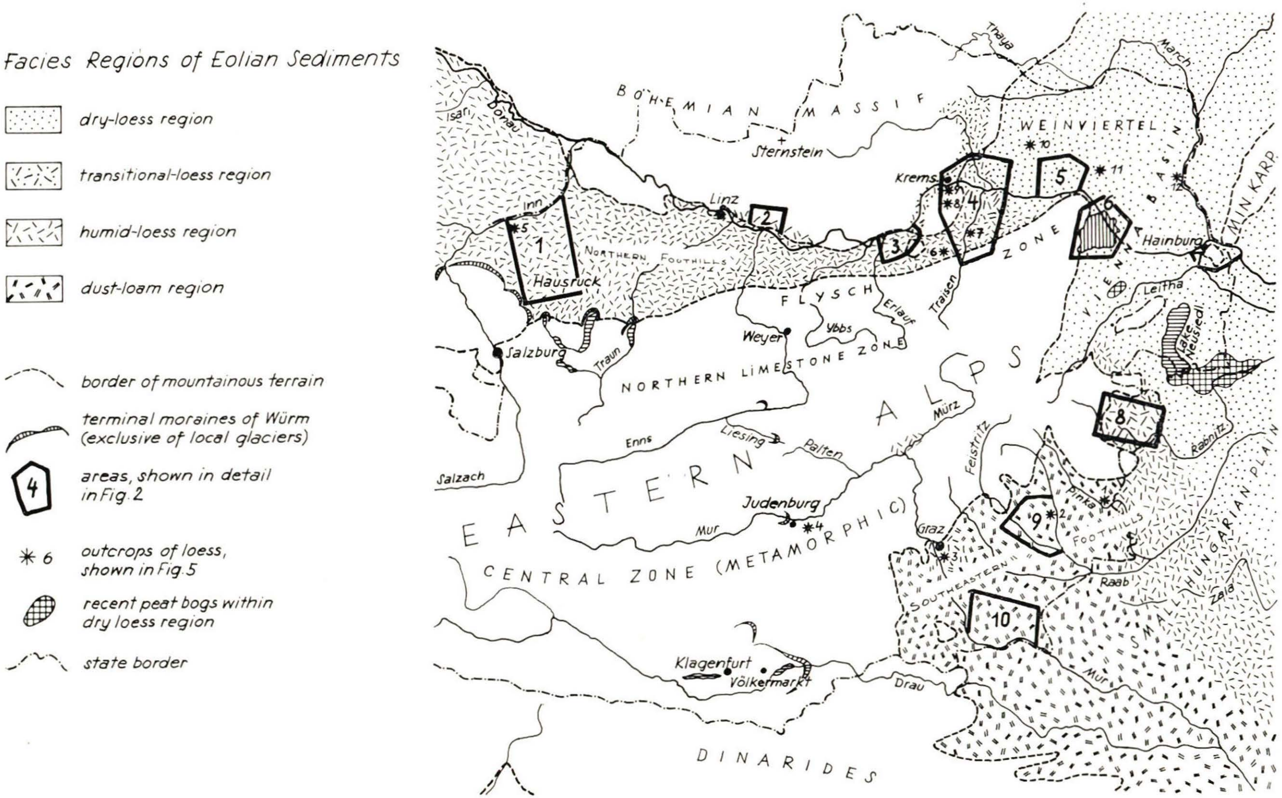


Figure 1. Generalized map of loess regions of central and eastern Austria

valley of the Enns River today (Fig. 1). Older terminal-moraine relicts may be observed even in the Weyer district, proving an old Pleistocene drainage into the Ybbs valley.

The glaciers of Mur and Drau valleys have a different history. During Würm glaciation the Mur glacier terminated west of Judenburg. This town is built on the sandr of the Niederterrasse. During Riss glaciation the glacier tongue extended no farther, and east of Judenburg the Hochterrasse with well-preserved cover beds occurs. Toward the east well-preserved younger Deckenschotter prove that Mindel glaciers also did not extend farther than the Würm glaciers. The Drau glacier in the Würm terminated at the eastern border of the Klagenfurt basin. Ground moraines of Riss glaciation are exposed in the clay pit east of Völkermarkt. Terminal moraines outside of the Würm ridges are uncertain.

With the exception of the valleys and basins mentioned earlier only local glaciers of minor dimensions existed. They occurred in the higher parts of the northern "Limestone Alps" as well as in the central metamorphic zone. The larger part of the eastern Alpine area as well as the adjacent foreland was free of ice, having formed under periglacial climate. The Bohemian massif was also sculptured under periglacial conditions but shows land forms somewhat different from those of the central Alps because the Bohemian massif is a peneplain. It is still questionable if the highest regions of the Bohemian massif have been covered by local glaciers; a niche on the east flank of Sternstein (elevation 1125 m) has been interpreted as a glacial cirque, and several boulder ridges as moraines. After close observation I believe that this question of glaciation must be answered negatively.

Relicts of intensive weathering (until Pliocene) under tropical conditions exist at several places, including kaolin deposits of economic interest. Various rocks (mostly coarse-grained granites) are deeply weathered, especially along faults and joints. Pippan (1955) describes the widely known debris cover as Tertiary. During cold periods of the Pleistocene frost cliffs and pillow forms were exposed by cryoturbation processes. Demek (1964) has discussed the mechanism of exposure.

In Austria as well as in other parts of Europe the accumulation of loess is confined to valleys. Loess was deposited even in the inner mountain valleys of the Alps. At the junction of the Mur and Mürz rivers and in the Mur valley near Graz several small islands of loess are known. Here climatic conditions must have been drier than along the relatively near margin of the Alps, where "Staublehm" ("dust loam") of eolian origin covers large areas.[2] All these sediments originated not only from the wide, vegetation-free

[2] The term Staublehm (dust loam) was introduced by Krauss and others (1939) and Krauss and Oelberg (1953) for fine-grained loamy sediments in Saxonia and the same sediments overlying the Deckenschotter in Suebia and Bajuvaria. Fink (1961b) described the same sediments from several

fields of the Niederterrasse but also from the periglacial landscape in which constantly new material was produced by periglacial frost-weathering. Mineralogical investigations of the heavy-mineral content gave specific spectra for the loesses originating from different erosional districts. The eolian accumulation is found up to elevations of approximately 450 m. This can be observed in the marginal areas of the Bohemian massif as well as in the Alps. The different facies in a vertical profile correspond perfectly to the sequence of dry to humid landscapes. Loess deposits on the Bohemian massif exist from its eastern border far into its central part. For the transportation of the loess east winds must be assumed. This does not exclude the presence of west winds but shows that the widely discussed question of east or west winds is complicated.

Terraces

During glacial epochs, especially in the first cool and wet stage, important morphological changes occurred in the periglacial landscape. Frost-weathering and solifluction produced large quantities of debris and gravel so that the rivers deposited thick fluvial terraces. Not only did larger streams connected with glacier tongues form terraces but small (autochthonous) streams did also. For example, the Perschling, a small river in the eastern part of the northern foothills of the Alps, produced gravel terraces of the same thickness as the River Traisen, a much more important stream that was fed by a local glacier (Fink, 1961a). The same phenomena have been observed in the southeast foothills of the Alps. Here autochthonous rivers such as the Raab, Feistritz, and Pinka show the same sequence of terraces as the Mur, which came from a glacier. The only difference between autochthonous and glaciofluvial rivers is the development of the Holocene level. The former did not deepen their beds in late-glacial time. Therefore, fine-grained fluvial sediments accumulated on top of gravel beds of the Niederterrasse. The latter deepened their beds considerably, following the melting of the glaciers, and their Niederterrasse became dry. The fine-grained alluvial sediments were deposited on a separate, deeply eroded level (Fink, 1961b).

In most cases in Austria, terraces of rivers can be clearly differentiated. This is important for Pleistocene stratigraphy because most of the significant prehistoric, palynologic, or paleopedologic exposures are located in the periglacial area, often several hundred kilometers from the former ice margin. These outcrops can be dated stratigraphically by fixing their

locations in Europe, especially from the surroundings of the Pannonian basins. Fink (1961b) defined dust loam as an eolian sediment, accumulated only in very humid regions of the periglacial areas. Figure 1 shows the transition of the dust-loam region to the other loess regions. Dust loam differs from typical loess and also from the so-called "loess loam" by its higher clay content and by the distinct indications of surface-water gley processes. The latter took place during the sedimentation.

position on the terraces. Many type localities are limited to certain terrace levels.

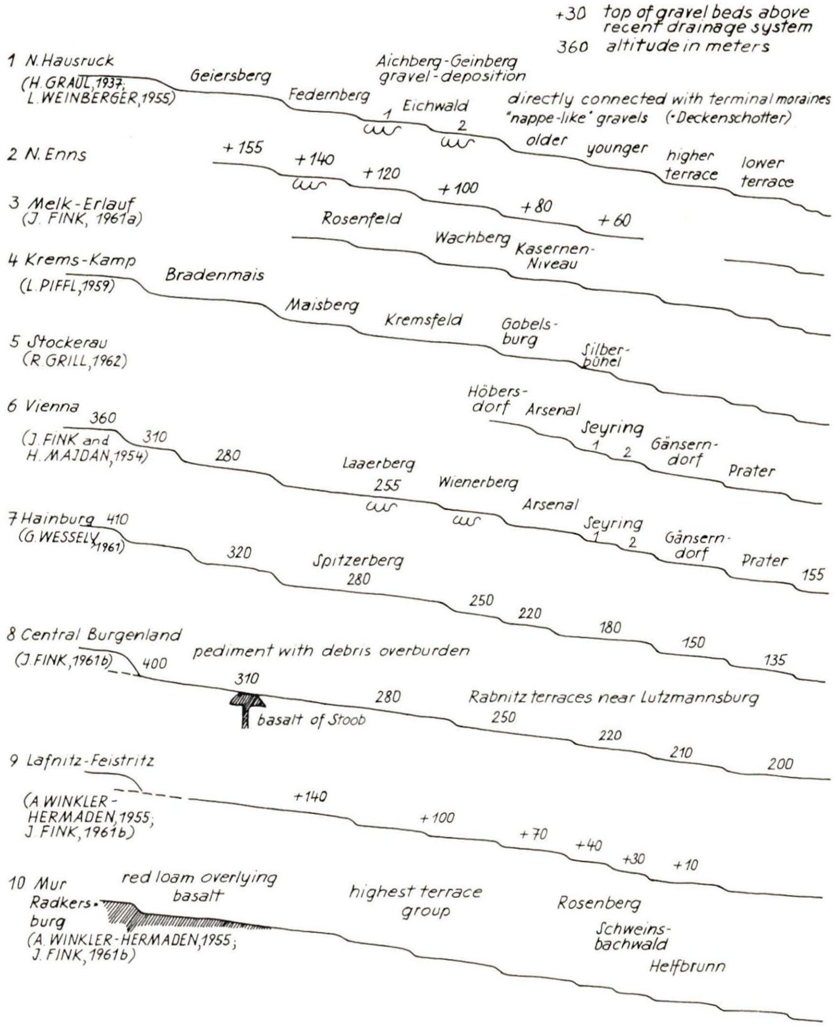
Terraces of the various glacial epochs normally have the same stratification. The gravels lie with sharp boundaries on the basement (mostly soft Tertiary rocks, locally harder strata). The basal layers of the gravels are formed of very coarse boulders, which must have been transported by ice blocks. A fossil soil lies on top of the gravel body, followed by eolian sediments such as loess and dust loam. The lower terrace (Niederterrasse) is the only exception to this sequence: there is, of course, no fossil soil and no loess, but the sharp boundary of the gravel body against the basement as well as the horizon of coarse boulders are always discernible.

Considering the proportional development of terraces of different ages, one can assume a genetic relationship. As a result of the gradual uprising of the Alps the rivers could erode linearly during the interglacial. With the beginning of glaciation soil frost produced large quantities of loose material; heavy rains brought sufficient water. The cool and wet period was called "solifluction-time" by Büdel (1950). In this stage strong lateral erosion dissected the older gravel beds into terraces. At the same time new material was accumulated.

Several terraces were brought together this way, and from these Penck and Brückner derived their widely used "alpine" terminology. These terraces are very important. Their sequence and correlation of local terraces is shown in Figure 2 (*see also* Fink, 1960, Table 2). For most topographic units local names are given, but in the western foothills of the Alps (the regions near the large glaciers) alpine terminology was used.

In the field one can see that several terraces lie on top of the "Ältere Deckenschotter." Similar terraces in the Suebian-Bajuvarian areas were connected with a "Danube glaciation" by Eberl (1930). The question of pre-Günz phenomena has been discussed in detail by Graul (1949) and Schaefer (1953). In Austria, pre-Günz terraces are preserved north of Hausruck (Fig. 2, cross section 1). They have been dated as "oldest Pleistocene," approximately "Villafranchian."[3] Along the Danube valley a multiform terrace-system shows that in pre-Günz times two or three independent cold periods normally occurred. Terraces from these periods have the same features as the younger terrace levels: syngenetic cryoturbations, coarse boulders at the base, fossil soils on top, *etc.* Their extension, their elevation above the Danube (Fig. 2), and their relationship to the younger terraces indicate that the time interval of the oldest Pleistocene was probably as long

[3] The term "oldest Pleistocene" was chosen because the time interval between Günz and today was divided during the INQUA Congress at Leningrad in 1932 into "young, middle, and old Pleistocene." Schaefer (1953) uses the term "oldest Diluvium." Consequently, the author introduces the term "oldest Pleistocene" for the pre-Günz terraces.



Upper Pannonian	Upper Pliocene	Oldest Pleistocene several pre-Günz glaciat.	Old Pleistocene		Middle Pleist.	Young Pleist.	Holocene
terrestrial:	Daz Levantin	Villafranca					
marine:	Piazenca Asti	Calabriano	Günz	Mindel	Riß	Würm	
Mastodonts M. longirostris	M. Borsoni M. arvernensis	Elephants					

Figure 2. Levels and terraces of the Alpine foothills, eastern Austria. Tertiary stratigraphy from Papp and Thenius (1959, p. 194–205), Quaternary from Fink (1960). For location of sections, *see* Figure 1.

as the time between Günz and today. It was impossible to show the true relationship of the time intervals in Figure 2 because the Pleistocene must be divided into two parts. In the first division, periglacial features are present (such as terraces with cryoturbations), but there are no terminal moraines to prove that glaciers existed. The second division corresponds to the "classic" Diluvium as defined by Penck and Brückner (1909), and glacial sediments of the various glacial stages of this division have been preserved. One could compare a time interval of "cold epochs" with periods of "glaciation."

Tectonic Effects on Land Forms

The terraces along the Alps are climatic; tectonic influences can be considered only for the Vienna Basin and the "Small Hungarian Plain."[4] Tectonic movements leading to the origin of the Vienna Basin occurred at the boundary between Helvetian and Tortonian. The basin subsided also during the Pleistocene. The Danube, after leaving the "Vienna Gates," accumulated its gravel in the form of a large alluvial fan. Within the city of Vienna the sequence of terraces is normal; the observable influence of tectonic movements is slight. Toward the east, however, gravel deposits of several glaciations are united into a single gravel fan. This partly reduced the terraces, making correlation very difficult. However, the tectonic subsidence of the Vienna Basin was not strong enough to form such crossing of terrace profiles as in regions of the "Small and Large Hungarian Plain" (Pécsi, 1958; 1960).

Recent subsidence is restricted to a few places, which can be seen in present-day soils. In the middle of the Pannonian climatic zone, in which chernozem and rarer solonchak soils occur, peat bogs locally can be found (Fig. 1). They are developed in centers of settling in which ground water accumulates. Muck can also be seen in these areas. Today they are mostly dry, with soils similar to chernozems. The peat bog east of Lake Neusiedl is important, showing the youngest center of settling in the "Small Hungarian Plain." This center originally was located in the middle of the "Small Hungarian Plain," where the Raab River now flows. All rivers in the southeastern foothills originally trended southeastward toward the tectonic longitudinal axis of the "Small Hungarian Plain." During the Pleistocene the center of settling moved toward the northwest. During the Riss-Würm Interglacial Lake Neusiedl was formed, and streams were diverted eastward or northeastward, toward the youngest center of settling. Vertical movements around the Neusiedl Lake made it possible for the Danube, after

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[4] For most terraces of the southeastern foothills of the Alps Winkler-Hermaden (1955) postulated eustatic fluctuations. The latter could have affected only the regions outside of the "iron gate" at the Danube. The hypothesis of Winkler-Hermaden would mean the acceptance of interglacial terraces alternating with glacial terraces. This is impossible because along the marginal zones of the Alps the same climatic conditions dominated.

reaching the "Small Hungarian Plain," to accumulate an alluvial fan during the Würm which extends into the area east of Lake Neusiedl.

Vertical movements within the basins have been strong. The adjacent mountains, however, have been relatively quiet or have undergone a movement *en bloc*. This is of great importance, since the northeastern margin of the Alps offers an opportunity to fix the time boundary between Pliocene and Pleistocene.[5] For this problem, mostly morphologic criteria must be used; sedimentologic or paleopedologic evidence is scarce. Levels at uniform elevations occur along the marginal zones of the Alps. These levels within the Vienna basin have been associated with regressional phases of the Pannonian Sea (Hassinger, 1905). True marine tidal flats certainly exist but are mostly exhumed Tortonian features, as Küpper (1958) showed. Most other levels in the vicinity of the Vienna Basin must be associated with analogous levels in the northern foothills of the Alps, which were not covered by the sea during Pannonian times. Pannonian and upper Pliocene land forms and sediments are well preserved at the easternmost part of the Central Zone of the Alps, which lies within "Burgenland," the easternmost province of Austria on the Hungarian border (Fig. 3). One may associate the morphologic features of the northern Vienna Woods (northeast part of the "Flyschzone") with the northern foothills of the Alps and the Bohemian massif and also with the southeastern margin of the Alps, especially the central part of Burgenland. New studies in the Vienna Basin are in progress. Therefore I refer only to the northern foothills of the Alps (Fig. 1) and the central part of Burgenland (Fig. 3). In this article the latest results of Riedl (1964) have not been considered.

In the northern alpine foothills levels as high as 400 m are considered upper Pannonian. At the marginal zones of the Alps these levels do not coincide with the lithologic boundary between the "Flyschzone" and the "Molassezone" (harder and softer rocks); they are therefore true pediments (Fig. 4, Probstwald). Such levels are widely distributed also along the Dunkelsteiner Wald and in western Weinviertel. At Weinviertel they cut into the Hollabrunn gravel fan, which accumulated in the lower Pannonian. Upper Pannonian levels have an elevation of 400 m (the sea level of the Vienna Basin was at 360 m at this time). The upper Pliocene levels along Traisen valley have an elevation of 360 m; they are covered locally by coarse gravel. The highest Pleistocene terraces have an absolute altitude of approximately 300 m. At Maisberg, within the oldest Pleistocene gravel beds, remains of *Elephas planifrons* have been detected. This fossil indicates an oldest Pleistocene age for this terrace (relative altitude 140 m; Fink, 1961a).

Central Burgenland is surrounded on three sides by mountainous terrain

[5] This problem is hard to solve because the stratigraphy of the upper Pliocene in southeastern Europe is still full of questions. The main difficulty lies in the fact that the marginal zones of the mountain ranges have been areas of erosion, whereas the Pannonian basins were filled with sediments.

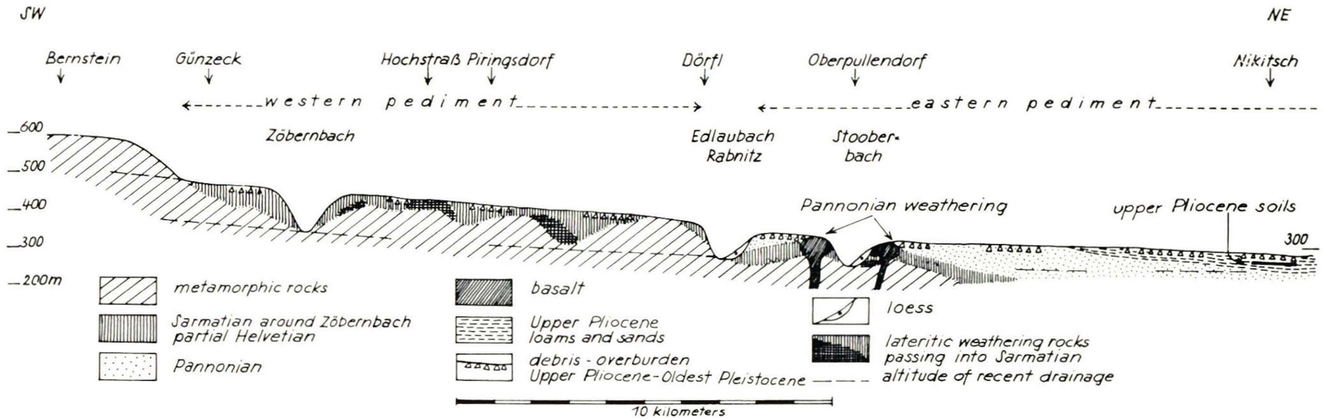

Figure 3. Schematic geologic cross section along the central Burgenland, eastern Austria

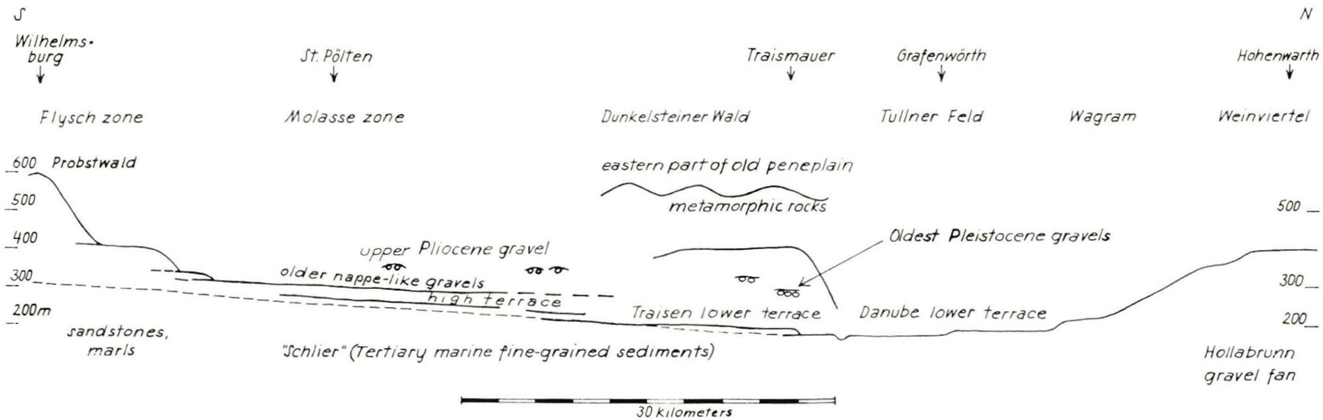

Figure 4. Schematic geologic cross section of the Traisen Valley and Weinviertel, eastern Austria

and is drained by small streams only (Fig. 3). The old land forms are therefore well preserved (Fink, 1961b). Two large pediments occur, on the west and east.[6] Both plains have a different altitude along the line of the cross section in Figure 4. Farther southeast, however, near the state border, both plains converge. Both pediments are covered by a thick and extensive layer of debris, resting on various Tertiary rocks. The easternmost strata, dated by Winkler-Hermaden (1962) as Dacian, resemble "cross-bedded sands" from the eastern and southeastern margin of the "Small Hungarian Plain." The pediment continues at Lutzmannsburg (Fig. 2) into the highest terrace of Rabnitz. Central Burgenland is therefore a model for the land forms of the marginal zones of the Alps: *Quaternary terraces are cut into the youngest pediments.* Generally, the process of landscape evolution that occurred under tropical-subtropical humid conditions as well as under semiarid conditions changed at the end of the Pliocene into a fluviatile period, leading to the formation of terrace steps in the rhythm of cold and warm times.

This process differs slightly along large streams such as the Danube, where fluviatile action started earlier, probably in upper Pliocene. In isolated areas like central Burgenland the process of pedimentation continued until oldest Pleistocene.

Correlation of Terraces and Moraines

Terraces are the most important tool used in the field to divide the Pleistocene in Austria. Terraces differ widely in their morphology, in their relative altitude, and in their overburden of fossil soils and other sediments. We propose the following scheme, based on the "classic" stratigraphy:

Würm	Niederterrasse (lower terrace)	morphologically undisturbed	no fossil soil
Riss	Hochterrasse (higher terrace)	cut by small valleys	fossil soil, typologically similar to recent soils
Mindel and older	Deckenschotter (nappe-like gravels) and older terraces	strongly dissected by valleys	ferretto formation in upper part of gravels

This scheme was adopted primarily for the northern foothills of the Alps,

[6] The western pediment is geologically interesting. It cuts an old Sarmatian surface with signs of intensive tropical weathering; laterites can be observed *in situ* near Hochstrass.

but it is valid also for the southeastern marginal zones of the Alps. In the latter region the periglacial processes are less marked. Dry valleys and cryoturbations in the terraces are rare. The cover beds differ completely: loess is abundant in the northern foothills, whereas in the southeast only dust loam can be observed. The Mindel-Riss interglacial marks a significant change; it is rightfully called the "great interglacial." Extensive weathering and long duration are important: the latter permitted a strong linear erosion. Riss terraces, therefore, lie at lower elevations. The Riss glaciation was much less prominent, and terraces are restricted to the valleys. Gravel accumulations of Günz and Mindel represent widely extended "nappes" (nappe-like gravels, "Deckenschotter"). The terminal moraines of Riss glaciation, less significant than Mindel moraines, are sunk into Mindel tongue basins.

It is an important fact that several terminal moraines belong to the same glaciation. Their gravel beds unite to form a single terrace a few kilometers outside their ice margin. This proves that *in periglacial regions each glaciation is represented by a single terrace*. Only the lower terrace apparently is divided: it is dissected by late-glacial or early Holocene erosional terraces without stratigraphic value. The younger terraces have better-preserved cover beds. Their fossil soils offer the possibility for stratigraphic determination. The Mindel and especially the Riss terraces exhibit a clear stratigraphy in their cover beds. In the same way, it is possible to identify the Würm glaciation by its cover beds. Figure 5 shows typical profiles that have stratigraphically fixed terraces.

Most fossil soils lie directly on the gravel body of the preceding glacial epoch. One assumes that in late-glacial times, after accumulation of the gravel, rivers eroded linearly so that the gravel body could not be covered with fine-grained fluvial sediments. This differs from the recent soils of the valley bottom, which lie on top of (mostly thick) fine-grained fluvial sediments that cover the basal gravel beds.

The results of weathering in the "great interglacial" are much stronger than in the Riss-Würm interglacial: limestone and dolomite pebbles are dissolved to a depth of about 70 cm, and only metamorphic rocks and sandstone fragments are preserved. The gravel of the higher terraces ("Hochterrasse") is less intensely weathered. The degree of weathering corresponds to that of today; this is true also for interglacial soils originating from loess or dust loam. Figure 5 shows several loess profiles, selected from various paleoclimatic regions. Riss-Würm soils correspond perfectly with modern soils. Only the "dry loess region" (explanation follows) is different, having steppe-type soils today, whereas in the Riss-Würm interglacial a distinct forest-soil type was present.

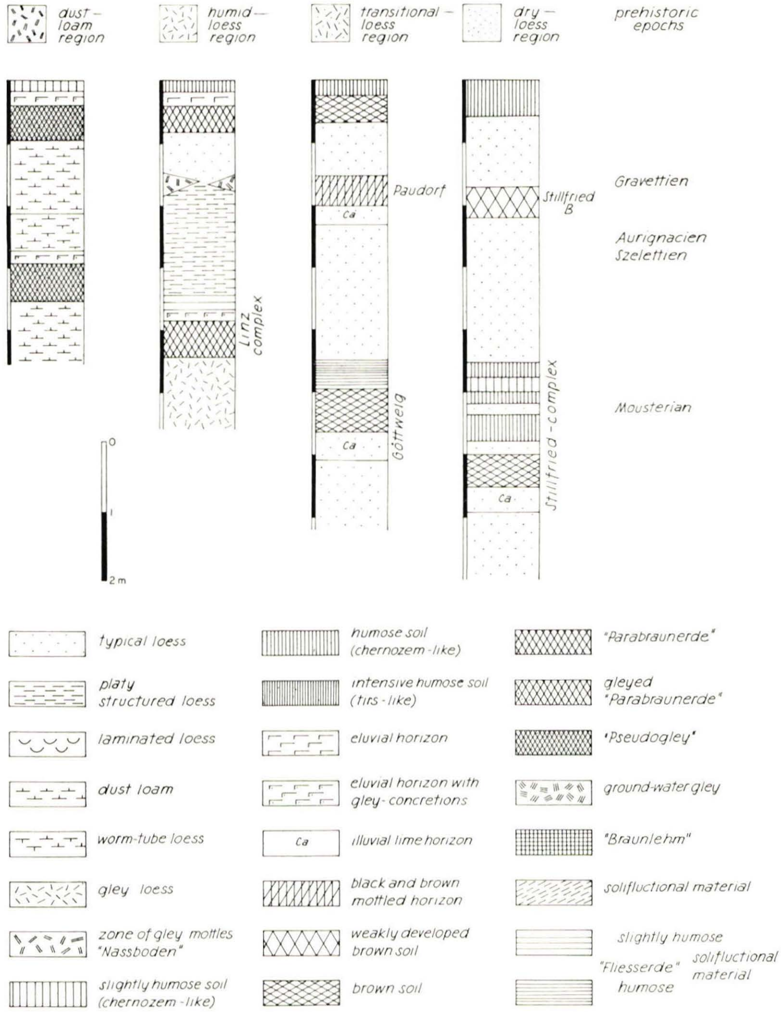

Figure 5. Standard loess profiles in Austria. For location of outcrops, *see* Figure 1.

Paleosols and Eolian Sediments

Because investigations of fossil soils are an important branch of Quaternary research, some general remarks are warranted before the cross sections shown in Figure 5 are discussed. Modern paleopedologic investigations are based on several concepts:

(1) Recent soils show great variations because of different relief, parent

material, and climate. The same important variations are true also for paleosols.

(2) Pleistocene eolian sediments have been deposited in various paleoclimatic areas and therefore vary widely. These sediments are visually and analytically distinct but show clear patterns in their regional disposition.

(3) Within the same paleoclimatic unit various sediments and soils have been formed corresponding to the various climatic phases of a glacial epoch. Today these soils and sediments, one above another, can be found in vertical sequence.

Recognition and determination of paleoclimatic units are the key for further studies. Within Austria, four paleoclimatic regions can generally be distinguished (Fig. 1). Fink (1956, Fig. 1) distinguishes three paleoclimatic units within the northern foothills of the Alps. The southeastern foothills form the fourth unit. The "transitional region" between the "dry" and the "humid" loess region is relatively narrow but very significant because of its well-known type localities (Paudorf, Göttweig, Krems).

The paleoclimatic regions of Austria, which correspond approximately with geologic facies, continue into the adjacent countries. The humid loess region of the Austrian northern foothills reaches into Bavaria, the dry loess region into Slovakia, and the dust-loam region into western Hungary and Croatia.

Certain paleosols and eolian sediments dominate within these particular regions. A facies differentiation of soils and eolian sediments can be observed (Fig. 5; Fink, 1962b). This concept is certainly valid for all European countries as well as for all parts of the world in which Pleistocene eolian sediments have been deposited. A comparison of loess and dust loam is shown in Table 1.

Both these sediments of eolian origin are final products of a continual process. Earlier, they were not recognized as genetically connected, but today we know several exposures from which facies relationships can be derived. Particularly the sediments of the latest glaciation have been studied in detail. Again, the sequence of soil profiles determined in Austria is significant for all other European areas.

A general outline of the latest glacial sedimentation within the four facies regions of Austria is given in Figure 6 (*see also* Fink, 1956, Fig. 5; 1961a, Fig. 9). In each region the Riss-Würm interglacial soil has a distinct typological development: in the dust-loam region it is a pseudogley, in the humid-loess region a "Parabraunerde," and in the transitional-loess region and in the dry-loess region a brown soil. With the exception of the dry-loess region the named soils correspond to modern soils. The sediments of the early glaciation differ distinctly. In the dry-loess region normal chernozems with intercalated loess dominate. In the transitional region are tirs-like soils and humic solifluction soils, in the humid-loess region are slightly humic solifluction soils, and lastly in the dust-loam region are sediments with platy structure and abundant clay coatings, earthworm tubes, and excrements. I called the latter type "worm-tube loess." It shows that during the early glaciation soil development was possible even during dust accumulation.

TABLE 1. PROPERTIES OF LOESS AND DUST LOAM

	Loess	Dust loam
Clay content (grain size smaller than 0.002 mm)	less than 10 per cent	more than 20 per cent
$CaCO_3$	5–30 per cent	0 per cent
Structure and soil fabric	abundant pores (capillary cavities, mostly calcified), massive	few pores, large prismatic and thick platy structured, many coatings of clay
Color	yellow	abundant Mn and Fe concretions and reduction-spots and thus a mottled pattern

The same can be said of chernozem and solifluction soils of the other facies regions.

A differentiation of facies can be observed in the sediments. Whereas true loess has been deposited in the dry-loess and the transitional regions, carbonate-free loess and dust loam (both with laminated structures) prevail in the more humid regions. The most significant interruption during the Würm sedimentation then followed. Within the dry loess region light brown steppe soils were formed (Stillfried B). In the zone of transition, however, a humic and brown mottled soil of peculiar appearance can be observed (Paudorf). In the humid loess region, a zone of gley mottles ("Nassboden") is found. In the dust-loam region, where Würm sediments are only 2–2.5 m thick, no exact marker bed has been observed. Above this hiatus true carbonate loess follows not only in the dry loess region and in the transitional zone but also in the humid loess region, proving that in the humid region dry periods also occurred. In the dust-loam region this time period is marked by dust loam with vertical, narrow, polygonal network. This dust loam also forms the subsoil of the present pseudogley, which covered the prismatic particles

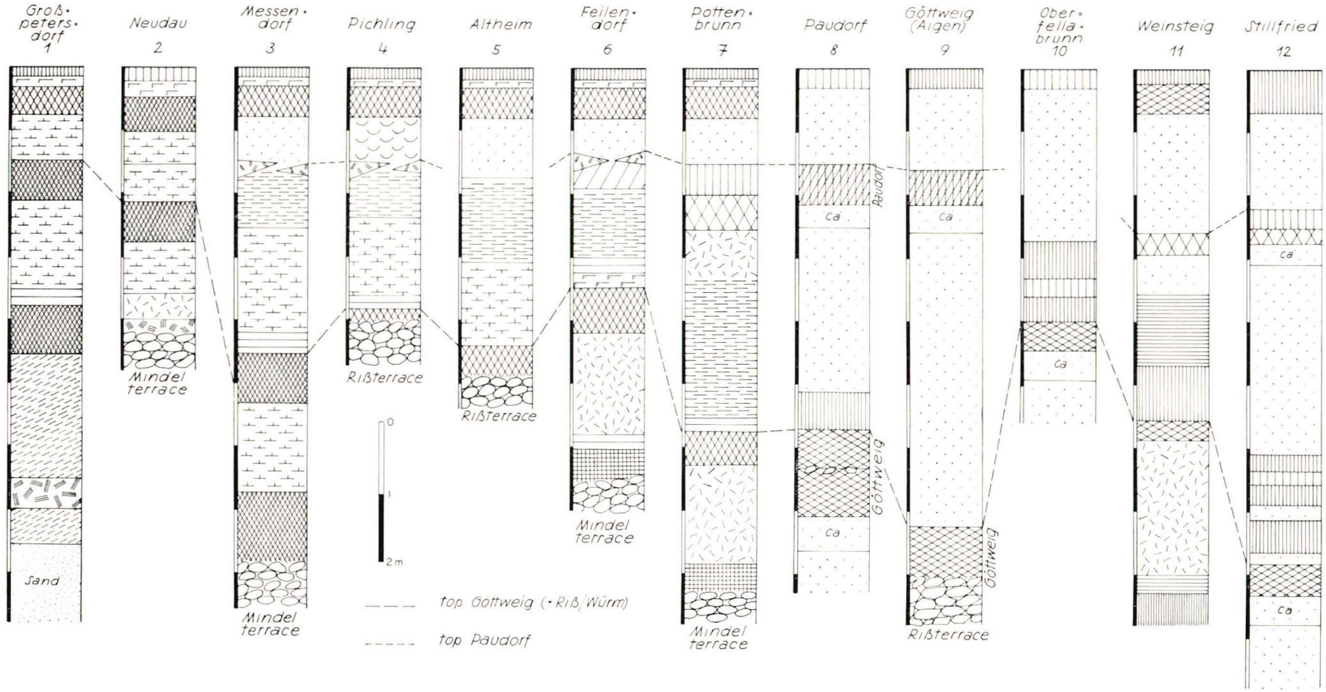

Figure 6. Schematic profiles of Austrian loess regions. For explanation of symbols, *see* Figure 5.

originating from polygonal cracks with thick reductional crusts. The polygonal network indicates extremely cold temperatures for this phase of Würm Glaciation.

The color of loess within the transitional region is interesting. The loess *below* Paudorf is brownish, and *above* Paudorf is grayish. Similar observations can be made also in other European areas, showing a distinct change of climate within the Würm Glaciation—generally in the first part cool-wet conditions, and in the second part dry and cold (Büdel, 1950).

Subdivision of Würm Glaciation

The clear sequence of soils and sediments and their connection with terrace gravels permits stratigraphic conclusions. We know today that the *Göttweig soil is Riss-Würm Interglacial* because it can be correlated with the top of the Riss terrace (Wright, 1961) and because it is typologically a distinct forest soil that did not occur during the Würm Glaciation. Furthermore, several important loess deposits in Austria have been studied palynologically (Frenzel, 1964). The results confirm the field-geological evidence. For several years radiocarbon dating has been in use (Felgenhauer and others, 1959; Fink, 1962a).

The Würm Glaciation is divided into two parts, the Paudorf representing the most important interruption. The period of maximal glaciation took place in post-Paudorf time. Therefore, and by comparing American results, we can rightly speak of "Würm Age" and "Würm Glaciation" (*see also* Flint, 1963; Frye and Willman, 1960; Leighton, 1965; and others). During the glacial maximum most of the circulating water was transformed into ice, the sea level was lowered, and dry cold conditions prevailed also in the humid loess regions. On the contrary in pre-Paudorf times a cold-humid climate dominated. The accumulation of loess was interrupted many times by development of soils that had been only slightly weathered, as shown by the early Würm chernozems of the dry loess region. These early Würm chernozems probably equal the palynologically well-defined interstadials of Amersfoort and Brørup. *This "bipartition" of Würm differs strongly* from the theory of Penck (1922) and others, who did not recognize any interstadial during the Würm. It also differs from Soergel's (1919) theory of tripartition, accepted by many authors, mostly prehistorians.[7]

In trying to discover how the erroneous theory of a tripartition could have been adopted so widely we must consider the geographic position of the various fields of research. Previously, the main interest was focused on glaciated regions. Only after the INQUA Congress in 1936 did investigations of periglacial areas gradually begin. In glaciated regions only the records of

[7] The difficulty in the terminology for the proposed bipartition of the Würm rests mostly on the fact that all terms in use are based on a tripartition.

maximal stage of glaciation, the terminal moraines, are visible. Local climatic or topographic factors often make regional investigations of glaciated areas difficult.[8] The long and fluctuating phases of glacier movements generally lack interpretable traces. Therefore the correlation with loess deposits comprising the maximum cold time led to fatal errors. Correlation with various sea levels also can lead to incorrect conclusions. The confusion culminated when the same symbols were used for both the terminal moraines of different regions and the Würm stratigraphy of Soergel.

Recent results of these loess studies are a big step toward exact stratigraphy, especially for the latest glaciation. However, one should not overestimate their importance for an interpretation of the older stages of the Pleistocene, because (1) there are too few exposures with old soils, and (2) eolian sediments and soils are easily eroded and seldom preserved. On the basis of my experience in the INQUA Subcommission for the Stratigraphy of Loess I believe that paleopedologic methods will render safe stratigraphic data for the younger Pleistocene, including the Mindel-Riss Interglacial. Only the beginning of a glacial epoch cannot be determined exactly because of intensive redeposition by solifluction. For an exact determination of the phases of the early glacial and also for the end of the interglacial, one should consider outcrops in resistant sediments such as travertine. In Austria travertine deposits are rare; all have been studied stratigraphically except the one in the Erlauf valley. The well-known locality of Weimar-Ehringsdorf in East Germany records a cold phase in the late interglacial. Such time marks in interglacial soils are visible only in special circumstances. Certain profiles in the transitional-loess region, in which the Riss-Würm soil occurs twice partly divided by a solifluction layer, may offer a possible comparison with the type locality of Weimar-Ehringsdorf.

Single phases of the late-glacial in eastern Austria cannot be reconstructed easily, because the development of soils in the foothills began very early, during a time when the ice fields of the Alps were gradually melting. Many soils were already in their present form in the late-glacial. The youngest strata in some sediments such as loess, deposited near areas of eolian erosion (that is, near lower terraces), show an alternation of soil formation and sedimentation. Such cases are exceptional, because in most places the accumulation of loess finished with the end of the maximal extension of the glaciers. Proof of late-glacial fluctuations in eastern Austria has been found only in peat deposits. Klaus (1960) could identify the Alleröd interstadial interval in the Bohemian massif and could connect it with other central European peat deposits. Morphogenetic processes in the Holocene are very slight. The

[8] The numbers of terminal moraines of the Würm glaciation in Austria differ widely in the various glaciated regions. The Salzach glacier generally has three Würm terminal moraines (Weinberger, 1955). From the Mur glacier two glacial stages have been described by Spreitzer (1953). From the Drau glacier we have to assume four to five independent terminal moraines (Bobek, 1959; Lichtenberger, 1959).

rivers compensate their longitudinal segments, eroding in segments of tectonic uprising and meandering in segments of tectonic subsidence. Coarse material is transported only in the river beds. High floods deposit only fine-grained alluvium. Some erosion takes place even in densely cultivated areas and especially in loess areas, but it never reaches the amount of soil erosion that is found in the American Midwest. Vegetation on the thick soil cover protects the surface of the landscape, resembling interglacial conditions.

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