

A NEW SUBDIVISION OF CRYSTALLINE FENNOSCANDIAN ERRATIC PEBBLE ASSEMBLAGES (SAALIAN) IN THE CENTRAL NETHERLANDS¹

– In honour of prof. J. D. de Jong, author of the only find of a possible Finnish erratic bloc of orbicular diorite in The Netherlands (DE JONG, 1943 a, b) –

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ABSTRACT

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The inland-ice cap in the Saalian in the central part of The Netherlands caused the formation of glacial basins and ice-pushed ridges and the deposition of till as well as glaciofluvial and glaciolacustrine material (Drente Formation). Crystalline assemblages of pebbles in these deposits, especially in till, are discussed and a new subdivision based on the Fennoscandian area of origin is introduced. The composition of the indicator pebbles made it possible to distinguish various deposition areas as the effect of one inland-ice cap.

INTRODUCTION

Quantitative studies on crystalline indicator pebbles in glacial deposits form the most direct approach for determination of the origin of a pebble assemblage and thus also of the inland-ice as transport medium. In the most favourable case, the composition of the pebble content differs between glaciation phases, and this permits reconstruction of the chronology of the events and the sedimentary units (till, sandur, kame, kame-terrace, and mass-flow deposits, lacustrine deposits). As a rule however, the situation is more complicated in practice. Reworking and incorporation of material from older glacial deposits strongly influenced the composition locally and later, partially postglacial processes may have led to mixing of pebbles from different phases, making it difficult or impossible to recognize the original assemblages. For Denmark, where deposits of different pleistocene glaciations in several glacials occur, the use of indicator pebbles for regional stratigraphic purposes is not recommendable (MARCUSEN, 1973, 1978).

In the German Federal Republic the use of counts of indicator pebbles proved to be more successful. SCHLÜTER (1978) distinguished Drente and Warthe sediments (both Saalian) in Schleswig-Holstein with the aid of crystalline indicator pebbles, and HÖFLE (1978) reported that the four Lower Saxonian tills can be distinguished on the basis of characteristic pebble assemblages. SCHUDDEBEURS (1959, 1967) found two completely different crystalline assemblages in the Hümmling (E of the Ems) and in Ostfriesland (NW of Oldenburg). MEYER (1976) pointed out the importance of the analysis of indicator pebbles in the tills of the northwestern part of the German Federal Republic; his investigation in Ostfriesland (MEYER, 1970), which offers a good example of the application of the method to glacial pebbly sands, showed clearly that pebble analysis does not always lead with certainty to dating of the deposits.

In The Netherlands, the results of pebble counts have for more than seventy years provided a basis for theories concerning inland-ice streams and glaciation phases during one or more glaciations (e.g. VAN DER LIJN, 1941a, b; DE WAARD, 1949; THOME, 1959; TER WEE, 1962; DE JONG, 1967; ZONNEVELD, 1975; SCHUDDEBEURS, 1981; SCHUDDEBEURS & ZANDSTRA, 1983). Since the central part of The Netherlands (Fig. 1) was only glaciated during the Saalian, the Fennoscandian pebbles cannot have become mixed with material from older glacials locally, and

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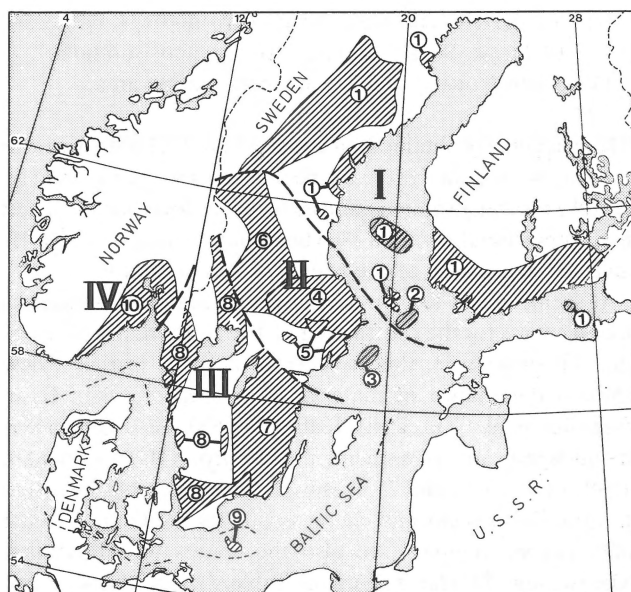
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SCHUDEBEURS & ZANDSTRA, 1983). The subject was studied by many geologists and geographers even before 1913, but MILTHERS was the first to perform a quantitative analysis of some types of crystalline indicator pebbles. His visit in 1912 yielded counts near Hilversum in the Gooi area, in the vicinity of Den Dolder and Maarn in the province of Utrecht, near Epe in the northeastern Veluwe, and near Markelo farther east (Fig. 1). MILTHERS' Gooi and Utrecht counts with extremely high amounts of Brown Baltic porphyry, are comparable, whereas the Veluwe count shows much less Brown Baltic porphyry and many more pebbles from Dalarna, which explains why MILTHERS linked Epe with the eastern and northern parts of The Netherlands on the basis of the pebble content (Table I).

In 1930 in Germany, HESEMANN introduced a method in which all known crystalline indicator pebbles measuring 2.5 cm or more are taken into account. Per location about hundred pebbles were determined and then divided into four count groups according to origin (HESEMANN 1930; Table II; Fig. 3):

I: East Balticum (SW Finland, Åland Archipelago, Baltic S of Åland, Gulf of Bothnia, Finnish Gulf, and N Sweden).

II: Central Balticum (Baltic near the coast of Stockholm, Stockholm and surroundings, Örebro, Uppland, and Dalarna).



I, II, III, IV Subdivision in accordance with Hesemann (1930)

--- Boundary Hesemann

① ② ③ etc. Subdivision in accordance with the R.G.D. in Haarlem

Fig. 3

The areas of origin of erratic pebbles in Fennoscandia.

Table I
Counts of some indicator pebble groups (MILTHERS, 1913, 1934).

	Hilversum No. 79	Dolderse Weg No. 80	Maarn No. 81	Epe No. 83	Markelo No. 84
East Baltic rocks	4%	23%	10%	23%	39%
Red Baltic quartzporphyry	—	—	—	2	—
Brown Baltic porphyry	75	70	80	21	13
Dalarna porphyries	21	7	10	54	48
Småland porphyries	—	—	—	—	—
Rhomb porphyry	—	—	—	—	—

Table II
Subdivision of the Fennoscandian provenance area.

HESEMANN, 1930		R.G.D. SUBDIVISION 1980	
I	East Balticum	1	East Balticum
		2	Baltic S. of Åland Archipelago
II	Central Balticum	3	Baltic Sea near Stockholm
		4	Uppland
		5	Stockholm and surroundings; Örebro
		6	Dalarna
III	South Balticum	7	Småland and surroundings
		8	Bohuslän; Blekinge; Skåne
		9	Bornholm
IV	South Norway	10	South Norway and surroundings

III: South Balticum (Småland and surroundings, Bohuslän, Blekinge, Skåne, southern Baltic, and Bornholm).

IV: South Norway and the adjacent marine area.

The percentages obtained for count groups I, II, III, and IV in this way are rounded off to the nearest ten and then divided by ten; the resulting values arranged in series, form what is called the proportional formula (= Hesemann formula). Table III gives an impression of the results of this operation.

It seems useful to give a brief general review of the published counts for the central part of The Netherlands (Appendix A). In general, the Hesemann formulas in this review show a dominance of material from area of origin II; in formulas 0820, 0730, 0640, 1640, and 1630 this dominance is highly significant. To a smaller degree, group II is dominant in 1530, 1531, 1540, and 2530 as well. Such assemblages rich in Central Baltic rocks and characteristic for the Gooi, Utrecht and Veluwe regions (see also the counts for Hilversum, Maarn, and Dolderse Weg in Table I); for the western, eastern, and northern parts of The Netherlands no analyses representing very high group-II values are known. Up to 1981, the typical formulas for the last-mentioned areas, which usually have a high value for group I or III, were unknown for the central part of The Netherlands except for HF (2341) at Oldebroek (see SCHUDEBEURS, 1980-1981 and 1981). Two years later, Bommel was found to show HF 4330, a result that differs considerably from the general rule; we shall return to this divergence and its implications below.

Since 1974, new counts have been performed by the Sedimentary-Petrology Department of the Geological Survey of The Netherlands at some locations in the central part of The Netherlands and one count has been made by A. P. Schuddebeurs and H. Jager near Markelo in the eastern part of the country. Appendix B gives a short review (see also Table III; Figs. 2 and 6).

The above-mentioned new counts, three of which were made in the province of Utrecht (Amersfoort Monnikenbos, two in Leusderheide West), one in the Gooi area (Hilversum NOS), two in the Veluwe (Ermelo Ullerberg, Heerde), one E of the IJssel (Markelo), and five in the region of the large rivers (Weurt, Latham, Varsselder, Netterden, Twello), show the existence of two totally different pebble assemblages in the central part of The Netherlands; transitional compositions also occur.

Only the counts made at Amersfoort Monnikenbos and Hilversum NOS fulfilled expectations; at these locations HF 0820 and HF 0810 show a strong dominance of group II, in agreement with most of the previously published counts for the central part of The Netherlands. In the Leusderheide count (No. 237) group II is dominant as well, but in addition group I accounts for 26%, which is a considerably higher percentage than that in the above-mentioned assemblage characteristic for the central part of The Netherlands and leads to a formula starting with 3 (HF 3520) and in the 1.5-2.5 cm grade with 4 (HF 4520 in No. 238); HF 3520 resembles

HF 2530 near Wezep. In the remaining counts the dominance is found in group I (Latham HF 4330) and group III (Weurt HF 2350, Varsselder HF 3250, Ermelo HF 3340, Heerde HF 1270, Markelo HF 2260, Netterden HF 3160) or groups I and III are in equilibrium (Twello HF 4240). The results of these analyses, especially those of Leusderheide HF 3520 (and HF 4520) and Ermelo HF 3340, are remarkable. Counts with more than 14% East-Baltic material had never been found before in the Gooi, Utrecht, and Veluwe regions (with the exception of the northeastern parts; the western boundary lines of the areas, i.e., with 15-25% and 25-35% in count group I (see Fig. 7 in ZANDSTRA, 1976) require correction and should now be taken south of Ermelo and Amersfoort.

A NEW TEN-GROUP SUBDIVISION

The method derived by HESEMANN has the advantage of giving, in one formula usually comprising four numerals, a compressed and clear compilation of the shares taken by indicators from the East, Central, and South Balticum regions; the fourth area of origin, South Norway and surroundings, is seldom of any importance in the Netherlands deposits. However, the distinction of only four areas of origin has disadvantages too; for instance, the proportional formula provides no indications about the behaviour of a given rock type or about a group of rocks from a given sub-area, such as the Red Baltic quartzporphyry in group I and the Brown Baltic porphyry in group II. The Hesemann formula does not indicate whether one of these diagnostically very important and moreover easily recognizable porphyry types can play a role of importance in efforts to distinguish different transport lines and deposition areas.

Another objection to the four-group method is the limitation of area of origin II; Hesemann places the Brown Baltic porphyry, the rocks from Uppland, Stockholm and surroundings, and Dalarna in this group, but practice shows that in counts with a high percentage of material from the eastern part of the Central Balticum (Brown Baltic porphyry, Uppland, Stockholm) the western part is of less importance. In the Saalian Drente Formation in the northern part of The Netherlands, rocks from Dalarna appear preferentially together with rocks from Småland in group III; this association cannot be deduced from the proportional formula. Some maps (see Fig. 4) will serve to illustrate the preferential distribution area of a number of the above-mentioned rocks.

In the Geological Survey of The Netherlands these disadvantages of the four-group method have been avoided since 1980 by the use of ten areas of origin (Table II and Fig. 3). This ten-group subdivision shows that only the Baltic south of Åland, with the Red Baltic quartzporphyry, became detached

Table III (facing page)
Inventory of new counts, subdivided mainly in accordance with HESEMANN (1930).

	151 Heerde	152 Weurt	162 Twello	200 Amersfoort	234 Ermelo	236 Lathum	237 Leusderheide	238 Leusderheide	242 Markelo	252 Varsselder	259 Hilversum NOS	260 Netterden
GROUP I												
Åland rapakivi/-granite	3	7	8	4	17	24	21	9	17	22	1	13
Prick granite						1						
Åland porphyries					1	4	3			4		
Finnish rapakivigranite			1			1						
Pyterlyt		1										2
Rödö rapakivi/-granite		1	3									2
Ångermanland twomicagranite	1	1				2						
Ragunda granite					1							
Grey Refsund granite		1		1		2						
Red Baltic quartzporphyry			1				1	2				1
Sum	4	11	13	5	19	34	25	11	17	26	1	18
GROUP II												
Brown Baltic porphyries		2		35		3	10	2	2	4	11	1
Uppsala- and Sala granite	4	6	2	47	7	14	11	2		1	17	
Vänge granite				4	2	1					2	
Arnö granite				1								
Various Uppland granites				2			2				4	
Stockholm granite		7		13	5	4	9	1			7	
Mälär porphyry			1									
Various Dalarna granites		1		1				2	1		1	1
Bredvad-, Asen-, Heden porphyry	1		3	5	2	2	9	4	7	3	1	4
Garberg graniteporphyry		1				1	1					
Brown Särna porphyry			1									
Grönklitt porphyrite					3			1		2		
Venjan porphyrite						3	2					
Various Dala porphyries	1				2	2	5	3	4			1
Digerberg tuffite				1								
Sum	6	17	7	109	21	30	49	15	14	12	43	7
GROUP III												
Filipstad granite					2	1						
Red and Dark Graverfors granite	1	1										2
Småland granites	11	15	8	11	16	17	11	4	43	35	2	34
Småland porphyries	2	3	1	3	1		8	1	6	2	2	1
Småland ignimbrites	1	1										
Karlshamn granite		1										
Bohuslän-/Blekinge granites		2		1			1		1		1	
Basalt	3											
Bornholm granites	2	5	3	6	4	5	2		1	4	2	6
Sum	20	28	12	21	23	23	22	5	51	41	7	43
GROUP IV												
Rhomb porphyry						1	1					
Sum						1	1					
Total number	30	56	32	135	63	88	97	31	82	79	51	68
% Group I	13.3	19.5	40.6	3.7	30.2	38.7	25.8	35.5	20.7	32.9	2.0	26.5
% Group II	20.0	30.4	21.9	80.7	33.3	34.1	50.5	48.4	17.0	15.2	84.3	10.3
% Group III	66.7	50.1	37.5	15.6	36.5	26.1	22.7	16.1	62.2	51.9	13.7	63.2
% Group IV						1.1	1.0					
Hesemann-Formula	1270	2350	4240	0820	3340	4330	3520	4520	2260	3250	0810	3160
Rock combination (Fig. 6)	18	5	31	1	25	11	8	36	16	26	1	27

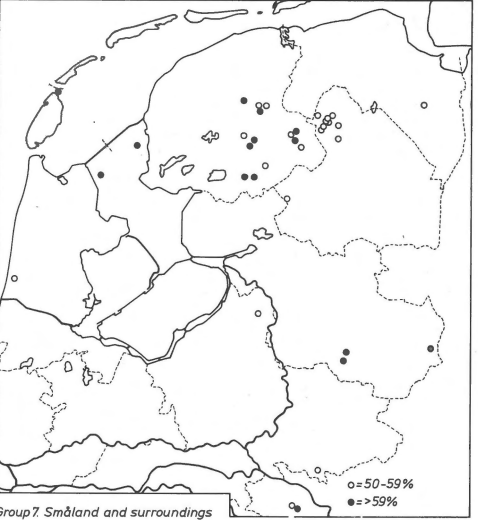
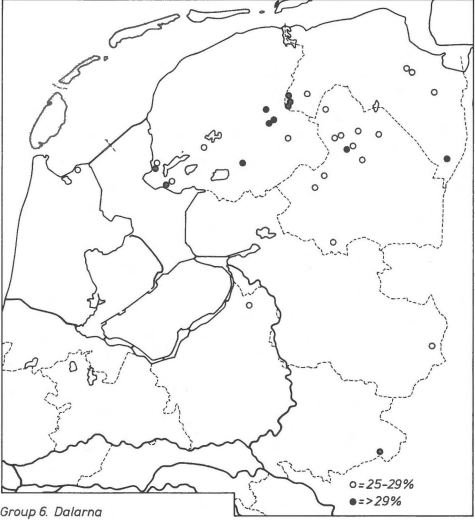
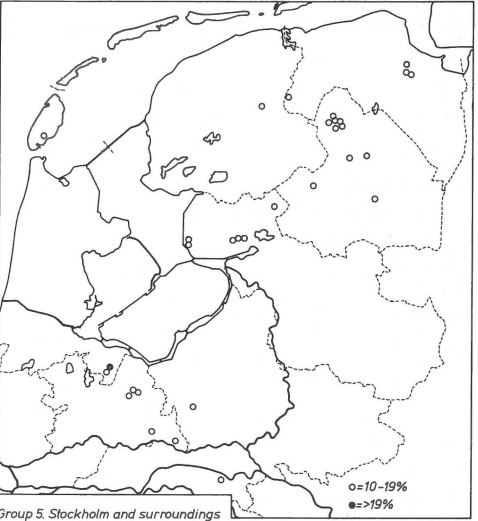
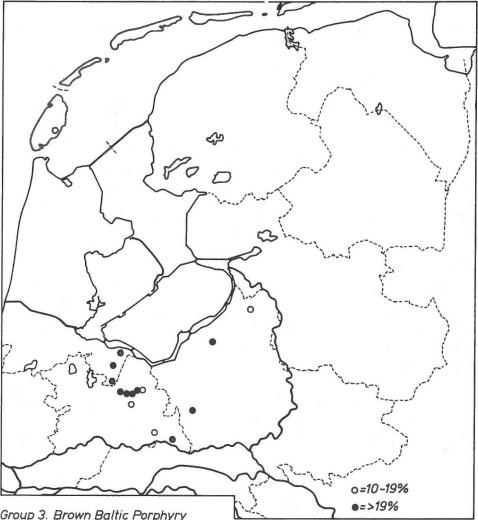


Fig. 4 The distribution of high percentage localities of crystalline indicator pebbles from the Fennoscandian areas 2, 3, 4, 5, 6 and 7 in The Netherlands (see Fig. 3).

from group I; the possibility of taking N Sweden (Ragunda, Rödö, Angermanland, Jämtland) out of group I and consider it as a separate count group was rejected because it is not always feasible to distinguish all types of North Swedish, Bothnian, and Åland rapakivi. Group II was subdivided into four parts to allow expression of the divergent behaviour of Dalarna relative to the eastern part of the Central Balticum.

The subdivision into ten groups makes it possible to prepare a separate distribution map for each count group. Figure 4 shows a limited application of this approach.

ROCK COMBINATIONS ON DISTRIBUTION MAPS

The mapping of ten groups to delineate the pebble assemblages encounters technical and visual problems. To avoid these difficulties, use was made of combinations of rock groups, according to the following key:

- Areas of origin 1 + 2 : East Balticum (including Red Baltic quartzporphyry)
- Areas of origin 3 + 4 : Eastern Central Balticum (Brown Baltic porphyry and Uppland)
- Area of origin 6 : Western Central Balticum (Dalarna)
- Areas of origin 7 + 8 + 9 : South Balticum

With this simplification, group 5 is not taken into consideration. The reason for this omission is that although Stockholm granite, the principal representative of the group, reaches the highest percentages in counts with large amounts of Brown Baltic porphyry and Uppland granites, it also occurs widely throughout the glaciated area in the Saalian (Fig. 4).

The contribution of group 10, which is usually composed solely of Oslo rocks, is too small to reach expression on a map; calculated for 268 counts (as of 31-12-1982) values higher than 5% were only found twice. Thus, the repeatedly expressed opinion that Oslo rocks occur abundantly in the northern part of The Netherlands has not yet been confirmed by quantitative investigation. In the central part of The Netherlands, representatives of group 10 are with only one exception very scarce (Tables IV and V).

This condensed classification makes it possible to assign the results of the analysis to 35 rock combinations (see Fig. 5). Actually, not more than ten of these combinations occur rather to very commonly in The Netherlands, and in the central part of the country only two of them (combinations 1 and 2 in Table IV). Some of these combinations are characteristic for certain till types; others are the product of postglacial mixing and may represent the pebble assemblages of more than one glaciation phase.

In addition to the map legends and the composition of the rock combinations, figure 5 shows the relationship with till groups and types (ZANDSTRA, 1983b). Furthermore it must be kept in mind that this subdivision is intended only for the preparation of distribution maps (Fig. 6).

Because indications for the origin of inland-ice are most distinct in till, which is the immediate residue of melting, the

studies were done in till whenever possible. Till is, however, not always available and it was necessary to resort to sandur, kame, lacustrine, and mass-flow deposits or, at worst, postglacial formations, where mixing of pebbles of different glaciation phases may be considerable.

RESULTS

ZANDSTRA (1983b) distinguishes four till groups in the Saalian Drente Formation in The Netherlands (see Fig. 5). One of these represents clay-rich till floes (Voorst Group), the others, i.e., the Rhenen, Heerenveen, and Assen groups, mainly subglacial and possibly also supra- and englacial tills. From southwest (Utrecht) to northwest (Drente, Groningen, Twente) there is a transition from the Rhenen Group into the Heerenveen Group and from the latter into the Assen Group; the distribution areas are contiguous or separated by variably wide transitional zones of overlapping. Cross-sections of deposits never show two different till groups, even separated by either glacial sand or clay deposits (till floes excepted). For the central part of The Netherlands, the results of pebble counts and the correlation with the till groups are discussed in the following section, and for the sake of completeness the assemblages occurring north and east of the investigated area are briefly mentioned as well.

The area rich in pebbles from the eastern part of the Central Baltic region

Assemblage rich in East-Central Baltic pebbles (A in Table IV)

– The relationship between this assemblage and the Rhenen Till Group has been confirmed at Craailo, Hilversum NOS, Rhenen, Leersum, Lunteren, and Amersfoort Monnikenbos. Identical counts were obtained at Den Dolder, Lage Vuursche, Soestduinen, and Nunspeet; in these places the material was collected from gravelly sand. In addition, the results of the counts of a limited number of rock types point to the same assemblage at the sites in Maarn, Dolderse Weg, and Hilversum (Table I).

The assemblage is characteristic for the southeastern Veluwe, Utrecht, and Gooi regions and occurs only there; no other area shows such high values for Brown Baltic porphyry (up to about 20-40% of the total count sum), and Uppland and Stockholm also are represented in substantial percentages. The western part of the Central Balticum, with the rocks of Dalarna, lags far behind in this respect, seldom showing more than 15% and frequently less than 10%. The absence of Red Baltic quartzporphyry and the paucity of East Baltic repakivi are noteworthy. Among the sedimentary rocks the abundance of Purple Dala sandstone, often of considerable size, should also be mentioned; further, the absence or scarcity of flint is indicative. Neither flint nor Dala sandstone, being sedimentary rocks, were included in the count.

Several authors (MAARLEVELD, 1956; VEENSTRA, 1963;

Table IV
Pebble Assemblages in the central part of The Netherlands. A – The Assemblage rich in East-Central Baltic pebbles. After different authors mentioned in text and new counts. For rock combinations see figure 5.

Area of origin	52 Soestduinen I	90 Lage Vuursche	91 Nunspeet	150 Rhenen	200 Amersfoort	259 Hilversum NOS	53 Soestduinen II	54 Den Dolder	71 Leersum	72 Lunteren	73 Huizen	2 Amersfoort Frisia	28 Craailo
1	-	-	3	2	4	2	-	9	3	6	13	8	2
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	35	29	40	20	26	22	28	41	15	22	35	13	-
4	20	22	14	37	40	44	21	4	31	17	6	18	13
5	5	8	5	15	10	14	10	3	11	16	6	16	45
6	11	8	18	4	5	4	8	13	2	4	8	6	6
7	20	27	15	-	10	8	22	19	14	17	21	16	13
8	4	2	2	9	1	2	3	-	3	-	6	8	-
9	5	4	3	13	4	4	8	11	21	18	4	5	23
10	-	-	-	-	-	-	-	-	-	-	1	10	-
HF	0730	0730	0820	0820	0820	0810	0730	1630	0640	1640	1530	1531	0640
Rock comb.	1	1	1	1	1	1	2	2	2	2	2	3	20

A

characteristic groups

ZANDSTRA in OVERWEEL & ZANDSTRA. 1967; OVERWEEL. 1977) anticipated correspondence between the 'red' till in some locations in the central part of The Netherlands (e.g. Lunteren, Lage Vuursche) and the clay-rich, highly calcareous till floes in the Noordoostpolder (DE WAARD. 1944, 1949; WIGGERS. 1955). However, later grain-size analyses and analyses of the gravel, pebble, and heavy-mineral contents showed that there could be no question of till floes here (ZANDSTRA. 1982: Voorst Group) and that the till should be classified as the Rhenen Type. In the field there is a superficial resemblance between this type and the above-mentioned till floes due to the often brown or reddish-brown colour and the clay content, and, after analysis in the laboratory, the relatively high percentages of green hornblende in the transparent heavy minerals. Clay-rich floes of the Voorst Group have not been found in the central part of The Netherlands (see SCHUDEBEURS. 1980-1981).

Assemblage with moderate amounts of East-Central Baltic pebbles (B1 and B2 in Table V) – In the northern part of the central Netherlands, assemblage A shows a change. The combined share taken by East-Central Baltic groups 3, 4, and

5 has dropped to 25-32%. The Dalarna share has increased to 18-25% and that of the East-Baltic group 1 to 14-25% (assemblage B1). The correspondence with till at the investigated locations (Hilversum, Wezep, Leusderheide West) is unknown. In the river region near Arnhem and Nijmegen (Lathum, Bommel, Weurt), the basal layers of the Kref-tenheye Formation contain an assemblage showing resemblance with those of Hilversum, Wezep, and Leusderheide, but with an essential difference formed by the lower value for Dalarna (4-9%). Since this points to reworked pebbles from the Rhine or IJssel, nothing can be said about a relationship with a particular till group (assemblage B2).

The zone with a transitional pebble content

Mixed Baltic Assemblage (C in Table V) – Counts performed in the Ullerberg pit near Ermelo (northern part of the Veluwe region west of the Leuvenumse Beek) and near Twello (glacial IJssel valley near Deventer) show a pebble assemblage in which the East-Central Balticum plays no role of any importance, but there is resemblance to assemblage B2. The absence of Brown Baltic porphyry and the low amounts of

Table V

Pebble Assemblages in the central part of The Netherlands and near Moyland (Western Germany).

B – Assemblages with moderate amounts of East-Central Baltic pebbles (B1 with moderate and B2 with low amounts of Dalarna).

C – The mixed Baltic Assemblage.

D – The Assemblage rich in South Baltic pebbles (mainly Småland).

After different authors mentioned in text and new counts. The counts from Moyland are without helleflint and diabase.

Area of origin	20 Hilversum			152 Weurt			234 Ermelo		242 Markelo		151 Heerde		27 Markelo		252 Varselder		Moyland II		260 Netterden		Moyland I			
	55 Wezep	237 Leusderheide West		236 Lathum	239 Bemmel		162 Twello																	
1	14	19	25	19	39	36	30	38	21	13	15	33	19	26	22									
2	-	-	1	-	-	-	-	3	-	-	-	-	8	1	3									
3	8	15	10	4	3	6	-	-	2	-	3	5	5	1	3									
4	11	2	13	11	17	12	14	6	-	13	-	1	4	-	1									
5	8	9	9	12	5	6	8	3	-	-	5	-	-	-	-									
6	19	25	18	4	9	7	11	13	15	7	5	9	8	9	11									
7	30	22	20	36	20	31	31	28	60	50	69	47	53	54	60									
8	5	2	1	5	-	-	-	-	1	10	3	-	-	-	-									
9	5	6	2	9	6	1	6	9	1	7	-	5	-	9	-									
10	-	-	1	-	1	1	-	-	-	-	-	-	3	-	-									
HF	1540	2530	3520	2350	4330	4330	3340	4240	2260	1270	2170	3250	3250	3160	3260									
Rock comb.	6	6	8	5	11	11	25	31	16	18	18	26	26	27	27									
	B 1			B 2			C		D															

Dalarna rocks are conspicuous. Quantitatively, the East Balticum and Småland are the most strongly represented.

At Twello, the rocks derive from till belonging to the Heerenveen Group and the Ullerberg-pit material originates mainly from till lumps within mass-flow deposits. The brown sandy till from the Ullerberg contains on average 12% flint in the gravel-sized fraction and the heavy-mineral assemblage includes 15-39% green hornblende; these features too point to the Heerenveen Till Group.

The area rich in South-Baltic pebbles

Assemblage rich in South-Baltic pebbles (D in Table V) – On the western periphery of the IJssel valley near Heerde and east of this valley near Markelo, i.e., between the Oude IJssel and the Rhine (Varselder, Netterden), as well as south of the Rhine near Moyland in Germany, a pebble assemblage is found that is characterized by a high proportion of erratic pebbles from Småland and surroundings together with a varying percentage of East-Baltic material. Småland material is occasionally accompanied by Bornholm rocks. The influence of the eastern Central Balticum is minor, like that of

Dalarna. The Moyland counts show 3-8% Red Baltic quartz-porphry.

The pebbles derive from different formations: those near Heerde originate from flow till belonging to the Drente Formation (with 9% flint in the 3-5 mm gravel fraction), those near Markelo from till forming the type locality of the Markelo Type, the pebbles near Varselder and Netterden from the Kreftenheye Formation, and those near Moyland from Saalian sandur deposits (letter from Professor J. Hesemann dated May 16, 1978; BRAUN, 1978). The direct or indirect relationships between this assemblage and the Heerenveen Till Group are obvious. In the western and northern parts of The Netherlands this assemblage rich in Småland rocks and poor in Dalarna material is rather common; and in the eastern part of the country this combination of rocks is characteristic for the Losser and the Markelo Till types (local modifications of the Heerenveen Group; see ZANDSTRA, 1983b).

The area rich in Dalarna and South-Baltic pebbles

The inland-ice with large amounts of pebbles from Dalarna and the South Balticum rarely or never reached the central

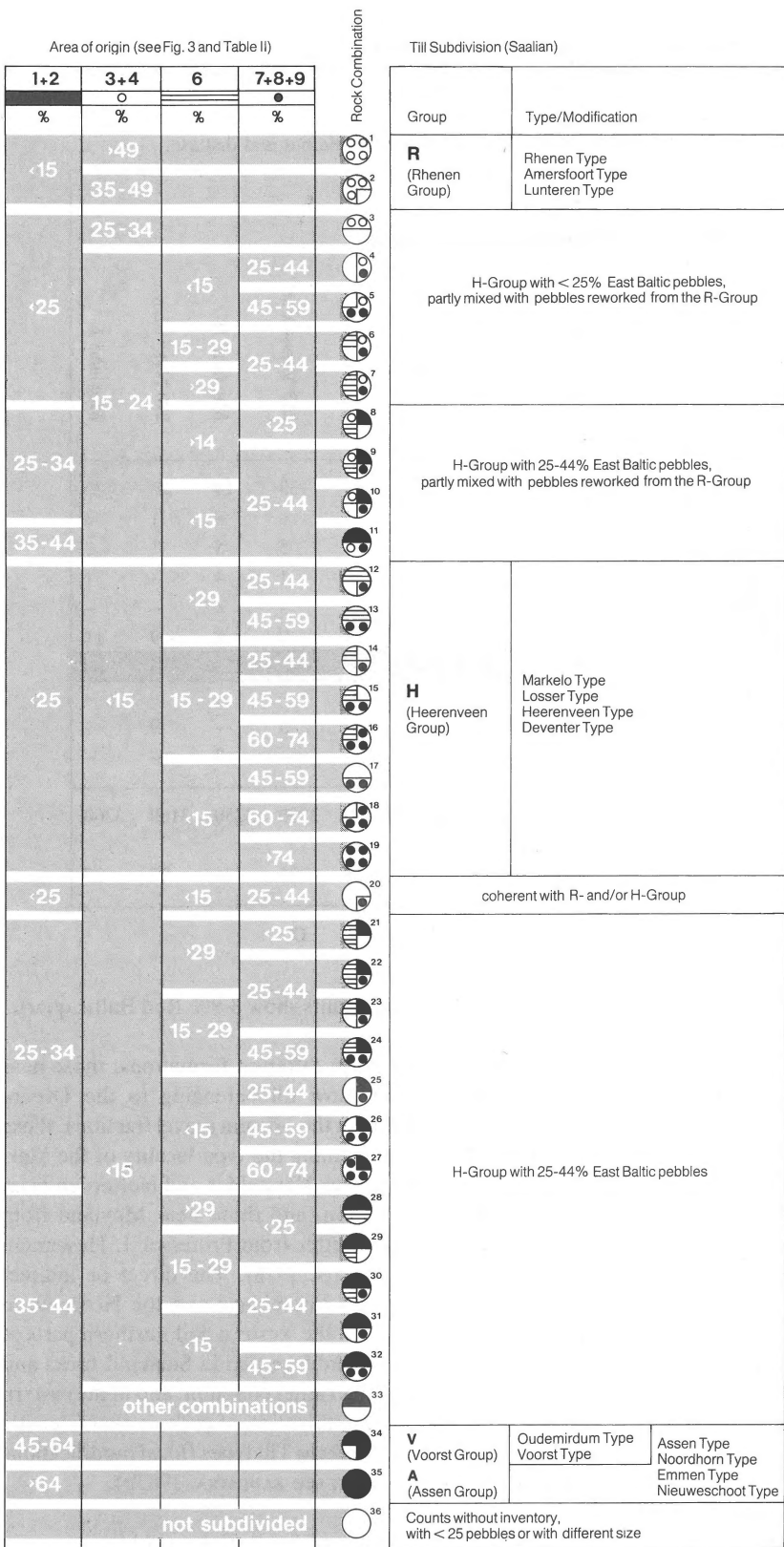


Fig. 5 Complete legend showing circular symbols subdivided on the base of the RGD concept regarding the ten groups of Fennoscandian crystalline indicator pebbles (= rock combinations used on maps).

part of The Netherlands. Only the count for Het Loo near Wezep, situated at the foot of the Woldberg in the northern Veluwe (assemblage B1, with 25% Dalarna material, Table V), indicates the proximity, during deposition, of a southern outpost of this ice-field, whose typical pebble assemblage is found mainly in Friesland (Gaasterland, Koudumer Hoog, north of Drachten). In the northern part of The Netherlands this assemblage is found in the Heerenveen Group; in the eastern part of the country the Dalarna-rich assemblage is known from De Lutte and the surroundings of Winterswijk (see Group 6 in Fig. 4).

The area extremely rich in East-Baltic pebbles

Pebble assemblages with more than 45% East-Baltic rocks are not known for the central part of The Netherlands (SCHUDEBEURS & ZANDSTRA, 1983). Compositions of this kind occur in the clay-rich red till floes of the Voorst Group (Noordoostpolder), within the Assen Till Group (Hondsrug, Central Drente, Eastern Groningen, Eastern Twente) and sporadically within the area with the Heerenveen Till Group.

DISCUSSION AND CONCLUSIONS

Investigations in recent years have shown that in the central part of The Netherlands two erratic pebble assemblages occur in the Saalian Drente Formation and in the formations, containing material deriving from it. Assemblage A contains many East-Central Baltic rocks and assemblage D much material from Småland; assemblages B1, B2, and C are intermediate between A and D (Tables IV and V). A and B1 typify the till of the Rhenen Group and D is characteristic for the Heerenveen Group (till subdivision according to ZANDSTRA, 1983b). B2 is mainly related to the Rhenen Group and C to the Heerenveen Group. The intermediate form C (transitional zone) is the result of a gradual change in the composition of the pebbles in the southwest (area rich in East-Central Baltic indicators, Rhenen Group) toward the northwest, east, and north (area rich in pebbles from Dalarna and the South Balticum, Heerenveen Group); assemblage B2 is the result of later (post-morainial) mixing and redeposition, for instance by action of the Rhine and the IJssel.

The question as to whether the composition of the crystalline pebble assemblages within sandur, kame, mass-flow, and coarse glaciolacustrine deposits deviates from the till content cannot yet be answered conclusively, but at least in the area with assemblage A no divergence has been found. Morphological criteria have always received much attention in theories on the genesis of the ice-pushed ridges (reviewed in TEUNISSEN, 1961). MAARLEVELD (1953) considered not only morphological features but also measurements of dips and strikes of the ice-pushed deposits, and distinguished some pushing or glaciation phases; later, this reconstruction was revised to some degree (MAARLEVELD, 1981, 1982). JELGERSMA & BREEU-

WER'S (1975) paper is particularly important because of its interesting discussion of the mode of genesis and the shape and depth of the glacial basins.

The investigation of pebbles requires a completely different approach. Till and other glacial products of melting form the cover on the flanks of the ice-pushed ridges and plateaus and the basin-filling material. The time of deposition will often differ from the phase in which the underlying ice-pushed ridges came into existence. Analysis of the pebble, fine-gravel, and heavy-mineral components of the above-mentioned glacial deposits to supplement the reconstruction pertaining to the entire glaciated part of The Netherlands during the Saalian (ZANDSTRA, 1983b) led to the following synopsis, which is given with some reserve because the network of sites for pebble counts still has large gaps and locally is very wide-meshed.

According to the present picture, the oldest part of the ice-field, which has a high percentage of East-Central Baltic pebbles, entered the central part of The Netherlands from a NNW to N direction and covered this landscape as far as the Betuwe region. Along the flanks of the Gelderse Vallei, ice-pushed ridges arose; because this phenomenon is generally thought to develop during more than one phase, it is remarkable that appreciable amounts of ice-pushed till are lacking, as usually are, according to present knowledge, ice-pushed upper-sandur deposits. The ice-pushed ridges in the central part of The Netherlands were generally built up of large-scale thrust sheets in which till is absent. These findings raise the question whether the second oldest and later pushing phases should be seen as limited in extent. In our opinion, the possibility of small positive ice-front displacements during the deglaciation deserves consideration.

The typical assemblage of the central part of The Netherlands (A; see Table IV), which is related to the Rhenen Till Group, shows in the Gooi and northern Veluwe areas signs of the onset of the transition to the 'Småland-rich' assemblage D and in one case to a 'Dalarna-Småland-rich' assemblage (Wezep). Towards the NNW and N (the western part of The Netherlands), till or other glacial deposits of the Rhenen Group are unknown; a transitional type, assemblage B2 with 24% eastern Central Balticum, was found on the island of Texel (ZANDSTRA, 1971). These data indicate that there is in fact only one Saalian till sheet in The Netherlands, its composition changing a number of times, from southwest to northeast, either suddenly or gradually and perhaps with overlapping (ZANDSTRA, 1983b).

The composition at Epe (Table I), to the extent that it is known, points to a transition from the Rhenen to the Heerenveen Group. The pebble contents of flow till on the eastern slope of the eastern ice-pushed ridge in the Veluwe near Heerde (assemblage D), the till at the bottom of the glacial basin in the IJssel valley near Twello (assemblage C), and the till east of the IJssel valley near Markelo (assemblage D), all show the properties of the Småland-rich Heerenveen Group; no trace of Central-Netherlands assemblages A and B1 has

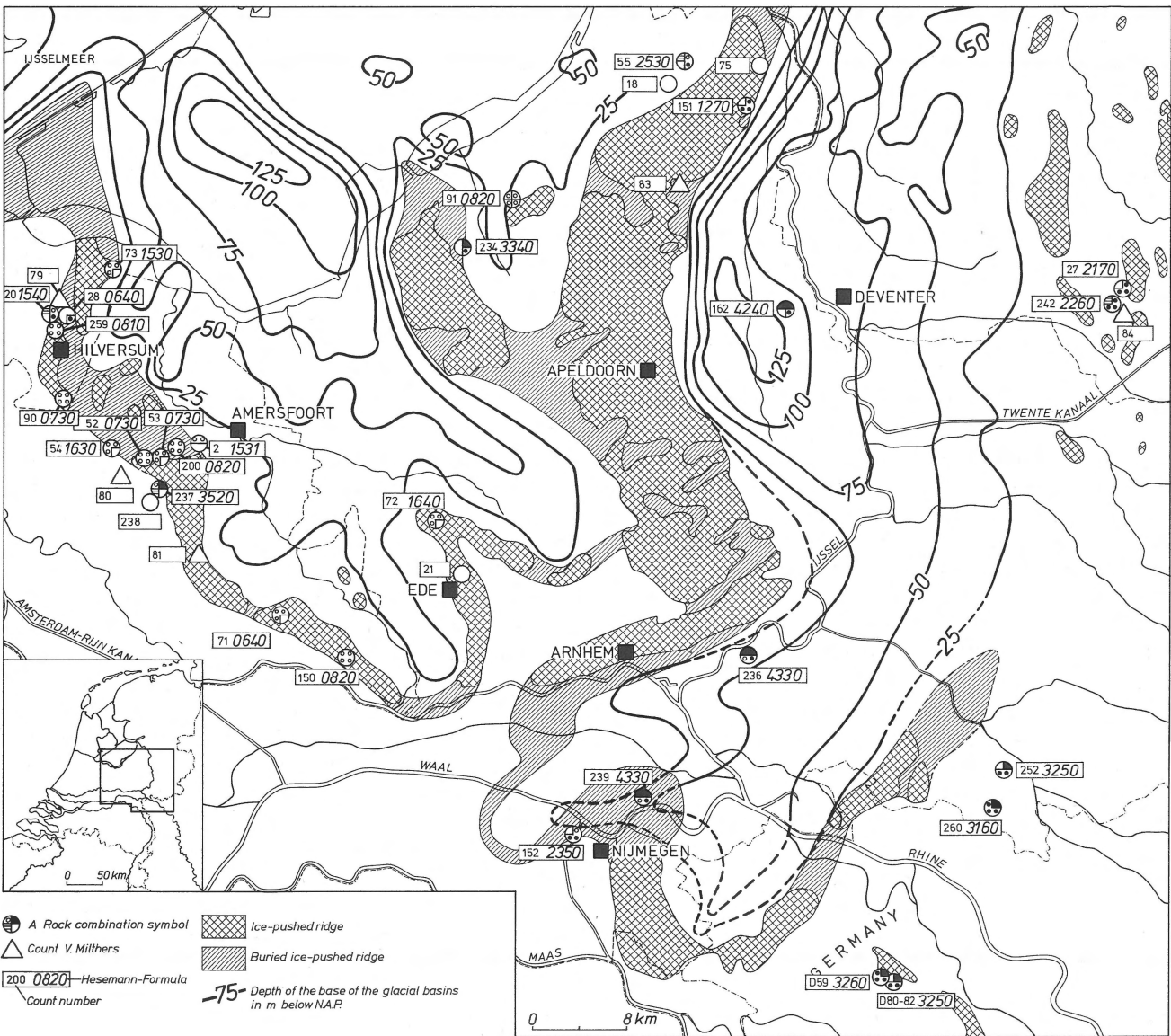


Fig. 6
 Pebble (= rock) combinations in the investigated region. (basins and ridges after JELGERSMA & BREEUWER, 1975, slightly modified). Legend see figure 5.

been found. These data gave rise to the following theory.

During or immediately after the glaciation of a large part of the central region of The Netherlands (area rich in East-Central Baltic indicators, see above), the inland-ice in the eastern part of The Netherlands spread S and SSE, reaching far into the valley of the Rhine in Germany and with branches into the Over-Betuwe region and close to Kranenburg (area rich in South-Baltic indicators). The formation of the deep glacial basins of Velsen, Amsterdam, Zuidelijk Flevoland, and the IJssel valley are related to this movement, as is the case for the formation of the ice-pushed ridges of the eastern Veluwe, the Montferland, those surrounding the Over-Betuwe basin, and the ice-pushed ridges and sandur plains along the left side of the Rhine between Kleef and Mörs in

Germany; during this phase the ice may have penetrated into the already created Gelderse Vallei.

In the present region of the large rivers (Over-Betuwe), after the melting of the inland-ice, Fennoscandian erratics from the Drente Formation were removed and displaced by, i.a., the Rhine system. The river deposits near Arnhem and Nijmegen (Lathum, Weurt, Bommel; see Figs. 2 and 6) still contain some constituents of the Central-Netherlands assemblage, but the pebbles of the Heerenveen Group predominate by far (assemblage B2, see Table V). In the eastward direction the influence of the Central-Netherlands assemblage decreases rapidly and is already absent south of Terborg (Varsselder, Netterden); at the latter locations the pebble content closely resembles that of the sandur deposits in

the Reichswald near Kalkar (location Moyland; BRAUN, 1978, and Table V). For a reconstruction of the glacial events it seems relevant that the pebble assemblage of the so-called *Uedemer Sandebene* (BRAUN, 1956) is representative of the ice-field with many South-Baltic constituents (assemblage D) and differs totally from that of the Central-Netherlands ice-field (assemblage A).

The inland-ice rich in rocks from Dalarna and Småland (Heerenveen Group) did not penetrate into the central part of The Netherlands, and the extension of the inland-ice very rich in East-Baltic rocks (Assen Group) was limited to the north-eastern part of the country.

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APPENDIX A

REVIEW OF PUBLISHED COUNTS

The number preceding the place name corresponds with the number of the file in the Sedimentary Petrology Department of the Geological Survey of The Netherlands, the abbreviation HF refers to Hesemann's formula.

No. 2: *Amersfoort, Frisia pit near the former railroad station Vlasakkers*. HF 1531 – First count made according to the Hesemann method in The Netherlands, performed and published by VAN DER LIJN, first in the Zeitschrift für Geschiebeforschung (1932) and later in De Levende Natuur (1934). The analysis did not conform with the modern criteria, because sedimentary rocks such as Dala sandstone and flint were included, as were gabbro, diabase, and varieties of helleflint. When these rocks are not taken into consideration, the formula changes from 1711 to 1531. More than half of the material is Central Baltic. The site lies at the back (northern slope) of the ice-pushed ridge running between Den Dolder and Amersfoort; the pebbles derive from decalcified till.

No. 18: *Oldebroek*. HF (2341) – The circumstances of the find pertaining to this count in the northern part of the Veluwe region are

unknown; the value of the analysis is limited, because the absence of a rock inventory (VAN DER LIJN, 1941a, b) makes correction of the formula impossible. The site is associated with the Woldberg. The formula between brackets underlines the limited value.

No. 20: *Hilversum*. HF 1540 – The inventory of this count by VAN DER LIJN (1941a, b) has been included in DE WAARD (1949). The revised formula 1540 reflects the strong resemblance to No. 2 at Amersfoort. In VAN DER LIJN's publications the question of the number of glacials with an inland-ice cap in The Netherlands occupies a central position, the author adhering to the two-glaciation theory, at least for the northeastern part of The Netherlands, on the grounds of the divergence between the counts in the Hondsrug and in the central part of the province of Drente. This theory did not find general acceptance.

No. 21: *Ede*. HF (1540) – Further information about this count in the ice-pushed ridge of Ede-Wageningen is not available (VAN DER LIJN, 1941a, b).

No. 27: *Markelo*. HF 2170 – The analysis, published by DE WAARD (1944), concerns erratic pebbles from one of the till pits between Rijssen and Markelo in the eastern part of The Netherlands.

No. 28: *Hilversum (Craailo)*. HF 0640 – In a location with decalcified till in the heath area near the Aardjesberg, N of Hilversum, DE WAARD (1945) performed counts comprising the pebbles with a diameter between 2 and 5 cm and the larger rock fragments. Since the results show no essential differences, they have been pooled. The Aardjesberg is situated W of the ice-pushed ridge running between Huizen and Hilversum.

No. 52: *Soestduinen I*. HF 0730 – This count was performed by SCHUDEBEURS (1949) in a reclamation field N of the ice-pushed ridge running between Den Dolder and Amersfoort and situated half-way between the railway stations at Soestduinen and de Vlasakkers near Amersfoort. Data concerning the formation are not available; the pebbles probably originated from sandur deposits.

No. 53: *Soestduinen II*. HF 0730 – Count as for No. 52.

No. 54: *Den Dolder*, HF 1630 – Count by SCHUDEBEURS (1949) in a gravel pit on the grounds of a psychiatric hospital (the Willem Arntzhoeve). During the author's fieldwork, vertical sections with till were exposed. The pebbles used for the analysis concern components of the coarse sieve fraction of pebbly sand (sandur deposits?). The site is WNW of the ice-pushed ridge Den Dolder-Amersfoort.

No. 55: *Wezep, Het Loo*. HF 2530 – This analysis by SCHUDEBEURS (1949) was made possible by collecting pebbles from a large reclaimed field N of the Woldberg; the coarse erratics occurred in pebbly sands.

No. 71: *Leersum, Donderberg pit*. HF 0640 – The old pit behind the swimming-pool was poor in northern erratics; the analysis concerns mainly rock fragments from the till, which was reduced to a stone layer, and a few erratics from the sandur deposits overlying the till (ZANDSTRA, 1974); the site is situated within the ice-pushed ridge running between Rhenen and Amerongen.

No. 72: *Lunteren, Vink pit*. HF 1640 – The pebble used for the analysis originated from calcareous and decalcified till. Lunteren is the type locality of the Lunteren Till Type (ZANDSTRA, 1974). The pit is situated in the northwestern part of the ice-pushed ridge running between Lunteren and Oud-Reemst.

No. 73: *Huizen, excavation 400 m E of the brick factory*. HF 1530 – Erratics from a stone layer to be primarily seen as reduced till (ZANDSTRA, 1974). The sand pit is situated on the northwest side of the small ice-pushed ridge incorporating the Warandebergen and running between Huizen and Blaricum.

No. 75: *Wapenveld, Keyl pit*. HF 3430 – Geologists of the Geology Department of the University of Groningen collected pebbles near the sieve apparatus at the bottom of this pit. Probably the erratics are predominantly constituents of fluvial deposits older than Saalian. The analysis is otherwise left out of consideration in the discussion of Saalian Drente Formation. The inventory of the count has been included in the sixth edition of Het Keienboek (VAN DER LIJN, 1974).

No. 90: *Lage Vuursche*. HF 0730 – Pebbles from a road-construction pit situated N of Maartensdijk and along the north side of the

viaduct in highway between Utrecht and Hilversum, have been analysed (SCHUDEBEURS, 1980-1981); in the author's opinion the material originated from Saalian glacial sandy and pebbly deposits.

No. 91: *Nunspeet*. HF 0820 – Small pits in gravelly sands in the woods S of Nunspeet in the northern part of the Veluwe region, 0.5–1 km SE of the Hulshorster Zand, supplied the erratics for this analysis (SCHUDEBEURS, 1980-1981). The site is situated N of the Stakenberg and W of the Leuvenumse Beek.

No. 150: *Rhenen (= Veenendaal), Kwintelooijen pit*. HF 0820 – A count made by ZANDSTRA in pebbles originating mainly from decalcified till (SCHUDEBEURS, 1980-1981); Rhenen is the type locality of the Rhenen Till Type (ZANDSTRA, 1983b). The sand pit is at the back (slope toward the Gelderse Vallei) of the ice-pushed ridge Rhenen-Amerongen.

No. 239: *Bemmel, sand and gravel-dredging pit*. HF 4330 – The location lies in the Over-Betuwe region, a few km N of the morphologically very pronounced ice-pushed ridge of Nijmegen; locally, the sub-soil probably contains a buried ice-pushed ridge (Figs. 2 and 6). To the north lies the glacial 'Betuwe Basin' that once contained the Valburg ice lobe (VERBRAECK, 1975). The pebbles used for the count originated from the basal beds of the Kreftenheye Formation, which here consists of Rhine sediments deposited after the disappearance of the inland-ice cover (ZANDSTRA, 1983a).

APPENDIX B

REVIEW OF NEW COUNTS

No. 151: *Heerde, sand pit near the Koerberg*. HF 1270 – Topogr. map sheet 27B (1:25000), co-ord. 199.40/491.65. In the NE wall of the old sand pit behind the camping site, pebbles of a flow till were sampled; supplementary material was provided by incidental finds at the bottom of the pit. The till is composed exclusively of northern components. The unpushed Saalian Drente Formation forms the cover of the east slope of the eastern ice-pushed ridge in the Veluwe region.

No. 152: *Weurt, lock-construction pit in the Maas-Waalkanaal*. HF 2530 – Topogr. map sheet 40C (1:25000), co-ord. 184.88/429.56. The site lies in front of a buried ice-pushed ridge that continues to the south as the non-buried ice-pushed ridge between Nijmegen and Mook and to the north connects with the ridge of the southern Veluwe (JELGERSMA & BREEUWER, 1975; VERBRAECK, 1975; MAARLEVELD, 1981). As in Bemmel, the erratics originate from the basal beds of the Kreftenheye Formation, a sedimentary unit of the Rhine formed after melting of the inland-ice cover during the Saalian; the percentage of assimilated northern pebbles is very small.

No. 162: *Twello, grounds of the Water-Supply Pumping Station*. HF 4240 – Topogr. map sheet 33E (1:25000), co-ord. 202/474. At this site near Deventer, four exploratory bores were made in 1978 (file nos. 33E/225, 33E/226, 33E/227, 33E/228). Pebbles occurring in the lowest layers of these bores were collected by J. Breeuwer for counts. The material consists of pebbles from till together with a stone layer on top of the till at a depth of 107–114 m below the surface (= 102–109 m below Dutch O.D.). Twello is situated in the valley of the IJssel in the area of the glacial basin W of Deventer.

No. 200: *Amersfoort, Monnikenbos pit*. HF 0820 – Topogr. map sheet 32D (1:25000), co-ord. 151.10/462.20. The excavation is in the lower part of the northern slope of the ice-pushed ridge Den Dolder-Amersfoort. The collected pebbles were found spread over the surface of the pit; the majority must have originated from one or more till localities exposed in the past. The sandur deposits exposed in this pit are very poor in northern rocks. The Monnikenbos pit is the type locality of the Amersfoort Till Type (ZANDSTRA, 1983b).

No. 234: *Ermelo, Ullerberg pit*. HF 3340 – Topogr. map sheet 26H (1:25000), co-ord. 175.50/479.50. Very large excavation along the

western boundary of the present valley of the Leuvenumse Beek. Saalian glacial mass flow deposits (POSTMA ET AL., 1983 in press) are exposed; these sands, which slumped down from an ice-pushed ridge, sporadically contain northern rocks and lumps of till, whereas the bulk consists of rocks primarily transported by the river Rhine.

No. 236: *Lathum, sand-dredging pit*. HF 4330 – Topogr. map sheet 40B (1:25000), co-ord. 199.50/444.50. The pebbles of this site situated E of Arnhem in the valley of the IJssel, probably originate from the basal beds of the Kreftenheye Formation and, less probably, also from the underlying Drente Formation (see location Duiven in sections C-C¹ and D-D¹ in VAN DE MEENE, 1977). The southern gravel and pebble assemblage is here enriched with a few northern constituents.

No. 237: *Leusderheide West*. HF 3520 – Topogr. map sheet 32C (1:25000), co-ord. 149.70/458.60. During construction of the A 28 highway between Utrecht and Amersfoort, pebbles from sandur deposits were collected at the bottom of the cutting over a distance of about 1 km. Most of the coarse rocks are Rhine and Meuse material. The Fennoscandian assemblage contains many angular flint fragments. The site is situated in front of the ice-pushed ridge running between Den Dolder and Amersfoort, 1 to 2 km east of sand pit II (AUGUSTINUS & RIEZEBOS, 1971).

No. 238: *Leusderheide West*. HF 4520 – Count of the 1.5–2.5 cm subfraction, otherwise as for No. 237.

No. 242: *Markelo*. HF 2260 – Topogr. map sheet 34B (1:25000), co-ord. 230.51/474.79. In the most recent and southernmost till pit in the brick-works at Rijssen, a count was performed by A. P. Schuddebeurs with the collaboration of H. Jager. The pit complex forms the type locality of the Markelo Till Type (Heerenveen Till Group). Markelo lies E of the glacial basin of the IJssel valley.

No. 252: *Varsselder, sand-dredging pit*. HF 3250 – Topogr. map sheet 41C (1:25000), co-ord. 221.15/434.80. The dredged pebbles at this location in the valley of the Oude IJssel probably originate from the Kreftenheye Formation. The share taken by northern pebbles amounts to at most a few per cent, the remainder being Rhine and Meuse constituents.

No. 259: *Hilversum NOS*. HF 0810 – Topogr. map sheet 32A (1:25000), co-ord. 140.20/472.55. In 1982, indicator pebbles were collected in a construction pit on the grounds of a radio and television station (the Nederlandse Omroep Stichting). The erratics derive from the decalcified Rhenen Till Type (Rhenen Group) occurring almost 8 m below the original land surface.

No. 260: *Netterden, De Ronde Morgen*. HF 3160 – Topogr. map sheet 41C (1:25000), co-ord. 220.37/431.39. During the autumn of 1982, a currently unused sand-dredging pit yielded the pebbles required for the analysis. The site lies S of that of count No. 252 near Varsselder, between the Oude IJssel and the Rhine. The northern erratics derive from the Kreftenheye Formation (see location Netterden in cross-section G-G¹ in VAN DE MEENE, 1977).