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THE SANGATTE RAISED BEACH AND THE AGE OF THE OPENING OF THE STRAIT OF DOVER[1]

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ABSTRACT

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This study is a pedological and mineralogical diagnosis of the loamy cover deposits of the Sangatte raised beach (Strait of Dover), presently at almost 10 m N.G.F.[4], to determine their chronostratigraphy.

The analytical data are compared with those obtained for the Cagny-la-Garenne (Somme, Picardie) section, which is considered a stratotype for Middle Pleistocene loesses of Northern France.

Our results support the notion that formation of the Sangatte raised beach can be attributed to a high sea level of the Middle Pleistocene. This provides further evidence on the paleogeographical evolution of the Southern North Sea Basin during the latter half of the Middle Pleistocene. It confirms the previous assumption of an early opening of the Strait of Dover in the Middle Pleistocene.

Furthermore, it demonstrates that the loesses with high green hornblende and garnet content, that were previously supposed to be restricted to the Weichselian, were already deposited during the Saalian.

INTRODUCTION

The raised beach of Sangatte is located at the edge of the Strait of Dover, at the border between the coastal plain and the northern flank of the Weald-Boulonnais horst (Fig. 1A). It was formed during a period of high sea level culminating at an altitude of 4.8 m relative to the present day beach, i.e. approximately 10 m N.G.F.[4] It was preserved up to the village of Sangatte thanks to a thick cover of Quaternary chalky and loamy deposits (Fig. 1B).

By its location at the southern limit of the North Sea Basin, the raised beach appears to be an important landmark in the evolution of the Strait of Dover and a useful reference datum for the reconstitution of the Pleistocene shore lines, as are the sites of Herzeele in the Yser Basin and of Carrière du Fart at Wissant (SOMMÉ, 1975).

The section of Sangatte has been thoroughly studied in the past, but its chronostratigraphical context is still controversial, as the presently available data have failed to provide unequivocal conclusions (SOMMÉ, 1975). DUBOIS (1924), ZEUNER (1958), DE HEINZELIN (1966) and GUILCHER (1969) ascribed the raised beach to the Last Interglacial. This was based mainly on the relative altitude of the beach, which was referred to either the Monastirian stage or the Normanian stage (DANGEARD, 1936), both supposedly of Eemian age. Subsequently, however, the Eemian age has been contradicted in the Seine Bay and in the Contentin, where raised beaches about 5 m high have been ascribed to the Middle Pleistocene (ALDUC ET AL., 1979)

On the contrary, according to BRIQUET (1930) and BOURDIER (1969) the Sangatte raised beach could predate the Eemian, as suggested by the presence of a thick decalcified horizon in the upper third of the cover deposits; this would be in evidence of an interglacial pedogenesis.

Recently, SOMMÉ (1975) made a further detailed survey of the Sangatte section, which confirmed the existence, within the cover deposits, of two periglacial sedimentary cycles that are separated by a decalcified horizon. However, the absence of remnants of an interglacial soil of the 'sol de Rocourt' type at this level prevented that author from definitely attributing, this raised beach to a Middle Pleistocene Interglacial. Accord-

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[4]N.G.F. (Niveau General Français) is French mean sea level. Zero N.G.F. is similar to zero N.A.P. (Normaal Amsterdams Peil, Normal Amsterdam Ordnance Datum).

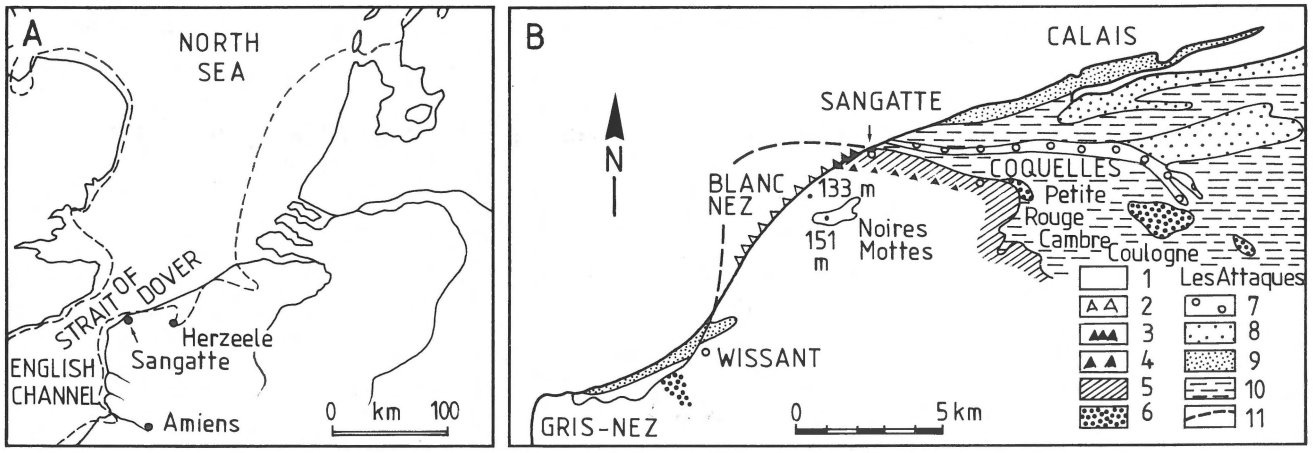


Fig. 1
A. Locality map. Dashed: Middle Pleistocene shore lines.
B. Distribution of the Pleistocene and Holocene deposits in the surroundings of Sangatte. (modified after J. Sommé (1975). Legend: 1. Cretaceous substrate; 2. Chalky cliff; 3. Cliff within Pleistocene formations; 4. Pleistocene dead cliff of Sangatte; 5. Pleistocene cover loams; 6. Supposed Middle Pleistocene offshore-bars; 7. Supposed Eemian offshore-bars; 8. Flandrian offshore-bars; 9. Recent dunes; 10. Holocene coastal plain; 11. Supposed extension of the Pleistocene shore line.

ing to SOMMÉ, the only argument in favour of a pre-Eemian age is the geometry of the offshore bars, that presumably extend the raised beach. The former are intersected by an erosion level which is connected under the coastal plain to an erosional surface which could be pre-Eemian.

The remaining arguments are scarcely cogent. The malacological fauna of the beach deposits is of a boreal aspect *(Cardium edule, Mytilus edulis, Tellina balthica, Littorina obtusata, Purpura lapillus, Littorina littora, Modiola modiolus, Buccinum undatum)*, uncharacteristic of the Eemian

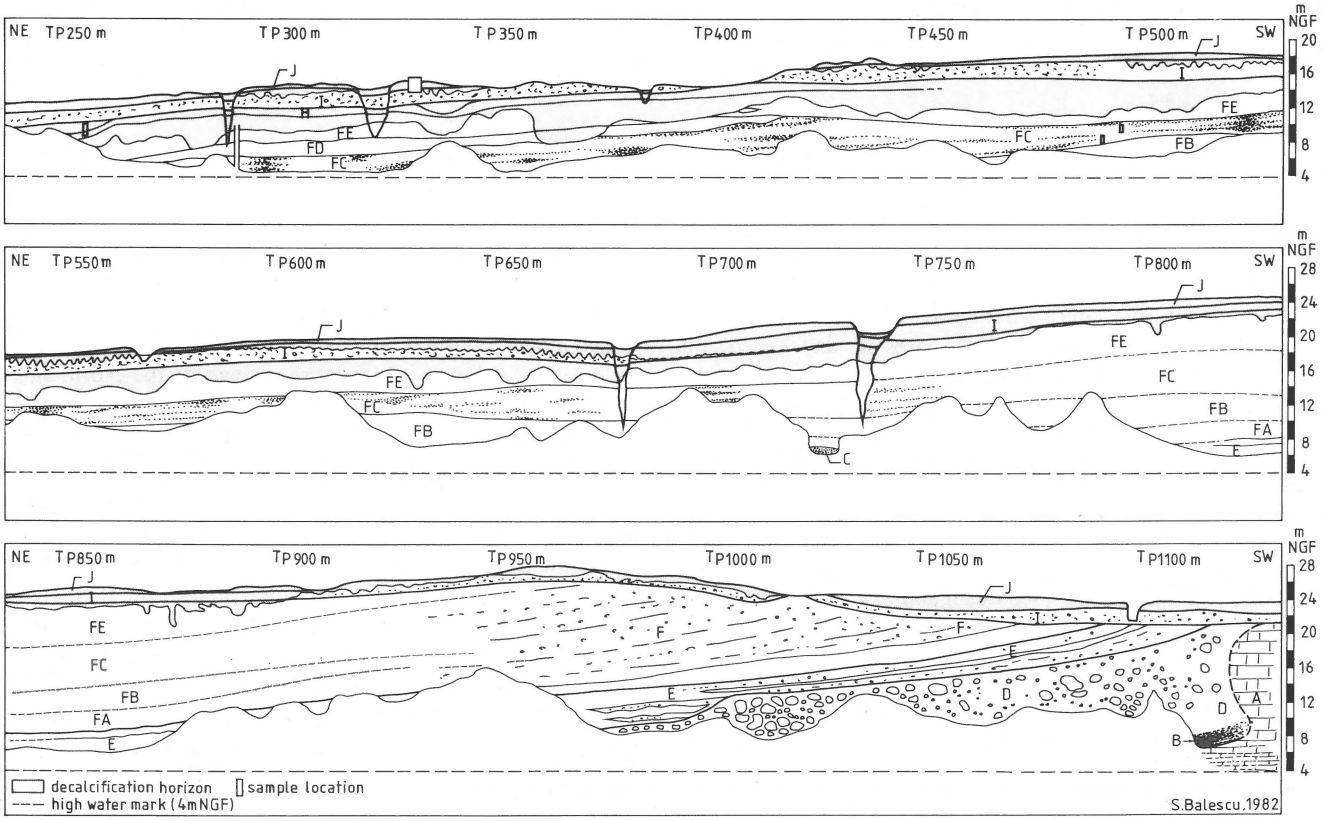


Fig. 2
Section at Sangatte. Legend: A. Chalky dead cliff; B. Marine pebbly spits; C. Glauconitic beach sand; D. Heterogeneous chalky falls; E. Chalky flows; F. Undifferentiated chalky and loamy deposits; FA and FB. Chalky loamy deposits; FC to FE. Calcareous loesses; H. Sandy loam; I. Chalky gravels; J. Loamy-sandy cover deposit.

(DUBOIS, 1924). Remains of *Mammuthus primigenius* have been found in the cover deposits (LEFEBVRE, 1968) but this species, certainly abundant in the Upper Pleistocene, was present in Europe much earlier (ALDUC ET AL., 1979)

In the present study, we adopt two new approaches to complement the earlier researches:

1 – a pedological diagnosis of the decalcified horizon to demonstrate the possible existence at that level of an interglacial illuviated soil which remained as yet controversial'

2 – an analysis of the heavy mineral content of the loamy deposits, to establish their chronostratigraphical position.

For this purpose, we referred initially to the work of JUVIGNÉ (1976) on the mineralogy of the loess of Belgium, which led to the differentiation of the Weichselian loess from the earlier ones. Furthermore to assess JUVIGNÉ's stratigraphical conclusions, the mineralogical study has been extended to the section of Cagny-la-Garenne, near Amiens (Somme), most generally considered as a stratotype for the Middle Pleistocene loess of Northern France.

LITHOSTRATIGRAPHY OF THE QUATERNARY DEPOSITS AT SANGATTE

In Sangatte, the raised beach is fossilized by chalky and loamy deposits, the thickness of which reaches 20 m. These deposits are accessible over more than 1 km along the present day seashore.

The lithostratigraphic units (see BALESCU, 1982) can be grouped into two distinct categories: one of marine origin (units B and C), solely present at the base of the section, the other cover deposits of subaerial origin (units D to J), extending from the dead cliff up to the limit of Sangatte village (Fig. 2).

The marine complex: units B and C.

It consists of several marine pebbly spits (units B), reaching almost 10 m N.G.F. and grading laterally into a glauconitic beach sand (unit C), (see DE HEINZELIN, 1966 and SOMMÉ, 1975).

The subaerial complex: units D to J.

This complex comprises six lithological units, the succession of which is as follows (in ascending order).

Units D and E: chalky deposits. These are heterogeneous chalky falls (unit D) and chalky flows (unit E), derived from the chalky dead cliff by fluxing and discordantly overlapping the underlying units C and D.

Units FA to H: loamy deposits. These attain locally a thickness of more than 6 m and spread over almost the whole length of the section. It consists of a succession of three lithological groups (in ascending order): –chalky loamy deposits (FA and FB); –calcareous loesses (FC to FE); –sandy loam (H).
The entire unit H was decalcified and so was the underlying unit FE, and locally also the top of FD. This decalcified horizon reaches a thickness of 3-4 m.

Unit I: chalky gravels. This deposit, 2-3 m thick, lies clearly discordantly over the underlying units, and is exposed continuously from the dead cliff up to the village of Sangatte.

Unit J: loamy-sandy cover. It consists of non calcareous sandy aeolian deposits, that occur consistently at the top of the section. The surface soil, brownish and weakly podzolic, developed in the upper part of this loamy sand. Oblong pockets starting from te top of unit I, are filled with brown argillaceous sand. They result from dissolution processes which probably occurred during the tardiglacial and Holocene pedogeneses (SOMMÉ, 1975).

ANALYTICAL DATA OF THE QUATERNARY DEPOSITS AT SANGATTE

Weathering horizon.

Our pedological diagnosis focused on the decalcified horizon in the upper part of the loamy deposits (units H, FE and FD). A remnant of illuviated soil has been found in P260 in a loamy lens of the upper part of unit H.

Micromorphological analysis of this horizon revealed the presence of at least two generations of clay coatings, indicating a two-fold illuviation process. A first generation of grayish-yellow coatings, which are highly fragmented and dispersed throughout the mass, is followed by a second generation of yellowish-brown coatings which are clearly in situ. The whole sediment shows a network of fissures, enhanced by a grain size distribution, which is similar to that formed by the iced-segregation in the upper part of a permafrost (HAESAERTS & VAN VLIET-LANOE, 1981). Therefore, at Sangatte, the decalcification probably preceded the development of this illuviated soil, the main horizons of which were completely eroded before the deposition of the overlying chalky gravels (unit I).

In conclusion, these observations demonstrate the existence in the upper part of unit H, of a complex illuviated soil, probably displaced in part by solifluxion and later dislocated by frost action. Taking account of the complexity of the soil and of its location in the Sangatte sequence, we infer its equivalence to the Rocourt pedocomplex, attributed in Belgium to the Eemian Interglacial (HAESAERTS & VAN VLIET-LANOE, 1981). However, because of the relatively poor preservation and development of this soil, we cannot exclude a possible parallelism with the Vaux soil at Harmignies (Belgium) within the Middle Weichselian loams (HAESAERTS ET AL., 1981)

Mineralogy

Methodology. The mineralogical analysis of the cover deposits of the Sangatte raised beach was based on sequential sampling of all the loamy units, i.e. units FC, FD, FE and H. Thirty-nine samples, were collected at approximately 10 cm intervals from P260, P292, P492 and P500 (Fig 2).

The experimental procedure adopted here follows JUVIGNÉ (1976). It is based on bromoform separation (specific density: 2.9) of the heavy minerals of the loessic fraction between 30μm and 60μm, slide-mounted in Canada balsam. Statistical counting of 300 grains in each slide ensured that the width of the confidence interval of the highest proportion (p = 20%) was at most 4%, with a probability of 95%, knowing that the sampling distribution of the proportions is binomial.

Sedimentological discussion. A grain size analysis was made of the 39 loamy samples to help establish the depositional environment. The samples of units FE and FD show indisputable loess characteristics (Fig 3). By contrast, the samples of the middle part of unit FC are characterized by very high sand contents (30%-60%). This local sandy drift, probably derived from the inland Tertiary outliers (Noires Mottes), was incorporated into the allochtonous loessic drifts through rilling. This is also suggested by the abundance of ferruginous sandstone blocks in the gravelly lenses of FC, FE and H.

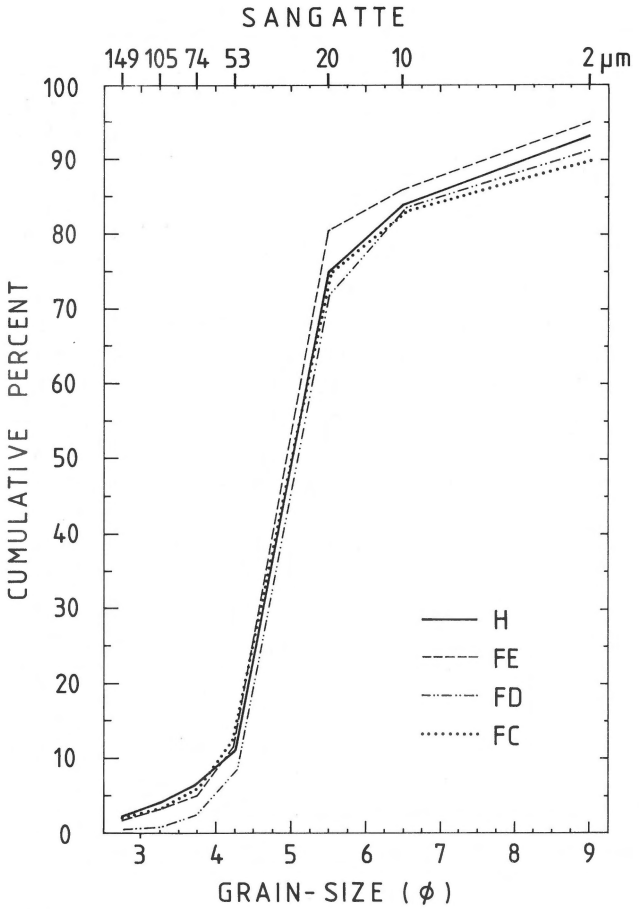


Fig. 3
Sangatte: grain-size distributions of loamy deposits.

Mineralogical composition. The heavy minerals identified in these loesses are essentially green hornblende, garnet, zircon, rutile, tourmaline, epidotes, as well as accessory minerals such as sphene, disthene, augite and glaucophane. According to JUVIGNÉ (1976), the heavy mineral composition of loess is best expressed by a mineralogical index, defined as the ratio

$$\frac{\%\text{green hornblende} + \%\text{garnet}}{\%\text{zircon} + \%\text{rutile}}$$

calculated on total count of transparent grain minerals.

The data collected in Table I enable recognition of four distinct mineralogical groups within the loessic deposits of Sangatte. The bounderies of these groups coincide in most cases with those of the lithostratigraphic units. On the other hand, within each mineralogical group, the calculated indices do not exhibit important deviations, nor show any overlap with the index of adjacent groups. It is possible therefore to characterize each of these groups by an average index:

H: i = 0.4; FE: i = 1.1; FD: i = 1.7; FC: i = 0.6

Nevertheless the influence of the local drifts, perceptible in the middle part of unit FC, as revealed by grain size analysis, induces very low indices. Indeed, the mineralogical composition of the Tertiary sand of the Noires Mottes differs from these loesses by a predominance of zircon, rutile and tourmaline and the complete absence of green hornblende and garnet. Therefore, the samples FC4 to FC7 and FC14, have not been included in the calculation of the average index of unit FC. By contrast, the other samples of unit FC, as well as those of FD, FE and H, show practically no relationship between sand content and mineralogical index.

In conclusion, there appears to be no perceptible contamination of the loamy deposits of Sangatte by the neighbouring Tertiary sediments. It is therefore possible to recognize within the loamy sequence four generations of allochthonous loessic drifts having distinct mineralogical assemblages.

COMPARATIVE DATA

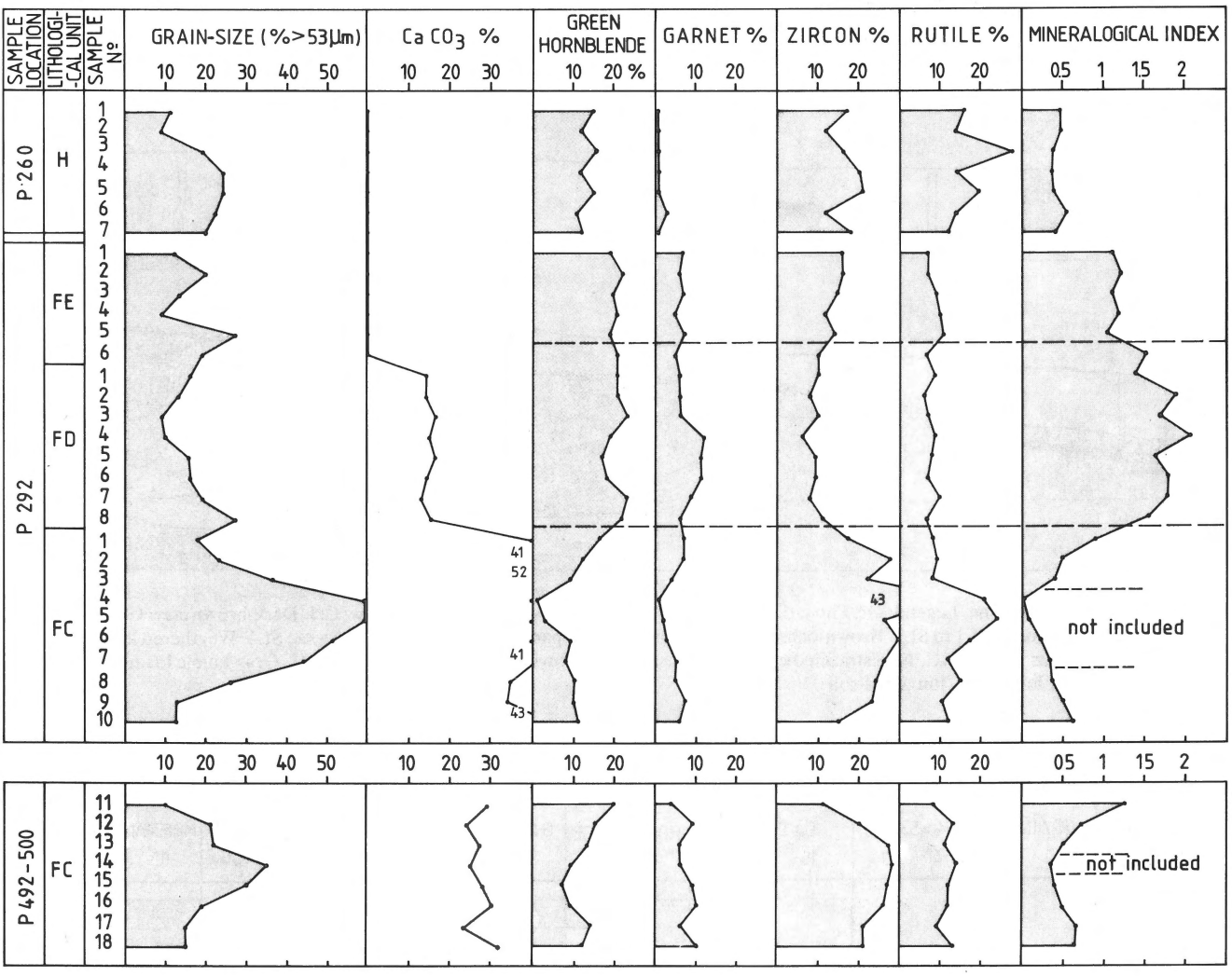
Loess mineralogy of Belgium

As the Sangatte loamy deposits belong to the same regional entity as the loess of Belgium, it is relevant to compare the heavy mineral composition of the former with that of the loesses analyzed by JUVIGNÉ (1976).

According to JUVIGNÉ, the Middle Pleistocene loess of Belgium differs from the Weichselian loess in its high content

Table I
Heavy mineral content of the loamy cover at Sangatte.

SANGATTE



of ubiquitous minerals (zircon and rutile) and in its lower green hornblende and garnet content. Consequently, the mineralogical index lies between 0.0 and 0.6 for old loesses, and between 0.7 and 4.1 for Weichselian loesses.

If one refers to the chronostratigraphical scheme established by JUVIGNÉ, the whole of the units FD and FE in Sangatte (having high mineralogical index) would be ascribed to the Weichselian. In this case, the weathering horizon registered in unit H would correspond to an interstadial event of the Middle Weichselian. The Sangatte raised beach would then be dated as Eemian or Early Weichselian. This interpretation would also imply the deposition, in the Lower Weichselian, of an initial loessic cover of low mineralogical index (unit FC): but this has not as yet been recorded in Belgium.

A second hypothesis would ascribe the complex pedogenesis of unit H to the Eemian. In this case, the underlying loesses with high mineralogical indices (units FE and FD) would be dated as Middle Pleistocene, but this would contradict JUVIGNÉ's chronostratigraphical scheme.

Cagny-la-Garenne

To resolve the above contradiction, we refer to the section of Cagny-la-Garenne near Amiens (Somme) which is considered as a stratotype for Middle Pleistocene loesses of Northern France (BOURDIER ET AL., 1974; AGACHE, 1976; HAESAERTS ET AL., 1984).

Lithostratigraphy. The section of Cagny-la-Garenne is located in the Avre valley, south-east of Amiens, at a small distance from its confluence with the Somme. It embodies a gravelly fluviatile nappe (unit GR, Fig 4), 48 m in altitude, which represents an extension of the Somme middle terraces. The cover deposits include a chalky flow (PR), several loamy deposits separated by well-defined weathering horizons (SL1

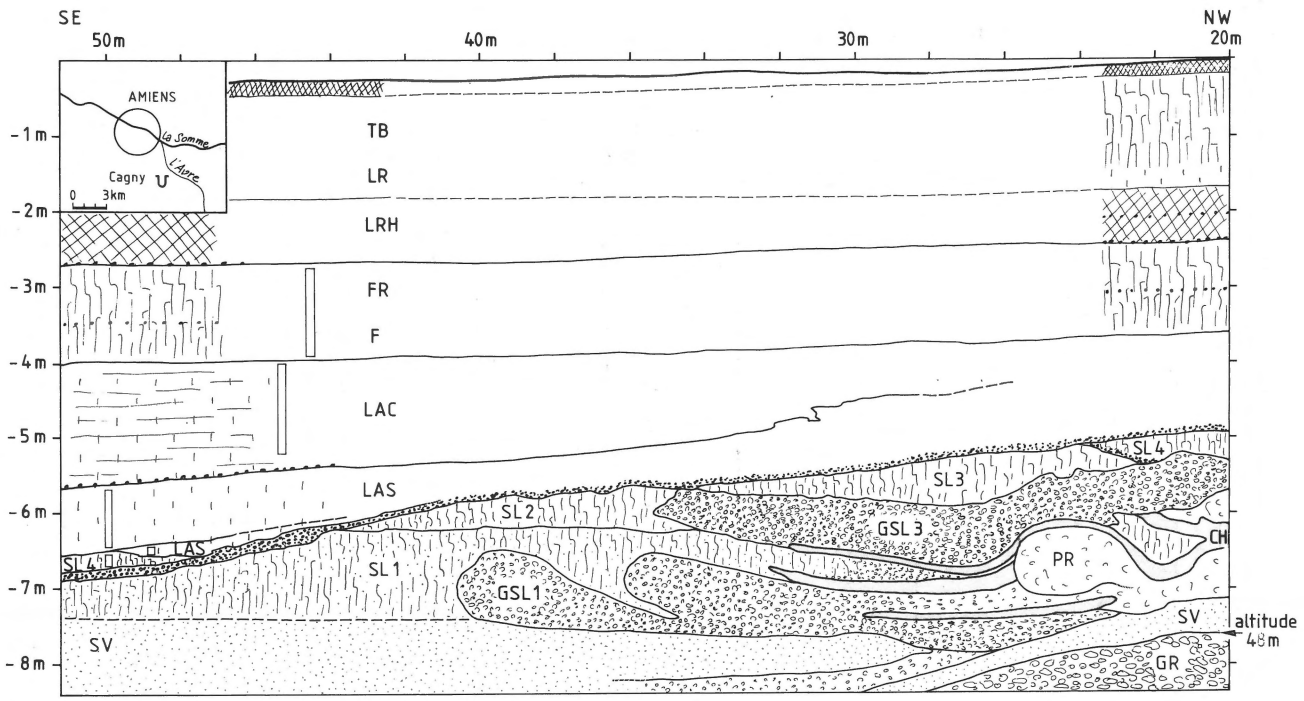


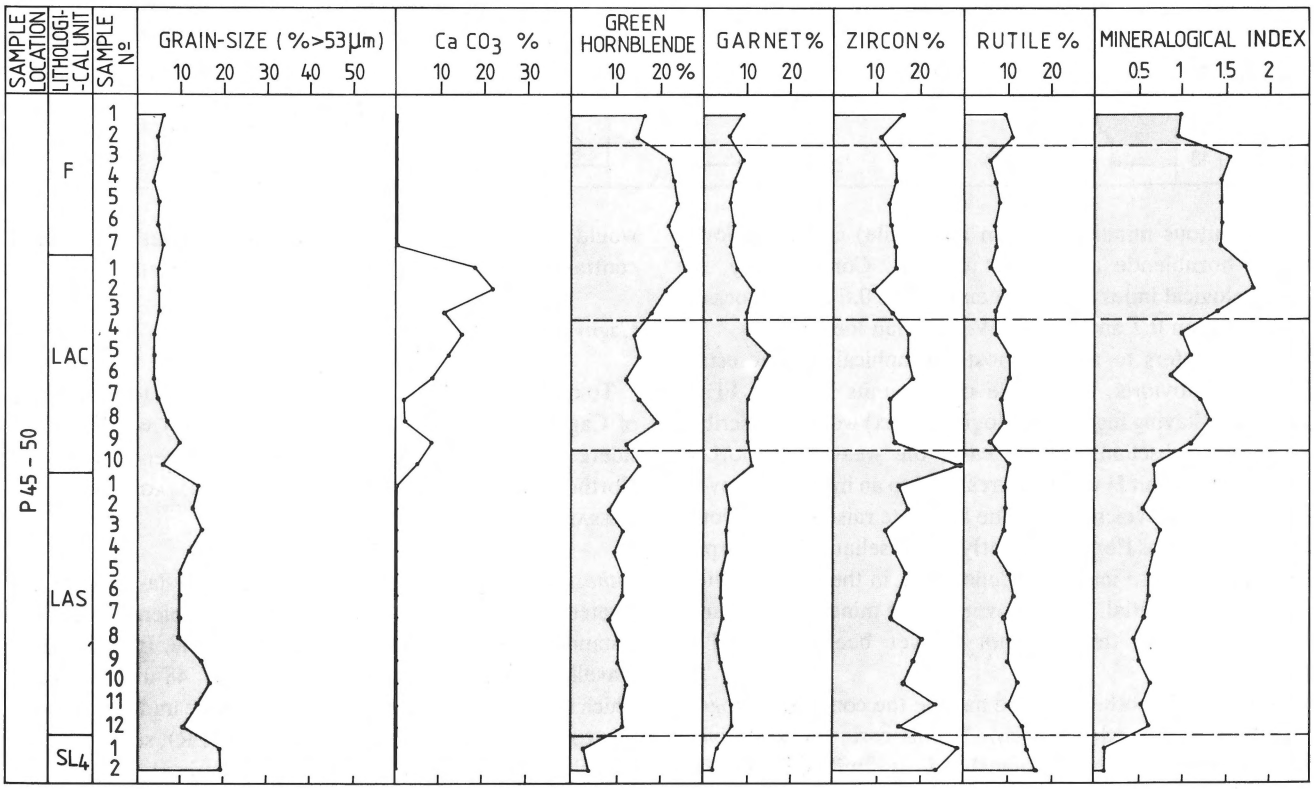
Fig. 4

Section at Cagny-la-Garenne. Legend: Gr. Fluviatil gravels; SV. Fluviatil green sand; PR. Chalky flow; CH. Dark-brown clay; GSL1 to GSL3. Solifluxed gravelly lenses; SL1 to SL3. Brown-ochre sandy loamy deposits separated by weathering horizons; SL4. Weathered loamy deposit; LAS. Non calcareous loam; LAC. Fine stratified calcareous loess; F–FR. Illuviated soil (BtHorizon); LRH. Gray humic loam (steppe soil); LR. Homogeneous loess; TB. Illuviated soil.

Table II

Heavy mineral content of the loamy cover at Cagny-la-Garenne.

CAGNY-LA-GARENNE



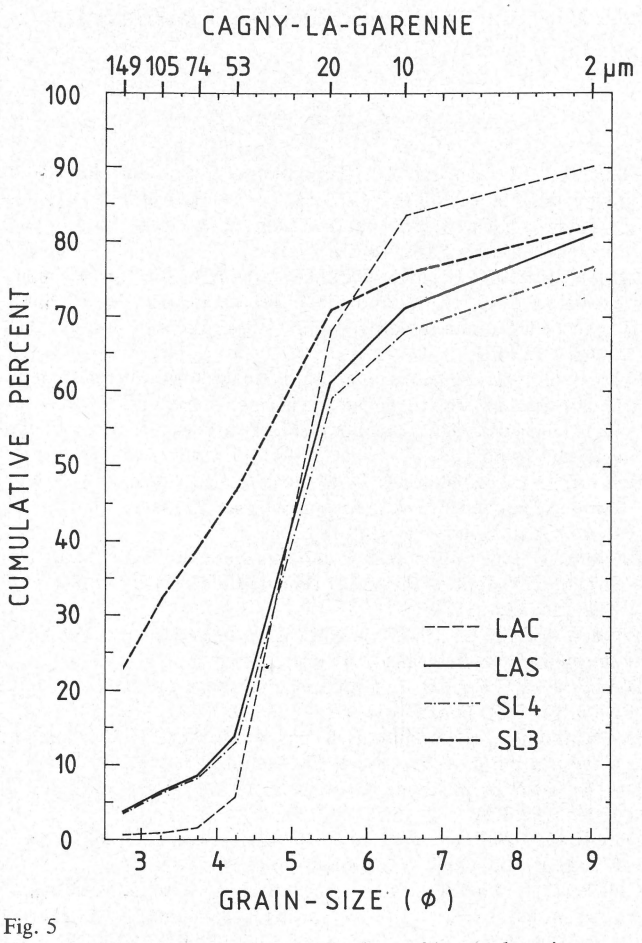


Fig. 5
Cagny-la-Garenne: grain-size distributions of loamy deposits.

to SL4) and a succession of two loamy deposits: a non calcareous loam (LAS), and a fine stratified calcareous loess (LAC). A complex illuviated soil (F and FR) is developed in the upper part of the loess LAC. Its facies is similar to the Rocourt soil and could therefore represent the Eemian Interglacial. This illuviated soil is overlain by Weichselian loess (LRH and LR). In its upper part it shows a remnant of the Holocene pedogenesis (TB).

Mineralogy. A total of 35 samples, collected in the interglacial illuviated soil (FR and F) and in the underlying loamy and sandy-loamy deposits (LAC to SL1), were analyzed in the same way as adopted for Sangatte.

The grain-size analysis of these samples confirmed the loessic character of the units FR to SL4, whereas the units SL3 to SL1 appeared to be of colluvial origin (Fig 5).

The heavy mineral composition of the loessic deposits (FR to SL4) enabled recognition of five mineralogical groups, the limits of which are surimposed on those of the main litho-stratigraphical units (Table II). They are characterized by the following average indices, (in ascending order): –F to LAC: i = 1.1, 1.5, 1.1; –LAS: i = 0.6; –SL4: i = 0.1.

Even lower values were obtained for the underlying sandy loamy deposits (SL3, SL2 and SL1), but were not included in Table II because of the colluvial character of these deposits.

DISCUSSION AND CONCLUSIONS

The mineralogical analysis of the loamy cover of Cagny-la-Garenne clearly demonstrates the existence of a generation of calcareous loesses with high mineralogical indices, underlying the Eemian interglacial soil.

These results therefore resolve the contradiction which appeared in the interpretation of the Sangatte data, because the two sections of Sangatte and Cagny-la-Garenne show a similar succession of mineralogical assemblages. The succes-

Table III
Summary of mineralogical data percentages of the loamy cover at Sangatte and Cagny-la-Garenne.

Lithological unit	Number of samples	Green Hornblende			Garnet			Zircon			Rutile			Mineralogical index		
		Range of percentages	Mean (%)	Standard deviation	R. %	M. %	S.D.	R. %	M. %	S.D.	R. %	M. %	S.D.	R. %	M. %	S.D.
SANGATTE																
H	7	11-16	13.3	1.83	1-3	1.3	0.7	12-21	16.6	3.29	12-28	16.9	5.11	0.38-0.50	0.42	0.05
FE	5	19-22	20.2	1.17	5-7	6.4	0.8	12-16	14.6	1.50	7-11	8.8	1.60	1.04-1.22	1.14	0.06
FD	9	17-23	20.6	2.00	5-12	8.0	2.58	6-11	9.0	1.41	6-10	7.78	1.23	1.42-2.07	1.71	0.17
FC	12	9-14	11.6	1.59	6-10	7.4	1.68	15-28	23.0	4.17	9-13	10.9	1.46	0.50-0.65	0.56	0.07
CAGNY-LA-GARENNE																
F	2	15-16	15.5	0.50	6-9	7.5	1.50	11-16	13.5	2.50	9-11	10.0	1.00	0.95-1.00	0.98	0.02
	8	18-26	22.5	2.24	6-11	8.0	1.73	9-14	13.0	1.58	6-9	7.13	0.93	1.40-1.78	1.52	0.14
LAC	6	12-19	14.5	2.36	10-15	11.2	1.86	13-18	15.3	2.05	6-10	8.3	1.49	0.86-1.32	1.10	0.14
LAS	13	8-15	10.6	1.73	3-11	5.2	1.89	12-29	17.1	4.42	9-13	9.9	1.44	0.43-0.76	0.59	0.10
SL4	2	2-3	2.5	0.50	2-3	2.5	0.50	23-28	25.5	2.50	14-16	15.0	1.00	0.12-0.13	0.13	0.01

sion is characterized by superposition of a low-index group (i = 0.6) at the base, and by a high-index group (i = 1.5) in the middle part, followed at the top by a lower-index group (i = 1.1).

On the other hand, in both cases this succession was obtained in loessic deposits underlying a complex illuviated soil, which could represent the Eemian Interglacial. As a result, the interglacial event associated with the raised beach of Sangatte could correspond to one of the three illuviated soils recorded within the compex SL1–SL4 at Cagny-la-Garenne.

In conclusion, the combination of mineralogical and pedological data obtained for the loamy deposits of Sangatte and Cagny-la-Garenne support SOMMÉ's (1975) assumption that the Sangatte raised beach can be attributed to a high sea level of the Middle Pleistocene. This attribution to the Middle Pleistocene brings new insight into the paleogeographical evolution of the Southern North Sea Basin.

On the one hand, it demonstrates that the opening of the Strait of Dover already occurred in the Middle Pleistocene, as previously suggested by studies on other offshore deposits of Northern France. Indeed, the estuarine deposits of the Herzeele Formation in the Yser Basin were attributed by SOMMÉ ET AL. (1978) to the Holsteinian on the basis of palynological arguments. Also, at Wissant, deposits culminating at an altitude of 13 m N.G.F. and containing *Elephas meridionalis* and *Hippopotamus major* (DE HEINZELIN, 1964), were attributed to the Cromerian by TERS & PINOT (1969).

On the other hand, the mineralogical content of the Sangatte and Cagny-la-Garenne loessic deposits, indicates that the transition from low to high-index loesses must have occurred during the Saalian, and not in the Weichselian as suggested by JUVIGNÉ (1976).

Such a change in loess composition, revealed by an increase in green hornblende and garnet percentages, should be related to an important environmental modification within the Southern North Sea Basin during the latter half of the Middle Pleistocene. It could either be the result of a change in the source area of the loess, or a modification of the mineralogical assemblage of their original sediments suggesting a change in sediment provenance within the North Sea Basin.

At present, however, this change in composition, still remains unexplained and requires further investigations on the stratigraphical and spatial distribution of the Middle Pleistocene loesses of Northwestern Europe.

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