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Pole to Equator Temperature Gradient for Coniacian Time, Late Cretaceous: Oxygen and Carbon Isotopic Data on the Koryak Upland and Hokkaido

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ABSTRACT: The purpose of this study was to estimate the Coniacian latitudinal thermal gradient in the Northern Hemisphere. Both hemipelagic (ammonoids) and benthic (brachiopods and bivalves) δ^{18}O and δ^{13}C records were used. They originated from Coniacian shallow-water sequences across a wide range of paleolatitudes, from the Koryak upland (northern Kamchatka, Russian Far East) in the north, to Hokkaido (Japan) in the south. Among Coniacian ammonoids, both migrants from Hokkaido living in high latitudes (Kamchatka) and endemic forms dwelling in middle-low latitudes (Hokkaido) indicate seemingly close optimal growth temperatures. Nevertheless, certain differences in climatic conditions, prevailing during high-latitude coldest seasons, undoubtedly provoked growth cessation in some groups of ammonites. Our isotopic study suggests latitudinal temperature changes of only 0.12 ℃ per degree of latitude for the Northern Hemisphere in Coniacian times, while the average annual temperature in North Kamchatka seems about 3.3 ℃ lower than that in Hokkaido.

KEY WORDS: Coniacian, oxygen and carbon isotope, paleotemperature, Kamchatka, Hokkaido.

INTRODUCTION

Isotopic paleotemperatures were calculated for the Coniacian and Coniacian-Santonian transition of different regions of Eurasia (Zakharov et al., 2005; Teiss and Naidin, 1973; Bowen, 1969; Lowenstam and Epstein, 1954), North America (Golbert, 1987),

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New Zealand (Clayton and Stevens, 1968), Australia (Golbert, 1987), central Pacific, Magellan rise (Coplen and Schlanger, 1973), central Caribbean (Coplen and Schlanger, 1973), southern Atlantic, Falkland plateau (Huber et al., 1995) and Southeast Indian Ocean, Naturaliste plateau (Huber et al., 1995). There is, however, no clear evidence that all these calculations are acceptable, being due to various reasons, among them diagenetic artefact (Zakharov et al., 1999; Douglas and Savin, 1975; Veizer, 1974).

It has been claimed that pole to equator temperature gradients were relatively low during the Cretaceous (Hay, 2010; Gale, 2000). According to Hay's (2010) information, the modern pole-to-equator sea-level temperature difference is about 50 ℃, but that of the Mid-Cretaceous ranged from 30 ℃ to as little as 24 ℃, implying a much more equable climate. Wolf and Upchurch (1987), using the leaf-physiognomic method, suggested latitudinal temperature changes for the entire Cretaceous of about 0.3 ℃ per degree of latitude. But the information we have on this topic for some Cretaceous stages (among which especially the Coniacian) is very limited.

Huber et al. (1995) on the basis of oxygen data from surface-dwelling planktic foraminifera from the Equatorial Pacific, DCDP Sites 463 and 305 (about 3ºN–8ºN paleolatitudes), the Southeast Atlantic and Indian oceans, DCDP Sites 258 and 511 (about 57ºS–58ºS paleolatitudes), concluded that there was essentially no latitudinal temperature gradient for the Coniacian-Santonian interval. This assumption is drawn from seemingly very close: surface-water isotopic paleotemperatures for that time in the Southern Hemisphere, about 24 ℃ for tropical and 21–24 ℃ for high latitudes, respectively. This oxygen isotope record, however, conflicts with data from the Northern Hemisphere high latitudes, where the leaf-physiognomic investigation of some Coniacian plants from the north slope of Alaska and Koryak upland (Kamchatka) has revealed that mean annual temperatures for these areas seem to be only 12.5 and 9.0 ℃, respectively (Spicer, 2000; Herman and Spicer, 1996).

Attempts were made to calculate approximately the Coniacian latitudinal temperature gradient for the Northern Hemisphere (Teiss and Naidin, 1973; Teiss et al., 1960). These revealed, based on oxygen-isotopic analysis: 13.2–19.3 ℃ for some calcitic belemnite *Goniocamax* and *Actinocamax* rostra from the Russian platform (Sozh and Sura rivers, at 54ºN present latitude) and 20.1–21.3 ℃ for *Goniocamax* rostra from Uzbekistan (south Aral Sea coast, 43ºN present latitude). But these results are impaired by limited information on Coniacian season temperatures in both regions, first of all of Aral.

The purpose of the present study in the Far East was thus to estimate the latitudinal thermal gradient in the Coniacian, using both the hemipelagic (ammonoid) and the benthic (brachiopod and mollusc) δ^{18}O records from Coniacian shallow-water sequences across a wide range of palaeolatitudes, from northern Kamchatka in the north to Hokkaido in the south.

MATERIAL AND METHODS

The macrofossil samples used in this isotopic study were collected mainly by the Russian-Japanese geological expeditions, organized at the lower reaches of the Talovka River, western Koryak upland and the Utakazawa River, Hokkaido (Fig. 1). These collections consist of well-preserved brachiopods, bivalves, including inoceramids, gastropod, and ammonoids. A total of 151 shell samples were analyzed. In addition, some isotopic data on eight samples of three ammonoid shells from the Nakafutamata River, Hokkaido (K Tanabe's collection) (Zakharov et al., 1999) were used in our estimation. Full information on isotopic composition of Coniacian invertebrate shells from the Talovka River (northern Kamchatka) and Nakakutamata (Hokkaido) has been published by us earlier (Zakharov et al., 2002, 1999).

Diagenetic alteration is an important factor in limiting preservation of the primary original isotopic composition of fossil shells. This renders the screening of mollusc shells for diagenetic alteration necessarily. The following signs were used in this study.

(1) Visual signs: natural colour and structure.

(2) Analyzing the percentage of aragonite in shells represented by 100% of aragonite; four stages were recognized, among which only material of the two first stages seems to preserve more or less its primary original isotopic composition.

1st stage: secondary calcite is absent or is represented by a small portion, not more than 1%–5%; 2nd

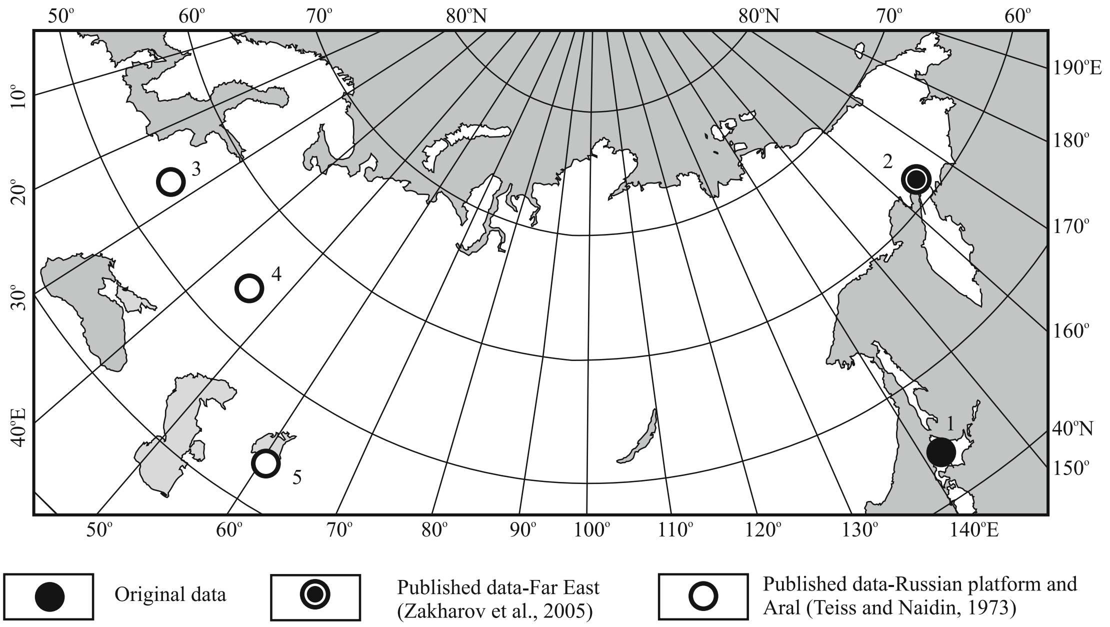

Figure 1. Occurrence of Coniacian faunas in Far East. 1. northern Hokkaido; 2. western Koryak upland (northern Kamchatka area); 3 and 4. Russian platform; 5. Aral, Middle Asia.

stage: appearance of a larger portion, 5%–30% of approximately 30%–50% of secondary calcite; 3rd stage: shell material consists of approximately 30%–50% of secondary calcite; 4th stage: presence of more than 50% secondary calcite, which seems to be followed by very pronounced change in isotopic composition.

(3) Microscopic determination (including SEM) of degree of safety of the skeletal microstructure.

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, selected after careful visual inspection, seemed to be suitable for analysis of their original oxygen and carbon isotopic records.

Oxygen and carbon isotope measurements were carried out at the Analytical Center of the Far Eastern Geological Institute (FEGI), Vladivostok, using Finnigan MAT-252 mass spectrometer. The laboratory gas standard used in the measurements was calibrated relative to calcite NBS 19 standard δ^{13}C=1.93‰ and δ^{18}O=2.20‰ (Coplen et al., 1983). Reproducibility of replicate standards was always better than 0.10‰.

In calculating the temperatures, the period was assumed to be free or mainly free of icecaps, and therefore, a δ^{18}O of -1.2‰ VPDB (equivalent to secondary calcite; 3rd stage: shell material consists of -1.0‰ VSMOW) was thought to be appropriate (Savin, 1977).

Two scales were used for paleotemperature calculation: Anderson and Artur's (1983) one (under investigation of calcitic material) and Grossman and Ku's (1986) one (under investigation of aragonitic material).

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

PALEOGEOGRAPHICAL POSITION

Two Cretaceous faunal realms are distinguished in the Northern Hemisphere, on the basis of ammonite distributions—the Boreal (Boreal-Pacific, Boreal-Atlantic and Arctic Provinces/Realms) and Tethyan Realms (Belts, Super-realms) (e.g., Rawson, 2000).

Throughout the Cretaceous, Tethyan areas (Hokkaido and South Sakhalin, for example) were characterised by diversity of the ammonoid fauna, all showing a marked decrease in diversity northwards higher palaeolatitudes. During the Cretaceous, the Koryak upland was located mainly within the Boreal-Pacific Province, but there is only a little evidence on its permanent connection with the Arctic Province in the Barremian-Maastrichtian interval (Zakharov Y D et al., 2011; Baraboshkin, 2007; Naidin, 2007; Herman, 2004; Spicer et al., 2000; Zakharov V A et al., 1996; Pokhialaynen, 1994). During the Albian-Cenomanian time interval, ammonoid faunas of the Koryak upland were very similar to those of North America; while subsequent Late Cretaceous faunas of this area show great affinity with those from South Sakhalin and Hokkaido only (Shigeta et al., 1999).

According to paleomagnetic data, the Cretaceous paleolatitude of the Kamchatka Talovka River basin seemed to be at about 69ºN (Spicer et al., 2002), while that of Hokkaido sites was below 35ºN (Kadama et al., 2000), respectively (Fig. 2).

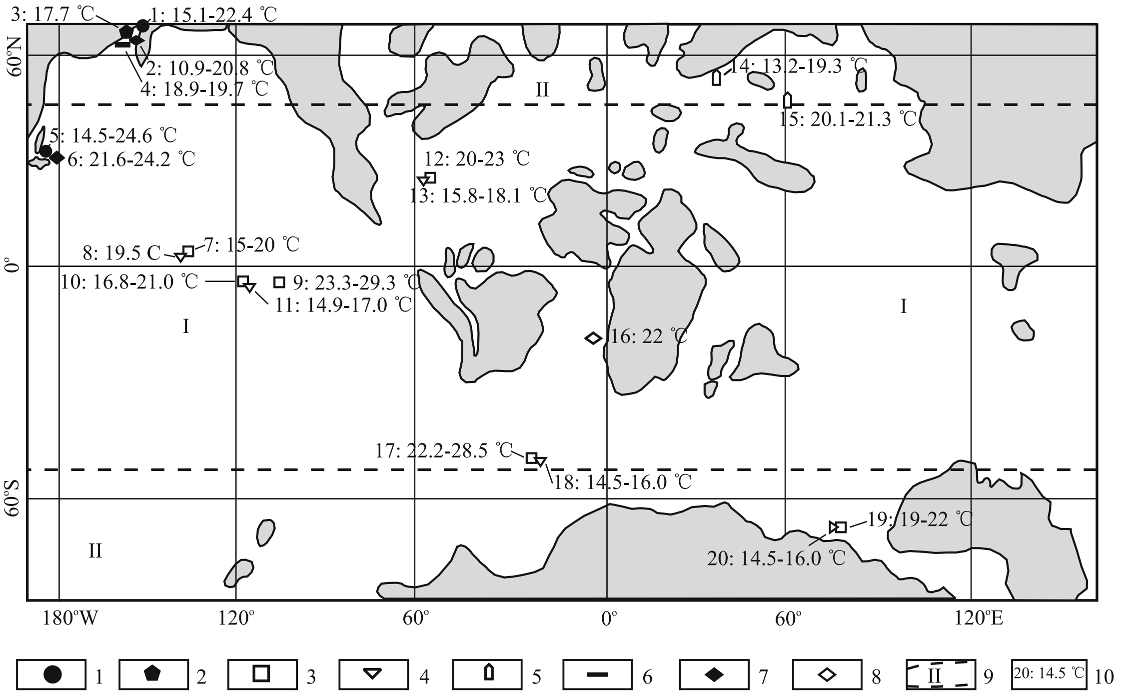

Figure 2. Map showing isotopic paleotemperatures for the Coniacian. 1. From ammonoids of Far East; 2. from brachiopods of Far East; 3. from planktic foraminifera of Pacific and Atlantic; 4. from benthic foraminifera of Pacific and Atlantic; 5. from belemnites of the Russian platform; 6. from gastropods of Far East; 7. from bivalves of Far East; 8. from bivalves of Atlantic; 9. boundaries of climatic zones; 10. locality number and palaeotemperature. Localities: 1–4. Talovka (Zakharov et al., 2002); 5 and 6. Hokkaido (Zakharov et al., 1999 and original data); 7 and 8. Shatsky rise (Barrera, 1994); 9. DSDP hole 171 (Barrera, 1994); 10 and 11. Central Pacific (e.g., DSDP hole 463) (Barrera, 1994; Boersma and Shackleton, 1981); 12 and 13. DSDP hole 1050 (Huber et al., 2002); 14. Sozh and Sura rivers, Russian platform (Teiss and Naidin, 1973; Teiss et al., 1960); 15. south Aral Sea area (Teiss and Naidin, 1973); 16. DSDP hole 530A (Huber et al., 2002); 17 and 18. DSDP hole 511 (Huber et al., 2002); 19 and 20. DSDP hole 258 (Huber et al., 1995).

δ^{18}O AND δ^{13}C IN CONIACIAN INVERTEBRATE SHELLS OF THE FAR EAST

Talovka River Section (Koryak Upland)

The lower course of the Talovka River exposed part of the Penzhinskaya Formation for which a Santonian-Campanian age was assumed (e.g., Alabushev, 1989a, b; Pokhialainen, 1985). Our revision of the mollusc assemblages of the section mentioned above (Zakharov et al., 2005, 2002) shows that these strata can be assigned to the upper part of the Penzhinskaya Formation (Coniacian), but not to the Bystrinskaya Formation, as Alabushev (1989a, b) expected. The uppermost part of the Penzhinskaya Formation in the Talovka River (about 260–280 m) consists mainly of siltstone with lenses of calcareous sandstone and calcareous-marly boulders with abundance of invertebrate fossils, including preserved aragonitic ammonoid shells and inoceramid bivalves (77%–100% of aragonite) (Zakharov et al., 2005). Three members are recognized in the section: Lower

(18 m), Middle (about 220–240 m) and Upper (about 22 m) (Zakharov et al., 2005, Fig. 6 therein).

Lower member

From the middle part of the Lower member, the aragonitic shells of five ammonoid species and some bivalve species were isotopically investigated: *Gaudryceras denseplicatum* (Jimbo) (six samples), *Gaudryceras* sp. (one sample), *Tetragonites glabrus* (Jimbo) (one sample), *Kossmaticeras japonicum* Matsumoto (one sample), *Scalarites* sp. (one sample), *Nannonavis sachalinensis* (Yokoyama) (one sample) *Nannonavis* sp. (one sample) and *Goniomya* sp. (one sample) (Zakharov et al., 2005, Table 5 therein).

Their δ^{18}O values fluctuate from -1.5‰ to -0.5‰ (δ^{13}C values vary between -1.0‰ and 2.3‰). δ^{18}O values from bivalve *Nannonavis* and *Goniomya* shells range from -1.0‰ to 0.2‰ (δ^{13}C values change from 0.2‰ to 2.1‰).

Middle member

For the analysis of the lower portion of the Middle member, the aragonitic shells of three ammonoid species were used: *Gaudryceras* sp. (four samples), *Tetragonites popetensis* Yabe (one sample), *Kossmaticeras japonicum* Matsumoto (four samples). δ^{18}O values in them vary between -1.5‰ and 0.0‰ (δ^{13}C values change from -3.6‰ to 1.2‰) (Zakharov et al., 2005, Table 4 therein).

In middle portion of the Middle member, the aragonitic shells of five ammonoid species were analyzed: *Anagaudryceras* sp. (two samples), *Tetragonites popetensis* Yabe (one sample), *Yokoyamaoceras kotoi* (Jimbo) (one sample), *Scalarites* sp. (two samples).

δ^{18}O and δ^{13}C values in them fluctuate from -1.6‰ to 0.1‰ and from -2.7‰ to 1.2‰, respectively (Zakharov et al., 2005, Table 4 therein). δ^{18}O values in the calcitic bivalve *Acila* and *Nannonavis* shells range from -0.6‰ to 0.0‰ (δ^{13}C values fluctuate from -0.5‰ to 2.0‰).

δ^{18}O values in the aragonitic shells of two ammonoid species (*Gaudryceras* sp.: one sample and *Mesopuzosia* sp.: three samples) (Zakharov et al., 2005, Table 4 therein) from the upper portion of the Middle member fluctuate from -0.3‰ to 0.0‰ (δ^{13}C values change from -0.6‰ to 2.5‰).

Upper member

From the lower portion of the Upper member, the aragonitic shells of three ammonoid species were analyzed: *Anagaudryceras denseplicatum* (Jimbo) (one sample), *Kossmaticeras japonicum* Matsumoto (one sample), *Baculites* sp. (one sample) (Zakharov et al., 2005, Table 3 therein). In addition to these, an aragonitic gastropod shell—*Semifusus* sp. (one sample) and a calcitic bivalve shell—*Nannonavis* sp. were also investigated.

δ^{18}O values in the ammonoid shells fluctuate from -1.6‰ to -0.3‰ (δ^{13}C values change from -0.9‰ to 0.2‰); δ^{18}O values in the bivalve *Nannonavis* shell range from -1.1‰ to -0.7‰ (δ^{13}C=1.1‰–1.2‰); δ^{18}O value in gastropod *Semifusus* shell is -0.9‰ (δ^{13}C=0.1‰) (Zakharov et al., 2005, Table 3 therein).

From the middle portion of the Upper member, the aragonitic shells of three ammonoid species were analyzed: *Mesopuzosia yubarensis* (Jimbo) (one sample), *Kossmaticeras japonicum* Matsumoto (eight samples), *Baculites* sp. (one sample).

δ^{18}O and δ^{13}C values in them vary between -1.6‰ and -0.8‰ and between -3.6‰ and -0.8‰, respectively (Zakharov et al., 2005, Table 3 therein).

δ^{18}O value in the single fragment of an aragonitic inoceramid shell is -0.2‰ (δ^{13}C=0.0‰); δ^{18}O values in the calcitic bivalve *Acila* and *Nannonavis* shells range from -0.9‰ to 0.1‰ (δ^{13}C=0.2‰–1.2‰); δ^{18}O value in the single calcitic rhynchonellid brachiopod shell is -1.4‰ (δ^{13}C=1.6‰).

From the upper portion of the Upper member, the aragonitic shells of four ammonoid species—*Gaudryceras denseplicatum* (Jimbo) (one sample), *Mesopuzosia yubarensis* (Jimbo) (one sample), *Yezoites* sp. (one sample), *Kossmaticeras japonicum* Matsumoto (one sample), and also a gastropod *Harpogodes* sp. shell (one sample) were analyzed. δ^{18}O values in ammonoid shells fluctuate from -1.1‰ to -0.2‰ (δ^{13}C values change from -2.8‰ to 0.1‰); δ^{18}O value in the aragonitic gastropod shell equals -0.1‰ (δ^{13}C=1.3‰). Primary calcitic material isotopically investigated had been collected from bivalve *Acila* and *Nannonavis* shells (δ^{18}O and δ^{13}C values fluctuate from -1.8‰ to -0.7‰ and from 0.2 to 1.6, respectively).

Yutakazawa River Section (Hokkaido)

In the Yutakazawa River Section (Sakasagawa River basin, Haboro area), only the upper part of the Coniacian is exposed, consisting of the upper part of Lower Haborogawa Formation (lower part of Upper Yezo Group), characterised by the *Inoceramus uwajimensis*—*I. mihoensis* Zone. It consists mainly of clayey mudstone with calcareous-marly concretions, frequent intercalations of acidic tuff and some thin interbeds of sandstone (about 360 m) (Toshimitsu, 1988). Calcareous-marly concretions are characterised by abundance of aragonitic ammonoid shells: *Neophylloceras* cf. *ramosum* (Meek), *Anagaudryceras limatum* (Yabe), *Gaudryceras tenuiliratum* Yabe, *G. denseplicatum* (Jimbo), *Gaudryceras* sp., *Tetragonites glabrus* (Jimbo), *T. popetensis* Yabe, *Pachydesmoceras* sp., *Jimboiceras* cf. *mihoense* Matsumoto, *Mesopuzosia* cf. *pacifica* Matsumoto, *M. yubarensis* (Jimbo), *Damesites* cf. *damesi* (Jimbo), *Hauriceras*? sp., *Kossmaticeras* sp., *Yokoyamaoceras* sp., *Protexanites* sp., *Nipponites*? sp., *Scalarites* sp., *Polyptychoceras* sp., *Yezoceras* sp., *Baculites* cf. *princeps* Matsumoto and Obata, *Otoscaphites* sp., *Scaphites pseudoequalis* Yabe, *Clioscaphites* sp..

The aragonitic shells of 12 ammonoid and two inoceramid bivalve species were analyzed: *Anagaudryceras limatum* (Yabe) (S-6-1, S-20-2a and S-27-1 71%–95% of aragonite, with ceolite), *Gaudryceras* sp. (S-8 96%), *Tetragonites glabrus* (Jimbo) (S-24-1 and S-24-1-1 74%–100%, with trace of α-SiO_2 and ceolite), *Pachydesmoceras* sp. (S-13-2, S-15, S-15-1 and S-15-2 100%), *Mesopuzosia yubarensis* (Jimbo) (S-11-1 and S-11-2 78%–89%, with trace of α-SiO_2), *Damesites* cf. *damesi* (Jimbo) (S-14-4a and S-27-2 74%–82%, with trace of α-SiO_2 and ceolite), *Hauriceras* sp. (S-11-1-1 and S-11-2-1 95%), *Kossmaticeras* sp. (S-10, S-16-1, S-16-2, S-21, S-21-2 83%–100%), *Yokoyamaoceras* sp. (S-19 90%, with small portion of clinoptilolite), *Protexanites* sp. (S-5a-1 100%), *Scalarites* sp. (S-18-3 91%, with trace of α-SiO_2 and ceolite), *Polyptychoceras* sp. (S-17-1, S-17-2 97%–100%), *Baculites* cf. *princeps* Matsumoto et Obata (S-18-1b, S-18-1c and S-18-2 38%–97%, with trace of α-SiO_2), *Scaphites pseudoequalis* Yabe (77%, with trace of α-SiO_2), *Inoceramus uwajimensis* (Yehara) (S-6-2, S-12,S-14-7, S-18-1a-1, S-20-1 and S-23 77%–98%, with trace of α-SiO_2 and ceolite), *Inoceramus* sp. (S-22-3, S-22-5, S-22-6, S-22-7 and S-26 78%–100% of aragonite) (Table 1).

However, the two investigated bivalve shells seem to be diagenetically altered: S-22-2 (*Inoceramus uwajimensis* (Yehara) 53% of aragonite, with trace of α-SiO_2) and S-5-1 (*Propeamussium* sp., calcitic one) (Table 1). Besides, seven samples of well-preserved inoceramid bivalves shells (S-18-1a-1, S-201, S-22-3, S-22-5, S-22-6, S-22-7 and S-26) show unusually low δ^{18}O values (Table 1) in spite of mainly high percentage of aragonite in them (77%–100%).

Nakafutamata Creek Section (Hokkaido)

Toshimitsu (1988) recognizes a full Coniacian sequence, of over 900 m thickness, in the separate outcrops of the Lower Haborogawa Formation, in the Nakafutamata Creek area, 2 km N from the Yutakazawa River Section. Lithological and paleontological characteristics of the Lower Haborogawa Formation are the same as in the previously described Sakasagawa River Section.

We have investigated some well-preserved aragonitic *Anagaudryceras limatum* (Yabe) shells (Zakharov et al., 1999, Table 3 therein), collected by K. Tanabe from the upper portion of the section (Late Coniacian): samples HB3435p-1, 2, 3, 4, 5, 6 and 7.

δ^{18}O and δ^{13}C values in investigated three ammonoid shells fluctuate from -1.16‰ to 0.19‰ and from -0.33‰ to 1.77‰, respectively (Zakharov et al., 1999).

DISCUSSION

Seasonal Aspect of Temperature Fluctuation in Northern High (Northern Kamchatka Area) and Middle-Lower (Hokkaido) Latitudes during the Coniacian

Isotopic paleotemperatures for the Koryak upland interpreted as winter ones have been obtained only from the Coniacian shallow-dwelling water calcitic bivalve *Acila* and *Nannonavis* shells. They fluctuate from 10.9 to 14.1 ℃ (δ^{18}O values change from -0.5‰ to 0.3‰). Isotopic paleotemperatures for presumably

Table 1 Carbon and oxygen isotope analyses of aragonitic ammonoid and inoceramid shells nd calcitic *Propeamussium* from the Coniacian (Upper Lower Haborogawa Formation) of the Yutakazawa River, Hokkaido

Sample number	Species	Location (H in mm)	Diagenetic alteration				δ^{13}C (PDB) (‰)	δ^{18}O (PDB) (‰)	T (℃)
			Aragonite (%)	α-SiO$_2$	Admixture	Colour			
S-5a-1	*Protexanites* sp.	H=7.0	100	-	-	Cream	0.8	-2.0	24.2*
S–6-1	*Anagaudryceras* sp.	H=40.0	95±3	-	-	Silvery-cream	-1.6	-0.2	16.4
S-8	*Gaudryceras* sp.	H>20.0	96±3	Trace	Ceolite	Silvery-cream	0.3	-0.1	15.9
S-10	*Kossmaticeras* sp.	H=16.0	96±3	-	Ceolite	Silvery-white	-1.4	-0.3	16.8
S-11-1	*Mesopuzosia yubarense* (Jimbo)	H=40.0?	89±3	Trace	-	Silvery-white	-0.2	-0.6	18.1
S-11-1-1	*Hauriceras*? sp.	H=11.5	95±3	-	-	Silvery-white	-4.8	-0.5	17.7
S-11-2-1	Same shell	H=10.5	97±3	-	Ceolite	Silvery-white	-3.6	-0.5	17.7
S-11-2	*Mesopuzosia yubarense* (Jimbo)	H>35.0	78±5	Small	-	Silvery-white	-3.0	-2.1	24.6
S-13	*Scaphites pseudoaequalis* Yabe	H=13.5	77±5	Trace	Ceolite	Cream	-0.5	-1.6	22.3
S-13-2	*Pachydesmoceras*? sp.	H>100.0	100	-	-	Cream	-3.8	-0.3	16.8
S-14-6	*Mesopuzosia* sp.	H>40.0	72±5	Trace	Ceolite	Cream	-3.8	-1.9	23.8
S-14-4a	*Damesites* cf. *damesi* (Jimbo)	H=17.0	74±3	Trace	-	Reddish-cream	-6.4	-0.2	16.3
S-15	*Pachydesmoceras* sp.	H>100.0 (dorsal side)	100	-	-	Silvery-white	-0.2	0.0	15.5
S-15-1	*Pachydesmoceras* sp. (associated with S-15)	H>150.0	100	-	-	Cream	-1.2	0.1	15.1
S-15-2	Same shell	H>150.0 (septum)	97±3	Trace	-	Cream	0.0	-0.3	16.8
S-16-2	*Kossmaticeras* sp.	H=20.0	100	-	Ceolite	Cream	-0.4	0.0	15.4
16-1	*Kossmaticeras* sp.	H=20.0	97±3	-	Ceolite	Cream	-0.5	0.0	15.4
S-17-2	*Polyptychoceras* sp.	H=9.0	100	-	-	Cream	0.5	-0.5	17.7
S-17-1	*Polyptychoceras* sp.	H=55.0	97±3	Small	-	Cream	-1.8	-0.7	18.4
S-18-1B	*Baculites* cf. *princes* Mat. et Obata	H=11.0	38±3	-	-	Cream	1.0	-0.3	16.8
S-18-1a	*Gaudryceras denseplicatum* (Jimbo)	H=6.0	81±3	Trace	-	Cream	-0.5	-0.7	18.5
S-18-1c	*Baculites* cf. *princes* Mat. et Obata	H=9.0	97±3	Trace	-	Cream	-2.3	-1.3	21.1
S-18-2	*Baculites* cf. *princes* Mat. et Obata	H=11.5	79±5	Small	-	Cream	-8.6	-0.3	16.7
S-18-3	*Scalarites* sp.	H=5	91±3	Trace	Ceolite	Silvery-cream	-1.9	-1.1	20.2

Continued

Sample number	Species	Location (*H* in mm)	Diagenetic alteration				$\delta^{13}C$ (PDB) (‰)	$\delta^{18}O$ (PDB) (‰)	*T* (℃)
			Aragonite (%)	α-SiO_2	Admixture	Colour			
S-19	*Yokoyamaoceras* sp.	*H*>45	90±5	-	Clinoptilolite	Golden	-1.5	-1.4	21.6
S-20-2a	*Anagaudryceras limitum* Yabe	*H*=340 (dorsal side)	71±3	-	Ceolite	Silvery-white	-8.6	-2.1	24.6
S-21-2	*Kossmaticeras* sp.	*H*=19	90±3	-	Ceolite	Cream	-0.1	-1.2	20.7
S-21	*Kossmaticeras* sp. (associated with S-21-2)	*H*=10	83±3	-	Ceolite	Cream	-0.8	-1.3	21.0
S-24-1-1	*Tetragonites glabrus* (Jimbo)	*H*=23	74±5	Trace	Ceolite	Cream	-4.4	-1.2	20.7
S-24-1	Same shell	*H*=20	100	-	Ceolite	Cream	-3.1	-1.2	20.7
S-27-1	*Anagaudryceras* sp.	*H*>40	93±3	-	Ceolite	Cream	-2.1	-0.6	18.1
S-27-2	*Damesites* sp.	*H*>30	82±3	Trace	Ceolite	Cream	-6.3	-0.1	15.8
S-6-2	*Inoceramus uwajimensis* (Yehara)	*H*=30	86±3	Trace	-	Cream	2.9	-2.0	24.2
S-12	*I. uwajimensis* (Yehara)	*H*=30	97±3	Trace	-	Silvery-cream	3.6	-1.5	21.9
S-14-5	*I. uwajimensis* (Yehara)	*H*=50	85±5	Trace	Ceolite	Cream	3.0	-1.9	23.8
S-14-7	*I. uwajimensis* (Yehara)	*H*=50	98±2	-	Ceolite	Cream	4.4	-1.4	21.6
S-23	*I. uwajimensis* (Yehara)	*H*=40	96±3	-	Ceolite	Cream	3.7	-1.4	21.6
S-18-1a-1	*Inoceramus uwajimensis* (Yehara)	*H*=50	77±3	Trace	-	Cream	2.6	-2.2	[25.1]
S-20-1	*I. uwajimensis* (Yehara)	*H*=70	91±5	Small	-	Cream	3.2	-2.2	[25.1]
S-22-2	*I. uwajimensis* (Yehara)	*H*=21	53±3	Trace	-	Cream	-1.9	-3.0	[28.4]
S-22-3	*Inoceramus* sp. (smooth shell)	*H*=22	78±3	-	-	Cream	0.1	-2.8	[27.7]
S-22-6	*Inoceramus* sp. (smooth shell)	*H*=17	89±3	-	-	Silvery-cream	1.4	-2.5	[26.4]
S-22-7	Same shell	*H*=13	87±3	-	-	Silvery-cream	1.2	-2.3	[25.5]
S-22-5	Same shell	*H*=22	82±3	Trace	-	Silvery-cream	1.0	-2.3	[25.4]
S-26	*Inoceramus* sp.	*H*>35	100	-	-	Cream	5.4	-2.2	[25.1]
S-5-1	*Propeamussium* sp. (calcitic)	*H*=7	0	-	-	Cream	-10.2	-3.5	[30.6]**

*Grossman and Ku (1986); **Anderson and Arthur (1983). Unrealistic paleotemperatures, indicated in square brackets, were possibly provoked by fresh-water influence and diagenetic changes.

spring-and-fall seasons of Coniacian age in the Koryak upland fluctuating from 14.1 to 17.7 ℃ have been obtained from both calcite of the bivalve *Acila*, *Nannonavis*, *Inoceramus* and *Goniomya* ($\delta^{18}O$ values vary between -1.4‰ and -0.5‰), and aragonite of the ammonoid *Anagaudryceras*, *Gaudryceras*, *Tetragonites*, *Mesopuzosia*, *Kossmaticeras* and *Scalarites* ($\delta^{18}O$ values fluctuate from -0.7‰ to 0.1‰) shells.

Presumably summer isotopic paleotemperatures for Coniacian time fluctuating from 17.7 to 22.4 ℃ were obtained from calcite of rhynchonellid brachiopod (δ^{18}O=-1.4‰), bivalve *Nannonavis* (δ^{18}O values fluctuate from -2.1‰ to -0.5‰) and also aragonite of ammonoid *Anagaudryceras*, *Gaudryceras*, *Tetragonites*, *Mesopuzosia*, *Kossmaticeras*, *Yokoyamaoceras*, *Yezoites* and *Baculites* (δ^{18}O values fluctuate from -1.6‰ to -0.5‰) and gastropod (δ^{18}O=-0.9‰) shells.

Results of oxygen-isotopic investigation of well-preserved calcitic and aragonitic invertebrate shells from the Coniacian of the lower course of the Talovka River also seem to be evidence of sufficiently high summer temperatures of shallow water basins during Coniacian time, but average annual temperature value for the Coniacian of the Koryak upland seems to be not to overdraw 14.9 ℃ (it was estimated only from calcitic bivalves inhabited in conditions of normal salinity here and characterised by more or less capability for steady growth through the year). There is a ground to suggest that some differences in bivalve and ammonoid optimal temperatures of their growth took place in northern high latitudes during the Coniacian (Fig. 3).

During Coniacian time, middle-low shallow waters in Hokkaido were warmer, ranging between 14.5 and 24.6 ℃ (as compared with 10.9–22.4 ℃ in the Koryak upland). Real isotopic paleotemperatures were obtained from the ammonoid (*Anagaudryceras*, *Gaudryceras*, *Tetragonites*, *Pachydesmoceras*, *Mesopuzosia*, *Damesites*, *Hauriceras*?, *Kossmaticeras*, *Protexanites*, *Scalarites*, *Polyptychoceras*, *Baculites*, *Scaphites*) and bivalve shells of the Lower Haborogawa Formation (Tables 1 and 2). Their bottom temperature level corresponds, apparently, to winter months, but the top one conforms to summer season (Fig. 4). Average annual temperature value for the Coniacian of Hokkaido estimated from 37 aragonitic ammonoid shell samples seems to be about 18.2 ℃.

Local Freshening in the Coniacian

Some well-preserved Coniacian inoceramid shells from Hokkaido (six samples with 77%–100% of aragonite) and isolated Coniacian aragonitic inocera-

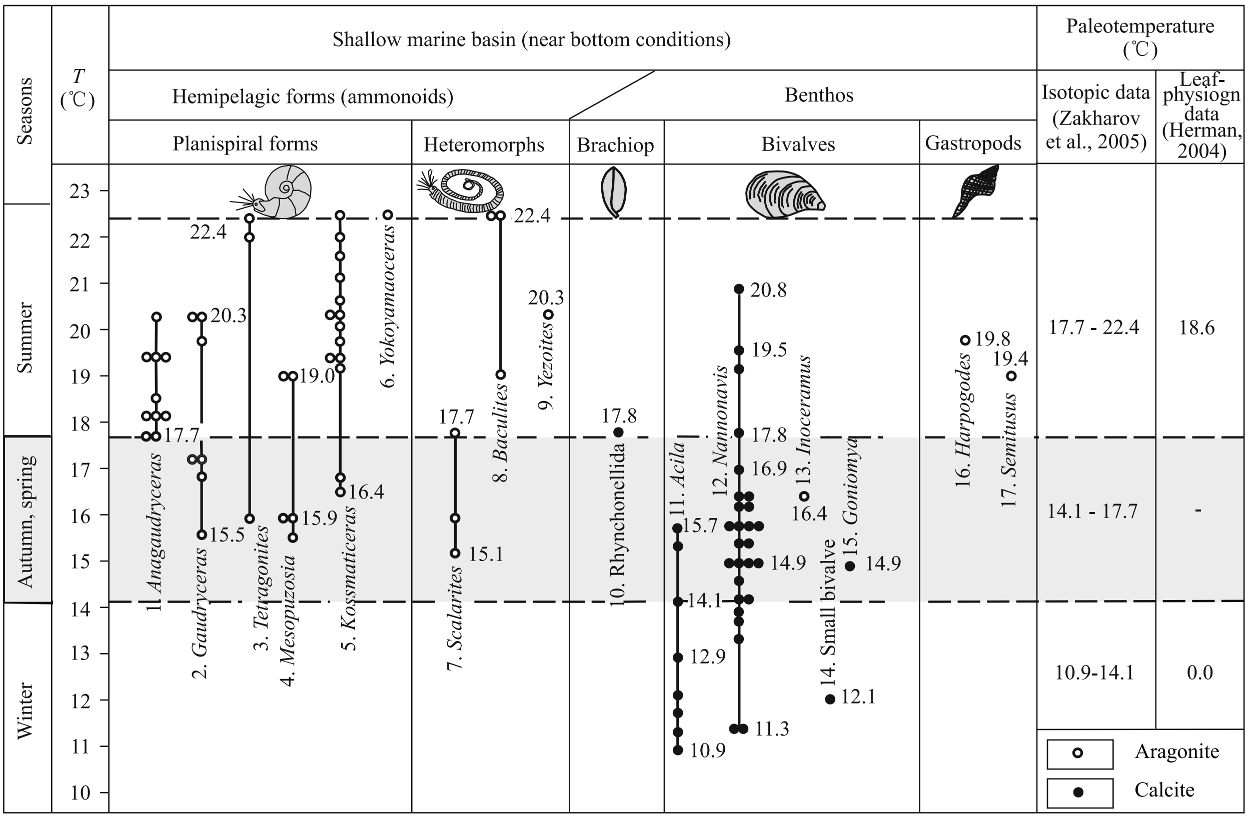

Figure 3. Seasonal growth temperatures for the calcitic and aragonitic benthic and hemipelagic form shells from the Coniacian (Penzhinskaya Formation) of the Talovka River basin (observations from 96 specimens).

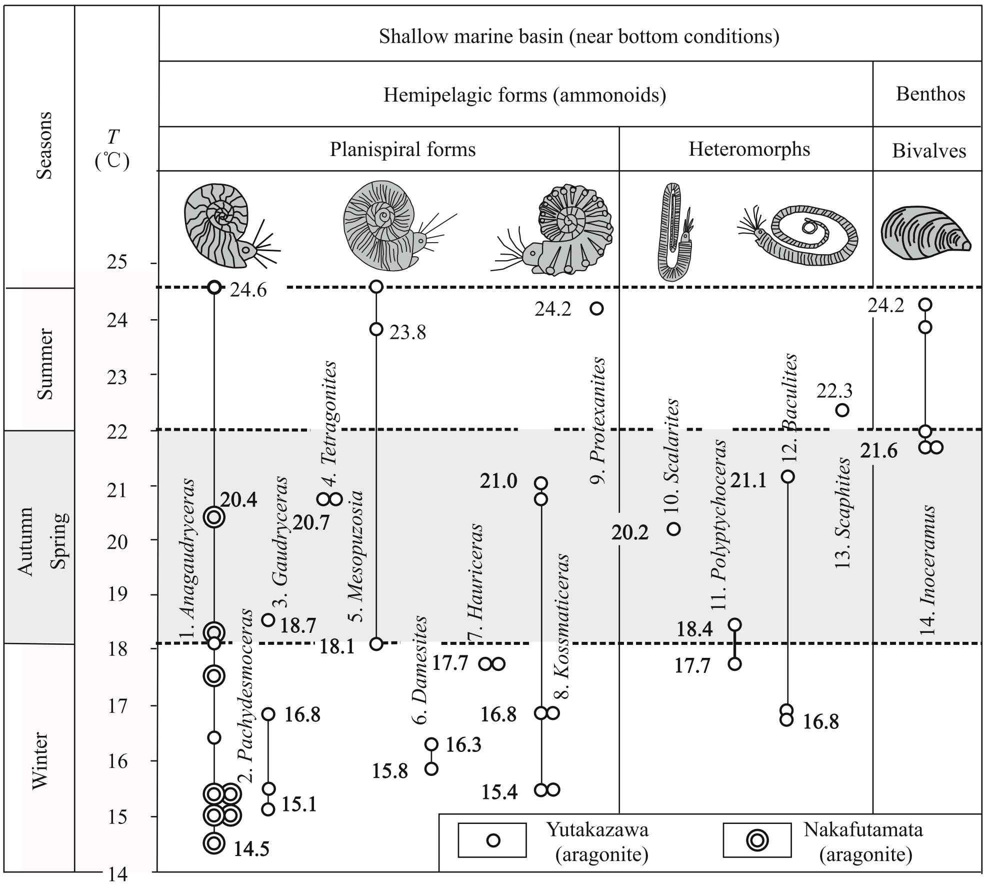

Figure 4. Seasonal growth temperatures for the aragonitic benthic and hemipelagic form shells from the Coniacian (the upper portion of the Lower Haborogawa Formation) of the Yutakazawa River and Nakafuamata Creek area (observations from 43 specimens).

mid shells from the Koryak upland (three samples with 86%–90% of aragonite) are characterised by very low δ^{18}O values (till -3.0‰ for Hokkaido and till -3.9‰ for the Koryak upland), corresponding to unlikely high isotopic "paleotemperatures", and seem to be dwellers of estuarine parts of basins or more or less freshening gulfs. It may be due to more or less development of humid climate, which is likely to have occurred over the Hokkaido-South Sakhalin area, but, apparently, to a lesser degree over the Koryak upland area. Freshening influence in the Koryak upland area was more marked in the Cenomanian-Turonian (Zakharov et al., 2002) than in the Coniacian.

Problem of Biological Productivity of North Boreal and Subtropical Seas during Coniacian Time

The analysis of some positive carbon-isotopic anomalies made it possible to assume that during the Late Cretaceous, there were at least five events, fixed by them, part of which proved to be global: (1) Cenomanian-Turonian (e.g., Hasegawa and Hatsugai, 2000; Toshimitsu et al., 2000; Voigt, 2000; Erbacher, 1994; Naidin and Kiyashko, 1994; Zachos and Arthur, 1986; Boersma and Schackleton, 1981; Douglas and Savin, 1975); (2) Late Turonian (Zakharov et al., 2001; Voigt, 2000); (3) Late Santonian (Hasegawa et al., 2003; Zakharov et al., 2001, 1999; Jenkins et al., 1994); (4) Early Campanian (Huber et al., 1995); (5) Late Maastrichtian (Hasegawa et al., 2003; Corfield et al., 1991). Coniacian anomalies (Zakharov et al., 2001; Toshimitsu et al., 2000) need verification. The analysis of Cretaceous ammonoid in Japan shows their high diversity in the lower Barremian, upper Aptian, upper Albian, middle and upper Turonian, middle Coniacian and Santonian, with highest diversity in the upper Albian (Toshimitsu et al., 2000).

Within the Coniacian of the Talovka (western Koryak upland) and Yutakazawa (Hokkaido) rivers anomalously high δ^{13}C values reflecting usually high biological productivity of seas (Alcala-Herrera et al.,

1992) were discovered only in some mollusc shells, mainly in inoceramid bivalves, common inhabitants of marine shallow-water basins and, as shown above, their estuarine parts.

Talovka River

Highest $\delta^{13}C$ value (4.7‰) found for the Talovka River basin in the Koryak upland was obtained from the *Bairostrina concentricus costatus* Nagao et Matsumoto shell element represented substantially by aragonite (86%±3%). The shell was collected from the Lower member of Coniacian sediments of the Penzhinskaya Formation exposed in the lower reaches of the Talovka River. $\delta^{13}C$ values in the four other investigated inoceramid (*Inoceramus tenuistriatus* Nagao et Matsumoto and *Inoceramus* sp.) shells discovered in the same section are 0.0‰, 2.1‰, 3.3‰ and 3.7‰. In numerous aragonitic ammonoid shells found in the section, uppermost $\delta^{13}C$ value reaches 2.5‰, but average $\delta^{13}C$ value from 50 samples is only -0.4‰. $\delta^{13}C$ value in a calcitic rhynchonellid brachiopod shell is 1.6‰; in calcitic bivalve (*Acila* and *Nannonavis*) shells and aragonitic gastropod shell, it is about 1.5‰ and 0.1‰, respectively.

Yutakazawa River

Late Coniacian anomalously high $\delta^{13}C$ value (5.4‰) was discovered in a good preserved aragonitic *Inoceramus* sp. shell element (100% of aragonite) from the Yutakazawa River, Hokkaido. $\delta^{13}C$ values in the four other investigated Late Coniacian inoceramid (*Inoceramus* sp.) shells discovered in the same section fluctuate from 2.7‰ to 3.7‰. $\delta^{13}C$ values in the next six other investigated Late Coniacian inoceramid shell samples are predominantly positive and fluctuate from -1.9‰ to 2.6‰. Average $\delta^{13}C$ value from 11 inoceramid shell samples is 2.1‰.

In numerous Late Coniacian aragonitic ammonoid shells collected from the same section, $\delta^{13}C$ values are predominantly negative (fluctuate from -0.1‰ to -8.6‰), excluding four ammonoid shells, $\delta^{13}C$ values of which fluctuate from 0‰ to 1.0‰. Average $\delta^{13}C$ value from 32 Late Coniacian ammonoid shell samples examined in this study is -2.1‰.

Nakafutamata River

$\delta^{13}C$ values of different places of the three ammonoid *Anagaudryceras limatum* (Yabe) shells from the Upper Coniacian of the Nakafutamata River fluctuate from -0.13‰ to 1.77‰, and average $\delta^{13}C$ value from 8 samples is 0.3‰.

Thus, high biological productivity in some water areas of the northern high and middle-low latitudes during Late Coniacian time reflected in anomalously high $\delta^{13}C$ values (till 5.4‰ in Hokkaido and 4.7‰ in the Koryak upland) in biogenic carbonates seems to be connected only with local (not global) events, which were confined to brackish waters of some gulfs and estuarine parts of shallow epicontinental seas of that time.

CONCLUDING COMMENTS

In Coniacian times, both the ammonoid migrants from Hokkaido that inhabited the high latitudes of the Northern Hemisphere (northern Kamchatka area, Koryak upland) and the endemic ammonoids living in the middle-low latitudes (Hokkaido) seem to be characterised by close optimal growth temperatures. Nevertheless, certain differentiation in climatic conditions during the coldest/darkness seasons of the mentioned regions that time undoubtedly provoked a growth cessation in some groups of high-latitudes ammonoids.

The Coniacian average annual temperature value in near bottom water of shallow epicontinental seas was estimated from calcitic bivalves living in conditions of normal salinity and characterised by more or less capability for steady growth through the year, and seems to be about 14.9 ℃ in the northern high latitudes (Koryak upland). That of aragonitic ammonoids that lived in the middle-low latitudes (Hokkaido) was estimated to be about 18.2 ℃.

There is indeed strong evidence for a reduced pole to equator temperature gradient in the Coniacian. Summer, winter and average annual paleotemperatures in near bottom water of shallow epicontinental seas at high latitude (Koryak upland) seem approximately of 2.2, 3.6 and 3.3 ℃ lower, respectively, than those for the middle-low latitudes (Hokkaido).

Thus, our study suggests that between the western Koryak upland (northern Kamchatka) and northern Hokkaido (Japan)-Coniacian Northern

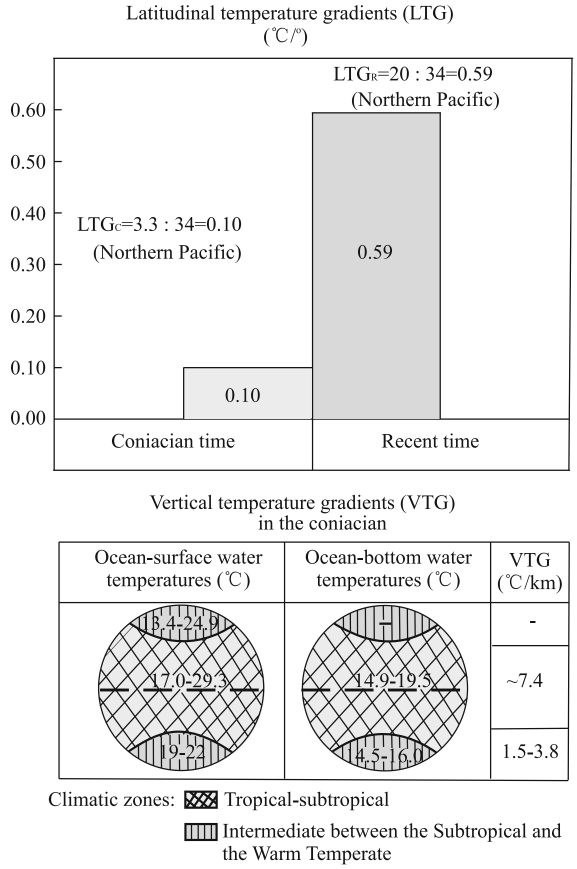

Figure 5. Latitudinal and vertical temperature gradients, calculated for Coniacian and recent times.

Hemisphere paleolatitudinal temperature changes amount to only 0.10 ℃ per degree of latitude, which shows that a Coniacian climate was six times more equable than that of modern time (Fig. 5). Evidence obtained is in agreement with data on planctic foraminifera from the Southern Hemisphere (e.g., Huber et al., 2002, 1995; Huber, 1998; Barrera, 1994; Boersma and Sgackleton, 1981).

Herman and Spicer (1996), using the leaf-physiognomic method, expected slightly lower temperatures for Alaska and North Kamchatka during the Coniacian than those estimated by us, using isotopic method. This discrepancy may possibly be due partly to differences between oceanic and atmospheric temperatures in Arctic and north Boreal-Pacific regions during the Coniacian. In contrary to some authors' (Li and Keller, 1999) version, we assume, following Herman's (2004) remark, that the relatively higher temperatures in the water, compared to the cooler atmospheric ones, may be due to predominance of oceanic pole-ward heat flow.

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