CLIMATIC FLUCTUATIONS AND OTHER EVENTS IN THE MESOZOIC OF THE SIBERIAN ARCTIC

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ABSTRACT

During the Mesozoic, a semi-humid subtropical climate with small fluctuations prevailed in the Siberian part of the Arctic. Five episodes with a particularly warm climate are recognized (lower Induan, the beginning of Toarcian, the middle Portlandian, the middle Albian, and lower Santonian), as are three episodes of cool climates (the boundary of Aalenian and Bajocian, the early Hauterivian, and the lower Maastrichtian). The $\delta^{18}0$ data indicate a continuous decrease in average annual water temperature in the paleo-Arctic ocean, from +27 °C at the beginning of Olenekian to +15 °C in Maastrichtian. "Hedge-hogs" are found in abundance at two stratigraphic levels, at the boundary between Aalenian and Bajocian, and in the lower Hauterivian. Although marine transgressions may have controlled minor climatic fluctuations, the greatest influence seems to have been the presence of open seaways and marine connections between the paleo-Arctic and other oceans.

INTRODUCTION

Recently, many specialists in the Earth sciences have come to agree with the hypothesis of Neumayer (1883) that there were two climatic regions in the northern hemisphere during the Mesozoic, the warm Tethyan (southern) and the temperate Boreal (northern) regions. We support the opinion of Pompeckj (1901), who considered Siberia to have been the coldest region on the Earth during the Jurassic. Although the temperature contrasts during the Mesozoic were much less than observed in Recent time, the difference in average annual temperature between the northern and southern regions was at least 6 to 8 degrees.

CLIMATIC FLUCTUATIONS

There was an alternation of warm and cold epochs during the Mesozoic in Siberia. As is shown on the climatic curve in Fig.1, the warmest stages were at the beginning of the Triassic, in the Early and Late Jurassic, and in the Middle Cretaceous. The most significant cold stages occurred in the Middle Jurassic, and at the beginning and end of the Cretaceous.

Features that indicate the warm, semi-arid climate at the beginning of the Triassic are limestones and red-colored rocks. The lower Olenekian (late Scythian, Lower Triassic) is the only stratigraphic interval in the Mesozoic that is represented by such limestones. The Tethyan mollusks are another indicator of the warm climate (Fig.2).

Two ammonite genera, *Euflemingites* and *Meekoceras*; three nautilide genera, *Taimonautilus* (early Induan; early Scythian), *Phaedrysmoceras*, and *Anoploceras* (late Olenekian); and two bivalve genera, *Panope* and *Pseudolimea*, have been found in the Lower Triassic (Dagis et al., 1979; Sobolev, 1989). They are accompanied by the megaspore *Pleuromeia*, which is a mangrove plant (Krasilov and Zakharov, 1975). Some decrease in temperature during the Middle Triassic resulted from an increase in humidity. This is indicated by coal layers and low-grade hydrogoethite-chamosite iron ore in the Ladinian (Kazakov et al., 1982). Then, the Late Triassic was characterized by a warm and humid climate as shown by the unusual abundance of thermophilic ferns *Matoniaceae* and *Marattiaceae*, and the abundance of *Dipteridaceae* (up to 74%) and *Benettitales* pollen (up to 30%) in spore and pollen assemblages.

In spite of a reduction in the total number of ammonoides, some Tethian genera, such as *Proarcestes* in early Carnian and *Pinacoceras* in early Norian, as well as Tethian nautiloides such as *Cosmonautilus* in early Carnian and *Grypoceras* in the Rhaetian, penetrated into Siberian seas (Fig.2) (Dagis et al., 1979; Sobolev, 1989). There are over 45 bivalve genera in Norian benthic communities among which Tethian trigoniids have been identified.

Skeletal fragments of the large *Ichthyosaurus* and *Plesiosaurus* have been found in the north Siberian Upper Triassic. Some decrease in temperature took place at the end of the Triassic, in the late Norian and Rhaetian. This was brought about, as in the Middle Triassic, by an increase in humidity, as shown by coal layers and thin interbeds of leguminous-oolitic ferrugineous rocks.

Palynological data indicate that the beginning of the Jurassic was characterized by a relatively warm, humid climate. A significant cooling event occurred at the end of late Pliensbachian (Lower Jurassic). The rocks of this age yield diverse seleginel spores and the maximum number of sphagnum spores (*Stereisporites*) (Ilyina, in press).

Ilyina (in press) concludes that another cooling period occurred in the middle Aalenian (Middle Jurassic). These two episodes of cooling are separated by a climatic maximum at the beginning of the early Toarcian (Lower Jurassic), which is indicated by the diversity of Euro-Sinian pteridophytes and gymnosperms. From paleontological and mineralogical data, the well-

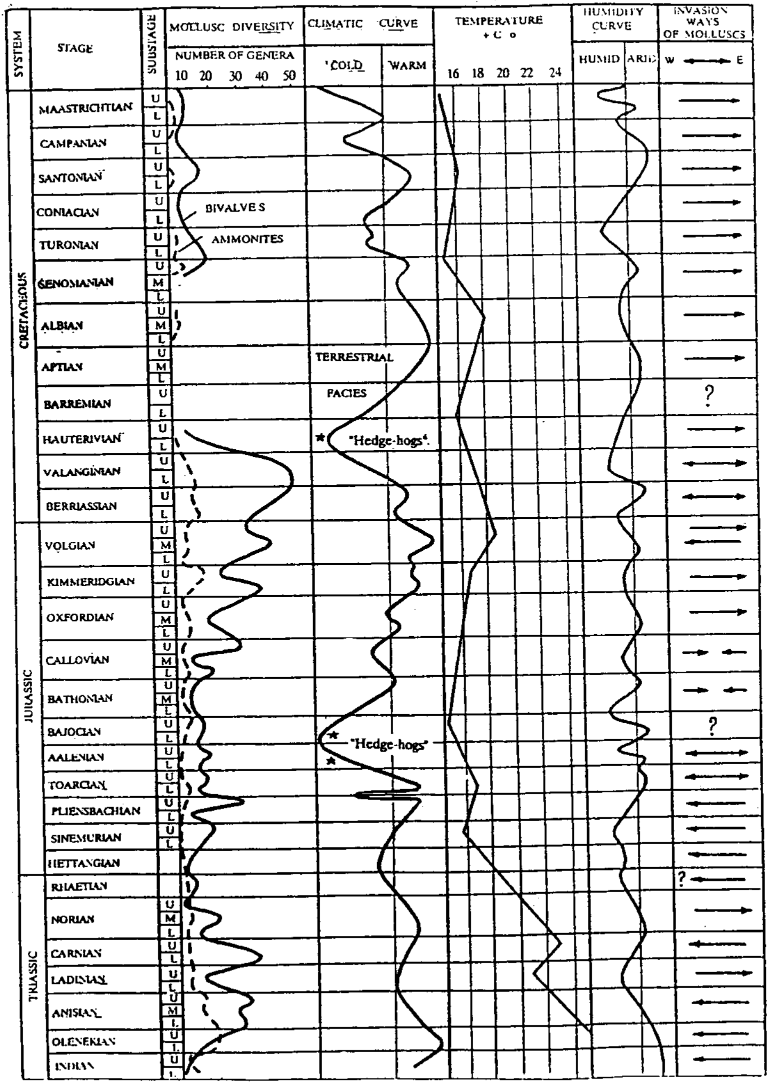

Fig.1. Primary events in the Mesozoic of Northern Siberia (modified from Zakharov et al., 1992).

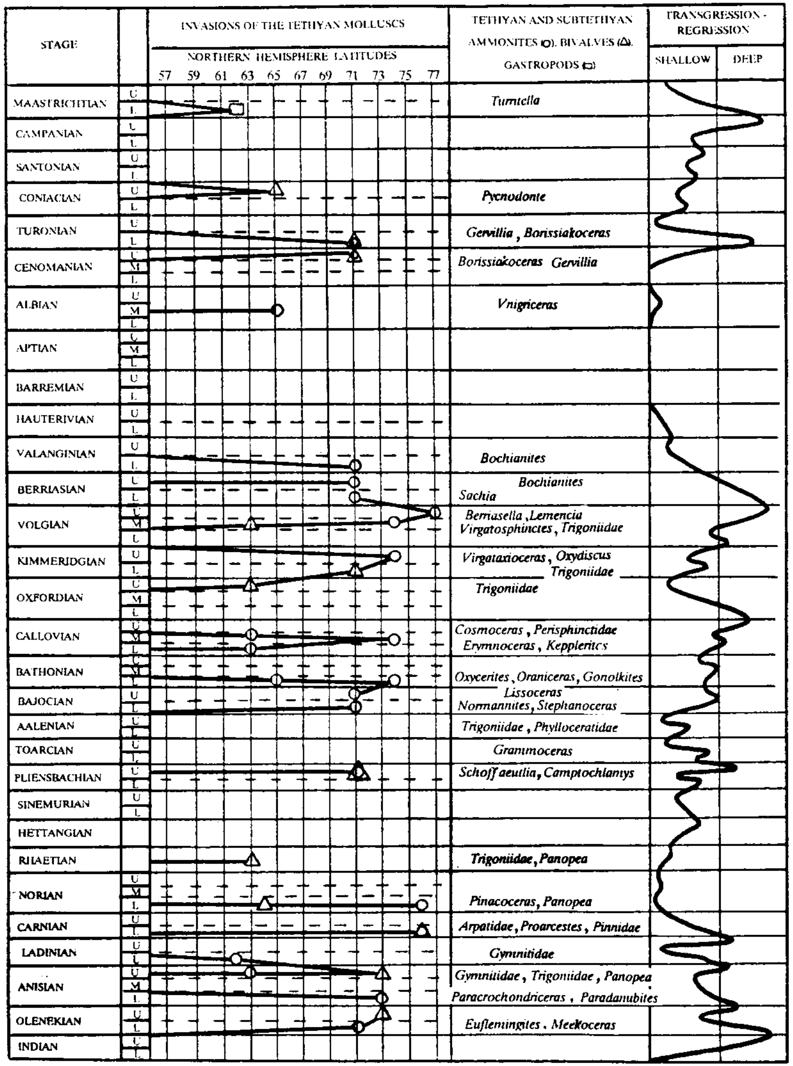

Fig.2. Tethyan influence on Mesozoic biota of Northern Siberia (data on ammonites adopted from unpublished materials by A.L. Beisel, A. G. Konstantinov, and S. V. Meledina with the permission of the authors).

documented Jurassic decrease in temperature took place in the Middle Jurassic, at the boundary between the Aalenian and Bajocian. This is indicated by both the decrease in diversity in all groups of marine invertebrates (Fig.1), and the fact that benthic communities were dominated by boreal bivalves such as *inoceramids*. Furthermore, sediments contain many specific calcium aggregates, called "hedge-hogs" by Kemper and Schmidtz (1975), which are presently forming in the White and Greenland seas at temperatures close to 0 °C, and are thought to be indicators of zero bottom temperature. The average annual temperature in Jurassic Siberia, as measured using oxygen isotopes, is 15 °C. This is the lowest temperature determined for the Jurassic.

Hallam (1969) proposed that the low diversity of the Arctic marine Jurassic fauna was due to the low salinity of the Arctic seas, not climate. Our data on the Pliensbachian - Toarcian crisis dispute such a suggestion. Fig.3 shows the biogeographical composition of bivalves before and after this crisis. The majority of Arctic groups disappeared only temporarily from the geological record after this crisis and then later reappeared. In contrast, the majority of Boreal groups became extinct, and then a number of new taxa appeared. Finally, Tethyan taxa all disappeared, and later only two new genera appeared. Apparently, this was associated with a fall in temperature, not in salinity, because only Tethyan molluskan genera were strongly affected. Climatic zonation became more pronounced beginning with Callovian (late Middle Jurassic). Due to a Boreal transgression, the climate became arid in southern Siberia and humid in northern Siberia (Zakharov et al., 1983). Continental flora in the south are dominated by cheirolepidian plants (*Classopollis* pollen) and by temperate to warm-climate pterido-spermaphytes, while in the north by gymnosperms with rare immigrants from the Euro-Sinian region (Ilyina, in press).

During the Late Jurassic, the climate in general grew warmer as indicated by the increasing diversity of invertebrates (Fig.1). Many mollusks with big, strong shells appeared. An average annual temperature of +19 °C is established for the middle Volgian (Portlandian) based on oxygen isotopes in belemnites. It is the highest inferred temperature for the Jurassic. Fig.1 shows that the climate curve falls rapidly in Valanginian and reaches its lowest point for the whole Cretaceous in the early Hauterivian. This period is characterized by a low diversity in mollusks and other benthic groups. The Boreal bivalve *Buchia* dominated the benthic communities. Many "hedge-hogs" are found in these rocks. A decrease in water temperature to lower than 16 °C is indicated at the Hauterivian - Barremian boundary. After this time, an increase in temperature is observed, based on paleobotanical, pollen, and spore data, with a maximum at the Aptian - Albian boundary. An average annual temperature for the Albian was about +18 °C.

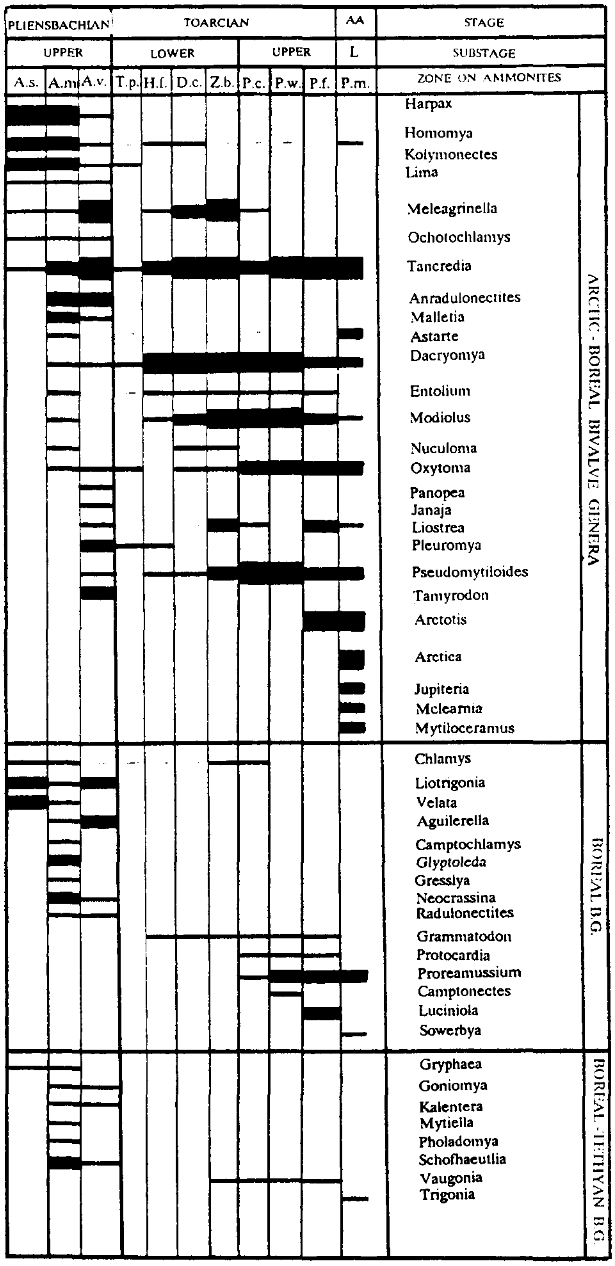

Fig.3. Pliensbachian - Toarcian North Siberian biota crisis (prepared by B. N. Shurygin and V. A. Zakharov). Ammonite zonations: A.s. - *Amaltheus stokesi*, A.m. - *A. margaritatus*, A.v. - *A. viligaensis*, T.p. - *Tiltoniceras propinquus*, H.f. - *Harpoceras falcifer*, D.c. - *Dactylioceras commune*, Z.b. - *Zugodactylites braunianus*, P.c. - *Pseudolioceras compactile*, P.w. - *P. wurttenbergeri*, P.f. - *P. falcodiscus*, P.m. - *P. mclintocki*.

There are three warm events in the Late Cretaceous: (1) at the end of Cenomanian, (2) in the middle Santonian, and (3) at the end of Campanian and in the early Maastrichtian. They are determined on the basis of increases in molluskan diversity and invasions of Tethyan faunal groups; for example, the ammonite

Borissiakoceras at the end of Cenomanian to earliest Turonian, the bivalve *Pycnodonte* in the Coniacian, and carbonate sedimentation in the early Maastrichtian up to latitude 65° N. (Fig.2). There was an alternation of semi-humid and semi-arid climates in the Cretaceous period based upon the presence of coals at some stratigraphic levels. Apparently, there was a decrease in temperature at the end of the Maastrichtian, and the amount of pollen and spores, as well as marine invertebrates, decreased. On the other hand, the degradation of marine biota probably was the result of a marine regression. The average annual temperature at the end of the early Maastrichtian decreased to no more than +15 °C. Two major factors, climate (temperature) and humidity, have prominent fluctuations at the end of the Late Cretaceous.

REASONS FOR CLIMATIC CHANGES AND OTHER EVENTS

Two main groups of events were analyzed to identify the reasons for the climatic changes: (1) the northern invasion of Tethyan mollusks and (2) the history of transgressions and regressions. As shown in Figs.1 and 2, there is a good correlation between the climatic (temperature) curve and the transgression-regression curve in the Triassic and Jurassic. Warm climate intervals generally coincide with transgressions. This is true for almost all main warm events, although not for the smaller ones. The invasion events of Tethyan ammonites (circles) and bivalves (triangles) also coincide with warm events in the Arctic, and even better with transgression events (Fig.2).

These correlations fail, however, during the time from the end of the Hauterivian to the beginning of the Cenomanian. This warm interval is not associated with a transgression, and almost all of Siberia was emergent under continental conditions. Thus, the main events in climatic development were probably related to Arctic paleogeography. The predominantly warm, semi-humid climate in Triassic is explained by the existence of wide marine connections between the Arctic Basin and the North Pacific. This is based on the similarity of Triassic fauna in both basins. Mollusk migration in the Triassic was directed from east to west (Fig.1).

The first sharp decrease in temperature at the end of the Aalenian (early Middle Jurassic) was probably associated with changes in the paleogeography of the Arctic-Pacific boundaries. Any barrier between Paleo-Alaska and Paleo-Chukotka could restrict the access of warm sea-water from the North Pacific to the Arctic Basin. Such a barrier could have developed as a result of the accretion of the "Kolyma" microplate (Churkin, 1981) to the Siberian craton at the beginning of the Cretaceous. Paleontological data support such a reconstruction, if the time of accretion was Early or Middle Jurassic. We suggest that the increase in temperature in the Volgian (Portlandian) was associated with an increase in Atlantic influence due to marine mixing. As shown in Fig.1, the faunal migration was directed from the west to the east through epicontinental seas on the Russian Platform and the North Atlantic (Zakharov et al., 1983). Pacific marine connections must have been very limited at this time.

The rise in temperature at the end of the Cenomanian is the result of a eustatic event. The Maastrichtian temperature increase is associated with the opening of the Turgai Strait (northern Kazakhstan to the West Siberian Lowlands) to northern Siberia, and the Santonian warming was caused by the opening of seaways in North America. The decrease in temperature at the end of the Maastrichtian probably was due to the closing of the Arctic Basin.

The main faunal crises at the boundaries of the Triassic system were associated with global events. All groups of biota were affected, especially bivalves. Fig.4 shows the decrease in diversity of bivalve genera, with the greatest decrease (45%) at the Permian-Triassic boundary.

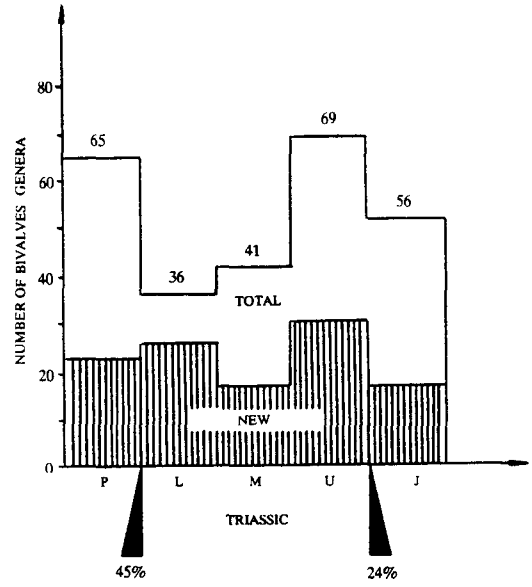

Fig. 4. The fall in diversity of bivalve genera at the boundaries of the Triassic System boundary (data from N. I. Kurushin, with permission). P - Permian, J - Jurassic, L - Lower, M - Middle, U - Upper.

PERIODICITY IN CLIMATIC CHANGES

An examination of the relationship between faunal crises and periodic climatic changes was based on results of catastrophy analysis, and the results for different events in the Mesozoic Arctic are presented in Fig.5. The size of the arrow reflects the rank of the crisis. Although both high- and middle-rank crises recurred at an average of every 30 m.y. (varying from 24 to

36 m.y.), and small crises have a periodicity of from 1 to 8 m.y., there is no true periodicity for crises of high rank. It is therefore concluded that there is no strong periodicity in climatic changes in the Mesozoic of the Arctic.

CONCLUSIONS

The Mesozoic of Arctic Siberia was characterized by a temperate warm, semi-humid climate with an average annual temperature of about +15 °C. However, temperature fluctuations with large and small amplitudes are recognized.

The Early and Late Triassic, Early and Late Jurassic, and Middle Cretaceous were warmer periods. Gentle increases in temperature were recorded by the more than 20 invasions of Tethyan mollusks into the Mesozoic Arctic. These invasions correlate well with transgression events. However, marine connections with the North Pacific (Triassic and Early Jurassic), North Atlantic (Late Jurassic and Neocomian), and open seaways in southwestern Siberia and North America (Late Cretaceous) exerted the most significant influence on the climate of the Arctic.

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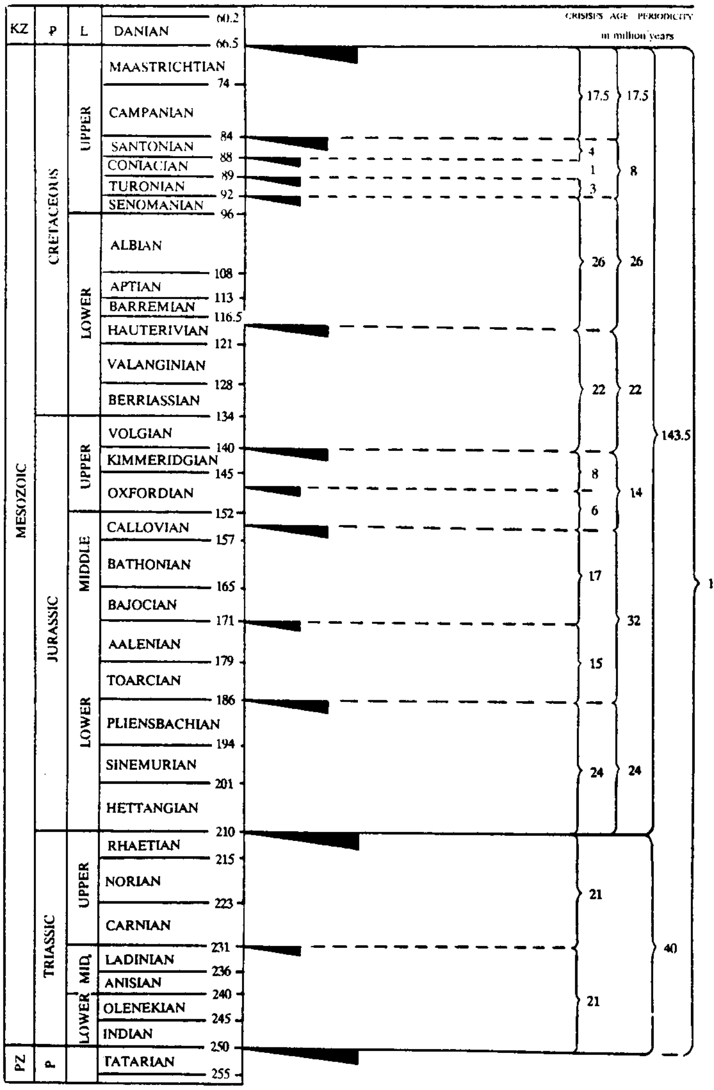

Fig. 5. Crisis and turnover periodicity of the Mesozoic biota in the Arctic. Data on absolute age adopted from Exxon publication, 1987, Version 3.1A.

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