FLUVIAL SEDIMENTATION FROM THE FENNOSCANDIAN AREA INTO THE NORTH-WEST EUROPEAN BASIN DURING THE LATE CENOZOIC

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ABSTRACT

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Late Cenozoic deposits in the North-West European Basin with a typical gravel composition, called the Baltic Gravel Assemblage, have been studied from the literature and in the field. The gravel indicates a provenance from the Fennoscandian area and is characterized by a high proportion of translucent quartz and the presence of silicified Palaeozoic sediments.

From the available data it is concluded that one river system, called the Baltic River System, was the transporting agent of the Miocene, Pliocene and Pleistocene deposits containing the Baltic Gravel Assemblage. In the Miocene the sedimentation was to the south and west. From the Late Miocene into the Early Pleistocene the main transport was towards the west.

The Baltic River System was destroyed by the inland-ice of the Menapian glacial.

INTRODUCTION

During the Cenozoic a large tectonic basin covers the north-western part of Europe: the North-West European Basin. It extends over a distance of more than 2000 km from the northern North Sea to Poland. The basin is flanked to the northeast by the Fennoscandian Shield and the Baltic Platform, to the south by the Variscan Massifs and to the west by the Scottish Caledonides (ZIEGLER, 1978: Encl. IV).

In the basin two areas can be distinguished: the western part or the North Sea Basin where the Cenozoic sediments reach a thickness of more than 3000 m (ZIEGLER, 1978) and the eastern part, the East German-Polish Basin with Cenozoic sediments up to 1000 m thick (Fig. 1).

The infill of the North-West European Basin was mainly marine in the Palaeocene, Eocene and Oligocene (FAY, 1977). After the Oligocene fluvial sediments also became important, especially in the East German-Polish Basin and the southern part of the North Sea Basin (QUITZOW, 1953; ZAGWIJN & DOPPERT, 1978). Rivers from the north, draining the Fennoscandian Shield and the Baltic Platform, and rivers from the south, draining the Variscan Massifs, supplied material to the basins.

In this review, which is based on data obtained from litera-

ture and field work, the deposits of the rivers draining the eastern part of the Fennoscandian Shield and the Baltic Platform will be discussed.

The study of the deposits is hampered by a thick overburden of Pleistocene fluvial and glacial deposits. Outcrops are scarce and are mostly located in ice-pushed ridges, where the Pleistocene inland ice pushed the deposits to the surface (MAARLEVELD, 1956; GRIPP, 1964; ZANDSTRA, 1971). Isolated outcrops are found where the deposits were pushed up by halokinetic movements (GRUBE, 1957). In East Germany deep exposures were made for the exploitation of brown-coal layers in and underneath the deposits (QUITZOW, 1953; AHRENS ET AL., 1968). Erosion by the Pleistocene inland ice-sheets probably removed much of the deposits in the area at present occupied by the Baltic Sea (QUITZOW, 1953). Thus the original extent of the deposits is not known in the northern part of the East German-Polish Basin.

CHARACTERISTICS OF THE DEPOSITS

Lithology

The deposits under discussion are white or grey-white sands with subordinate clay, gravel and brown-coal beds (QUITZOW, 1953; GRIPP, 1964; DOPPERT ET AL., 1975). The colour is deter-

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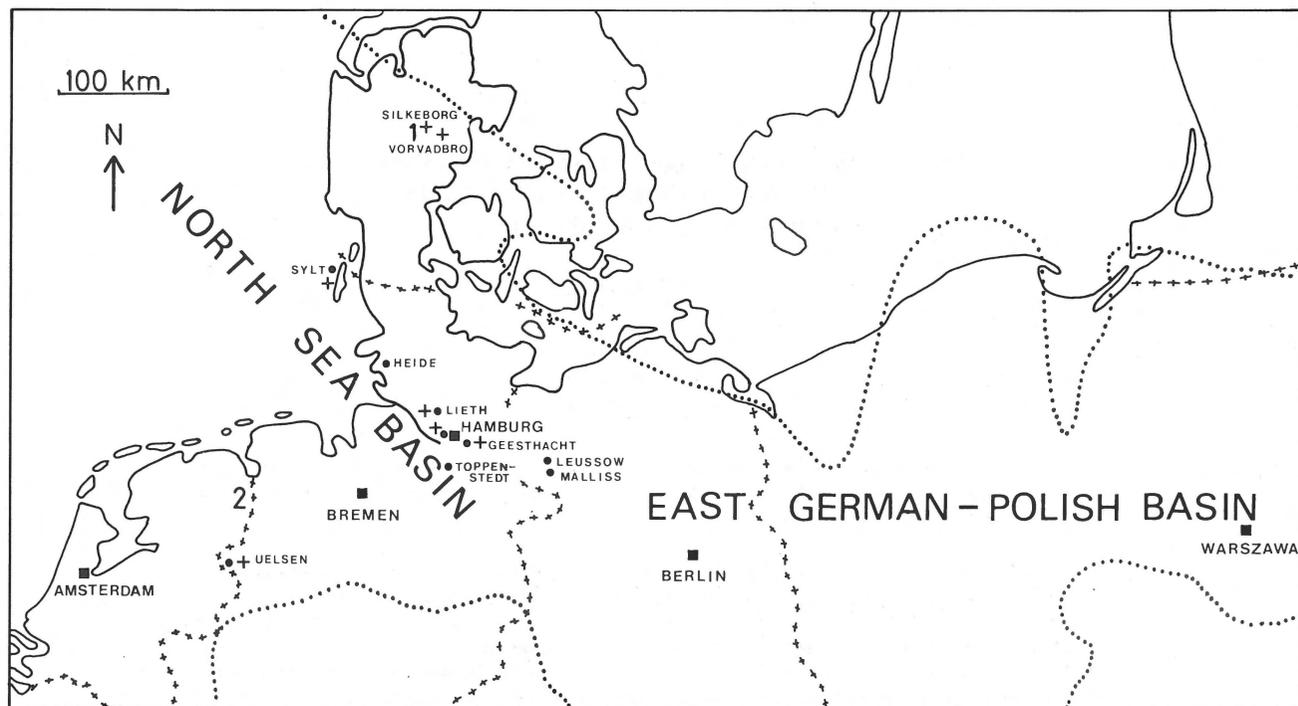
Fig. 1   ···· BORDER OF THE NORTH–WEST EUROPEAN BASIN   + GRAVEL SAMPLES   • HEAVY-MINERAL SAMPLES
Location map. 1 = area sampled for heavy minerals by Friis (1974), see table II; 2 = area sampled for heavy minerals in The Netherlands, see table II. The border of the North-West European Basin has been drawn after Ziegler (1978).

mined by a high amount of translucent quartz grains and the presence of white alkali feldspar (CROMMELIN, 1954; FRIIS, 1974) both in the sand and the gravel fraction. Dark-coloured grains are almost completely lacking and the heavy-mineral content is generally low (FRIIS, 1974). In part of the deposits the white colour is intensified by the presence of feldspar dust (ZANDSTRA, 1971) or kaolin clays (MAARLEVELD, 1956; GRIPP, 1964) coating the sand and gravel grains.

Gravel composition

The most useful characteristic of the deposits is the petrographic composition of the gravel. In all size fractions of the gravel well rounded clear or translucent quartz with blue and grey colours is the main component. Grey or white feldspar and quartz with adhering white or grey feldspar are usually present. The remainder, which is often less than 3%, consists of quartzites and silicified sediments (mainly silicified limestones). In the cobble and boulder fractions (> 64 mm) quartzites and silicified sediments are more common (RICHTER, 1955; MAARLEVELD 1956; ZANDSTRA, 1959).

Typical of the gravel is the age of the silicified sediments. Most are of Late Ordovician age and few are of Cambrian or Silurian age (HUCKE, 1967; NEBEN & KRUEGER, 1979). The quartzites seem generally to be of Palaeozoic age (HUCKE, 1967).

In this review the gravel assemblage with the above mentioned characteristics is called the Baltic Gravel Assemblage (BGA).

PROVENANCE

The gravel components, especially the silicified sediments, point to a source area in the eastern part of the Fennoscandian Shield and the southern part of the Baltic Platform. Only there rocks with an identical lithology and fossil content are found (HUCKE, 1967). Outcropping Palaeozoic rocks are found at present in a belt-shaped area from the south of Sweden to Estonia (HUCKE, 1967).

The quartz and the feldspar in the gravel must have had their source in an area with igneous rocks to explain the high content of translucent and clear quartz. Only the Fennoscandian Shield north of the outcrop of the Palaeozoic sediments can be considered as the source area (ZANDSTRA, 1971).

Judging from the gravel composition the drainage area must have been the Fennoscandian Shield and the western part of the Baltic Platform. The most probable course of the rivers is through the area now occupied by the Baltic Sea.

In this review this river or these rivers are called the Baltic River System.

STRATIGRAPHICAL DESCRIPTION OF THE SEDIMENTS CONTAINING THE BALTIC GRAVEL ASSEMBLAGE

The Miocene of East Germany and Poland

The first fluvial sediments containing the BGA are known

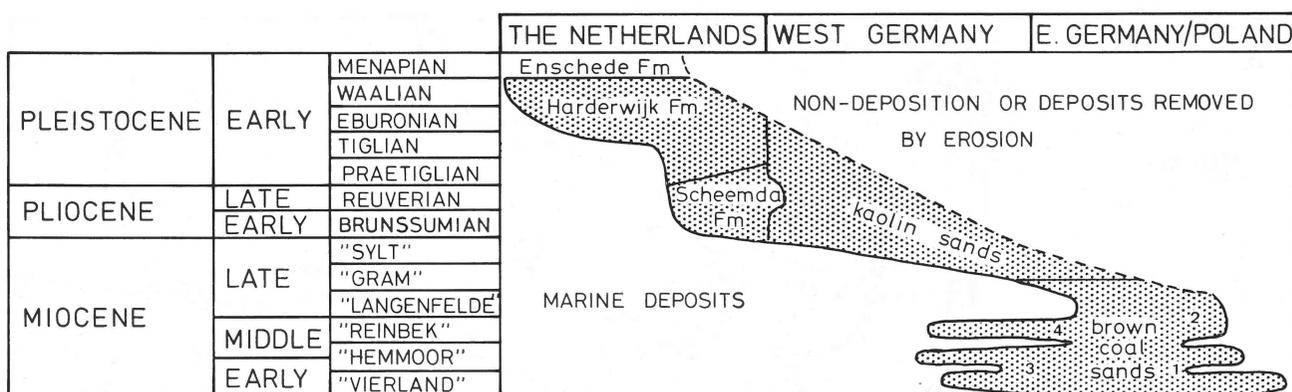|			THE NETHERLANDS	WEST GERMANY	E. GERMANY/POLAND
PLEISTOCENE	EARLY	MENAPIAN	Enschede Fm	NON-DEPOSITION OR DEPOSITS REMOVED BY EROSION	
		WAALIAN	Harderwijk Fm		
		EBURONIAN			
		TIGLIAN			
		PRAETIGLIAN			
PLIOCENE	LATE	REUVERIAN	Scheemda Fm	kaolin sands	
	EARLY	BRUNSSUMIAN			
MIOCENE	LATE	"SYLT"	MARINE DEPOSITS		
		"GRAM"			
		"LANGENFELDE"			brown 2
	MIDDLE	"REINBEK"		4	coal
		"HEMMOOR"		3	sands 1
	EARLY	"VIERLAND"			

Fig. 2
Stratigraphical correlation of the deposits of the Baltic River System in a schematic cross-section from the southeastern part of the North Sea Basin to the East German-Polish Basin. 1 = deposits of the first cycle of Quitzow (1953); 2 = deposits of the second cycle of Quitzow (1953); 3 = lower Brown-Coal Sands, including the Ribe Formation; 4 = upper Brown-Coal Sands, including the Odderup Formation.

from the Early and Middle Miocene and are described in connection with brown coal deposits.

In the literature before 1941 these deposits are correlated with the Pliocene so-called Kaolin Sands on the island of Sylt because of their identical gravel composition (HUCKE, 1928-a, b; RICHTER, 1935; KRAUSE, 1933). BERGER (1941) was the first to note that correlations based on gravel composition could be erroneous. He established that the BGA was also common in Miocene deposits. QUITZOW (1953) showed that at least a large part of the deposits containing the BGA in East Germany and Poland were of Miocene age. Both BERGER (1941) and QUITZOW (1953) still assigned the deposits at Finkenheerd and Petersdorf (south of Berlin) to the Pliocene, as did CEPEK (1958). AHRENS ET AL. (1968) could establish that these deposits containing the BGA were also of Miocene age.

From the occurrence of brown coal layers in the continental Miocene deposits QUITZOW (1953) recognized three sedimentation cycles (see Fig. 2).

The sediments of the first cycle partly cover marine or limnic Early Miocene deposits. The sediments at the base of this cycle are usually very coarse. According to QUITZOW (1953) the main part of the sediments containing the BGA described by HUCKE (1928-a, b) has to be assigned to this cycle. From the descriptions of QUITZOW (1953) it can be assumed that in the first-cycle deposits containing the BGA reached their easternmost and in some areas their southernmost extension.

Deposition of the second-cycle sediments started in the Middle Miocene. The sediments are generally fine grained (QUITZOW, 1953), but coarse deposits are found in the area south and east of Berlin. QUITZOW (1953) assigned these coarse deposits to the Pliocene but, according to AHRENS ET AL. (1968), they were deposited in the Middle Miocene and should be placed in the second cycle. Thus in the second cycle the deposits containing the BGA in East Germany seem to reach their southernmost limit.

Sediments of the third cycle have been deposited in the Late Miocene (QUITZOW, 1953). Deposits containing the BGA are not described from this cycle but fine-grained sediments of the Baltic River System may be present in the north of East Germany.

Figure 3A shows the maximum extent of the Miocene deposits of the Baltic River System in East Germany and Poland.

The Miocene in the southeastern part of the North Sea Basin

In the North Sea Basin fluvial and coastal sediments of Miocene age containing the BGA are known from Denmark and West Germany.

In Denmark they were described by JØRGENSEN (1944) who thought them to be of Pliocene age, as they had the same gravel composition as the Pliocene deposits on the island of Sylt. RASMUSSEN (1961) and SORGENFREI (1961) established their Miocene age by correlation with marine deposits. The stratigraphy of the fluvial deposits was described by Rasmussen (1966, cit. in KOCH & FRIEDRICH, 1970). He distinguished two formations: the Ribe Formation and the Odderup Formation, in the west separated by marine deposits. The Ribe Formation is of Early to Middle Miocene age, the Odderup Formation is of Middle Miocene age.

Summaries of the investigations in West Germany are given by GRIPP (1964), HINSCH (1974) and HINSCH & ORTLAM (1974). The fluviatile and coastal sands containing the BGA are called the Brown-Coal Sands. They consist of coarse and fine sands with clay and brown coal layers. Their gravel content is generally low.

The development of the Miocene deposits in the northernmost part of West Germany, north of Hamburg, is identical to that in Denmark and the same formations are recognized (HINSCH & ORTLAM, 1974).

In the Hamburg area two units are recognized in the Brown-Coal Sands: an upper and a lower unit, in the west separated by an estuarine clay unit, the Hamburg Clay (GRIPP, 1964). The sedimentation of the Brown-Coal Sands started in the Early Miocene and they reach their westernmost extent in
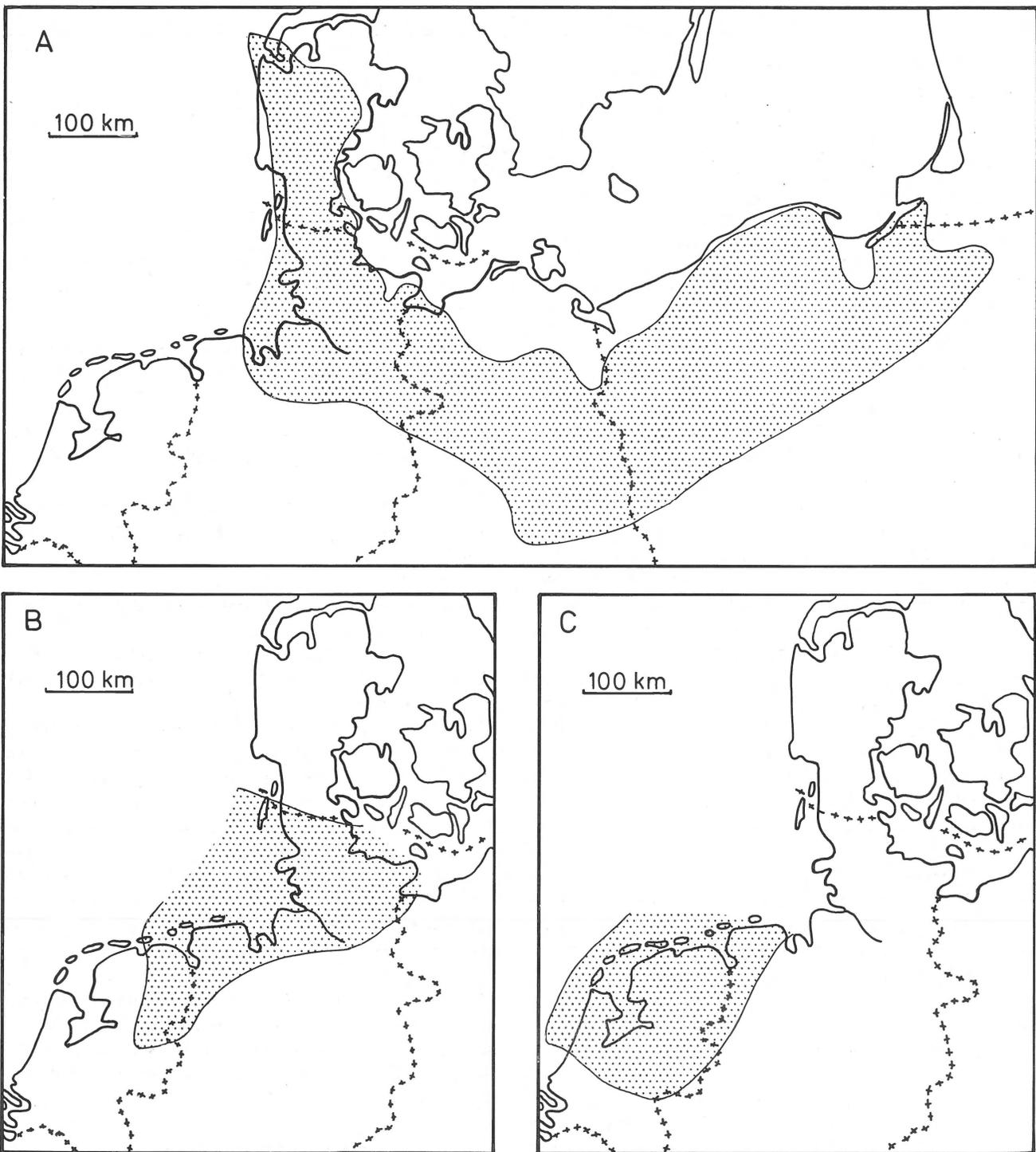
Fig. 3
Areal extent of the deposits of the Baltic River System.
A = Miocene deposits; B = Pliocene to late Tiglian deposits; C = late Tiglian to Menapian deposits.

the Upper Hemmoor Stage. The Hamburg Clay is deposited in the youngest part of the Hemmoor Stage and indicates an interruption in the fluvial sedimentation. In the Reinbek Stage the fluvial sedimentation again reached further to the west. In the younger part of the Reinbek Stage the fluvial influence diminished and a marine transgression took place (HINSCH & ORTLAM, 1974; see Fig. 2).

In the area between Hamburg and Bremen the stratigraphy of the fluvial sediments is comparable with that in the Hamburg area. The Miocene fluvial and coastal deposits reach

their westernmost extension at the transition between the Hemmoor and the Reinbek Stage and reach then to the Bremen area (KÖWING, 1956; RICHTER ET AL., 1968; HINSCH & ORTLAM, 1974).

Of Late Miocene deposits containing the BGA little is known. In the southeastern part of the North Sea Basin the sea penetrated far inland. In the Gram-Sylt Stages of the Late Miocene fluvial deposits are formed again in the area between Hamburg and the Danish border (HINSCH & ORTLAM, 1974), but they have not been accurately dated. It is not known whether the fluvial sedimentation stopped in the Late Miocene or was restricted to areas that were later stripped of their younger sediments by the Pleistocene ice sheets.

The maximum extent of the Miocene deposits of the Baltic River System in West Germany and Denmark is given in figure 3A; for the stratigraphy see figure 2.

The Pliocene

Pliocene deposits containing the BGA are known from West Germany and The Netherlands. In West Germany they are called Kaolin Sands.

The distribution of the Kaolin Sands in the northernmost part of West Germany has been described by HINSCH (1974). In the Miocene and Pliocene this area was strongly influenced by halokinetic movements. The Kaolin Sands reach their greatest thickness in the troughs between salt diapirs. In the areas that were uplifted by the salt they were either never deposited or eroded after the deposition. In the area with strong halokinetic movements the Kaolin Sands are found in isolated patches. Outside this area they have a larger extent (HINSCH, 1974).

On the island of Sylt (see Fig. 1) the Kaolin Sands are exposed in excavations and coastal cliffs in an ice-pushed ridge (GRIPP, 1964). They are composed of coarse and fine sands deposited first in a coastal and later in a fluvial environment. They are dated as Pliocene, probably Brunssumian, by WEYL ET AL. (1955).

Kaolin Sands have also been described from the boring Oldenswort about 70 km south of Sylt by MENKE (1975). This boring lies in a trough formed by halokinetic movements and the Pliocene deposits are very thick. Kaolin Sands were deposited here after the marine Sylt-Gram Stage throughout the whole Pliocene, interrupted by lacustrine deposits with thick brown coal layers.

The Kaolin Sands at Lieth, 30 km northwest of Hamburg, have been described by WEYL (1949), GRUBE (1957) and MENKE (1975). They are found in a solution hollow on top of a salt dome. Only the lowermost part of the exposed deposits consists of Kaolin Sands. The main part of the exposure consists of fine sands with brown coal layers of Early Pleistocene age (MENKE, 1975). As these probably lacustrine deposits overlie the Kaolin Sands the latter are probably of Pliocene age, but an exact dating cannot be given.

In the Hamburg area Hallik (in KOCH, 1954) dated a brown-coal layer in the Kaolin Sands as Reuverian so at least part of the deposit is of Pliocene age.

SINDOWSKI (1973) described Pliocene Kaolin Sands from the area between Wilhelmshaven and the German-Dutch border. Their areal extent is not known.

In the northeastern part of The Netherlands fluvial deposits containing the BGA of Pliocene age are known. They are included in the Scheemda Formation (DOPPERT ET AL., 1975). The lower part of this formation consists of coarse and fine sands and is of Brunssumian age, the upper part is fine-grained and is of Reuverian and possibly Early Pleistocene age (TER WEE, 1979).

The maximum extent of the Pliocene deposits of the Baltic Rivers in the Pliocene is shown in figure 3b. The stratigraphic correlations are given in figure 2.

The Pleistocene

Pleistocene sediments containing the BGA are only known from the southeastern part of the North Sea Basin. DUPHORN ET AL. (1973) mention these sediments from the area between Wilhelmshaven (north of Bremen) and the German-Dutch border. Their areal extent is not known.

In The Netherlands the Pleistocene sediments containing the BGA are included in the Harderwijk Formation (DOPPERT ET AL., 1975). The formation consists of coarse fluvial sand with fine gravel and subordinate fine sands and clays. DOPPERT ET AL. (1975) assign the basal part of the formation to the Early Tiglian. This implies a hiatus between the Pliocene Scheemda Formation and the Harderwijk Formation. However, according to TER WEE (1979) the Scheemda Formation may be in part of Pleistocene age so the hiatus does not necessarily exist.

Until the Late Tiglian sediments of the Harderwijk Formation were restricted to the northeastern and eastern part of The Netherlands. In the Late Tiglian, the Eburonian and the Waalian the sediments of the Harderwijk Formation reach far south and westwards and cover a large part of The Netherlands (ZAGWIJN & DOPPERT, 1978; Fig. 2; Fig. 3C).

No deposits containing the BGA are known in The Netherlands that are younger than the Waalian.

In the Enschede Formation (see Fig. 2), dating for a large part from the Menapian (DOPPERT ET AL., 1975), components of the BGA occur as an admixture in gravels derived from the German Variscan Massifs (ZANDSTRA, 1971). In the basal part of this formation one or more layers of cobbles and boulders occur, the so called Hattem Complex (LÜTTIG & MAARLEVELD, 1961) or Hattem Layers (ZANDSTRA, 1971). In the Hattem Layers the components typical of the BGA are conspicuously larger than ever before in The Netherlands. For the first time also crystalline rocks from the Fennoscandian area are found. They occur as well rounded, weathered cobbles and boulders. Also cobbles and boulders from the German Variscan Massifs and from the Rhine and Meuse area are found. The genesis of the Hattem Layers is still not well understood.

SEDIMENTARY-PETROLOGICAL INVESTIGATIONS

If the areal extent and the thickness of the deposits containing the BGA are taken into account little systematic work has been done on the sedimentary-petrology. Only from the deposits in the North Sea Basin are enough data available from literature and from fieldwork for an evaluation.

Gravel composition

Systematic analyses of the composition of the BGA have been made by RICHTER (1955), MAARLEVELD (1956) and ZANDSTRA (1959, 1971, 1975, 1977, 1978).

As in this review the gravel composition is the principal characteristic of the sediments of the Baltic Rivers, additional samples have been analyzed. To be able to study sufficient grains in samples from borings and relatively fine-grained deposits the size interval of 3-5 mm has been used. An additional advantage of the use of this size interval is the possibility of comparison with the work of ZANDSTRA (1959, 1977). The well established stratigraphy of the gravel associations in The Netherlands could thus be used.

Usually 200 or 300 grains are counted (MAARLEVELD, 1956; ZANDSTRA, 1978) but for this investigation 900-1000 grains have been counted to get a better representation of the small non-quartz group.

Table I shows the average composition of the gravel at the sampled locations and of the two gravel associations recognized in The Netherlands by ZANDSTRA (1977). The composition of the fine gravel is essentially identical in all sampled localities and the samples obviously belong to one gravel type.

All samples from the Miocene are poor in feldspar and quartz with white or grey feldspar. Only the sample from Hamburg is relatively rich in quartz with white or grey feldspar. The samples from the Pliocene deposits are generally richer in feldspar and quartz with grey or white feldspar, with exclusion of some coastal deposits. In The Netherlands the BGA is included in the Hellendoorn Gravel Type (MAARLEVELD, 1956). ZANDSTRA (1959) subdivided this gravel type into two associations: an association extremely rich in quartz (HO-ek) and an association rich in quartz and in feldspar (HO-kv). Table I shows the average composition of these associations after ZANDSTRA (1977). The HO-ek association is characteristic of the Pliocene Scheemda Formation and of the basal parts of the Pleistocene Harderwijk Formation. The HO-kv association is characteristic of the upper part of the Harderwijk Formation (ZANDSTRA, 1978).

In general the feldspar content of the gravel is higher if the deposits are younger. However, in coastal deposits feldspar may sometimes be absent. This is probably caused by a rapid disintegration of feldspar in a turbulent coastal environment. A further subdivision in gravel associations does not seem feasible. Only the subdivision already used by ZANDSTRA (1959) seems useful and only the youngest sediments of the Baltic Rivers have a gravel composition that is really different. The gravel in all deposits older than the upper part of the Harderwijk Formation must be included in one gravel association.

Heavy-mineral composition

Heavy-mineral analyses of deposits containing the BGA have been published by WEYRICH (1961, 1963) for deposits in East Germany, by WEYL (1949, 1952, 1953), WEYL & WERNER (1951), CROMMELIN (1954), VALETON (1959) and BRUNNACKER ET AL. (1975) in West Germany and by FRIIS (1974) in Denmark.

Table I
Average composition of the gravel in the 3-5 mm fraction. For sample locations see figure 1.

Sample location	Age	Clear quartz	White quartz	Quartz with white or grey feldspar	Feldspar	Other crystalline	Others	Grains per sample	Number of samples
Denmark, Vorvadbro	Miocene	94	3	1	1	0	1	900	4
Denmark, Silkeborg	Miocene	94	2	1	x	0	3	900	2
W.Germany, Geesthacht	Miocene	93	4	x	x	0	3	900	3
W.Germany, Hamburg	Miocene	91	2	4	1	2	x	900	1
W.Germany, Hamburg	Pliocene	93	2	3	1	1	x	900	8
W.Germany, Sylt	Pliocene	89	3	5	2	1	x	900	45
W.Germany, Lieth	Pliocene	89	4	2	5	x	x	1000	8
W.Germany, Uelsen	Pliocene	93	3	1	2	2	x	300	7
The Netherlands, HO-ek	Pliocene/ Pleistocene	93	3	0	2	2	0	(1)	
The Netherlands, HO-kv	Pleistocene	77	6	3	10	2	2	(1)	

x: less than 1%   (1) average after Zandstra (1977)

Several authors have studied the composition of the heavy-minerals in The Netherlands. For a compilation see DOPPERT ET AL. (1975) and TER WEE (1979).

In table II averages have been computed from the published data for each locality. Not all data could be used in this table. Sometimes too divergent grainsize intervals were analyzed and enough data were not always available to compute an average. The data given by WEYL & WERNER (1951) and WEYL (1952) could only partly be used as their averages do not sum up to 100% or are obviously not computed from homogeneous populations. The data from the northeastern part of The Netherlands have been computed from borings published in DOPPERT ET AL. (1975) and TER WEE (1979). In table II the mineral zone of Scheemda has been subdivided in subzones as otherwise this zone was too inhomogeneous to allow the computation of an average. Zone B represents the normal Scheemda mineral zone. Zone A is found in some borings directly beneath zone B. Zone C is also found in some borings beneath zone B.

Despite differences in the techniques used by the various authors the computed averages can easily be grouped into three heavy-mineral associations: an epidote-garnet (E-G), an epidote-metamorphic (E-M) and a metamorphic association (M). A fourth association, often with more than 50% hornblende, can also be recognized from the published data. As this association is only found in full-marine deposits it is not included in table II.

WEYL (1962), VALETON (1959 and FRIIS (1974) assume that only one heavy-mineral association was originally deposited: a garnet-epidote-hornblende association. Selection of the minerals during transport and deposition followed by weathering caused the differences found.

No large amounts of hornblende were ever found in the fluvial sediments, even in subsiding troughs or in fluvial clays. So hornblende was probably not a main constituent component in the original association. Large amounts of hornblende are only found in marine deposits and a seperate source must be assumed. This was also the conclusion of FAY (1977) from a statistical study of heavy-mineral data from marine deposits in the northern part of West Germany.

Within the fluvial deposits the E-G association must be a representative of the original heavy-mineral composition. The E-M and the M associations were formed by post-depositional weathering that selectively removed garnet and epidote. Also dynamic selection during transport may have caused differences in the heavy-mineral composition, but this is considered to be of small importance by FRIIS (1974).

As in several profiles the M association was found beneath deposits with the E-G or E-M association of about the same age (WEYL, 1952; FRIIS, 1974; TER WEE, 1979) intrastratal solution can be excluded. Weathering very shortly after the deposition or before the transport must be assumed. As the sediments with the M association can be at least 60 m thick (WEYL, 1952) the M association seems to indicate periods or areas with a very slow sedimentation, probably combined with periods of stronger weathering in the source area.

Post-depositional weathering must have been important as partially dissolved mineral grains were frequently observed in the deposits with the M assemblage (WEYL, 1952; FRIIS, 1974). In the fluvial deposits on the island of Sylt containing the M association post-depositional weathering is also noticeable in the gravel. Most of the felspars are so heavily weathered that they fall apart if the gravel is sieved. The heavily weathered feldspars and the partially dissolved mineral grains were probably not transported in this condition. In deposits with other heavy-mineral associations no heavily weathered feldspars were observed.

Table II

Averages of the heavy-mineral composition in deposits of the Baltic Rivers in % of the non-opaque fraction. For sample locations see figure 1.

Sample location	Age	garnet	epidote	hornblende	staurolite	kyanite	sillimanite	andalusite	tourmaline	others	association	Reference	number of samples	investigated grainsize in μm
Denmark, metamorphic ass.	Miocene	12	0	0	20	28	12	2	9	17	M	Friis, 1974	*	74-250
Denmark, epidote ass.	Miocene	3	40	1	3	8	6	3	8	28	E-M	Friis, 1974	*	74-250
West Germany, Toppenstedt	Miocene	10	24	6	28	7	5	1	7	12	E-M	Valeton, 1959	2	100-200
West Germany, Geesthacht	Miocene	2	48	5	7	7	10	4	14	3	E-M	Bijlsma, in prep.	3	150-210
West Germany, Hamburg	Miocene	6	46	2	7	11	8	7	9	4	E-M	Bijlsma, in prep.	3	150-210
West Germany, sandy clays	Miocene	29	20	1	5	24	4	0	7	10	E-G	Weyl 1952	17	100-200
East Germany, Leussow	Miocene	7	52	4	10	6	x	x	14	7	E-G	Weyrich, 1963	6	100-200
East Germany, Malliss	Miocene	16	1	5	8	31	15	0	7	17	M	Weyrich, 1961	2	100-200
West Germany, Sylt	Pliocene	1	6	4	17	21	13	6	17	15	M	Bijlsma, in prep.	15	150-210
West Germany, Hamburg	Pliocene	9	28	2	14	15	11	5	11	5	E-G	Bijlsma, in prep.	8	150-210
West Germany, Heide	Pliocene	1	3	1	13	28	19	0	10	23	M	Weyl, 1952	4	100-200
West Germany, Lieth	Pliocene	46	25	1	5	4	4	2	8	5	E-G	Bijlsma, in prep.	8	150-210
West Germany, Uelsen	Pliocene	2	21	4	12	6	7	7	33	8	M	Bijlsma, in prep.	7	150-210
Netherlands, Scheemda zone A	Pliocene	13	37	7	4	10	2	4	8	15	E-G	Zandstra (1)	5	63-500
Netherlands, Scheemda zone B	Pliocene	8	8	4	13	12	4	6	29	16	M	Zandstra (1)	8	63-500
Netherlands, Scheemda zone C	Pliocene	9	20	21	8	7	2	4	19	10	E-M	Zandstra (1)	10	63-500
Netherlands, Noordlaren zone	Pliocene	19	30	17	5	4	2	3	7	13	E-G	Zandstra (1)	32	63-500
Netherlands, Zuidlaren zone	Pleistocene	23	25	5	8	11	4	2	10	12	E-G	Zandstra (1)	15	63-500
Netherlands, Harderwijk zone	Pleistocene	32	35	3	4	4	1	1	6	14	E-G	Zandstra (1)	5	63-500

x: included in 'others'   * average given by author   (1) personal communication

EVOLUTION OF THE BALTIC RIVER SYSTEM ALLUVIAL FAN

During the Palaeogene sedimentation in the North-West European Basin was mainly marine. During the Late Oligocene strong tectonic uplifts influenced the basin and its flanks and a regression of the sea took place.

During the Early Miocene the sea again penetrated into the eastern part of the North Sea Basin and into the western part of the East German-Polish Basin. Influenced by the uplift of the flanks coarse fluvial sediments were brought into these basins by rivers from the Fennoscandian area and from the Variscan massifs. The Baltic River System, draining the eastern part of the Fennoscandian Shield and the Baltic Platform, formed a large alluvial fan reaching from Poland to the north of Denmark (Fig. 3A).

During the Middle Miocene the alluvial fan was locally built out further to the west and the south and in the eastern part of the North Sea Basin it covered the Early Miocene marine deposits.

During the Late Miocene the sea again penetrated into the southeastern part of the North Sea Basin and the alluvial fan was covered by marine sediments of the Upper Reinbek Stage. In the East German-Polish Basin no marine influence is found. In the Late Miocene sediments were probably only deposited in East Germany by the Baltic River System.

During the Pliocene coarse sands with gravel of the Baltic River System were again deposited in the North Sea Basin. Sedimentation occurred in a rather narrow zone between Hamburg and the West German-Danish border. After this the much stronger subsidence of the North Sea Basin determined the course of the Baltic River System. The East German-Polish Basin subsided very slowly or not at all. Fluvial sedimentation in this basin was from the south. Since coarse sands with gravel were deposited both from the North and from the South a new uplift of the flanks is likely. The Baltic River System formed an alluvial fan in the North Sea Basin that already reached the eastern part of the Netherlands in the Early Pliocene (Fig. 3B). In the Late Pliocene and possibly in the Praetiglian only fine sands reached The Netherlands. Coarse sands with gravel were probably deposited in the northwestern part of West Germany.

During the Tiglian coarse sands with gravel reached The Netherlands again and formed the lower part of the Harderwijk Formation. As the areal extent of these deposits in West Germany is not completely known it is uncertain whether an uplift occurred in the Fennoscandian area or that the Baltic River System just altered its course.

During the Late Tiglian the alluvial fan of the Baltic River System in The Netherlands was built out very fast. During the Waalian it covered the northern and middle parts of The Netherlands and probably extended far into the present North Sea (Fig. 3C). The sediments of the Baltic River System in this part of the alluvial fan are generally coarse sands with fine gravel and are included in the Harderwijk Formation. The

rivers from the German Variscan massifs were probably tributaries of the Baltic River System. In the southernmost part of the alluvial fan the sediments of the Baltic River System mixed with those supplied by the Rhine.

In the Menapian great changes occurred in the Baltic River System. In the northern and central parts of The Netherlands sediments of the Enschede Formation were deposited. In this formation the BGA occurs mixed with gravel from the Mid-German Variscan massifs. It is not known whether the Baltic River System was still active or the rivers from Mid-Germany eroded the older deposits of the Baltic River System. From the petrographic composition of the Hattem Layers it seems that the Fennoscandian area still contributed in the sedimentation, but in a different way than before. Inland ice probably covered a large part of the Fennoscandian area in the Menapian and the meltwater streams brought coarse material to the south. There it was mixed with sediments supplied by the rivers from Mid-Germany.

After the Menapian no direct influence of the Baltic River System can be found in the sediments. A hypothetical explanation is that the inland ice of the Menapian glacial destroyed the upper course of the Baltic River System and eroded the basin of the present Baltic Sea. A new river system could not be formed because of the presence of the basin of the Baltic Sea.

The available sedimentary petrological evidence from gravel and heavy-mineral analyses do not indicate alterations in the source area of the Baltic River System during its existence. The composition of the heavy minerals seems to be mainly determined by the degree of weathering in the source area and by post-depositional weathering. In the composition of the gravel an increase of the feldspar content in younger deposits can be observed.

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