CENTENAIRE DE LA SOCIÉTÉ GÉOLOGIQUE DE BELGIQUE
L'ÉVOLUTION QUATERNAIRE DES BASSINS FLUVIAUX
DE LA MER DU NORD MÉRIDIONALE, LIÈGE, 1974, 1-19

GEOLOGICAL HISTORY OF THE RIVER ELBE, MAINLY OF ITS LOWER COURSE

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RÉSUMÉ

Les premiers débuts du bassin fluvial de l'Elbe peuvent être retracés jusqu'au début du Miocène.

Avec le soulèvement du Thüringer Wald, du Fichtelgebirge et de l'Erzgebirge, des remblaiements d'origine fluviale dirigés vers le nord se formèrent dans le bassin de lignite de l'Allemagne centrale, tandis qu'un remblaiement d'origine scandinave et de direction nord-est - sud-ouest atteignait le nord du bassin actuel.

Dans l'Eopléistocène préglaciaire, une rivière formée par la confluence de la Saale et de l'Elster Blanche (Weisse Elster), ainsi que l'Elbe supérieure elle-même s'écoulaient séparément vers le nord, la première vers la région de Berlin, la seconde par le cours ancien de l'Oder. Les masses glaciaires de la Thuringe et de la Saxe déterminèrent de profonds changements dans les tracés hydrographiques. Mais ce n'est que par la moraine terminale du stade de Warthe que l'Elbe fut refoulée vers l'ouest et, de ce fait, forcée de confluer avec la Saale. Le fleuve s'écoulant ainsi dans la région de l'Elbe inférieure connut cette existence particulière jusqu'à la glaciation Weischsel. Et ce n'est qu'à partir de ce dernier moment que l'Elbe suit complètement son lit actuel.

1. Preface

The Elbe is a river the upper and lower courses of which have had different geological histories. They developed in entirely different ways and have joined together only in the recent past. For this reason, a separate description of the single areas of the present river system is warranted. We first deal with the development of the upper course of the Elbe River and its abandoned channels and continue with the history of the River Saale, the most important tributary of the Elbe. Finally, we give a description of both the development of the lower course of the Elbe River and the unification of the individual elements to form the present river.

K.-D. Meyer is the author of chapter 5, whereas G. Lüttig wrote the other chapters.

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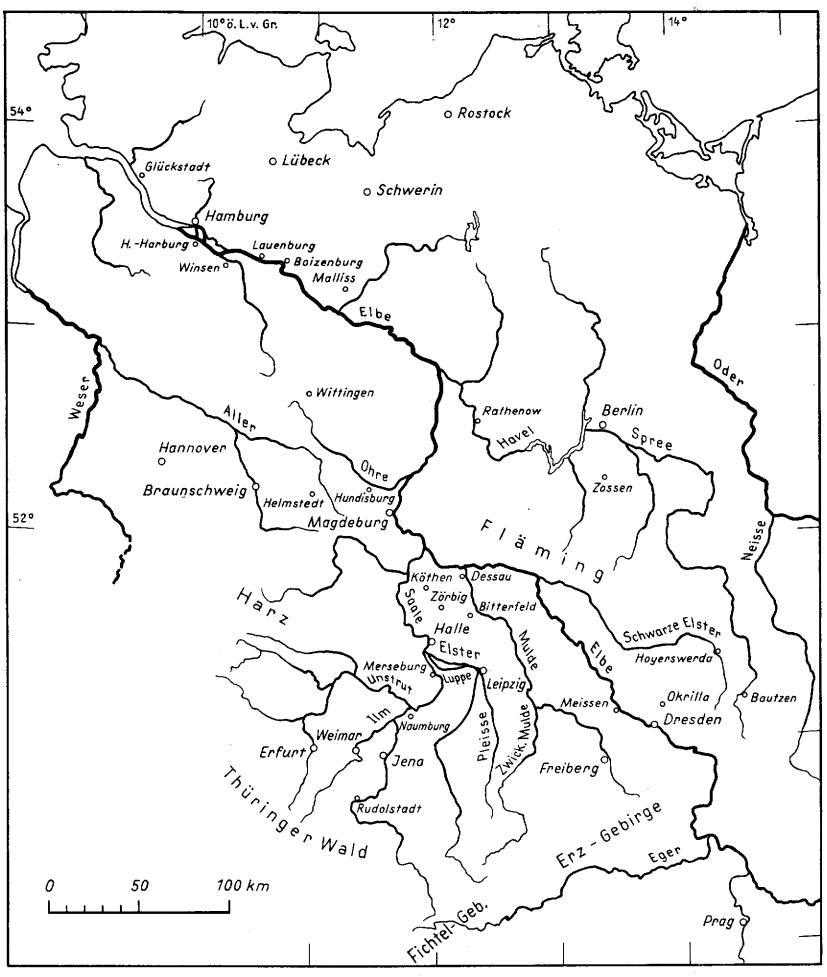

FIG. 1

2. Brief description of the present hydrography of the River Elbe

Today, the Elbe River is 727.2 km long and, up to the Glückstadt gage (excluding the Stör, Oste and Aue Rivers), includes a drainage area of 146 541 km²; total drainage area is about 150 000 km². Large parts of the total area are in Czechoslovakia and the German Democratic Republic whereas only a smaller portion is in the Federal Republic of Germany.

Near Dresden, the slope is 0.27 %, near Darchau (about 40 km upstream from Lauenburg), which is the last gaging station without tidal influence, it is 0.13 %.

Until 1955, the average flow was 22 km³/year; total flow in 1956 was 27 km³/year. In 1956, the minimum, mean, and maximum flows averaged 240 m³/sec, 564 m³/sec, and 1 970 m³/sec near Darchau.

In 1969, the corresponding values measured near Neu-Darchau averaged 296 m^3/sec, 803 m^3/sec, 1 670 m^3/sec, and for the years from 1926 till 1965 the average flows near Neu-Darchau were 268 m^3/sec, 700 m^3/sec, and 1 870 m^3/sec.

3. Brief history of the upper course of the Elbe River

(Neogene and later)

The knowledge on fluviatile material transported from the area of the present upper Elbe into the Central German lignite basin during the Paleogene remains in the dark. After the Middle Oligocene transgression and the deposition of the younger Lignite Formation, there are local indications that linear flow elements developed beginning in the Miocene (Berger, 1941; Mielecke, 1965). Present are quartz and quartzose "southern" pebbles. A relationship may have existed between the forming of the depression in which the Pliocene Posen Clay was deposited and the tendency of the Elbe River to flow north and northeast.

By the end of the Tertiary, the upper Elbe had already cut the valley crossing the Northern Bohemian and the Elbsandstein mountains. The course, which can be traced northward from Dresden to Okrilla-Cunnersdorf-Hoyerswerda, is termed the Senftenberg Elbelauf (Genieser, 1955, 1957).

The traces of this old and preglacial river course are lost at the Niederlausitzer Grenzwall; presumably, the river reached the area of the lower-course of the Oder River. It is possible that in that area the Elbe River came into contact with the Scandinavian detritus facies which had accumulated here since the Neogene (W. von Bülow, 1969) as is shown by the quartz and quartzose pebbles commonly observed in North Germany. It is conceivable that a relationship also existed with the Loosen-Malliß-Rüterberg gravels which have been described from southwest Mecklenburg where they were transported to the southwest (W. von Bülow, 1969). However, there are no indications of a westward connection of the Elbe in the Plio-Pleistocene.

Kurtz's concept of an old westward course of the Elbe River (published in several papers of 1912, 1916, 1926) is incorrect. Although rejected already by Grahmann (1935, 1937) and others, this view is still held by some. The existence of former courses of the Elbe running north of the Central German uplands and westward to the Netherlands is supported neither by primary deposits of upper Elbe "guide" gravels nor by evidence of former river beds. Unsubstantiated is Šibrava's (1972) proposal of "depressions in the pre-Quaternary relief" which can be traced from Central Germany to the Netherlands. The "eastern" mineralogical association described from sand and gravel beds of the Netherlands by Crommelin (1954) is related to fluviatile material of the Saale and Elster Rivers (for instance, topaz from the Vogtland) and not to material from the upper Elbe.

The E-terrace (Engelmann, 1938), the highest terrace system in the Northern Bohemian mountains, correlates with the Senftenberg Elbe course. This river terrace indicates that after previous drainage in the Bohemian Elbe area towards the east and southeast, there was for the first time a change to drainage towards the north.

At present, it is uncertain if the Senftenberg Elbe course existed in the Miocene already (Cepek, 1967), in contradiction to Genieser's interpretation that it was

restricted to the early Pleistocene. There is no doubt that the upper part of the river deposits shows cryomeric features and is, therefore, Quaternary.

Previously, the primarily locally-derived gravels of the next younger river course, the Bautzen Elbe (Genieser, 1955, 1957, 1962), have been explained as having been deposited by the Neisse River or a river coming from the Silesian area. In the reconstruction of Genieser, the river ran from the Dresden area to Klotsche-Okrilla-Cunnersdorf and then turned eastward to Bautzen and the Oder River. This course is considered to have existed during the earliest Pleistocene before the formation of the Cromer complex (Schubert, 1963; Präger, 1966). Other authors believe that the river followed this course during the early Elster Glaciation (Grahmann, 1932; Genieser and Diener, 1957; Šibrava, 1972). In the uplands, the Bautzen Elbe course may correspond to the E-terrace of Engelmann (1938). According to Šibrava (1972), the E-terrace can be separated into two units, the E-I terrace (= Nestemice terrace) which formed before the Elster I ice advance, and the Bohatice terrace which may have formed between the Elster I and Elster II ice advances. Elster I and Elster II in this context are two phases which divide the general Elster advance into the Spree and Röder cold-periods (Präger, 1970). The subdivisions are probably time-equivalent to the Penig and Borna ice margins in the Leipzig area.

Genieser and Diener (1957) and Genieser (1962) have correlated the Schmiedeberg Elbe course with the I-terrace of Engelmann (1938). They assume that this course correlates with the late Elster Glaciation, for the main ground moraine of the Elster Glaciation overlies sediments of the Schmiedeberg Elbe course. In the Schmiedeberg course an ancient river channel of the Freiberg or Oschatz Mulde River ran and, for a short time, the Zwickau Mulde River was its tributary. This northeastward trend of the Freiberg Mulde River continued until the early Drenthe Stage (Riesa Mulde course; Eissmann, 1964*a*, 1965). In the Bohemian area, the I-terrace can be divided into two units.

Gravel derived from the south has been known since the last century from the area south of Berlin. Much of this southern gravel has been reworked into outwash gravels of the Elster Glaciation or younger glacial beds. Detritus from an ancient Elbe course with indicator pebbles of the Bohemian and Eastern Erzgebirge area has been described mainly in the Rathenow, Wietstock, and Zossen area and areally and stratigraphically near the *Paludina* beds of the Holstein-Interglacial period (Kummerow, 1939; Reiche, 1939; Bennhold, 1940; Genieser, 1953, 1955; Genieser and Mielecke, 1957).

These gravel deposits belong to the Berlin Elbe course (Genieser, 1955, 1957), the sediments of which are to be found in two valleys cut into sediments deposited during the Elster Glaciation. Elster glacial material has been reworked into the Berlin Elbe course gravel. This mixture has led to the term "Mixed diluvial sediments" (Klockmann, 1884). The lower part of this sequence underlies the *Paludina* beds (the *Paludina* Gravels and Phöben Gravels, Genieser, 1962).

The upper part of the "mixed" sequence is the Wietstock Gravel which was deposited during the first ice advance of the Drenthe Stage of the Saale Glaciation.

The northward continuation of this river course is as unknown as the flow direction of its predecessor, the Bautzen Elbe course. Until now, no gravels or ancient valleys of the Holstein Interglacial or Drenthe Glacial river system north of Berlin have been found. Maps of the base of the Quaternary rocks do not indicate the direction of the rivers before the Elster Glaciation. This is especially

so since the deep valleys cut into the pre-Quaternary basement are not the result of river erosion but of glacial destruction or glacifluviatile exaration (Hannemann and Radtke, 1961; Eissmann, 1967). The glacial effects may have followed lineaments striking along Erzgebirgian, Rhenian, and Hercynian trends (Solger, 1935; compare the map of Cepek, 1967).

Beneath upper Pleistocene deposits, no sediments have been found which demonstrate the existence of a deep and integrated valley system which may have brought rivers or meltwaters to the west or northwest and into the North Sea. Whether this uncertainty is due to only a lack of data (Cepek, 1967) or there was no such drainage system (Eissmann, 1967) cannot be resolved at present. If the map of Heck (1963) is correct, the northward continuations of all former river systems of the Elbe River cannot be traced west or north of the Berlin area. From Cepek's (1967) map, one gets the impression that the channels can be followed into the Hamburg area. However, the investigation of many boreholes by the Niedersächsisches Landesamt für Bodenforschung in recent years has indicated that the ancient channels ran northwards from the Lüchow-Dannenberg area and joined valleys found in the Mecklenburg area. In no case has a connection from the upper Elbe area towards Hamburg been found.

Consequently, during the deposition of the *Paludina* strata and in the early Drenthe Stadial, the Elbe flowed northwards. To the west, the Saale and Mulde Rivers also flowed north (Genieser, 1962). The present upper course of the Elbe crossing the Meißen area was not established before the Holstein Interglacial.

With the advance of the ice of the Drenthe Stadial into the Meißen area, sand deposits accumulated in ice-dammed lakes [the Heller terrace or Heide Sand of Grahmann (1932*a*, 1934*b*)] in the area of Dresden. The sand deposits overlie terrace gravels of the Middle Terrace (the O-Terrace of Engelmann, Grahmann, 1933) and are, in turn, overlain by glacilimnic clay. Equivalent are the Okrilla Sands. Due to later erosion, the O-Terrace can be subdivided locally into several units. In Czechoslovakia the Main or Middle Terrace of the early Drenthe Stadial is important as a standard morpho-stratigraphical unit (Šibrava, 1966, 1972). The gravel of the O-Terrace (mostly about 12 to 20 m above the present floodplain) in this region forms the base of younger, Warthe Stadial terrace gravel such as the famous Lovosice terrace (8 m above floodplain, Ložek and Šibrava, 1968). However, it does not seem necessary to propose a subdivision of the terrace bodies (the "double terrace" of Šibrava, 1972) as a consequence of this not unusual circumstance.

With the Warthe Stadial of the Saale Glaciation the history of the upper Elbe River changed remarkably. The upper Elbe was impinged upon by the Fläming ice margin and forced to flow westward instead of northward. For the first time in its history, the Elbe joined the Mulde and Saale Rivers. From this moment these two rivers stopped having their own lower courses and became tributaries of the Elbe River (Woldstedt, 1956). Some authors (for example, F. Hoffmann, 1824; Klockmann, 1884) have postulated that the valley of the Ohre River should have been the outflow of the ancient Elbe in the direction to the Aller and Weser Rivers. However, investigation of the Hundisburg gravel deposits (Wiegers, 1905, 1919; Wahnschaffe and Schucht, 1921; Glapa, 1970) shows that this valley drained to the east and was the valley of the Wipper River of the Holstein Interglacial (compare chapter 4). The famous Breslau-Hannover ice stream (Berendt, 1882) developed only after the ice of the Warthe Stadial blocked

the lower Wipper and Ohre valleys. The flow was about 80 m above sea level and was directed westward, towards the Aller. A lower terrace about 60 m above sea level was thought to correspond to this outflow. Klafs (1963) has shown that this former valley floor has no connection to this outflow direction. According to Klafs, the breakthrough of the Elbe River to the north must have occurred after the main Warthe Stadial (Letzlinger ice halt). The middle Elbe River followed the retreating ice by flowing through glacial channels and topographic lows on its way to the western Baltic Sea, together with the Saale and Mulde Rivers. The river did not flow towards the area of the present lower Elbe River. Woldstedt (1956) has given two possibilities for the course of the late Warthe Stadial Elbe:

a) following the Lewitz depression across the Schwerin Lake area ;

b) following the Warnow valley to Rostock-Warnemünde and then to the Baltic Sea.

At present, there is no proof for either possibility. The integration of the Bohemian-Saxonian river system with the lower Elbe occurred during the Eem Interglacial and was operating during the Weichsel Glaciation (Grimmel, 1973).

The lower terrace of the Weichsel Glaciation (U-terrace of Engelmann, 1938) or the Tallehm terrace of Grahmann (1933) can be followed along the whole river valley and into the upper Elbe area as far as the Budweis basin. There are three terrace levels in the Dresden area (Präger, 1966). In the Magdeburg area the sedimentation of the terrace gravel began with the accumulation of the Eem interglacial lower gravelsand (Steiner and Steiner, 1963).

The Recent and Holocene river sediments of the Elbe River are located in a depression cut into the lower terrace body. The lower part of the sequence is mainly late glacial to early Holocene gravel (upper gravel sands) which is covered by high-flood loam. This loam unit can be subdivided into an older high-flood loam that was deposited during the Atlanticum (Grahmann, 1931; Händel, 1967) and younger high-flood loam of medieval age. Deposition of the latter began essentially after A.D. 800 (Grahmann, 1932, 1934*b*; Steiner, 1972; Neumeister, 1964; Händel, 1964, 1967) and ended almost everywhere after A.D. 1200. In some regions the Löbschütz soil which was formed about 4000 B.C. to 0 divides these high-flood loams. This is similar to the development of the Holocene sediments in the Weser River area (Lüttig, 1960).

4. Brief history of the Saale River

As described in chapter 3, the history of the Saale River (including the tributary Weisse Elster and Zwickau Mulde River) differed from that of the upper Elbe River until the Warthe Stadial. The history of the Saale since the middle Late Eocene can be traced. In the Miocene we can recognize gravel components derived from the Thüringer Wald, the Fichtelgebirge, and the western Erzgebirge. This material was deposited in the Saxonian-Thuringian lignite basin (M. Rost, 1933; Steinmüller and Ortmann, 1970). In the Neogene, the basin of the Weisse Elster and outcropping Permian and Triassic sediments in Thuringia and the central uplands were cut by a peneplain. At some period within the Pliocene, this surface was cut by predominantly northward flowing drainage. One may recognize the Saale and Weisse Elster Rivers.

Various authors have used several numbering systems for the former valley floors which developed at this time. However, these pre-glacial terraces are not listed and described here; it is sufficient to know that various terraces and local river courses developed at that time.

Through the pioneering publications of Soergel (for example, 1921, 1924) the river system of the Saale has been used as a standard for Pleistocene sedimentation and erosion as well as for the differentiation of the smaller units of the glaciation. Unfortunately, the commonly correct and astute opinions and explanations of Soergel are too often not based on good field evidence.

The basin of Thuringia and the Weisse Elster River is also a standard region for the differentiation of the glacial deposits of the Elster and Saale Glaciations. These glaciations had an enormous influence on the hydrographical development of the present river courses.

The pre-Elster river system in the western Thüringer Wald has been long known (Soergel, 1921). It was responsible for the transport of crystalline pebbles to the Werra and Weser Rivers. The Apfelstädt River flowed across the Gotha area towards the Unstrut River. It crossed the Schmücke mountains and captured the Gera River which drained northwards from the Arnstadt region and across Erfurt. The Ilm River flowed from the Ilmenau area and crossed the Weimar area where it deposited the famous pre-Elster Süssenborn gravel (Weiss, 1899). It continued across the Finne mountains and entered the Unstrut valley near Freiburg where the Unstrut River ran north of Naumburg and into the Saale River. The upper Saale River followed the present course from Rudolfstadt via Jena to Naumburg and Weissenfels. There, it turned eastward towards Leipzig (Siegert and Weissermel, 1911; Schulz, 1962, 1963; Eissmann, 1962*a*, 1964*b*; Ruske, 1964), then turned northward and, using different channels at different times, ran westward from Leipzig in the direction of Bitterfeld-Dessau. The upper course of the pre-glacial Weisse Elster can be found locally. It ran past Luckau into the area of the city of Leipzig and then turned northwestward towards the ancient Saale. The Zwickau Mulde River, which in former times had followed a northward course crossing the Grimma area (Eissmann, 1962*b*), joined the Elster River north of Leipzig.

The pre-glacial rivers running down from the East Harz mountains followed courses similar to the present ones so that carpolith slate pebbles (the classical "guide" pebble from the East Harz mountains) can be found near Bernburg. Porphyry pebbles from the southern Harz are found in gravels of the ancient Wipper River (Ruske, 1964) and gravels of the ancient Bode River near Hohenwarthe near Magdeburg (Wiegers, 1929; Ruske, 1964; Glapa, 1970). Pre-glacial Wipper and Salzke gravels have been found near Hettstedt-Könnern (Kunert and Altermann, 1965).

There is no evidence as to the course and age of those rivers that deposited Central German pebbles found in glacial and preglacial gravel in the Braunschweig area. The suggestions of Kurtz (1912, 1916) are too vague and lack petrographical basis. Material derived from the east is present in the Asse mountains (Stolley, 1914), in the valley between Helmstedt and Königslutter east of Braunschweig, near the village of Rieseberg (Harbort, 1913), and north of Hannover. Pebbles derived from Central Germany (primarily from the Halle area) have been found by F. Preul and G. Lüttig during as yet unpublished analyses of several drillholes in the Braunschweig area. This fluvial material may correlate with the Saale-Elster

heavy minerals association (with topaz grains from the Vogtland) which has long been known from the Netherlands (Crommelin 1953, 1954; Maarleveld, 1954). It is also possible that this river material resulted from a diversion of the Central German rivers when the Elster ice reached Central Germany (Bettenstaedt, 1934). There is no field evidence for this theoretical concept. The subglacial drainage postulated by Grahmann (1933) and others appears to have been important in some areas (for example, in the Thuringian Basin during the greatest advance of the Elster ice and in the Elbe valley near Dresden during the Drenthe Stadial).

The rivers were dammed and, together with the ice meltwater, formed ice lakes when the advancing Elster ice reached the Halle-Leipzig area. Glacilimnic clay (Leipzig and Dehlitz varved clay) was deposited over the youngest pre-glacial gravels (Grahmann, 1925; Schulz, 1962, 1963; Eissmann, 1962*a*, 1964*b*). The glacilimnic clay is overlain by the ground moraine of the Elster-I advance. To the southwest, this advance reached the flint limit in the Thuringian basin; it also overrode the eastern Harz. After an ice retreat, the Elster-II advance followed, and its moraine can be found in many places in Saxony but has been mostly eroded from the plateau west of the Saale River. The Penig-Borna varved clay was deposited at this time. Complete sections of the moraine sequence can be found in the lignite basins (Mania, 1967; Schulz, 1961). It is uncertain if the two Elster moraines recognized here are the same as the two found in the classical section of Voigtstedt in Thuringia (Erd, 1965). There it is possible to clearly recognize a true interglacial, the Voigtsted warm period (corresponding to the Cromer complex). If this warm period is correlative with the retreat known from the Leipzig area, where Elster-I and Elster-II moraines are recognized, is unknown.

The retreat of the ice from the marginal moraines of the Elster Glaciation caused a change of the Central German rivers' courses. In some cases, the upper course was cut off from the lower course by moraines. In other cases, sub-glacial valleys allowed drainage to the north. In some rivers, glacioclimatic sedimentation occurred. The Saale, Elster, and Mulde Rivers formed one single river from the Zörbig area northwards (Knoth, 1964; Ruske, 1964).

The Unstrut River briefly followed the famous Zeuchfeld valley which has been described in many publications. Erd (1965), Cepek (1967), Mania and Altermann (1970) have shown that in this region the Holstein Interglacial period consisted of two thermomeres which are separated by the Fuhne Kryomere. The older part of the interglacial is the Holstein Interglacial *sensu stricto*, the younger one is the Dömnitz Interglacial.

Erosion accompanied the first warm period. Thus the Elster ground moraine of the plateaus was heavily eroded. The Saale River occupied the Riesdorf course in which the interglacial deposits of Edderitz accumulated. Sedimentation occurred again in the Fuhne cold period. Corresponding terrace bodies, the so-called Upper Middle Pleistocene terrace, can be found in many places ten meters above the Main Terrace of the Saale River (better names are First Middle Terrace and Middle Terrace, respectively, Knoth, 1964). Examples are terraces in the Salzke River area (Schulz, 1961, 1963), the Wallendorf terrace (Ruske, 1964), and the Edderitz terrace in the Köthen area. In the Holstein Interglacial, the Elster and Mulde Rivers joined north of Leipzig and flowed northwards across Delitzsch and Dessau. They did not intersect the Elbe River which was further to the east. It is uncertain if Woldstedt (1956) was correct in assuming that the Saale River at that time entered the bay of the Holstein sea near Boizenburg.

Downcutting began again during the Dömnitz warm period and continued until glacioclimatic sedimentation began at the end of the Holstein complex (Holstein *sensu lato*). These deposits can be found throughout the glaciated area of northern Europe and form the famous Middle Terrace in all river systems. In the Saale River area it is called "main terrace" by most of the authors, or "the second middle terrace" by Knoth (1964). These deposits can be subdivided into smaller units similar to those in the Weser River area. Apparently, the history of the rivers in Central Germany has many parallels (Knoth, 1964) to the history of the Weser River as interpreted by Lüttig (1952, 1958*c*, 1960*b*).

We can follow the early Drenthe Middle Terrace of the lower course of the Saale River as far as the present-day Elbe valley. In the Salzke valley the terrace body contains the famous *Corbicula fluminalis* gravels of Köchstedt (Diezemann, 1939; Schulz, 1961). In the area south of Leipzig, the Markkleeberg Pleisse gravels with the internationally wellknown Levallois artifact strata (Grahmann, 1925, 1931, 1951) belong to this unit. This is also true for the famous Körbisdorf terrace in the Unstrut valley.

In the upper part of the terrace sediments one can observe the increasing influence of the glacial features of the Drenthe Stadial. The ice of this stadium advanced as narrow glaciers following the valleys and, therefore, these are called valley advances. The Drenthe Stadial history is divided into the basal advance (Siegert and Weissermel, 1906; Bettenstaedt, 1934) with clay sedimentation in ice-dammed lakes, the main advance with synchronous deposition of glaciolimnic clay, one main retreat, an overriding advance, and ice halts during the retreat phase of the Drenthe Stadial (Schulz, 1961, 1963; Ruske, 1964).

The moraines of the Drenthe Stadial had filled the valleys in such a way that the rivers in the following Gerdau Interstadial period had to cut new valleys. Thus, for example, the Unstrut could not follow the famous Zeuchfeld valley and was shifted to the south and followed the former valley which had been abandoned during the Elster Glaciation. Downstream from Merseburg, the Saale River changed its course to the west and the Elster was turned by the Breitenfeld moraine also to the west (Schulz, 1962).

In contrast with the other Central and Northern German river systems, a Warthe Stadial river terrace of the Saale River has been recognized (Ruske, 1963). The surface of this terrace is 7-10 m above the present river level. It can be followed from the lower Saale valley to the Magdeburg area where the terrace sediments near Gerwisch contain pebble tools of the Acheulian IV period (Toepfer, 1961). The sediments were transported northwards. No material from the upper Elbe has been found in these gravels because the Elbe was first forced to flow west to the Saale River by the Fläming ice margin (chapter 3). The Saale and its tributaries developed normally during the Eemian Interglacial, during the Weichsel Glacial period (the glaciers of which had no influence on the history of the Saale and Elbe Rivers), and in the Holocene. Normal development in this sense means:

a) downcutting by the river in the Eemian Interglacial;
b) accumulation of the Lower Terrace during the Weichsel Glacial;
c) erosion at the beginning of the Holocene followed by accumulation of a first cycle of gravel, sand and highflood loam due to the post-glacial climatic optimum; then a second cycle ending with a high-flood, anthropogene loam in the medieval period.

Table 1 gives a generalized subdivision of the Pleistocene in the Elbe-Saale area.

TABLE 1. — *Generalized review of the Pleistocene in the Saale and Elbe areas*

Neopleistocene	Weichsel Glacial Period		Accumulation of the Lower Terrace Solifluction soils Upper Loess
	Eem Interglacial Period		Primarily erosion, soil development Rabutz, Jeetze, and Phöben Interglacials
	Saale Glacial Period	Warthe Stadial	End moraine of the Lausitzer Phase (Lausitzer boundary wall) Rügen Interval End Moraines of the Fläming phase (main Fläming ice margin) 9-10 m terrace of the Saale
		Gerdau Interstadial	Primarily erosion
		Drenthe Stadial	Schmiedeberger end moraine Overriding advance Main advance Halle and Leipzig area } Loess Basal advance Halle and Leipzig area } Solifluction soils Deposits of ice-dammed lakes in Halle-Leipzig-Dresden area Middle Terrace *(sensu stricto)*, "cold part"; Wietstocker Gravels
	Holstein Interglacial	Dömnitz Interstadial	Middle Terrace, lower part, Körbisdorfer, Köchstedter, Markkleeberger terrace deposits Primilary erosion
		Fuhne Stadial	Upper Middle Terrace, solifluction soils, loess
		Paludina Interstadial (Holstein, *sensu stricto*)	**Paludina** Beds, Edderitz, etc. Primarily erosion, Berlin course of the Elbe
	Elster Glacial	Upper Elster Stadial	"Upper" Elster moraine, Schmiedeberger course of the Elbe
	Elster Glacial / Cromer Complex	Voigtstedt Interstadial	Voigtstedt Fauna Primarily erosion
	Elster Glacial / Cromer Complex	Helme Stadial	"Lower" Elster moraine Elster I and II (?) in the Halle-Leipzig area
	Cromer Complex	Artern Interstadial	Voigtstedter Muschelton Primarily erosion
Eoplei-stocene	Eopleistocene cold and warm periods		Senftenberger course of the Elbe mainly erosion

5. Development of the lower course of the Elbe

The Elbe has crossed the present lower Elbe area for only a relatively short time. Consequently, older deposits of the Elbe do not exist in the well-studied Hamburg area. Neither are Elbe deposits known from the last interglacial period when, according to Woldstedt (1956), the Elbe should have run northward to the western Baltic Sea. The Elbe river may have cut through the moraines of the Warthe Stadial near Magdeburg during the retreat of the ice sheet (Woldstedt, 1956), but did not succeed in crossing the same moraines in the northern Lüneburg Heath near Harburg.

Illies (1954) suggests that the erosion through the moraine chains near Harburg took place when the ice margin had retreated to a line between Bergedorf and Winsen. He called this late Warthe Stadial meltwater river the primitive Elbe ("Urelbe"), in agreement with Stoller (1914). The deep erosion is thought to have taken place in the beginning of the following interglacial. There is evidence that the late interglacial accumulation of the so-called "20 m terrace" began at or below the elevation of the present valley.

Illies (1954) has stated that the surface of the "20 m terrace" should be found 10 m above the flood plain at the present river mouth, at 20 m near Harburg, and 30 m above the present flood plain near Hitzacker. According to Illies, the following conclusions should be drawn about the development of this terrace.

a) In no place have the terrace sands been pushed or deformed by the ice or covered by moraine. Consequently, they are younger than the Warthe moraines.

b) At the classical Lauenburg section, sands of the "20 m terrace" cover the Eem Interglacial peat deposit of the Kuhgrund. Apparently, sediment transport and accumulation reached a maximum not before the end of the Eemian Interglacial.

c) Most of the sand deposits of the terrace contain allochthonous plant debris along bedding planes. The sand is strongly bleached and relatively fine-grained indicating interglacial weathering during relatively quiet sedimentation. Apparently, the flow of the river had not been increased by glacial meltwater.

d) Near Harburg and Ashausen, this fine-grained sand is covered by two to four meters of coarse outwash-plain gravel. This suggests that meltwater again attained access to this region only after the sand had accumulated.

e) The surface of the terrace and the margins of the terrace facing the valley bottom are covered in many places by periglacial sediments. Erosion must have replaced sedimentation just before the maximum of the periglacial climatic period of the last glaciation. Consequently the surfaces and the slopes of the terrace were influenced by the glacial climate of the last glaciation.

f) The terrace sands are poor in minerals of southern origin indicating that, despite headward extension, the ancient Elbe had no connection with its present-day upper course.

g) Single cross-bed sets within the fine-grained sands are commonly more than 1 m thick. Consequently, sedimentation was probably very rapid.

h) Near the mouth of the river, the terrace gravels are about 10 m above the valley floor indicating that the river mouth and sea level were at different

elevations than at present. A glacial-eustatic sea level rise is necessary to explain the elevation of the 20 m terrace in the present mouth area of the river (Illies, 1952).

After the covering of the fine-grained sand with coarse out-wash plain gravel, the meltwater of the advancing Weichsel ice, according to Illies, should have caused much erosion.

This would have resulted in deposition of the first meltwater detritus in the Elbe valley near Hamburg at an altitude as much as 30 m below present sea level (Koch, 1913). This meltwater system should have captured the Bohemian-Saxonian river system so that, in the maximum of the last glaciation, the ancient lower Elbe should have become the Elbe glacial outlet ("Elbe-Urstrom"). This concept will be discussed in the light of recent field investigations.

Illies reports traces of his 20 m terrace north of the recent Elbe River in the area between Lauenburg and Geesthacht. The Lauenburg deposits are of special importance as it is possible to date the sand with the help of the underlying peat deposit of the Kuhgrund Interglacial. However, according to Meyer (1965), the fine-grained sand, which is up to 12 m thick, and which has an upper surface up to 30 m above sea level, and overlies the peat, can in no case be interpreted as terrace sand of the former Elbe. The sand is typically limnic and was deposited in a basin which can be followed to the north within the north-south trending valley in which the deposits occur. Nowhere are the sands covered by ground moraines as has been suggested by Grimmel (1973). The ground moraine covers older sand further upstream along the valley (Artlenburg Geological Map sheet). This is an example of how various deposits of fine-grained sand (which are unrelated to Elbe River deposits) have been considered parts of the so-called 20 m terrace.

In the area of Scharmbeck, Ashausen, and Stelle (Stelle sheet, no. 2626 of the 1: 25 000 Geological Map) the "terrace sands" should, according to Illies, be widely distributed. This supposition can be investigated at the following locality.

Outcrop No. 1 (old sand pit north of point 12.0, just northwest of Ashausen, Geological Map 2626, Stelle; coordinates: re 35 75 300, h 59 15 400; elevation up to +25 m).

The geological section of the north-northeast slope in this abandoned and recultivated pit was studied between 1967 and 1968. Under an unstratified, gravelly "Geschiebedecksand" (glacial cover sand), up to 1 m thick and interfingering with remnants of glacial till, is an approximately 3 m thick, light brown, slightly gravelly, bedded to cross-bedded, medium to coarse-grained sand with silt and fine to coarse-grained gravel interbeds. At the base is a 0.4 to 0.6 m thick pebble horizon containing some cobbles. Locally, this gravelly sequence fills channels up to 4 m deep in the underlying fine-grained sand. The fine-grained sand is whitish in the upper part and contains some interbeds of medium and coarse-grained sand. This sand sequence is horizontally bedded with local cross-bedding and contains detrital humous interbeds.

The gravelly upper sequence seems to be of meltwater origin. There are no indications of fluviatile sedimentation by an ancient Elbe. Slight disturbances of the ice-push type and the till remnants (even though sparse) speak against deposition by the Elbe and for a greater age. On the basis of counts of erratic boulders in the gravel bed, a TGZ (theoretical erratic boulder centre, after the method of Lüttig, 1958*a*) of 16.24-57.96 has been determined. The F/K (flint-

crystalline coefficient) is 0.70. The Q/K (quartz-crystalline coefficient) has been determined as 0.013. The determinations indicate that the gravel is of Warthe age. This is not the case for the underlying fine-grained sand which has shown to have been deposited in the Drenthe Stadial. The sand can be found between the main Drenthe moraine and the younger Drenthe moraine.

Near Ashausen, Schroeder-Lanz (1971*a*, 1971*b*) found sand attributed to the "20 m terrace" but ice-pushed and covered by ground moraine. He drew a very interesting conclusion (1971*b*, p. 176-177) "Either the stratigraphic assignment of the fine-grained sands is not correct or ice of the Weichsel Glaciation advanced westward to the Lüneburg Heath." However, he did not consider that the sand might not be a terrace deposit. From the area of Ashausen-Wulfsen, Schroeder-Lanz (1971*b*) describes lydite-containing gravel and sand which was transported in a direction approximately down the Elbe River. This deposit covers the so-called "20 m terrace" and is overlain by ground moraine. K. Richter (1964) also described lydite pebbles from near Ashausen (in the area of Alt-Garge, Gusborn, and Woltersdorf). He considers these gravels to be an "Upper Elbe Middle Terrace" which is presumably older than the Warthe ground moraine. Besides lydite, these gravels are rich in vein quartz and are supposed to contain porphyry from the Thüringer Wald (not at the Ashausen section).

The age and genesis of the lydite-containing gravels cannot be discussed in detail here. However, it should be mentioned that there is no direct proof of porphyry clasts from the Thüringer Wald. At the outcrop near Ashausen, the authors have found no lydite clasts. One lydite pebble each was found in the centers of two neighbouring gravel pits. However, a few lydite pebbles are not uncommon in this area. It is possible that they have been derived from older Pleistocene beds and several times reworked as is true of preglacial quartz sand and gravel in the Garlstorf ice-pushed moraine which crops out in the Brunsberg gravel pit near Nindorf. It is possible that this gravel is similar to the deposits described by W. von Bülow (1969) from southwestern Mecklenburg (see chapter 3).

The above explanation is probably not valid for the abundant lydite clasts (up to 7.5 %, K. Richter, 1964) found in gravels in the Lüchow-Dannenberg area. Although there was an introduction of lydite-containing southern material in the later Quaternary, there is no proof that this material came from the Elbe River. Lydite-containing gravels in this area are not restricted to the recent Elbe valley. They can be followed southward past the Bodenteich-Wittingen-Gifhorn area and to the Aller River. Here, glaci-fluviatile sediments and moraines locally contain southern material which has been reworked from sediments of the Middle Terrace.

An "upper Elbe Middle Terrace" cannot be discussed until after a thorough study of the distribution and stratigraphic position of the lydite-containing gravels in eastern Lower Saxony, especially since typical Elbe "guide" pebbles are lacking. However, these sediments cannot be taken into consideration with respect to the question of the "20 m terrace."

The outcrops in the Harburg area (Illies, 1954, fig. 4) are no longer accessible. What can be seen there indicates that the upper outwash plain gravels are of Drenthe age. We can study the sediments at the slope of the Geest on the Buxtehude (2524) sheet.

Outcrop No. 2. Gravel pit west of the Wesenberg, southwest of Neu-Wulmstorf.

In the large gravel pit near Neu-Wulmstorf, the conditions of the outcrops changes very quickly, due to the enormous production of gravel. Since 1967 it has

been continuously possible to study the middle brownish till covering whitish, fine-grained sand at the north wall of the pit (re 35 52 440, h 59 25 190). In the southern parts of the pit, ice pressure features can be studied while in the northern part the fine-grained sand has not been disturbed. The sand contains a lot of mica and is mainly horizontally bedded with some "ripple bedding." Important is that the surface of the sand is as much as 30 m above sea level. This is higher than it should be if Illies (1952, fig. 9) were correct.

In the sand pits of the Este valley it can be seen that the fine-grained sand complex has no connection with the trend of the Elbe River valley but can be followed for kilometers into the Geest hills. This is also true for the area on the Hittfeld sheet.

The following topics are important:

1. The "fine-grained sand" of the "20 m Elbe terrace" does not exist. The sediments included in this unit differ in age and genesis.
2. In most cases this complex is covered by glacio-fluviatile, gravelly sand and/or till.
3. There is no definite proof of the presence of Elbe pebble material.
4. The interpretation about the sea level of that time is invalid.

In addition, the suggestion that thick sediments accumulated up to 30 m above sea level from the end of the Eemian to the Weichsel Glacial period is also invalid. This conclusion is based on the elevation of the erosional base during the Eemian in the Hamburg area. This erosional base can be found at sea level, whereas the base of the river sands of the late Saale Glacial in the area of the Binnenalster can be found as much as 16 m below sea level (Grube, 1971, 1972).

Consequently, the question of the origin of the present Elbe valley arises again, particularly following the time when the river first ran along its present course.

We can assume that the Holstein Interglacial "fjord," which extends far landwards, was filled completely by the glaciers of the Saale Glaciation. The valley may have been blocked by ice masses with the initial drainage to the south. When the ice retreated, the depression may have been used as a channel for the outwash coming from the relatively distant ice margin. This could have been the case during the formation of the limnic sands in the Lauenburg area which Illies believed were transported to the northwest. However, this is no reason to call these deposits "Elbe River sands." Thickness, distribution, lithology, and texture of the sand indicate meltwater conditions or glaciolimnic genesis. This does not mean that the local fluvial regime could not have had any influence during the formation of this very heterogenous sediment. Thus, we find that in the lower Elbe valley there may have been local rivers which were unrelated to the middle and upper Elbe. At the latest, the connection to this upper river system must have been formed when the ice of the Weichsel glaciation blocked the outlet of the northward-flowing middle Elbe and forced it to flow towards Hamburg. We must not look at the Geest margins for sediments deposited by the late Warthe Stadial, Eemian Interglacial or Weichsel Glacial Elbe, but rather in the valley itself. Such Elbe River sediments have not yet been found. Only sedimentological methods, in particular, heavy mineral and large-clast analyses of borehole samples, can be used to find these sediments (and also to subdivide the entire terrace system of Lower Saxony). Such studies have only just begun.

Morphostratigraphical indications show that during the maximum of the Weichsel Glaciation the Elbe River drainage system had its present form. The lower terrace of the Elbe dips under the Holocene river beds near Geesthacht (Grahmann, 1931).

After erosion during the Weichsel Glaciation, the ocean entered the North Sea and the estuary of the Elbe resulting in an estuarine transgression by which marine mollusks were transported to near the mouth of the Oste River (Simon, 1960). The base of the late glacial sediments in the Hamburg area is between −4.5 and −15.1 m below sea level, near Geesthacht it was at elevations from −2.7 to 4.3 m (Hallik, 1962). The following perimarine complex was deposited in this basin during the Holocene: younger silt and clay, organogene detrital sediments and peat, clay, river sand, older sand and gravel.

According to Hallik (1962) the ocean did not reach the area of Hamburg in the Holocene. But there is no doubt that the Holocene transgression greatly influenced the history of the river. This could be seen during recent flood periods of the river.

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DISCUSSION

J. I. S. ZONNEVELD. — *Crommelin and Maaskant stated that the topaz found in the Enschede sands in Eastern Netherlands were supplied by a "proto-Elbe?" from Bohemia. If the upper Elbe did not flow to the Northwest, but instead to the North (East), how were Bohemian topaz grains transported to the Netherlands? Or have topaz bearing rocks been found within the watershed areas of the Saale River?*

G. LÜTTIG. — The interpretation of Edelman and others, to my knowledge, was only talking about Eastern material, so the only problem is to avoid speaking of *Elbe* material (which in reality is Saale, Weser, and other material).