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THE LAST INTERGLACIAL-GLACIAL CYCLE AT GRANDE PILE IN NORTHEASTERN FRANCE.

par Geneviève WOILLARD (*).

RESUME. - La tourbière de la Grande Pile est un des sites clés dans l'étude du Pléistocène. Son diagramme continu est en effet le seul, dans le Nord de l'Europe, à couvrir entièrement le dernier cycle interglaciaire-glaciaire suivi de l'Holocène. Son information climatostratigraphique est directement comparable à celle fournie par les carottes océaniques. Mais certains problèmes se posent pour établir une corrélation précise avec la stratigraphie du Nord-Ouest de l'Europe. Où situer à la Grande Pile les interstades du début du Weichselien ? Deux solutions possibles sont envisagées; elles démontrent cependant toutes les deux l'existence d'une lacune dans le schéma stratigraphique classique du Pléistocène Supérieur.

SUMMARY. - Grande Pile peat bog is one of the key Pleistocene sites. Indeed, it gives the only continuous pollen diagram, for Northern Europe, extending through the whole last interglacial-glacial cycle into the Holocene. The climatostratigraphic information, revealed by this diagram, is directly comparable to those obtained in the oceanic records. But, some problems remain to be solved for an accurate correlation with the Northwestern European stratigraphy. Where are located at Grande Pile the Early Weichselian interstadials ? Two possible correlations are considered; but both of them show a gap in the classical Late Pleistocene stratigraphic scheme.

INTRODUCTION.

One of the best stratigraphic scheme for the whole Pleistocene is provided for the oceans by a lot of continuous oxygen isotope records first reflecting global ice volume. This is well demonstrated in SHACKLETON and OPDYKE (1973), EMILIANI and SHACKLETON (1974), DUPLESSY et al. (1975), HAYS, IMBRIE and SHACKLETON (1976), SHACKLETON (1977a, 1977b). But, many problems remain about the possible correlations with continental records unfortunately represented too often by fragments only. Long continental pollen sequences are still rare and generally not detailed enough. The best record is that of the Tenagi Philippon in northern Greece (WIJMSTRA, 1969; van der HAMMEN et al., 1971, WIJMSTRA and van der HAMMEN, 1974). Recently palynological

(*) Chargé de Recherches F.N.R.S., Institut de Botanique, Laboratoire de Palynologie et Phytosociologie, Université Catholique de Louvain, place Croix-du-Sud, 4 B-1348 Louvain-la-Neuve.
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investigations were made from two continuous records through the last glacial-interglacial cycle : Clear Lake in the northern Coast Range of California (ADAM, 1977) and Pulbeena Swamp in northwestern Tasmania (COLHOUN et al., 1977). Grande Pile peat bog in north-eastern France (47°44'N, 6°30'14"E, 330 m altitude) provides a more detailed story of the vegetated landscapes following one another, without interruption, during the last 140,000 years. The bog, situated between the morainic deposits of two different glaciations (SERET, 1967; SERET and WOILLARD, 1976; THEOBALD, 1969; CAMPY and THEOBALD, 1976), is about 20 meters high above the neighbouring valleys and therefore, was never reached by any streams. What a bit of luck, or rather thanks to Professors MULLENDERS and SERET for finding this bog in a so favorable situation.

It is not the purpose of the present contribution to describe in detail all the pollen assemblage zones of that sequence. This has already been done previously (WOILLARD, 1973, 1974, 1975, 1977a, 1977b, 1978; SERET and WOILLARD, 1976). But after the Xth INQUA Congress in Birmingham (1977) where this interval of time was discussed by several scientists, it is necessary to emphasize the points clearly established at Grande Pile and those remaining to be proved.

POLLEN SEQUENCE.

The study of Grande Pile peat bog is relying on 14 cores. Glacial till was reached in five of them (cores II, III, X, XIII, XIV). Earliest and new of the most important pollen results are summarized in the figures. Fig. 1 demonstrates the very good correlation between four of the cores taken from two different sites of the bog (25 Hectares) cores II and III from the edge, cores X and XIV from the middle. The latter site, the deepest, was more favorable for palynological studies. The detailed pollen analyses of cores II, III and X are published by WOILLARD (1975, 1978). Principal pollen results of core XIV and the correlations with core X are given in Fig. 2.

Thus, a pollen profile continuous from the end of the Saalian glaciation until today is now available, as shown in Fig. 3, in an area close to the stratotypes. This spans the whole major climatic cycle B of KUKLA (1970) and RUDDIMAN and MCINTYRE (1976), that is, the complete interglacial-glacial cycle, bounded by two levels of very abrupt environmental change called Termination I and II in deep-sea sediments and situated at about 11,000 and 127,000 yr. BP (BROECKER and van DONK, 1970). The similarity between the pattern of the fluctuations based on pollen analyses at Grande Pile and that obtained in far regions by other techniques, as described in WOILLARD (1977a, 1978) is striking. This suggests that climatic fluctuations in Grande Pile pollen profiles represent global climatic fluctuations.

A complementary example is given in Fig. 4 where the arboreal-nonarboreal pollen curve of Grande Pile is compared with two of the best deep-sea curves published by SHACKLETON (1977b). These curves are based on the variations in the oxygen isotopic composition of the carbonate in fossil shells of foraminifera from the northeastern Atlantic and from the east equatorial Pacific. An attempt is made to recognize in these two records all the warm and cold events of Grande Pile. The correlations are very clear in the deep-sea stages 6, 5, 4 and 1, possible in stage 3, but not yet quite sure in stage 2 except for the Late Glacial (number 18 in Fig. 4). This picture further confirms the validity of oxygen isotope studies as an accurate stratigraphical tool. But the variations of the pollen rain composition in continuous records like Grande Pile seem to provide still more refinement of the climatic evolution. Thus, Grande Pile can be a rather good reference locality for paleoclimatic changes during the last interglacial-glacial cycle.

LAST INTERGLACIAL.

Palynology at Grande Pile reflects vegetation changes and thus climatic changes since an old glaciation (Linxert Glaciation), through three main temperate intervals (Eemian, St. Germain I, St. Germain II) separated by two cold periods (Melisey I, Melisey II), then through the obvious last glaciation (Lanterne Glaciation) to the Holocene (Fig. 3).

The first important point to be emphasized is the following: The earliest temperate period is undoubtedly the Eemian Interglacial as defined by ZAGWIJN (1961) at Amersfoort in Holland. Both Eemian periods do not reveal any cold phase, even by a detailed pollen analysis (WOILLARD, 1975, 1978). Therefore, the Eemian certainly corresponds to the deep-sea substage 5e only, as shown in Figs. 3 and 4 and by SHACKLETON (1969), and not to the whole stage 5. But the pertinent question is: does the Eemian represent the last interglacial? If not, where lies the boundary between the last interglacial and the last glacial? This limit has not yet been clearly defined (WOILLARD, 1978, fig. 5).

In fact, the answer to these questions depends on the definition of an interglacial period, because several criteria were used until now to differentiate an interglacial from an interstadial. A lot of definitions of "interglacial" are described by SUGGATE (1965, p. 619 and 620).

- "period comprising the following series of climates: arctic, sub-arctic, boreal, temperate, boreal, subarctic, arctic" (after JESSEN and MILTHERS, 1928);
 - "period which was warm and long enough to permit full immigration and expansion of thermophilous trees" (after ZAGWIJN, 1957);
 - "period of warmth long enough to permit the development of temperate forests indicative of climates at least as warm as during the Postglacial climatic optimum" (after West, 1961);
 - "period showing the changes from the end of the last glaciation through the postglacial thermal maximum, and thus having a duration of a few ten thousands of years" (after WEST and GODWIN, 1958).
- Through these definitions, SUGGATE (1965, p. 624) proposes: "An interglacial is a warm period between two glaciations, during which the temperature rose to that of the present day. Neither duration nor wetness is used in this definition".

TURNER and WEST (1968) distinguish four sub-periods of vegetational development during each interglacial: "I - Pre-temperate zone (*Betula-Pinus*), II - Early-temperate zone (mixed oak forest), III - Late-temperate zone (*Carpinus-Abies*), and IV - Post-temperate zone (*Pinus-Betula*).

KUKLA et al. (1972) understand the term interglacial as "an uninterrupted warm interval, in which the environment on a global scale reached at least the present level of warmth".

For MANGERUD et al. (1974, p. 116), "the interglacials are characterized by evidence of a warm climate and continuous forest successions. Furthermore, eustatically conditioned marine transgressions have been recognized in several cases. The interglacials and the interstadials are warm phases of two different orders, and their distinctiveness is possibly only a matter of duration".

Thus the confusion is great, and none of these definitions gives an obvious criteria for the last interglacial-last glacial boundary.

At Grande Pile, we showed that the Eemian interglacial was followed by two interglacial periods (St. Germain I and II, see Fig. 3). "Interglacial" is understood here from a palynological point of view, that is, from the point of view of the vegetational development. The criteria by which "interglacials" and "interstadials" are recognized are published by WOILLARD (1978). St. Germain I and II were rather warm, as revealed, for instance, by the presence of *Viscum*, *Ilex* and *Hedera* during their climatic optimum, like during the warmest part

of the Eemian. *Viscum album* (mistletoe), a continental species, requires relatively high summer temperatures (+ 15,5°C, after IVERSEN, 1944); *Ilex* (holly) and *Hedera* (ivy), species of oceanic distribution, require mild winters (temperatures respectively above -0,5°C and -1°C, after IVERSEN, 1944). Thus the climatic optimum of these three interglacials was characterized by warm summers and mild winters. However, the Eemian interglacial seems to have been the warmest of the three, as indicated by the more regular appearance of *Viscum*, *Ilex* and *Hedera*, and the absolute dominance of the hardwood forest during the climatic optimum (see comments of the column "climatic trend" in Fig. 3).

As the most important cooling since the Eemian occurs above St. Germain II (between Ognon III and Goulotte climatic improvements) (Figs. 2 and 3), we are induced to believe that the three interglacials of Grande Pile constitute together the "Last Interglacial Interval". This interpretation is supported by the opinion of several scientists. SUGGATE (1974), finding the disagreement on the dating of the last interglacial end (73,000 yr. BP, 97,000 yr. BP or 116,000 yr. BP depending from the authors), adopts for the lasting of the last interglacial the period about 128,000-73,000 yr. BP, equivalent to stage 5 of SHACKLETON and OPDYKE (1973). The remark made by RUDDIMAN and McINTYRE (1976) may satisfy most of the workers: for the oceanographers, an interglacial is formed by "short-term (10,000 years) warm-cold oscillations that continental workers treat as discret units". SHACKLETON and MATTHEWS (1977) are of the same opinion, and consider stage 5 as "the last predominantly interglacial stage". The earliest substage 5e, correlated with Barbados III terrace and with other terraces dated at around 125,000 yr. BP, probably represents "the last interglacial in a more strict sense". A clearer definition of the last interglacial finally appears in this paper: "the last interglacial (strict sense) formed the last time that continental ice volume was as small as it is today". The Grande Pile pollen sequence might be explained using this definition: Eemian, St. Germain I and St. Germain II forming the Last Interglacial Interval within which the Eemian interglacial probably represents the last interglacial (strict sense) (see Figs. 3 and 4) that is, the last time which was as warm at least as the climatic optimum of the present interglacial. Indeed, at Grande Pile, as shown by Fig. 3, although St. Germain I and II present an interglacial succession, there are still more similarities between the vegetational development of the Eemian and the Holocene (see comments of the column "climatic trend", in Fig. 3). Furthermore, the Eemian was probably a little warmer than the Holocene.

Fig. 1 Arboreal Pollen-Non Arboreal Pollen curves in the four most complete cores from Grande Pile peat bog. Correlation of their pollen zones. (A) Linxert (with Zeifen oscillation); (B) Eemian, Melisey I, St-Germain I A-B-C, Melisey II, St-Germain II; (C) Lanterne I (Ognon I, II, III); (D) Lanterne II (Goulotte, Pile A-B, Charbon, Grand Bois A-B-C); (E) Lanterne III (Marcoudan I, II, III, Late Glacial); (F) Holocene. In the little columns white patches indicate the warmings, and black patches mark the coolings. The detail of the biostratigraphy is given in Fig. 3. Our recent pollen investigations lead us to modify somewhat the subdivision in the upper half of the diagrams II and III published in 1974 and 1975. In both, Ognon III is now seen instead of Ognon II. In diagram III, Ognon II lies at about 927 cm. In diagram II, Ognon II lies between 906 and 894 cm (hiatus between two core segments); Goulotte and Pile oscillations lie between 810 and 780 cm; Charbon oscillation is seen between 760 and 740 cm; Grand Bois oscillation is found from 648 to 513 cm, with zone A (648 to 620 cm), zone B (620 to 605 cm), zone C (605 to 513 cm). The modifications in diagram X are shown in Fig. 2.

Fig.1

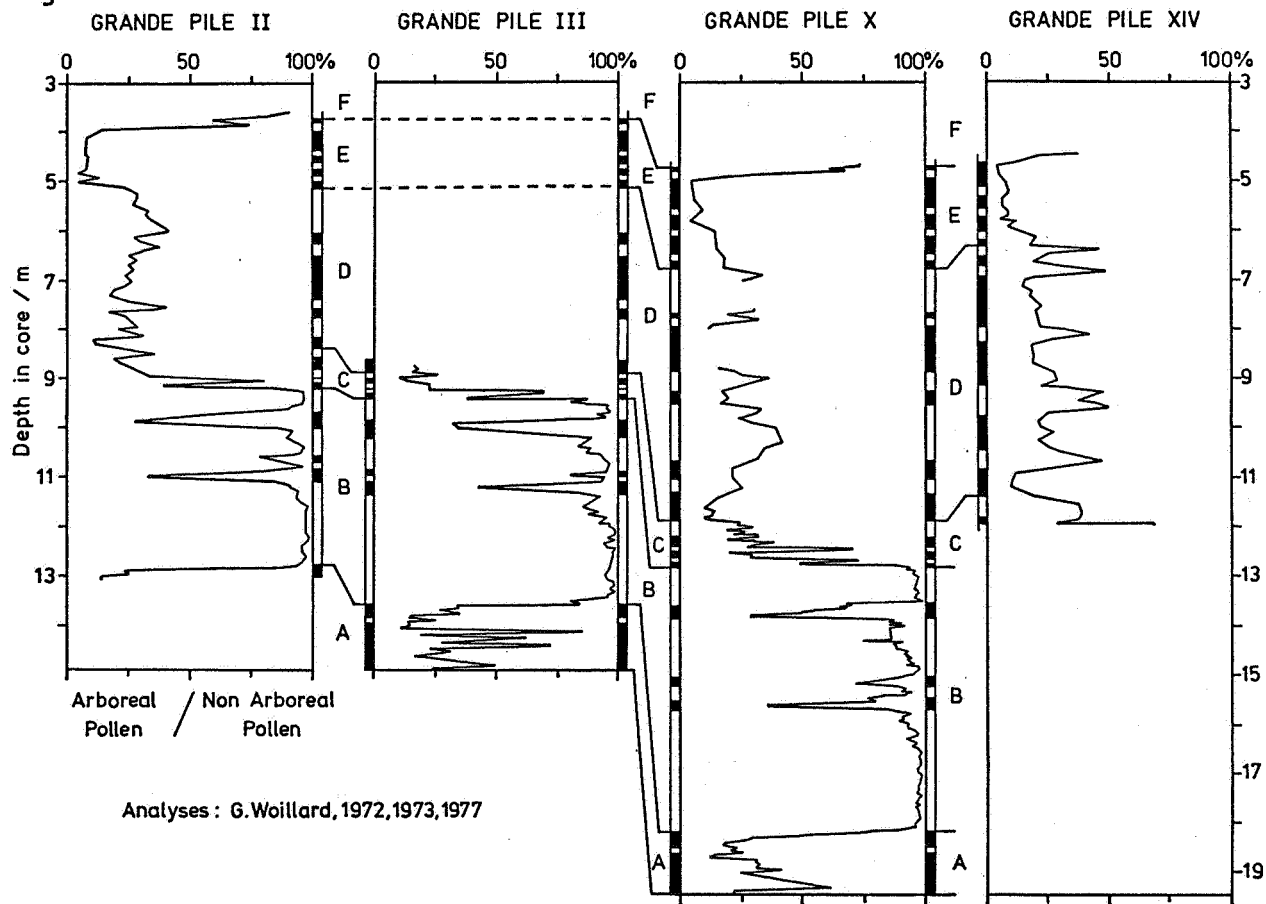


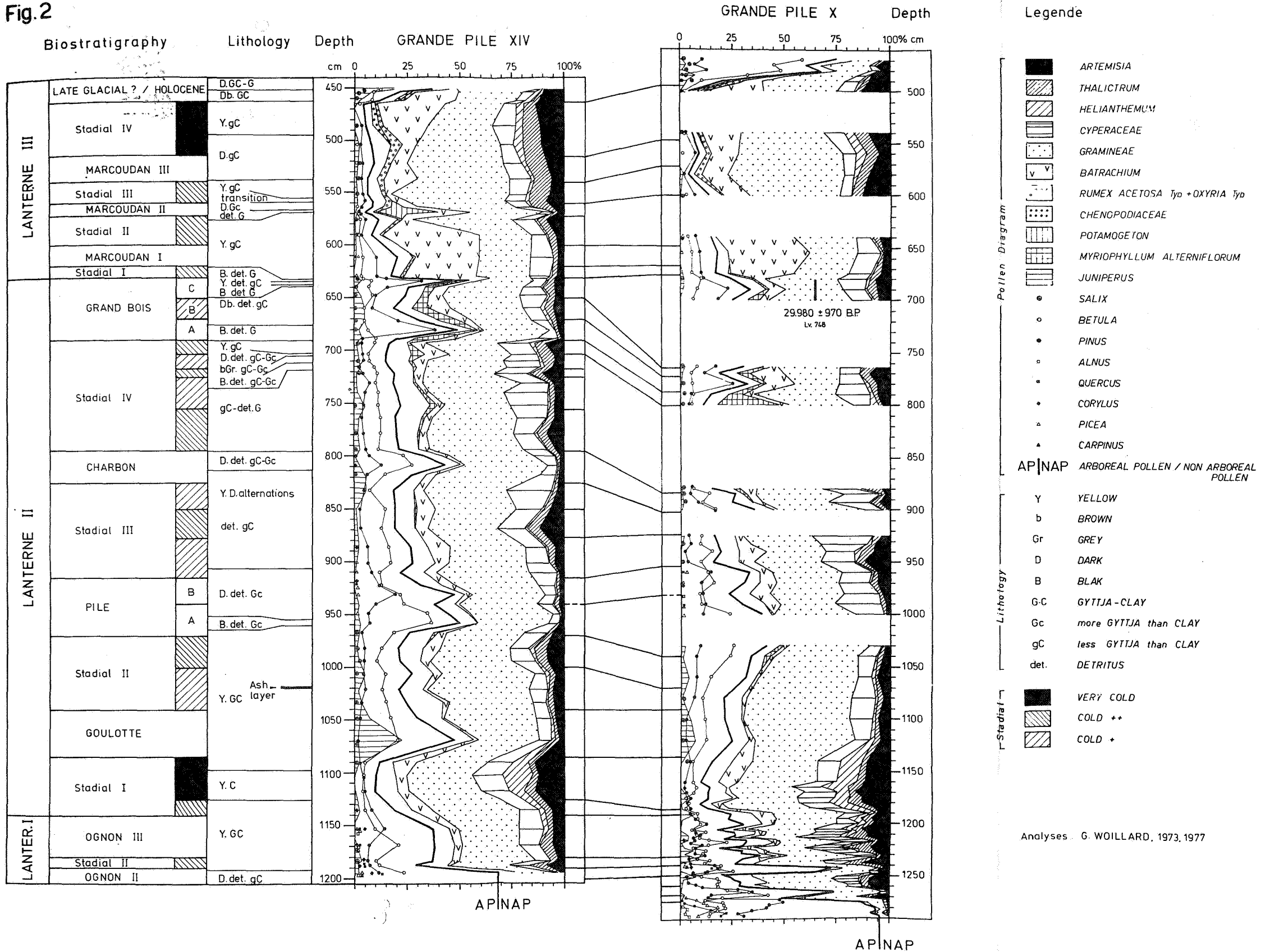
Fig. 2 Comparison between the pollen diagrams of the upper half of cores Grande Pile X and XIV close to each other (the complete diagram X is published by WOILLARD, 1975 and 1978; the complete diagram XIV will be published later). Percentages are based on the pollen sum excluding *Isoetes* often too important. *Cyperaceae* are represented by horizontal lines indicating each analysed level. Core X was sampled with a jack-drill (samples 1 m long and 10 cm in diameter), in 1973, by the SMET team from Dessel (Belgium); core XIV was collected with the Swedish foil piston corer (a continuous core 7 m long and 3,5 cm in diameter), in 1977, with MORNER from Stockholm. The correlations between the two cores are very good; the hiatuses in core X are only due to sampling problems. Therefore, core XIV will replace core X in its upper part to establish the complete sequence shown in Fig. 3. The climatic trend given for the stadials is based on the variations in pollen assemblage, in particular on the fluctuations of *Artemisia* and *Juniperus*: "very cold": *Artemisia* = 10-14 %, *Juniperus* absent; "cold ++": *Artemisia* = 5-10 %, *Juniperus* \leq 2%; "cold +": *Artemisia* = 3-5 %, *Juniperus* = 2-6 %. The lithology (after MORNER, in press) is given for the core XIV. It is to be noted that the "ash layer" indicated by MORNER at level 1,019 cm in core XIV corresponds to the loess layer at level 1,075 cm in core X, described previously by SERET (SERET and WOILLARD, 1976; WOILLARD, 1978). The detail of the pollen curves in the two cores clearly shows that these layers represent the same level. In core X, SERET has indicated two thin loess layers, at levels 1,075 cm and 1,031 cm; heavy minerals content of them excludes any confusion with ash layers. Respectively 335 and 420 grains were counted excluding the oxides, micas and opaques :

	level 1,075 cm	level 1,031 cm
	%	%
Green hornblende	44	39
Tourmaline	17	10
Epidote	3	9
Zoïsite	4	9
Andalusite	Tr. (3 grains).	3
Anatase	6	3
Garnet (?)	4	2
Glaucofane	Tr. (3 grains).	2
Rounded zircon	9	1
Monazite	-	1
*Aphatite	1	7
*Sphene	3	2
*Enhedral zircon	3	1
*Basaltine	Tr. (1 grain) .	Tr.(2 grains)
*Pleochroic augite	Tr. (3 grains).	Tr.(3 grains)
Calcite	Tr. (2 grains).	1
Rutile	Tr. (2 grains).	-
Undetermined	6	10

Tr. = Trace = less than 1 % (non totalized in percentages)

* = can be partly of Pleistocene volcanic origin.

Fig.2



And now, what about the lasting of these three interglacials ? According to WRIGHT (1972), SANCETTA et al. (1973), SHACKLETON and OPDYKE (1973), MULLER (1974), RUDDIMAN and McINTYRE (1976), and others, a period of time of about 10,000 years is likely for the Eemian and maybe for the two upper interglacials too. The Eemian seems to be clearly fixed at around 125,000 yr. BP by the study of SHACKLETON and MATTHEWS (1977) (see above). The major shift registered by RUDDIMAN (1977) during the last interglacial-glacial cycle in the North Atlantic ice-rafting deposition occurs approximately at 75,000 yr. BP. But already 40,000 years before (at about 115,000 yr. BP) the first signs of the last glaciation are seen. Correlations with deep-sea stages are made by RUDDIMAN in sense that : stage 5 includes the peak interglaciation from 125,000 to 115,000 yr. BP and the early glaciation from 115,000 to 80,000 yr. BP; stages 4, 3 and 2 represent the main glaciation from 75,000 to 10,000 yr. BP. This is indicated by an abrupt increase in ice-rafting at 75,000 yr. BP and maximum values between 25,000 and 13,000 yr. B.P.

In the pollen diagram of Grande Pile (Fig. 3), the first cooling signs occur at the end of the Eemian. Melisey I was certainly very cold (see reasons in WOILLARD, 1978). If our correlations with SHACKLETON stages are right (Fig. 4), Melisey I (=substage 5d) (number 4 in Fig. 4) was characterized by a climate of glacial character (SHACKLETON, 1977b). It might correspond to the event of 115,000 yr. BP (RUDDIMAN, 1977). On the other hand, the main change in our diagrams lies at the start of Lanterne II, that is correlated with stage 4 (between numbers 12 and 13 in Fig. 4). It might represent the event of 75,000 yr. BP (RUDDIMAN, 1977). As to Melisey II, palynological and diatoms analyses (for the latters : see GHOUNDIHAL, 1976 and LOUIS, 1976) show that it was colder than Melisey I. This seems also indicated in oxygen isotopic records (Fig. 4 : numbers 4 and 8). Therefore, Melisey II (=substage 5b) is probably situated between 105,000 yr. BP (=Barbados II) and 82,000 yr. BP (=Barbados I) (SHACKLETON and MATTHEWS, 1977).

EARLY WEICHSELIAN.

If no great difficulties are met in the correlations between Grande Pile and the oceans, it is not the same with continental sequences, even with the stratotypes. The possibilities of correlation between Grande Pile and the Northwestern European stratigraphy are shown in Table 1, and maybe there are still others. The problem is chiefly due to the presence in Grande Pile sequence of three relatively warm periods which do not exist in the general stratigraphy of Northern Europe, as proposed by van der HAMMEN et al. (1971) and MANGERUD et al. (1974) : either St. Germain I-A, I-C and II, either Ognon I, II and III. These periods were rather important as they are seen in the ocean isotopic records (Fig. 4 : numbers 5, 6, 7, 9, 10, 11 and 12). Now, the $\delta^{18}O$ record in deep-sea sediments has a resolution limited at about 1000 years because of low sedimentation rate and thus bioturbation (SHACKLETON, 1977b).

The mistake made by some palynologists is at any cost to find in their pollen profiles from everywhere the characteristic sequences of the stratotypes in northwestern Europe, although the vegetation is completely different. Even between the stratotypes of Holland, NW Germany and Denmark problems of correlation exist. This is well discussed by MENKE (1975, 1976, 1978 written communication). For instance, questionable is the correlation between the Dutch Amersfoort Interstadial (ZAGWIJN, 1961) characterized by *Pinus*, *Betula*, *Picea* and some thermophilous trees like *Alnus*, *Quercus*, *Corylus*, and the Danish Rodebaek Interstadial (ANDERSEN, 1961) chiefly characterized by aquatic plants, in their type locality. Besides, several correlations between the stratotypes were proposed (MENKE, 1976).

The Dutch Amersfoort (ZAGWIJN, 1961) was compared with the Danish Brörup (ANDERSEN, 1961) and the Dutch Brörup with the NW German Odderade (AVERDIECK, 1967) by MENKE (1970) MENKE and BEHRE (1973) and BEHRE (1974). But ERD (1973) and MENKE (1976, 1978, written communication) proposed that Amersfoort and Brörup in Holland together represent the whole Brörup in Denmark and the whole Brörup in NW Germany. On the other hand, the existence of the three interstadials, Amersfoort, Brörup and Odderade, in the Early Glacial (=Early Weichselian) of NW Europe seems quite established for other scientists (e. g. MANGERUD et al., 1974; GROOTES, 1977a, 1977b).

As the immigration of plants is not yet clearly understood, the interpretation of diagram fragments require a great carefulness. And a general stratigraphy based on fragments from different localities remains questionable. The necessity of continuous continental sequences, and the prominent part played by deep-sea curves that give the pattern of the complete stratigraphy, can be seen here again.

Where lies the Early Weichselian in Grande Pile sequence? If the existence of the three Dutch or the two Danish and NW German early glacial interstadials may be accepted as proved, two possibilities can be seen, as shown in Table 1.

According to the first, Ognon I, II and III (Figs. 2 and 3) represent Amersfoort, Brörup and Odderade of Holland (WOILLARD, 1974, 1975, 1977a, 1978 : SERET and WOILLARD, 1976) :

- Ognon I is characterized by the development of the boreal forest with *Betula* and *Pinus*;
- Ognon II shows an important expansion of thermophilous trees, especially *Quercus*, *Corylus* with some *Alnus* and *Carpinus*, and the expansion of *Picea*;
- Ognon III is indicated by a new expansion of *Betula* and *Pinus*, and the continuous presence of thermophilous trees and *Picea*.

The species of the heath, such as *Calluna*, *Empetrum* and *Ericales*, are more important from the beginning of Ognon I; they indicate the start of the Amersfoort interstadial in Holland (ZAGWIJN, 1961). Ognon II is the warmest of the three climatic improvements, like Brörup in Holland. The pollen of *Brückenthalia* (*Ericaceae*) (MENKE, 1970; BEHRE, 1974) occurs during these both periods. If this correlation is correct, the interglacials St. Germain I and II are not recognized in the stratigraphy of Northern Europe. They do not exist in Northern Europe or they are mistaken for parts of the Eemian interglacial.

According to the second possibility of correlation :

- St. Germain I-A = the Dutch Amersfoort or the lower part of the Danish and NW German Brörup (=zone WF IIa1 MENKE, 1976, 1978 written communication);
 - St. Germain I-C = The Dutch Brörup or the upper part of the Danish and NW German Brörup (= zones WF IIa3 and WF IIb of MENKE);
 - St. German II = the Odderade interstadial (= zone WF IV of MENKE).
- In that case, Ognon I, II and III interstadials are new for the Northwestern European stratigraphy.

So far we have proposed the first solution because of the great difficulty to admit that interglacials, such as St. Germain I and II, situated at 47° Lat. N, correspond to interstadials, such as Amersfoort in Amersfoort locality (52° Lat. N) situated only at 500 km away from Grande Pile. Recently, GROOTES (1977a, 1977b) has established by radiocarbon dates "the existence in North-West Europe, of three interstadials shortly following one another in the early phase of the Last Glacial", Amersfoort starting at about 68,000 yr. BP, Brörup at about 64,000 yr. BP, and Odderade at about 60,000 yr. BP. If St. Germain I-A, I-C and II really correspond to Amersfoort, Brörup and Odderade respectively, how to imagine that thermophilous trees had time enough, within the space of 2000 to 3000 years, to immigrate again from their refuges in successive

well-ordered waves. On the other hand, the chronology suggested by the deep-sea curves seem to indicate a lasting of about 10,000 years for each interglacial : Eemian, St. Germain I and St. Germain II (see above). Moreover, GROOTES (1977a, 1977b) proposes a correlation between the early Weichselian and the upper part of the isotope substage 5a. The first alternative in Table 1 leads us to the same conclusion (Fig. 4 : numbers 10, 11, 12). However, an important problem remains for an absolute chronology. The stage 4 is found at about 53,000 yr. BP on the radiocarbon time scale (GROOTES 1977a, 1977b), and is fixed at about 75,000 years by the oceanographers (RUDDIMAN, 1977; SHACKLETON and MATTHEWS, 1977) using ^{14}C datings and other techniques such as the K/Ar method, the $^{230}\text{Th}/^{234}\text{U}$ method and the $^{231}\text{Pa}/^{235}\text{U}$ method. Thus, as yet, it may only be demonstrated at Grande Pile that the Early Weichselian (alternatives 1 and 2 in Table 1) lies between the Eemian (= isotope substage 5e, at 125,000 yr. BP) and the predominantly cooling of isotope stage 4. Indeed, the upper part of the Grande Pile pollen sequence (Figs. 2 and 3) is fortunately easily explained using the Northwestern European stratigraphy (see Table 1).

PLENIGLACIAL.

It is to be noted that for the first time the Middle Pleniglacial is clearly and completely represented in a pollen diagram. This section is designated here by the local name "Lanterne II" (the new diagram XIV is the best at Grande Pile for these periods; the complete diagram with the detail of all the herbs will be published later. The fluctuations of the principal species are shown in Figs. 2 and 3. Lanterne II starts with an important cooling correlated with the deep-sea stage 4 and marked by the development of a *Gramineae-Artemisia* steppe. The "climatic trend", based on the variations in the pollen assemblage (see comments of Figs. 2 and 3), given to this stadial is "very cold". It is characterized by the maximum of *Artemisia* and the absence of *Juniperus* (see further). A sharp rise in tree pollen up to 50 % (correlated with the beginning of the deep-sea stage 3) indicates the start of the warming with the "Goulotte oscillation". The vegetation chiefly consists of shrubs (*Salix*, *Juniperus*, *Betula*) with still high values of *Gramineae*, *Artemisia*, *Thalictrum*, *Helianthemum* and the *Cyperaceae* remain in continuous curves till the Holocene, expanding during each colder period. Above the first rise in temperature, the pollen diagram shows three obvious climatic improvements in which the values of *Betula* decrease and those of *Pinus* increase from the first to the third. But the percentage reached by the trees in each warming is always 50 % of the total sum. Each of those periods are bounded at bottom and top by an expansion of *Juniperus*. The two first warmings, the "Pile oscillation" and the "Charbon oscillation" are indicated by the development of an open *Betula-Pinus* forest. The third oscillation called "Grand Bois" is warmer, characterized by two expansions of *Pinus* separated by a colder phase. Aquatic plants are important during all the section. *Isoetes* (non contained in the total sum because generally too important) shows higher values in the warmings. *Batrachium* remains rather regular but slightly expands during the stadials. *Myriophyllum alterniflorum* occurs in a continuous curve just after the Charbon oscillation, with the highest percentages around the Grand Bois oscillation. This confirms the warmer character of that period compared with the two first climatic improvements. Between these three ameliorations, climatic conditions were more severe, as indicated by the rise of the *Artemisia*, *Thalictrum* and *Helianthemum* curves chiefly, the *Gramineae* and *Cyperaceae* remaining constant.

As a radiocarbon date of 29,980 \pm 970 yr. BP (Lv. 748; WOILLARD, 1975, 1978) is obtained in the Grand Bois oscillation, as one of the three most important coolings (the one correlated with the deep-sea stage 4) of Grande Pile sequence occurs just below the Goulotte oscillation at the beginning of Lanterne II, and as three clear climatic ameliorations are seen during Lanterne II, we are extremely inclined to correlate Lanterne II of Grande Pile with the Middle Pleniglacial of the Northwestern European stratigraphy (see correlations in Table 1), although the pollen diagrams are completely different from one another, and the "warmings" in NW Europe often not at all obvious. Indeed, for instance, the Hengelo interstadial described by ZAGWIJN (1974) is characterized by about 30 % (at the utmost) of shrubs (*Salix*, *Betula*) and an increase of *Artemisia*, *Thalictrum* and aquatic plants (*Batrachium*, *Myriophyllum*, *Pediastrum*). The coolings are indicated by high values of herbs, but low values of *Artemisia*, *Thalictrum* and *Batrachium*. On the other hand, at Grande Pile, the interstadials show 50 % of trees (*Betula*, *Pinus*) and a minimum of *Artemisia*, *Thalictrum*, *Batrachium*, while the stadials are revealed by an increase of these herbs and the continuous presence of *Jupinerus*. Moreover, so far, the Moershoofd, Hengelo and Denekamp interstadials are very badly demonstrated by palynology in their type locality and in other regions of the Netherlands (ZAGWIJN and PAEPE, 1968; van der HAMMEN et al., 1967; van der HAMMEN and WIJMSTRA, 1971; van der HAMMEN et al. 1971; ZAGWIJN, 1974; KOLSTRUP and WIJMSTRA, 1977). Even the Hengelo interstadial which seems to be the best indicated in the pollen curves of ZAGWIJN (1974), is described by the author as a "shrub tundra". A recent study (KOLSTRUP and WIJMSTRA, 1977) establishes the existence in the Netherlands of three interstadials Moershoofd, Hengelo and Denekamp. However, each period is "seen" or rather guessed in a separated diagram. The maximum value of the trees is 20 % (and often less) during the warmings, but sometimes reaches more than 10 % during the coolings. Thus the interpretation can only be based on the radiocarbon dates. Although, the July temperature is believed to have reached 13° C during the Moershoofd interstadial, 15° C during the Hengelo interstadial, and 10° C during the Denekamp interstadial, it is to be noted that those temperatures are only deduced from species very scarcely represented.

The most severe conditions of the Last Glaciation are observed at Grande Pile in Lanterne III which is likely to represent the deep-sea stage 2 (see numbers 17 and 18 in Fig. 4). The vegetation is characterized by very high values of herbs with a maximum in the curves of *Artemisia*, *Thalictrum*, *Helianthemum*, *Chenopodiaceae*, *Rumex acetosa* + *Oxyria*, *Batrachium*, and the absence of *Isoetes*. *Gramineae* and *Cyperaceae* do not show any changes (Fig. 2). However, three temporary climatic ame-

Fig. 4 Attempt of a detailed correlation between the Arboreal Pollen - Non Arboreal Pollen curve of Grande Pile (NE France) and two oxygen isotope records published by SHACKLETON (1977b) : core 12392-1 from NE Atlantic and core V 19-20 from East Equatorial Pacific, based on analyses of foraminifera. Numbers signification is as follows : (1) Linexert, (2) Eemian (hardwood forest); (3) Eemian (expansion of coniferous trees), (4) Melisey I, (5) St. Germain I-A, (6) St. Germain I-C (after Montaigu cooling), (7) St. Germain I-C (after the second cooling of St. Germain I), (8) Melisey II, (9), St. Germain II, (10) Ognon I, (11) Ognon II, (12) Ognon III, (13) Goulotte, (14) Pile, (15) Charbon, (16) Grand Bois, (17) Lanterne I (Marcoudan I, II, III not distinguishable), (18) Late Glacial, (19) Holocene.

liorations may be observed; they are designated by the local names : Marcoudan I, II, III. They are chiefly marked by a decrease of *Artemisia*, *Thalictrum*, *Helianthemum* and *Batrachium* and by an increase of *Isoetes* (non contained in the pollen sum). Marcoudan II is the best indicated : it corresponds to a layer of gyttja, and the rise in temperature is reflected by the sharp expansion of *Potamogeton* (up to 28.8 %), an aquatic species. According to IVERSEN (1954) and ANDERSEN (1961) aquatic plants can more quickly respond to a climatic improvement and disperse than other species which immigrate slower. Lanterne III (except the Late Glacial) probably represents the Upper Pleniglacial of the Northwestern European stratigraphy (see Table 1). A correlation between Marcoudan I, II, III and Tursac, Laugerie, Lascaux (LEROI-GOURHAN, 1973) is still rather difficult. Complementary investigations and radiocarbon datings are necessary here for a more definite correlation.

LATE GLACIAL AND HOLOCENE.

After a last very cold episode (Lanterne III : Stadial IV), the climate becomes warmer. The Late Glacial is not obvious at Grande Pile in the general diagram (Fig. 3) because it is probably situated between two core segments. It is marked in cores Grande Pile II and X (WOILLARD, 1975, 1978) by the maximum in *Juniperus* curve and the sharp expansion of *Betula*, followed by an increase of *Artemisia* and the *Gramineae*. This zone was not recognized before as Late Glacial, and was placed within the Preboreal period. But, recent radiocarbon dates obtained by GILOT (Laboratoire de Chimie Inorganique et Nucléaire, Université Catholique de Louvain, Belgique) on samples from the Grand Chemin peat bog (47°52'13"N, 6°39'34"E, 680-m altitude; diagrams published by WOILLARD, 1975), in the same area than Grande Pile, lead us to modify our interpretation. In that bog the maximum of *Juniperus* after the last predominantly cooling is dated of $11,860 \pm 240$ yr. BP (Lv. 819, Grand Chemin IV, level 587 tot 575 cm); this optimum and the following expansion of *Betula* is dated of $11,150 \pm 100$ yr. BP (Lv. 818, Grand Chemin IIIb, level 472 to 460 cm); the maximum of *Betula* and the following increase of *Pinus* is dated of $11,090 \pm 110$ yr. BP (Lv. 820, Grand Chemin IV, level 575 to 555 cm). Therefore, the age of this sequence is certainly the Late Glacial instead of the lower part of the Preboreal (Holocene). The Bölling and the Alleröd interstadials are not clearly separated. The Bölling might be represented by the sharp expansion of *Juniperus*, as proposed by de BEAULIEU (1977), although the ^{14}C date is 1000 years too young at least. The Late Glacial of Grand Chemin is followed by a cooling corresponding to the Younger Dryas (interpreted before as Preboreal B, that is Piottino cold episode). A ^{14}C date, in favor of the Preboreal period, is given for the *Betula-Pinus* forest which occurs after this cooling : $9,310 \pm 85$ yr. BP (Lv. 824, Grand Chemin IV, level 520 to 510 cm). The modifications of our interpretation, described above,

Table 1 Two possibilities of correlation between Grande Pile pollen sequence and the Northwestern European stratigraphy.

(1) The Dutch Amersfoort and the Dutch Brörup probably together form the whole Danish and NW German Brörup (MENKE, 1976) (see comments in text). "Warthe" after MENKE and BEHRE (1973); "Eemian" and "Amersfoort" after ZAGWIJN (1961); "Brörup" after ANDERSEN (1961); "Odderade" after AVERDIECK (1967); "Early Glacial, Pleniglacial (Lower, Middle, Upper), Late Glacial" after van de HAMMEN et al. (1967); "Early Weichselian, Middle Weichselian, Late Weichselian" after MANGERUD et al. (1974); "Moershoofd" after ZAGWIJN and PAEPE (1968); "Hengelo" and "Denekamp" after van der HAMMEN et al. (1967), van der HAMMEN and WIJMSTRA (1971); "Arcy-Kesselt, Tursac, Laugerie, Lascaux" after LEROI-GOURHAN (1973).

Table 1. TWO POSSIBILITIES OF CORRELATION BETWEEN GRANDE PILE POLLEN SEQUENCE AND THE NORTHWESTERN EUROPEAN STRATIGRAPHY

GRANDE PILE (NE FRANCE) BIOSTRATIGRAPHY		OXYGEN ISO- TOPE STAGES (SHACKLETON 1969, 1977)	NW EUROPEAN STRATIGRAPHY				
			1		2		
HOLOCENE		1	HOLOCENE		HOLOCENE		
LAST GLACIAL INTERVAL	LANTERNE III	Late Glacial	Late Glacial (= Late Weichselian)		Late Glacial (= Late Weichselian)		
		Stadial IV Marcoudan III Stadial III Marcoudan II Stadial II Marcoudan I Stadial I	2	Pleniglacial (= Middle Weichselian)	Upper Pleniglacial	(Lascaux ?) (Laugerie ?) (Tursac ?)	Upper Pleniglacial
	LANTERNE II	Grand Bois {II I}			3	Middle Pleniglacial	Denekamp {II I} (=Arcy Kesselt) Hengelo
		Stadial IV Charbon Stadial III Pile Stadial II Goulotte Stadial I	Moershoofd "complex"	Moershoofd "complex"			
LAST INTERGLACIAL INTERVAL	LANTERNE I	Ognon III Stadial III Ognon II Stadial II Ognon I Stadial I	4	Early Glacial (= Early Weichselian)	Odderade	NEW	Brörup Amersfoort } 1
		a					
	St. Germain II Melisey II St. Germain I-C St. Germain I-B (= Montaignu) St. Germain I-A Melisey I	5	NEW	Early Glacial (= Early Weichselian)	Odderade Brörup Amersfoort } 1		
						b	
						c	
d							
Eemian S.S.	e	Eemian	Eemian				
LINEXERT		6	WARTHE (SAALIAN)		WARTHE (SAALIAN)		

Fig. 3

Complete Grande Pile sequence from the end of the Saalian Glaciation to the Holocene. This pollen diagram is established with three cores : core X for the lower part, core XIV for the middle part, and core I for the Holocene. Cores X and XIV were taken from the same place of the bog, while core I was taken 300 m away, close to the sites II and III (see Figs. 1 and 2). There is no hiatus between 1,250 cm (core X) and 1,200 cm (core XIV); the difference of 50 cm in depth is only due to the difference between the two boring surfaces chosen as 0 cm. Between 450 cm (core XIV) and 310 cm (core I) some material is lost as it is seen in the upper levels of core X (Fig. 2) and of core II (see in Fig. 1 the relationship between the upper levels of the cores II, X and XIV).

The biostratigraphy is based on the pollen zones ; local names are used except for the Eemian and the Holocene. The pollen diagram contains 268 levels in total, at which 200 to 500 pollen grains were counted. Percentages were based on the total pollen grains sum including AP (arboreal pollen + shrubs) and NAP (non arboreal pollen + spores of ferns : *Isoetes* was excluded). 119 pollen types were recognized; they are arranged here in 14 groups of trees (1 to 14 from the left) and 7 groups of herbs (1 to 7 from the right). "*Quercetum-Mixtum*" groups *Quercus* + *Ulmus* + *Fraxinus* + *Tilia* + *Acer* + *Prunus*.

(3) "Other trees" and "Other herbs" represent all the pollens of trees or herbs in insufficient percentages to be drawn. *Buxus*, in a continuous curve of 1 to 3,5 % in the upper Eemian, is rare in St. Germain I and II, and absent during the Holocene. *Taxus*, important in the lower Eemian, is rare in St. Germain I and II, and reappears during the Holocene at the end of the Atlantic (1 to 2% non represented in the figure). *Abies*, important during the upper Eemian, is rare in St-Germain I and II, and reappears in a continuous curve of 1 to 2% (non represented in the figure), with *Fagus*, during the Holocene, in the Subatlantic. The column "climatic trend" is based on the variations in pollen assemblage (see also comments of Fig. 2) :

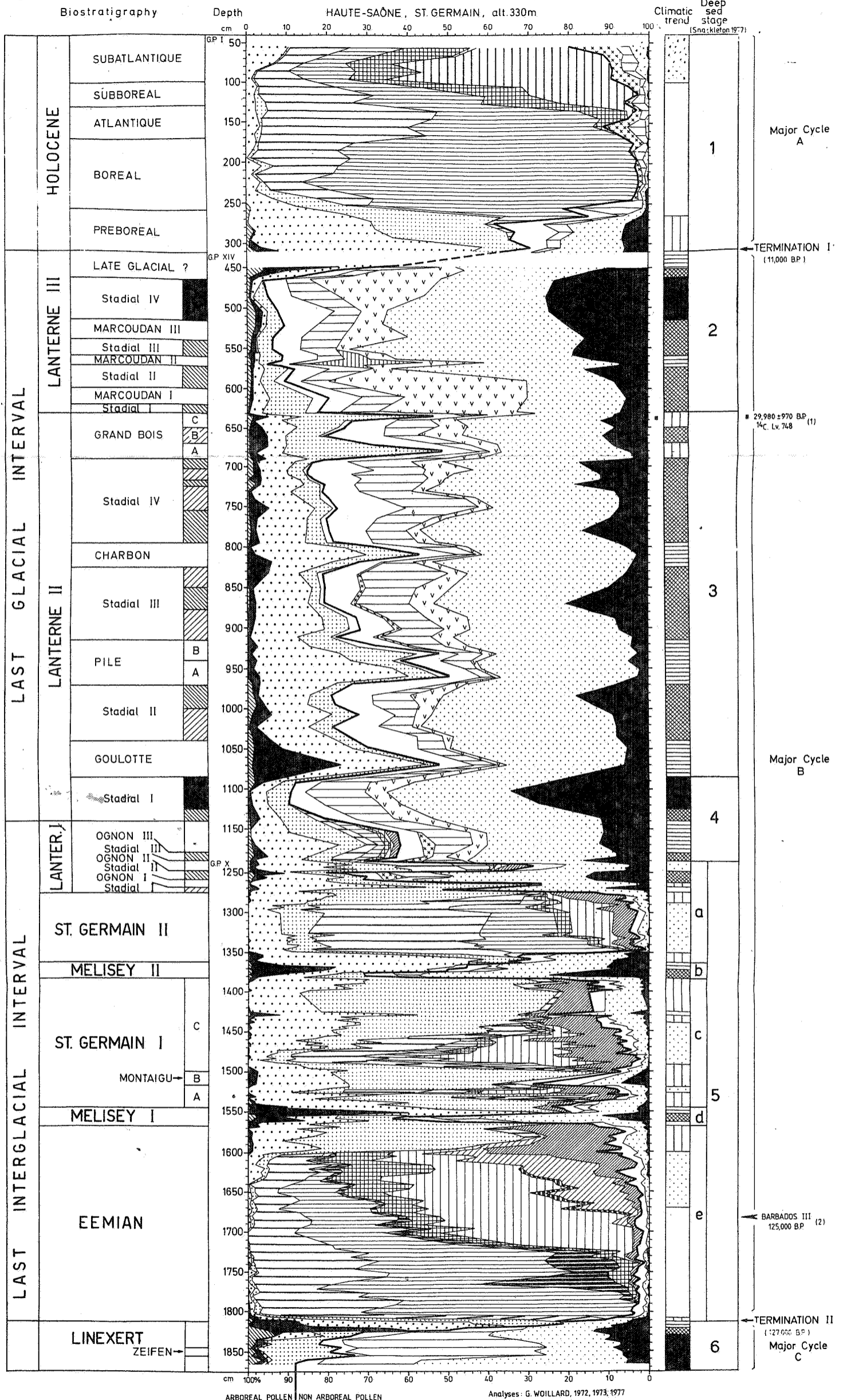
- 1 - (very cold) : absolute dominance of NAP, with a maximum in the curves of *Artemisia*, *Thalictrum*, *Helianthemum* and *Chenopodiaceae* (= groupe 1);
- 2 - (cold) : dominance of NAP, with a lot of shrubs (*Salix*, *Juniperus*, *Betula*); "cold ++" : *Artemisia* more important than *Juniperus*; "cold +" : *Artemisia* less (or equal) important than *Juniperus*;
- 3 - (medium cold) : NAP = 50 %, AP = 50 % (shrubs, *Betula*, *Pinus*);
- 4 - (medium warm) : dominance of AP : boreal forest (*Betula*, *Pinus*; *Picea*);
- 5 - (warm) : absolute dominance of AP : hardwood trees more important than coniferous trees;
- 6 - (very warm) absolute dominance of AP : hardwood forest.

Deep-sea stages are after EMILIANI and SHACKLETON (1974), SHACKLETON 1969, 1977b), SHACKLETON and OPDYKE (1973) (see Fig. 4); Major Climatic Cycles A-B-C are after KUKLA (1970) and RUDDIMAN and McINTYRE (1976); Terminations I and II are after BROECKER and van DONK (1970).

- (1) The ¹⁴C date of 29,980 ± 970 yr. BP (Lv. 748) (WOLLARD 1975, 1978) was obtained on the profile Grande Pile X (see Fig. 2).
- (2) Barbados III terrace (125,000 BP) is correlated with the substage 5e by SHACKLETON and MATTHEWS (1977), and thus is also correlated with the Eemian interglacial of Grande Pile (see Fig. 4).

Fig. 3

GRANDE PILE Pollen Diagram



- | | | | | | | | | | | | | | | | | | | | |
|---------------------|-----------|------------|------------|------------------|--|-----------|-------|-------------|-------------|-------|-----------|-----------|-----------------|----------------|-------------|-------------|-------------|------|-----------|
| Arboreal Pollen | | | | | | | | | | | | | | Climatic Trend | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 1 | 2 | 3 | 4 | 5 | 6 |
| SALIX | JUNIPERUS | BETULA | PINUS | QUERCETUM MIXTUM | CORYLUS | TAXUS | ALNUS | CARPINUS | FAGUS | BUXUS | ABIES | PICEA | Other trees (3) | VERY COLD | COLD | MEDIUM COLD | MEDIUM WARM | WARM | VERY WARM |
| Non Arboreal Pollen | | | | | | | | | | | | | | Climatic Trend | | | | | |
| 8 | 5 | 4 | 3 | 2 | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | | |
| POTAMOGETON | ERICALES | CYPERACEAE | BATRACHIUM | GRAMINEAE | ARTEMISIA + THALICTRUM + HELIANTHEMUM + CHENOPODIACEAE | VERY COLD | COLD | MEDIUM COLD | MEDIUM WARM | WARM | VERY WARM | VERY COLD | COLD | MEDIUM COLD | MEDIUM WARM | WARM | VERY WARM | | |

are also valid for other diagrams of the same area, published before (WOILLARD, 1975) :

- Grand Chemin I (47°52'13"N, 6°39'34"E, 680-m altitude),
- Machey II (48°00'24"N, 6°57'48"E, 993-m altitude),
- Etang du Boffy (47°48'49"N, 6°39'14"E, 540-m altitude),
- Grands Prés I (47°48'41"N, 6°35'34"E, 460-m altitude).

In these diagrams the following changes are to be made :

- Preboreal A1 = Bölling ?
- Preboreal A2 = Alleröd
- Preboreal B = Younger Dryas
- Preboreal C, D, E = Preboreal.

Thus, it is noteworthy that the start of the Late Glacial in the Vosges is likely indicated by the very high values of *Juniperus* (20 to 45%) immediately following the last predominantly cold of the Last Glaciation (Lanterne III, Stadial IV at Grande Pile).

The Grande Pile sequence ends with a typical pollen profile for the Holocene warm period, subdivided into the characteristic zones : Preboreal, Boreal, Atlantic, Subboreal and Subatlantic (Fig. 3).

CONCLUSIONS.

We can conclude from the present synthesis that the continuous Grande Pile pollen profile constitutes a very good example of the climatic fluctuations characteristic of the last interglacial-glacial cycle, that is, of the last 140,000 years. Although discussions over the correlations with the Northwestern European stratigraphical sequence remain, we can firmly establish, even in detail, a good agreement between our data and those obtained in the deep-sea records. It is obvious that the difficulties encountered in continental correlations are chiefly due to the number of record fragments and the scarcity of continuous sequences (even their absence in Northern Europe). However, the available data from Grande Pile give us the solution of some problems :

- The classical Eemian interglacial must be correlated with the oxygen isotope substage 5e (125,000 yr. BP) only, and not with the whole stage 5;
- Although it is as yet still impossible to fix the absolute age of the oxygen isotope stage 4 (53,000 or 75,000 yr. BP), it must be correlated with the Lower Pleniglacial, and not with one of the cold periods between the Eemian and the Lower Pleniglacial, like Melisey I or Melisey II at Grande Pile;
- The limit "Last Interglacial-Last Glacial" depends on the definition of an interglacial period. At Grande Pile the three interglacials Bemian, St. Germain I and St. Germain II, form together the Last Interglacial Interval, that is the whole stage 5, within which the Bemian (= substage 5e) is likely the Last Interglacial in a more strict sense, that is, the last time as warm at least as the present interglacial climatic optimum.
- The Middle Pleniglacial, characterized by three well-marked interstadials, is completely and clearly observed for the first time in a same pollen diagram.

But a major problem remains to be solved : the definite correlation between St. Germain I, II interglacials, Ognon I, II, III interstadials from Grande Pile and the Northwestern European stratigraphy. Where lies the Early Weichselian at Grande Pile ? As yet, we can only demonstrate that it is contained in the oxygen isotope stage 5, and lies between the substage 5e (= Eemian) and the predominant cooling of stage 4 (= Lower Pleniglacial). It seems being two possible correlations : either the upper part of substage 5a and the lower part of stage 4 (= Ognon I, II, III) (correlation which is preferred), either substages 5d, 5c, 5b and the lower part of

substage 5a (Melisey I, St. Germain I, Melisey II, St. Germain II); but three of the six warmings do not occur in the general stratigraphy of Northern Europe. The answer to that question is absolutely necessary to progress in the Late Pleistocene stratigraphy.

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SESSION EXTRAORDINAIRE 1978

de la Société belge de Géologie et de la Société géologique de Belgique, tenue dans le Grand-Duché de Luxembourg, les 22-23 et 24 septembre 1978.

NOTE COMPLEMENTAIRE (*)

Lors de la Session Extraordinaire organisée au Grand-Duché de Luxembourg en 1978, Mr. BINTZ, Directeur du Service Géologique de Luxembourg, nous fit découvrir entre autres, la carrière de Walch à Bettendorf.

Là, les excursionnistes ont longuement examiné des structures sédimentaires particulières appelées "cratères" (voir Bull. Soc. belge de Géol., 87, pp. 195, 1978). De nombreuses hypothèses furent émises quant à l'origine de ces cratères d'un diamètre de 15 à 20 cm et visibles sur la face supérieure d'un banc dolomitique du Groupe de la Lettenkohle (Keuper inférieur).

Une nouvelle hypothèse vient d'être émise par ULF BAYER, dans le *News Jahrbuch für Geologie und Paläontologie, Monastshäfte, Jahrgang 1979, Heft 4, pp. 193-200* - dans un article intitulé "A diagenetic deformation pattern of algal mats" et je crois utile d'en extraire le passage suivant, à l'intention de nos membres :

"The form of the dikes and the textural differentiation allow another genetic explanation. The craters resulted from cryptalgal stromatoliths and the patches of dolomitized mudstone have to be classified as typical bindstone. The space between the stromatoliths was filled by ooids and small onkoids which led to a washed grainstone. Desiccation and dolomitisation of the algal mat then caused cracks as well as the fenestral fabric inside the stromatoliths. Finally, "the craters" were formed from the cracks under compaction".

(*) note recueillie par E. GROESSENS, Service Géologique de Belgique.

