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THE TERRACES OF THE MAAS (AND THE RHINE) DOWNSTREAM OF MAASTRICHT

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RÉSUMÉ

Les cours inférieurs du Rhin et de la Meuse se dirigent tous deux vers le Graben du Bas-Rhin. La direction du Rhin, cependant, est parallèle à la direction principale du graben, tandis que la Meuse pénètre dans cette région tectoniquement affaissée en traversant perpendiculairement les failles de son bord ouest. Les terrasses des deux fleuves montrent toutes deux le phénomène appelé « croisement des terrasses » : à l'amont d'une « charnière », les terrasses apparaissent dans la topographie, les plus élevées étant les plus anciennes ; à l'aval, par contre, la sédimentation a été prédominante, et les sédiments anciens sont enterrés sous les dépôts plus récents.

Dans le Rhin, le croisement se fait graduellement et est dû au simple fait que les plaines alluviales anciennes ont aujourd'hui des profils longitudinaux à pente plus forte que les terrasses plus jeunes. Le long de la Meuse, par contre, les croisements se produisent là où les terrasses traversent les zones de failles (voir fig. 2).

Dans la région immédiatement à l'aval de Maastricht, on a cartographié quelque treize à quatorze terrasses (voir fig. 1). Ces terrasses ont pu y être distinguées en mesurant l'altitude de la base de leurs dépôts, en analysant la pétrographie des graviers et en analysant les minéraux denses des sables. Les dépôts les plus anciens de la région appartiennent à la « Traînée mosane », une large plaine alluviale, formée dans une vallée très vaste et très peu profonde de la pénéplaine ardennaise pendant le Tertiaire le plus récent et peut-être très tôt dans le Quaternaire. Ces dépôts se retrouvent encore au sommet de l'Ubagsberg. Un peu plus jeunes sont les sédiments de la « Oostmaas » (Meuse de l'est), qui se présentent dans la région au sud de l'Ubagsberg et ont été déposés pendant une période (approximativement le Tiglien) où la Meuse suivait un cours allant directement de Liège vers l'est-nord-est et y formant les « très hautes terrasses ».

Après le Tiglien, la Meuse trouva un autre cours au nord-ouest de l'Ubagsberg. Dans la suite, les différentes « hautes terrasses » furent formées pratiquement près du sommet de la pénéplaine ardennaise qui descend doucement vers le nord dans cette région.

Les sédiments de presque toutes les terrasses montrent des caractères qui indiquent un dépôt sous un climat froid, périglaciaire. On peut supposer que dans cette région, pendant le Quaternaire, en principe une érosion verticale se produisit, qui fut interrompue par des phases d'accumulation. Cette accumulation était due à la production d'une grande quantité de matériel gélivé, fourni par les pentes des versants des Ardennes pendant les périodes périglaciaires et transportés par la Meuse (alors fleuve anastomosé). Pendant les interglaciaires (et peut-être pendant les périodes de transition), l'érosion verticale pouvait être à nouveau active.

Il est possible que cette érosion soit due à une (légère) surrection tectonique de (la partie nord de) l'Ardenne, mais on doit garder à l'esprit que la différence de climat entre le Tertiaire

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et le Quaternaire peut aussi en être la cause. Car on sait que, sous des conditions climatiques subtropicales semblables à celles qui prévalurent pendant le Tertiaire, les rivières n'étaient pratiquement pas capables d'approfondir leurs vallées. Sous les conditions plus tempérées du Quaternaire, par contre, leur capacité d'érosion était beaucoup plus grande, et l'érosion était — comme déjà dit — simplement interrompue par des phases de sédimentation durant une partie des (ou les) périodes (péri-) glaciaires.

Dans les régions subsidentes du Graben, la sédimentation ne s'est pas produite uniquement dans les conditions périglaciaires. Des formations comme celles de Sterksel et de Veghel comprennent des dépôts interglaciaires.

Les sables du Rhin et de la Meuse diffèrent beaucoup en ce qui concerne la composition de leurs minéraux denses. Les sables rhénans sont caractérisés par des « minéraux alpins » tels que le grenat, des épidotes, de la hornblende et de la saussurite, avec des pourcentages variés. Depuis le Pléistocène moyen, des minéraux d'origine volcanique fournis par le volcanisme de l'Eifel sont présents dans les sables du Rhin en quantités relativement grandes, et surtout dans les fractions grossières.

Les minéraux denses de la Meuse montrent beaucoup de tourmaline et des minéraux métamorphiques tels que staurotides, andalousite et disthène. De plus, beaucoup de dépôts contiennent une hornblende particulière, provenant des Vosges (après la capture de la Moselle par la Meurthe cette « source » fut supprimée). Dans les terrasses les plus jeunes la « chloritoïde trouble », et le grenat (trouble) se présentent avec de forts pourcentages. Tous deux sont fournis par les Ardennes.

INTRODUCTION

The Rhine and the Maas, the two rivers which enter the Lowlands around the Northsea from the South and the Southeast via the Ardennes-Rhenish Schiefergebirge, show some remarkable differences. The Rhine is longer and apart from gravel from the Schiefergebirge it also carries sandy material from the Alps. The Maas is shorter and has less water, its material comes from northern France and the Ardennes. However, the most conspicuous difference in our areas themselves lie in the stream-direction, which the rivers follow in relation to the tectonic lines. After flowing through the Schiefergebirge the Rhine follows the Lower-Rhine Graben practically over its entire length. The stream-direction lies parallel to the bordering faults (the Rhenic direction). The Maas, however, after flowing through the Ardennes, at Namur makes a sharp bend to the East, over some distance till Liège follows the main direction of these mountains and then enters the graben over the western bordering faults. Curiously enough it has not been diverted to the northwest by the subsidence of this graben zone, but it first passes the Peel "horst" before gradually following the Rhenic direction.

This difference in position in relation to the active faults has yielded considerable differences to the aspect of the terraces, which is shown by both rivers. On the other hand the two rivers have enough resemblances and mutual characteristics to make possible comparison and correlations of their terraces and deposits.

THE MAAS

As to the Maas it can be stated with respect to its stream basin downstream of Liège that the belt of terraces, which in Belgium is only a few kilometers wide, widens considerably in the Kempen and in Dutch southern Limburg and adopts the shape of a fan.

In the south, particularly in southern Limburg, the terraces are covered with more or less thick layers of loess, in some places the original relief has even been blurred by this cover and some terrace edges are not visible as clear steps in the area. Further to the north cover sands take over the part of the loess. In some places the sand deposits only have a slight thickness, but there are zones where they are some tens of meters thick, e.g. in the Central Graben.

In the course of the last decades, the Maas deposits and terraces have been studied by a number of investigators (among others by Briquet, 1907; Klein, 1914; Pannekoek, 1934; Macar, 1938; Van Rummelen, 1942; Brueren, 1945; Van Straaten, 1946; Zonneveld, 1949, 1955*a*; Maarleveld, 1956; Paulissen, 1973). Some of them have used the elevation of the surface to distinguish the terraces. Others have taken into consideration the possibility of later erosion and especially the covering by loess that may have influenced the height of the surface considerably. Therefore, they have used, whereever possible, elevation data concerning the basis of the terrace deposits (e.g. Macar, 1938; Brueren, 1945). Investigations have been made with regard to the composition of the gravel. Thus Pannekoek (1934) calculated the percentages of quartz. He found that this percentage dropped with decreasing age. He established that the oldest terraces mainly exist of quartzy material, coming from the Ardennes peneplain, which by then had not yet been cut to such an extent. The proceeding incision during the Pleistocene times however, yielded more and more new non-quartzy gravel. Van Straaten (1946) not only determined a quartz value but also established relative values for other components. Maarleveld (1956) applied his well-known counting method also to Maas deposits and like van Straaten he not only found that with decreasing age a drop occurs in the percentage of quartz but also that within one and the same terrace body the percentage of quartz increases in downstream direction. Both investigators attribute this to the circumstance that the river while flowing takes up material older and therefore richer in quartz from he subsoil and from the adjoining terraces. A survey of what could be established by the study of heavy materials has been given by Zonneveld (1949). It appeared that the different terrace levels were characterized by their "own" heavy mineral association. In 1955 the same author summarized the results which the investigation of Brueren, van Straaten and himself had yielded.

The oldest Maas terraces have been described by Macar (1938) as "Traînée mosane." As to their deposits they consist of gravel very rich in quartz and as a rule they contain some pieces of silicified oölite. In the South Limburg area the gravel on top of the Ubachsberg may be correlated with these young pliocene Maas gravels. The Maas used to flow by then in a broad and very shallow valley over the peneplain and carried practically only such material which had not been destroyed by tropical and subtropical erosion, i.e. quartz, quartzite and flint. The deposits at Brunssum are of the same age; they were, however, deposited in (the border area of) the Graben and therefore obtained more substantial thickness. Their composition, according to van Straaten (1946) does not lead to considering them to Rhine deposits, moreover the sedimentary structures point at a southwest-northeastern stream direction. However, in these times there has probably been less difference between Maas and Rhine gravel, both rivers flowing over a peneplain and obtaining only resistent material rich in quartz. Moreover, one can imagine that in this area where the Maas discharges into the Rhine the influence of Maas gravel will have been considerable.

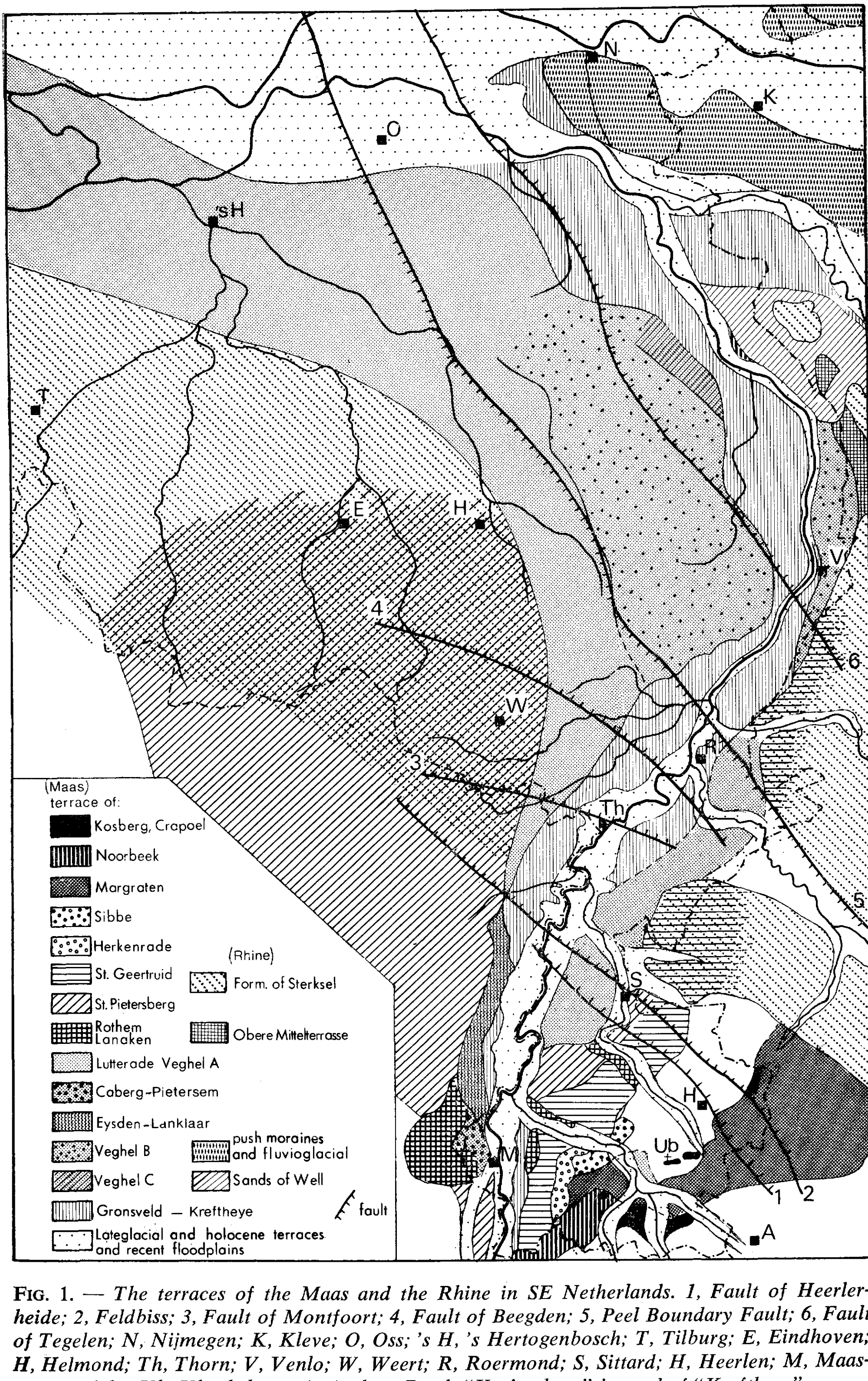


FIG. 1. — *The terraces of the Maas and the Rhine in SE Netherlands. 1, Fault of Heerlerheide; 2, Feldbiss; 3, Fault of Montfoort; 4, Fault of Beegden; 5, Peel Boundary Fault; 6, Fault of Tegelen; N, Nijmegen; K, Kleve; O, Oss; 's H, 's Hertogenbosch; T, Tilburg; E, Eindhoven; H, Helmond; Th, Thorn; V, Venlo; W, Weert; R, Roermond; S, Sittard; H, Heerlen; M, Maastricht; Ub, Ubachsberg; A, Aachen. Read: "Kreftenheye" instead of "Kreftheye".*

Between the present Ubaghsberg and the high grounds of the "Vylener Forest" lies the valley of the "Oostmaas" (Hol, 1949). In the transition from pliocene to pleistocene the river flowed in southwest-northeastern direction and was probably forced to cut itself a (shallow) valley. In the valley of this Oostmaas several levels have been distinguished. The highest is the level of Kosberg with a basisheight of around 190 m. The percentage of quartz of this deposit is high, the heavy mineral association consists mainly of resistent minerals such as tourmaline, staurolite and zircon. Moreover, for example in the gravels near Huls weathering phenomena are found which closely resemble weathering like it occurred in the Tertiary (v.d. Broek en v.d. Waals, 1967).

Some less important gravel deposits with basisheights around 180 m lead Brueren to distinguish his "Crapoel level (?)." At around 170 m (basisheight) between Noorbeek and Gulpen the Noorbeek-level was distinguished. It shows quartzvalues, distinctly lower than those of the preceding terraces. The contents of heavy minerals, however, still mainly consists of resistant minerals.

The next terrace, that of Margraten, is clearly different from its predecessors; in most samples from the deposits at this level sometimes very important percentages of hornblende are found, a brown-green variety coming from the Vosges. In the gravel porphyry—also originating from the Vosges—occurs for the first time.

In the Dutch-German border area the terrace deposits have been strongly influenced by later tectonic movements along the bordering faults of the Graben. It is difficult there to distinguish them on the ground of their elevation height and also the differences with respect to the heavy mineral composition and the percentage of gravel are not always clear, owing to contamination. But it is clear that near Jülich in Germany beneath a layer of clay which should have a Tiglian age Maas sand is found in which a certain percentage of Vosges-hornblende could be demonstrated (Zonneveld, 1956). Apparently these deposits are the Northeastern continuation of the Oostmaas, possibly the equivalent of the Margraten level.

From the position of the remains of the Margraten level southwest of the Ubachsberg it can be concluded that the Maas as early as then had an inclination to go a more Northern direction. The situation at the time of the formation of the Margraten level gives the impression of a wide bend directed to the North in the course of the Maas. This bend apparently has broken through to the North or Northwest, the Northern slope of the Maas valley giving little resistance. The latter probably was not very high. Once the break (during a period of strong sedimentation?) had taken place the new direction as a result of the tectonic dip in the area North of Sittard-Heerlen appeared to be more attractive to the river than the former, which lead to parts of the Graben where the subsidence was less important.

From the investigation by Van der Broek and Van der Waals (1967) moreover, it appeared that the terraces in large parts of South Limburg, namely in the area Northwest of the Ubaghsberg are rather ephemeral forms: at various points beneath the terracedeposits of the middle and North of South Limburg they have found traces of weathered soils and deposits (the so-called Basal Gravel Complex) which were characteristic of the late-tertiary peneplain. Apparently only little relief had to be removed on this peneplain, slanting in Northwestward direction.

The Northwestwards "sliding" Maas successively formed some terracelevels, viz. those of Sibbe, Herkenrade, St. Geertruid and St. Pietersberg. There is not much difference in height between them, in most cases 10 to 15 m. Macar (1938) put them together in the group "hautes terrasses" ("high terraces") and thus distinguished them from the group of the "Oostmaas" terraces, which he called "très hautes terrasses" ("very high terraces").

The Sibbe terrace, Macar's level No. 6 (basis at about 144 m) seems to contain less hornblende from the Vosges than its predecessors. One might suppose that the supply of this mineral was interrupted, but the value of porphyry also coming from the Vosges does not decrease. The same applies to the Herkenrade level, Macar's level 5, which lies at 125 to 130 m (basis height).

The most important terrace levels from this group, however, are those of St. Geertruid and St. Pietersberg, Macar's No. 5 and No. 4, respectively. They can both be followed to the north far into the area of the dominating Rhine deposits and are known in these regions as "zone of Budel". Near Maastricht the basis of the St. Geertruid terrace lies at around 110 m, the heavy mineral association (again) shows high percentages of Vosges hornblende, moreover an increase in the percentage of a special type of chloritoid ("turbid" chloritoid) can be observed. In the gravel the porphyry value is higher than ever. North of the Geul the level drops to about 100 m and North of the large faults (e.g. the Feldbiss) to around 50 m.

North of Sittard and near Roermond Maas sands are present in the terrace edge of Koningsbosch and the Meinweg, underneath a Rhine deposit at heights of around 35, 55 and 65 m, depending on the tectonic position.

West of the Maas—near Maastricht—the basis of the terrace of St. Pietersberg is at a somewhat lower level than that of St. Geertruid, viz. around 100 m. It continues in the Kempen Plateau (Halet's zone E, 1932). The St. Pietersberg level is also present on the eastern Maasbank, namely in the western part of the Schinnen Plateau. It seems as if these two levels show increasingly fewer differences in height towards the north. Nevertheless, southeast of Sittard a difference in level of about 10 m can be observed, although the occurrence of the fault zone of the Feldbiss etc. makes an exact determination rather difficult. The composition of the heavy fraction and the gravel showing no useful distinction between the terraces of St. Geertruid and St. Pietersberg, it is however impossible to decide whether these Maas deposits belong to the one or the other of these levels. On the strength of their geographical situation the Maas deposits of the Echterbos and the Meinweg (S. and S.E. of Roermond) perhaps may be correlated with the St. Geertruid terrace.

The next group of terraces which can be distinguished is the "Middle terrace" group. Apart from some local terrace remains at various heights Brueren maps a Wilre "terrace level?," which he regards as a polygenetic terrace, formed by a river, which moving sideways, cut itself from around 70 m to 50 m. Halet, however, who published the data on the strength of which Brueren drew his conclusions, distinguished three levels in this area. The basis of Halet's level D lies at 70-74 m. Macar (1938) indicates part of the area here mentioned with the signature of his terrace No. 3. East of the Maas the Rothem terrace forms a distinct terrace step. The basis lies at approximately 60 m, at the same height as the basis of the Lanaken terrace, which Paulissen (1973) distinguishes west of the Maas (Halet's level B and Macar's terrace No. 2). Paulissen is of opinion that this Lanaken terrace originated in an interglacial period. This observation tallies with Krooks (1961) conclusion as far as in the Rothem terrace the gravels have been deposited under warm, at any rate non-glacial conditions.

On the map published in 1955 (Zonneveld, 1955) the next terrace is the one of Caberg-Lutterade. Paulissen (1973), however, points out that the Elslo and Lutterade parts of the terrace lie too high to regard them as ordinary downstream continuations of the Caberg level. He therefore distinguishes between the Lutterade- and the Caberg-Pietersem terrace, which near Maastricht has a basis height of around 45 m. The top of the Caberg-Pietersem gravels lies at 57 m. It is Halet's level A. The composition of the gravel and heavy mineral association do not show much differences, but they are not in contradiction with the subdivision.

At a level a few meters lower lies the Eisden-Lanklaar terrace (Paulissen, 1973). Near Maastricht the basis of this terrace lies at 43 m, the top at 51 to 52 m.

Further to the north, in Middle and North Limburg and the bordering part of northern Brabant over large areas the presence of Maas sediments could be demonstrated, which had been deposited in a (now buried) valley. This "Stramproy-valley" shortly before had been scoured out in the high terrace deposits. The deposits mentioned were originally called the Veghel Zone, later: Veghel Formation (Zonneveld, 1947, 1958) and were regarded as the continuation of the terrace deposits of Caberg-Lutterade (Zonneveld, 1948). However, by van der Toorn's study (1967) it has become evident that the Veghel Formation itself also consists of more divisions, Veghel A, B and C, respectively, which are situated in the area terrace wise. In the lower part of the Formation of Veghel A, clay deposits of interglacial character have been found. Doppert and Zonneveld (1955), and De Ridder and Zagwijn (1962) dated them Holstein [but according to the newest views (cf. Bisschop, 1973) the clay of Veghel (A) Formation is older than Elster]. On the strength of this observation it would be possible to correlate this part of the Formation of Veghel A with the terrace of Lanaken-Rothem, mentioned before. It is tempting to suppose correlations between the upper part of the Veghel A Formation, the Veghel B and the Veghel C in the north with respectively the Terraces of Lutterade, Caberg-Pietersem and Eisden-Lanklaar in the south. In this moment, however, no real geomorphological or palaeontological evidence for such a correlation is available other than the mere presence of three terraces in both regions.

It has appeared that deposits of the Veghel A Formation may be followed well into the Central Netherlands and Veghel B may find its continuation in a rather deep valley (see next chapter and fig. 5).

Finally, to the group of middle terraces the Gronsveld Terrace is reckoned. Near Maastricht it appears to be somewhat lower than the Caberg-Pietersem terrace, viz. at 39 to 40 m far as the basis is concerned (Zonneveld, 1955*a*). In this respect it exactly corresponds to the terrace of Mechelen-aan-de-Maas (Paulissen, 1973). A closer investigation of the gravel composition, heavy mineral associations (1) and also of the occurrence of fossil soils still has to be done.

The here mentioned terraces of Caberg-Lutterade, Gronsveld and Mechelen-aan-de-Maas in Macar's map fall into one area, where his terrace No. 1 is indicated.

In the subsoil of Horn, near Roermond in the deepest part of the "Central Graben" a Maas deposit has been found, characterized by a high percentage of "turbid" chlorotoid. The sands here rest on top of the Veghel Formation, which locally have undergone a strong tectonic subsidence. Sideways the sands of Horn

(1) The recent study by Bustamante yields some interesting data (cf. note at the base of page 153).

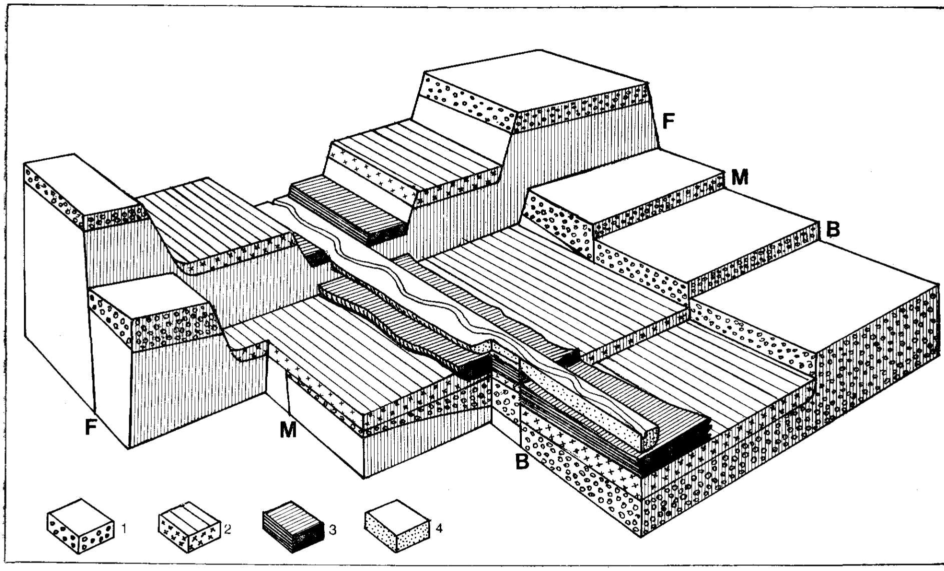


FIG. 2. — *Schematic blockdiagram, representing the fluvial deposits between Sittard and Roermond. The (mainly eolian) coversands have been omitted. 1, High terrace and Formation of Sterksel; 2, Terrace of Lutterade and Formation of Veghel A; 3, Terrace of Gronsveld-Mechelen and Formation of Horn; 4, recent flood plain and holocene deposits. F, Feldbiss; M, Fault of Montfoort; B, Fault of Beegden.*

wedge out into layers of cover sands that attain here a thickness of some tens of meters (cf. fig. 2). To the south they can be traced to the surroundings of Thorn. Their top here lies at about 22 m. Paulissen (1973) establishes that here too the deposits merge sideways into, or at least rest against covering sands. He regards the coarse grained layers concerned as part of the terrace deposit of Mechelen. Along this way it becomes clear that the sands of Horn and those of Mechelen-aan-de-Maas are the same. It is interesting that at the strength of an analysis of heavy minerals the sands of Horn were correlated with those of Gronsveld (Zonneveld, 1948) the same therefore as those which could be considered equivalent to the terrace deposits of Mechelen-aan-de-Maas by geomorphological reasons.

In North Limburg the Grubbenvorst zone was distinguished (Zonneveld, 1947). Presumably it is largely a continuation of the Horn zone. It also contains "turbid" chloritoid and garnet, but—as a consequence of much admixture of (Rhine) material from the subsoil—in far smaller quantities.

In later publications, e.g. van den Toorn (1967), the Grubbenvorst Formation no longer is mentioned separately, but together with the Rhine deposits of the same age it is indicated as the Kreftenheye Formation. Moreover van den Toorn was in the position to distinguish a Kreftenheye B and a Kreftenheye C.

The youngest terraces in the Maas valley are the late-glacial and holocene steps, which were distinguished by van den Broek and Maarleveld (1963) as Terrace I, II, II*a* and III respectively. Terrace I apparently corresponds with the top of the Formation of Kreftenheye-Grubbenvorst, viz. the Formation of Kreftenheye C. I and II were formed in Early-Allerød times, Terrace II*a* and *b* in the Allerød-period and Terrace III in the Preboreal. Finally the present alluvial plain was formed. A schematic representation of the longitudinal profiles of these terraces between Roermond and Venlo is given in fig. 3. South of Roermond Paulissen (1973) distinguished the Geistingen terrace, which may be correlated with Terrace III just mentioned.

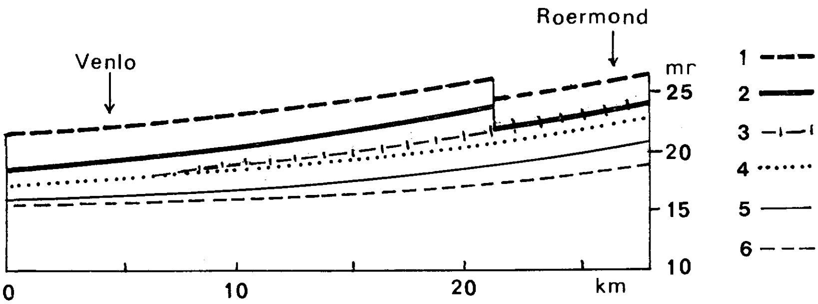


FIG. 3. — *The Late glacial and Holocene terraces of the Maas (according to v.d. Broek and Maarleveld, 1963). 1, Terrace I; 2, Terrace II; 3, Terrace II*a*; 4, Terrace II*b*; 5, Terrace III; 6, alluvial plain.*

THE LOWER RHINE

The oldest quaternary Rhine-deposits, known in the area where the Maas joins the Rhine, are those of the Pretiglian, the time (in Pleistocene) preceding Tiglian. These deposits are classed with the "Kiezelooliet"-deposits (Zagwijn, 1963) and they show the same heavy mineral associations as the deposits found in South Limburg of the same age: an association with tourmaline, zircon and other resistent minerals derived from the peneplain of the (Ardennes-) Schiefergebirge. Accordingly the gravel has a high percentage of quartz.

The somewhat younger coarse Rhine-sands, which lie directly beneath the clay of Tegelen (and with which this clay forms part of the Tegelen Formation), however are characterized by garnet, epidote, hornblende and saussurite, minerals originating from the Alps (van Andel, 1950; Zonneveld, 1955*b*). It is true that in these periods the river still transported sediments derived from the peneplain —i.e. material rich in quartz—its heavy mineral content, however, apparently was low enough to be "overshadowed" by the relatively great masses of minerals that were supplied by Alpine rivers since the beginning of the Pleistocene. Before that moment the Aare and the Reuss flowed westward towards the Rhone. Not earlier than about the transition of Pliocene into Pleistocene this part of the Alpine Rhine system was connected to the "Middle Rhine."

During practically the entire Early Quaternary the Rhine has been depositing sandy material in South and Central Netherlands, deposits that were characterized by heavy mineral associations in which epidote, garnet, green hornblende and saussurite are present in fluctuating percentages. One of these deposits is the Formation of Sterksel, attaining a thickness of more than 50 m in the Central Graben. Outside the typical subsidential areas the deposits are considerably thinner,

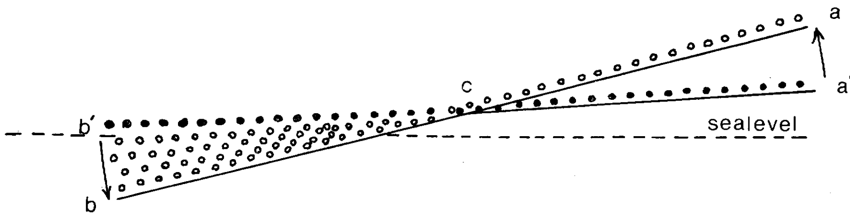


FIG. 4. — *Accumulation and terrace formation in a case of tilting. c, hinge.*

they even can be absent, either by subsequent erosion or by the fact that they were not deposited at all. As a rule it can be stated that in those areas where the river is in "equilibrium" (and according to this neither erodes nor accumulates), the sediments in the alluvial plain are continuously replaced. There where accumulation predominates the older parts of the Formation continuously are buried by younger ones. If anywhere a Formation passes from a slightly rising or stable area into a subsiding region it therefore must be held in mind that in most cases the terrace deposits of the former only can be correlated with special layers (for instance the top layer) in the latter (cf. fig. 4). In this way the Formation of Sterksel, present in the tectonically "high" horst region of Venlo. Tegelen cannot be correlated with the entire Formation of Sterksel in the Central Graben under e.g. Eindhoven, but only with the upper part of it. The heavy mineral situation is in complete agreement with this conclusion: The deposits of the Formation of Sterksel, present in the horst area between Venlo and Roermond is characterized by an association poor in garnet (association of Weert). The same association is found in the Graben area, but only in the top layers of the Sterksel Formation.

Also the pollen analytical data give evidence of this difference in completeness of the Formation between the horst- and the graben-area. In 1956 Zagwijn and Zonneveld found that in the lower part of the Sterksel Formation ("Cromer") interglacial clays were present. According to Zagwijn, v. Montfrans and Zandstra (1971) in the Sterksel Formation not less than two interglacials and three glacials can be recognized! Investigating a boring near 's Hertogenbosch (Waardenburg) they could establish that the lowermost layers of the Sterksel Formation were deposited during the Menapian glacial, then follow respectively the indications of "Cromer-interglacial I", "Glacial A," "Cromer-interglacial II" and "Glacial B". In the sediments originated in the last mentioned glacial period the mineralogical association of Weert was found, the same that is typical for the Sterksel sediments in the horst area between Venlo and Roermond.

Palaeomagnetically it could be established that the Matuyama-Brunhes boundary (700 000 years) is situated between interglacial I and II.

Among the sediments of the Formation of Sterksel, present in the Central Graben in some places a deposit is found that is characterized by the occurrence of high percentages of Maas-minerals. As stated in the preceding chapter, these deposits, called "Zone of Budel" are the northward continuation of the deposits of the St. Pietersberg terrace. Perhaps, they were formed during "Glacial A."

Also in the surroundings of Roermond and Venlo—on the Peel-horst—a Maas-deposit is found underneath the sands of the Formation of Sterksel. Possibly, however, these Maas sands are not to be correlated with the St. Pietersberg terrace.

Perhaps they correspond with the St. Geertruid level. In the region northeast of Sittard some evidences are in favor of the hypothesis that these sands belong to the Formation of Kedichem (preceding the Sterksel Formation and mainly consisting of local material); these Maas sands therefore might be considerably older than the zone of Budel indeed (Zonneveld, 1957).

The top surface of the Formation of Sterksel East of the Maas is the vast plateau of the "Jüngere Hauptterrasse" (Younger Main terrace) that dominates the landscape between Venlo-Roermond and Bonn (cf. Quitzow and Zonneveld, 1956; Quitzow, 1956, 1974). In course of time the Rhine has carved a broad valley into this plain and subsequently laid down sediments that in the Dutch-German frontier area are known as "Sands of Lingsfort." The heavy mineral association of these sands is characterized by a high percentage of brown hornblende, possibly a prelude on the very important supply of volcanic materials from the Eifel in Middle Pleistocene times (Zonneveld, 1956*b*). The "Sands of Lingsfort" can be correlated with the sediments of the "Obere Mittelterrasse" (Higher Middle Terrace) in the neighbourhood of Bonn.

The deposits of the next Rhine terrace, the "Mittlere Mittelterrasse" (Middle Middle Terrace) (see Quitzow, 1956, 1974) are found in the subsoil of the Netherlands as well. They are described as the Formation of Urk (s.s), present underneath the clays of Holstein (Mindel-Riss = Elster-Saale) age. The heavy mineral association shows high percentages of augite and other volcanic materials, produced by the Eifel volcanoes. Probably this first supply of volcanic material can be dated around 400 000 years ago (Frechen and Lippolt, 1965).

On top of the Holstein clays in the Central Netherlands coarse sands are found with quite the same mineralogical association. Originally they were called Formation of Vianen (Zonneveld, 1958). The Holstein clays not always being present, however, distinguishing these two sandy deposits can be very difficult. In those cases it proved to be appropriate to indicate the whole series with the name Formation of Urk-Vianen (Zonneveld, 1958). At present for purposes of convenience only the term Formation of Urk is used for the whole series (v.d. Heide and Zagwijn, 1967).

In the surroundings of the Gelderse Vallei, northwest of Wageningen Maarleveld (1956) was in the position to establish the presence of Maas gravel in the sands that have been pushed up by the Riss (= Saale) glaciers. In the same sands also the heavy mineral content points at a contribution by the Maas. The area concerned links up with the region where the formation of Veghel (A) could be mapped as an undisturbed deposit. Obviously the mentioned Maas deposits in the Central Netherlands can be regarded as the continuation of (the upper part of) the Formation of Veghel A.

The Formation of Urk (-Vianen) is present over a vast area in the Central and northern Netherlands, especially in the area where the general subsidence was the most pronounced, i.e. the region of the (former) Zuiderzee.

It is assumed that the Maas has carved out a valley into these deposits, probably under the influence of a lowering sea level; perhaps during the Elster glacial period or possibly in the time that the (Riss-Saale) ice caps were growing but before the moment that the coalesceing of the ice masses of Scotland and Scandinavia did disturb the direct connection with the general ocean level. This valley, of which, according to Zonneveld (1958), traces have been found in the Central and Northern Zuiderzee area had a depth of some dozens of meters and was situated exactly in the northwest extension of the area covered by the Formation of Veghel B in the unglaciated area. It is possible to see also in the longitudinal profile a relation between the Formation of Veghel B and the mentioned valley (fig. 5).

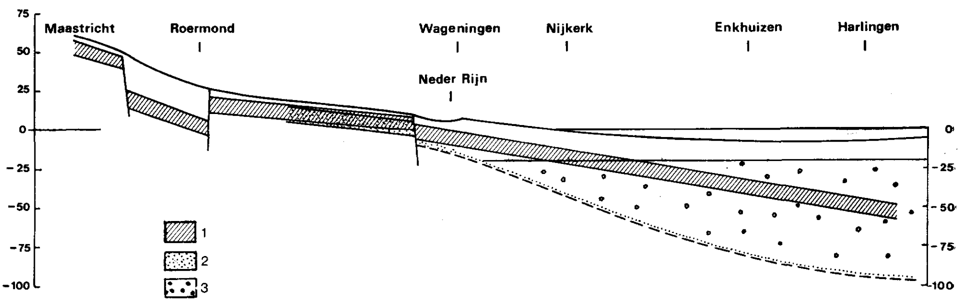


FIG. 5. — *Longitudinal profile between Maastricht and Harlingen (Northern Netherlands) with: 1, Formation of Veghel A; 2, Formation of Veghel B and 3, valley of Enkhuizen.*

The height differences between the bottom of this valley (that might be called the "valley of Enkhuizen") and the surface of the Urk-Vianen Formation diminishes when going from north to south. South of Wageningen, in the neighbourhood of Oss and 's Hertogenbosch this height (here represented by the Formations of Veghel A and B) is not more than a few meters.

In the same time also the Rhine must have eroded a valley that from the surroundings of Kleve-Emmerich stretched away to the north in the direction of Deventer and Zwolle. Perhaps it was connected with the valley of the Maas in the region of the Zuiderzee. But possibly its northern extension is to be found in the subsoil of Friesland in one of the (buried) valleys that were postulated by comparing the results of heavy mineral analysis of many borings.

At any rate these valleys of the Maas and the Rhine, as well as other valleys that were present in the northern part of the Netherlands, were filled up completely by fluvio-glacial, glacio-lacustrian and eolian sands. This filling up took place before the moment that the Riss (-Saale) ice front arrived in the Netherlands. Apparently at a certain moment during the advance of the Scottish and the Scandinavian (Elster and/or Saale) ice sheets the coalescing of these two resulted in a damming up of the southern part of the North Sea Basin. Valley erosion was succeeded by accumulation in such a way that the in the Northern part of the Netherlands the valleys were buried completely.

In the central parts of the country, however, the original topography did not disappear alltogether, the valley walls protruding partly or entirely above the fluvioglacial filling (fig. 5). Here the ice advancing from the north had the opportunity to follow the course of the valleys of the Maas and the Rhine, it transformed the valley walls into push-moraines and deepened the valley bottoms enormously. In this way the glacial basins of the "Gelderse Vallei" and the IJssel Valley came about (fig. 6, map No. 6).

Finally the advancing ice reached the line The Hague-Amsterdam-Wageningen-Arnhem-Nijmegen-Kleve-Krefeld. The Rhine was forced by then to flow to the west, along this ultimate ice front. The sands of Well (Zonneveld, 1956) and the Formation of Veghel C (Van den Toorn, 1967) originated during this period.

In the same area are found Rhine and Maas sands belonging to the Formations of Kreftenheye and Grubbenvorst. The bottom layers are slightly younger than the above mentioned sands of Well and Veghel C Formation; they are overlain by clays and peats that were formed during the Eem interglacial. Obviously they originated during the period after the glacial maximum in which the ice cap started to melt down and the northern half of the Netherlands finally was characterized by the occurrence of scattered dead ice masses.

The deposits concerned are now known under the name "Formation of Kreftenheye 1" (Ter Wee, 1966). The sands on top of the Eemian clays are called Formation of Kreftenheye B (Van den Toorn, 1967), the accumulation started in Early-Würm (= Weichsel) times and coincided with an important part of this glacial period. The Rhine and the Maas were braiding rivers and the flood plain of that time is called "Lower terrace of Heumen" by Pons (1957) and Pons and Bennema (1958).

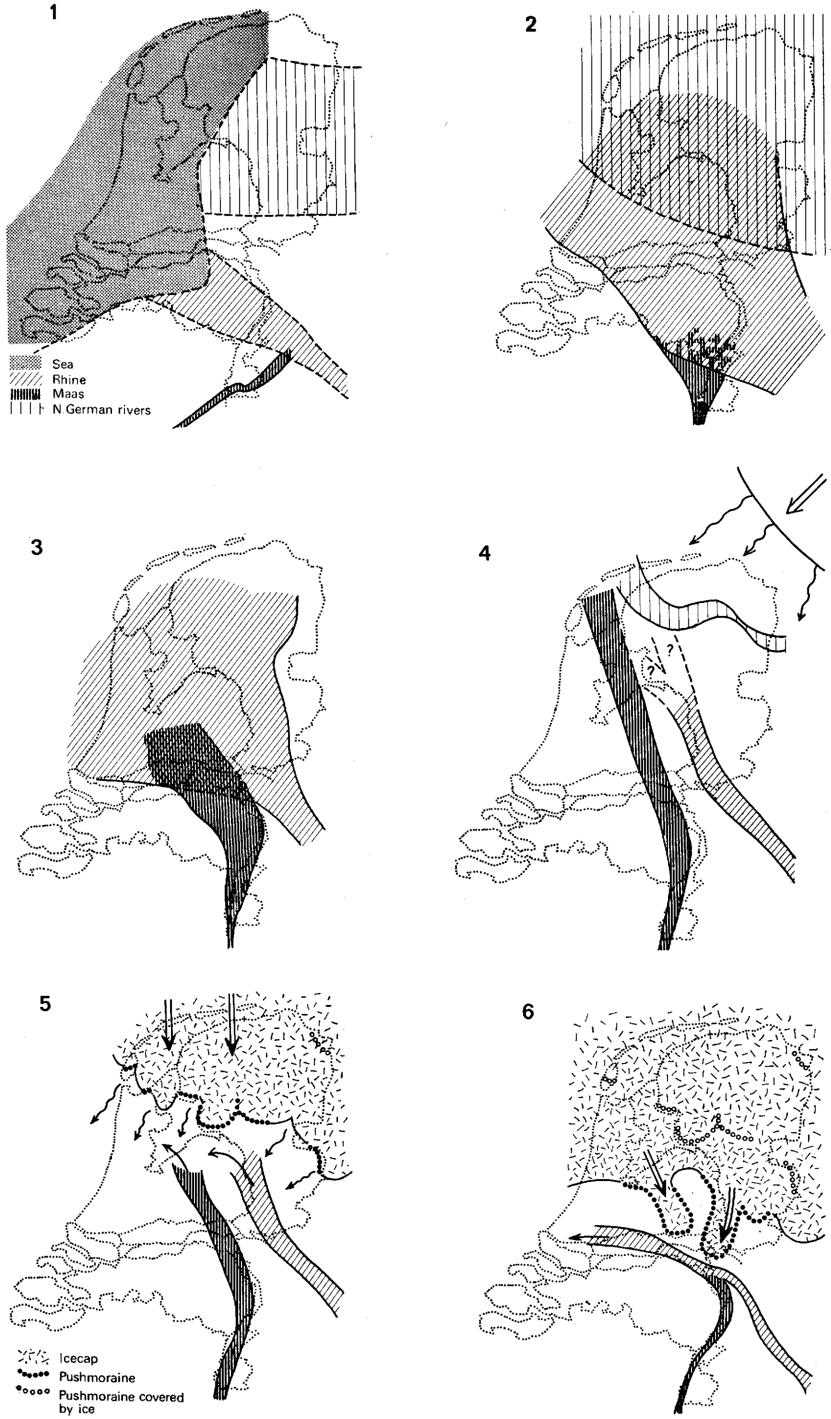
During the final stages of the Würm (= Weichsel) period, shortly before the Bølling interglacial the sedimentation started that gave rise to the Kreftenheye C formation in the Maas region (Van den Toorn, 1967). According to Van den Toorn the upper surface of this formation is the same as that of Van den Broek and Maarlevelds Terrace I (early Allerød); the loamy deposits that were laid down during floods by the river that gradually lost its typical braiding character are called "Hochflutlehme" in Germany.

Finally, a slight incision took place and during the Youngest Dryas (and/or Preboreal) times "Terrace X" was formed (fig. 7), also called "Jüngere Mittelterrasse" or "Lower Terrace of Overasselt" (Quitzow and Zonneveld, 1956; Pons, 1957; Pons en Bennema, 1958). It has been correlated with Terrace III along the Maas (Van den Broek and Maarleveld, 1963). The heavy mineral content of all the younger Rhine deposits show high percentages of volcanic minerals derived from the Eifel. The (post Allerød) deposits of Terrace X, the "Lower terrace of Overasselt" however contain traces of Laacher See eruptions in the form of pieces of pumice (cf. Steeger, 1954).

During the pleniglacial phases of the Würm (= Weichsel) time the Rhine entered the Netherlands in not less than three branches: one in the south, using the area south of the push moraine of Nijmegen, another in the area of Kleve-Nijmegen and a third one flowing to the north into the "IJssel-valley."

In the Allerød period, however, the river abandoned the first and last mentioned branches. Only the "central" branch was used by the Rhine that formed terrace X (Pons, 1957). The holocene Rhine maintained this direction, its alluvia are deposited in the recent flood plain. This flood plain is present in a very shallow valley cut out into the above-mentioned sediments upstream of Nijmegen. Downstream of this point the older terraces and deposits are buried by holocene sediments, due to the post-glacial rise of sea-level.

In this way it was possible to distinguish a series of terraces and terrace


1
2
3
4
5
6
Sea
Rhine
Maas
N.German rivers
Icecap
Pushmoraine
Pushmoraine covered by ice

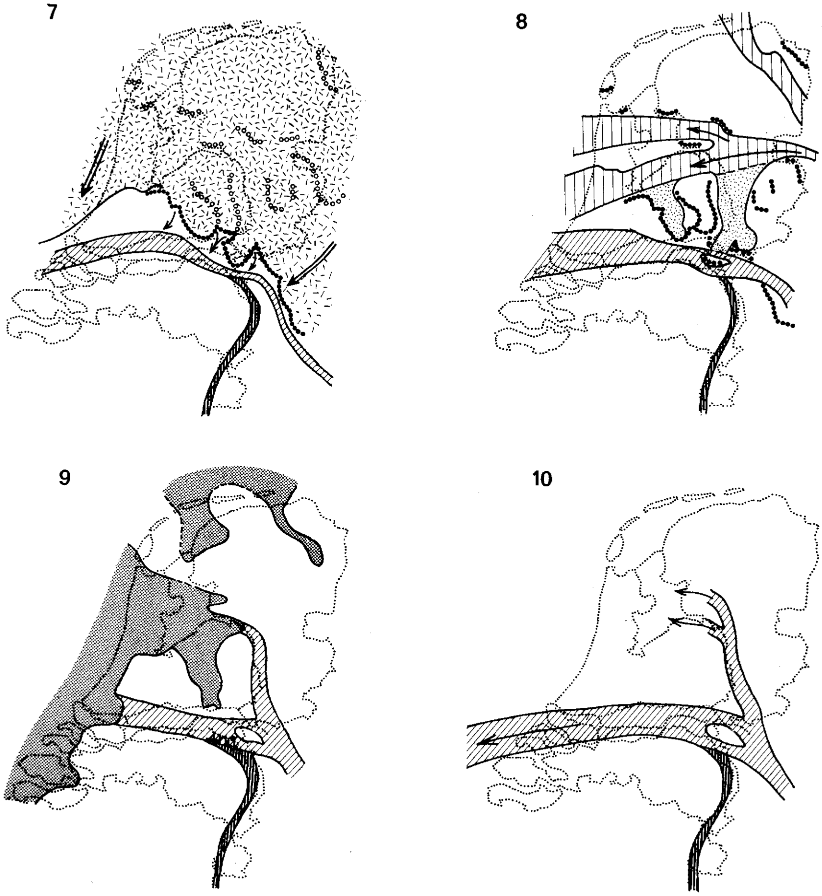


FIG. 6. — *The palaeogeographic history of the Maas and the Rhine in the Netherlands. 1, Early Pleistocene (Tiglien); 2, Early "Cromer"-periods; 3, Elster (Mindel); 4, Saale-Riss during advance of ice; 5, Ditto, Rehburger stadium; 6, Ditto, ice lobes in valleys of Maas and Rhine; 7, Ditto, maximum extension of ice cap; 8, Ditto, after melting of ice cap; 9, Eem (Riss-Würm); 10, Weichsel (Würm).*

TABLE 1

		MAAS South	MAAS North	RHINE
Holocene		Alluvial plain	Alluvial plain	Alluvial plain
			Terraces I-III	Terrace X
Würm/Weichselian		Form. of Horn, Terr. of Mechelen- Gronsveld	Form. of (Grubbenvorst) Kreftenheye	Form. of Kreftenheye
Eemian				
Riss/Saalian		Terr. of Eisden-Lanklaar	Form. of Veghel C	Sands of Well
Holsteinian				Form. of Vianen and Urk
(Mindel) Elsterian		Terr. of Caberg Terr. of Lutterade Terr. of Lanaken-Rothem	Form. of Veghel B	
"Cromerian"	Interglacial III ??		Form. of Veghel A	Sands of Lingsfort
	Glacial B			Zone of Weert
	Interglacial II			
	Glacial A	Terr. of St. Pietersberg	Zone of Budel	Zone of Budel
	Interglacial I	Terr. of St. Geertruid		
Menapian				
Waalian			Form. of Kedichem	Form. of Kedichem
Eburonian		Sibbe, Herkenrade	(only partly fluvial)	
Tiglian		Terraces of Margraten Noorbeek Kosberg		Form. of Tegelen: Clay of Tegelen Gravels of Tegelen Clay of Belfeld Gravels of Belfeld
Pretiglian				Pretiglian Sands and Kiezeloölite
Pliocene		"Kiezeloölite" Form.		

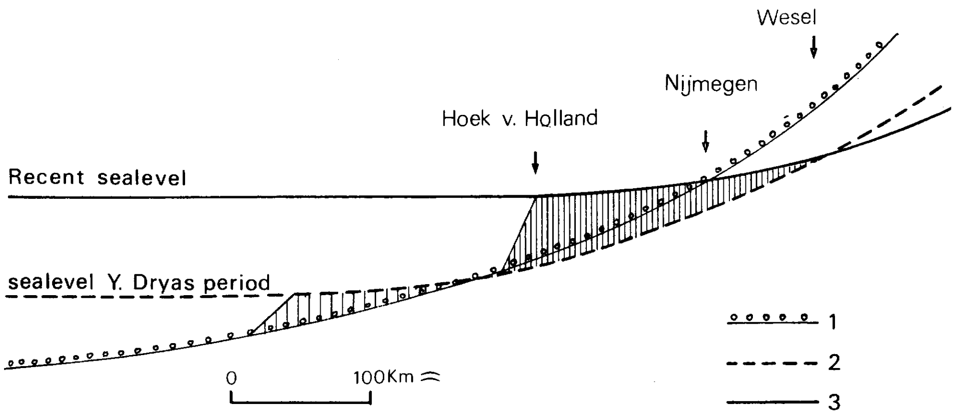


FIG. 7. — *The longitudinal profiles of the Rhine during the formation of the "Lower terrace", the "Terras X" and the recent flood plain (according to Pons, 1957). 1, Lower terrace; 2, Terrace X; 3, Recent flood plain.*

deposits and to correlate them mutually on account of geomorphological, sediment-petrographical and palaeontological considerations. Moreover they could be regarded in relation to the quaternary chronology. The results of these attempts have been represented in Table 1.

THE ORIGIN OF THE TERRACES

In general it can be stated that the formation of terraces deposits and terraces is connected with changes in the longitudinal profile of the river due to:

a) tectonical movements,

b) changing of sea-level or

c) climatic changes.

a) As to the terrace *deposits* and especially their thickness it is an established fact that the tectonical movements played a very important role. We could indicate above that the deposits are much thicker in the subsidential areas than on the horsts. Moreover is not impossible that the tectonical uplift of the Rhenish Schiefergebirge during the Pleistocene period, has contributed to an intensified supply of debris in the form of sand and gravel.

As to the formation of the *terraces* as geomorphological phenomena (in other words as the result of the alternating vertical erosion and widening of the alluvial plain by the rivers) it is clear that intermittent uplift or slanting of a region can give rise to terraces. These terraces then will diverge in the direction of the strongest upheaval. There where a rising area is adjacent to a subsiding one the result will be a terrace crossing (fig. 4).

The terrace system of the Rhine shows examples of a divergence in upstream direction as well as of a terrace crossing (Zonneveld, 1963). Perhaps a slight divergence in upstream direction of the terraces in South Limburg and the adjacent parts of Belgium are indicating that the terraces of the Maas up to some extent are related to an analogous principle, i.e. a tectonic upheaval in the neighbourhood of Liège (cf. Pissart, 1975).

Moreover it is known that the Maas is crossing some important faults that were active during pleistocene times. In several localities movements along these faults have lead to a (relative) subsidence of parts of the river course, thus causing lowering of the (local) base level and subsequent erosion.

Upstream of such a fault the former alluvial plain is left behind by the incising river in the form of a river terrace. Downstream of the fault, however, the river is not dissecting its alluvial plain. Sometimes even accumulation is taking place.

This situation is found near Sittard and south of Roermond where the Maas crosses respectively the Feldbiss and the Fault of Beegden (fig. 2).

Perhaps the terraces like those of Herkenrade and Sibbe that are known only "upstream" of a fault (the Fault of Heerlerheide) can be regarded as being caused by movements along that fault.

Terraces also can originate if a river crosses a rising horst and is capable of maintaining its course by antecedence, thus dissecting its former alluvial plain. In figure 3 this is the case with "Terrace II*a*."

Yet the importance of tectonic movements like uplift and faulting for the genesis of individual terraces must not be overemphasized in spite of the presence of so many faults in this region. In many cases it is observed that terraces as well as terrace deposits can be traced over the faults and far beyond, without any other influence than a mere vertical displacement along the faults. Obviously in these cases the dislocation occurred after the formation of the terraces, the tectonic movements in these cases cannot be held responsible for the existence of the terraces and deposits. A good example is the relation between the Formation of Veghel A on one hand and the Peel Boundary Fault and the Fault of Beegden on the other hand. The faults have not influenced the thickness of the Formation nor even the depth of the (buried) valley of Stramproy (fig. 2).

A final evidence against overemphasizing the (local) tectonic background of the terraces of the Maas is to be found in the fact that many of them can be correlated with terraces of the Rhine, a river that does *not* cross the faults, but follows a course parallel to the boundaries of the graben.

b) Also a lowering sea-level (i.e. a lowering base level) is generally regarded as a possible cause of terrace formation. It must be kept in mind, however, that this holds true only in those cases where the dropping sea-level lets free a sea bottom with an inclination that is steep enough to induce erosion by the river. No erosion will take place if the inclination is less; it is even conceivable that the river in such a case will accumulate in its new lower course.

In the longitudinal profiles of a terrace system terraces caused by a lowering of the sea level always show a convergence in upstream direction. This convergence is also visible in figure 5 giving a rough indication of the position of the valley of the Veghel-B-Maas and the top of Veghel A-Urk (Vianen) formation in Central and north Netherlands. It is not yet clear if the position of the bottom of the Urk formation (deposited in a kind of valley, hence the name "Rinnenschotter" in Germany) is related to a low sea-level as well (cf. Zonneveld, 1956*a*), but at any rate it seems that regressive erosion, caused by fluctuation of the sea-level was responsible to the formation of real eustatic terraces only in a few cases.

Some authors of textbooks seem to have the opinion that the accumulation of deposits on eustatic terraces is due to a kind of "regressive aggradation," caused by the rising of the sea-level. It is evident, however, that this "regressive aggradation" has still less influence in the areas upstream of the proper lower course than the regressive erosion. In figure 7, where the influence of the rising holocene sea-level in the Lower Rhine dsitrict is shown, obvioulsy this influence does not extend beyond Nijmegen.

c) The relation between the terraces and deposits on one hand and the changes of the Quaternary climate on the other hand deserves much more attention. It is striking that in South Limburg practically all terrace deposits were accumulated under cold, periglacial conditions. In nearly all quarries that could be investigated phenomena like syngenetic cryoturbations were observed (Krook, 1961 ; Paulissen, 1973) and an analysis of the roundness of the gravels gave the same impression. Richter (1952) also has established that in the "Jüngere Hauptterrasse". East of Venlo the roundness value of the gravels corresponds with values indicating a (peri-) glacial environment. Finally Van den Toorn (1967) mentions that in the Formation of Veghel B clays are found that were deposited under cold "glacial" conditions. It is true that the lower part of the Veghel-A Formation contains "warm" clays: but it is shown that the greater part of the Veghel A-sands were deposited in the colder periods after the interglacial, i.e. in the (early phases of the) next glacial.

At any rate from these facts it is evident that the deposition of the proper terrace sediments in nearly all cases was related to cold conditions. One might assume that during the glacial periods the (braiding) rivers supplied large amounts of debris from the hills of the Ardennes and the Rhenish Schiefergebirge, regions where in these periods mechanical weathering by frost was predominant. During the interglacials the supply of material was considerably less important, the rivers had the opportunity to carve out a new valley in this way changing the former alluvial plain into a terrace.

In the subsiding regions, however, coarse material could be deposited also during interglacial periods. In the preceding discussion of the Rhine sediments, for instance, could be established that in the Central Graben, parts of the Formation of Sterksel appear to be deposited in warm, partly interglacial times (Doppert en Zonneveld, 1955; Zagwijn, 1962; Zagwijn and Zonneveld, 1956*a*). Perhaps the supply of so much sandy material under non-periglacial conditions is related to a more intense tectonical activity in the Rhenish Schiefergebirge during Middle Pleistocene times.

It was especially the Rhine, not the Maas that supplied much material, it is not impossible therefore, that the uplift of the Schiefergebirge was stronger than that of the Ardennes.

As a rule the longitudinal profils of a braiding river is steeper than that of a meandering one. That means that erosion will occur if a river passes from braiding to meandering, Both the Rhine and the Maas have displayed this phenomenon in Late glacial and still in Early Holocene times (figs 3 and 7).

Summarizing, it is very probable that quaternary climatic changes have played an important role with the formation of the individual terraces. These changes, however, acted in superposition on changes of a much greater magnitude like the gradual uplift of the Ardennes-Schiefergebirge during the pleistocene. In this view the river could be erosive only during the interglacials when the valley walls, covered by vegetation, did not supply much debris. Perhaps also in early and late glacial phases of the different glacials analogous conditions prevailed. During the glacial periods themselves, however, the erosion was interrupted, the river receiving too much debris.

In 1968 Rohdenburg defended the opinion that the elevation above the base level was not caused by tectonical uplift, but by a gradual lowering of the sea-level since the Tertiary.

Some years ago Heine (1971) showed that a certain tectonical uplift must be responsible for the general height above base level, but he indicated that the mutual differences in elevation between the terraces are no accurate measure for estimating the velocity of the tectonic uplift. It is possible, that in Tertiary and in early Quaternary times under tropical semi-arid or subtropical conditions the rivers were not able to exercise vertical erosion in spite of a relatively strong gradient. The same phenomenon is known in recent tropical rivers where erosional tools are scarce.

The repeated occurrence of glacial periods during the Pleistocene, however, would have fostered the vertical erosion: Heine is of opinion that during the cold periods themselves frost weathering in the immediate surroundings and the subsoil of the river would facilitate its erosional activity (the so-called Eisrinden-effect of Büdel, 1969). In the foregoing, some doubt was shown regarding this idea, but at any rate it can be assumed that especially in the periods during which the rivers were not choked by an overproduction of debris—i.e. during the interglacials and transitional times—enough sand and gravel was available to be used as erosional tools.

FINAL REMARKS

Apart from the correlation, the origin and the age of the terraces, some remarks can be made concerning the fact that certain events in the upstream parts of the river basins are reflected in the sediments present in the region described in this paper.

One of these events was the diversion of the Pliocene Alpine Rhine (the Aare-Reuss-system; the Upper Rhine of Graubünden did not yet belong to the Alpine Rhine system, it was one of the headwaters of the Danube). As has been stated above this river that during the Pliocene formed part of the Rhone system, left its course south of the Vosges and flowed into the Upper Rhine Graben, thus supplying from that moment to the Middle and the Lower Rhine sands with epidote, hornblende, garnet and saussurite (Van Andel, 1948; Zonneveld, 1955*b*).

Another event that is reported by the mineral content of the Rhine sands is the rise of the Mid-Pleistocene volcanism of the Eifel. It is true that in the deposits of the Sterksel Formation always some grains of augite are present, but it is not before the deposition of the sands of Lingsfort and the lower part of the Formation of Urk that the volcanic minerals (volcanic hornblende, augite, titanite) are present in high percentages (Zonneveld, 1956*b*).

Kaiser (1960) however is of opinion that it is not necessary to connect the appearing of volcanic minerals in the sands of the Lower Rhine with a (new) activity of the Eifel volcanos. He supposes that the stronger vertical erosion by the rivers during the Middle Pleistocene was responsible for the stronger erosional attack of wider areas covered with volcanic material.

The Maas deposits in South Limburg in their turn indicate a capture that must have taken place in very early pleistocene times in the neighbourhood of Mézières. The Maas of Dinant then captured the Lotharingian Maas, that formerly flowed westward in the direction of the Oise and the Seine (Pissart, 1961). This diversion might have been the reason why in the early Pleistocene the Maas started supplying "cementquartzite," originating from north-eastern France (Van Straaten, 1946).

Also the well-known "capture" of Toul has left its vestiges in the composition of the sands and gravels of the Maas. In the early quaternary Maas deposits rock types like granite and porphyry are fairly well represented. In the heavy mineral associations the brown green hornblende is a common component.

Granite, porphyry and brown green hornblende come from the Vosges. They are present in the Middle Terraces of South Limburg, e.g. those of Lutterade and Caberg (up till now the Terrace of Eisden-Lanklaar has not yet been investigated in this respect). In the deposits of the Terrace of Gronsveld, however, suddenly the values for these components are dropping (Zonneveld, 1949). Apparently by the time of the sedimentation of the Gronsveld sediments the Upper Maas no longer supplied the Vosges materials to the Middle Maas, but instead to the Moselle. According to the latest pollen analytical investigations the age of the lower part of the Formation of Veghel (A) is: (Upper) "Cromerian." The upper part of Veghel A and the terrace deposits of Lutterade and Caberg therefore possibly originated during the Elster glacial period. Those of the Gronsveld terrace however were deposited during the Würm = Weichsel glacial.

The stagnation of the supply of Vosges material will have taken place in the time lapse between these two periods. An investigation of the heavy mineral content of the Eisden-Lanklaar deposits (Riss-Saale age?) is needed for more specification (2). Tricart (1949-1951) studied the area of the "capture" geomorphologically. He established that the diversion took place during the deposition of the sediments of the large terrace, which is attributed to the Riss glacial period.

(The author is indebted to Dr. W. H. Zagwijn who gave him some informations concerning recent, partly unpublished pollen analytical results.)

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(2) A few days before sending this Ms. to the editor I received the short note of L. Bustamante Santa Cruz, "Les minéraux lourds des alluvions du bassin de la Meuse" (*C. R. Acad. Sci. Paris*, t. 278, série D, p. 561, 1974). In figure 2 *B* of this publication the mineral associations are shown, occurring in the different Belgian terraces. It appears that during the formation of the Eisden-Lanklaar deposits the supply of "Vosges hornblende" already had been cut off. This would mean that the "diversion of Toul" would have taken place during the Elster/Mindel glacial or perhaps in early Riss/Saale times.

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DISCUSSION

G. LÜTTIG. — *Coming back to your stratigraphical column I would like to bring to knowledge that in the elsterian type region Elster I is starting within the Cromer complex so that what you call Glacial A is Elster already, so that there is a representation of parts of Cromer by Elster in the following way:*

<table>
<tr><td colspan="2">ELSTER sensu stricto</td><td rowspan="5">ELSTER</td></tr>
<tr><td rowspan="5">CROMER</td><td>INTERGLACIAL III</td></tr>
<tr><td>GLACIAL B</td></tr>
<tr><td>INTERGLACIAL II</td></tr>
<tr><td>GLACIAL A</td></tr>
<tr><td>INTERGLACIAL I</td><td>CROMER</td></tr>
</table>

(If the Cromer III exist). The Hattem-complex in the Netherlands seems to correspond with the "Glac. A" after recent investigations on erratic boulders in Northern Germany and Denmark.

L. BUSTAMANTE. — *La terrasse principale est caractérisée par des associations minéralogiques:*

— A l'amont de l'Ourthe: Association à chloritoïde Fe s.s., hornblende brune, épidote, chloritoïde, grenat.

— A l'aval du confluent Meuse-Ourthe jusqu'à Neeroeteren: hornblende brune, chloritoïde (Mn, Fe), hornblende brune, épidote et grenat.

— A Neeroeteren: confluent Meuse-Rhin au Mindel épidote à grand diamètre, hornblende verte, grenat.

Dans les problèmes de corrélation de terrasses, il faut tenir compte des conditions climatiques sous lesquelles évoluent les rivières.

K. M. CLAYTON. — *I should like to take up Dr. Zonneveld's remarks on the origin of river terraces. I would certainly wish to agree with his view that changes in the level of the sea had nothing to do with the stairway of terraces upstream, and that in this case at least, tectonic movements have not triggered terrace formation. The overall tectonic situation has, I agree, provided a framework within which climatically-induced changes of regime have operated. Of course, since at all times the rivers reached the sea, each terrace must in fact be linked with a particular sea-level.*

What I would whish to comment on is the prevailing European view of the way in which climatic changes have induced changes in river regime, and so caused the formation of a flight of terraces. It seems necessary to warn against too great a simplification of the situation: it is attractive to imagine that all terraces are the result of braided stream patterns under conditions of what we may loosely call periglacial conditions. I do not know how secure is the sedimentological evidence that these large European rivers always adopted a braided form under cold conditions with a high rate of sediment supply. It is clear from American work on channel processes that it is just as possible for a meandering channel to form a flood-plain (which will in time be converted by incision to a terrace) by cut-and-fill processes—indeed this is just as effective as the processes associated with a braided situation. I take it that such a terrace, formed by what Leopold and Wolman have called cut-and-fill is the equivalent of what European workers are calling (in translation) an "erosional terrace."

To clarify this point may I refer to the British situation. I know of no evidence that the River Thames ever departed from a meandering channel, even at times of high sediment load when the climate was cold. More significantly, we should note that at least one of the best developed terraces of the Thames, the Boyn Hill terrace, is undoubtedly of interglacial origin and formed by the cut-and-fill of a meandering channel. It may be that regime changes were more limited in the British Isles than on the continent, but I do believe it is important to bear in mind the ability of any river, whatever its regime, to form a floodplain which *with time may become a terrace. There seems to me a danger that we may oversimplify the situation, and so at times fail to examine the field evidence with sufficient care.*

J. I. S. Zonneveld answers. — I completely agree with prof. Clayton when he says that both meandering and braiding rivers might erode a valley. The thing I wanted to mention is that in the Ardennes-Schiefergebirge during the Pleistocene a general trend of incision is to be observed and that this general valley-cutting was interrupted by phases in which the river was in the position to construct a flood plain.

In most cases the material of this flood plain shows traces of periglacial conditions (syngenetic icewedges or cryoturbations; roundess ratios, more or less characteristic for periglacial river gravels, in one case even pollen evidence). We know that during periglacial periods the supply of slope material to the rivers was much more important than during interglacial times. The mentioned data therefore tally with the idea that the interruptions in the general valley cutting (i.e. the formation of flood plains) were not only coinciding with the cold periods but in reality were caused by the great supply of material. In some cases it could be shown that the rivers during such a cold period were braiding rivers (for instance the Lower Terrace of the Rhine near Nijmegen).

Professor Clayton rightly warns against oversimplification. It would be wrong indeed to state now that everywhere and always river terraces are caused "by the climate." It must be held in mind, of course, that other phenomena can cause terraces as well. But it is a fact that for instance the Rhine and the Maas show practically the same sequence of terraces in spite of the fact that the tectonic situation are not alike and sea-level changes are not important. This seems to indicate that the role of changes in the supply of slope material to the rivers (which was highly dependent of the changes in the pleistocene climates) cannot easily be overestimated.