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Early-Late Cretaceous climate of the northern high latitudes: Results from brachiopod and mollusc oxygen and carbon isotope ratios, Koryak Upland and Alaska

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ABSTRACT

Reliable high paleolatitude isotopic paleotemperature data for the Northern Hemisphere are very rare. Evidence on this topic has been obtained only for the Valanginian of Svalbard (7.7°C) (Ditchfield, 1997), Turonian of the Pakhacha River basin, eastern Koryak Upland (14.1-16.3°C) (Zakharov et al., 1996, 1999) and Coniacian-Santonian of Greenland (about 17.3°C) (Lowenstam and Epstein, 1959). In this study new data, based on oxygen stable isotopic paleothermometry of well preserved Lower and Upper Cretaceous brachiopod, bivalve, including inoceramid, scaphopod and ammonite shells from the Penzhinskaya Guba area and Talovka River basin, western Koryak Upland, (95 samples) and also Southern Alaska (3 lower Albian ammonoid shells), are presented. Warming maxima have been recognized in the early Barremian (24.5°C), Aptian-early Albian (18.4-25.9°C), marked by an anomalously high ^{13}C value (up to 6.6%for the lower Albian of Koryak Upland), late Cenomanian (20.8-23.3°C) and late Campanian (20.6-26.1°C). The early Maastrichtian shallow-water cooling (10.2-16.9°C) was also discoverd there. The strongly negative ^{18}O values found in aragonite of good preserved middle and late Turonian inoceramid bivalves ranging from –4.3 to –5.9‰ seem to be connected with the freshening of the Penzhinskaya Guba basin and are evidently a result of a sharp development of humid climate in the northwestern circum-Pacific mainly during Turonian time. Data obtained agree with both the isotopic data for the Southern Hemisphere (Huber et al., 1995), and the paleobotanical evidences from the Koryak Upland and neighbour territories (Golovneva, 1998; Golovneva and Herman, 1998; Lebedev, 1990a; Markevich, 1995), recently published. We believe that great and more or less coeval poleward heat transport took place in both the Southern and the Northern Hemispheres during the most part of Cretaceous time.

INTRODUCTION

There is contradictory evidence on climatic conditions for high latitude areas during Cretaceous time (Barron et al., 1981; Douglas and Williams, 1982; Axelrod, 1984; Spicer and Parrish, 1986; Barrera et al., 1987; Parrish et al., 1987; Spicer,1987; Parrish and Spicer, 1988; Nesov and Golovneva, 1990; Pirrie and Marshall, 1990; Askin, 1992; Ditchfield et al., 1994; Huber et al., 1995; Spicer et al., 1996; Ditchfield, 1997; Golovneva, 1998; Golovneva and Herman, 1998; Miller et al., 1999), when the magnetic North Pole located a little bit to the north of Bering Land Bridge (Smith, 1981). The exact location of the Cretaceous spin poles is a matter of question. The Early Cretaceous spin North Pole, in some author's opinion, seems to be located north of Prince Patrick Island, Arctic Canada (Paul, 1988). We follow this interpretation in this stage of knowledge, but there are some recent data, needed in some verification, according which the spin North Pole may be located near the Yana River basin for the Hauterivian, near the Indigirka River basin for the Aptian, a little bit to the north of the Novaya Sibir Islands for the Cenomanian, somewhat north of Chukotka for the Coniacian, and to the north of Alaska for the Maastrichtian (C.R. Scotese's personal communication). The Cretaceous spin South Pole located, apparently, within Antarctica (Golonka et al., 1994). Relatively any of these interpretations, both the Koryak Upland and the Southern Alaska areas, where we got material for isotopic analyses from, located within high latitudes (not less than 60-70°N) during Early and Late Cretaceous. Representations on a climate in Southern Hemisphere polar regions have been added mainly on the basis of isotopic paleotemperature data, but information on a climate of high latitude areas of the Northern Hemisphere, on the contrary, have been obtained mostly on the basis of paleobotanical studies in the Koryak Upland and Alaska.

Oxygen-isotope analyses of Late Cretaceous belemnite rostra from New Zealand (Stevens and Claton, 1971), bivalves and cephalopods from James Ross and Vega Islands, Antarctica (Pirrie and Marshall, 1990) and also planktonic foraminifera from Maud Rise, Antarctica (Stott and Kennett, 1990) gave rather low paleotemperatures for surface marine water in the Santonian-Maastrichtian ranging from 8°C to 16 °C. Lower temperatures (4.5-10.5°C) were calculated by E. Barrera et al. (Barrera and Huber, 1990; Barrera et al., 1987) for shelf environment on the basis of isotopic data on Maastrichtian benthic foraminifera from Seymour Island, near the coast of Antarctica.

Recently, Huber et al. (1995) investigated planktonic foraminifera from Falkland and Naturaliste plateaus in high latitudes of the Southern Hemisphere and obtained unexpectedly high paleotemperatures for the Albian (about 17°C), Cenomanian (about 23°C), Turonian (about 33°C), and Campanian (25-28°C), in contrast with a low paleotemperature (10°C) for the Lower Maastrichtian interval. They determined relatively low vertical oxygen-isotopic gradients for the Albian (1.0-1.2‰), Cenomanian (1.0‰), Coniacian-Santonian (1.7‰), Late Campanian (1.59‰), and Early Maastrichtian (1.7‰), but higher for the Turonian (3.0‰) (calculated Turonian paleotemperatures for the South Hemisphere are likely unreliable). They agree with Barrera et al. (1987) who considered Maastrichtian south polar region to be an important source of deep-water formation.

However, reliable high paleolatitude paleotemperature data for the Northern Hemisphere are still rare: Cretaceous isotopic paleotemperatures have been obtained only for (1) the Valanginian of Svalbard (Ditchfield, 1997), (2) Turonian of eastern Koryakia (Zakharov et al., 1996, 1999) and (3) Coniacian-Santonian of Greenland (Lowenstam and Epstein, 1959; Lowenstam, 1968; Teiss and Naidin, 1973).

Zakharov et al. (1996, 1999) obtained relatively high paleotemperatures (14.1-16.3°C) for the Turonian, apparently upper Turonian, of the Pakhacha River basin from isotopic analyses of the different parts of the single ammonoid shell. H.A. Lowenstam and S. Epstein (1959) calculated higher paleotemperatures (about 17°C) from few Coniacian-Santonian belemnite rostra of Eastern Greenland. P.W. Ditchfield (1997), on the contrary, adduced low paleotemperatures (5.3-10.4°C) calculated on the basis of isotopic data from 43 belemnite rostra from the Tordenskjoldberget Member of the Kongsoya Formation (Lower Valanginian) of Kong Karls Land.

Restricted isotopic data on the Cretaceous of high latitudes of the Northern Hemisphere in a large measure are compensated by abundant of paleobotanical publications on Cretaceous climatology on north-east Asia (Krassilov et al., 1990; Lebedev, 1990a,b; Markevich, 1990; Nesov and Golovneva, 1990; Herman, 1996; Golovneva and Herman, 1998) and Alaska (Parrish et al., 1987; Parrish and Spicer, 1988; Spicer et al., 1996).

This study has been focused on the following:
(1) To obtaine oxygen-isotope, carbon-isotope and Ca-Mg data from all stage intervals of the post-Valaginian Cretaceous of high latitudes of the Northern Hemisphere.
(2) To compare new results with those from the Southern Hemisphere.

MATERIAL AND METHODS

Macrofossil samples for isotope analyses in this study were collected mainly by the 1998 Russian-Japanese geological expedition, organized at the eastern coast of the Penzhinskaya Guba (Penzhina Gulf), western Koryak Upland (Fig. 1).

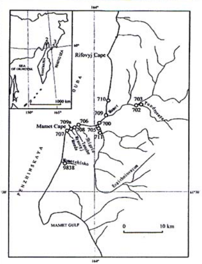


Fig. 1 Location of the Penzhinskaya Guba (Penzhina Gulf) area (1), Talovka River basin (2) and Pakhacha River basin (3) sequences. Localities: 9838 – Mametchinka River (lower Tylakryl Formation, Hauterivian); 707 – Mamet Cape (upper Karmalivayam Formation, Lower Aptian); 709a – Mysovyj Creek (lowermost Mamet Formation, Upper Albian?-Lower Cenomanian); 708 – Tanabe Creek (lower Mamet Formation, Lower Cenomanian); 706 – Shigeta Creek (upper Mamet Formation, Lower Cenomanian); 705 – Penzhinskaya Guba, 1 km W of the Esgichninvayam River mouth (lower Penzhinskaya Formation, Upper Cenomanian); 711 – Esgichninvayam River (left bank), 1.5 km upper of its mouth (middle Penzhinskaya Formation, lower Middle Turonian); 700 – Penzhinskaya Guba, 0.1-0.5 km NE of the Esgichninvayam River mouth (middle Penzhinskaya Formation, middle Middle Turonian); 709 – Mamet River mouth (upper Bystrinskaya Formation, Upper Campanian); 710 – middle Penzhinskaya Formation (middle Middle Turonian); 702 – Mamet River, 5.5 km upper its mouth (lower Pillalvayam Formation, Upper Campanian); 703 – Tundrovaya River (middle Pilallvayam Formation, Lower Maastrichtian).

During the Barremian to Paleogene the Penzhinskaya Guba area was at a palaeolatitude of approximately 62° N (Alaxyutin and Sokolov, 1998). The collection from that area is represented by good preserved invertebrates of different ecological types: brachiopods, bivalves, including inoceramids, scaphopods, ammonoids and worms (86 invertebrate samples were analyzed). In addition to these some our unpublished data on Albian brachiopods, Coniacian bivalves and ammonoids (five samples) from the Talovka River basin, located about 60-100 km NE of the Penzhinskaya Guba area, have been used for completeness of the Lower – Upper Cretaceous isotopic succession picture, because of lacking of well preserved fossils in both the Albian and the Coniacian of the Penzhinskaya Guba area. Callovian calcitic brachiopod and belemnite and aragonitic ammonoid material from the Russian Platform (seven samples - Y.L. Bolotsky's coll.), small portion of Albian aragonite ammonoid material from the Talkeetna Mountains, southern Alaska (three samples - Y. Shigeta's coll.) (Fig. 2), and also two Coniacian aragonitic mollusc shells from Hokkaido, were also analyzed for comparative purposes.

Following signs were used for control the diagenetic alteration in the investigated fossil shells: (1) visual signs (natural colour and structure), (2) percentage of aragonite in a skeleton in case, when we are analyzing shells originally represented by 100% of aragonite) (Zakharov et al., 1975, 1999); (3) a degree of safety of skeleton microstructure, determined by a microscopic method, including SEM. Becides, to find signs of alteration in well-preserved brachiopod shells, a prelimanary luminiscent test was used. The results of x-ray diffraction analyses and microscopic observations reveal that most of the aragonitic ammonoid and inoceramid samples from the Cretaceous of the Koryak Upland, carefully selected after visual inspection, seem to be suitable for distinguishing their original oxygen and carbon isotopic records. Judging from isotopic data on Recent *Nautilus* (Spaeth and Hoefs, 1986; Oba et al., 1992), ammonoids seem to be capable of steady grow through the year.

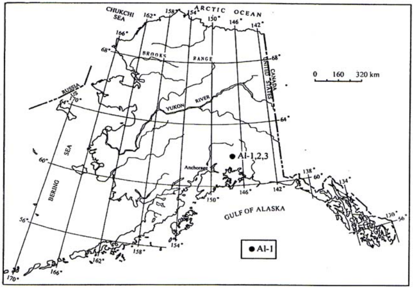


Fig.2 Location of Ammonite Creek Talkeetna Mountains, South Alaska; Matanuska Formation, upper Lower Albian. Al-1,2,3 locality of Albian *Grantziceras affine* (Whiteave) (Al-1), *Freboldiceras singulare* Imlay (Al-2) and *Brewiceras hulen* (Anderson) (Al-3).

Oxygen and carbon isotope measurements were made at the Far Eastern Geological Institute (FEGI), Vladivostok, using Finnigan MAT-252 mass spectrometer (Germany). The laboratory gas standard used in the measurements was calibrated relative to calcite NBS (National Bureau of Standards) 19 and equals 1.8±0.10% or oxygen relative to PDB (Pee Dee belemnite) and – 0.9± 0.10% or carbon. Reproducibility of replicate standards was always better than 0.10% In calculating the temperatures, it was free or mainly free from icecaps and therefore a $\delta^{18}O$ of –1.2%PDB (equivalent to –1.0‰ SMOW) was thought to be appropriate (Savin, 1977).

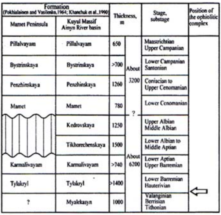
X-ray analyses were carried out using a DRON-3 diffractometer following the method of Davis and Hooper (1963).

TECTONIC POSITION OF THE PENZHINSKAYA GUBA AREA

Lower Cretaceous sediments of the Penzhina-Anadyr superterrane (Parfenov et al., 1993; Nokleberg et al., 1998), attributed to the turbidite formation, were deposited at a deep-water zone of the forearc basin, in condition of significant influence of the island arc volcanism, especially of the Hauterivian-Barremian one. Deposition of mentioned sediments seems to be a facies of the avalanche-type because they are very thick (about 6,200 m). The Lower Cretaceous is usually represented in the western Koryak Upland by the five subdivisions: (1) Myalekasyn, with the exception of the basal beds (Berriasian-Valanginian); (2) Tylakryl (Hauterivian–lower Barremian); (3) Karmalivayam (upper Barremian–Lower Aptian); (4) Tikhorechenskaya (upper Aptian–lower Albian); and (5) Kedrovskaya (middle-upper Albian) Formations (Avdeiko, 1968; Pokhialainen and Vasilenko, 1971; Pokhialainen, 1994; Alabushev, 1995; Map of mineral resources, 1999). The most part of these sediments believes to be originally formed in conditions of shallow-water shelf and after they were threw down, apparently, together with their fossils, to the base of the continental slope. Consedimented plates of the ophiolite (serpentinized harzburgite, clinopyroxenite, troctolite, gabbro, gabbro-norite, plagiogranite, sheeted dike complex, pillow lavas) and products of their destruction (serpentine breccia, gravelstone and sandstone) usually found at the base of the Tylakryl Formation.

Upper Cretaceous sediments in Western Koryakia, on the contrary, belong to facies mainly of the shelf type, characterized by wide development of benthic forms (Pergament, 1961). They are represented here by the four subdivisions: (1) Mamet (with the possible exception of the basal beds) (lower Cenomanian); (2) Penzhinskaya (upper Cenomanian to Coniacian); (3) Bystrinskaya (Santonian-lower Campanian) and (4) Pillalvayam (upper Campanian–Maastrichtian) Formations, with total thickness about 3,200 m.

Within the Mamet Peninsula, the main area of our isotopic study, sediments of the Myalekasyn Formation (Tithonian, Berriasian and Valanginian) known at the Kuyul Massif and the Ainyn River basin (Khanchuk et al, 1990; Pokhialainen and Vasilenko, 1971) are not exposed; the ophiolitic part of the Hauterivian –Barremian Tylakryl Formation composes here the core of the narrow anticlinale. The thick flyschoid sequences of the Lower Cretaceous Tylakryl and Karmalivayam Formations are very similar in lithology, and the boundary between them is recognized by the first appearance of *Aucellina*. Early Aptian age of the upper part of the Karmalivayam Formation at the Mamet Peninsula is confirmed by the finding of ammonoid *Sanmartinoceras* and *Australiceras* (Pokhialainen, 1994). Mamet Formation sediments overlie graywacke rocks of the Karmalivayam Formation at the Mamet Peninsula with unconformity and erosion (Albian sediments of the Tikhorechenskaya and Kedrovskaya Formations are not saved here) (Fig. 3).



Formation (Pokhialainen and Vasilenko, 1964; Khanchuk et al., 1990)		Thickness, m		Stage, substage	Position of the ophiolitic complex
Mamet Peninsula	Kuyul Massif Ainyn River basin				
Pillalvayam	Pillalvayam	650	About 3200	Maastrichtian Upper Campanian	
Bystrinskaya	Bystrinskaya	>700		Lower Campanian Santonian	
Penzhinskaya	Penzhinskaya	1260		Coniacian to Upper Cenomanian	
Mamet	Mamet	780		Lower Cenomanian	
			?		
	Kedrovskaya	1250	About 6200	Upper Albian Middle Albian	
	Tikhorechenskaya	1500		Lower Albian to Middle Aptian	
Karmalivayam	Karmalivayam	>740		Lower Aptian Upper Barremian	
Tylakryl	Tylakryl	>1400		Lower Barremian Hauterivian	⇦
?	Myalekasyn	1000		Valanginian Berrisian Tithonian	

Fig. 3 Stratigraphic summary of the sampled Cretaceous sediments of western Koryakia.

Other Upper Cretaceous Formations, for exception of the Campanian-Maastrichtian one, overlie underground sediments without any interruption. The upper part of the Mamet Formation is characterized by the Lower Cenomanian ammonoid assemblage (*Neogastroplites, Eogannarites, Puzosia, Tetragonites and Stoliczkaia).* The age of the lower part of the Penzhinskaya Formation has been determined by us as Late Cenomanian on the basis of finding of ammonoid *Eomadrasites* and *Marshallites* in its upper beds. The presence of Upper Turonian, Santonian-Campanian and Maastrichtian sediments at the

Penzhinskaya Guba area is argued by presence of ammonoid *Jimboiceras planulatiformis* Mat. in the Penzhinskaya Formation (new finding), *Menuites naumanni* (Yok.) in the Bystrinskaya Formation and *Pachydiscus japonicus* Mat. in the Pillalvayam Formation (Pergament, 1961), correspondingly.

$\delta^{18}O$, $\delta^{13}C$ and Ca-Mg ratio in carbonate fossils from the Cretaceous of the Penzhinskaya Guba, Koryak Upland

Tylakryl Formation
(Hauterivian-lower Barremian)

Hauterivian–lower Barremian sediments at the Mamet Peninsula, Penzhinskaya Guba area, are represented by the Tylakryl Formation (Pokhialainen and Vasilenko, 1971). In the exposed part of the Tylakryl Formation, containing plates of the ophiolites in its basal part, we recognize only a single member now:

1. Grey serpentinite sandstone with volcanic rocks debris and interlayers of siltstone, conglomerate-breccia, tuffaceous siltstone and siliceous siltstone (9838-1, 9838, 9838-2-1,2), more than 1,400 m thick. Yields rare bivalves *Inoceramus colonicus* and *Astarte* sp. (M.A. Pergament's determination), scaphopods (*Dentalium* sp.) and radiolarians.

Because of restriction of material suitable for distinguishing the true oxygen and carbon isotopic record, the sampling was made only from two levels of the lower part of the Tylakryl Formation, exposed at the Mametchinka River (Fig. 4).

A shell of *Dentalium* sp. (9838-1), represented by original calcite with marked diagenetic alterations (a small touch of clinoptilolite and laminated silicates), very well preserved prismatic shell material of *Inoceramus* sp. (9838, 9838-2-2) and also small portion of the same *Inoceramus* sp. shell with partly intact aragonitic material (9838-2-1) were used for geochemical analyses. The *Dentalium* shell was found about 100 m above the plate of the ophiolites in the investigated section (about 80 m from the Mametchinka River mouth); the *Inoceramus* shell analyzed was discovered about 20 m above the bed 9838-1.

The $\delta^{18}O$ value in Hauterivian inoceramid prismatic layers (9838, 9838-2-2) is –0.8%(Ca/Mg=174.3); in the aragonite bearing part of the same shell (9838-2-1) it is lower (-3.4% because of significant recrystallization. Very low $\delta^{18}O$ value (-4.6% (Ca/Mg= 175.8) was obtained from the *Dentalium* shell (9838-1). Samples from the lower part of the Tylakryl Formation show a range in $\delta^{13}C$ from +0.9 ‰ to +2.5% (Table 1).

From results on $\delta^{18}O$ mentioned above only material from Hauterivian inoceramid prismatic layers seems to be suitable for paleotemperature reconstruction (21.0-21.3°C); at the same time all $\delta^{13}C$ values obtained from both aragonite and calcite of Hauterivian *Inoceramus* and *Dentalium* seem to resemble original ones. Judging from the mark on the Tylakryl Formation, made above, the paleotemperature data presented here suggest their shelf seawater origin.

Karmalivayam Formation
(middle Barremian to lower Aptian)

Middle Barremian to lower Aptian sediments at the Mamet Peninsula represented by the Karmalivayam Formation overly the Tylakryl Formation conformably. The base of the formation was determined on the first appearance of the bivalve *Aucellina* sp.

In descending order, the sequence of middle Barremian to lower Aptian sediments in the section is:

5. Greyish green siliceous siltstone, and medium-grained sandstone (707-2,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 707-1), 59 m. Yields many bivalves, identified by V.N. Vereschagin as *Aucellina aptiensis* (Orb.) and *A.* cf. *A. caucasica* Buch.

4. Greyish green siliceous siltstone, intercalated with coarse-grained sandstone, medium-basic ashstone and volcanoclastic, 410 m. Contains rare ammonoids (*Anagaudryceras* sp. and *Holcodiscoides* sp.) in the upper part.

3.Grey conglomerate-breccia (Maeda Creek), 0.5 m. Yields rare *Aucellina aptiensis* (Orb.).

2. Greyish green siliceous siltstone and medium-grained tuffaceous sandstone (707-4, 707-5-1), 275 m . Yields rare bivalves *Aucellina* sp.

The thickness of the Karmalivayam Formation is 747 m.

Original calcite of the well preserved silvery white *Aucellina* shells (only with a very small touch of analcime, rarely laumontite or kaolinite) was used for isotopic analyses. The analyzed shells were collected (1) from the base of the Member 2 (707-4), (2) from the bed, located about 120 m above the base of the Member 2 (707-5-1, middle Barremian), (3) from the base of the Member 5 (707-2,3,4,5,6,7,8,9,10,11,12,13,14,15,16, lower Aptian), and from its top (707-1, lower Aptian). The $\delta^{18}O$ and $\delta^{13}C$ values for the most good preserved mid-Barremian shell of *Aucellina* sp. are –2.9%(T=24.9°C) and +3.9% respectively. The $\delta^{18}O$ and $\delta^{13}C$ values for early Aptian *Aucellina aptiensis* (Orb.) ranged from –5.7 to –1.6‰ (mean of –3.2% and +1.3 to +6.6%(mean of +4.4%, respectively. Calcite of early Aptian *Aucellina* differs from Hauterivian *Dentalium* material by lower Mg content (Ca/Mg=191.67) (Table 2). Material of eight shells of *Aucellina aptiensis* from 17 investigated ones appear to be preserved its original oxygen isotopic composition and therefore they can be used in calculating the early Aptian paleotemperatures (the range of $\delta^{18}O$ values in the calcitic bivalve shells suggests the temperature values to be 18.4-25.9°C).

Mamet Formation
(upper Albian?-lower Cenomanian)

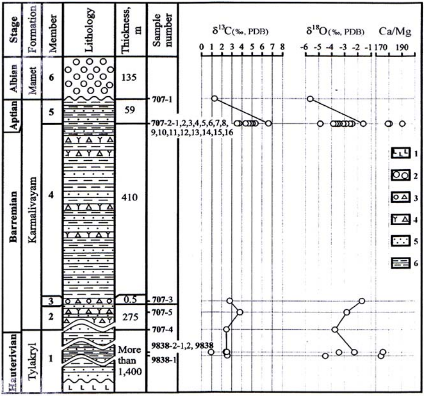


Fig.4 The $\delta^{18}O$ and $\delta^{13}C$ values and Ca-Mg ratios of Hauterivian, Barremian and Lower Aptian invertebrate calcite shells from the Penzhinskaya Guba. 1 – ophiolite, 2 – conglomerate, 3 – breccia, 4 – ashstone, volcanoclastic, and breccia, 5- sandstone, 6 - siltstone.

Upper Albian?–lower Cenomanian sediments of the Mamet Cape area represented by the Mamet Formation overly the Karmalivayam Formation with unconformity and erosion. In descending order, they are (Fig. 5):

14. Intercalation of dark grey siltstone and greyish green medium-grained sandstone, 70 m.
13. Dark grey siltstone with large calcareous-marly boulders and rare interlayers of grey medium- grained sandstone (Shigeta Creek, 706-1), 117 m. Contains bivalve inoceramid (gigantic *Inoceramus* sp.) and rare ammonoid (*Marshallites* sp., *Anagaudryceras sacya* (Forbes)) shells.
12. Black mudstone with large calcareous-marly boulders and rare interlayers of grey medium-grained sandstone, 170 m.
11. Dark grey siltstone with interlayers of grey medium-grained sandstone (Tanabe Creek area), 30 m. Yields bivalves (*Paratrigon a* sp.) and ammonoids

Table 1 Carbon and oxygen isotope analyses of calcitic and aragonitic elements of mollusc shells from the Tylakryl (lower part) and Karmalivayam Formations of Penzhinskaya Guba and Hauterivian-Barremian paleotemperatures for high latitudes of the Northern Hemisphere (D, diameter, W, width, H, height).

Sample	**Species**	**Stage, formation**	**Location (D,W & H, in mm)**	**Diagenetic alterations**				**Ca/Mg**	**$\delta^{13}C$ (PDB) (‰)**	**$\delta^{18}O$ (PDB) (‰)**	**T° C**
				Calcite (ori-ginal) (%)	**Arago-nite (%)**	**Admixture (%)**	**Colour**				
9838-1	*Dentalium* sp.	Hauterivian, Tylakryl	W=2.5	>70 (?)	0	Clinoptilolite (very little), layered silicates	White	175.8	2.5	-4.6	-
9838	Same shell	- " -	Prismatic layer (W=7.0)	100	0	-	Yellowish -white	" -	2.4	-2.2	21.0*
9838-2-2	*Inoceramus* sp.	- " -	Prismatic layer (W=7.5)	100	0	-	Yellowish -white	-	2.5	-2.2	21.3*
9838-2-1	Same shell	- " -	Aragonitic layer (H=39)	0	Little	Calcite (much)	Yellowish -cream	-	0.9	-3.4	-
707-4	*Aucellina* sp.	Barremian, Karmalivayam (lower part)	H=11	>70 (?)	0	Laumontite, analcime	White	-	2.8	-3.8	-
707-5-1	*Aucellina* sp.	- " –	H over 15	100	0	-	Silvery-white and pink	-	3.9	-2.9	24.5*

* Anderson and Arthur (1983)

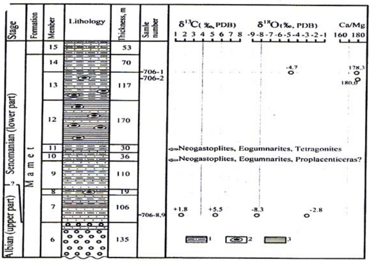


Fig. 5 The ^{18}O and $\delta^{13}C$ values and Ca-Mg ratios of Lower Cenomanian bivalve calcite shells from the Penzhinskaya Guba. 1 – sandy siltstone, 2- boulders, 3 – mudstone. Other designation as in Fig. 4.

Table 2 Carbon and oxygen isotope analyses of calcitic bivalve and brachiopod shells from the Karmalivayam and Kedrovskaya Formations of the Koryak Upland and aragonitic ammonoids from the Matanuska Formation of Southern Alaska and Aptian-Albian paleotemperatures for high latitudes of the Northern Hemisphere (H, height, L, lenght).

Sample	Species	Stage, formation	Location (H & L, in mm)	Diagenetic alterations				Ca/Mg	$\delta^{13}C$ (PDB)‰	$\delta^{18}O$ (PDB)‰	T° C
				Calcite (original) (%)	Aragonite (%)	Admixture (%)	Colour				
707-3	*Aucellina aptiensis* (Orb.)	Lower Aptian, Karmalivayam	H=20	About 100	0	Analcime, kaolinite (little)	Silvery-white	-	2.9	-1.8	18.4*
707-2-2	*Aucellina aptiensis* (Orb.)	-"-	H=16	-"-	0	-"-	-"-	-	5.2	-2.4	22.2*
707-2-3	Same shell	-"-	H=28	-"-	0	Analcime (very little)	-"-	-	5.4	-3.0	24.7*
707-2-4	Same shell	-"-	H=34	-"-	0	-"-	-"-	-	4.8	-3.1	25.4*
707-2-5	Same shell	-"-	H=45	-"-	0	-"-	-"-	191,67	3.7	-1.6	18.6*
707-2-6	*Aucellina aptiensis* (Orb.)	-"-	H=21	No data	No data	No data	Silvery-white	-	4.1	-2.6	23.1*
707-2-7	*Aucellina aptiensis* (Orb.)	-"-	H=27	-"-	-"-	-"-	Creamish-white	-	3.6	-2.9	24.2*
707-2-8	*Aucellina aptiensis* (Orb.)	-"-	H=33	-"-	-"-	-"-	Silvery-white	-	6.6	-3.7	-
707-2-9	*Aucellina aptiensis* (Orb.)	-"-	H>20	-"-	-"-	-"-	Silvery-white	-	4.6	-4.9	-
707-2-10	*Aucellina aptiensis* (Orb.)	-"-	H=34	About 100	0	Analcime (very little)	Silvery-white	180,0	4.9	-4.9	-
707-2-11	*Aucellina aptiensis* (Orb.)	-"-	H=25	No data	No data	No data	Silvery-white	-	4.7	-3.8	-
707-2-12	*Aucellina aptiensis* (Orb.)	-"-	H=22	-"-	-"-	-"-	Silvery-white	-	4,6	-3.8	-
707-2-13	*Aucellina aptiensis* (Orb.)	-"-	H=21.4	-"-	-"-	-"-	Серебристо-белый	-	4.2	-3.4	-
707-2-15	*Aucellina aptiensis* (Orb.)	-"-	H=23	-"-	-"-	-"-	Silvery-white	178,47	5.4	-3.6	-
707-2-16	*Aucellina aptiensis* (Orb.)	-"-	H=19	-"-	-"-	-"-	Silvery-white	-	3.5	-3.2	25.9*
707-2-1	*Aucellina aptiensis* (Orb.)	-"-	H=20	About 100	0	Analcime (very little)	Silvery-white	-	4.8	-3.9	-
707-1	*Aucellina aptiensis* (Orb.)	-"-	H=23	No data	No data	No data	Cream	-	1.3	-5.7	-
727-2-3	*Penzhinothyris plana* Smirnova	Albian, Kedrovskaya (Melkaya River)	L=35	-"-	-"-	-"-	Silvery-white	-	-2.1	-1.6	18.6*
Al-1	*Grantziceras affine* (Whit.)	Upper Lower Albian, Matanuska	H=25	0	100	0	Greyish-cream	-	+0.6	-0.8	19.0**
Al-2	*Brewiceras hulense* (Ander.)	Upper Lower Albian, Matanuska	H over 25	0	65±3	α-SiO_2 (trace)	Greenish, silvery-white	-	-3.5	-1.4	21.6**

* Anderson and Arthur (1983); ** Grossmam and Ku (1986)

(*Neogastroplites* sp., *Eogunnarites* sp., *Puzosia* cf. *P. nipponica* Mat., *Tetragonites* sp., *Stoliczkaia* sp.).

10. Dark grey sandy siltstone with large calcareous concretions and interlayers of grey fine- and medium-grained sandstone, 36 m. Contains ammonoids *Neogastroplites* sp.

9. Intercalation of grey medium-grained sandstone and dark grey siltstone with ripples at bed surfaces and wood pieces, 110 m. Contains small bivalves *Inoceramus* sp.

8. Dark grey sandy siltstone with ripples at bed surfaces, 19 m. Contains echinoid remains.

7. Greyish green medium-grained sandstone with interlayers and lenses of conglomerate, siltstone, sandy siltstone and coaly rocks (Mysovyj Creek, 706-8,9), 107 m. Yields abundant of bivalves (*Modiolus* sp., *Nucula* sp., *Pleuromya* sp., *Tancredia* sp., *Solecuratus* sp., *Variamussium* sp., *Aucellina?* sp.).

6. Conglomerate with intermediate sized pebble and lenses of coarse-grained sandstone, 135 m.

The thickness of the Mamet Formation is 783 m.

Calcite of only two shells of *Aucellina?* sp. from Member 7 (61 m above its base, 706-8,9) and prismatic layers of *Inoceramus* sp. from Member 13 (706-1) was used for isotopic investigations. The $\delta^{18}O$ value for one of the *Aucellina?* shells is -2.8% which corresponds to paleotemperature of 24.0°C. The $\delta^{13}C$ values in *Aucellina?* shells fluctuate from +1.8 to +5.5%Values of $\delta^{18}O$ in prismatic bivalve fragments is lower (-4.3% because of their marked diagenetic alterations, but their $\delta^{13}C$ value (0.8% believe to be close to their original one (Table 3).

Penzhinskaya Formation
(upper Cenomanian - Coniacian)

Upper Cenomanian–Coniacian sediments at the Mamet and Esgichninvayam River basins represented by the Penzhinskaya Formation overly the Mamet Formation conformably. In descending order, they are (Fig. 6):

Tectonic fault with amplitude of about 100 m (Mamet River).

33. Dark grey sandy siltstone with calcareous-marly boulders and rare interlayers of greyish green medium-grained sandstone (704-5-1, 2,4,5,7,8,9,10,13,14,18,19, 21), 500 m. Yields bivalves (*Inoceramus teshioensis* Nagao et Mat., *I. tenuistriatus* Nagao et Mat.), ammonoids (*Jimboiceras planulatiformis* Mat., macroconch of *Yezoites puerculus* (Jimbo), and wood debris (in the lower and middle parts of the member).

32. Dark grey sandy siltstone with calcareous-marly boulders, 225 m.

Tectonic fault with amplitude of some tens m (between the Mamet and Esgichninvayam River mouths).

31 Grey sandy siltstone with calcareous-marly boulders, 21 m.

30. Grey medium-grained sandstone, 7 m.

29. Dark grey sandy siltstone with large calcareous-marly boulders (right Esgichninvayam River valley slope, 700-1, 700-1a-1, 700-1a-2, 700-1d, 700-5), 60-75 m. Contains bivalves (gigantic *Inoceramus iburiensis* Nagao et Mat., *Ostrea* sp.) ammonoids (micro- and macroconchs of *Yezoites puerculus* (Jimbo), *Scalarites* sp., *Tetragonites glabrus* Jimbo, *Gaudryceras* sp.), terebratulid brachiopods and flowering plant remains.

Unexposed interval at the Esgichninvayam River valley (apparently, the first tens m in thickness).

28. Grey silt sandstone, 3 m (left Esgichninvayam River valley slope, 711-3-1). Contains bivalves (gigantic *Inoceramus* sp., *Ostrea* sp.)and ammonoids *(Scaphites* sp.).

27. Dark grey sandy siltstone with large calcareous-marly boulders (left Esgichninvayam River valley slope, 711-1,2, 711-1-4,6), 15 m. Yields rhynchonellid brachiopods (in the lower part of the member), bivalves (gigantic *Inoceramus* sp.), ammonoids (*Scalarites scalaris* (Yabe), *Scaphites* sp.) and large plant seeds.

Unexposed interval at the Esgichninvayam River mouth (over 150-200 m in thickness).

26. Intercalations of dark grey sandy siltstone and greyish green medium-grained sandstone (Penzhinskaya Guba, 1.1 km W of the Esgichninvayam River mouth, 705-2, 3a, 3c, 3d, 3d-1), 17 m. Contains brachiopods *Penzhinothyris plana* Smirnova, bivalves *Inoceramus pennatulus* Pergament, ammonoids *Marshallites* sp. (in the lower part of the member), *Anagaudryceras sacya* (Forbes), *Desmoceras* sp., *Eomadrasites* sp. (in the middle and upper parts of the member), and worm tubes.

25. Dark grey sandy siltstone with interlayers of greyish green medium-grained sandstone in the upper part of the member, 70 m. Yields bivalves *Inoceramus* sp. and ammonoids *Marshallites* sp.

24. Greyish green medium-grained sandstone with interlayers of grey silt sandstone, 83 m. Contains *Inoceramus* ex gr. *I. concentricus costatus* Nagao et Mat.

23. Greyish green medium-grained tuffaceous sandstone with large boulders of calcareous sandstone and interlayers of micaceous silt sandstone, 35 m. Yields bivalves *Inoceramus* sp. and plant detritus.

22. Greyish green medium grained sandstone with interlayers of gravelstone, 55 m.

21. Thin intercalations of greyish green medium-grained sandstone and black siltstone, 20 m.

20. Greyish green medium-grained sandstone, 15 m.

19. Thin intercalations of greyish green medium-grained sandstone and black siltstone, 20 m.

18. Greyish green medium-grained sandstone with interlayers of black siltstone, 40 m.

17. Intercalations of greyish green medium-grained sandstone and black siltstone, 78 m.

16. Grey medium-grained sandstone with boulders of calcareous sandstone, 5 m.

15. Intercalations of black silt sandstone and grey medium-grained sandstone, 53 m.

The thickness of the Penzhinskaya Formation in the section is 1,240-1,260 m.

The analyzed late Cenomanian brachiopod *Penzhinothyris plana* Smirnova with well preserved microstructure from member 26 were found in the beds (705-2,3a,3c,3d,3d-1), exposed at Penzhinskaya Guba beach, 1 km W of the Esgichninvayam River mouth. *Penzhinothyris* $\delta^{18}O$ and $\delta^{13}C$ values range from –2.7 to –2.0% (mean of –2.3%) and from –0.4 to +1.8%(mean +0.3%, correspondingly (Table 3). Judging from data on isotopic investigations of brachiopod calcite, calculated paleotemperatures for the late Cenomanian shallow water facies of the Penzhinskaya Guba reach 20.4-23.3°C.

From the lower Middle Turonian (members 27 and 28) exposed on the left Esgichninvayam River valley slope, 1.5 km upper its mouth, both the original calcite material (rhynchonellid brachiopods (711-1,2), *Ostrea* sp. (711-3-1) with well preserved structure) and the aragonite of *Inoceramus* sp. (711-1-4,6) were analyzed. In spite of high content of aragonite in analyzed *Inoceramus* sp. samples (95-98±3%) and very low content of analcime and α-SiO_2 admixture, which show, apparently, on low degree of diagenetic alterations, they characterized by low $\delta^{18}O$ values (ranging from –3.6 to –2.5% mean –3.1%. Paleotemperature estimates from this fossils seem to be unreliable ("T"°C=26.3-30.9). At the same time they are

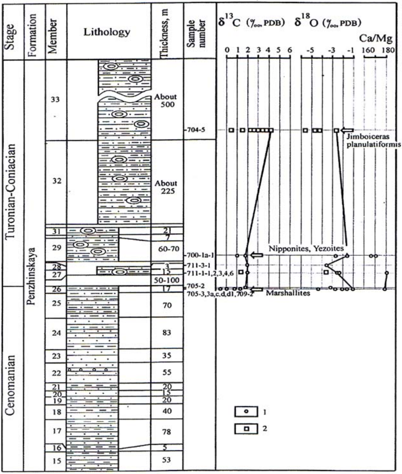


Fig. 6. The $\delta^{18}O$ and $\delta^{13}C$ values of Late Cenomanian – Turonian brachiopod and inoceramid bivalve calcite and inoceramid bivalve aragonite shells from the Penzhinskaya Guba. 1 – calcite, 2 – aragonite. Other designation as in Figs. 4 and 5.

characterized by high $\delta^{13}C$ values, ranging from +1.3 to +4.4%(mean 3.3%. Low $\delta^{18}O$ value (–3.0% was determined for the shell of *Ostrea* sp., which was met in association with *Inoceramus* sp. and also characterized by normal $\delta^{13}C$ value (+2.0%. More or less real paleotemperatures for the beginning of the middle Turonian were obtained from calcite of rhynchonellid brachiopod shells, which were located isolate from analyzed *Inoceramus* and *Ostrea* shells in the section. $\delta^{13}C$ value in lower Middle Turonian brachiopod shells reaches +2.1%

For the middle part of the Middle Turonian (Member 29) exposed at the Penzhinskaya Guba, 100-500 NE of the Esgichninvayam River mouth, both original calcite of *Ostrea* sp. (700-1a-1), undetermined bivalve (700-5) and *Inoceramus* sp. (700-1, 700-1a-2) and aragonite of *Inoceramus hobetenis* Nagao et Mat. (700-1d) were used for isotopic investigations. Besides, middle Turonian brachiopod *Penzhinothyris* sp. shell (709-2) from the separate tectonic block, located along the Penzhinskaya Guba, 3.2 km N of the Mamet River mouth was also analyzed. From obtained results only isotopic data on *Ostrea* sp. ($\delta^{18}O$=-2.6% $\delta^{13}C$=+0.9% and undetermined bivalve ($\delta^{18}O$=-2.6% $\delta^{13}C$=+0.9% seem to be suitable for paleotemperature reconstruction (23.1°C). *Inoceramus* sp. and *Penzhinothyris* sp. $\delta^{18}O$ are very low (-3.1 and –4.7 - –3.1% respectively), but their $\delta^{13}C$ values appear to be "normal" (about +1.2 and –0.5% respectively). Similar picture takes place with the *Inoceramus hobetsensis* Nagao et Mat. shell, consisted of 80±3% of aragonite ($\delta^{18}O$=-3.9% $\delta^{13}C$=-0.3% (Tables 3,4,5).

Table 3 Carbon and oxygen isotope analyses of bivalve, brachiopod and worm calcite from the Mamet and Penzhinskaya Formations and latest Albian? – late Cenomanian paleotemperatures for high latitudes of the Northern Hemisphere (D, diameter, W, width, L, lenght, H, height).

Sample	Species	Stage, formation	Location (D,W,L & H, in mm)	Colour	Ca/Mg	$\delta^{13}C$ (PDB) (‰)	$\delta^{18}O$ (PDB) (‰)	T° C
706-8	*Aucellina*? sp.	Lower Cenomanian, Mamet (lower part)	H=42	Silvery-white	-	1.8	-2.8	24.0*
706-9	*Aucellina*? sp.	- " -	H=18.9	- " -	-	5.5	-8.3	-
706-1	*Inoceramus* sp.	Lower Cenomanian, Mamet (upper part)	W=12 (prismatic layers)	Yellowish-white	-	0.8	-4.3	-
705-2	Worm (tube)	Upper Cenomanian, Penzhinskaya	D=7.6	White	180.0	1.4	-3.0	-
705-3a	*Penzhinothyris plana* Smirnova	- " -	L=25	Silvery-white	-	-0.4	-.7	23.3*
705-3c	*Penzhinothyris plana* Smirnova	- " -	L=30	- " -	-	-0.1	-2.5	22.6*
705-3d	*Penzhinothyris plana* Smirnova	- " -	L=27	- " -	-	0	-2.1	20.8*
705-3d-1	*Penzhinothyris plana* Smirnova	- " -	L=28	- " -	-	1.8	-2.0	20.4*

* Anderson and Arthur (1983)

Table 4 Carbon and oxygen isotope analyses of calcitic brachiopod and inoceramid bivalve shells from the middle part of the Penzhinskaya Formation of the Koryak Upland and Middle Turonian paleotemperatures for high latitudes of the Northern Hemisphere (H, height, L, lenght, W, width).

Sample	Species	Location (H, L & W, in mm)	Calcite (original) (%)	Colour	Ca/Mg	$\delta^{13}C$ (PDB) (‰)	$\delta^{18}O$ (PDB) (‰)	T° C
711-1-1	Rhynchonellida	Two shells L=15	100	Silvery-white	182.9	2.1	-2.7	23.5*
711-1-2	Rhynchonellida	L=15	- " -	- " -	-	2.1	-2.6	23.1*
711-3-1	*Ostrea* sp.	H=12	- " -	White	-	2.0	-3.5	-
701-1	*Inoceramus* sp.	W=7.2	- " -	- " -	-	1.2	-4.7	-
701-1a-2	*Inoceramus* sp.	W=6.5	- " -	Yellowish-white	166.4	1.0	-3.4	-
700-1a-1	*Ostrea* sp.	H=26	- " -	White	171.2	0.9	-2.6	23.1*
700-5	Bivalve shell	H=29	- " -	Silvery-white	-	0.9	-2.6	23.1*
709-2	*Penzhinothyris plana* Smirnova	L=15	- " -	- " -	-	-0.5	-3.1	-

* Anderson and Arthur (1983)

Table 5 Carbon and oxygen isotope analyses of aragonitic elements of inoceramid bivalves from the middle and upper parts of the Penzhinskaya Formation (Middle – Upper Turonian) of the Koryak Upland (H, height).

Sample	Species	Stage	Location (H, in mm)	Diagenetic alterations			$\delta^{13}C$ (PDB) (‰)	$\delta^{18}O$ (PDB) (‰)
				Aragonite (%)	Admixture (%)	Colour		
711-)1-3	*Inoceramus* sp.	Middle Turonian	H>300	95±5	α-SiO_2 (trace)	Cream	1.3	-3.6
711-1-4	*Inoceramus* sp.	- " -	H=350	98±3	0	- " -	4.4	-2.8
711-1-6	*Inoceramus* sp.	- " -	H=350	97±5	Analcime (little)	- " -	4.3	-2.5
700-1d	*Inoceramus hobetensis* Nagao et Mat.	- " -	H=300	80±3	0	- " -	-0.3	-3.9
704-5-1	*I. teshioensis* Nagao et Mat.	Upper Turonian	H=20	88±3	0	- " -	3.2	-4.5
704-5-2	*I. teshioensis* Nagao et Mat.	- " -	H=25	87±3	0	- " -	2.7	-5.2
704-5-3	*I. teshioensis* Nagao et Mat.	- " -	H=31	93±3	0	- " -	2.3	-4.3
704-5-4	*I. teshioensis* Nagao et Mat.	- " -	H=27	90±5	0	- " -	2.7	-5.7
704-5-5	*I. teshioensis* Nagao et Mat.	- " -	H=20	89±3	0	- " -	2.8	-4.2
704-5-7	*I. teshioensis* Nagao et Mat.	- " -	H=41	83±3	0	- " -	0.7	-5.2
704-5-8	*I. teshioensis* Nagao et Mat.	- " -	H=26.8	97±3	0	- " -	3.9	-5.2
704-5-9	*I. teshioensis* Nagao et Mat.	- " -	H=21	83±3	0	- " -	1.5	-5.9
704-5-10	*I. teshioensis* Nagao et Mat.	- " -	H=8	87±5	0	- " -	2.4	-4.2
704-5-13	*I. teshioensis* Nagao et Mat.	- " -	H=26	95±5	0	- " -	3.4	-4.4
704-5-14	Same shell	- " -	H=33	97±3	0	- " -	3.4	-3.4
704-5-15	*I. teshioensis* Nagao et Mat.	- " -	H=14	93±5	Analcime (trace)	- " -	3.7	-4.5
704-5-18	*I. teshioensis* Nagao et Mat.	- " -	H=31	90±3	0	- " -	2.6	-4.3
704-5-19	*I. teshioensis* Nagao et Mat.	- " -	H=16	97±3	0	- " -	3,4	-4,8
704-5-21	*I. teshioensis* Nagao et Mat.	- " -	H=34	96±5	Analcime (little)	- " -	3,5	-4,5

Ca-Mg ratios in the prismatic layer of *Inoceramus* sp. (166.4) indicate higher Mg content as compared with calcite from *Ostrea* sp. (177.2), in spite of that fossils were found together in the same boulder.

Upper Turonian *Inoceramus teshioensis* Nagao et Mat. (704-5-1, 2,4,5,7,8,9,10,13,14,18,19 and 21) located in the Member 33 (exposed 1.2 km NE of the Mamet River mouth) and consisted of mainly aragonite (87-98±3%) with lacking any admixtures except of minor portion of secondary calcite, are characterized by constantly very low $\delta^{18}O$ values, which mostly range between –5.9 and –3.4% ("T"°C=30.2-41.1), averaging –4.7% Another peculiarity of that aragonitic shells is their comparatively high $\delta^{13}C$ values (ranging from +0.7 to +3.9%.

Bystrinskaya Formation (Santonian-lower Campanian)

Santonian-lower Campanian sediments exposed along the Penzhinskaya Guba at the Esgichninvayam-Mamet interfluves and northern of the Mamet River mouth and represented by the Bystrinskaya Formation overly the Penzhinskaya Formation, obviously, conformably. In descending order, they are (Fig. 7):

Tectonic fault with amplitude of over 100 m (at the Mamet River mouth).

53. Intercalations of dark grey siltstone with calcareous-marly boulders and grey silt sandstone (about 2.7 km N of the Mamet River mouth along the Penzhinskaya Guba and along the Mamet River, about 5.0-5.5 km NE of its mouth), about 170 m.

52. Greyish green medium-grained sandstone, 25 m. Yields ammonoid *Tetragonites glabrus* Jimbo.

51 Dark grey siliceous sinter, in the lower portion of the member, and dark grey sandy siltstone, 9 m. Contains bivalves (*Sphenoceramus* sp. or *Inoceramus* sp.) and ammonoids (*Neophylloceras* sp., *Eupachydiscus?* sp.).

50. Greyish green medium-grained sandstone with layers of grey sandy siltstone, in the lower portion of the member,

and intercalations of dark grey siltstone with calcareous-marly boulders and grey silt sandstone, in its upper portion

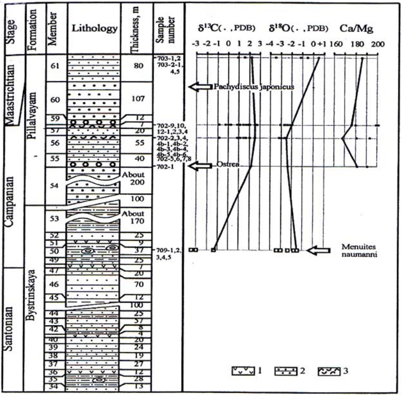


Fig. 7 The $\delta^{18}O$ and $\delta^{13}C$ values of Early Campanian ammonoid aragonite shells, Late Campanian bivalve calcite and Early Maastrichtian brachiopod calcite shells from the Penzhinskaya Guba. Other designation as in Figs. 4, 5 and 6.

yields bivalves (*Inoceramus* sp.) and ammonoids *(Menuites naumanni* (Yok.) and *Menuites* aff. *M. deccamensis* (Stoliczka).

49. Intercalations of greyish green medium-grained sandstone, dark grey silt sandstone and siltstone with calcareous-marly boulders and plant detritus, 25 m.

48. Dark grey siliceous sinter (Mamet River mouth), 7 m.

47. Dark grey fine-grained sandstone with plant detritus, 20 m. Contains bivalves (*Inoceramus amakusensis* Nagao) and flowering plant remains.

(350 m N of the Mamet River mouth, 709-1-1,2,3,5), 37 m.

46. Grey medium-grained sandstone with boulders of calcareous sandstone, 70 m.

45. Dark grey siliceous siltstone, 12 m.

44. Intercalations of dark grey medium-grained sandstone, dark grey sandy siltstone, over 25 m. With ammonoid *Menuites naumanni* (Yok.) and nautiloid *Kymatites* sp.

43. Greyish green medium-grained sandstone, 57 m. Yields ammonoid *Menuites naumanni* (Yok.) and flowering plant remains.

42. Intercalations of dark grey silt sandstone and medium-

grained sandstone, 8 m.

41. Dark grey siliceous sinter, 4 m.
40. Dark grey medium-grained sandstone, 20 m.
39. Greyish green medium- and fine-grained sandstone, 24 m.
38. Intercalations of greyish green medium-grained sandstone and dark grey silt sandstone, 19 m.
37. Grey medium-grained sandstone, 27 m.
36. Dark grey siliceous sinter, 12 m.
35. Grey silt sandstone and siltstone with calcareous-marly boulders, about 28 m.
34. Grey medium-grained sandstone (Penzhinskaya Guba between the Esgichninvayam and Mamet River mouths), about 13 m.

Tectonic fault with amplitude of about 100 m.

The thickness of the Bystrinskaya Formation is over 700 m.

Only one aragonite bearing *Menuites* aff. *M. deccamensis* (Stoliczka) (709-1-1,2,3,5; with 85-100% of aragonite) found in the member 50, 350 m N of the Mamet River mouth has been used for isotopic investigations (most part of *Menuites naumanni* shells from the Bystrinskaya Formation is replaced by a large portion of clinoptilolite). Samples from the most good preserved parts of *Menuites* aff. *M. deccamensis* shell show a range in $\delta^{18}O$ and $\delta^{13}C$ values from –2.3 to –1.6%, and from –3.0 to –0.7%, respectively. These give calculated Late Campanian paleotemperatures ranging from 22.4 to 25.5° (Table 6).

Pillalvayam Formation (upper Campanian–Maastrichtian)

Upper Campanian–Maastrichtian sediments represented by the Pillalvayam Formation (Pokhialainen and Vasilenko, 1971) overly with erosion on Bystrinskaya Formation sequences. At the middle reaches of the Mamet River and its tributary Tundrovaya River, the lower portion of the Pillalvayam Formation in descending order is:

61. Grey and greyish green medium-grained greywacke sandstone (703-1, 703-2-1,4,5), 80 m. Yields hexacorals (Caryophyllidae), colonial octocorals, bryozoans, rhynchonellid brachiopods (abundant), bivalves (*Truncacila* sp.) and shark teeth.
60. Greyish green coarse-grained obliquely laminated sandstone, 107 m.
59. Conglomerate with small sized pebble, 12 m.
58. Oyster coquina (702-3,4,5,7,9,10,11,12), 7 m. Contains bivalves (abundant *Ostrea* sp.).
57. Greyish green medium-grained sandstone, 20 m.
56. Greyish green medium-grained sandstone with interlayer of oyster coquina in the upper portion of the member (702-1), 55 m. Yields bivalves (*Ostrea* sp., *Trigonia* sp., *Isocardia* ex gr. *I. zitteli* Hozaphel) (Pergament, 1961) and nautiloids.
55. Conglomerate with small sized pebble, gravelstone and coarse-grained sandstone, 40 m.
54. Greyish brown coarse-grained sandstone with pebbles and interlayers of gravelstone, 200-325 m. Contains bivalves (*Ostrea* sp. indet. and *Trigonia* sp.).

The thickness of the formation 630-690 m (Pokhialainen and Vasilenko, 1971). The thickness of the investigated portion (lower and middle parts of the formation) is about 500 m.

From the lower portion of the Pillalvayam Formation (members 56 and 58) calcite of well preserved *Ostrea* sp. (702-1,3,4,5,7,9,10,11,12) have been analyzed. The $\delta^{18}O$ and $\delta^{13}C$ values for the *Ostrea* samples ranged from –3.2 to 2.1‰ (which correspond paleotemperatures of 20.6-25.4°C) and –1.1 to 2.5‰, respectively. Mg content in the late Campanian *Ostrea* sp. shells is very variable (Ca/Mg=166.9-200.4), which caused, apparently, by significant variable of season environment of their inhabitation.

From the middle portion of the formation (Member 61), only brachiopod calcite with well preserved structure was investigated (703-1, 703-2-1,4,5). The $\delta^{18}O$ and $\delta^{13}C$ values for the Early Maastrichtian rhynchonellid samples ranged from –1.2 to +0.5%(which corresponds to 10.2-16.9°C) and +0.6 to +1.8%, respectively (Table 6). The investigated shells are characterized by comparatively low Mg content (Ca/Mg=186.0).

$\delta^{18}O$ and $\delta^{13}C$ in ammonoid shells from the Lower Cretaceous of South Alaska

The three late Early Albian ammonite shells from the Matanuska Formation (*Brewericeras hulense* Zone, the middle and the upper parts of the unit A-2) of Ammonite Creek, Talkeetna Mountains, South Alaska (Fig. 2), were used for isotopic analyses in comparative purpose. The unit A-2 about 73 m thick is represented by yellowish brown siltstone with fossil wood at the base and light-olive-grey silty cleystone containing fossiliferous limestone concretions in the middle and upper parts (Jones, 1967).

From investigated shells the *Grantziceras affine* (Whiteave) (Al-1) was found most useful for analyses because it is characterized by minor diagenetic alterations (consists of solely by aragonite – 100%, and has not any admixtures). $\delta^{18}O$ value in aragonite equals –0.8% which corresponds to 19.0°C, $\delta^{13}C$ value reaches +0.6%(Table 2). *Brewiceras hulense* (Anderson) shell (Al-3) contains only 69% of aragonite and has α-SiO_2 trace. Its $\delta^{18}O$ value equals –1.4% which corresponds to 21.6°C, $\delta^{13}C$ value is negative (-3.58$^{o}/_{oo}$). Investigated *Freboldiceras singulare* Imlay (Al-2) seems to be unsuitable for distinguishing true isotopic record.

Early Albian paleotemperatures obtained for South Alaska (19.0-21.6°C) are closely similar those of the Koryak Upland.

The main tendencies in change of a climate in the northern high latitudes during Cretaceous (on paleobotanical and isotopic data)

Isotopic paleotemperature data reported in this study are combined with the Valanginian paleotemperature records of Ditchfield (1997) for Svalbard and paleobotanical evidences for Koryak Upland and adjacent territories (Herman and Lebedev, 1991; Golovneva, 1998; Golovneva and Herman, 1998; Lebedev, 1990a,b; Markevich, 1995; Nesov and Golovneva, 1990) to reconstruct the history of climatic change in the northern high latitudes from the Berriasian through Maastrichtian.

Table 6 Carbon and oxygen isotope analyses of aragonitic ammonoid shells from the Bystrinskaya and calcitic bivalve and brachiopod shells from the Pillalvayam Formations of the Koryak Upland and Campanian – Maastrichtian paleotemperaturesfor high latitudes of the Northern Hemisphere (H, height, L, lenght).

Sample	Species	Stage	Location (H & L, in mm)	Diagenetic alterations				Ca/Mg	$\delta^{13}C$ (PDB)‰	$\delta^{18}O$ (PDB)‰	T° C
				Calcite (original) (%)	Aragonite (%)	Admixture (%)	Colour				
709-1-5	*Menuites* aff. *M. deccamensis* (Stoliczka)	Lower Campanian	H=140	0	100	0	Cream	-	-0,7	-1,6	22,4**
709-1-3	Same shell	- " -	H=100	0	89±3	0	Greenish-cream		-3.0	-1.7	22.9**
709-1-2	Same shell	- " -	H=80	0	77±3	0	- " -		-3.3	-3.4	-
709-1-1	Same shell	- " -	H=50	0	85±5	Kaolinite (little)	- " -		-3.4	-2.3	25.5**
702-1	*Ostrea* sp.	Upper Campanian	H=27	100	0	No data	Silvery-white	-	2.2	-2.5	22.4*
702-2	*Ostrea* sp.	- " -	H=	100	0	- " -	- " -	-	0.4	-2.4	22.2*
702-3	*Ostrea* sp.	- " -	H=60	- " -	- " -	- " -	- " -	179.35	1,8	-2,7	23.5*
702-4b-1	*Ostrea* sp.	- " -	H=12	- " -	- " -	- " -	- " -	-	0.8	-2.5	22.4*
702-4b-2	Same shell	- " -	H=11	- " -	- " -	- " -	- " -	197.68	1.4	-3.0	24.7*
702-4b-3	Same shell	- " -	H=17	- " -	- " -	- " -	- " -	182.02	1.2	-2.6	23.1*
702-4b-4	Same shell	- " -	H=27	- " -	- " -	- " -	- " -	191.67	1.5	-2.6	23.1*
702-4b-5	Same shell	- " -	H=31	- " -	- " -	- " -	- " -	192.70	1.4	-2.9	24.5*
702-4b-6	Same shell	- " -	H=40	- " -	- " -	- " -	- " -	190.50	2.5	-2.5	22.6*
702-4	*Ostrea* sp.	- " -	H=40	- " -	- " -	- " -	- " -	179.70	2.0	-2.7	23.5*
702-5	*Ostrea* sp.	- " -	H=40	- " -	- " -	0	- " -	193.34	-1.1	-3.1	25.4*
702-7	*Ostrea* sp.	- " -	H=40	- " -	- " -	Undetermined	- " -	166.90	0.9	-3.1	25.4*
702-9	*Ostrea* sp.	- " -	H=20	- " -	- " -	- " -	- " -	173.68	-0.3	-3.1	25.4*
702-10	*Ostrea* sp.	- " -	H=50	- " -	- " -	- " -	- " -	178.57	2.5	-2.6	23.1*
702-11	*Ostrea* sp.	- " -	H=30	- " -	- " -	- " -	- " -	176.18	1.0	-2.2	21.3*
702-12-1	*Ostrea* sp.	- " -	H=37	- " -	- " -	- " -	- " -	200.40	1.5	-2.4	22.2*
702-12-2	Same shell	- " -	H=57	- " -	- " -	- " -	- " -	199.30	0.9	-2.1	20.6*
702-12-3	Same shell	- " -	H=60	- " -	- " -	- " -	- " -	-	0.0	-2.3	21.7*
702-12-4	Same shell	- " -	H=69	- " -	- " -	- " -	- " -	-	0.6	-2.2	21.3*
703-1-2	Rhynchonellida	Lower Maastrichtian	L=5	- " -	- " -	- " -	- " -	-	1.8	0.5	10.2*
703-2-1	Rhynchonellida	- " -	L=6	- " -	- " -	- " -	- " -	186.00	0.6	-0.6	14.4*
703-2-4	Rhynchonellida	- " -	L=11	- " -	- " -	- " -	- " -	-	1.0	-1.2	16.7*
703-2-5	Rhynchonellida	- " -	L=12	- " -	- " -	- " -	- " -	-	1.8	-1.2	16.9*

* Anderson and Arthur (1983); ** Grossmam and Ku (1986)

Berriasian-Valanginian

On the basis of analyses of the Matsijsky and the Solonijsky paleofloristic assemblages from Okhotsk-Chukotka volcanic belt and of the Bureya River basin Lebedev (1990a,b) expects a climatic optimum in Far East during Berriasian-Valanginian time, because thermophyle cycadophyte plants were dominated at extensive territory from Anadyr and Yakutsk area in the north to western Okhotsk region and the Amur River basin in the south this time. On palynological criterions (Markevich, 1995) Berriasian climate in Russian Far East was indeed warm and sufficiently wet, but during Valanginian was not so warm, because she recognized a reduction of *Glosspolis* in the Valanginian palynological succession. Ditchfield's data show cool high latitude marine paleotemperatures (5.3-10.9°C) during early to mid Valanginian, based on oxygen stable isotope paleothermometry of endemic belemnite species (*Acroteuthis, Hibolites*) from Kong Karls Land, Svalbard.

Hauterivian-Barremian

Data on Ozhogin and Chemchukin paleofloristic assemblages from north-east Asia (Golovneva, 1998) and the Bureya River basin (Lebedev, 1990b), correspondingly, confirm the existence of warm humid climate in Neocomian, including Hauterivian-Barremian, characterized by development of ferns, ginkgoaleans, czekanowskialeans and archaic conifers; cycadophytes are characterized also by the comparatively high taxonomic diversity. At the same time there are paleobotanical evidences on some cooling in Hauterivian time (Lebedev, 1990b). Our stable isotopic data obtained from calcite shallow water bivalve *Inoceramus* and *Aucellina* of the Mamet Peninsula, Penzhinskaya Guba, show higher temperature of surface water in north high latitudes in Barremian (24.5°C) than in Hauterivian (21.3°C).

Aptian-early Albian

Analyses of the Silyap, Buorkemyus and Tyl assemblages from north-east Asia (Golovneva, 1998) and Khabarovsk region (Lebedev, 1990b) confirm the continuation of epoch of warm humid climate in Aptian and early Albian time. The early Albian Buorkemyus and Tyl floras are especially characterized by the high taxonomic diversity on the whole and abundance of cycadophytes, that appear to reflect climatic optimum. From Albian a noticeable role in the flora began to play flowering plants. The paleotemperatures obtained from lower Aptian bivalve *Aucellina* of the Mamet Peninsula (18.4-25.9°C) seem to be the same or relatively warmer than those from early Albian brachiopod *Penzhinothyris* of the Talovka River basin (18.6°C).

Middle Albian

A reduction of cycadophytes and domination of coniferous related to a marked deterioration of climatic conditions have been recognized in middle Albian floristic assemblages by Golovneva (1998) (Topan assemblage of North-East Russia) and Lebedev (1990b) (Enmanrin one of Khabarovsk region).

Late Albian–early Cenomanian

The Late Albian–early Cenomanian Arman flora of North-East Russia differs from the previous Topan flora by increase of diversity of cycadophytes and platanoids, but domination of coniferous, which indicates on getting warmer and humid during the Early-Late Cretaceous transition. Oxygen-isotopic analysis of *Aucellina?* calcite from the lower part of the Mamet Formation in the Penzhinskaya Guba indicates on rather high temperature (24.0°C) of shallow-water of the North Kamchatka area during the sedimentation of the Mamet Formation basal beds.

Late Cenomanian – early Turonian

Both the Late Cenomanian–early Turonian Grebenkinskiy floristic assemblage of north-western Kamchatka (Herman and Lebedev, 1991; Golovneva, 1998; Golovneva and Herman, 1998) and the contemporaneous Dukchandin assemblage of the Khabarovsk region (Lebedev, 1990b) are characterized by development of cycadophytes, abundant of large-leafed platanoids, ginkgoaleans, decreasing of the role of coniferous, but increasing of diversity of the flora on the whole, which corresponds to epoch of cold humid climate. The results of oxygen-isotope investigation of calcite of shallow-water brachiopod *Penzhinothyris* from the lower part of the Penzhinskaya Formation confirm some paleobotanical data, showing rather high paleotemperatures (20.4-23.3°C) of shallow waters of North Kamchatka in late Cenomanian. Somewhat higher paleotemperature (24.9°C) was obtained on the basis of data on the calcitic tube of marine worm discovered at the same locality.

Turonian–early Coniacian

For both the Penzhinskiy floristic assemblage of north-western Kamchatka (Herman and Lebedev, 1991; Golovneva, 1998; Golovneva and Herman, 1998) and the Ketandin one of the Khabarovsk region (Lebedev, 1990b) of Turonian–early Coniacian age, the disappearance of cycadophytes, domination of large-leafed platanoids, development ferns and coniferous, following by a sharp reduction of taxonomic diversity on the whole is characteristic. These events correspond to the stage of development of more or less cold, but very humid climate. Obtained data on isotopic composition of calcite of middle Turonian brachiopods and some bivalves from the middle part of the Penzhinskaya Formation allow to expect rather high shallow-water temperatures (23.1-23.5°C) for the Penzhinskaya Guba region during middle Turonian time. At the same time oxygen-isotopic data obtained by us some years ago on Turonian (apparently, late Turonian) ammonite *Mesopuzosia* from eastern Koryakia (Zakharov et al., 1996, 1999) testify, obviously, on lower shallow-water paleotemperatures for north Kamchatka at the end of Turonian (14.1-16.3°C) in comparison with middle Turonian ones. Comparatively low paleotemperatures for the late Turonian were recently determined by isotopic investigation of brachiopod shells also for south England (16.0-18.2°C) and (14.2°C) (Voigt, 2000).

Coniacian

The main features of the Coniacian Kaivayam flora of northwestern Kamchatka (Herman and Lebedev, 1991; Golovneva, 1998; Golovneva and Herman, 1998) are (1) development of magnolia-form plants and (2) domination of large-leafed platanoids, which indicates on more or less warm and very humid climate here during middle and late Coniacian. Judging from isotopic composition of bivalve *Nannonavis* calcite from the upper part of the Penzhinskaya Formation of the low reaches of the Talovka River, shallow-water paleotemperature value for north Kamchatka during Coniacian was 16.3°C, but data from aragonite of ammonoid *Kossmaticeras* and *Anagaudryceras* from other beds of the same section show higher paleotemperatures (18.5-20.6°C) (Table 7). The Coniacian paleotemperatures obtained from the Koryak Upland are only at 3-9°C cooler than those from Hokkaido (Table 7).

Santonian

For the Santonian Velizhgen floristical stage in north-eastern Asia the abundance of cycadophytes, disappearance of large-leafed platanoids, reduction of plant species diversity and abundance of ferns are characteristic that corresponds to development of a warm arid climate in middle Santonian (Golovneva, 1998; Golovneva and Herman, 1998).

Campanian

The Campanian Barykov floristical stage in north-east Asia is characterized by development of cycadophytes, appearance of rare platanoids and reduction of fern diversity, that corresponds to Campanian thermal maximum following by reduction of aridity (Golovneva and Herman, 1998). Judging from isotopic composition of aragonitic shell of *Menuites* from the Bystrinskaya Formation of the Penzhinskaya Guba, shallow-water paleotemperature of northern Kamchatka reached 22.4-25.5°C in early Campanian. Analysis of the calcite shells from the middle part of the Pillalvayam Formation of the Penzhinskaya Guba shows that shallow-water paleotemperature was not essentially varied (21.3-25.4°C) during late Campanian.

Early-middle Maastrichtian

Judging from oxygen isotope composition of brachiopod calcite from the upper part of the Pillalvayam Formation of the Tundrovaya River area, Penzhinskaya Guba, through the course of the late Campanian - early Maastrichtian, paleotemperatures in north Kamchatka dropped sharply (from a high of over 20°C to 10.2-16.9°C), as well as in many other districts of the world (Teiss and Naidin, 1973; Douglas and Savin, 1975; Boersma and Shackelton, 1981; Barrera et al., 1987; Pirrie and Marshall, 1990; Huber et al., 1995; Zakharov et al., 1999).

Paleobotanical evidence on the Gornorechensk and Kakanaut assemblages of Koryak Upland allows to expect a warm humid climate there for the mid-Maastrichtian, when the significant role in these floristic associations began to play cycadophytes, as well as large-leafed platanoids and ginkgoaleans (Nesov and Golovneva, 1990; Golovneva, 1998; Golovneva and Herman, 1998). Compared to the middle-late Cretaceous, Middle Maastrichtian climate appears to be not so warm, but to be markedly more humid than Campanian one.

Late Maastrichtian – Danian

Judging from absence of cycadophytes, rarity of ginkgoaleans, development of large-leafed platanoids and ferns, and also domination of coniferous in the Rarytkin assemblage of the north Koryak Upland, cold humid climate seems to be present during the late Maastrichtian–Danian time (Golovneva and Herman, 1998).

Cretaceous thermal maxima and Turonian fresh water influence in high latitudes of the Northern Hemisphere

Thus, on the basis of data on isotopic thermometry and paleobotanical observation (first of all registration of epochs of development of thermophyle cycadophytes and moisture-loving large-leafed platanoids) made for the Koryak Upland the next thermal maxima for high-latitudes of the Northern Hemisphere have been recognized: (1) Berriasian (humid), (2) Barremian (humid), (3) Aptian–early Albian (humid), (4) late Albian (?)–early Cenomanian (humid), (5) Cenomanian-Turonian (humid), (6) middle Coniacian (with indications of aridity), (7) mid-Santonian (arid), (8) early Campanian (with reduction of aridity), (9) late Campanian (with reduction of aridity), and (10) mid-Maastrichtian (humid) (Fig. 8).

The strongly negative $\delta^{18}O$ values found in aragonite of good preserved middle and especially late Turonian inoceramid bivalves from the one of regions of western Koryakia (Esgichninvayam and Mamet River basins), ranging from –4.3 to –5.9% seem to be connected with the freshening of the Penzhinskaya Guba basin (Fig. 9). It may be due to sharp development of humid climate (firstly, warm and after cold) (Golovneva and Herman, 1998), which is likely to have occurred over the Koryak Upland area mainly during Turonian time. Similar picture took place, apparently, during early Turonian in high latitudes of the Southern Hemisphere, which is confirmed by isotopic data on Early Turonian planktonic foraminifers from the Southern Atlantic and discovering of relatively high vertical oxygen-isotopic gradient just for the Turonian of the Southern Atlantic (Huber et al., 1995). It thus seems that supposed fresh-water input from high latitude continents in both the Northern and the Southern Hemispheres during Turonian, with formation of a freshened surface layer in some neighboring aquatories, is likely connected with extensive humidisation of climate of that time.

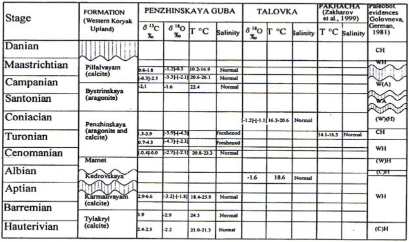
Epochs of a relatively mild climate in high-latitudes were favorable in particular for the dinosaurs inhabitation and their long-term migrations through the

Bering Land Bridge: high temperatures promoted to successful completion of an incubation period of their life (Nesov, 1995, 1997) and warm humid climate favorably influenced on development of their cycadophyte forage base (Krassilov, 1981; Krassilov et al., 1990) during all their way from Koryakia to Alaska and back. In the Kakanaut River basin, Bering

Table 7 Carbon and oxygen isotope analyses of aragonitic and calcitic mollusc shells from the Penzhinskaya Formation of Talovka River, Koryak Upland and *Inoceramus uwajiensis* Zone of Sakasa-gawa River basin, Hokkaido, and Coniacian paleotemperatures of high and middle latitudes of the Northern Hemisphere (H, height, L, lenght).

Sample	Species	Formation, zone	Location (H & L, in mm)	Diagenetic alterations				$\delta^{13}C$ (PDB) (‰)	$\delta^{18}O$ (PDB) (‰)	T° C
				Aragonite (%)	Calcite (original) (%)	Admixture (%)	Colour			
713-7-1	*Kossmaticeras japonicum* Mais.	Penzhinskaya	H=45	96±4	-	Clinoptilolite (trace)	Silvery-white	-1.1	-1.2	20.6**
718-14-2	*Anagaudriceras denseplicatum* (Yok.)	- " -	H=400	100	-	-	- " -	-0.5	-0.7	18.5**
713-13-1	*Kossmaticeras japonicum* Mais.	- " -	H=50	95±5	-	α-SiO$_2$ (little), clinoptilolite (trace)	- " -	-2.5	-1.0	19.8**
713-5a-3	*Nannonavis* sp.	- " -	L=13	0	100	-	- " -	1.1	-1.1	16.3*
S-19	*Yokoyamoceras* sp.	*Inoceramus uwajiensis* Zone	H over 45	90±5	-	Clinoptilolite (trace)	Aureate-cream	-1.5	-1.4	21.6**
S-26	*Inoceramus sp.*			100	-	-	- " -	5.4	-2.2	25.1**

* Anderson and Arthur (1983); ** Grossmam and Ku (1986)



Stage	FORMATION (Western Koryak Upland)	PENZHINSKAYA GUBA				TALOVKA			PAKHACHA (Zakharov et al., 1999)		Paleobot. evidences (Golovneva, German, 1981)
		$\delta^{13}C$ ‰	$\delta^{18}O$ ‰	T °C	Salinity	$\delta^{18}O$ ‰	T °C	Salinity	T °C	Salinity	
Danian											CH
Maastrichtian	Pillalvayam (calcite)	0.6-1.8	-1.2]-0.5	10.2-16.9	Normal						WH
		-0.3]-2.5	-3.3]-[-2.1]	20.6-26.1	Normal						
Campanian	Bystrinskaya (aragonite)	-2,1	-1.6	22.4	Normal						W(A)
Santonian											WA
Coniacian	Penzhinskaya (aragonite and calcite)					-1.2]-[-1.1]	16.3-20.6	Normal			(W)(H)
Turonian		.5-3.9	-5.9]-[-4.3]		Freshened				14.1-16.3	Normal	CH
		0.7-4.3	-4.7]-[-2.3]		Freshened						WH
Cenomanian		-0.4]-0.0	-2.7]-[-2.1]	20.8-23.3	Normal						
Albian	Mamet										(W)H (C)H
	Kedrovskaya					-1.6	18.6	Normal			
Aptian	Karmalivayam (calcite)	2.9-6.6	-3.2]-[-1.8]	18.4-25.9	Normal						WH
Barremian	Tylakryl (calcite)	3.9	-2.9	24.5	Normal						
Hauterivian		2.4-2.5	-2.2	21.0-21.3	Normal						(C)H

Fig. 8 Carbon and oxygen isotope values for well preserved benthic (shallow water) and semipelagic invertebrates from the Cretaceous of the Koryak Upland. Climate (based on paleobotanical evidences): CH – cold humid, (C)H – more or less cold humid, WH – warm humid, (W)H – more or less warm humid, WA – warm arid, W(A) – thermal maximum with a weak aridity, (W)(A) – some warming with a weak aridity.

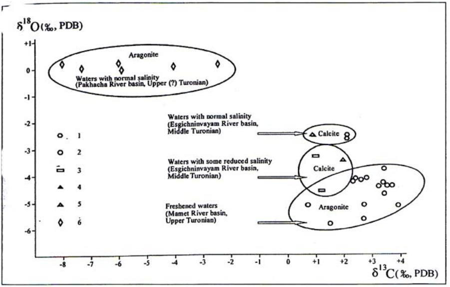


Fig. 9 Anomalously light and "normal" $\delta^{18}O$ signatures, preserved in Turonian brachiopod, bivalve and ammonoid shells from western and eastern Koryakia, and their interpretation. 1 – brachiopod calcite, 2 – inoceramid aragonite, 3 – inoceramid calcite, 4 – *Ostrea* calcite, 5 – undetermined bivalve calcite, 6 – ammonoid aragonite.

region of the Koryak Upland, remains of adult and juvenile teropod *Trooden* sp. cf. *T. formosus* Cope and hadrosaurs were associated just with abundance of cycadophyte *Encephalartopsis* leaves (Krassilov et al., 1990).

CONCLUSION

New evidence on relatively high shallow-water paleotemperatures of the Koryak Upland basin during many Cretaceous stages seems to be well correlated with both the correspond isotopic data (Huber et al., 1995) recently obtained for the Southern Hemisphere and paleobotanical evidences on the Northern Hemisphere (Vakhrameev, 1978; Nesov and Golovneva, 1990; Herman and Lebedev, 1991; Spicer et al., 1996; Golovneva and Herman, 1998).

All these data allow to expect considerable heat transport to high latitudes of both hemispheres during the most part of Cretaceous. It was most strongly pronounced, apparently, in Hauterivian-Barremian, early Aptian, early Albian, late Cenomanian, Santonian and Campanian, when it provoked the lowing of thermal gradients and development of warm, equable global climatic conditions, giving rise to a very weakly defined climatic zonation during many Cretaceous intervals, but seems to be blockaded in the early Valanginian and also in the beginning and the end of Maastrichtian.

The mechanism of heat transport to high latitudes still is insufficiently full researched. The hydrodynamic system of the Cretaceous ocean, main carrier of heat from the equatorial zone believes to be different from recent one (Nesov, 1997). In Nesov's opinion, some warm downwellings, for example, were of great importance for the planet temperature rate. Poleward heat transport seems to be realized true series of narrow, but very long meridional marine basins similar with the Cretaceous Turgai or Western Interior Basins (Fig. 10) (Slingerland et al., 1996; Nesov, 1997; Tsujita and Westermann, 1998; Naidin, 2001). This type of basins are absent in the hydrodynamic system of the Recent ocean.

Judging from some isotopic data from the Jurassic (Brand, 1986; Ditchfield, 1997), the most Cretaceous stages seem to be warmer than the middle or late Jurassic ones. This conclusion is confirmed by our analyses of well preserved brachiopod and cephalopod skeletons from the Lower Callovian (*Cadoceras elatmae* Zone) of the Russian Platform. Paleotemperature values calculated from the belemnite rostrum and the brachiopod and ammonoid shells are about only 11.9°C, 16.7 °C and 13.3-20.7 °C, respectively (Table 8).

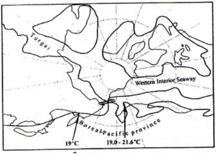


Fig. 10 Paleogeographic map for early Albian high latitudes of the North Hemisphere. 1 - The main ways for migrating polar dinosaurs upon the Bering Land Bridge during some ages of Cretaceous time.

Cool early Maastrichtian paleotemperatures (about 5°C) obtained for deep-water foraminifers from both low and high latitudes of the Southern Hemisphere and attend early Maastrichtian eustatic lowering (Miller et al., 1999) seem to be compatible with the short-lived formation of high latitude moderate-sized ice sheet for early Maastrichtian time, but corresponding defined glaciological evidence is lacking now.

Data on biological productivity of high-latitude seas of the Northern Hemisphere during Cretaceous are not full. Firstly, having only very restricted material (Zakharov et al., 1999), we expected their very low bioproductivity, connected with possible oxygen depletion of high-latitude marine waters, but it seems not confirmed by present carbon-isotopic investigation. The highest bioproductivity of Cretaceous high-latitude -seas of the Northern hemisphere, as well as other Cretaceous seas of the world (Gröcke et al., 1999), fall on the Aptian - maxima of $\delta^{13}C$ (+6.6%) have been recorded in the upper portion of the Karmalivayam Formation. It was rather high here also in middle Barremian sediments of the lower Karmalivayam ($\delta^{13}C$=4.3%). and Turonian sequences of the middle part of the Penzhinskaya ($\delta^{13}C$=3.3% Formations. New data may be one of arguments in favor of intensive marine water circulation in some ages of Cretaceous, which helps large volumes of warm water to reach pole area and favors to global development of phytoplankton, mainly responsible for a change of carbon isotopic composition in surface water of the World ocean. It is known that surplus of organic material in water of the World ocean in Aptian age and some other ages of Cretaceous was pronounced in development of carbonaceous facies (black clays), originated in these conditions as effect of consistent stratification of the water column and, in particular, appearance of anoxia zones in it (Krassilov, 1985; Naidin et al., 1986; Nesov, 1997), which confirms by cyclic composition of carbonaceous facies.

Table 8. Carbon and oxygen isotope analyses of ammonoid aragonitic and brachiopod and belemnite calcite from the *Cadoceras elathmae* Zone (Jurassic) of the Russian Platform and Early Callovean paleotemperatures of middle latitudes of the Northern Hemisphere (H, height, W, weight, D, diameter, L, lenght.

Sample	Species	Zone	District	Location (H, W, D & L, in mm)	Diagenetic alterations				Ca/Mg	$\delta^{13}C$ (PDB)‰	$\delta^{18}O$ (PDB) ‰	T° C
					Aragonite (%)	Calcite (original) (%)	α-SiO_2 (%)	Colour				
889-1-1	*Kepplerites gowerianus* Sow.	*Cadoceras elathmae*	KMA, Mikhailovsky mine	H=14	100	-	Trace	Silvery-white, cream	-	1.1	-0.6	18.1**
889-1-3	Same shell	- " -	- " -	H=16	100	-	0	- " -	-	1.4	-0.4	17.2**
889-1-4	*Cadoceras elathmae* Nik.	- " -	Ivanovo Region, Volga River right bank, 1 km upper Novoloki settlement	H=25	95±7	-	0	Cream	-	0.0	0.4	13.3**
889-1-10	Same shell	- " -	- " -	H = 26 (another side)	~ 100	-	Trace	- " -	-	2.1	-1.2	20.7**
889-1-11	*Cadoceras* sp.	- " -	- " -	W=75	~ 100	-	- " -	- " -	-	3.2	-0.5	17.6**
889-1-9	Belemnite rostrum	- " -	- " -	D=2.8	0	100	-	White	177.00	1.3	0.0	11.9*
889-1-6a	*Praecyclothyris badensis* (Oppel)	- " -	- " -	L=23	0	100	-	- " -	166.90	1.0	-1.2	16.7*

* Anderson and Arthur (1983); ** Grossmam and Ku (1986)

One of the important puzzles connected with global anoxia remains unanswered. The existence of anoxia zones in the marine water column believes to be widely spread event in the World ocean (Tsujita and Westermann, 1998) and therefore the thesis on global development of oxygen-free at ocean conditions during some ages of Cretaceous (late Barremian–Aptian–Albian, Cenomanian-Turonian transition, Coniacian-Santonian), postulated by many workers after Jenkyns (1980), seems to be incorrect, in our opinion. The high development of phytoplankton during Barremian, Aptian and Cenomanian-Turonian boundary transition, controlled by positive carbon-isotopic anomalies of corresponding levels, on the contrary, assumes both the pronounced saturation of oceanic water by organic carbonaceous and the significant increase in oxygen content in ocean and atmosphere at all because of its active phytoplankton photosynthesis on a global scale (and also terrestrial plant photosynthesis). Drop in oxygen production, naturally, falls only on the terminal Cretaceous, carbonates of which are characterized by extremely low $\delta^{13}C$ values. Therefore, the global anoxia during Cretaceous may be rather expected in the Maastrichtian-Danian boundary transition.

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