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Cadre climatique pour la fin du Pléistocène et de l'Holocène : variations climatiques durant les 35 000 dernières années

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Résumé de l'article

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CLIMATIC FRAMEWORK OF THE END OF THE PLEISTOCENE AND THE HOLOGENE: PALEOCLIMATIC VARIATIONS DURING THE LAST 35,000 YEARS

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ABSTRACT Paleoclimatic changes are recorded by several methods. These fluctuations follow cycles of different rank and duration. Seen in a global scale, there can be little doubt that the climatic changes generally occurred simultaneously all over the globe. This does not mean that they are equally expressed; on the contrary, these changes are quite locally expressed. It is the coincidence in time that reveals the global climatic background. The Gothenburg Magnetic Excursion and Flip, characterized by Pacific VGP positions, provide a new tool for global correlations. The radiocarbon calibration scale is extended back at least to 10,000 BP via a new method based on shorelines and varves. Because of necessary good dating control, the present analysis is confined to the last 35,000 years. 1) Correlations of global climatic data indicate a worldwide synchronism without any detectable time-lag between different variables. 2) Climatic, glacial and eustatic fluctuations follow four main cycles: a 21,000-yr cycle, a 5250-yr cycle, an irregular 1000-3600-yr cycle, an irregular 230-1000-yr cycle. 3) Geoidal-eustasy is a new factor which is related to fundamental geophysical processes. 4) Integrated studies of multiple parameters in the same long Holocene sediment cores have revealed a detailed correlation between climatic changes, eustatic changes, paleomagnetic intensity and polarity changes, atmospheric ^{14}C production changes, etc, suggesting a mutual origin. 5) The main cause of the 5250-yr cycle and the two irregular cycles seems to be changes of the core/mantle coupling and interface according to two different systems. This explains the correlations established and the absence of any time-lag.

RÉSUMÉ *Cadre climatique pour la fin du Pléistocène et de l'Holocène: variations climatiques durant les 35 000 dernières années.* Différentes méthodes peuvent enregistrer les changements climatiques. Ces fluctuations suivent des cycles de durée et d'ordre différents. À l'échelle mondiale, il y a peu de doute que ces changements climatiques se produisent simultanément à travers le globe. Par contre, ils ne se traduisent pas de la même façon; au contraire, ces changements s'expriment différemment selon les endroits. La cause climatique commune et globale est plutôt révélée par la coïncidence chronologique. Pour des raisons de contrôle chronologique précis, l'analyse qui suit se limite aux 35 000 dernières années. 1) Les corrélations des données climatiques globales indiquent un synchronisme mondial sans décalage mesurable entre les différentes variables. 2) Les fluctuations climatiques, glaciaires et eustatiques suivent 4 cycles principaux: un cycle de 21 000 ans; un cycle de 5250 ans; un cycle irrégulier de 1000-3600 ans; un cycle irrégulier de 230-1000 ans. 3) Les anomalies eustatiques, par rapport au géoïde, constituent un nouvel élément lié aux processus géophysiques fondamentaux. 4) La compilation des multiples paramètres, provenant de carottes holocènes comparables, fait apparaître une corrélation très étroite entre les changements climatiques, eustatiques, les variations de la polarité et de l'intensité paléoclimatique, les changements dans la production du ^{14}C atmosphérique, etc.: le tout suggère une origine commune. 5) La cause principale du cycle de 5250 ans et des 2 cycles irréguliers réside apparemment dans les variations de l'interface et du couple noyau/manteau, ce qui expliquerait les corrélations et l'absence de retard dans le temps.

РЕЗЮМЕ ХАРАКТЕР КЛИМАТА В КОНЦЕ ПЛЕЙСТОЦЕНОВОГО И ВО ВРЕМЯ ГОЛОЦЕНОВОГО ПЕРИОДОВ: ПАЛЕОКЛИМАТИЧЕСКИЕ КОЛЕБАНИЯ ЗА ПОСЛЕДНИЕ 35 000 ЛЕТ. Палеоклиматические изменения могут быть установлены несколькими методами. Эти колебания климата носят циклический характер и отличаются друг от друга как по размерам, так и по продолжительности. Если говорить о глобальных масштабах, то нет почти никакого сомнения в том, что вообще климатические изменения происходят одновременно на всем земном шаре. Это, однако, не означает, что они везде одинаковы; наоборот, эти флуктуации носят весьма локальный характер. Важно то, что климат начинает меняться везде одновременно, так как это служит доказательством того, что эти изменения вызваны причинами глобального порядка. Готенбургский Магнитный Сдвиг и Поворот, характеризующийся тихоокеанскими Вертикальными Основными Точками, открывает новые возможности для установления глобальных корреляций. Радиуглеродная шкала калибрования может быть теперь использована для выяснения положения минимум 10 000 летней давности благодаря новому методу изучения береговых линий и ленточных глин. Считая необходимым пользоваться только надежной датировкой, мы в настоящее время ограничиваемся рассмотрением только того, что происходило за последние 35 тысяч лет. 1) Корреляции данных о глобальном климате дают основания предполагать наличие общемировой синхронности, без каких-либо заметных отставаний одних изменений от других. 2) Климатические, ледниковые и эвстатические колебания происходят по следующим четырем основным циклам: 21 000 летний цикл, 5 250 летний цикл и два с непостоянной продолжительностью. Один из них составляет от 1 000 до 3 600 лет, а другой от 230 до 1 000 лет. 3) Геоид-эвстазия является новым фактором связанным с геофизическими процессами. 4) Одновременно проводившееся изучение многих параметров длинных голоценовых кернов, позволило установить подробную корреляцию между климатическими и эвстатическими изменениями, палеомагнитной напряженностью и переменной полярностью, флуктуации в образовании углерода C-14 в атмосфере и так далее. Все это дает основания предполагать наличие одной общей причины для этих явлений. 5) Главной причиной для цикла в 5 250 лет и двух не регулярных циклов является, видимо, характер сочленения поверхности раздела между мантией и ядром согласно двум разным системам. Этим объясняется образование корреляций и отсутствие какого-либо отставания во времени.

GLOBAL AND INTERREGIONAL CORRELATIONS

I have spent a lot of time and effort on the study of the Weichselian-Wisconsin ice marginal fluctuations and global correlations (MÖRNER, 1969, 1970a, 1970b, 1971a, 1971b, 1971c, 1972a, 1972b, 1972c, 1973a, 1973b, 1974a; MÖRNER and DREIMANIS 1973). The correlations for the last 35,000 years are the most well founded ones because this period is the best known and best dated (MÖRNER, 1973b, 1974b). The original correlations for this period (MÖRNER, 1973b, Fig. 1) have recently been reinforced by paleomagnetic records (MÖRNER, 1974b; MÖRNER and LANSEK 1975).

These studies have led me to the following series of statements and conclusions (MÖRNER, 1976b):

- 1) Theoretically, the Wisconsin and Weichselian ice marginal fluctuations (stadial/interstadial) in North America and Europe, respectively, may have occurred: a) in phase; b) out of phase; c) opposite to each other.
- 2) Overwhelming data — especially those of high precision and coming from thoroughly studied areas — indicate that the Wisconsin and Weichselian ice marginal fluctuations occurred simultaneously: in phase.
- 3) If the great majority of the Wisconsin-Weichselian ice marginal fluctuations are caused by synchronous global climatic changes, the local expression and amplitude may vary considerably. Therefore, the date and nature of an ice marginal change are much more significant than the magnitude of the corresponding ice marginal fluctuation.
- 4) The general correlation between the Wisconsin and Weichselian ice marginal fluctuations must be considered fully proven. Even the correlations of the short-period climatic and ice marginal fluctuations seem well established.
- 5) I think it is time to accept the theory that the Wisconsin and Weichselian ice marginal fluctuations occurred more or less simultaneously, even in details. We should concentrate on better registration and refined dating of these climatic fluctuations, their cyclicity and geophysical explanation. Knowing the global climatic signals, the local response can be interpreted.

Figure 1 gives the correlation between the glacial records from Southern Scandinavia, the East Baltic region, the Erie-Ontario region and Washington State, and a comparison with the St. Lawrence region of Québec according to different alternative correlations.

There are two new aspects on correlations that should be emphasized: (a) the north-south correlations within the main ice caps, and (b) the effect of geoid changes on the supposed "eustatic" records.

The Laurentide and Fennoscandian ice caps both exhibit three major glaciation maxima during the Last Ice Age. The ice marginal fluctuations along the southern and northern margins of these ice caps were in phase though of reversed order of magnitude so that they record a continuous southward (southwestward in northern Europe and southward and westward in North America) displacement of the centers and distribution of glaciation during the Last Ice Age (MÖRNER, 1974a, 1976a, 1977a). This explains the sawtooth pattern of the O^{18} records from deep-sea cores (BROECKER and van DONK, 1970) where the first glaciation maximum is underrepresented due to its distribution more to the north. This aspect needs further studies and consideration.

I have recently brought up the question about geoid changes and their effect on eustasy (MÖRNER, 1975a, 1975b, 1976b). It was found that there are strong indications of cyclic geoid changes during the Late Quaternary. It was also concluded that, if this is correct, "eustatic" fluctuations cannot be used as *a priori* evidence of interglacials and glacials or major interstadials and stadials (MÖRNER, 1976b). This is a new aspect that must be considered as it may change old concepts quite drastically.

MAIN CLIMATIC PATTERN OF THE LAST 35,000 YEARS

With regards to necessary good dating control, it is only for the last 35,000 years or so that we have really detailed records that provide a basis for global correlations. Figure 2 shows correlations between land, sea and air data (MÖRNER, 1973a, 1974b). The main pattern seems to record a 10,500 yr half-cycle responsible for major cold and warm periods. A closer analysis of the short period climatic changes, especially those of the last 13,000 years, reveals two irregular cycles: Cycle A of 230-1000 yr and Cycle B of 1000-3600 yr. Further studies have established an additional cycle of about 5250 yr (MÖRNER and RICHARD, 1974; MÖRNER, 1976b, 1977c) in the eustatic rate, the main temperature changes, the archaeomagnetic intensity, the atmospheric ^{14}C production, the geoidal-eustatic changes.

THE GOTHENBURG MAGNETIC EXCURSION

The Gothenburg Magnetic Excursion (13,750-12,350 BP) ending with the Gothenburg Magnetic Flip at 12,400-12,350 BP is — in opposite to overlying and underlying periods — characterized by a Pacific VGP position with an equatorial Central Pacific VGP position during the Gothenburg Flip (Fig. 3). During the last years, the Gothenburg Excursion and Flip have been established in numerous cores and sections and serve as an excellent tool for global and interregional cor-

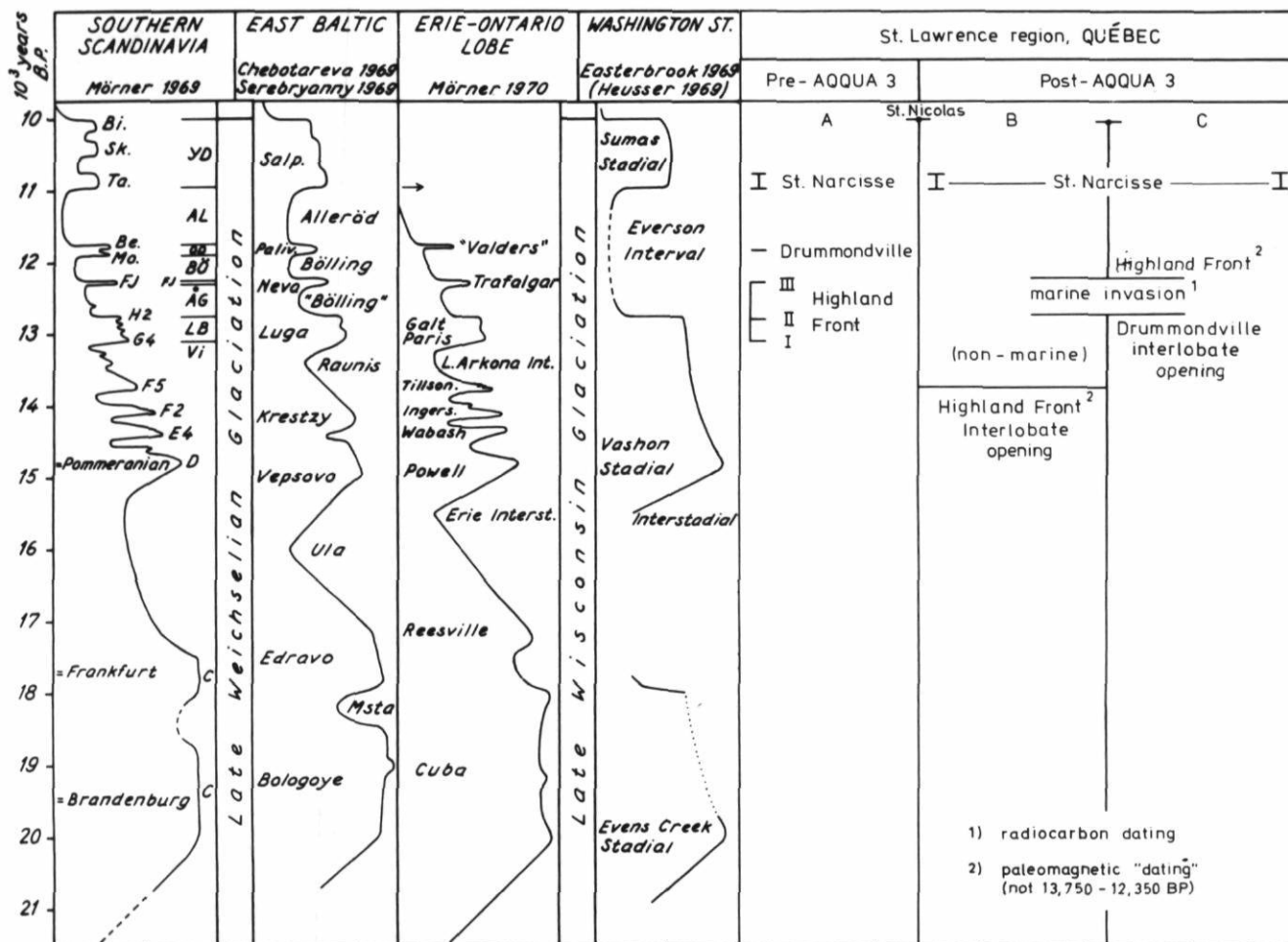


FIGURE 1. Correlation of ice marginal fluctuations in northern Europe and North America. The first four curves (from MÖRNER, 1970b, Fig. 1) exhibit detailed regional and inter-regional correlations, indicating that the fluctuations were in phase and consequently must have been triggered by global climatic changes. Columns 5-7 give the correlation of the deglaciation moraines in the St. Lawrence region, according partly to their original "pre-AQQUA 3" dates (A) and according partly to the new "post-AQQUA 3" data on the direction of ice movements and paleomagnetism (B-C). According to paleomagnetic data (MÖRNER, 1976c) the Highland Front Moraine system should either be older (B) or younger (C) than 13,750-12,350 BP.

relations. The South Scandinavian paleomagnetic records are directly linked to the detailed chronostratigraphy in Figure 4.

Paleomagnetic samples of varved clays between the moraines in the Lake Erie region record irregular magnetism between about 13,750 and 12,400 BP consistent with the Swedish data (e.g. Fig. 3, Loc. 95 and 75), while samples of clays related to the Highland Front

Corrélation des fluctuations de la marge glaciaire en Europe du Nord et en Amérique du Nord. Les quatre premières courbes (d'après MÖRNER, 1970b, fig. 1) montrent des corrélations régionales et inter-régionales détaillées qui indiquent des fluctuations en phase et par conséquent provoquées par des changements climatiques généraux. Les colonnes 5 et 7 donnent une corrélation des moraines qui accompagnent la déglaciation de la région du Saint-Laurent; leur chronologie est en partie celle qui était connue avant le 3^e colloque de l'AQQUA (A) et en partie celle proposée au cours de ce colloque (B) en fonction des nouvelles données sur la direction des mouvements glaciaires et sur le paléomagnétisme (B et C). Selon les données paléomagnétiques (MÖRNER, 1976c), le complexe morainique des hautes terres devrait être ou plus vieux (B) ou plus récent (C) que l'intervalle 13 750-12 550 BP.

Moraine system record totally normal polarity (MÖRNER, 1976c). Paleomagnetically, the Highland Front Moraine system, therefore, seems to be either older or younger than 13,750-12,350 BP (cf. Fig. 1 and the Round Table II discussion below). However, it is not until this AQQUA Meeting that such a drastic redating of the Highland Front Moraine system has become glaciologically possible.

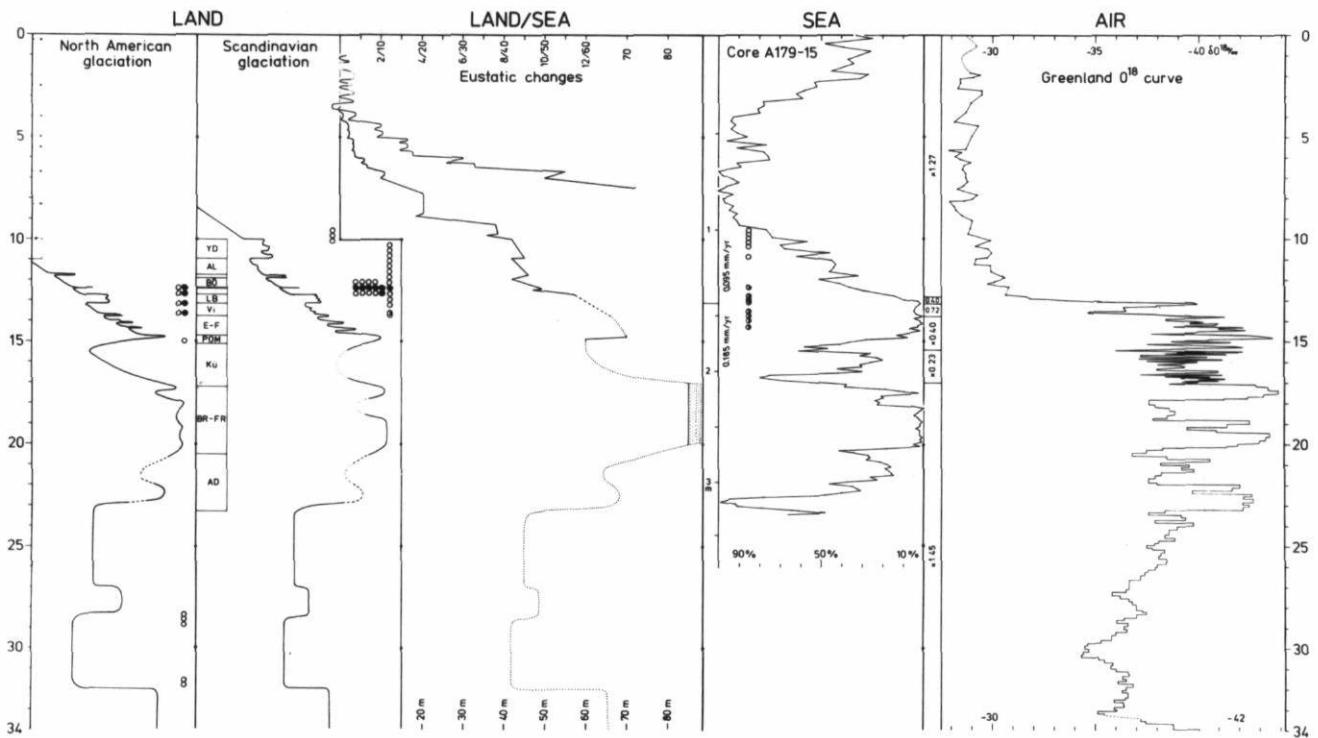


FIGURE 2. Climatic curves representing land (glaciation), land/sea (eustasy), sea (coiling direction of *Globorotalia truncatulinoides*) and air (Greenland O^{18} record) data (from MÖRNER, 1973a, 1974b). Age in 10^3 years BP. Warm towards the left, cold towards the right. Circles represent paleomagnetic data (MÖRNER and LANSER, 1975). The five curves show a remarkable similarity of general trends as well as of details, indicating therefore the recording of climatic changes on a global scale.

*Courbes climatiques à partir des données continentales (glaciations), littorales (eustasie), marines (direction d'enroulement de *Globorotalia truncatulinoides*) et atmosphériques (courbe ^{18}O du Groenland) (d'après MÖRNER, 1973a, 1974b). Chronologie en milliers d'années BP. Réchauffements vers la gauche, refroidissement vers la droite. Les cercles représentent les données paléomagnétiques (MÖRNER et LANSER, 1975). Les 5 courbes montrent une similarité remarquable aussi bien des tendances générales que des variations de détail et expriment par conséquent les changements climatiques à l'échelle mondiale.*

RADIOCARBON CALIBRATION

The radiocarbon method provides dates for regional as well as global correlations. Due to the atmospheric ^{14}C variations, however, the radiocarbon chronology is a non-absolute time-scale, hence preventing any reliable calculation of the cyclicity of various paleoclimatic indicators (MÖRNER, 1975c).

Continuous radiocarbon dates of dendrochronologically dated tree-rings (DAMON *et al.*, 1970; RALPH and MICHAEL, 1970; SUESS, 1970a), provide a calibration for the last 7000 sidereal years (approx. 6250 radiocarbon years).

Radiocarbon dates of certain varve-chronologically-dated levels in Sweden provide some information back to 12,000 radiocarbon years BP or perhaps even back to 13,500 BP (WENNER, 1968; MÖRNER, 1969; TAUBER, 1970; FROMM, 1970; MÖRNER, 1977b).

The author recently found a new comparison method of varve and radiocarbon dates (MÖRNER, 1973a, 1975c). The varve-dated sequence in the Angermanälven Valley (LIDÉN, 1938) includes a succession of varve-dated deltas, each of which corresponds to a period of aggradation and hence might have been formed during retardations in the relative uplift due to eustatic transgressions. Therefore, the PTM-shoreline of Southern Sweden (Postglacial Transgression Maximum) as established by MÖRNER (1969, 1976d) were extrapolated northwards to Ångermanland (Fig. 5). Figure 5 indicates that all deltas correspond to PTM-shorelines (*i.e.* transgression peaks). It also demonstrated that the "first Littorina Maximum", or PTM-2 in Mörner's system, dated at 7000 radiocarbon years BP corresponds not to varve 7100 BP as previously believed but to the delta at varve 7657 BP, and that the salinity maximum at varve 7100 BP (FROMM, 1938) corresponds to PTM-3B at 6250 radiocarbon years BP. On the whole, for the period

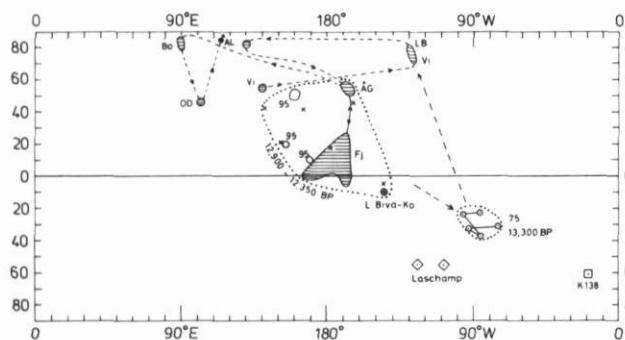


FIGURE 3. VGP migration 13,750-11,500 BP (zones Vi to AL of Fig. 4) according to Swedish data: dashed lines and hatched areas with zone letters (MÖRNER, 1977d). All Swedish records of the Gothenburg Magnetic Flip fall within the hatched Mid-Pacific equatorial area. Open circles = VGP of locality 75 and 95 in Ontario. Crosses = VGP of some of Easterbrook's samples from Washington. The data of the Gothenburg Magnetic Excursion cluster around two low latitude regions marked by dotted circles: (1) a Mid-Pacific centre at 12,900-12,350 BP ranging from the equator (= the Gothenburg Flip) up to 55-60°N Lat. and including the Swedish data belonging to the ÅG and Fj zones: this centre is established in numerous cores and sections, and (2) a SE Pacific centre at around 13,300 BP — the Port Dover Excursion (of the main Gothenburg Excursion) — as preliminarily established in locality 75 in Ontario: its chronological position within the Vi zone is indicated by dashed lines.

Migration V.G.P. entre 13 750 — 11 500 BP (zones Vi à AL de la fig. 4) selon les données suédoises: tiretés et surfaces hachurées et identifiées (MÖRNER, 1977d). Toutes les données suédoises du Renversement magnétique de Gothenburg se trouvent à l'intérieur de la surface hachurée de la région équatoriale du milieu du Pacifique. Cercles vides: V.G.P. des localités 75 et 95 en Ontario. Croix: V.G.P. de quelques échantillons d'Easterbrook, dans l'État de Washington. Les données de l'excursion magnétique de Gothenburg sont regroupées par les lignes pointillées: (1) un centre au Pacifique central à 12 900 — 12 350 BP s'étendant de l'Équateur (= le renversement Gothenburg) jusqu'à 55-60° de latitude Nord et incluant les données suédoises appartenant aux zones AG et Fj: ce centre est marqué dans plusieurs carottes et coupes, et (2) un centre du Pacifique du Sud-Est autour de 13 300 BP, l'excursion de Port Dover (de l'excursion principale de Gothenburg) tel qu'établi par la localité 75 en Ontario: sa position chronologique à l'intérieur de la zone Vi est donnée par les lignes tiretées.

of the last 7200 years, the Swedish varve chronology now shows exactly the same deviation towards the ¹⁴C flux as does the dendrochronology. It also provides additional data back to about 9300 sidereal years BP. The calibration established by this varve/radiocarbon shoreline method has been used in the author's papers since 1973 (MÖRNER, 1973b, 1975a, 1976b).

During the period 7000-9500 BP, there are indications of quite drastic atmospheric ¹⁴C variations (MÖRNER,

1	2	3	4	5	6	7	8	9
HOLOCENE	Postglacial	Subatlantic	SA	X IX	2200	2200	Vendysyselian Form IV	Littorina Sea
		Subboreal	SB	VIII	5000	5800	Kattegattian Formation III	
		Atlantic	AT	VII	7750	8000	Varbergian Form	Ancylus Lake
		Boreal	BO	VI	9700	9700	Gothenburgian Form I	Yoldia Sea
		Preboreal	PB	V	10000	10000		
PLEISTOCENE	Late Glacial	Younger Dryas	YD	III	10950	10950	Falkenbergian Formation B	Baltic Ice Lake (complex)
		Allerød	AL	II	11750	11750		
		Older Dryas	OD	Ic	11900	11900		
		Bølling	BO	Ib	12350	(12350)		
		Fjarðs	Fj		12400	(12400)		
		Ågård	ÅG		12700	(12900)		
		Low Baltic	LB		13100	(13250)	Lonstrupian Formation A	ice cover
Vintapper	Vi		13700	(13700)				

FIGURE 4. Chronostratigraphy of Southern Scandinavia (MÖRNER, 1977b): (1) global epochs; (2) local north European periods; (3) subdivision of the Postglacial and Late-Glacial with (4) corresponding zonation; (5) pollen zonation, (6) radiocarbon dates; (7) varve dates; (8) subdivision of the Kattegatt sediments, and (9) main Baltic stages.

Chronostratigraphie du sud de la Scandinavie (MÖRNER, 1977b): (1) époques globales; (2) périodes locales de l'Europe du Nord; (3) subdivision du Postglaciaire et du Tardiglaciaire avec (4) la zonation correspondante; (5) la zonation pollinique; (6) les dates au radiocarbone; (7) les dates varvaires; (8) la subdivision des sédiments de Kattegatt, et (9) les principaux épisodes de la Baltique.

1969, p. 181). In order to investigate these variations in greater detail, a continuous foil piston core of 68 mm diameter (labelled B 874) was taken through a gyttja sequence at Krokens Mosse that was known to range from about 6500 to 10,500 BP (MÖRNER, 1969, p. 161). Altogether 40 samples have been radiocarbon dated. Figure 6 gives the stratigraphy, sampling levels, pollen diagrams, zonations and radiocarbon dates with the age plotted against the depth. Using the calibrations established in Figure 5 and the age of the YD/BP boundary of 10,000 radiocarbon and varve years BP (MÖRNER, 1973 & 1976), the sedimentation rate can be fairly well established (dashed line) and the approximate atmospheric ¹⁴C variations calculated from the deviation between the dashed and dotted lines.

THE PLEISTOCENE/HOLOCENE BOUNDARY

In Scandinavia, the Pleistocene/Holocene boundary "at 10,000 radiocarbon years BP" corresponds to the Younger Dryas/Preboreal boundary (zone YD/BP), the pollen zone III/IV boundary, the clay/gyttja contact in numerous lakes, the drainage of the Baltic Ice Lake at varve 9965 BP, and the Baltic Ice Lake/Yoldia Sea boundary in the Baltic.

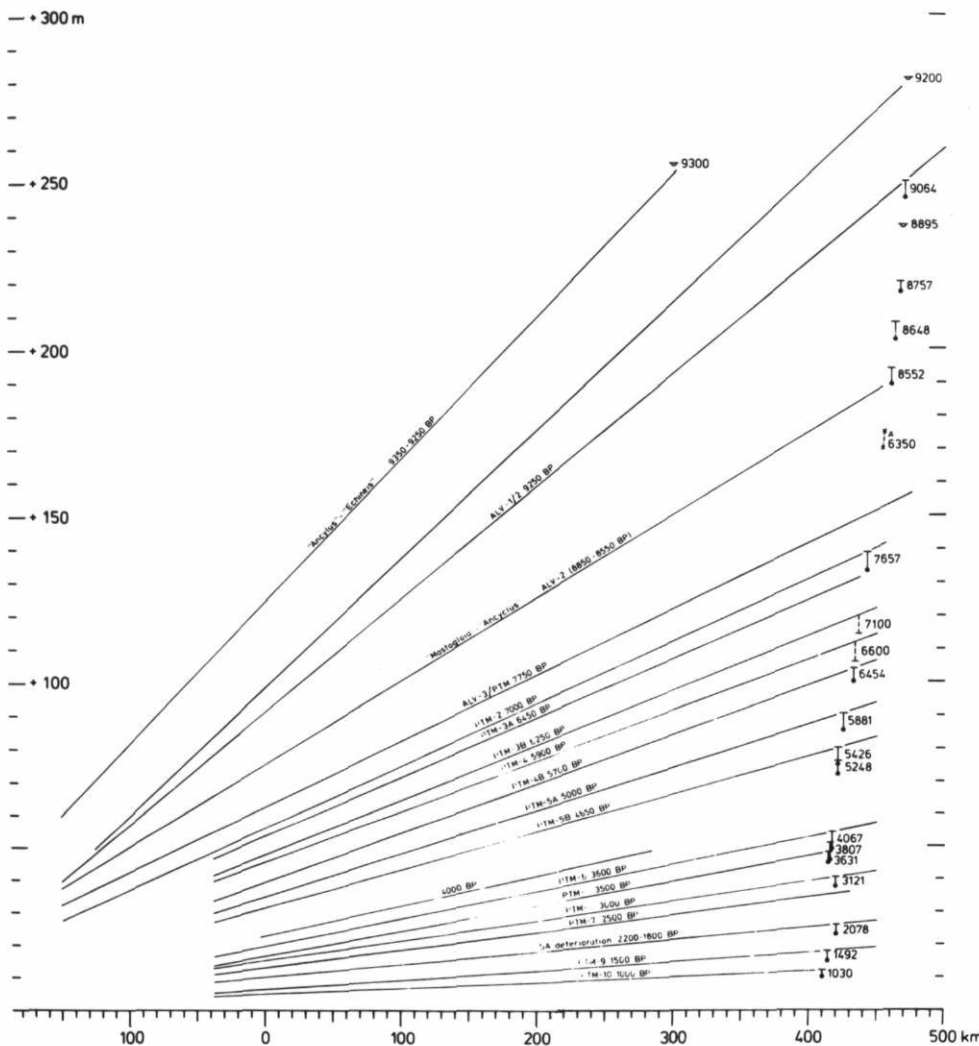


FIGURE 5. Shoreline diagram along the Swedish East Coast (distance: zero = Stockholm). Figures and symbols to the right refer to varve dates of deltas (black dots), the Highest Baltic Level (open half circles) and other varve dated levels (dashed). The figures on the shorelines give corresponding radiocarbon age. This diagram provides a new method of combining varve and radiocarbon dates (MÖRNER, 1973c, 1975c, 1976d). The deviation between the varve and radiocarbon dates is the same as the deviation between the dendrochronology and radiocarbon dates, and provides additional data back to about 9300 BP.

Diagramme des lignes de rivage le long de la côte est de la Suède (distance zéro = Stockholm). Les valeurs et les symboles à droite réfèrent aux datations varvaires de deltas (points noirs), au plus haut niveau de la Baltique (demi-cercles ouverts) et aux autres niveaux datés par les varves (tiretés). Les valeurs sur les lignes de rivage correspondent à l'âge au radiocarbonate. Ce diagramme fournit une nouvelle méthode pour combiner les dates varvaires et les dates au radiocarbonate (MÖRNER, 1973c, 1975c, 1977d). L'écart entre les dates varvaires et les dates au radiocarbonate est le même qu'entre les dates par dendrochronologie et les dates au radiocarbonate et fournit des données additionnelles jusqu'à environ 9300 BP.

Late studies have shown that there is a distinct paleomagnetic intensity peak right at the Pleistocene/Holocene boundary: the Gålön Magnetic Intensity Maximum. Its exact duration and age are established in varved sequences. The intensity increase starts some 10-20 years prior to the drastic climatic change at the Pleistocene/Holocene boundary. It is established in 17 different cores representing lacustrine, marine and Baltic environment and glacially varved as well as non-glacial sediments (*i.e.* all cores spanning this time, analyzed up to now).

In core B 911 (Fig. 7), it was established that the temperature rose by 5-7°C within one century from the Pleistocene/Holocene boundary (established by the clay/gyttja contact, the pollen zone III/IV boundary and the Gålön Magnetic Intensity Maximum).

A 14.6 m long core from the Botanical Garden of Gothenburg has been analyzed by a group of specialists and proposed as a boundary-stratotype for the Pleistocene/Holocene (MÖRNER, 1973 and 1976). With respect to the Québec region, it may be stressed that the St. Nicolas section in Québec (5 km SW of Québec City) was discussed in the aforementioned work (p. 257) and that it was concluded that "The St. Nicolas section, extended into the Pleistocene, may provide a very good marine hypostratotype of the Pleistocene/Holocene boundary".

INTEGRATED STUDIES OF LONG HOLOCENE CORES

Continuous long cores taken with the Swedish foil piston corer were analyzed by multiple parameters

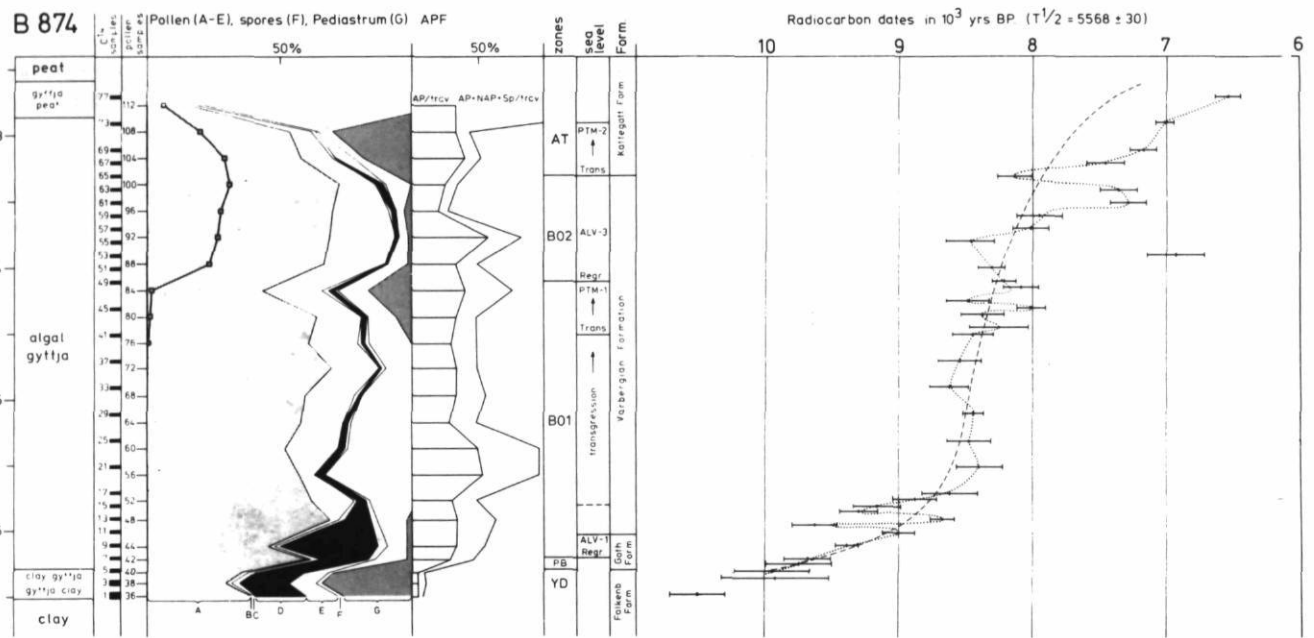


FIGURE 6. Chronostratigraphical records from Core B 874 (Krokens Mosse). The deviation between the dotted line (i.e. the mean curve through the radiocarbon dates) and the dashed line (i.e. the sedimentation rate in sidereal years) suggests rather drastic changes in the atmospheric ¹⁴C production.

Données chronostratigraphiques de la carotte B 874 (Krokens Mosse). L'écart entre la ligne pointillée (i.e. la courbe moyenne entre les dates au radiocarbone) et la ligne tirée (i.e. le taux de sédimentation en années sidérales) suggère des changements plutôt importants de production atmosphérique de ¹⁴C.

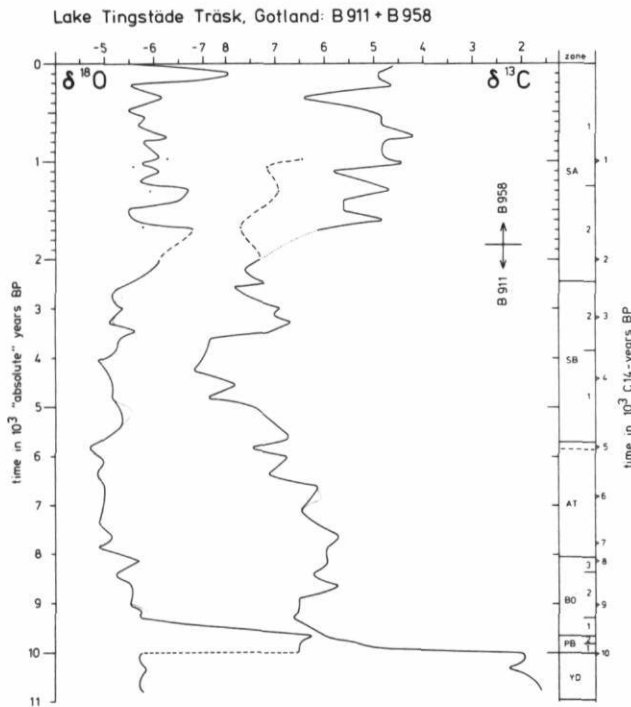


FIGURE 7. Isotope records from Lake Tingstäde Träsk with a two times enlarged time scale for the last 2000 years. Core B 911 ranges from 10,700 to 1000 BP (with only 4 analyses younger than 2000 BP: marked with dots in ¹⁸O and with a dashed line in ¹³C). Core B 958 ranges from 1700 to 0 BP. According to MÖRNER and WALLIN (1977), the ¹⁸O curve can be converted to temperature; the present value corresponding to +17.5°C and each δ ¹⁸O scale unit to about 2°C. The ¹⁸O values correspond well between two cores indicating reproducibility. The ¹³C values show fairly large deviations between the two cores suggesting local environmental differences.

Données isotopiques du lac Tingstäde Träsk selon une échelle de temps multipliée par 2 pour les 2000 dernières années. La carotte B911 va de 10 700 à 1000 BP (avec seulement 4 analyses plus jeunes que 2000 ans BP: marquée par des points pour les analyses de ¹⁸O et par une ligne tirée pour celles du ¹³C). La carotte B958 va de 1700 à 0 BP. D'après MÖRNER et WALLIN (1977), la courbe ¹⁸O peut être convertie en courbe de température; la valeur actuelle correspondant à + 17,5°C et chaque unité de l'échelle ¹⁸O valant 2°C. Les valeurs ¹⁸O correspondent bien d'une carotte à l'autre, ce qui indique la reproductibilité. Les valeurs ¹³C montrent de grands écarts assez importants entre les deux carottes, suggérant des différences locales de l'environnement.

(MÖRNER, 1975c, 1977c). The integration of the various analyses led to conclusions about the mutual interaction and origin of these variables (MÖRNER, 1975e, 1976b, 1977e). Some of these cores will be discussed.

a) Isotopic records from Lake Tingstäde Träsk, Gotland (Cores B 911 and B 958)

Lake Tingstäde Träsk on the island of Gotland in the Baltic has a submersed vegetation totally dominated by *Chara*. Because *Chara* assimilates CO₂ directly from the water, CaCO₃ is being precipitated (as *Chara* lime). As the assimilation by *Chara* takes place during the summer months, the isotopic composition of the precipitate should correspond to the mean summer composition of the water, and would hence register the climatic and environmental fluctuations with time (depth in the sediments). Sediment cores were, therefore, taken and analyzed as to their content of ¹⁸O and ¹³C (Fig. 7). The cores were also paleomagnetically analyzed. Core B 911 was taken with the Swedish foil piston corer at a place where a continuous sequence down to the basal glaci-fluvial sand from about 10,750 BP was known to occur, but where the topmost part (last 1000 years) unfortunately was known to be absent. Core B 911 is thoroughly discussed by MÖRNER and WALLIN (1977). Later, cores were taken at a place where rapid sedimentation was known to have occurred all through the Subatlantic up to the present. One of these cores (B 958) was subjected to isotope analysis.

Figure 7 gives the combined results of Cores B 911 and B 958 with an expanded time scale for the last 2000 years. According to MÖRNER and WALLIN (1977), the ¹⁸O curve can be converted to a temperature curve of mean summer water temperature in the lake. The ¹³C curve is a combined function of the temperature in the lake, the activity of *Chara* (also affected by temperature) and other environmental parameters. The curves show a drastic climatic rise at the Pleistocene/Holocene (YD/PB) boundary at 10,000 BP corresponding to a 5-7°C rise within a century. The curves register a continuously fluctuating climate throughout the Holocene with the peaks and bottoms corresponding very well with the eustatic fluctuations in the North Sea region (MÖRNER 1976d, Fig. 13) and other paleoclimatic records (Fig. 10). At about 2500 BP, there is a major climatic drop corresponding to the well-known deterioration at the Subboreal/Subatlantic transition. The Subatlantic period is characterized by generally lower temperature and increased fluctuations compared to the "climatic optimum" during the Atlantic and Subboreal periods. The magnetic records of the cores from Tingstäde Träsk correlate well with those of Cores B 903 and B 907 (and others) and yield important support and confirmation of the inter-core correlations.

b) Paleomagnetism of Cores B 903 and B 902

Cores B 903 (Söborg Sö) and B 902 (Varberg) have both a very well established sea-level record. After continuous measurements in the Digico Long Core system, these cores were cut up and measured in detail (MÖRNER, 1977e, Figs. 7, 9, 10).

Figure 8 gives the record from Core B 903 (ranging from 10,500 to 2000 BP): the stratigraphy with the seven black transgression layers, the intensity, the declination and the inclination. The intensity generally shows low values at the transgression peaks and high values (peaks) at the regressions. At any rate, there seems to be a clear correlation between eustatic and magnetic intensity changes. The declination (swinging around 360°) and the inclination (swinging around 70°) become scattered in the upper portion with low intensity. Despite this scatter, there is a clear tendency for magnetic fluctuations to coincide with eustatic changes. (The 90° departure in the basal part corresponds to the PTM-1, or ALV-2, transgression.)

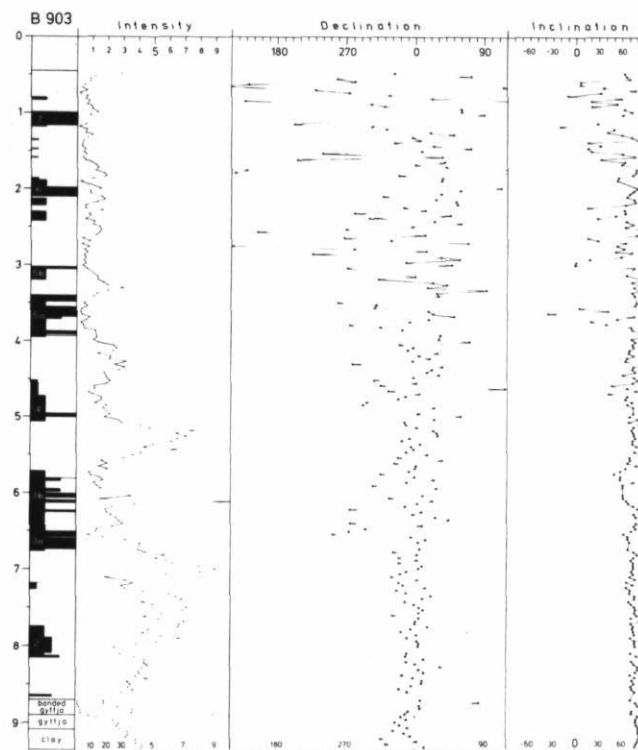


FIGURE 8. Stratigraphy (with seven black eustatic transgression layers = PTM 2-7; cf. MÖRNER 1976d) and complete paleomagnetic analysis of Core B 903 (Söborg Sö, Denmark) cut up in 229 separate samples.

Stratigraphie (avec sept couches noires de transgression eustatique = PTM 2-7; cf. MÖRNER, 1976d) et analyse paléomagnétique complète de la carotte B903 (Söborg Sö, Danemark) divisée en 229 échantillons.

Figure 9 gives the record of Core B 902 (ranging from about 10,200 to 7000 BP). The stratigraphy records the early Holocene sea-level changes with a mean sedimentation rate of 1.5 mm/yr. The declination shows drastic swings and the inclination distinct decreases right at the onset of the PTM-1 (samples 76-74) and PTM-2 (samples 50-45) transgressions indicating a causal relationship or mutual origin. The magnetic records of the levels PTM-3A in samples 1-2 and PTM-2 in sample 33 are quite similar to those of the corresponding levels in Figure 8.

SYNTHESIS, ORIGIN AND CYCLICITY

Cores B 903, B 907, B 911 and B 902 record climatic, eustatic, magnetic intensity and magnetic directional variations during the Holocene Epoch. Via their age, these records can also be correlated to the atmospheric ^{14}C productivity variations (equally via the PTM-shorelines as established in Fig. 5) and the global climatic changes (MÖRNER, 1973a, Figs. 1-2). This is illustrated in Figure 10 which gives the warm/cold changes as established in six deep-sea cores of high sedimentation rate (MÖRNER, 1973a), the eustatic transgression/regression amplitude (MÖRNER, 1975d, 1976d), the temperature changes according to Core B 911 (MÖRNER and WALLIN, 1976), the atmospheric ^{14}C variations according to RALPH *et al.* (1973) and the Swedish varve data (Fig. 5), the archaeomagnetic intensity curve of BUCHA (1970) and the palaeomagnetic mean inclination

and intensity records of Cores B 903 and 902 (with arrows in the intensity column marking eustatic PTM levels). These correlations together with those between volcanism and eustasy, climate and magnetism, geoidal changes and eustasy, atmospheric ^{14}C production and magnetism (MÖRNER, 1976b) — all correlations without any measurable time lag — indicate a mutual origin (and not a causal chain relationship as generally assumed). According to MÖRNER (1975c, 1976a, 1977e), the mutual origin lies in changes of the core/mantle coupling and interface. This is illustrated in Figure 11. It should be emphasized that the system is multidirectional and influenced also by many other factors as indicated by arrows at the margin of the "boxes". Changes of the core/mantle coupling and interface is a new factor for paleoclimatic analyses. It seems to stand as the dominant factor behind the Holocene paleoclimatic fluctuations.

Analyzing the paleoclimatic records of the last 35,000 years (MÖRNER, 1973a, 1973c), I found at least three major cycles: a 21,000-yr cycle (C), an irregular 1000-3600-yr cycle (B) and an irregular 230-1000-yr cycle (A). Later studies (MÖRNER and RICHARD, 1974) suggested the presence of one or more additional cycles between Cycles B and C (of the length of about 1/4 and 1/2 of the C Cycle). The multiple analyses of long Holocene cores and the changing-geoid concept of MÖRNER (1976b, 1977e) suggest that these cycles are caused by changes of the core/mantle coupling and interface according to two different systems (Fig. 13).

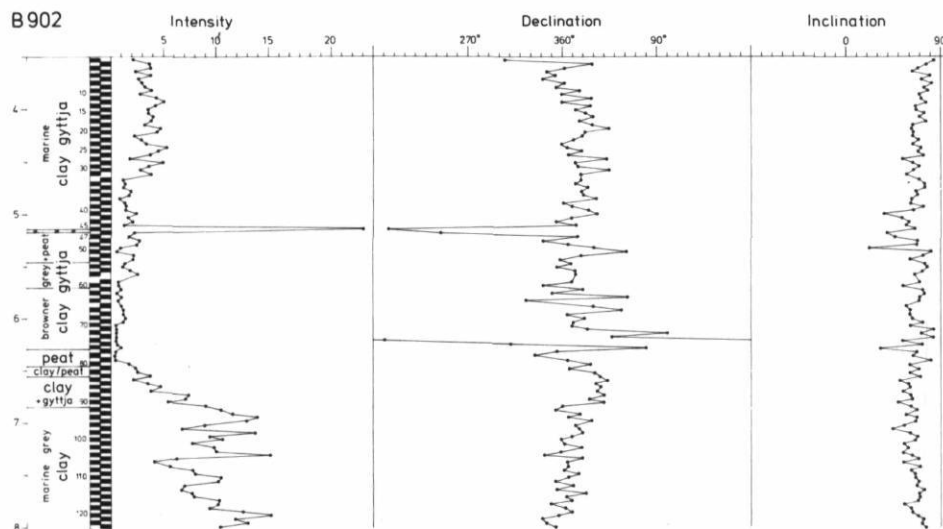


FIGURE 9. Stratigraphy and complete paleomagnetic analysis of Core B 902 (Varberg, Sweden) cut up in 113 separate samples. The stratigraphy registers the early Holocene sea level changes. The two levels with declination swings and decreasing inclination correspond to the onset of the PTM-1 and PTM-2 transgressions (peaking at the levels of samples 59 and 33).

Stratigraphie et analyse paléomagnétique complète de la carotte B902 (Varberg, Suède) divisée en 113 échantillons. La stratigraphie enregistre les changements de niveau marin au début de l'Holocène. Les deux niveaux avec des oscillations de la déclinaison et de l'inclinaison décroissante correspondent au début des transgressions PTM-1 et PTM-2 (atteignant les niveaux des échantillons 59 et 33).

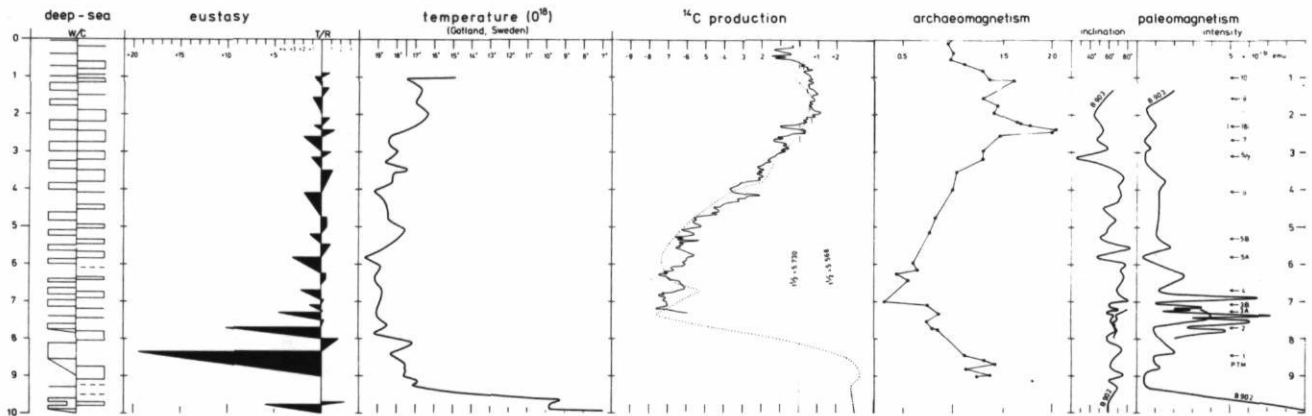


FIGURE 10. Synthesis of some Holocene variables of paleoclimatic significance establishing correlations between ocean climate (MÖRNER, 1973a), eustasy (MÖRNER, 1976d), temperature at Gotland (Fig. 7, MÖRNER and WALLIN, 1977), atmospheric ¹⁴C production (Fig. 5, RALPH et al., 1973), archaeomagnetism (BUCHA, 1970) and paleomagnetism (Figs. 7-8).

Synthèse de quelques variables de l'Holocène de signification paléoclimatique établissant des corrélations entre le climat maritime (MÖRNER, 1973a), l'eustasie (MÖRNER, 1976d), la température du Gotland (fig. 7, MÖRNER et WALLIN, 1977), la production atmosphérique du ¹⁴C (fig. 5, RALPH et al., 1973), l'archéomagnétisme (BUCHA, 1970) et le paléomagnétisme (fig. 7 et 8).

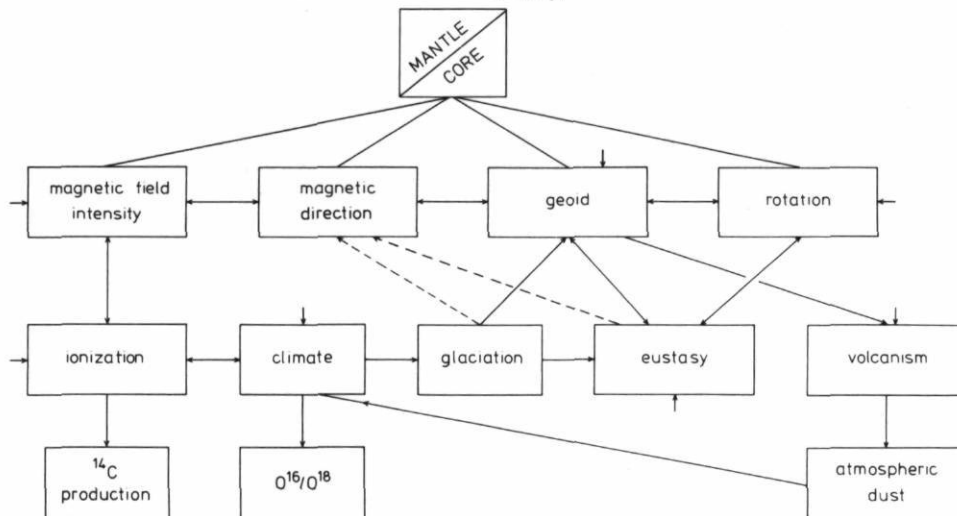


FIGURE 11. Multiple effects of short period core/mantle interface changes (MÖRNER, 1976b). The system is multidirectional and influenced by many other factors as indicated by short arrows at the margin of the boxes. The joint origin of the changes of the various factors explains the well established mutual correlations and absence of lag times.

Les effets multiples des changements de courte durée de l'interface noyau/manteau (MÖRNER, 1976b). Le système est multidirectionnel et influencé par plusieurs autres facteurs tel qu'indiqué par les flèches sur le périmètre des rectangles. L'origine commune des changements de certains facteurs explique les corrélations mutuelles bien reconnues et l'absence de retard.

MÖRNER (1976b) found that the various eustatic curves record a cyclic geoid change during the last 7700-7500 years which corresponds to the archaeomagnetic intensity cycle of BUCHA (1970), the atmospheric ¹⁴C productivity cycle of SUESS (1970b), the eustatic rate cycle of MÖRNER and RICHARD (1974) and the main Holocene temperature cycle according to, f.ex., Core B 911 (Fig. 12, cf. Fig. 10). This roughly 5250-yr cycle (1/4 of the precession cycle) seems to be generated by the precession torque acting differently on

the core and the mantle and/or the changes in rotation of the Earth (which may be caused by several factors) affecting the core/mantle coupling and interface hence generating gravitational and magnetic changes, i.e. changes of the geoid configuration and the geoid ellipsoid leading to geoidal-eustatic sea-level changes, and changes of the magnetic field and the ionization affecting the atmospheric ¹⁴C production and the incoming solar radiation.

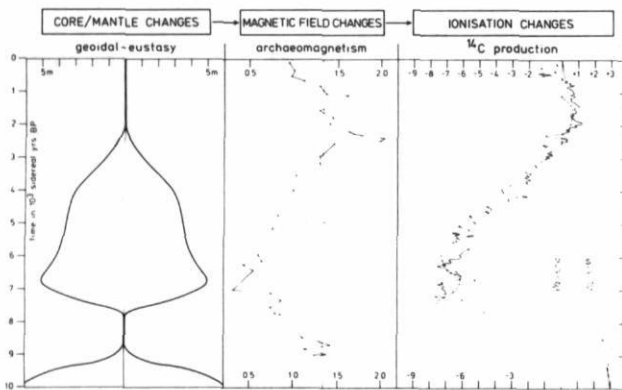


FIGURE 12. The correlation between geoidal-eustasy (MÖRNER, 1976b), archaeomagnetism (BUCHA, 1970) and atmospheric ¹⁴C production (Fig. 5, RALPH et al., 1973) indicate a basal origin in cyclic core/mantle changes with a periodicity of about 5250 years (i.e. 1/4 of the precession cycle).

La corrélation entre l'eustasie du géoïde (MÖRNER, 1976b), l'archéomagnétisme (BUCHA, 1970) et la production atmosphérique de ¹⁴C (fig. 5, RALPH et al., 1973) indique une origine commune liée aux changements cycliques du noyau/manteau selon une périodicité d'environ 5250 ans (i.e. 1/4 du cycle de précession).

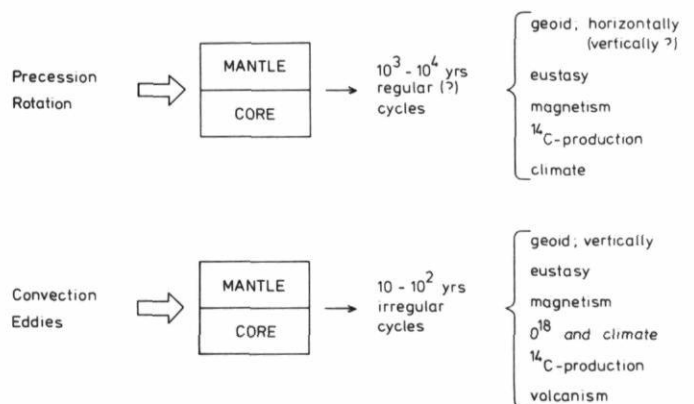


FIGURE 13. The two systems of short period changes of the core/mantle coupling and interface; causation, cyclicity and affected variables.

Les deux systèmes de changements de courte durée de l'interface et du couplage noyau/manteau; causes, cyclicité et variables affectées.

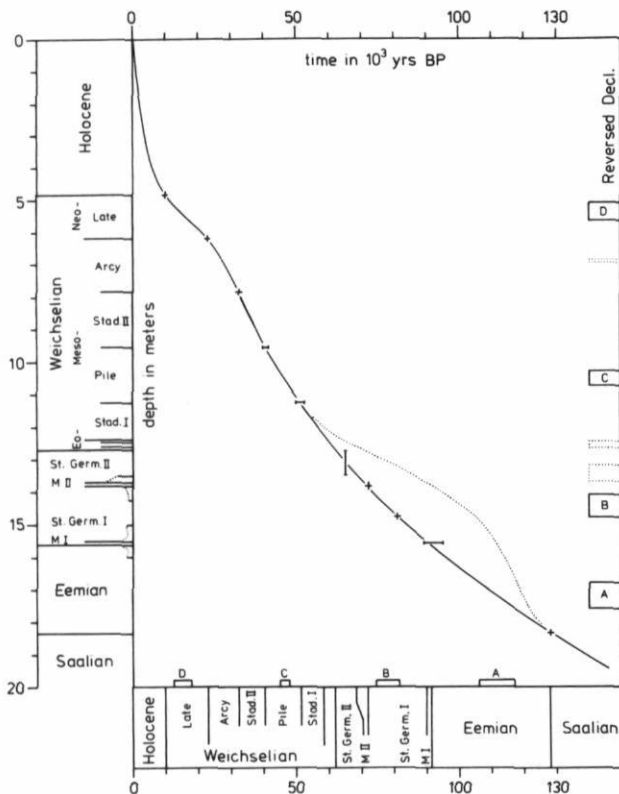


FIGURE 14. The Grande Pile (eastern France) record. Stadial/interstadial changes according to the pollen analysis by WOILLARD (1975), a time/depth curve according to indirect dating of certain levels (crosses and lines), and preliminary paleomagnetic records of reversed declination (A-D). Via the time/depth curve, the stadial/interstadial depth-scale (left) is converted to time-scale (at the base). Reversal A corresponds to the Blake Event and falls right in the middle of the Eemian interglacial. The continental Weichselian glaciation should probably begin with the Melisey II (M II) cooling around 70,000 BP, or Melisey I (M I) cooling around 90,000 BP.

Les documents de Grande-Pile (est de la France). Les changements climatostratigraphiques (stadiale/interstadiale) d'après l'analyse pollinique effectuée par WOILLARD (1975), une courbe temps/profondeur selon les datations indirectes de certains niveaux (croix et lignes), et les enregistrements paléomagnétiques préliminaires de la déclinaison renversée (A-D). À l'aide de la courbe temps/profondeur, l'échelle de profondeur stadiale/interstadiale (à gauche) est convertie en une échelle de temps (à la base). La déclinaison renversée A correspond à l'événement de Blake et tombe juste au milieu de l'interglaciaire Eemien. La glaciation continentale du Weichselien devrait probablement commencer avec le refroidissement Melisey II (MII) aux environs de 70 000 BP, ou au refroidissement Melisey I (MI) aux environs de 90 000 BP.

The irregular short period cycles, *i.e.* Cycles A and B of MÖRNER (1973a, 1973c), on the other hand, seem to draw their origin from rapid convections in the outer core and/or eddies at the core/mantle interface. Figure 13 illustrates the two systems of short period paleoclimatic changes via changes of the core/mantle coupling and interface.

According to this interpretation, the climatic changes are controlled by global signals. This agrees well with the correlations established between various records and the absence of any measurable times lag. It also means that deviations from this scheme may record the local response to those global signals, hence providing valuable information on the local dynamics (glacial, climatic, etc.) of a certain region.

CORE/MANTLE CHANGES AND 115,000 BP EVENTS

With respect to the effect of core/mantle changes, one may analyze the various geological-geophysical records from the period 110,000-115,000 BP. According to many colleagues (*Quaternary Research*, 1972, Vol. 2, No. 3), this period corresponds to a major climatic cooling with extensive glaciation, which with a cyclic climatic repetition would suggest that we are now rapidly approaching a similar period. The corresponding sea level records are controversial and may indicate geoidal-eustatic changes that differ significantly over the globe (MÖRNER, 1976b). The Blake Geomagnetic Event occurred at the same time period. The Milankovitch isolation curve shows a major minimum and large changes in the various components at around 110,000-115,000 BP. A geoidal-eustatic change at the same time as a major geomagnetic field change is to be expected as both are the effect of a change of the core/mantle coupling and interface. Furthermore, major changes of the earth/sun constellation must affect the core/mantle coupling. Consequently, there are geophysical reasons to expect major changes at around 110,000-115,000 BP which do not need to be linked to extensive continental glaciations.

Interesting data are obtained from Grande Pile in eastern France. This locality possesses a continuous lake sequence from the end of the second last ice age. It has been palynologically analyzed by WOILLARD (1975). Three cores are being paleomagnetically analyzed by the author. Figure 14 gives the main stadial/interstadial stratigraphy according to WOILLARD (1975), a time/depth graph and the levels of reversed declination according to the Digico Long Core Spinner record (A-D). The Blake Event (A) falls right in the middle of the Eemian Interglacial (at level 106,000-117,000 BP), where there are no signs of any cooling. By analogy, this seem to suggest that the climatic cycle which we reached into

some 2500 years ago is not likely to lead to any significant cooling and that the New Guinea sea level regression at about 115,000 BP (CHAPPELL, 1974) records a geoidal-eustatic event (*i.e.* core/mantle change) and not a glacial-eustatic lowering.

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