

THE LAST INTERGLACIAL-GLACIAL CYCLE: STATE OF AFFAIRS OF CORRELATION BETWEEN DATA OBTAINED FROM THE LAND AND FROM THE OCEAN

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ABSTRACT

An attempt is made to evaluate the state of affairs of correlation of deep sea curves, long palynological sequences in terrestrial deposits and the stratigraphical sequence in NW Europe. There seems to be little doubt about the correlation within the reach of normal ¹⁴C dating (approximately covering the last 50,000 years), corresponding with oxygen isotope stages 1, 2 and, at least partly, with 3. If the indirect dating of the temperature minimum of stage 4 as approx. 70,000 B.P. is correct, a correlation with the Lower Pleniglacial becomes less probable and a correlation with one of the cold phases in the Early Weichselian much more likely. In that case, at least as the Macedonian region is concerned, a correlation of stage 4 with the dry phase between the Drama and Elevation intervals seems to be the most probable.

INTRODUCTION

Until recently continuous pollen sequences from lake sediments or peat representing the entire Last Interglacial - Last Glacial - Holocene sequence were virtually unknown. The (chrono)stratigraphic sequence of NW Europe was relatively well-known. It was gradually construed by correlating partly overlapping sequences of sand and peat layers by means of pollen analysis and other stratigraphic criteria. Exposures in sediments from the last 50,000 years are frequent and with the aid of many ¹⁴C datings, the NW European temperature curve for the last 50,000 years became a relatively well-established one.

In the part of the sequence older than 50,000 years exposures are scarce, so that only the stratigraphical and pollen-analytical criteria could be used. Nevertheless the sequence from Eemian and Early Weichselian time could be established, apparently beyond reasonable doubt, and this part was added to the curve. Accurate dating of this part was impossible, however, and only tentative estimates could be made, based on a comparison with Emiliani's oxygen isotope curves (van der Hammen, et al., 1967).

From both Colombia and Greece continuous or almost continuous pollen diagrams for the last cycle are now avail-

able, however. Another, similar section has been recorded from Lake Biwa, Japan (Horie, 1974), but it seemed a little premature to use the recorded data, no ¹⁴C datings being as yet available. These types of continuous pollen diagrams are the only ones that may be directly compared with the deep sea curves based on a changing foraminiferal fauna, on oxygen isotopes, etc. For most of the deep sea curves the authors have given a time scale, partly based on direct dating and interpolation, partly on indirect criteria. For the pollen diagrams, ¹⁴C dating and extrapolation beyond the 50,000 limit are available. Using these independent scales, a direct comparison becomes interesting and this is certainly more rewarding than the simple matching of curves.

In the following we will deal shortly with the different diagrams and some representative deep sea curves and their dating. Subsequently the possibility of correlation will be assessed. Finally an attempt will be made to pin-point the problems that have to be solved before more reliable correlation of the continuous curves with the NW European (chrono)stratigraphical sequence can be accomplished.

THE SEQUENCE IN GREECE (MACEDONIA)

(figs. 1 and 2)

The pollen diagram of the last cycle is based on the analyses of 35 m of sediment from the Tenagi Philippon (Wijmstra, 1969; van der Hammen, Wijmstra, Zagwijn, 1971). The diagram shows changes between forest and steppe, basically, therefore, indicating changes of humidity. For the last 50,000 years ¹⁴C dating proved the coevality of the intervals with relatively high percentages of forest elements with the relatively warm intervals in NW Europe, and of those with relatively high percentages of steppe elements with colder intervals. We will accept, therefore, that the same holds for the lower half of the sequence. There are two very dry periods, judging by the high percentage of Chenopodiaceae as related to other herbs: at about 6.5-7 m and 23.5 m depth, corresponding with the period between the Philippi and Xanti intervals, and that between the Drama and Elevation intervals, respective-

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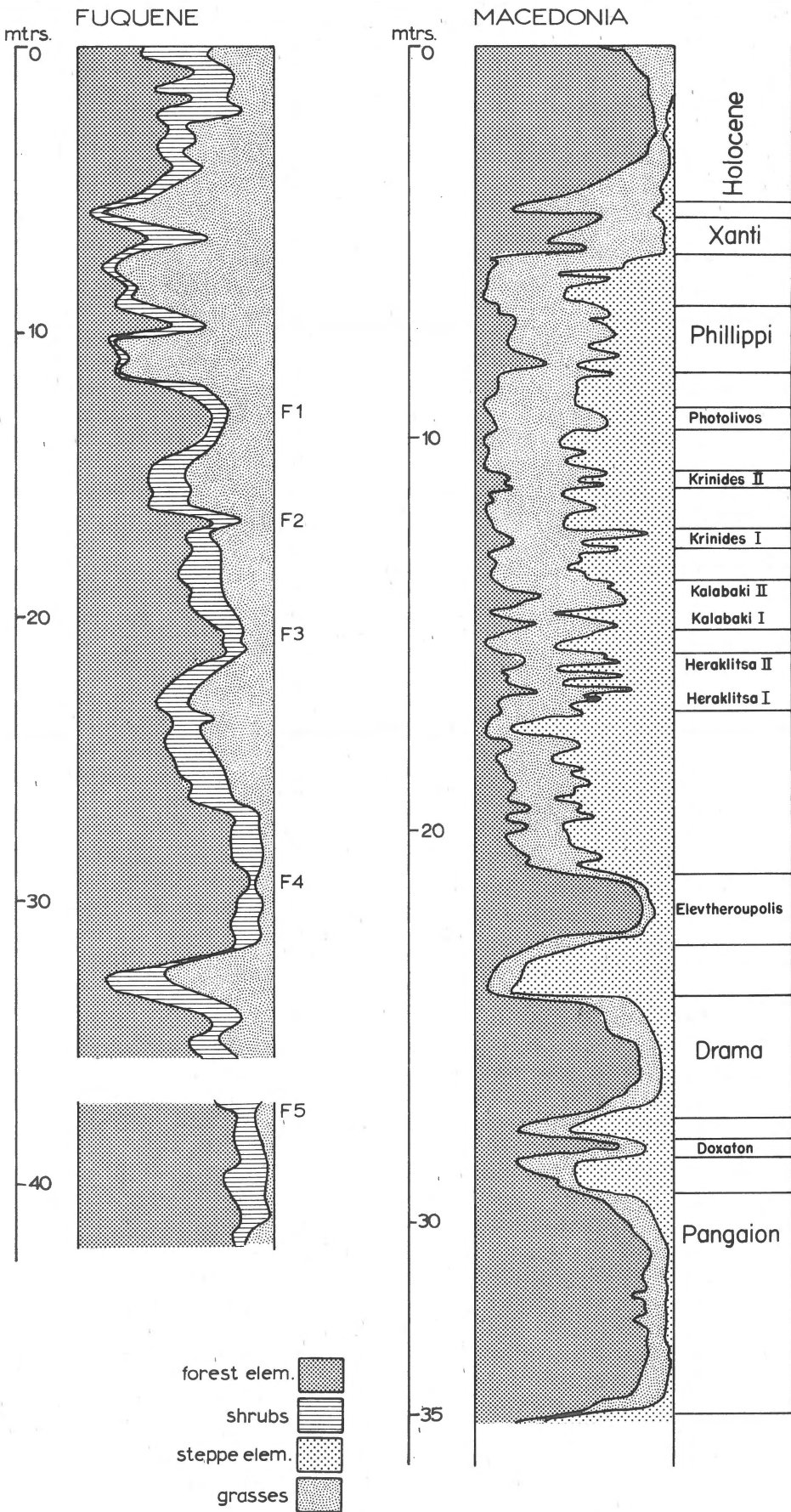


Fig. 1
Pollen diagrams of ca. 43 m of the sequence of Lake Fuquene (Cordillera Oriental, Colombia, alt. ca. 2,600 m) and ca. 35 of the Tenaghi Philippon (Macedonia, Greece, alt. ca. 50 m).

ly. Another relatively drier period seems to be present around 13 m. Because of the ^{14}C dating, there can be little doubt about the correlation of the Heraklitsa interval with the Moershoofd-interstadial, of Kalabaki with Hengelo, of Krinides with Denekamp and of Philippi with Lascaux. Tentative approximations of the ages of parts of the lower half of the section by extrapolation yield the following results: ca. 70,000 years for the top of the Drama, and ca. 110,000 years for the base of the Pangaion (van der Hammen, Wijmstra, Zagwijn, 1971). However, in the type of sediment we are dealing with (peat and organic lake sediments), an increasing compaction may be expected with increasing depth. If, in order to reduce this factor as far as possible, only the older ^{14}C dates are used, slightly older ages are found (e.g., ca. 74,000 years for the top of the Drama and ca. 115,000 years for the base of Pangaion; see fig. 2). In view of the probable increasing compaction these, at least the lower ones, represent minimum values. According to the time scale given in fig. 2, Eleutheropolis could have an age between 62,000 and 70,000, Drama between 74,000 and 85,000 and Pangaion between 92,000 and 115,000 years.

THE SEQUENCE IN COLOMBIA (FUQUENE)

(figs. 1 and 2)

Lake Fuquene, situated at ca. 2,600 m alt. in the Eastern Cordillera of Colombia, provided us already with a fine sequence for approximately the last 30,000 years (section Fuquene II: van Geel, van der Hammen, 1973). We tried to combine this section with the upper part of the deep section Bogotá (CUX), where there seemed to be a slowdown of sedimentation (or a hiatus) from about 30,000 to about 10,000 B.P. (Van der Hammen et al., 1971). Apart from the ^{14}C dates at the top, no other dates were available, however, and the correlation had to remain tentative only. Recently we obtained a more than 45 m deep core from lake Fuquene of which the first results (analysis by Mr. G.W. Noldus of our laboratory) are now available. The sample distance of this diagram is still rather large: 50 cm. The diagram (fig. 1) shows displacements of the vegetation zones (especially forest limit) mainly caused by changes in temperature. The upper 11 m of the section can be readily correlated with the Fuquene II section that provided material for two ^{14}C dates (approx. 10,820 and 20,575 B.P.: see van Geel & van der Hammen, 1973). The characteristic, absolute maximum of *Polylepis* is found in both sections at 11.5 m and, therefore, the average rate of sedimentation for the upper 11.5 m is the same. Between ca. 6 and 12 m there is an extremely cold phase corresponding in time to the maximum of the Last Glacial. Using a rate of sedimentation of ca. 4.5 m in 10,000 years, we find by extrapolation the following dates for the interstadial-like fluctuations below this very cold interval

F1 : ca. 27,000 - 33,000 B.P.
 F2 : ca. 37,000 - 39,000 B.P.
 F3 : ca. 45,000 - 50,000 B.P.
 F4 : ca. 59,000 - 71,000 B.P.
 F5 : ca. 74,000 - B.P.

Being an extrapolation over a long part of the section, this by itself does not provide cogent proof. There is, however, certainty about the age of some very similar intervals in the Sabana de Bogotá. These are the following:

- 1 - Interstadial peat layer under fluvioglacial gravels near Zipaquirá, comparable in its temperature range with interstadial F1: $27,905 \pm 410$ (GrN 5836) and $32,890 \pm 660$ (GrN 5838).
- 2 - Layer of humic clay of interstadial character, above fluvio-glacial gravel, near Tabio: $39,650 \pm \begin{matrix} 1.050 \\ 950 \end{matrix}$ (GrN 6002)
- 3 - Immediately below the lower limit of an interstadial of comparable character as F3, from the El Abra valley: $50,720 \pm \begin{matrix} 4.100 \\ 2.700 \end{matrix}$ (GrN 6548).

These data seem to corroborate the correctness of the ages by extrapolation in the deep Fuquene section. We will indicate these intervals provisionally as F(uquene) 1, 2, 3, 4 and 5 (see above). It must be pointed out that there is a conspicuous, relatively short temperature minimum between F4 and F5. The possible age (by extrapolation) of this minimum is slightly older than 70,000 B.P.

Specially dry periods marked by low lake levels are evident during the cold Fuquene stadial (shortly after 20,000 B.P.), immediately above interval F2, during the temperature minimum between intervals F4 and F5, and possibly during a part of F4.

OCEAN CURVES BASED ON FORAMINIFERAL FAUNA AND OXYGEN ISOTOPES

(fig. 2)

Recently a considerable number of curves based on quantitative faunal analysis, carbonate content, oxygen isotopes etc. of deep sea cores have been published. In fig. 2 we have added 5 of these ocean curves. The first (borrowed from Sancetta, Imbrie & Kipp, 1974) is based on quantitative palaeo-environmental analysis of a North Atlantic core and gives summer temperatures of surface water. The "absolute" chronology is estimated by linear interpolation between levels dated by ^{14}C or by stratigraphic correlation with other radiometrically-dated climatic records. In this chronology the beginning of the "last interglacial" lies at approx. 125,000, a minor temperature minimum at 110,000, a severe cooling at 73,000 and three short warm intervals at 59,000, 48,000 and 31,000 B.P. Strongly in favour of this chronology (in fact it is partly based on it) is

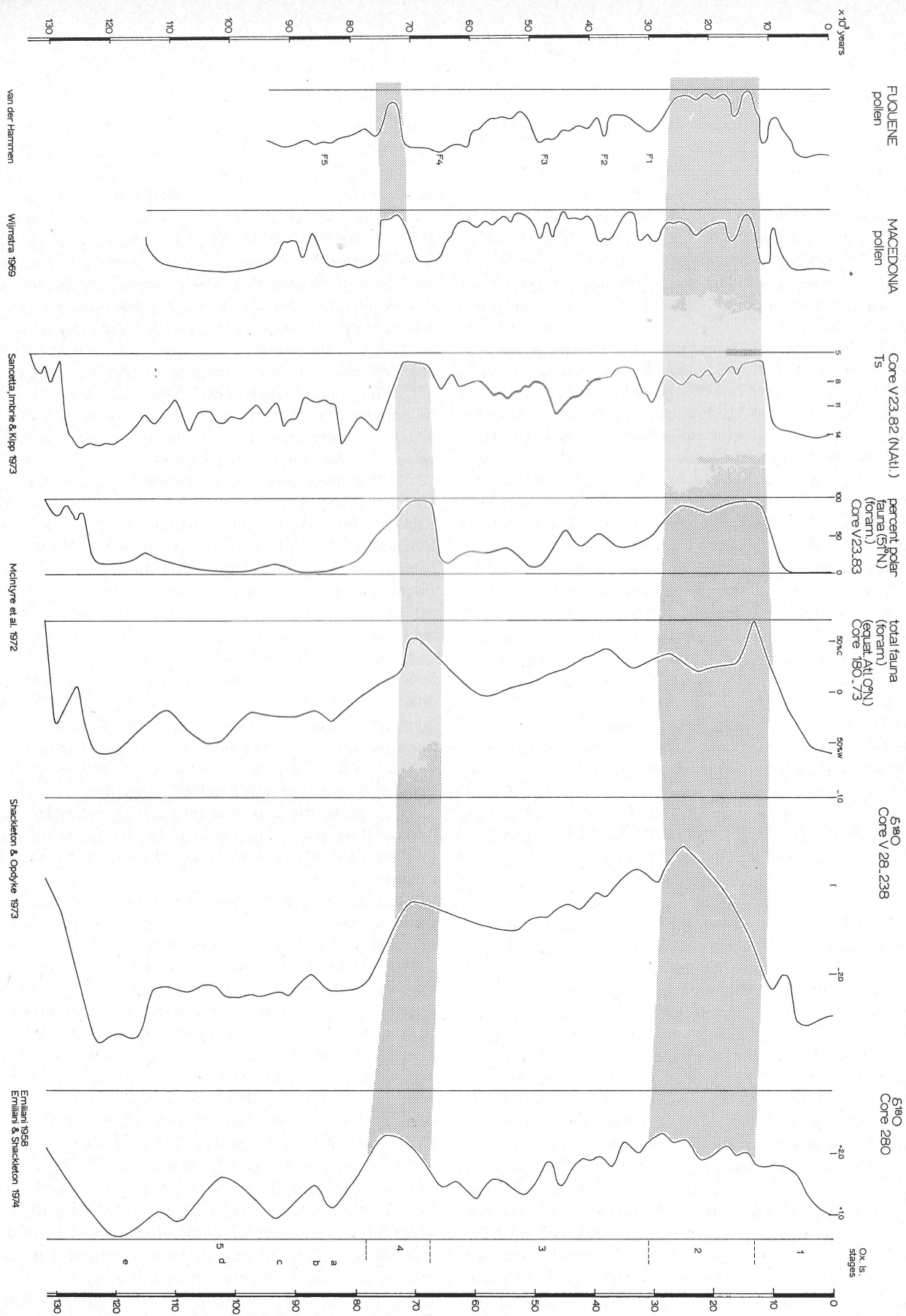


Fig. 2. Attempt of correlation of curves from land and ocean. All diagrams are drawn with the time scale as given by the original authors. The first two curves are from land (deduced from the pollen diagrams of fig. 1). The first one (from Fuquene) shows the percentage of tree pollen versus non-arboreal pollen (the total amplitude being 100%), interpreted as fluctuations of the tree line. The one from Macedonia equally shows the percentage of arboreal pollen versus non-arboreal pollen (total amplitude being 100%), interpreted as indicating the combined effect of temperature and rainfall. The other curves are from the ocean, based on variations in the foraminiferal fauna (Ts is summer temperature) or oxygen isotope data. The oxygen isotope stage numbers (or sub-stages respectively) are indicated.

the age of the Barbados terraces, between 124,000 and 81,000 B.P.

Next we give two curves from McIntyre, Ruddiman & Jantzen, 1972, directly based on changes in the foraminiferal fauna. They use the same chronology and their most obvious conclusions are: the long warm "interglacial", a marked minimum (maximum of cold fauna) around 70,000 years, followed by a strong rise and a gradually sloping down to the minimum around 18,000, and finally, a steep rise around 11,000 B.P.

The following two curves are oxygen isotope curves from Emiliani (1958), Emiliani & Shackleton (1974) and Shackleton & Opdyke (1973), the equatorial Pacific and North Atlantic, respectively. They are basically ice-volume curves and, hence, are easily correlated all over the oceans. Here again, the same time scale is used. The oxygen isotope stage numbers are added: 1 corresponds doubtlessly with the Holocene, 2 is the minimum around 18,000, 3 is the maximum of the "saw-tooth" in the middle of the "last glacial", 4 is the sharp and short minimum (here dated shortly before 70,000), and 5 is the maximum of the "last interglacial". It may be subdivided into substages a (max.), b (min.), c (max.), d (min.) and e (absolute maximum). The same division (warm and cool) can be seen in many of the faunal curves (fig. 2). Because of the possibilities of their universal use, the oxygen isotope stages are most important for correlation all over the oceans. There is very little doubt about their sequence and, for that reason, as far as the correlation between land and ocean is concerned, form the most convenient reference.

CORRELATION OF THE CONTINUOUS SECTIONS FROM LAND AND OCEAN (fig. 2)

There is little doubt about the correlation of the different kinds of ocean curves over most of the world, at least for the last "interglacial-glacial" cycle. Stages 1 to 5 or their equivalents may be recognized in almost every curve. The problem of the age of stages 4 and 5 is principally determined by the age of the temperature maximum of stage 5 (substage 5e). The existing doubt and possibilities are summarized in Emiliani & Shackleton, 1974. It depends whether one accepts the results of $^{18}\text{O}/^{16}\text{O}$ measurements and $^{230}\text{Th}/^{234}\text{U}$ of speleothems from France and West Virginia placing the temperature maximum at 100,000 B.P. (time scale E), or the age of the Bahama terraces and others in the world of ca. 125,000 as indicative of the highest sea level during the "last interglacial". This last date agrees with the date obtained by interpolation in Pacific core V28-238, accepting constant rate of sedimentation since the Brunhes-Matuyama boundary. Reviewing all the possibilities it is clear that the temperature minimum of the oxygen isotope stage 4 must in any event be older than 60,000 and younger than 75,000 B.P. However, there seem

to be more data pleading in favour of a date slightly older than 70,000. Similarly, the minimum for stage 5e is 100,000 and the maximum ca. 130,000. Most workers now seem to prefer a date of about 125,000. There is no doubt about the age of the temperature minimum of stage 2; it is generally placed around 18,000 B.P. Stage 1 begins at ca. 11,000 B.P. Stage 3 may show a number of minor maxima and minima, the highest lying immediately after stage 4. Its minimum age should, therefore, be near to 60,000, but more probably it will be nearer to 70,000 or very shortly before that time.

If we now turn to our two continuous curves from Greece and Colombia with their independent time scale (based on ^{14}C dating and extrapolation), it seems that they can easily be correlated with each other (fig. 2). There is no doubt about the correlation (by ^{14}C dating) of the last 30,000 years. For the three "interstadials" between 30,000 and 50,000 B.P. there seems to be reasonable evidence that they are contemporaneous (Fuquene 1 would correspond with Krinides, Fuquene 2 with Kalabaki and Fuquene 3 with Heraklitsa); the ^{14}C evidence is, however, indirect (via Sabana de Bogotá). If this correlation is correct, then Fuquene 4 would correspond with Elevationopolis; the extrapolation resulted for both in an age of somewhere between ca. 60,000 and 70,000 B.P. Both are very conspicuous intervals and they are both preceded by a remarkably deep and steep minimum of the curves. This phase is in Fuquene very cold and very dry and in Philippi it represents one of the driest intervals. This may be significant, since the other very dry interval lies between 20,000 and 14,000 in both sequence, the third somewhere between Fuquene 1 and 2 and near Krinides, respectively.

In Fuquene the sequence ends in the next older warm interval (F5) and no further correlation can be suggested than with the upper part of the complex Drama-Doxaton-Pangaion.

Although no definite proof exists on the correlation of the lower half of the two sections, there is no doubt that the similarity of the curves is most suggestive.

If we now compare and try to correlate the curves from the ocean with those from land (fig. 2), it will be evident that there is no doubt about the correlation of the upper ca. 30,000 years, directly substantiated by ^{14}C determinations. Stage 1 is the Holocene of the continents and stage 2 is the last major temperature minimum or drought in the curves from land. Similarly, there seems to be no doubt that Krinides, Kalabaki and Heraklitsa and three corresponding interstadials of the same ages in Colombia, fall within stage 3. Their age is between ca. 30,000 and 50,000 B.P. A much greater uncertainty about the correlation starts below this level. The indirect time scales of the curves seem to be in favour of a correlation of Elevationopolis and Fuquene 4 with the lower part of stage 3. This lower part is in most ocean curves the "warmest" part of this stage, the curve having the form of a saw tooth. The same form is evident in Fuquene, and in Macedonia the Elevationopolis is at least wetter and warmer than the later three interstadials. The

TABLE I

Two possibilities of correlation of the stratigraphic sequence in NW Europe and the pollen sequence in Macedonia with the oxygen isotope stages. The Early Weichselian has not been subdivided here to emphasize that in the second possible correlation, stage 4 might correspond with any of the cold phases of this interval.

NW Europe		Oxygen isotope stages		Macedonia
Holocene		1	1	Holocene 1
Late Glacial				
Pleniglacial	Upper	2	2	
	Middle	3	3	Krinides
				Kalabaki
	Lower	4	3	Heraklitsa
Early Weichselian		5	4	Elevtheroupolis
				Drama
				Doxaton
Eemian			5	Pangaion

indirect time scales and the form of the curves seem to be very suggestive of a correlation of the temperature minimum of oxygen isotope stage 4 with the sharp minimum between Fuquene 4 and 5 and the marked dry period between Elevtheroupolis and Drama. If these correlations are correct, oxygen isotope stage 5 would correspond with the entire interval Drama-Doxaton-Pangaion. That 5e, the absolute maximum of temperature, would correspond with (possibly only with the basal part of) the Pangaion, seems inevitable. The extrapolation gives an age of ca. 115,000 B.P. for the base of Pangaion, while an age shortly after 130,000 is suggested by the ocean curves. The difference might be caused by an increase of compaction with depth in the material from Macedonia (see above). However, at a first glance the comparison of the Philippi diagram and the oxygen isotope curves strongly suggests the correlation of the entire stage 5 (with its three maxima) with the total of Elevtheroupolis to Pangaion inclusive. This is not in agreement with the first possible correlation, mentioned above. As in this interval between ca. 60,000 and 130,000 no direct (absolute) dates are available, the matter of correlation of this part cannot yet be solved conclusively.

The basic question that has to be answered is the most

likely time equivalent on land of oxygen isotope stage 4. The answer may be e.g., the dry phase between Drama and Elevtheroupolis, as suggested by fig. 2. If, however, stage 4 would not be 70,000 years B.P. old but nearer 60,000 years, a correlation with the dry phase between Heraklitsa and Elevtheroupolis would become more probable.

CORRELATION WITH THE NW EUROPEAN STRATIGRAPHICAL SEQUENCE (table I)

The NW European sequence (van der Hammen et al., 1967; van der Hammen, Wijmstra & Zagwijn, 1971) is rather well known and includes a number of classical units, such as the Eemian.

The warmer phases from the last 50,000 years are well dated by ^{14}C and include the Holocene, the Late-glacial interstadials and the Denekamp, Hengelo and Moershoofd interstadials. There is no doubt that the extreme cold period with large frost wedges and cracks (the Upper Pleniglacial), registered between the Late-glacial and the Denekamp interstadial, corresponds to oxygen isotope stage 2.

The interstadials of Denekamp (ca. 29,000-33,000 B.P.), Hengelo (ca. 37,000-39,000) and Moershoofd (ca. 45,000-

50,000) are well dated by ^{14}C (van der Hammen & Wijmstra, 1971; Zagwijn & Paepe, 1968; Zagwijn, 1974) and correspond approximately to Krinides, Kalabaki and Heraklitsa from Macedonia and three interstadials from Colombia. All three correspond to oxygen isotope stage 3.

Below the Moershoofd interstadial a cold interval with frost wedges (the Lower Pleniglacial) has been established, although the details are but little known.

Below the Lower Pleniglacial is the Early Weichselian and Eemian sequence, studied in detail by Zagwijn (1961) and others (see van der Hammen et al., 1971). There seem to have been, after the full interglacial Eemian, three relatively warm interstadials, Amersfoort, Brørup and Odderade, respectively. There are still some minor correlation problems and perhaps the three might eventually turn out to represent only two. Although few exposures have been available, it is known that a zone of krypturbation may occur between Amersfoort and Brørup (Zagwijn & Paepe, 1968).

The quite different and clearly warmer character of the Early Weichselian interstadials as compared with the Moershoofd, Hengelo and Denekamp interstadials, lead to the supposition that Eemian and Early Weichselian together might correspond to oxygen isotope stage 5 (van der Hammen et al., 1967). Similar reasons led to the supposition that they might also correspond with the sequence Pangaion-Drama-Elevtheroupolis (Wijmstra, 1969; van der Hammen et al., 1971). If the first correlation is right and the dating of the deep sea curves is correct, then the Odderade and earlier phases must be older than ca. 70,000 B.P. If the second correlation is right and the time scale given in fig. 2 is correct, then part of the Early Weichselian must be younger than 70,000 (approximately between 60 and 70,000 B.P.).

The existing doubt may be resumed as whether the temperature minimum of oxygen isotope stage 4 corresponds with the cold of the Lower Pleniglacial or with one of the cold periods in the Early Weichselian (like the one between Brørup and Amersfoort, or between Amersfoort and Eemian). Recently a number of ^{14}C dates by enrichment have been obtained from the Early Weichselian interstadials by Grootes. The dates obtained all lie between ca. 57,000 and 68,000 B.P. (Grootes, priv. comm.). This could mean that all (or a part) of the Early Weichselian is younger than stage 4 and would correspond with the lower part of stage 3.

CONCLUSIONS

Until further and more conclusive evidence will have been found, the matter of the exact correlation of the lower half of the last interglacial-glacial cycle cannot be solved definitely. The main questions to be answered are (see also table I):

- How old is oxygen isotope stage 4 (60,000 or 73,000)?
- Does the minimum of stage 4 correlate with the Lower Pleniglacial or with one of the cold periods of the Early Weichselian (like the one between Brørup and Amers-

foort, or between Amersfoort and Eemian)?

- Does the cold minimum of stage 4 correlate with the cold one between Heraklitsa and Elevtheroupolis or with the cold one between Elevtheroupolis and Drama?

The available data (see fig. 2 and the former paragraph) now seem to favour the second possibilities more, although the available evidence can by no means be called decisive. We now seem, however, to be very close to a more definite solution of the problem.

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REFERENCES

- Emiliani, C. (1958) – Paleotemperature analysis of core 280 and Pleistocene correlations. *Journ. Geol.* vol. 60, p. 201-214.
- Emiliani, C. & N.J. Shackleton (1974) – The Brunhes Epoch. Paleotemperatures and isotopic geochronology. *Science*, vol. 183, p. 511-514.
- Hammen, T. van der, G.C. Maarleveld, J.C. Vogel & W.H. Zagwijn (1967) – Stratigraphy, climatic succession and radiocarbon dating in the Last glacial in The Netherlands. *Geol. & Mijnb.*, vol. 46, p. 79-95.
- Hammen, T. van der & T.A. Wijmstra (editors) (1970) – The Upper Quaternary of the Dinkel valley. *Med. Rijks. Geol. Dienst, Haarlem, N.S. vol. 22*, p. 55-213.
- Hammen, T. van der, T.A. Wijmstra & W.H. Zagwijn (1971) – The floral record of the Late Cenozoic of Europe. In K.K. Turekian (editor): *The Late Cenozoic Glacial Ages*. New Haven & London, Yale Univ. Press.
- Horie, S. (editor) (1974) – Paleolimnology of Lake Biwa. *Contr. Paleolim. Lake Biwa and the Jap. Pleistocene no. 43*.
- McIntyre, A., W.F. Ruddiman & R. Jantzen (1972) – Southward penetrations of the North Atlantic Polar Front: faunal and floral evidence of large scale surface water mass movements over the last 225,000 years. *Deep sea research*, vol. 19, p. 61-77. Pergamon Press.
- Sancetta, C., J. Imbrie & N.G. Kipp (1974) – The climatic record of the past 140,000 years in North Atlantic deep sea core V 23-82; correlation with terrestrial record. *Climatic Research Unit (Norwich), R.P. 2*, p. 62-65.
- Shackleton, N.J. & N.D. Opdyke (1973) – Oxygen isotope and Palaeomagnetic stratigraphy of Equatorial Pacific core V 28-238: oxygen isotope temperatures and ice volumes on a 10^5 year and 10^6 year scale. *Journ. Quat. Res.*, vol. 3, 1, p. 39-55.
- Wijmstra, T.A. (1969) – Palynology of the first 30 metres of a 120 m deep section in Northern Greece. *Act. Bot. Neerl.*, vol. 18, 4.
- Zagwijn, W.H. & R. Paepe (1968) – Die Stratigraphie der weichselzeitlichen Ablagerungen der Niederlande und Belgiens. *Eiszeit- alter und Gegenwart*, vol. 19, p. 129-146.
- Zagwijn, W.H. (1961) – Vegetation, climate and radiocarbon datings in the Late Pleistocene of The Netherlands. Part I: Eemian and Early Weichselian. *Meded. Rijks. Geol. Dienst, N.S. 14*, p. 15-45.
- (1974) – Vegetation, climate and radiocarbon datings in the Late Pleistocene of The Netherlands. Part II: Middle Weichselian. *Meded. Rijks. Geol. Dienst, Haarlem*, in print.