EUSTATIC FLUCTUATIONS OF THE BALTIC SEA IN THE HOLOCENE

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In recent decades much attention has been paid to the fluctuations of the world ocean and of its separate seas. Successful solution of this problem would enable to throw light upon such world-wide processes as the advance and degradation of Pleistocene glaciations, as well as to the development of natural processes, flora, fauna and human society in separate regions.

Such investigations are of great importance in the region of the Baltic basin where the immediate influence of the dynamics of spatial sea development on the specific character of the climatic conditions and on the nature of the organic world greatly determined the rate of migration of the flora and fauna of premevial community.

In connection with that intensive studies aimed at the reconstruction of the geological past of the Baltic Sea in the Holocene are being carried out in all the surrounding countries. A rich spectrum of coastal formations at different altitudes, findings of the remnants of subfossil fauna, buried lagoonal and lake-bog deposits all over the coast of the aquatorium have enabled to draw up a geomorphologically, biostratigraphically and geochronologically grounded systematisation of the geological past of the basin in its different parts. At the present moment the main task is that of interregional correlation, temporal comparison of separate stages in the history of the Baltic Sea on the entire surrounding territory. Still, it should be pointed out that in spite of comparatively thorough investigations the composition of an indisputable correlation scheme has up to now been unsuccessful. This is, first of all, due to different interrelations between the neotectonic component in the vertical movement of earth's crust and the eustatic component of sea level in different regions of the Baltic. This circumstance causes great difficulties in the application of geomorphological and biostratigraphical methods in interregional correlation: the shorelines of the same age are situated at different altitudes and the ecological conditions have been greatly influenced by local hydrological and mezoclimatic conditions.

The reconstruction of the eustatic curve in no doubt plays an important role in the correlation. Geomorphological and biostratigraphical distinction of separate indicator levels of the basin and their precise addition to the temporal scale appear to be the primary tasks in order to determine the eustatic fluctuations of the basin.

As the result of several years of investigation dozens of sections in the North Baltic have been studied by us (Kessel, Punning, 1984; Кессел, Пуннинг, 1969 a, b; Пуннинг,et al. 1982), which provides a reliable basis for the reconstruction of the eustatic curve.

As is known, the Baltic Shield and East European Platform are rather stable from the tectonical point of view and the tectonic regime derived from the Palaeozoic was evidently not subjected to considerable changes during the Holocene. Hence, the vertical movement of the earth's crust in the North Baltic results from the uplift which, having started in the Palaeozoic, is proceeding at a stable rate and to which a glacio-isostatic component decreasing logarithmically in time was added in the Holocene. Differences in the absolute height of ancient shorelines and lagoons have on one hand been caused by the eustatic fluctuations of the Baltic Sea and on the other hand by the total amplitude of the vertical uplift of the given territory during the past time interval. In order to distinguish these components the data obtained through the studies of North Estonia type sections have been made use of. Figure 1 shows the age of lagoonal deposits dated by the ^{14}C method and their absolute heights. The rate of the present

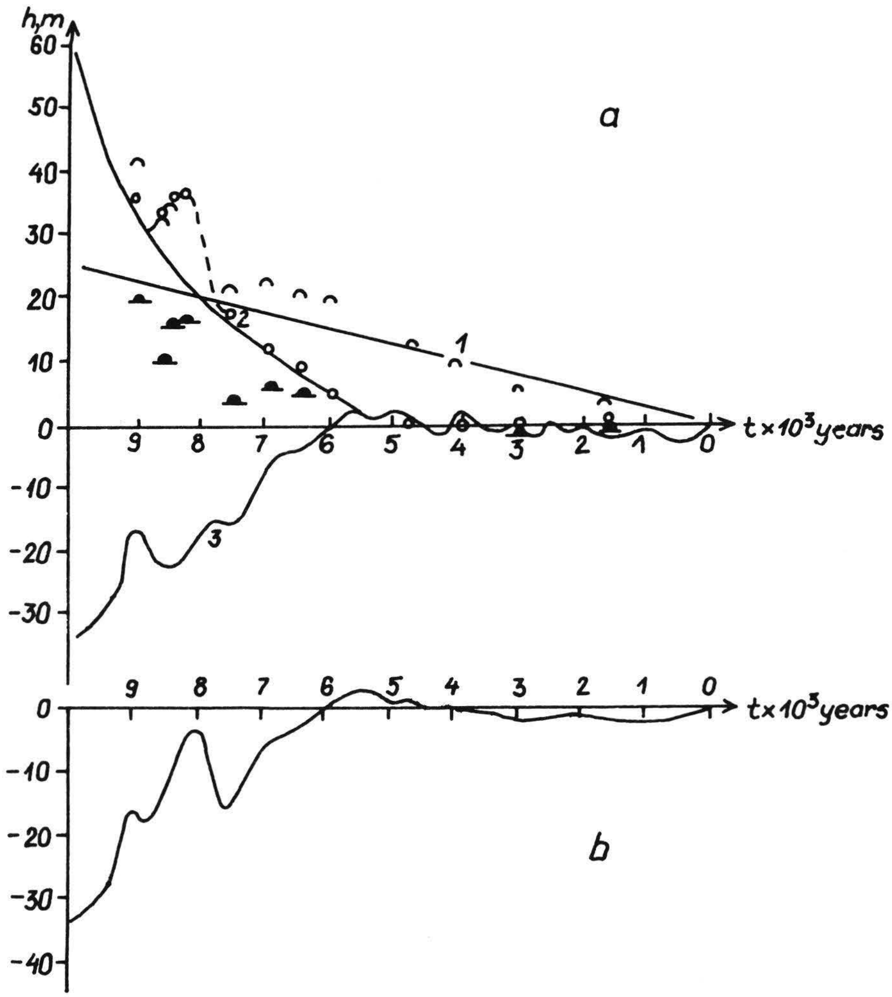

Fig. 1. A scheme of the reconstruction of the Baltic eustatic curve. a) 1— coastal lines dated by ^{14}C method (mainly lagoon deposits) in North Estonia; 2— glacioisostatic component; 3— height of coastal lines without the component of inherited tectonic uplift. Curves: 1— inherited tectonic uplift; 2— glacioisostatic uplift; 3— eustatic curve by R. Fairbridge (1961). b) the reconstructed eustatic curve of the Baltic Sea.

uplift in the study area (North Estonia) is 2,5 mm/year (Желнин, 1964). Extrapolating this rate in the past (curve 1) it is possible to eliminate the derived component from the total tectonic uplift. The differences from the height of the present sea level are caused by the changes in the level of the Baltic Sea and the value of total glacioisostatic uplift. The distinction of these two components is possible on the assumption that the fluctuations in the level of the Baltic Sea and the eustatic fluctuations of the world ocean were synchronous. The most informative eustatic curve is that of R. Fairbridge (Fairbridge, 1961, 1976) (Fig. 1, curve 3) which has been based on a great amount of factual material from tectonically stable platform areas in North Atlantic. If we add the absolute height of the ancient sea level (with the opposite sign) to that of the present coastline or lagoon we obtain the total value of the glacioisostatic uplift and by connecting the points get the curve of the glacioisostatic uplift (Fig. 1, curve 2).

Glacioisostatic uplift is known to be governed by logarithmic regularities (Kelly, 1973; Bergqvist, 1977; Артюшков, 1967). Thus, in the linear axes the geometrical form of the glacioisostatic curve must be that of the hyperbola. As can be seen from figure 1, the compiled curve (2) corresponds to a typical glacioisostatic one which approaches abscissa in the place where the age of coastal levels is about 5000 years. By that time the depression had been totally compensated (Mörner, 1976; Грачов, Долуханов et al. 1970). The deviation of the curve from the hyperbola during the time interval of 8900—8000 years ago shows that at that time the fluctuations in the water level of the Baltic Sea were not synchronous with those of the world ocean, which means that the Baltic Sea must have been isolated from the Atlantic Ocean. Thus, it becomes possible to determine precisely the duration of this lacustrine stage and to estimate differences in the levels of the lake and the world ocean. According to the obtained data the maximum difference of 16 m was reached about 8200 years ago. It also follows from the curve that the lacustrine (isolated) conditions governed in the basin of the Baltic Sea only once in the Holocene, during the Boreal climatic period. Taking into consideration the rectifications in the time intervals from 8800 to 8000 years and from the year 5000 up to the present time it becomes possible to reconstruct the eustatic curve of the Baltic Sea (Fig. 1 b).

The compiled curve makes it easier to reconstruct the palaeogeographical conditions in different regions and to carry out interregional correlations. For this purpose it is essential to know the rate of the derived vertical tectonic movement on the territory under investigation, which in the first approach is compared to the present one, and the parameters of the glacioisostatic curve. For the mathematical description of the latter the obtained data of the glacioisostatic uplift for North Estonia (taking into consideration the eustatic curve) are given in the polylogarithmic system of coordinates (Fig. 2). The compiled curve is expressed by the formula $\log h_t = - k\, t \log h_o$, where h_o is the value of total compensation (at the time of the unloading — t_o) and h_t = the residue compensation in t (t = time interval in thousands of years from the moment of the unloading). The fact that almost all the heights of the marking positions of ancient coastal levels are well suited to the proposed eustatic curve is a telling proof of its accuracy. Such polylogarithmic linear dependency of the value of glacioisostatic uplift facilitates considerably the reconstruction of separate components in the total uplift. In the first approach only knowledge of the rate of present vertical movement and of the height of two precisely dated shorelines in the given area is required in order to compile the curve of the glacioisostatic uplift. Figure 2 shows such curves for the territories with a high (West Finland, South West Finland, North Estonia) and a low (South East Estonia, South Sweden) gradient of uplift. The reconstruction has been based on the data obtained by B. Berglund (1964), M. Eronen (1974, 1976, 1983), H.

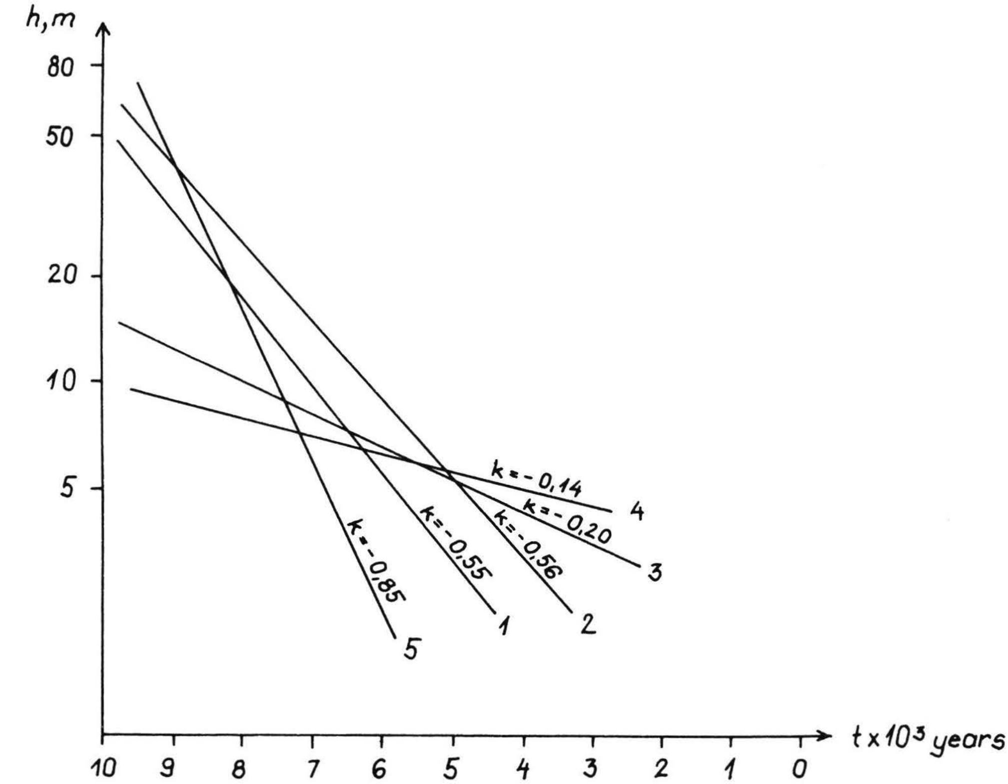

Fig. 2. Curves of glacioisostatic uplift: 1— Helsinki; 2— Tallinn; 3— Pärnu; 4— Blekinge; 5— Satakunta.

Kessel and J.-M. Punning (1984). The values of »k» decrease regularly from —0.85 (Satakunta) to —0.14 (Blekinge). Calculating the values of total tectonic movements and making use of the eustatic curve it becomes possible to reconstruct the relative amplitudes and time intervals of regression and transgression stages for different regions (Fig. 3). If $dE/dT > 1$, then the study area was inundated; if $dE/dT < 1$, then the area was governed by regressive conditions. The values dE (the changes in the water level of the basin) can be directly obtained from the eustatic curve of the Baltic, while dT (fluctuations in the amplitudes of vertical movement of the earth's crust) can be figured out using the formula $T = h_t + t \cdot T_o$, where h_t = glacioisostatic component (see fig. 2), T_o = the rate of present movements.

On figure 3 where the dE/dT ratios are given over periods of 200 years, 4 transgressive cycles in the first half of the Holocene (9600—9000; 8900—8100; 8000—6800; 6700—5600) can be distinguished which could be correlated with the Echeneis, Ancylus, Mastogloia and Littorina stages. These cycles are well pronounced everywhere in the studied areas, only the relative values of amplitudes differ greatly depending on the concrete regime of neotectonic movements. The transgressive — regressive phases are more explicitly expressed on the territories with a low gradient of tectonic uplift as, for instance, South Sweden and South West Estonia. Already in West Finland (Satakunta) with its present uplift rate of 6,5 mm/year (Eronen, 1983) the phases have become indistinct. Big differences in the morphology of the curves and a small temporal dis-

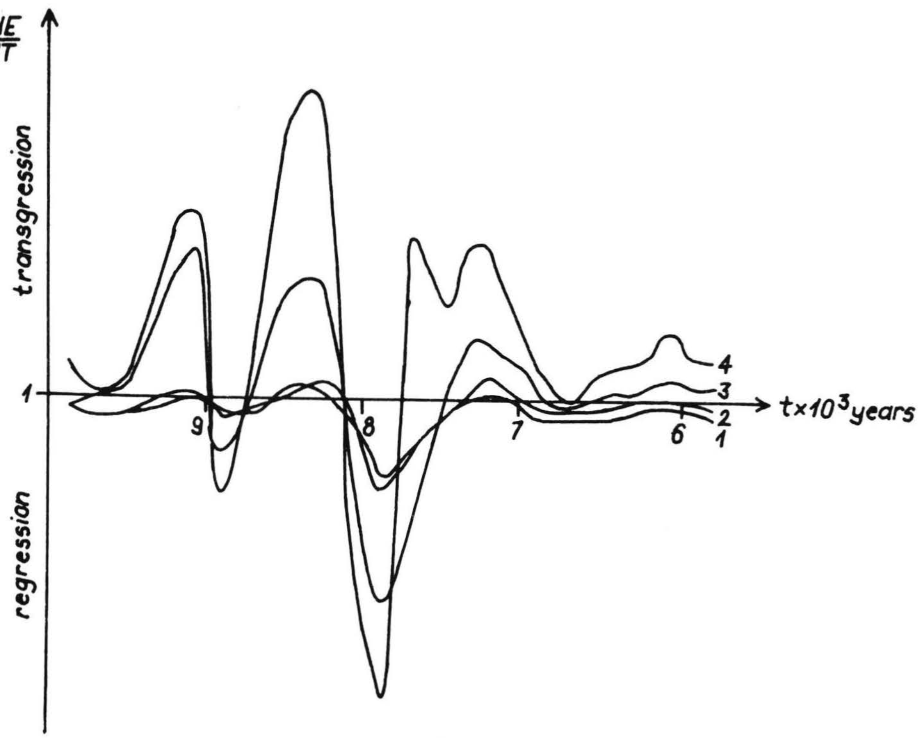

Fig. 3. Transgressive—regressive cycles in different regions of the Baltic Sea: 1— Helsinki; 2— Tallinn; 3— Pärnu; 4— Blekinge.

placement in the culminations of transgressions speak of different ecological conditions in various regions which aggravates interregional correlation on biostratigraphical basis. It can also be noticed that the smaller the value »k» of the curves of isostatic uplift, the earlier begin all the transgressions.

The eustatic curve of the Baltic Sea permits interregional correlations on rather safe grounds. After all, the only reliable method of correlating different transgressive or regressive stages in various places of finding is the ^{14}C method. Biostratigraphical methods of investigation, characterizing the change of ecological conditions, in this case reflect first of all such parameters of water as temperature, salinity, depth etc. But as can be seen from figure 2 essential differences in the ecological conditions of various parts of the sea were caused by the differences in the rate of neotectonic uplift as well as by variations in the geological and climatic conditions, dismemberment of the coasts, the influx of big rivers and many other reasons. It should still be pointed out that due to the inadequate representation of the dated material not all the ^{14}C datings reveal the actual time of the accumulation of the layer under study.

Knowing the altitudes of two dated shorelines and the rate of present vertical movement in the study area it becomes easy to reconstruct the spectrum of coastal levels making use of the formula $H_t = t\,T_o + h_t - E$, where H_t = the height of the shorelines in comparison with the present sea level; T = the rate of present vertical movement; t = time; h_t = residue compensation; E = the height of sea level in comparison with the present one.

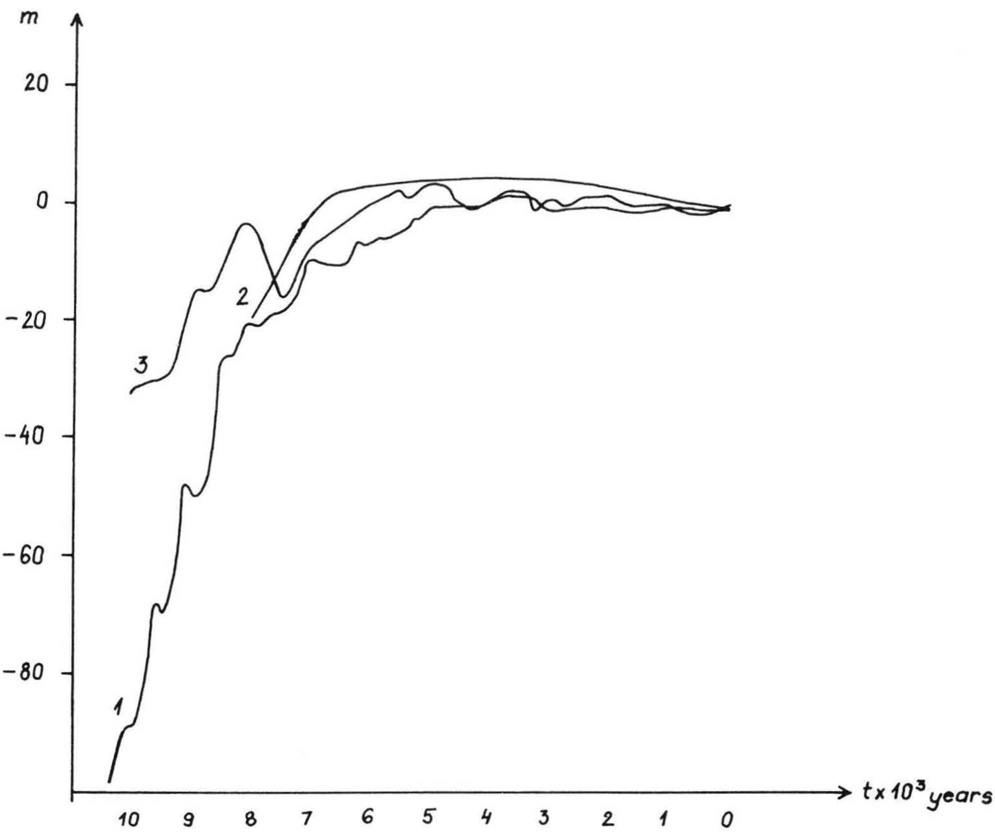

Fig. 4. Eustatic curves of the Baltic Sea: 1— by O. Kolp; 2— by M. Eronen; 3— by J.-M. Punning.

Up to now a number of eustatic curves for the Baltic Sea have been proposed (Fig. 4). The curve compiled by us is in rather good agreement with that of Eronen (1974) but differs greatly from the one of Kolp (1978). O. Kolp distinguishes a number of underwater terraces in the South Baltic and correlates their formation with a certain stage in the development of the Baltic basin. Although the 0-isobasis of this region drifted in the Holocene and the reconstruction of the value of tectonic movement is difficult, we do not consider the addition of the age of terrace formation to the temporal scale as done by O. Kolp to be entirely exact. Thus our dating of 9360 ± 110 BP (Tln.-318) based on the organogenous deposits from the core near Rügen Island with a depth of about 21 m, shows that the distinction of the Yoldia terrace in the depth of 60 m (Fig. 4) is not justified.

In such a way the proposed eustatic curve of the Baltic Sea helps to estimate the representativity of the dated material and to correlate different shorelines in all the regions surrounding the aquatorium of the sea. The curve is of great significance in specifying the development of premevial human community which was closely related to the development of ancient shorelines.

REFERENCES

Berglund B. E., 1964. The post-glacial shore displacement in eastern Blekinge, south-eastern Sweden. SGU. Ser. C, Nr. 599, 47 pp.

Bergqvist E., 1977. Post-glacial land uplift in Northern Sweden: some remarks on its relation to the present rate of uplift and the uncompensated depression. GFF 99, 347—357.

Eronen M., 1974. The history of the Littorina Sea and associated holocene events. Comment. phys-math. 44: 4, 79—195.

Eronen M., 1976. A radiocarbon dated Ancylus transgression site in Southeastern Finland. Boreas 5, 65—76.

Eronen M., 1982. The course of shore displacement in Finland. In: Holocene sea level fluctuations, Magnitude and Causes. Univ. of South Carolina, S.C., USA, p. 43—60.

Fairbridge R. W., 1961. Eustatic changes in sea level. In Physics and chemistry of the Earth v. 4, 99—185.

Fairbridge R. W., 1976. Shellfish-eating preceramic Indians in coastal Brasil. Science 191, 353—359.

Kessel H. and Punning J.-M., 1984. The development of the Baltic Sea in the Holocene. In Estonia. Nature, man, economy. Tallinn, p. 36—47.

Kolp O., 1974. Submarine Uferterrassen in der südlichen Ost- und Nord-sea als Marken eines Stufenweise erfolgten Holozänen Meeresanstiegen. Baltica 5, 11—40.

Mörner N.-A., 1976. Eustatic changes during the last 8000 years in view of radiocarbon calibration and information from the Kategatt region and other northwestern European coastal areas. Palaeogeogr., Palaeoclimatol., Palaeoecol. 19, 63—85.

Артюшков Е. В., 1967. Об установлении изостатического равновесия земной коры. — Физика Земли, № 1, с. 3—16.

Грачов А. Ф., Долуханов П. М., 1970. Послеледниковое поднятие Земной коры в Канаде и в Фенноскандии по данным радиоуглеродных датировок. — Балтика, т. 4, с. 297—312.

Желнин Г. А., 1964. Точность и возможности метода повторного нивелирования. — В кн: Современные и новейшие движения земной коры в Прибалтике. Вильнюс, с. 17—24.

Кессел Х. Я., Пуннинг Я.-М. К., 1969в. Об абсолютном возрасте голоценовых трансгрессий Балтики на территории Эстонии. — Изв. АН ЭССР, Хим. геол. т. 18, № 2, с. 140—153.

Кессел Х. Я., Пуннинг Я.-М. К., 1969а. О распространении и стратиграфии отложений Иольдевого моря на территории Эстонии. — Изв. АН ЭССР, Хим. геол., т. 18, № 2, с. 154—163.

Пуннинг Я.-М. К., 1982. Эвстатические колебания уровня Балтики в голоцене. — В сб. Колебания уровня морей и океанов за 15000 лет. с. 134—143.