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Glacials, interglacials and ice covers

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Abstract: A stratigraphic approach to the Quaternary which takes into account the changes in climate (Pleistocene cold stages = glacials, and Pleistocene warm stages = interglacials, with considerable variations in temperature and humidity), and appearance and disappearance of ice sheets in certain areas. Reduced ice sheets might have remained during the interglacials.

Key words: Mega-glacials/mega-interglacials, Pleistocene cold stages = glacials, warm stages = interglacials, ice covers = glaciations.

Introduction

The essential units of the stratigraphic division of the Quaternary are assumed to be the long stretches of time characteristic periods: cold stages ("glacials") and warm stages ("interglacials"). The term "glaciation" – exactly ice covers increase, however, is frequently applied as a synonym of "a cold stage," although the enormous spatial and temporal variability of the former does not warrant its identification with a glacial, or a long stretch of cold climate (Stankowski 1995).

Certain areas may become covered with ice during either a glacial or an interglacial. The present condition of the Earth furnishes clear proof of this postulate.

The current ice situation of the Earth illustrates the differences in the glaciation phenomena between the Southern and the Northern hemisphere, and between various areas within a hemisphere. More confirmation of this diversity may be found in the development of ice in ocean water and in the changes in the environmental properties of the oceans (which often appear at an angle to the parallels of latitude), as evidenced, e.g., by the distribution of the zones of the various spins of the shells of *Globigerina pachyderma* in the North Atlantic (Ericson & Wollin 1964).

The results of the latest isotope tests of ice profiles in the Antarctic and Greenland show that during the last 100,000 years the number of warm periods in the

Southern hemisphere (nine events) differed from their number in the Northern hemisphere (twenty-two events), see Bender *et al.* 1994. W. C. Broecker 1994 describes a major climatic fluctuation in the Northern hemisphere during the last 35,000 years, or during the most recent glaciation of this part of the planet.

It must be emphasized that geological, paleoenvironmental and paleoclimatic data proof the lack of coordination in the glaciation phenomena in the Northern hemisphere during the last cold stage, i.e., during the last 100,000 years. The development of the ice sheets in Europe and North America, the changes in their area over time, and the rate of their disappearance were not fully synchronous. Data in support of this statement may be found in Patterson *et al.* 1977; Kozarski 1981; Rasmussen 1982; Fulton 1984; Lindner 1987, 1992, etc. We are also aware of significant differences in the time of the glaciations of Spitsbergen on the one hand and Scandinavia and Central Europe on the other during the last cold stage (Baranowski 1977; Lindner *et al.* 1986).

The lack of simultaneity in the glaciation of the Earth becomes even more striking when we investigate the matter throughout the Cenozoic.

Depending on the adopted criteria, the Cenozoic is considered to have begun between 3.4 and 0.6 million years ago. Its commencement is usually considered to be marked by changes in the species of benthonic foraminifera: the extinction of *Globorotalia tosaensis*, *Globorotalia miocena* and *Globorotalia obliques*, which lived in warm water, and the development of *Globorotalia truncatulinoides*, adapted to cold water. This took place during the Olduvai positive paleomagnetic episode, app. 1.87–1.67 million years ago, during the middle part of the Matuyama geomagnetic epoch. Still, this period cannot be related to a relevant global milestone in the history of ice cover development – glaciations.

The earliest traces of small ice sheets appeared in the Northern hemisphere app. 2.5 million years ago. However, the last "ice age" – time with extensive ice covers development, started only 950,000 years ago, and possibly as recently as 700,000–600,000 years ago. The older, pre-glacial periods – time with no ice covers, of the Quaternary are referred to as the pre-Pleistocene, the proto-Pleistocene and the eo-Pleistocene.

Evidence from the Southern hemisphere proves that huge ice covers began there in mid-Eocene (app. 54 million years ago). As of mid-Oligocene (app. 32 million years ago) we are dealing with extensive glaciations. The Polish studies of the Antarctic contributed to confirming these postulates (Birkenmajer 1990, 1992). Since that period, the glacial phenomena have been continuing incessantly, although the area of the ice sheets has undergone substantial changes.

Mega-glacials and mega-interglacials

During many periods of the pre-Cenozoic, the glacial phenomena were extremely long and extensive, taking the form of glaciations and the development of periglacial areas (Hambrey & Harland 1981). The earliest geological data which are indicative of the cold stages and the concomitant glaciations, come from 2.3–2.6 billion years ago. Such periods are separated by equally lengthy periods when the phenomena typical of cold regions became insignificant or altogether ceased.

Thus, we may distinguish “mega-glacials” and “mega-interglacials” in the past of the Earth.

The last “mega-interglacial” took place during the Mesozoic and the early Tertiary. There is no evidence of cold climate, not to mention glaciations, neither in the far North nor in the far South. Even as recently as in the Paleocene, deciduous forests of a composition similar to the woods of present-day Southern Chile grew in the Antarctic.

The last “mega-glacial” started in the Eocene. This date is attested to by the paleotemperatures of ocean water inferred from the isotope composition of the shells of the planktonic and benthic foraminifera. Beginning with the Eocene, the temperature of ocean water both at the surface and at large depths started to fall down steadily, a general tendency whose effects were at times amplified by the markedly colder climate (van Andel 1991).

Between the Eocene and the Oligocene, the paleotemperature and paleoenvironment of the Earth abruptly changed. The composition of the vegetation in the Antarctic altered radically, with only patches of stunted plants surviving, and the developing ice sheets reaching the sea coast in numerous places. At the same time in Northern Canada, the local flora, fond of warm climate, was replaced by forests typical of a more moderate clime. Europe, including Poland, was invaded by several varieties of pine. The resin of these trees produced the large amounts of amber in late-Eocene deposits. The abundance of amber and its abrupt appearance are indicative of the changes in climate (the “Terminal Eocene Event”). A significant change in temperature occurred in the water of the North Sea, as testify the data on oxygen isotopes (Buchart 1978).

A characteristic of the last “mega-glacial” was the lack of simultaneity of the development and lateral extent of the cold areas, and in particular of the related glaciations. The paleogeographical evolution due to the plate tectonics was of primary importance. Secondary changes occurred in the orographical condition, producing differences in the elevation of land, and consequently affecting the organization of the tiers of climate.

The global geological processes were accompanied by modifications in the solar radiation, of varying intensity and duration (Imbrie & Palmer Imbrie 1979; Wysoczański-Minkiewicz 1981; Kozarski 1986; Lemon 1990; Han-Shou Liu 1992).

The cyclical quality of the changes in the thermal condition of the Earth is evidenced by numerous phenomena occurring both in water and on land. In the oceans, the number and characteristics of the planktonic foraminifera varied in keeping with such changes (Ruddiman & McIntyre, [in:] Lindner 1992), water level fluctuated extensively (Fairbridge 1961), and isotopic characteristics underwent modifications (Shackleton & Opdyke 1973). On land, periglacial landscape periodically appeared, and glaciations took place in mountains and large areas of continents (cf. the detailed discussion of this matter in Lindner 1992).

During the last "mega-interglacial" i.e. in upper Mesozoic and lower Cenozoic time, the climate fluctuated to cooler and warmer conditions, but all over the Earth not any glacials occur.

During the last "mega-glacial," there was a number of long periods of cold and warm weather, which ought be considered "cold stages" and "warm stages," what is tradicionally call glacials and interglacials.

Glacials and interglacials

In the course of the lengthy "cold stages," water and land were covered with ice at various moments and locations. This happened on several occasions during each stage; accordingly, a characteristic of a "glacial" is the occurring of a number of glaciations (ice covers) separated by periods during which the area of ice sheets was radically reduced. Even at the times when the ice sheets diminished maximally, certain locations in various regions of the Earth remained covered with ice.

It must be emphasized that during the "warm stages," i.e. the "interglacials", the ice sheets survived in a vestigial form, and in certain areas only slightly reduced. The current ice situation of the Earth is a case in point.

Based on the collected data on the warm and cold stages of the Quaternary and the glaciations, the stratigraphy of that period has been described. The first account of that issue was Penck & Bruckner 1909. Since that time, the terms "glacial period" and "glaciation" of any particular area very often are thought to be synonymous. In fact, they should be approached as representing different stratigraphic and environmental levels. Evidence in support of this postulate may be found in the characteristics of the sediments and relief of both oceans and continents.

The well-known climatological and stratigraphic division of the Pleistocene in Różycki 1964 should in fact be applied to all of the Quaternary, with the orders slightly rearranged.

Within the "mega-glacials," the units of the highest order are cold stages = glacials, and warm stages = interglacials. In the course of a unit of either type, the thermal condition of the Earth underwent considerable periodical variations. Accordingly, the essence of such units is the occurrence of a series of climatic pessimum and optimum. Their results were glaciation phenomena developing over time and space: on some occasions, increased ice cover on water and the expansion of areas of long-lasting permafrost; on other occasions, the spreading of the ice sheets, both on the water areas and principally on continents; and at yet other times, the virtual cessation of glaciation phenomena. Outside glaciated areas changes in temperature and humidity are noticeable during periods referred to as "pluvials" and "interpluvials (e.g., in Northern Africa)."

As we have already mentioned, a number of climatic pessimum and optimum may be distinguished in the course of a cold or warm stage, the magnitude of the pessimum being smaller during a warm stage, and of the optimum, smaller during a cold stage. This phenomenon contributes to the alternation of glacials and interglacials.

The latest data demonstrate that several ice covers = glaciations may occur in the course of a single glacial period, and several separate optimums, ranking as "interglacials" according to paleobotanical criteria, in the course of a certain warm stage.

Nevertheless, various regions of the Earth may remain frozen or glaciated during either a glacial or an interglacial (although to a distinctly lower degree). Glaciation takes place, and its most conspicuous sign is the development of ice sheets.

The development of ice covers – glaciation and disappearing of ice covers – deglaciation happening during a glacial period may be classified by units of a lower order, called glaci-stadials and interglaci-stadials. The latter are broken down into glaci-phases and interglaci-phases, and sub-phases, as defined in Kozarski 1962, may also be included in this taxon.

The taxonomic units of the lowest level are glaci-oscillations. Evidence of these is available both from the geological study of the Pleistocene and from historical records. Their instances are the oscillations described in Kozarski 1962 and it can be the Little Ice Age too.

Given this approach to the climatic changes during the Quaternary and the development and disappearance of well proved ice sheets in certain areas, the fundamental chronostratigraphy of the Polish Quaternary (based on the Różycki 1972, Lindner 1992 and Ber – in print) may be summarized in the following manner:

- the Quaternary
  - the pre-Pleistocene
  - the Pleistocene
    - the earliest glacial
      - the Narew ice cover (glaciation)
    - the Podlasian interglacial – equivalent of Cromer Complex
    - the South Polish glacial
      - the Nida ice cover (glaciation)
        - inter....... (deglaciation)
      - the San ice cover (glaciation)
    - the "Great Interglacial" – equivalent of Holstein Complex
    - the Middle Polish glaciation
      - the Odra ice cover (glaciation)
        - inter....... (deglaciation)

the Warta ice cover (glaciation)
the Eemian interglacial
the North Polish (Weichselian) glacial
long term periglacial conditions
the Baltic ice cover (glaciation)
the Holocene (the present interglacial)

References

Andel Tjeerd H., 1991: Historia Ziemi i dryf kontynentów; Morski szlak ku epoce lodowej (Continental drif and the history of the Earth, new views on an old planet, Cambridge Univ. Press 1985), Wyd Nauk. PWN.

Baranowski S., 1977: Subpolarne lodowce Spitsbergenu na tle klimatu tego regionu (Subpolar glaciers of Spitsbergen seen against the climate of this region) (in Polish). *Acta Univ. Wratislav.*, 393.

Bender M., Sowers T., Dickson M.-L., Orchardo J., Grootes P., Mayewski P. A. & Meese D. A., 1994: Cimate correlations between Grenland and Antarctica during the past 100,000 years. *Nature*, 372(6507).

Ber A. (in print): Plejstocen Polski północno-wschodniej w nawiązaniu do głębszego podłoża i obszarów sąsiednich.

Birkenmajer K., 1990: Geochronology and climatostratigraphy of tertiary glacial interglacial successions on the King George Island, South Shetland Islands (Western Antarctica), *Zbl. Geol. Paleont.*, Tiel I, Stuttgart, Juli 1990.

– 1992: Cenozoic Glacial History of the South Islands and Northern Antarctic Peninsula. Geol. de la Antartida Occidental, J. Lopez-Martinez (Ed.). Symp. T. 3, III Congr. Geol. de Espania, VIII Congr. Latinoam. De Geol., Salamanca, Espania 1992.

Broecker W. S., 1994: Massive iceberg discharges as triggers for global climate change. *Nature*, 372(6505).

Erickson D. B. & Wollin G., 1964: The deep and the past. Knopf, New York.

Fairbridge R. W., 1961: Convergence of evidence on climatic hange and ice ages. *Ann. New York Acad.*, *Sci.* 95.

Fulton R. J., 1984 (ed.): Quaternary stratigraphy of Canada – A canadian Contribution to IGCP Project 24. *Geol. Surv. Canada Paper*, 84–100.

Hambrey M. J. & Harland W. B., 1981: Earths pre-Pleistocene glacial record. Cambridge Univ. Press [za:] Lemon Roy R., Principles of Stratigraphy, Merrill Publ. Comp. 1999.

Imbre J. & Palmer Imbrie K., 1979: Ice ages solving the mistery. The MacMillan Press Ltd.

Kozarski S., 1962: Recesja ostatniego lądolodu z północnej części Wysoczyzny Gnieźnieńskiej, a kształtowanie się pradoliny Noteci–Warty (summ.: Recession of the last ice sheet from morthern part of Gniezno Pleistocene Plateau, amnd formation of the ice-marginal valley of the rivers Noteć–Warta). Pozn. Tow. Przyj. Nauk, *Prace Kom. Geogr.-Geol.*, T. 2, Z. 3.

– 1981: Stratygrafia i chronologia vistulianu Niziny Wielkopolskiej (summ.: Vistulian stratigraphy and chronology of the Great Poland Lowland), PAN Oddz. Poznań, Ser. Geografia, 6.

– 1986: Skale czasu a rytm zdarzeń geomorfologicznych vistulianu na Niżu Polskim (summ.: Timescales and rhythm of Vistulian geomorphologic events in the Polish Lowland), *Czas. Geogr*., 57, 2.

LEMON ROY R., 1990: Principles of Stratigraphy (part Pliocene-Pleistocene boundary). Merrill Publ. Comp.

LINDNER L., MARKS L. & PĘKALA K., 1986: Outline of Quaternary chronostratigraphy of the northern Hornsund area, Southern Spitsbergen. *Bull. Pol. Acad., Earth Sc.*, 34, 4.

LINDNER L., 1987: Main stratigraphic problems in the Pleistocene of Poland. *Bull. Pol. Acad., Earth Sc.*, 35, 4.

– 1992 (Red.): Czwartorzed – osady, metody badań, stratygrafia. Wyd PAE.

LIU H-S., 1992: Frequency variations of the Earth's obliquity in 100-kry ice-age cycles. *Nature*, 358 (6385).

PATTERSON W. S. B., KOERNER R. M., FISHER D., JOHNSEN S. J., CLAUSEN H. B., DANSGAARD W., BUCHER F. & OESCHAGER M., 1977: An oxygen isotope climatic record from the Deve Island ice cup. Arctic Canada. *Nature*, 266.

PENC A. & BRUCKNER E., 1909: Die Alpen im Eiszeltalter. Leipzig.

RASMUSSEN L. A., 1982: Weichselian stratigraphy in northern Jutland. *Denmark Quatern. Stud*., 3.

RÓŻYCKI S. Z., 1972: Plejstocen Polski Środkowej na tle przeszłości w górnym trzeciorzędzie (summ.: The Pleistocene of Middle Poland), Wyd. 1. 1967, PWN, Warszawa.

SHACKLETON N. J. & OPDYKE N. D., 1973: Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V 28-238; Oxygen isotope temperatures and icevolumes on a 10 5 years and 10 6 years scale. *Quatern. Res*., v. 3.

STANKOWSKI W., 1995: Taxonomy of glacials and disharmony of glaciations. *Quaestiones Geogr., Spec. Issue 4*. Late Quaternary relief evaluation and environment change. Wyd. Nauk. UAM.

WYSOCZAŃSKI-MINKIEWICZ T., 1981: Climatostratigraphic subdivision of the last cold period (Vistulian). *Quatern. Study in Poland*, nr 3.