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Alpine foreland-problems of Quaternary stratigraphy, nomenclature and interpretation

Předpolí Alp – problémy stratigrafie kvartéru, nomenklatury a interpretace

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Abstract: The alpine foreland has always been for many years one of the key regions for the study of European Quaternary. The quadriglacial system introduced by PENCK and BRÜCKNER (1909) influenced for decades the Quaternary studies not only in the alpine foreland, but their nomeclature has been used on a broad scale exceeding the Alpine foreland and has been used sometimes even on other continents. New studies led to the refinement and extension of this system and new glaciations were added. In spite of that many problems persist in particular in the mutual correlation of different stratigraphic schemes in the Alpine foreland as well in the correlation with the extraglacial area.

The use of different stratigraphic systems makes the mutual comparison of different regions difficult. The stratigraphic terms as introduced by Penck and Brückner are being used in different way by the authors working in different regions.The river terraces of Günz to Würm age are regarded by some authors to fall fully within the Brunhes Palaeomagnetic Epoch i. e. Middle to Upper Pleistocene, by others the Günz and Mindel are asigned to Matuyama Chron i. e. to Lower Pleistocene. The stratigraphy of the Quaternary sediments in the alpine foreland is being discussed and the author proposes to abolish the classical system and to introduce a new one, taking more into account the climatic cycles as reflected in the deep sea stratigraphy.

The Quaternary sedimentation and the landscape were strongly influenced by tectonic movements. The first tectonic phase, dated about 2.4 Ma and situated close or within the Gauss-Matuyama reversal, led to pronounced changes in the landscape and to the lowering of the base levels of erosion as well as to the uplift of mountain chains. In the alpine valleys the Lower Pleistocene sediments including those of oldest glaciations have been preserved. The Lower Pleistocene sediments of the Matuyama age have been described from the sunken area in the Lower Rhine region.

The second tectonic phase led to the formation of deep valleys, stretching from the north European seas to the Alpine foreland. It precedes the first north European glaciations and may be of precromerian age.

The regional tectonic movements were bound to different tectonic units and affected the region in different places and in different way. The stratigraphic evaluation of river terraces based on geomorphological observations only and disregarding other factors have led, (structure of fluvial and glacifluvial terraces, erosion, overlying and underlying formations,) to erroneous stratigraphic assignement of moraines, glacifluvial and fluvial sediments.

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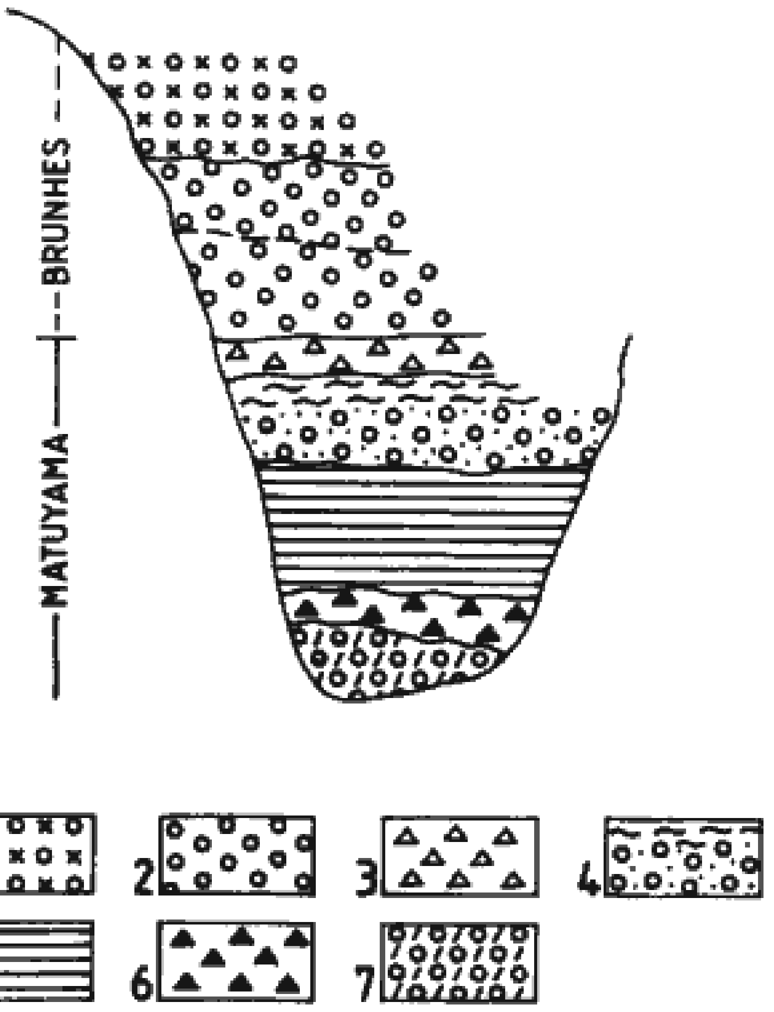
Introduction

The new studies of the Quaternary in the alpine foreland in the second half of the last and in the first years of this century led to the new interpretation of Quaternary stratigraphy in the circumalpine area. The alpine stratigraphy approached the polyglacial system as known from the extraglacial areas and areas of inland glaciations as recorded in the loess stratigraphy, development of the fluvial deposits and the sediments of continental glaciations. The organic interglacial sediments as well as weathered horizons made it possible to refine the alpine Quaternary stratigraphy and to compare the stratigraphical sequences in the northern and southern foreland of the alpine mountain chain.

The Quaternary stratigraphy in the northern Alpine foreland has been for many years based on the quadriglacial system of PENCK and BRÜCKNER (1909). Later on older glaciations, Donau (EBERL 1930) and Biber (SCHAFFER 1953) were added. Nevertheless the concept of four glaciations following the Donau glaciation remained unchanged for many years and defended by many authors up to present days. This system was not comparable with existing polyglacial systems neither in the extraglacial area and in the area of inland glaciations nor with the loess stratigraphy as in the foreland of the Alps or in the European extraglacial area. These differences led to some attempts to explain them the by crustal movements, regional tectonics or by quite different conditions of Quaternary sedimentation in the foreland of the Alps and in the remaining part of Europe.

The attempts to refine the Penck's and Brückner's system can be traced back to the twentieths of the last century, when Eberl and Knauer subdivided the Penck's



1. Scheme showing the sequence of Lower and Middle Pleistocene deposits in the alpine valleys. 1 – Middle Pleistocene glacial sediments, 2 – "Ceppo" sediments (Ceppo de la Olona in Italy underlain by Ceppo de la Bevera), 3 – till (the second glaciation in the Matuyama Epoch), 4 – glacifluvial sands and gravels with ice tectonic deformations on the top, 5 – glacilacustrine silts and shales, 6 – till (the first glaciation in the Matuyama Epoch), 7 – fluvial (glacifluvial) gravel and silt (using data published by Uggeri et al. 1995).

and Brückner's glaciations in more independent stages separated by warm, interglacial periods. But this observation remained unnoticed for a long time. Still to the end of the seventieth we encounter a strong defence of the quadriglacial system (Fink 1979, see Šibrava 1997). Neverthelees, new glacials and interglacials have been gradually added to Penck's and Brückner's glaciations, like "Haslach" glaciation described by Schreiner and Ebel (1981). The stratigraphic position of the Haslach glacial may be compared with the position of the "Weisse Nagelfluh" as described by Kohl (2000). Thus the typical four glaciations approach has been seriously shaken. The Penck's and Brückner's nomenclature – but it cannot be said the quadriglacial system itself – has been used by Ellwanger et al. (1995) in their stratigraphic chart, using the term "Complex" for grouping both glaciations in some type of higher units (Riss-Würm Complex comprising glaciations from Early Riss to Upper Würm) , and two "Deckenschotter Komplexes" the first one with Mindel-Haslach and Günz Complexes, the second one comprising Donau and Biber cold periods, also regarded as complexes. Nevertheless, this classification is still partly based on the original alpine system with one glaciation (Haslach) added. As to the magnetostratigraphy, the Mindel glaciation is situated within the Matuyama Epoch, i.e. within Lower Pleistocene, which represents a substantial difference compared with the classification of other, in particular Austrian authors (see below) as well as with the recently used L/M Pleistocene boundary.

Recently Kovanda (this volume) on the basis of palaeomalacozoological research and in particular of the position of the Fagotia fauna and its relation to alpine glaciofluvial sediments points out the differences in so far accepted stratigraphical assigment of alpine terraces. His palaeontological observation is supported as well by the loess stratigraphy. The Fagotia fauna according to Kovanda does not appear in the horizons postdating the warm period marked by the pedocomplex PK 7 in the loess sequence in the extraglacial area. In that way, the so-called High terrace (Hochterrase) on the locality of Moosburg (Germany) as well as at other localities in the alpine foreland, attributed according to the classical scheme to the Riss Glacial Stage may be substantially older.

In the southern foreland of the Alps the Quaternary stratigraphy as reflected in the papers of Italian and French scientists shows a different picture and a stratigraphic correlation between the northern and southern alpine foreland is still difficult. Most of the authors do not use the Penck's and Brückner's system, introducing their own local stratigraphic schemes instead. More glacial and interglacial cycles have been described by Billard (1982, 1983, 1995) and others. The Quaternary stratigraphy has been studied on the base of the lake deposits in the Leffe basin in norhern Italy (Lona 1950, Ravazzi, Strick 1995) and others, which made it possible to define more climatic oscillations within the Matuyama Epoch.

In contrast to the northern foreland, the river valleys in the south provide evidences for Pleistocene glaciations from the onset of the Quaternary. In the Fornace valley the till horizon cutting basal sediments of the socalled Unita della Fornace has been described by Uggeri et al. (1995). The till constitutes the base of the so called Vivirolo Formation attributed to the isotopic stage 96–100 with the estimated age 2,4 Ma, close to the Gauss-Matuyama palaeomagnetic boundary. Uggeri et al. (1955) regard this oldest glaciation as being of Pliocene age in accordance with the position of the Plio-Pleistocene boundary reccomended by the Comission on the Plio-Pleistocene boundary. The author of this paper prefers the boundary at the Gauss-Matuyama reversal (see Šibrava 1992).

Corresponding formations have been described from the Olona valley. They probably correspond in age with glaciomarine sediments in the Ivrea amphitheatre described by Carraro et al. (1975) indicating the first climatic deterioration and the first glacial advance in the Alps (see Šibrava 1997).

The stratigraphical sequences both in the northern and southern foreland of the Alps provide evidence for repeated climatic changes and glaciations through the whole Quaternary. Nevertheless in the north the evidence for the Early Pleistocene glaciations-till has not been identified so far and cold glacial periods are reflected in fluvial (glaciofluvial) deposits only.

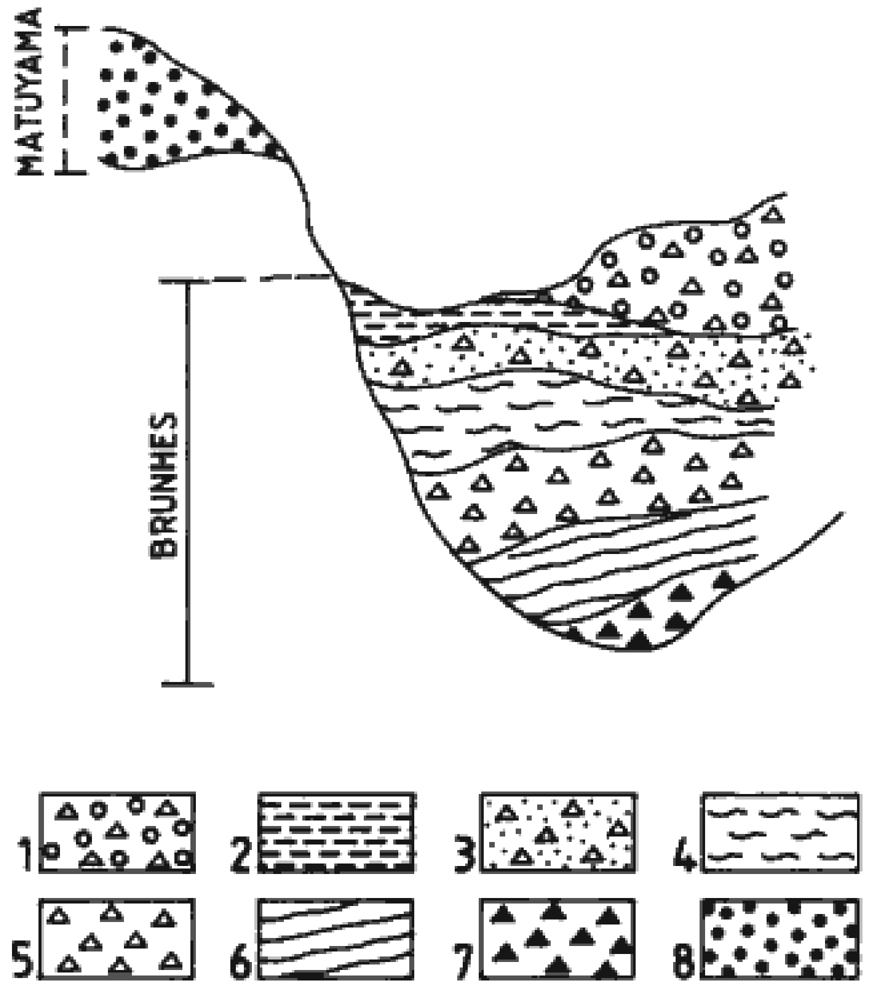
The stratigraphic correlation of the Quaternary in the northern and southern alpine foreland may be based so far on the paleomagnetic correlation, and in some areas on the palaeopedological comparison only. In addition, the stratigraphic studies in the northern foreland are complicated by using stratigraphic terms, that were introduced one hundred years ago. The classical names for alpine glaciations derived from the names of alpine rivers – Günz, Mindel, Riss and Würm are widely used for stratigrahic classification of Quaternary deposits – without having stratigraphic definition not speaking about type sections. Thus, the terms Günz, Mindel etc. may be used and are used, for gravel accumulations of different age. On the other side, the fluvial and glaciofluvial accumulations proved to be more complicated than has been supposed, the superposition of two ore more fluvial bodies separated by interglacial horizons, interglacial fauna in gravel deposits, tectonic movements and other factors make the stratigraphic interpretation more difficult.

The Penck's and Brückner's persisting quadriglacial system influenced the alpine stratigraphy for decades and still is defended, even if with some additional changes, by many authors. Nevertheless by comparing the stratigraphical schemes of the authors using this nomenclature, we find substantial differences.

Fink (1976 and others) regard the four Penck's and Brückner's glaciation fully falling into the Brunhes Normal Epoch and this point of view is followed by other Austrian authors. The position in this palaeomagnetic epoch may be supported by the correlation of the Mindel glaciation with the Elster glaciation in the North European Lowland and Saale with the Riss glaciation, as generally used by most authors. The preceding glaciation, theoretically correlated with the Glacial C of the "Dutch" Cromer would be situated in this Epoch as well.

Brunnacker et al. (1982) in his section of Pleistocene terraces of the Northern Iller-Lech Plateau between Zusam and Lech Rivers attribute to the Günz-Würm period four lowermost terrace levels, that are thus falling deeply into the Brunhes Chron. As reinterpreted by Šibrava (1997), the paleomagnetic Brunhes/Matuyama boundary, situated in the section in the so called Lower Upland Gravel, is preceded by seven gravel bodies, situated thus within the Brunhes Palaeomagnetic Epoch. It may be just mentioned, that a paleomagnetic research has been carried out at the locality Linz in Austria, where some values indicated the possibility of the presence of B/M boundary in these gravels have been found. But this interpretation was strongly opposed by Fink (1976).

A quite different intepretation of the statigraphical position of the Günz to Würm terraces is given in the stratigraphic scheme by Ellwanger et al. (1995). The Mindel, Haslach and Günz Komplex glaciations are placed within the Matuyama (Lower Pleistocene) Palaeomagnetic Epoch, what makes a substantial difference if compared with the stratigraphical position in Austrian alpine foreland and is contraversial in the correlation of alpine glaciations with the extraglacial area as well.



2. Scheme showing the filling of alpine valleys originated in the period following the Brunhes/Matuyama reversal and their relation to Early Pleistocene gravels. 1 – morainic sediments of the last glaciation, 2 – interglacial deposits with palaeosoil, 3 – moraine of the Middle Pleistocene glaciation, 4 – interglacial silty deposits, 5 – moraine of the Middle Pleistocene glaciation, 6 – interglacial silty sediments, 7 – moraine of the Middle Pleistocene glaciation, 8 – Early Pleistocene gravels. Discussion on the stratigraphic assignement in the text according to Elwanger et al., the sequence comprises the Lower Riss to Würm glaciations.

The problems of the age of alpine terraces seems to be existig from the beginning of the quadriglacial system-even Penck and Brückner by introducing their system in differents parts of Europe, attributed to their four glaciations the river terraces, that now have been dated in a different way, in particular with regard to palaeomagnetic data.

Fluvial series and their relation to stratigraphy

It has been generally accepted for a long time that fluvial and glaciofluvial terraces were bound to cold climatic conditions, meanwhile the erosion took place during interglacial periods. Some observation have been widely disregarded, in particular the sections showing more complicated structure of fluvial sediments and contradicting thus the simple explication of sedimentation and erosion processes.

Kohl (1975, 1986) described a complicated sequence of strata in the Krems valley in Austria near Kremsmünster where the Günz and Mindel terraces are composed of more glacial (morainic and glacifluvial) sediments separated by interglacial horizons. Two horizons, separated by a paleosol have been found in the Günz gravels directly at the classical locality at Günz in Southern Germany (FRENZEL 1973). SCHREINER and HAAG (1982) describe the doubling in the "Hochterrasse" in the Riss valley in the Iller-Riss Plateau in southern Germany. More examples, where the gravel bodies are separated by interglacial horizons are given by ŠIBRAVA (1972, 1997).

The superposition of fluvial or other genetic types of Quaternary sediments (may be of lacustrine, glacilacustrine or glaciofluvial origin as well) makes the theory on the deposition of cold deposits during the glacial stages and the erosion bound to warm periods questionable. On the contrary the theory on the fluvial sedimentation at the beginning and during the final phase of the glacial stage or in transition period between glacial and interglacial stages as described by ŠIBRAVA (1964) seems to be still valid. The lower horizon of superimposed gravels corresponds thus with the late glacial phase of the preceding glaciation, the gravels overlying the interglacial horizon may thus be attributed to the early phase of the following glaciation. Nevertheless the sequence of strata may be even more complicated and may reflect more complex processes in the development of river valleys. The sections both in the alpine foreland, as well as in the extraglacial area nevertheless clearly indicate that the concept of the formation of gravel terraces in the glacial period and erosion during the interglacial stages cannot be accepted.

Some sections in the alpine foreland in Bavaria point out the possibility of comparison of stratigraphical events in the northern and southern parts of the Alps.The presence of the "geological organs", in some places jointly with the paleosol, has been described from both areas. These horizons are bound to the interglacials. In Bavaria, the "geological organs" have been described from the Donau-Günz Interglacial, Günz-Haslach Interglacial and Mindel-Riss Interglacial. In the Italian sections in the Olona valley the "geological organs" and the corresponding palaeosol are situated close to the Brunhes/Matuyama palaeomagnetic boundary. The interglacial may thus correspond with the Cromer Interglacial s.l. of the North European Lowland. The following interglacial, marked again by the "geological organs" and a palaeosoil is already situated within the Brunhes Palaeomagnetic Epoch. Here the correlation with southern alpine foreland is more difficult as no direct palaeomagnetic data are available. The problems arise as well from the continuing use of the Penck's and Brückner's system in northern parts of the Alps.

In both Matuyama and Brunhes Palaeomagnetic Epochs, the climatic changes are marked by the till horizons and by fluvial and glacifluvial accumulations, characterized by superposed fluvial gravels as well as by morhologically pronounced terrace steps, where the oldest terraces are situated in higher positions. They wittness jointly with directly superimposed till horizons and glacifluvial sediments in the valleys separated by interglacial horizons the number of cold and warm periods within the Matuyama and Brunhes Palaeomagnetic Epochs.

Taking into consideration the glacigenic and glacifluvial sediments in northern and southern alpine foreland, we may conclude that about 5 glaciations are situated within the Matuyama Chron and about 8 in the Brunhes Positive Epoch. The gravel accumulations in the alpine foreland are differentiated as their relative heights are concerned; the erosion rate values depend on the mountain uplift in different areas.

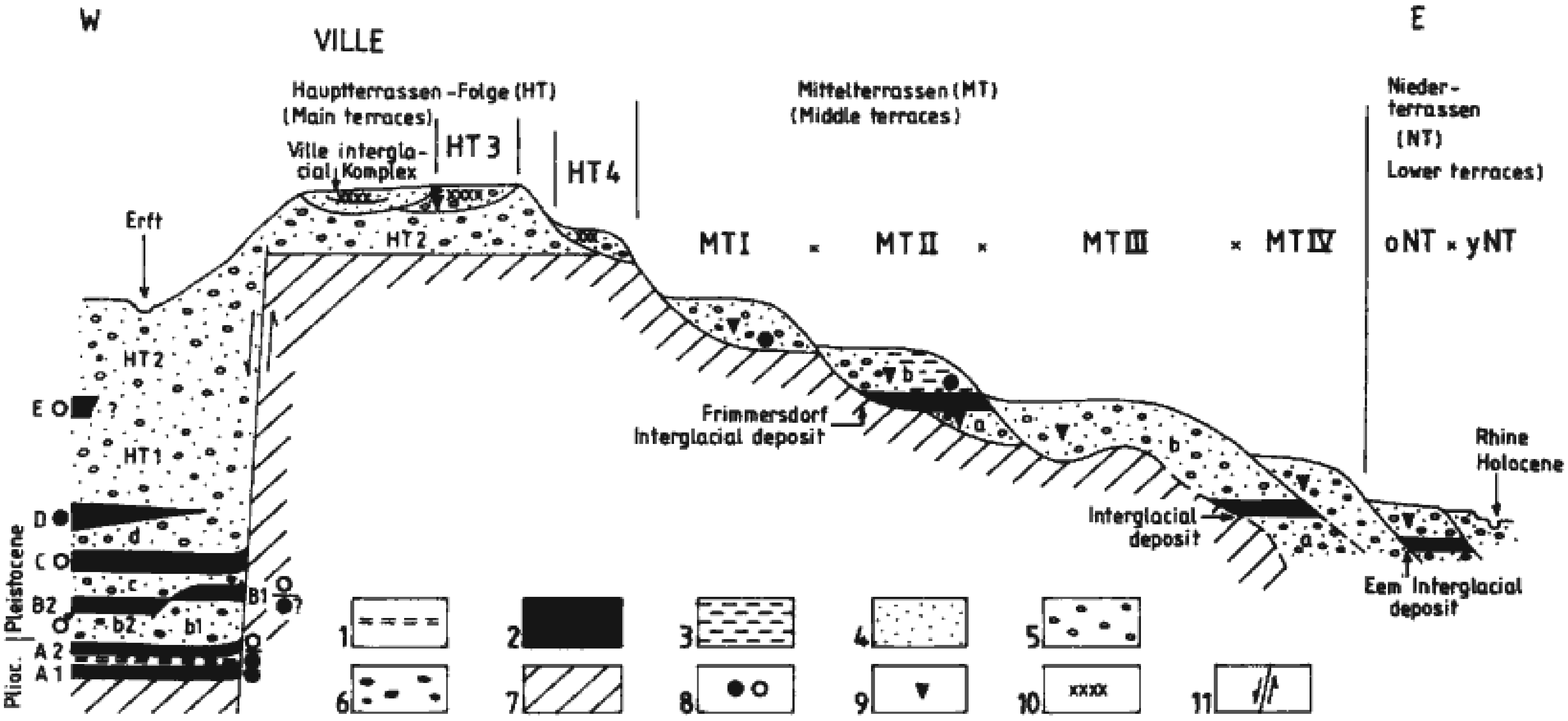
Climatic oscillations within the Matuyama Epoch as described from the lacustrine basins in Leffe exceed the number of those, known from the river valleys. Thus LONA (1950) and RAVAZZI and STRICK (1995) established seven climatic oscillations in the Early Pleistocene succession in Lona, nevertheless their correlation with the stages indicated by glacigene or glacifluvial sediments is not possible so far. As the uplift of the mountains and strong erosion within the Matuyama Epoch destroyed most of the sediments on the slopes and erosion removed partially the fillings of the alpine valleys, the alpine Early Pleistocene lacustrine deposits may provide valuable data for the studies of this period.

The number of cold and warm periods in the Brunhes Positive Epoch, if taken into account both the northern and southern foothills of the Alps, is close to the number of those indicated within the Brunhes Positive Epoch in the loess sections both in the extraglacial area and in some sections in the alpine foreland. It coinscides as well with the number of climatic oscillations as indicated in the deep sea stratigraphy. Nevertheless the possibility of their comparison with the deep sea stages be further studied with much attention taking into account the possibility of stratigraphic hiatusses both in continental and marine conditions as well as with regard to tectonic movements.

The studies of river terraces and their cover formations with palaeosoils in the southern foothill of the Alps by BILLARD (1982, 1983, 1995) provide evidence for the higher number of terraces, loess covers and fossil soils within the Brunhes Epoch and contradict the clasical conception of some authors. The author denies in particular the concept of the so called "Great Interglacial" corresponding in the classical alpine schemes with the period between the "Mindel" and "Riss" glaciations.

Some problems of alpine stratigraphy, correlation and nomeclature

The alpine stratigraphic system in particular in its northern foreland has been almost for one century strongly influenced by the quadriglacial system of Penck and Brückner and by continuing efforts of some authors to accomodate their observations with Penck's and Brück-



3. Cross section of the Ville profile in the southern part of the Lower Rhine basin (according to BRUNNACKER 1979). 1 – peat, 2 – clay, 3 – silt, 4 – sand, 5 – gravel (Quaternary), 6 – gravel (Tertiary), 7 – Tertiary rocks, 8 – normal/reversely magnetized, 9 – ice-wedge, 10 – palaeosoil, 11 – fault.

ner's scheme. Penck and Brückner based their system on geomorphological studies. Nevertheless the recent observation proved the existence of more glacial terraces not only more glaciations in the Alps (Haslach glaciation) but more authors approached already the multiglacial system, even if keeping the classical nomenclature and using the subdivision of Penck's and Brückner's classical glaciations into more cold and warm periods (ELLWANGER et al. 1995 and others).

Lately the term of "Complexes" has been introduced by several authors. This makes possible to include more glacials and glaciations into one complex, using the classical Penck's and Brückner's nomenclature. The Riss Complex may include according to this author 4 warm and 4 cold periods. This again created a problem in the correlation of these complexes with other areas in the alpine foreland. It concerns the position of the Holstein Interglacial generally correlated with the isotope stage 11. Bibus places the Holstein interglacial (corresponding the Samerberg 2 interglacial) into the Early Riss, meanwhile this interglacial is by other authors regarded as the interglacial preceding the first advance of the Saale glaciation if the North European Lowland and thus the Riss glaciation of the Alps. The preceding interglacial Samerberg 1, that according to Bibus corresponds with the Mindel-Riss Interglacial, may be one warm period older. This difference in the nomenclature – the real sequence of strata may be relatively well compared in the alpine foreland as well with the sequence in the deep valleys in the extraglacial zone – leads to different interpretation of the age of the deep valleys. It again points to the difficulties in using the classical Penck's and Brückner's system even if it is refined and subdivided.

ELWANGER et al. (1995) put in their stratigraphical chart (p. 259) the so called "Mindel-Haslach Komplex" as well as "Günz Komplex" into the Matuyama Chron, much deeper than the corresponding terraces are placed by other authors working in the alpine foreland (FINK 1979, BRUNNACKER et al. 1982, see above) who regard these glacifluvial gravels as situated fully in the Brunhes Chron. It may be added that according to the studies of Pavich and Vidic (undated reprint), based on the application of palaeomagnetic and ^{10}Be Analyses in the Sala River valley in Slovenia, the two terraces, originally mapped as Mindel and Günz terraces, may correspond with the Matuyama Epoch. Nevertheless here again the original stratigraphic assignement has been based on morphological observation only and the terraces have been dated according to the classical Penck's and Brückner's quadriglacial system.

In the stratigraphic chart published by ŠIBRAVA and BILLARD (1986) the Holstein Interglacial is correlated with the isoptope stage 11, which corresponds to the interpretation of most authors. This interglacial in the North European Lowland is preceded, taking into account the ZAGWIJN's division (1974, 1986) by two glacial stages, situated still in the Brunhes Chron. Even if this division has not been applied for the alpine area, the number of cold and warms periods in the alpine foreland may be hardly regarded as different from those defined in the North European Lowland.

The time span between the Holstein interglacial and the Brunhes-Matuyama reversal comprises thus two full glacials and two interglacials, the Brunhes-Matuyama boundary being placed within the third glacial stage, designated by ZAGWIJN (1974, 1986) as Glacial A, corresponding with the Helme Glacial in Northern Europe and correlated with the marine stage 20. The author of this paper regards this period as the time span where the glaciation and the sedimentation of glacifluvial gravels, attributed by many authors as Mindel and Günz may have taken place. It would be difficult to explain that the time span between the Holstein Interglacial and the Brunhes/Matuyama boundary, that means from the marine stage 11 to the stage 22 was without glacial sedimentation.

The author of this paper regards therefore two north European glaciations preceding the Holstein Interglacial as corresponding to two Elster glaciations in the North European Lowland that could match two glaciations in the alpine foreland corresponding to the marine stages 12 and 14. Two glacial stages, without ice advance in Northern Europe and preceding the Cromer interglacial Glacial IV according to Zagwijn may thus be compared with the stages 16 and 18 in the deep sea stratigraphy. The fluvial accumulations of these two cold stages may be those designated by many authors as "Mindel" and "Günz". With regard to the uncertainities in using this classical terminology the author doesn't use this terms and designates them as GL 7 and GL 8 accumulations as used in the stratigraphic chart of Šibrava and Billard (1986).

With regard to different points of view and different approach in using the classical Penck's and Brückner's system and the different stratigraphic assignement of morainic and glacifluvial sediments to four Penck's and Brückner's glaciations as well as regarding the complicated structure of fluvial and glaciofluvial sediments the author of this paper proposes the Penck'and Brückner's system be abolished and a new local system, based on the polyglacial division, introduced.

Major tectonic movements and tectonic phases in the Alps and in the Alpine foreland

In spite of many observation and references in the alpine quaternary literature the influence of tectonic movements during the Quaternary seems still underestimated. The different values of the inscision of alpine valleys, differences in erosion values between the terrace bodies in different tectonic units as well as the direct superposition of Quaternary sediments indicating the subsidence of the area provide evidence of tectonic activities in many regions. The whole alpine area and its foreland have been tectonically active through their whole geological history and recent tectonic movements can be observed even in these days. Major tectonic events that we designated here as tectonic phases, had a primary impact on the changes in the landscape, evolution of river systems and finally influenced the Quaternary sedimentation in large areas.

The first major tectonic phase may be assigned to the time span close to the Gauss-Matuyama palaeomagnetic boundary. The deposition of the Early Pleistocene glacial deposits in the Fornace and Olona valleys in northern Italy (Uggeri et al. 1995, Zuccoli and Bussolini 1995) must have been preceded by a deep incision of the rivers, caused by a sudden lowering of the erosion accompanied by a sudden uplift of the mountain chain. After that, the valleys were continuously filled by fluvial and glacifluvial sediments and till. This sedimentation continued through the Matuyama Chron to the Brunhes Positive Epoch, the oldest deposits being estimated as about 2,4 Ma in age.

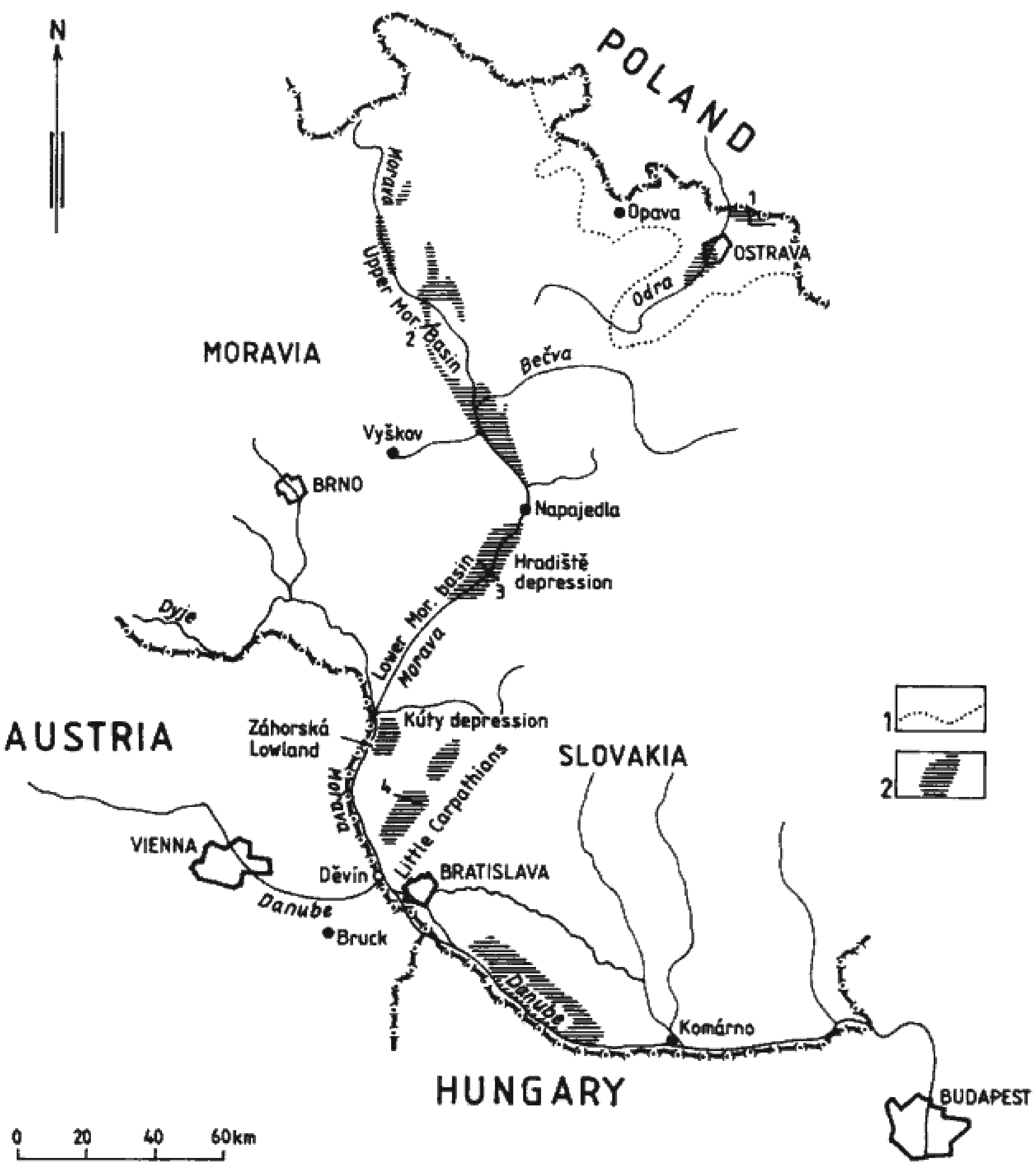
This tectonic phase caused changes in the hydrological network and general changes in the landscape. In Europe it represents the beginning of the development of the present river system. It affected the whole European continent and had most probably its impact on intercontinental scale.

The origin of the oldest overdeepened valleys with sedimentary fillings in the foreland of the Alps may be attributed to this period. The Gauss-Matuyama palaeomagnetic reversal corresponds as well with the global deterioration of climate and is characterized by the onset of the loess sedimentation both in Europe (locality Stranzendorf in Austria – Fink 1979, Kohl 1986, St. Vallier in France, Guerin 1980 and others) as well as in Asia (Loess plateau in China – Heller and Liu 1982, Liu and Ding 1982, Central Asia (Dodonov 1986, 1987, 1991).

In the alpine foreland this time span corresponds with the "1 morphologisch-tektonische Wende" (Ellwanger et al. 1995). In the Italian Alps the valleys of the Fornace and Olona rivers are filled by glaciofluvial and glacigene sediments situated within the Matuyama Epoch with the base dated about 2,4 Ma (Zuccoli and Bussolini 1995, Uggeri et al. 1995) overlain by younger sediments belonging already to Brunhes Chron. The origin of the valleys must have preceded the sedimentation of glacial deposits and thus must be again dated close or within the Gauss-Matuyama reversal.

Some deep valleys filled with the Pleistocene deposits in the Alps have been encountered in Switzerland by drilings, nevertheless the age of their sedimentary filling is not sufficiently known. In the alpine foreland in Germany the origin of the valleys precedes the sedimentation of the so called "Deckenschotterkomplex" that comprises two oldest glacial (not morainic) gravel bodies – Biber and Donau Complexes. The erosion phases in filling of these valleys are marked by erosion disconformity only, not by downcutting which could have led to the formation of terraces as morphological bodies.

In the Lower Rhine area Brunnacker (Brunnacker et al. 1976, Brunnacker 1978) in his cross profile through the system of terraces of the river Rhine between the Ville and Cologne describes a sunken block on the west side of the section. The prequaternary rocks of the sunken block are covered with the Lower Pleistocene sequence of strata represented by the four glacial gravel bodies of the so called Frechen Glacials (Frechen Gla-



4. Quaternary depressions in the Carpathian foredeep, Vienna and Komárno basin showing the penetration of these valleys from the glaciated to extraglacial area. 1 – boundary of inland glaciations, 2 – extent of Quaternary depressions.

cial 1a, 1b, II, and III) separated by corresponding Interglacials (Fortuna oscillation, Frechen Interglacial I–III. These are overlain by the gravels of the Main terrace 1 (Hauptterrasse 1 – HT 1) and the Main terrace 2 (Hauptterrasse 2, HT 2). The whole complex corresponds with the Matuyama Reverse Epoch covering thus the time span from Pretiglium to Menap of the Dutch stratigraphic system. The lowermost strata are again dated 2,4 Ma. This indicates thus the period during which the vertical displacement took place. In spite of the distance from the alpine chain and regarding the different tectonic units, the tectonic movements coincide or are very close in age with those in the alpine foreland.

The eastern part of the region, not affected by vertical movements, has a development of river terraces as known from the stable areas, the oldest terraces forming the highest levels. The terraces designated by Brunnacker as the Middle terrace II, Middle terrace III and the "Ältere Niederterrasse" (Older Low terrace) consist of two superposed fluvial gravel bodies, separated by interglacial horizons and belonging thus to two glacial stages. The section provides thus an example of the superpositon of gravel bodies caused by vertical movements in sunken areas as well as the superposition of bodies due to the climatic factors, where the lower accumulation can be attributed to the kataglacial phase of the preceding glacial and the upper one to the anaglacial phase of the following cold period (Šibrava 1964).

Another, younger event influencing the development of the Quaternary that must be related to tectonic activities is the formation of overdeepend valleys stretching from the Northern and Baltic seas to the alpine foreland. They were initially described from the north European glaciated area and regarded as subglacial valleys, that originated due to the exaration and erosion activity of the inland ice. It was found later, that these depressions continue through the Carpathian foredeep between the Bohemian Massif and the Carpathian system into the extraglacial area and further to the alpine foreland. Their formation precedes the first advance of the Elster glaciation. In the glaciated area and in the extraglacial zone in the Carpathian foredeep their sedimentary filling corresponds with two Elster glaciations and their equivalents in the non-glaciated area. In some places the occurrence of the sediments preceding the first Elster glaciation (in the glaciated area these gravels are avoid of material of Nordic origin) underlying the Elster deposits has been described. This points to the possibility of their higher, probably precromerian age.

In the Danube valley in Austria FINK (1966) indicates in his longitudinal profile of the Danube terraces two depressions below the present river valley. The first one, the so called "Mitterdorfer Senke" on the left side of the Danube river, attains the depth of about 50 m; the second one, "Lasseer Wanne" is more than 100 m deep. Both depressions are filled by sand and gravel. There are not direct data indicating the age of these morphological forms or the age of their sedimentary fillings. They are geographically linked to the depressions in the Carpathian Foredeep; they can be thus regarded as a part of the whole system of burried valleys, reaching from the north European sea basins to the Carpathians. The formation of these valleys and depressions in tectonically unstable areas may have continued to younger periods till the present time. It has to be mentioned that the area in the southern part of the Carpathian foredeep and the Carpathians represents a transition zone to the Hungarian Lowland with fault tectonics and the tectonically conditioned superposition of fluvial sediments that in the Hungarian Central Mountains form pronounced terrace levels (see ŠIBRAVA 1972).

The overdeepened valleys in the North European Lowland have been described from Germany, Poland and from the Russian plain as well from the Netherlands in the West. In the glaciated area they may have been overdeepened by the glacier activity as well, nevertheless their dephts in northern Europe, attaining up to 400 meters indicate that the levels of the seas must have been in the time of their origin several hundreds meters lower than in the present time.

The tectonic phase that led to the formation of deep valleys in the North European Lowland and in the extraglacial area influenced the Alpine foreland as well. The valleys and depressions as described from Bavaria in Germany may be with high probability regarded as their equivalents in spite of some differences in the stratigraphic interpretation of their fillings. Thus the Gernmühler Becken near Samerberg (JERZ 1995) with the "Mindel" moraine at the base and overlying lacustrine deposits with the Holstein Interglacial may be well compared with the valleys and basins in the area north of the Alps. Similarly, the section published by ELLWANGER et al. (1995) from the Riss valley in Baden-Württemberg may be compared with those in the extraglacial area, even if stratigraphic interpretation of filling differs to some extend depending on the different approach to the stratigraphic scheme and nomenclature.

These two pronounced tectonic phases, both situated close to palaeomagnetic events, are of wide continental and most probably of intercontinental extension as well. They had their impact in different geological and geomorhological units and strongly effected the development of the landscape, changed the position of erosion levels and thus the gradient curves of the rivers.

The relation of these tectonic activities to the changes of the palaeomagnetic field is to be studied in the future. The question remains if the tectonic movements and orogenesy are related to the changes in the palaeomagnetic field and if climatic changes that have taken place in particular in the time span around the Gauss-Matuyama reversal were due to these changes in the palaeomagnetic field or to which extend were bound to the changes caused by tectonic movements or to climatic changes in the high atmosphere.

Regional tectonic movements in the Alps and in the Alpine foreland

The Alps and their foreland belong to tectonically active areas with crustal movements continuing to present times. Unlike the tectonic activities of major tectonic phases the regional movements affect different areas in different time and are more bound to the behaviour of different tectonic units. These movements often led to the displacement of river terraces, moraines and may have affected the aeolian sedimentation as well. The faults and displacement attain the values of several up to tens of meters, in particular in the areas of high seismicity. Young tectonic movements may lead to displacements of terrace levels, originate the landslides and have their impact on the morphology of the region. Unlike the tectonic movements that took place during major tectonic phases, regional movements affect relatively small areas in the Alps and their foreland and have usually no equivalents in the extraglacial area. Nevertheless they must be taken into account by morphological studies, evaluation of the terrace levels and the studies of mountain glacial deposits. A special group of tectonic features are the icetectonic deformations, faults, folds and others, that are sometimes difficult to be distinguished from regional tectonic features or from landslide phenomena.

Conclusion

The hitherto achieved results of the studies in the alpine foreland, the comparison of the Quaternary events and sedimentation in both southern and northern foreland of the Alps as well as the comparison with adjacent areas allow to draw some conclusion that should be taken into consideration for further studies.

The stratigraphical studies in the alpine region cannot be based on morphological investigation only. The structure of fluvial and glaciofluvial sediments proved to be more complicated as supposed so far. The presence of interglacial horizons separating two overlying gravel bodies clearly proves that these bodies belong to two glacial periods. It can be supposed, even if from the analogy with the extraglacial area only, that the lower gravels correspond with the late glacial phase of the older glaciation, the upper one to the early phase of the following cold period. Originally the terms "anaglacial" and "kataglacial" phases have been used (ŠIBRAVA 1964). The climatic changes from the cold period to the interglacial and from the interglacial to the onset of the new glacial period reflected in the development of the molluscan fauna from the valley of the Elbe river has been described by LOŽEK and ŠIBRAVA (1968).

The morphological criteria may lead to erroneous conclusion even if the upper gravels have been removed by erosion and the lower accumulation thus represent a morphologically lower, but older level. The thickness of upper gravels also diminishes downstream and usually is not developed in the lower parts of the rivers. Another factor influencing the stratigraphic assigment of the terraces are regional tectonic movements, that jointly with the factors mentioned above may influence the position of gravel bodies. The studies by KOVANDA (2006) based on the occurrence of the interglacial Fagotia fauna in the sediments overlying the so called "Main terrace" near Moosburg in southern Germany as well at other localities point out to a higher age of the terrace gravels than supposed so far. This assumption is supported as well by the presence of the "Roterde" soil type in corresponding stratigraphic position.

Major tectonic phases most probably related to the changes of the palaeomagnetic field strongly influenced the development of the Quaternary on broader continental and probably on intercontinental scale. These movements reached in the Alps and their foreland an immense intensity. The sunken areas as well as overdeepened valleys that originated in that time made it possible to preserve the Early Pleistocene deposits posdating the Gauss-Matuyama palaeomagnetic boundary and providing data for the Early Pleistocene glaciations of the area.

Unlike the area of the north European glaciations the Alps and their foreland provide evidences for repeated Pleistocene glaciations for the period from 2, 4 Ma ago to the end of the ice age. In the North European Lowland the pre-Cromerian glaciations have been described from Poland and Russia (see stratigraphic chart by ŠIBRAVA and BILLARD 1986), but they are still a subject for discussion. None of them have been described from Germany or from the Carpathian Foredeep. On the other side, the sedimentation in the extraglacial area of the Carpathian foredeep in the period preceding the Elster glaciation seems according to geochemical analyses of loesses and the development of paleosols to be rather more influenced by the aridity of the region than by typical glacial conditions (ADAMOVÁ et al. 2002). Neverheless this must still be a subject for further research.

As to the stratigraphy, this cannot be based on classical division as introduced by PENCK and BRÜCKNER (1909) even if to the classical scheme additional glacials and interglacials have been added. The terms are being used in a different way in different areas and have been assigned to different palaeomagnetic epochs. No type section or type region has been defined. Therefore, the further research requires comprehensive data concerning the studies of the structure and sedimentology of terrace bodies, knowledge of underlying and overlying formations, studies of paleosols overlying or interrlying the gravels, paleontological contents of gravels, position in the length profile of the river, studies concerning the neotectonic movements etc. This regards as well the exposures in the sediments of glaciations or other genetic types of Quaternary deposits.

The hitherto achieved results have confirmed the primary role of climatic changes on the Quaternary sedimentation and soil forming processes even if these have been often influenced by other factors as well. The attention should be therefore paid to the correlation with the marine stages, reflecting the climatic changes on global scale. This could provide as well a base for further regional correlation.

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Předpolí Alp – problémy stratigrafie kvartéru, nomenklatury a interpretace

(Resumé anglického textu)

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Předpolí Alp představuje již po mnoho let jednou z klíčových oblastí pro studium evropského kvartéru. Penckův a Brücknerův (1909) systém čtyř zalednění ovlivnil po mnoho dekád výzkum a stratigrafii kvartéru nejen v předpolí Alp, ale jimi zavedená nomenklatura byla používána i mimo alpskou oblast a někdy i na jiných kontinentech. Novější studie rozlišily nová zalednění a rozšířily základní stratigrafický systém. Přesto však zůstává mnoho otázek zejména při korelaci různých stratigrafických schémat používaných v předpolí Alp i při jejich srovnávání s extraglaciální oblastí.

Stratigrafický systém Pencka a Brücknera je nyní často různými autory pracujícími v různých oblastech různě interpretován. Fluviální a glacifluviální terasy günzského až würmského stáří jsou některými autory kladeny do paleomagnetické epochy Brunhes (střední a svrchní pleistocén), zatímco jiní přiřazují günzské a mindelské sedimenty do epochy Matuyama (spodní pleistocén). V článku je diskutována stratigrafie kvartéru v předpolí Alp, zejména s ohledem na nejnovější výsledky z celé cirkumalpinního regionu. Autor navrhuje opustit dosavadní stratigrafický systém a zavésti nový, opřený o klimatické cykly, které jsou zaznamenány v hlubokomořských sedimentech.

Stratigrafie kvartérních sedimentů i vývoj celé oblasti byly silně ovlivněny tektonickými pohyby. První tektonická fáze, spadající do období kolem 2,4 Ma a nacházející se v časovém období paleomagnetické hranice Gauss-Matuyama vedla k výrazným změnám v morfologickém vývoji oblasti a měla za následek poklesy erozních bází i zdvih horských pásem. Nejstarší sedimenty alpských zalednění jsou zachovány ve vysokohorských údolích. Jejich stratigrafické ekvivalenty, spodnopleistocenní sedimenty epochy Matuyama byly popsány z poklesových oblastí na dolním Rýnu.

Druhá tektonická fáze vedla ke vzniku hlubokých údolí, sahajících od severoevropských moří až do předpolí Alp. Tato fáze předchází prvému zalednění severoevropské nížiny může být předcromerského stáří. Sedimentární výplně těchto depresí spadají do plaeomagnetické epochy Brunhes.

Regionální tektonické pohyby byby vázány na různé tektonické jednotky a postihly Alpy a jejich předpolí na různých místech s různou intenzitou. Výzkum ukázal, že stratigrafická klasifikace teras založená pouze na geomorfologických hodnotách bez vyhodnocení všech dalších faktorů (vnitřní stavba fluviálních a glacifluviálních akumulací, erozní pochody, interpretace nadložních a podložních vrstev, tektonika aj.) může vést k chybným stratigrafickým závěrům.

Vysvětlivky k obrázkům

1. Schéma spodno- a středněpleistocenních sedimentů v alpských údolích. 1 – středněpleistocenní ledovcové sedimenty, 2 – „Ceppo" sedimenty (Ceppo de la Olona v Itálii mají v podloží Ceppo de la Bevera), 3 – till (druhé zaledněné epochy Matuyama), 4 – glacifluviální písky a štěrky s glacitektonickými poruchami ve svrchní části, 5 – glacilakustrinní silty a břidlice, 6 – till (první zalednění epochy Matuyama), 7 – fluviální (glacifluviální) štěrky a silty (podle Uggeri et al. 1995).

2. Schéma výplně alpských údolí vzniklých v období po inverzi Brunhes/Matuyama a její vztah ke spodnopleistocenním štěrkům. 1 – morénové sedimenty posledního zalednění, 2 – interglaciální sedimenty s fosilní půdou, 3 – moréna středopleistocenního zalednění, 4 – interglaciální silty, 5 – moréna středopleistocenního zalednění, 6 – interglaciální silty, 7 – moréna středopleistocenního zalednění, 8 – spodnopleistocenní štěrky. Diskuze stratigrafické klasifikace v textu. Vrstevní sled zahrnuje spodnorisská a würmská zalednění (podle Ellwanger et al. 1995).

3. Příčný profil lokality Ville v jižní části dolnorýnského bazénu (podle Brunnackera 1986). 1 – slatina, 2 – jíl, 3 – silt, 4 – písek, 5 – štěrk (kvartér), 6 – štěrk (terciér), 7 – terciér, 8 – normální/inverzní magnetizace, 9 – mrazový klín, 10 – fosilní půda, 11 – zlom.

4. Schéma kvartérních depresí v karpatské předhlubni, vídeňské a komárenské pánvi, dokazující jejich pronikání ze zaledněné do extraglaciální oblasti. 1 – hranice kontinentálního zalednění; 2 – kvartérní deprese.

Vysvětlivky k příloze II

1. Glacilakustrinní silty a břidlice jednotky Vivirolo, překrývající till v údolí Fornace River v severní Itálii. Paleomagnetická epocha Matuyama.

2. Till jednotky Vivirolo v podloží glacilakustrinních sedimentů – paleomagnetická epocha Matuyama.

Fotografie: V. Šibrava

1. Glacilacustrine silts and shales of the Vivirolo unit overlying the till in the Fornace River valley in North Italy. Matuyama Palaeomagnetic Epoch.
2. Till of the Vivirolo unit underlying the glaciolacustrine deposits – Matuyama Palaeomagnetic Epoch.

Photos by V. Šibrava