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EUSTATIC AND CLIMATIC CHANGES DURING THE LAST 15,000 YEARS

NILS-AXEL MÖRNER

ABSTRACT:

This is a short description of the results concerning shorelevel displacement, isostasy, eustasy and climatic changes obtained from a comprehensive investigation of the Late Quaternary history of the Kattegatt Sea and the Swedish West Coast (Southern Scandinavia). This investigation has been described in its entirety in a thorough monography (Mörner 1969), to which I refer for further information.

INTRODUCTION

It has often been stated that an eustatic curve can only be determined in a so-called "stable area". However, I think a detailed eustatic curve can only be obtained from a suitably uplifted area, where a closely fixed and dated shoreline diagram over a large area can be worked out, leading to conclusions about the isostatic and eustatic changes at several different places in the direction of tilting.

The intensity of land upheaval, the direction of tilting, the distribution of sediments, the almost negligeable tide, the good pollen chronology, etc. all make the Swedish West Coast and the Kattegatt Sea uniquely suitable for a detailed investigation of shorelevel displacement.

Older investigations are marred by the absence of good dates. Thus one main purpose was to bring C^{14} dates into the history of deglaciation and shorelevel displacement. Totally 108 samples were C^{14} dated (besides numerous pollen analyses). The Kattegatt Sea has hitherto been a "white spot" on the map perventing correlations between Denmark and Sweden or leaving the field open to loose hypothesis.

THE LATE GLACIAL AND EARLY POSTGLACIAL CLIMATIC CHANGES

The ice marginal lines were mapped on land as well as in the seabed (M ö r n e r 1969, Pls. 1-3) giving a very detailed picture of deglaciation (Fig. 1). By comparing a large number of North European C^{14} dates, the Late Glacial pollen zone boundaries were fixed as follows: Ia/Ib = 10,300 BC, Ib/Ic = 9,950, Ic/II = 9,800 BC, II/III = 9,000-8,950 BC and III/IV = 8,050-8,000 BC. The Late Weichselian or Upper Pleniglacial Glaciation was shown to contain two distinct maxima separated by an interstadial, viz. the Middle Jylland Stadial or the C line (from 18.000 BC to unknown age) and the East Jylland Stadial or the D line (about 13,000-12,800 BC). These maxima correspond to North American glaciation maxima. The regression from the D line is here proposed to give the boundary between the Late Weichselian or the Upper Pleniglacial and the Late Glacial (of North Europe).

The glaciation curve for Southern Scandinavia (Fig. 1) gives the changes between colder and warmer periods. From the changes and C^{14} dates of the Late Glacial marine shell bearing faunas, a new interstadial period was established, viz. the Ågård Interstadial at about 10,750-10,350 BC. It is separated from the classical Bölling Interstadial (10,300-9, 950 BC) by the distinct Fjärås Stadial at about 10,350-10,300 BC. The Older Dryas (or Berghem) Stadial was shown to have lasted for 150 years and to have been divided in three stages: the Moslätt Phase (9,950-9,925 BC), the Agnesberg Interval (9,925-9,850 BC) and the Berghem Phase (9,850-9,800 BC). The Younger Dryas (or Ra-Billingen-Salpausselkä) Stadial was 950 years old and divided into five main stages: the Taberg (or

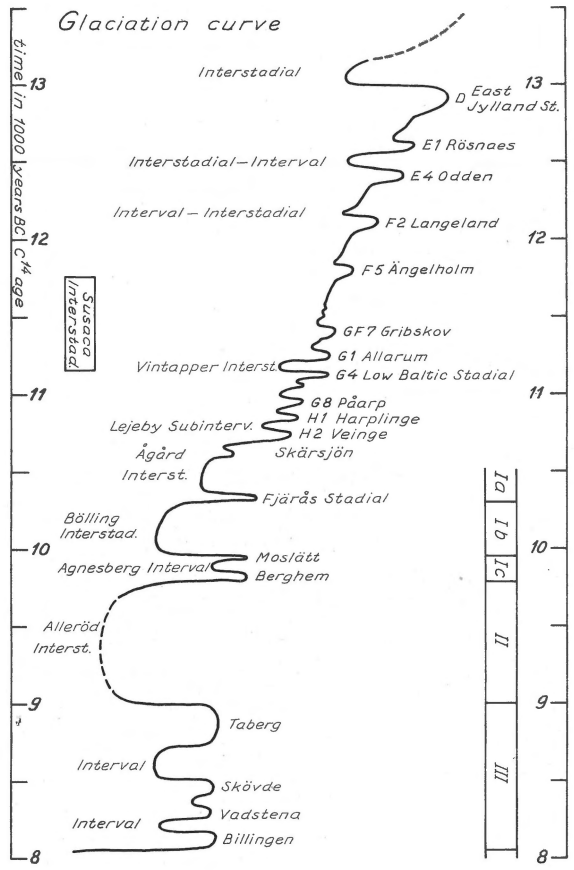


Fig. 1

Glaciation curve for the time 13,000-8,000 BC in the Denmark-Kattegatt-Sweden area (Southern Scandinavia).

Salpausselkä I) Stadial, an interval, the Skövde (or Salpausselkä II) Stadial, an interval and the Billingen (or Salpausselkä III) Stadial. After an early Preboreal interstadial, the Friesland Interstadial, there was a stadial, the Eidfjord (or Preboreal) Stadial at about 7,800-7,700 BC. After a very distinct early Boreal climatic amelioration (7,330-6,900 BC) there was a new stadial, the Cochrane (or Boreal) Stadial about 6,850-6,550 BC. These climatic changes are all very well reflected in the eustatic curve here presented (Fig. 8).

THE SHORELINE DIAGRAMS

The different shorelines were followed 250-350 km in the direction of tilting (M o r n e r 1969, Pls. 4-6). The oldest Swedish shore mark was cut by the sea at about 11,750 BC. From that time onwards the shorelevel displacement can be studied. Some additional information for the period prior to that time was obtained from Northern Jylland and the island of Anholt.

Two very distinct ice marginal lines – the Fjärås line and the complex Moslätt/Berghem line – were morphologically followed along the whole Swedish West Coast. The Marine Limit (ML) was measured along these synchronal ice marginal lines. In the shoreline diagram these ML observations form two quite straight, tilted shorelines. The correctness of the gradient of these shorelines was later confermed by C^{14} dated isolation contacts in bogs situated far outside the corresponding ice marginal lines (e.g. Höghults Mosse and Klinehögkärret; M ö r n e r 1969). The Fjärås line was formed during a cold stadial between the Ågård and Bölling Interstadials. It corresponds to the very end of the classical Oldest Dryas (zone Ia). The Moslätt/Berghem line was formed during the Older Dryas. These shorelines are indeed well fixed in age and gradient.

The shorelevel displacement during Alleröd and Younger Dryas is based upon pollen and C^{14} dated isolation contacts. Consequently, the gradients of these shorelines are not as closely fixed as those of the older and younger shorelines. The very common Late Glacial shore marks were not believed to represent synchronal shorelines. The formation of these shore marks seems instead to depend upon local conditions, e.g. the gradient of the slope, the material in the slope, the degree of exposure, etc.

The shorelines from the transition period between Late Glacial regression and Postglacial transgression (i.e. the ALV shorelines) were very closely fixed and dated within the Viskan Valley, forming an ideal base for the amplified investigation (in time and space). The submarine continuations of these shorelines were followed across Kattegatt (M o r n e r 1969, Pls. 5 and 7). Submarine dunes, shore features, peat and lacustrine layers in situ, ground crusts and shallow sea deposits were found. The first Postglacial transgression started (contemporarily along the whole diagram) at 7,330 BC and reached its maximum (PTM-1) at about 6,900-6,800 BC. (A small eustatic transgression was also found between 8,050 and 7,800 BC). The second or classical Postglacial transgression, which rose above the thresholds in the SW Baltic Sea, started (contemporarily along the whole diagram) at

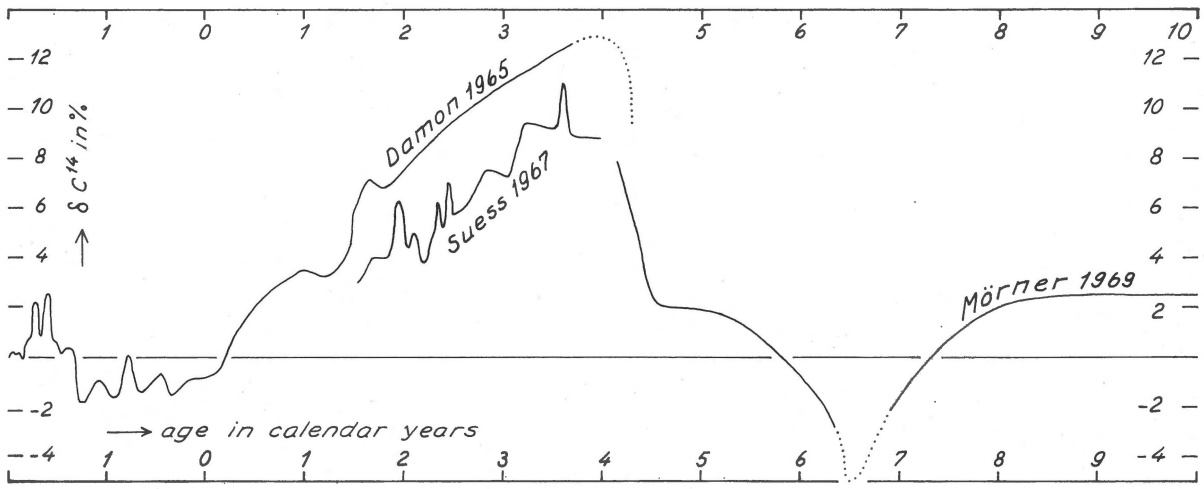


Fig. 2
Atmospheric ^{14}C activity in per cent deviation from age-corrected oxalic acid, standard variations during the last 12,000 years.

5,800 BC. The classic "Ancylus transgression" in the Baltic must now be reinterpreted as follows: an eustatic transgression (the main part) + isostatic transgression (about 8 m) + a regression caused by erosion in the thresholds (about 7-8 m). ALV-1 (7,750-7,330 BC) and ALV-3 (6,550-5,800 BC) are along the whole diagram characterized by syngression, i.e. no changes in level either of isostatic or eustatic courses. This seems curious. However, the explanation is partly that the length of these periods is in reality too long, due to the variations of C^{14} in the atmosphere (M o r n e r 1969, Figs. 40-41), and partly that the centre and margin of land upheaval has shifted, and that the margin of land upheaval during these periods has been situated further inland (Fig. 2; cf. M ö r n e r 1969). The given duration of the large transgression up to PTM-1 (= ALV-2) is too short, due to the variations of C^{14} in the atmosphere (Fig. 2), and was in reality longer, thus giving a more reliable rate of the eustatic rise of sea level.

A very detailed picture of the Postglacial fluctuations of sea level was obtained (e.g. Fig. 7B) thanks to the suitable intensity of land upheaval, the closely fixed isobase system, numerous new localities and, above all, the C^{14} dates allowing reliable correlations. The PTM shorelines were identified, followed and checked over a very large area. The transgression maxima are termed PTM and the regressions PR. The following transgression maxima (PTM) were indentified and dated: PTM-2 = 5,000 BC, 3A = 4,500 BC, 3B = 4,300 BC, 4A = 3,900 BC, 4B = 3,700-3,550 BC, 4.5 = about 3,250 BC, 5A = 3,000 BC, 5B = 3,650 BC, 6 = 2,100 BC, 7 = 1,650-1,400 BC, 8 = 1,000 BC, 9A = 500 BC, 9B = 250 BC and 10 = a complex of younger Sub-Atlantic maxima. The PTM/PR changes are shown in Fig. 3.

SHORELEVEL DISPLACEMENT, ISOSTASY AND EUSTASY

For relative sea level *(S)*, eustasy *(E)* and isostasy *(I)* the following equations apply: $S + E = I$ or $I - S = E$. The relation between the eustatic curve *(E)* and shorelevel displacement curves (= relative sea level) in uplifted *(I+)* and sunken *(I–)* areas respectively are illustrated in Fig. 4. From this relationship the following conclusions are reached:

1. The shorelevel displacement curves in areas of land subsidence (e.g. the Dutch coast) are too smooth, as eustatic regressions are here decreased or absent.

2a. The shorelevel displacement curves in areas with low intensity of land upheaval (e.g. the areas studied by me) are too fluctuating, as eustatic regressions are increased and a flattening out of the eustatic rise may be enough to cause a transgression + regression of relative sea level.

2b. The shorelevel displacement curves in areas with high intensity of land upheaval (e.g. Northern Sweden) are stepped, as eustatic regressions are increased and eustatic transgressions are transformed to retardations of a continuous regression.

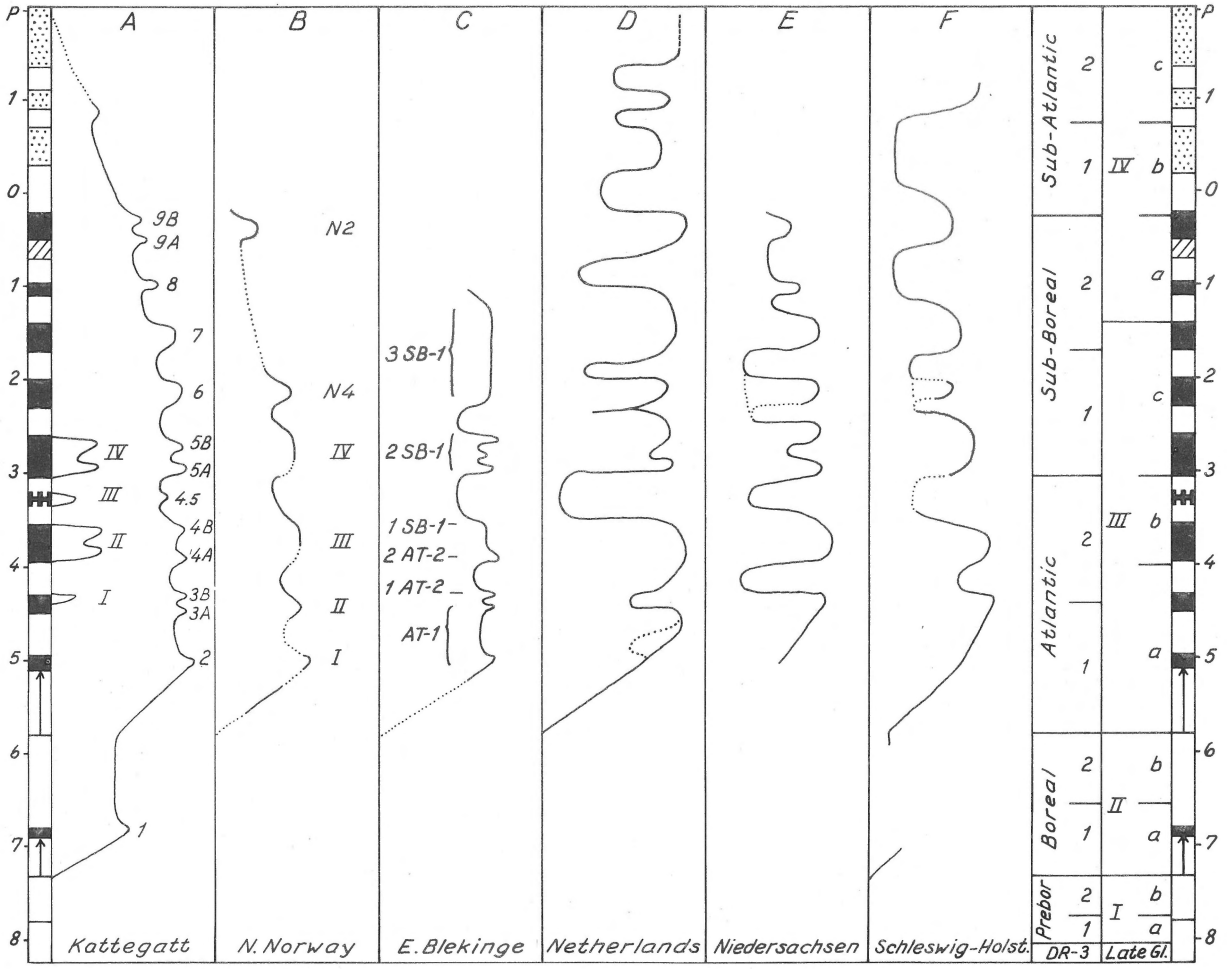


Fig. 3

Postglacial changes between transgressions (PTM) and regressions (PR) in different North European areas. Scale does not represent amplitude of the fluctuations. Black areas show PTM identified and dated in the Kattegatt area. Dotted areas show some younger PTM as indicated by results from the Netherlands. The column to the right gives the subdivision of the Postglacial here proposed for climatic-eustatic reasons.

As the shorelines in my diagrams (M ö r n e r 1969, Pls. 4-6) are closely fixed in age and position, they can be used for calculations of the isostatic land upheaval and the eustatic rise of sea level in detail. These calculations are based upon the above equation and the following knowledge (a priori) about its three units:

S (relative sea level or shorelevel displacement) was very well known for about 250 km in the direction of tilting (Fig. 6A). It is of fundamental importance that shorelevel displacement curves (closely fixed in age and altitude) existed from several places with different isostatic intensity, making possible a necessary check of the eustatic curve.

I (isostatic changes) was fairly well known from the curves of changes in gradient (Fig. 5). First of all these curves are uneven, clearly indicating that the intensity of tilting (prior to 5,000 BC) was fluctuating (an important fact in the interpretation of isostasy). Secondly these curves show the following about the fluctuations in themselves: Late Glacial cold periods (stadials) meant retarded land upheaval, Late Glacial warm periods (interstadials) meant accelerated land upheaval, Early Postglacial eustatic transgressions meant accelerated land upheaval and even land subsidence, and Early Postglacial eustatic

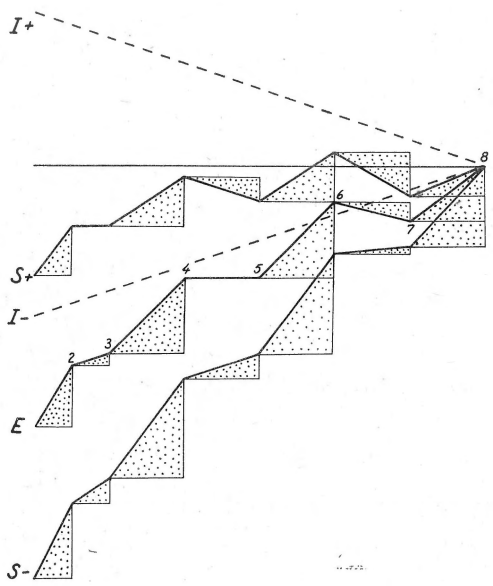


Fig. 4

Relation between eustatic curve (E) and the shorelevel displacement (S+ and S-) in uplifted (I+) and sunken (I-) areas. The hight of the dotted areas gives shorelevel displacement between two points.

stagnation meant stagnated land upheaval. This means that the isostatic land upheaval was influenced by:

1. fluctuations in the Late Glacial recession of land ice (= glacio-isostasy)
2. fluctuations in the eustatic rise of sea level (= hydro-isostasy)

On the whole the curves of changes in gradient have given very important information about the isostasy. Curves of this type have not earlier been used to express the land upheaval, but this is necessary if one wants to make deductions about isostasy. (A shorelevel displacement curve is not enough.) However, this type of curve requires a closely determined direction of tilting and a detailed and well dated shoreline diagram.

E (eustatic curve) was the unknown unit, which had to be calculated. Eustatic curves published by others (none offering more than an approximation) gave quite unrealistic isostatic curves if added to my shorelevel displacement curves. J e l g e r s m a's (1961, 1965) curves represent a sunken area and must thus lie below the eustatic curve. Scholl's curve from Florida (S c h o l l 1964, S c h o l l and S t u i v e r 1967) has often been thought to give the eustatic rise of sea level during the last 4,000 years. However, also this curve gave unrealistic isostatic curves, indicating a slight subsidence of Florida.

The curves of changes in gradient (Fig. 5) show that the land upheaval from 5,000 BC onwards is charaterized by a more or less continuous tilting. During this period the shorelevel displacement curves are very detailed (Fig. 7A). Thus it was used for the first calculation of isostasy and eustasy. Fig. 7A gives the shorelevel displacement curves for every 50 km in the direction of tilting (the one of -200 km turned out almost exactly to correspond to the eustatic curve). The corresponding isostatic curves (Fig. 7B) give a very reliable picture of land upheaval, with land subsidence outside -200 km and increasing land upheaval from -200 km to +50 km. If the eustatic curve (Fig. 8) is changed the isostatic curves become unlikely. The older part (back to 11,750 BC) was calculated in the same way, giving quite likely isostatic curves (Fig. 6B) that include all the details indicated by the curves of changes in gradient (Fig. 5), the shorelevel displacement curves (Fig. 6A) and the shoreline diagrams.

The isostatic curves (Figs. 6B and 7B) allowed a detailed reconstruction of the land upheaval (M o r n e r 1969, Fig. 147). It was found that the intensity of land upheaval in general decreased with time and distance towards the periphery, that the centre and

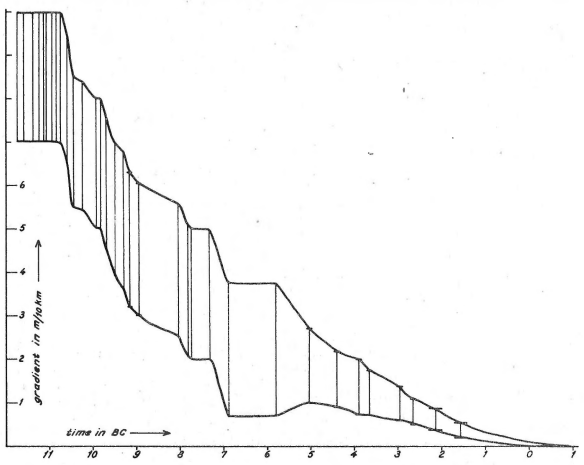


Fig. 5

Curves of changes in gradient. The vertical lines give the shorelines identified. The two curves are parallel up to 5,800 BC,i.e. to the time when the bend was created (cf. M ö r n e r 1969). Time scale in thousand of years.

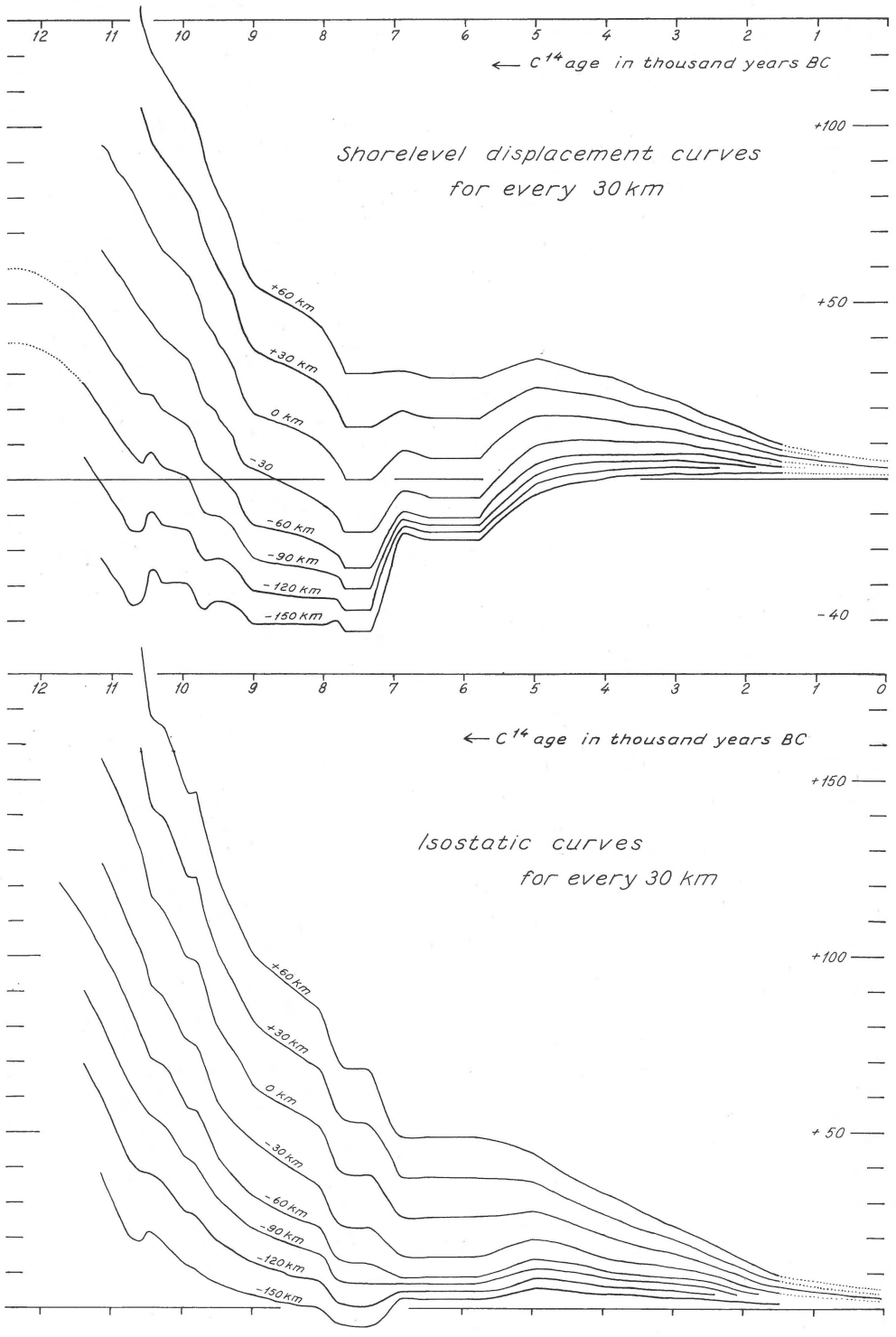
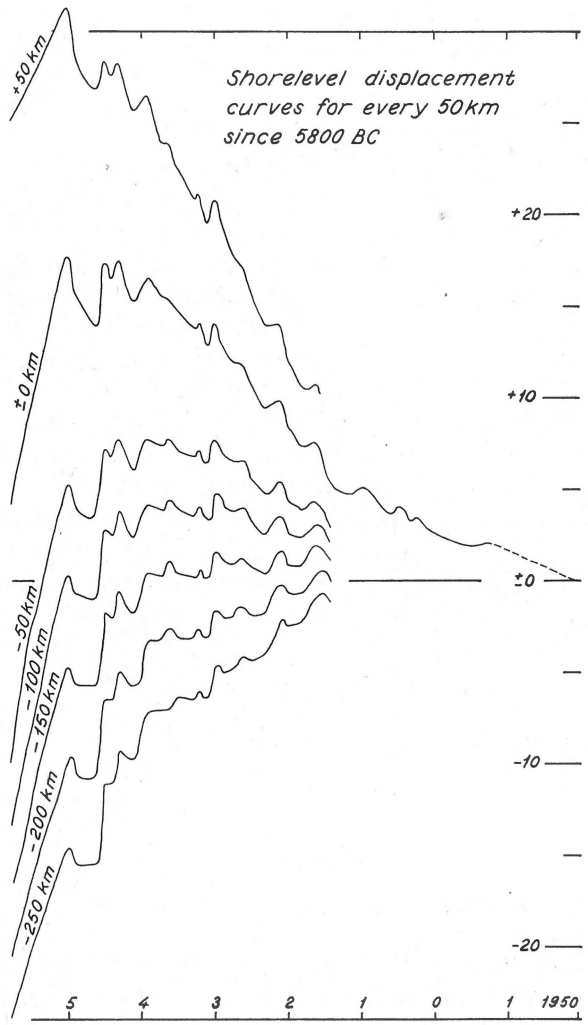


Fig. 6

A: (above) shorelevel displacement curves. B: (below) coresponding isostatic curves (S + E = I).



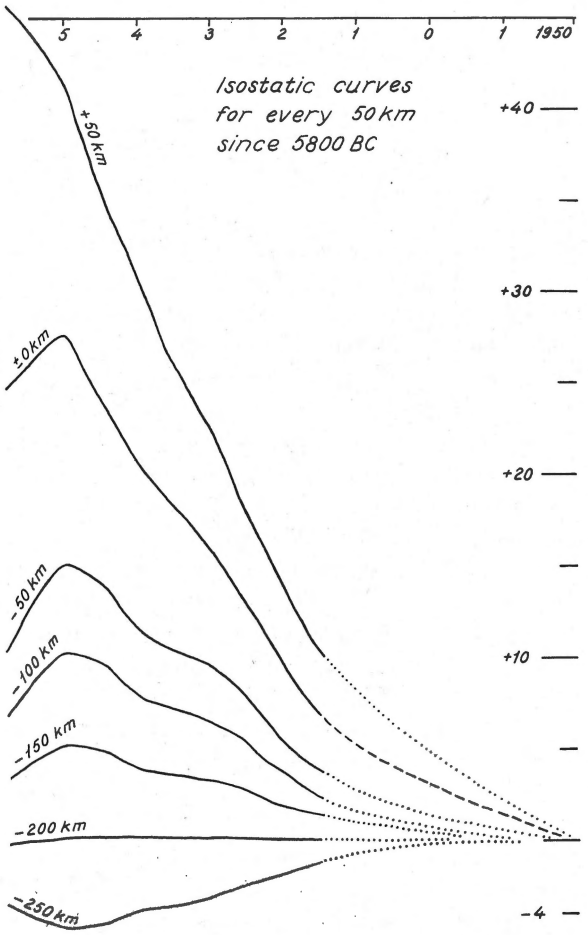


Fig. 7

A: (to the left) shorelevel displacement curves for the PTM/PR changes at different parts of the shoreline diagram.

B: (to the right) corresponding isostatic curves, giving a quite likely picture of land upheaval. The shorelevel displacement curve at the point -200 km almost exactly corresponds to the eustatic curve, indicating that this point (isobase) has been more or less stable during this period.

margin of land upheaval had changed position, and that the sensivity to changes in the load of ice (= glacio-isostasy) and water (= hydro-isostasy) was high.

The detection of changes in the land upheaval caused by hydro-isostasy is important, as it means that the transgressed shelf areas of the world most probably have sunk hydro-isostatically. Thus it must be very hard to find a real "stable area". This actualizes some words written by N e w m a n and M u n s a r t (1968, p. 95) "..we suspect that coastal stability is a myth and that curves depicting land-sea relationship probably are valid only locally. We doubt that any coast has remained stable during the Pleistocene Epoch..", as well as the first paragraph of this paper.

The eustatic curve here presented (Fig. 8) is the only one that can in a reliable way express the shorelevel displacement and isostasy of the area investigated. But of course this does not preclude further details (expected for the Alleröd and Younger Dryas periods) or minor changes. My eustatic curve is highly fluctuating.

Concerning the Late Glacial part there is an

obvious connection between the changes in climate and the fluctuations of the eustatic sea level. The Ågård, Bölling and Alleröd Interstadials all correspond to transgressions, while the Fjärås, Older Dryas (or Berghem) and Younger Dryas (or Ra-Billingen-Salpausselkä) Stadials correspond to regressions of 2-4 m. This also confirms the Ågård Interstadial and Fjärås Stadial as established by this investigation. Additional information about the eustatic changes from Northern Jylland and the NW Gulf of Mexico (cf. Mörner 1969) indicate a distinct regression corresponding to the East Jylland Stadial at about 13,000-12,800 BC. The average annual rise of the eustatic sea level during the last 15,000 years is 4,6 mm, while during the last 7,000 years it is only 1.5 mm and during the last 3,500 years it has been fluctuating around the present sea level.

The Early Postglacial eustatic fluctuations are important, indicating worldwide climatic changes (cf. Mörner 1969). During the Preboreal there is a transgression (= the Friesland Interstadial), a regression at about 7,800-7,700 BC (= the Eidfjord or Preboreal Stadial) and a syngression. During the Boreal there is a very distinct transgression (= a very distinct global amelioration of the climate), a regression at about 6,850-6,550 BC (= the Cochrane or Viskan Stadial) and a syngression. Concerning the eustatic fluctuations younger than 5,000 BC, the corresponding global climatic changes are as yet fairly incompletely known, though there are several indications of climatic deteriorations, corresponding to my PR stages, from the studies of glaciers "Little Ice Ages", the peat bogs (recurrence surfaces) and the vegetational history (pollen analysis). Apparently the eustatic changes between transgressions (PTM) and regressions (PR) reflect global climatic changes; PTM corresponds to ameliorations and PR to deteriorations of the climate.

Seen as a whole, the eustatic curve rises, with fluctuations, to PTM-7 at +0.4 m at 1,650-1,400 BC. Consequently, PTM-7 would correspond to the climatic optimum during the Postglacial and Holocene. However, as earlier pointed out (M ö r n e r 1969), this is not at all certain. The melting of the ice cover may have been retarded, so that the real climatic optimum does not necessarily correspond to the highest eustatic position, but can be older. Nevertheless, PTM-7 corresponds to a distinct climatic peak, called the Dosinia Optimum after its characteristic Lusitanic shell fauna in Kattegatt. The subsequent regression down to PR-8 at about 1,300-1,100 BC shows a distinct climatic deterioration (cf. M ö r n e r 1969), the Strandby Deterioration, marking the end of the Postglacial, Flandrian Interglacial and Holocene Epoch period of optimal climate (stage III in Fig. 2).

If my eustatic curve is true, it must in comparison with every true shorelevel displacement curve also give a true isostatic curve. However, very few sufficiently well fixed and closely dated shorelevel displacement curves exist. I have earlier (M ö r n e r 1969) compared my eustatic curve with available data

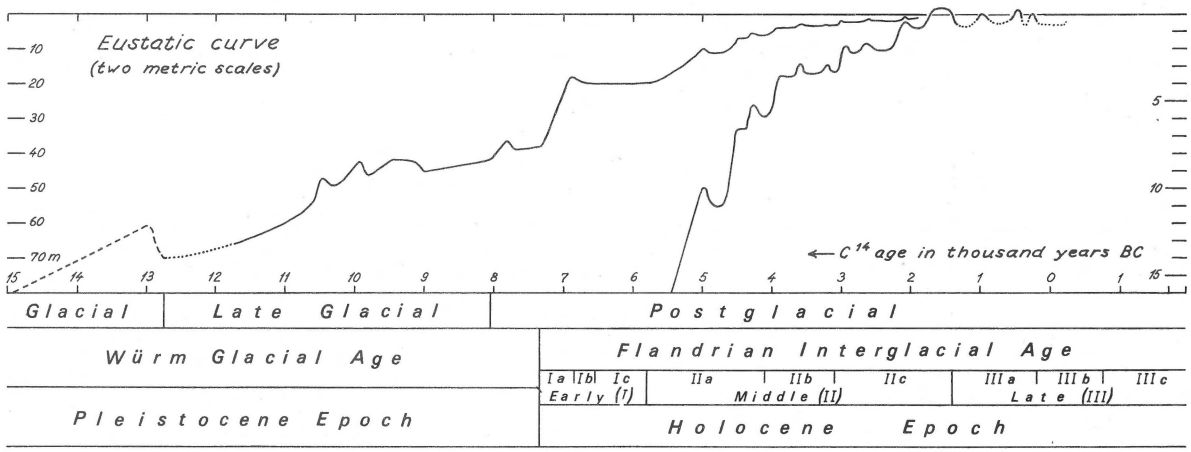


Fig. 8

Eustatic curve for the last 17,000 years. The younger part is enlarged in order to show the fluctuations. The subdivision of the Late Quaternary (three different systems) here proposed is shown below the eustatic curve.

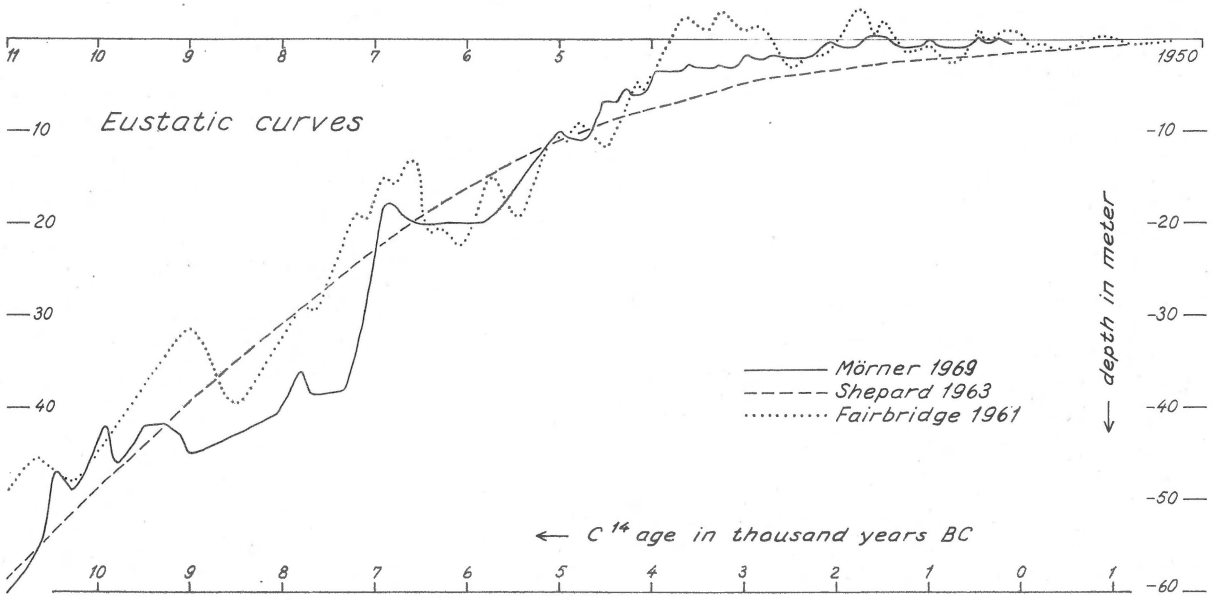


Fig. 9

Comparisons of different eustatic curves. Though differing in many important respects the general agreement is striking.

from areas all over the world. Here, I will only recall some of the main results.

The results from Eastern Blekinge, SE Sweden (Mörner 1969, Fig. 150), Northern Norway (Mörner 1969, Fig. 151) and maybe also the Firth of Tames, New Zealand (Mörner 1969, Fig. 155) and Christchurch, New Zealand (Mörner 1969, Fig. 156) were shown to correspond in detail with my eustatic curve. The fluctuations found on the NE coasts of the North Sea (Fig. 3) fit in age very wel with my eustatic fluctuations, but as the amplitude of these fluctuations cannot yet be fixed (the tide), only hypothetical isostatic curves can as yet be drawn (Mörner 1969, Fig. 152). Curray's (1960) data of the rise of sea level in the NW part of the Gulf of Mexico fall close to my curve (Mörner 1969, Fig. 154), suggesting that this area has been more or less stable during the last 17,000 years. The varied subsidence of the North American East Coast has been discussed (Mörner 1969). Scholl's time-depth indications from Florida (Scholl 1964, Scholl and Stuiver 1967) were shown to reflect a slight subsidence and not at all to contradict (maybe even support) the fluctuations of my eustatic curve (Mörner 1969, Fig. 153). In Fig. 9 my eustatic curve is compared with the curves by Fairbridge (1961) which, as has been shown from many different parts of the world, need to be reinterpreted, and Shepard (1963), which is only an average curve. Though differing in many respects the general agreement is striking.

The results of my investigation (Mörner 1969) show a striking agreement between the changes in ice recession, climate as recorded by pollen and molluscs, shorelevel displacement, isostasy and eustasy. In my opinion these results must be considered as more reliable than older ones for the following reasons: the uniquely suitable conditions in this area for the reliable determination of the shorelines, the large area in the direction of tilting over which the shorelines were followed and the isostatic and eustatic curves checked, and the great number of good datings (radiocarbon and pollen).

THE LATE QUATERNARY SUBDIVISION

The results of the present investigation have actualized the question of the boundaries in the Late Quaternary. Global climatic changes can hardly be better determined than by eustatic fluctuations. Fig. 8 shows the boundaries, here proposed, for the following three systems:

1. the local North European Glacial – Late Glacial – Postglacial system
2. the global Glacial – Interglacial system (Ages of the Quaternary Period)
3. the global Epoch system of the Quaternary, i.e. Pleistocene – Holocene

The Glacial – Late Glacial – Postglacial boundaries

For stratigraphical, climatical and historical reasons the Late Glacial – Postglacial boundary must be placed between Younger Dryas (zone III) and Preboreal (zone IV) at 8,050-8,000 BC. For climatic-eustatic reasons the Postglacial was subdivided into four periods (I-IV) as shown in Fig. 3 (cf. M ö r n e r 1969, Fig. 138). The boundary between the Glacial (Upper Pleniglacial or Late Weichselian Glaciation) and the Late Glacial can be placed either at the end of the East Jylland Stadial (about 12,750 BC), or at the onset of the Susaca Interstadial (about 11,750 BC; V a n d e r H a m m e n and V o g e l 1966) or at the onset of the Ågård Interstadial (10,700 BC). In my opinion this boundary is most suitably placed at about 12,750 BC,i.e. where the eustatic curve started to rise and the ice to recede after the East Jylland Stadial.

The Glacial – Interglacial boundary

The generally cold climate prior to 8,000 BC clearly contradicts an onset of the present Interglacial at any of the climatic ameliorations prior to that time. For climatic-eustatic reasons the boundary between the Würm (Weichselian, Wisconsin) Glacial Age and the Flandrian Interglacial Age can be placed either at 8,050 BC, i.e. at the onset of the Preboreal and Postglacial, or at 7,330 BC,i.e. at the onset of the Boreal and the very distinct eustatic rise of sea level, or at 5,800 BC,i.e. at the onset of the Atlantic and the rapid eustatic rise of sea level. From the North European point of view the oldest date may be preferable. However, this does not apply in other areas, e.g. in North America, nor does it fit with the eustatic curve. The very distinct eustatic rise of sea level and climatic amelioration starting at 7,330 BC are here supposed to give the most logical boundary between the Würm Glacial Age and the Flandrian Interglacial Age.

The Pleistocene – Holocene boundary

This boundary has been placed very differently. From deep sea studies it has been proposed at about the Alleröd Interstadial. However, the climatic-eustatic change is here supposed not to have been drastic enough to justify its placing it there. In North Europe, the Holocene and Postglacial have often been given the same age (e.g. T. N i l s s o n 1965). In North America the Holocene (= Recent) is generally supposed to start much later, at about 3,000 BC. Furthermore, many geologists dislike distinguishing a special Late Quaternary Epoch. Thus it is very suitable to make the onset of the Holocene Epoch equivalent to that of the Flandrian Interglacial, so that people reluctant to distinguish the Holocene Epoch can instead use the Flandrian Interglacial Age. Recent (with capital R) is then a useful local North American period, which must not be correlated with the global Holocene Epoch. The Holocene Epoch and Flandrian Interglacial Age are for climatic-eustatic reasons subdivided as follows:

Period I: 7,330-5,800 BC (corresponding to the Boreal), divided into Ia (= zone Va) 7,330-6,850 BC, Ib (= zone Vb) 6,850-6,550 BC, and Ic (= zone VI) 6,550-5,800 BC.

Period II: 5,800-1,400 BC, the period of optimal climate (corresponding to the Atlantic and early Sub-boreal), divided into IIa (=early Atlantic) 5,800-4,100 BC), IIb (= late Atlantic) 4,100-3,100 BC, and IIc (early Sub-Boreal) 3,100-1,400 BC.

Period III: 1,400 BC onwards, the period of climatic deterioration (corresponding to late Sub-Boreal and Sub-Atlantic), divided into IIIa (= late Sub-Boreal) 1,400-200 Bc, IIIb (= zone SA-1) 200 BC to 750 AD, and IIIc (= zone SA-2) after 750 AD.

These periods can also be termed Early (I), Middle (II) and Late (III) Holocene or Flandrian.

REFERENCES

Curray, J.R. (1961) – Sediments and history of Holocene transgression, continental shelf, Northwest Gulf of Mexico. *In* Recent sediments, Northwest Gulf of Mexico. Am. Assoc. Petr. Geol., p. 221-256.

Fairbridge, R.W. (1961) – Eustatic changes in sea level. Physics and Chemistry of the Earth, Vol. 4, p. 99-185.

Hammen, T. van der and J.C. Vogel (1966) – The Susaca-Interstadial and the subdivision of the Late-Glacial. Geol. en Mijnb., 45, p. 33-35.

Jelgersma, S. (1961) – Holocene sea level changes in the Netherlands. Med.Geol.Sticht., Ser.C-VI, 101 pp.

—— (1965) – Sea-level changes during the last 10,000 years.Roy. Met. Soc. Proceedings of the Symposium on world climate from 8000 to O BC, p. 54-71.

Newman, W.S. and G.A. Munsart (1968) – Holocene geology of the Wachapreague lagoon eastern shore Peninsula Virginia Marine geology, vol. 6, p. 81-105.

Nilsson, T. (1965) – The Pleistocec-Holocene boundary and the subdivision of the Late Quaternary in Southern Sweden. Report of INQUA VI Congress in Warsaw 1961, vol. 1, p. 479-494.

Mörner, N.A. (1969) – The Late Quaternary history of the Kattegatt Sea and the Swedish West Coast: deglaciation, shorelevel, displacement, chronology, isostasy and eustasy. Sweriges Geol. Unders., Ser. C, No. 640.

Scholl, D.W. (1964) – Recent sedimentary record in mangrove swamps and rise in sea level over the southwestern coast of Florida: Part 1. Marine Geol., Vol. 1, p. 344-366.

Scholl, D.R. and M. Stuiver (1967) – Recent Submergence of Southern Florida: A comparison with adjacent coasts and other eustatic data. Bull. Geol. Soc. Am., Vol. 78, p. 437-454.

Shepard, F.P. (1963) – Thirty-five thousand years of sea level. *In* Essays in marine geology. Univ. S. Calif. Press, Los Angeles.

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