Position of Quaternary Lower Boundary of the Arctic Chukotka According to Diatom Analysis

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ABSTRACT: The International Union of Geological Sciences proposed to establish the lower boundary of the Quarter at a level of 2.58 million years ago (Norway, 2009), and this was then adopted on the proposal of the International Commission on Stratigraphy. This decision caused heated discussion, requiring substantiation of the new position of the stratigraphic boundary and inclusion of the Gelazian stage of the Pliocene in the Quarter. This positioning could significantly affect the development of the structure and hierarchy of stratigraphic units of the Quarter. The issues of the criteria for drawing a new border, their unification in various geographic regions and regional geological stratotypes are principally considered. This paper examines the queries of the criteria and eligibility of a new Neogene-Quaternary boundary in the Upper Cenozoic continental sediments of the Chukotka using data derived from diatoms.

KEY WORDS*:* Pliocene, Quarter, moraines, paleoclimate, Chukotka

INTRODUCTION

The decision to place the lower boundary of the Quarter at a level 2.58 million years ago was made by the International Union of Geological Sciences (IUGS) in 2009, after a discussion at the 33th International Geological Congress (Oslo, Norway, 2008) (Ogg, Pillans, 2008; Pillans, Gibbard, 2012). In 2011, on the recommendation of the Neogene and Quaternary Commissions of the Interdepartmental Stratigraphical Committee (ISC) together with the Commission of RAS on the Quaternary period, the boundary between the Neogene and Quarter was also adopted at a level of 2.58 million years ago which further

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created heated discussion regarding the problem of its identification in sections of the quaternary deposits (Modern…, 2011). Such a decision requires setting the criteria of the lower Quarter boundary in recognition of the Arctic regions of North-East Asia (Melles et al., 2012; Brigham-Grette et al., 2013).

It is also important to bear in mind different criteria of identifying the layers on the International stratigraphic scale and regional stages of the Arctic. In case of interregional correlation of stratigraphic units, in particular at the Gelazian stage, complications caused by differing degrees of complex knowledge of deposits and facial dissimilarity will always be present.

In the 1990s, initial data on the Pliocene-Early Pleistocene moraines, left by the valley glaciers in the north of the Chukotka Peninsula, more truly, in the Vankarem Lowland (Laukhin et al., 1990) was published. At the time, this attracted interest but did not come as a breakthrough since glaciations of such age had been earlier identified in the north-east of Asia. Evidence of the age of moraines corresponded to the stratigraphic position of the Late Pliocene and Quaternary glacial events in the Northern hemisphere (Laukhin et al., 1999). The glaciations named Zhuravliny and Okanaansky aged between 3.5–3.2 and 2.5–2.4 million years ago respectively, were determined practically according to the same indirect data. Later, a variant of the detailed zonal scale using diatoms for subdivision of the Pliocene and Quarter of the North Pacific, Chukotka and Alaska was proposed (Pushkar et al., 2014). New palynological, diatomic and geochemical data on the continuous paleoclimate records obtained for sediments of the Lake Elgygytgyn located in the Arctic Chukotka emerged. At the same time, correlation of lake deposits with the isotopic stages of Greenland was carried out, which resulted in the development of the age model of the interchange of glacial and interglacial stages of the eastern regions of the Arctic (Melles et al., 2012; Andreev et al., 2013; Brigham-Grette et al., 2013; Lozhkin, Anderson, 2013). Therefore, (this new data allowed a more substantiated interpretation of the ages of the Zhuravliny and Okanaansky glaciations in the north of the Chukotka Peninsula, which served as the purpose for this paper.

MATERIALS AND METHODS

Both moraines are presented in the well bore at site 28 (67°58′ N and 171°25′ W), drilled in the vicinity of the Zhuravliny River, 17.5 km from the Vankarem lagoon in the submeridional buried valley (Fig. 1). The well Site (borehole) 28 has uncovered sediments of the Rygytgynian Formation with a total thickness of more than 100 m, which was then divided into 6 units (from the bottom upwards):

1) 106.0–97.8 m – interbedding of fluvioglacial sands and sandy loam;

2) 97.8–90.4 m – bluish-gray unsorted boulder loams with glacial boulders (moraine), at the top, thin bands of fluvioglacial sand;

3) 90.4–82.4 m – well sorted sand with layering typically found in coastal-marine sediments, at a depth of 88 m, including broken chunks according to sand stratification;

4) 82.4–75.2 m – grey pebble unsorted sandy loam stratified within the sorted sand;

5) 75.2–47.6 m – boulder ash-grey unsorted sandy loam with glacial boulders (moraine);

6) 47.6–4.0 m – interstratifications of sands, loams and sandy loams.

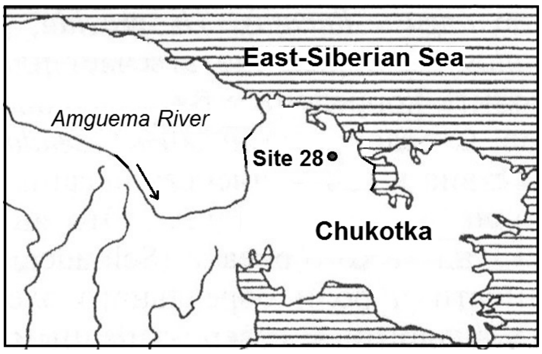

FIG. 1: Location of Site 28 (Vankarem Lowland)

Accordingly to the age model the dated levels of evolutionary appearance and disappearance of zonal species of sea diatoms, together with the newest palynological and bioclimatostratigraphic data were used; providing well-defined conclusions regarding the age of moraine complexes of the Vankarem Lowland (Pushkar et al., 2014).

RESULTS AND DISCUSSION

According to the textural features of sediments and the ecological structure of the explored diatom complexes, all the layers of the Rygytgynian Formation (apart from the interval of 70.8–54.4 m) have the coastal-marine and glacial-marine origin. This is borne out by the existence of marine arcto-boreal species such as *Bacterosira bathyomphala* (= *B. fragilis*), *Detonula confervacea*, *Thalassiosira kryophila*, *T. hyalina*, *T. gravida*, as well as cryophilic forms *Fragilariopsis cylindrus* and *F. oceanica*), which have a lower bluish-grey moraine of the Zhuravliny (Unit 2) and a grey moraine of the Okanaansky (Unit 5) glaciations.

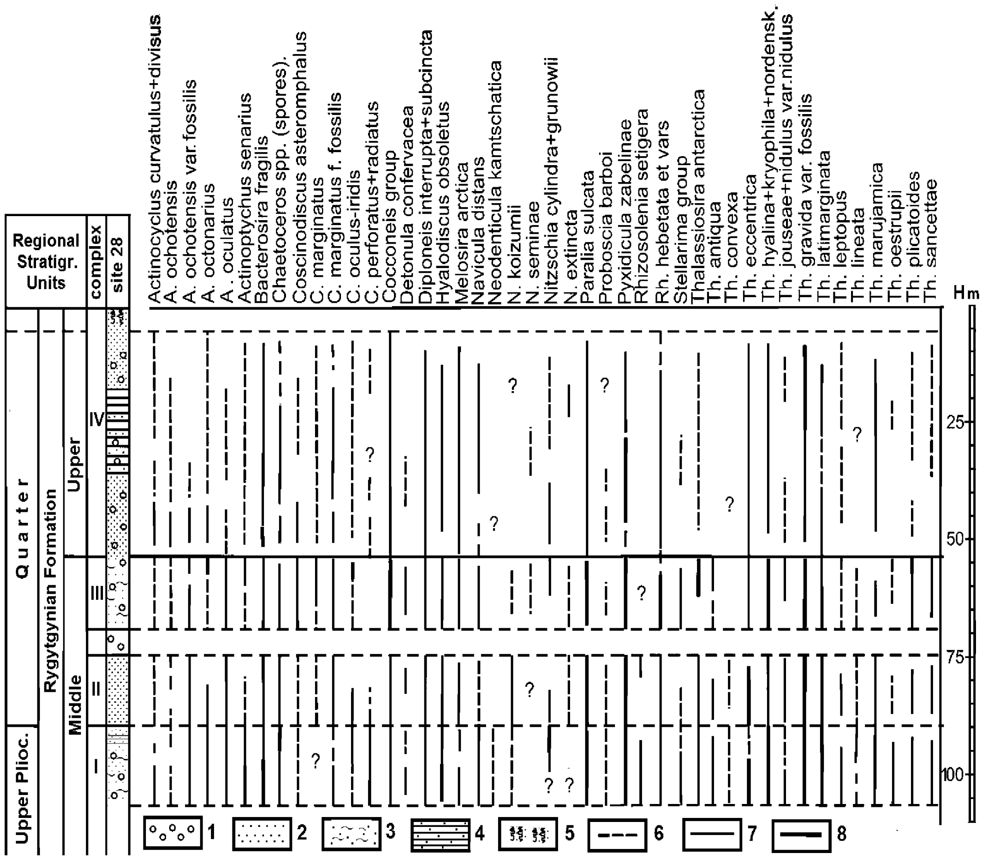

FIG. 2: Diatom diagram of the deposits of Site 28 (Vankarem Lowland):
1 – pebbles and boulders, 2 – sand, 3 – sandy loam, 4 – loam, 5 – peat; grades of diatom abundance: 6 – single (1–10 valves per slide), 7 – rare (11–79 valves per slide), 8 – few (1, 2 valves in each horizontal traverse (X400) 18 mm length)

In the sediments of the interval 105.8–54.4 m, 62 taxa of diatoms were determined that mainly belong to the *Thalassiosira*, *Coscinodiscus*, *Diploneis* and *Cocconeis* genera, characterized by the coastal-marine genesis of sediments. Based on the analysis of the distribution in the sediments of diatom valves, 3 complexes (Fig. 2) were identified. In the composition of the identified complexes, several of the stratigraphically important species were found at the levels of appearance or disappearance of which are used as dated in the zonal scales on diatoms (Pushkar et al., 2014). This helps to determine the age of the explored in the section of the diatom associations, which were also compared with the palynological analysis.

Complex I (interval 105.8–90.4 m) is most ancient. It contains the rare *Neodenticula kamtschatica* and *N. koizumii*, with dominants *Thalassiosira gravida* var. *fossilis*, *Pyxidicula zabelinae*, *Hyalodiscus obsoletus* as well as group *Actinocyclus oculatus – A. ochotensis*. This complex can be compared with the association of the North Pacific diatom Zone *Neodenticula koizumii – N. kamtschatica* (3.5–2.58 million years). A notable feature of the complex is the participation in the ecological structure of the diatom assemblage in the lower part of Unit 1 of rare warm-water species: *Coscinodiscus asteromphalus*, *C. perforatus + C. radiatus*, *Thalassiosira convexa*, *T. convexa* var. *aspinosa*, *T. oestrupii*, *T. lineata*, which sharply decrease in quantity towards the upper part of this sediment interval.

Complex II (interval 90.4–75.2 m) is identified according to the disappearance of *Neodenticula kamtschatica*, an abundance of *Pyxidicula zabelinae*, as well as the occasional occurrence of *Thalassiosira convexa.* It is aligned with Zone *T. convexa* (2.58–2.3(2.2) million years ago).

Complex III (interval 70.8–54.4 m) is characterized by the dominant presence of *Pyxidicula zabelinae*, *Thalassiosira gravida* var. *fossilis*, and *Paralia sulcata*. The total disappearance of *T. convexa* from the sediments means this complex can be ascribed to Zone *P. zabelinae* – 2.3 (2.2) – 1.95 million years ago.

The complex of diatoms in the upper part of the section (interval 54.4–5.6 m) contains the highest percentage of re-deposited diatoms, which typically includes *Stephanopyxis schenckii*, *P. zabelinae*, and *Coscinodiscus marginatus* f. *fossilis* in the pieces, presented by extra coarse silicified forms. The quantity of the re-deposited sea and freshwater diatoms (up to 53%) at the depth of 42.9–47.6 m is extra large. The freshwater diatoms (up to 34%) of *Aulacoseira*, *Cyclotella*, *Pinnularia*, *Navicula*, and *Cymbella* genes include about 16% of the Neogene taxa of the “prae…” group (*Aulacoseira* genus),which play a significant role in the complex. The same picture was revealed for the re-deposited palynomorphs (Laukhin et al., 1999).

Thus, according to diatoms, the Zhuravliny moraine is probably dated by the interval of 3.4–2.58 million years ago, while the Okanaansky moraine is dated by an interval of 2.3(2.2)–1.95 million years ago. The interpretation of the moraines age can be specified based on the paleoclimatic rhythmic established on the pollen spectra of the moraine and intermoraine sediments and their correlation with the neighbor regions (Laukhin et al., 1999).

The palynospectra of units 1–5 correspond to the palynospectra rhythmic of the Lower Pliocene Kutuyakh Formation at the mouth of the Kolyma River (Laukhin et al., 1999). However, the re-deposition of palynomorphs is characteristic of the glacial series and coastal-marine sediments, therefore it is more reliable to focus on data on palynospectra of the Lake Elgygytgyn (67°30′ N, 172°05′ E), where the re-depositions of palynomorphs are practically non-existent (Andreev et al., 2013). Both sections are present in the northern hypo-Arctic part of tundra: well Site 28 in the coastal plain of the sedge-cotton-grass tundra, while the Lake Elgygytgyn is at a height of 492 m among the suffruticose-lichen tundra of the Anadyr plateau, elevated 600–1000 m above sea level.

The variety of vegetation and climatic events represented in the sediments of Lake Elgygytgyn, as well as the refinement of their stratigraphic position between the intervals of 3.6– 2.1 million years ago is discussed in many articles (Melles et al., 2012; Andreev et al., 2013; Brigham-Grette et al., 2013). According to the palynological data, prior to the period – 3.6 million years ago, forests of spruce, larch, pine, hemlock, birch, alder and some broad-leaved species predominated.

Between 3.5–3.25 million years ago the climate became close to the modern one and corresponded to the Kutuyakh time (Laukhin et al., 1999): at the same time the quantity of hemlock and silver-fir pollen in the palynospectra deposits became significantly lower. This is consistent with the moderately warm-water ecological structure of the diatom complexes of the *Neodenticula koizumii – N. kamtschatica* Zone. The appearance of the diatom *Actinocyclus oculatus* in this diatom complex, *Actinocyclus ochotensis*, *A. ochotensis* var. *fossilis* specify the beginning of the Unit I formation no earlier than 3.45 million years ago. Two warming fixed for this time in the sediments of the Lake Elgygytgyn, of which the abundance of silver-fir and fir is characteristic, and are divided by two cooling whereby the areas of treeless spaces are occupied by broadening sedge-grass associations.

Subsequent spore-pollen complexes testify to a directed cooling in the range of 3.25–2.61 million years ago. This is also characteristic of the upper part of the *Neodenticula koizumii – N. kamtschatica* Zone. Towards the upper boundary of the zone, the abundance of north- and arctoboreal species increases.

Between 3.25–3.19 million years ago, the climatic conditions become dry and cold, as is evidenced by the abundance of pollen of the dwarf birch and alder. Sections of the larch forests have retained. In the interval between 3.14–3.05 million years, the “paleotundra-steppe” close to one that was characteristic of the periglacial zone at the time of the Pleistocene glaciations has expanded (Laukhin et al., 1999). Generally, the vegetation was mosaic.

Between 3.05–2.82 million years, the dwarf alder, birch and willow expanded in vegetative cover. Open grassy spaces predominated by the end of the period, and silver-fir forests appeared in some places. The period between 2.82–2.78 million years ago was characterized by the predominance of treeless spaces, with *Betula* sect. *Nanae* and grasses. The climate has conformed to condition of the continental glaciations of the Northern hemisphere (Andreev et al., 2013).

Between the periods of 2.78–2.7 million years, an increase in the role of coniferous species (fir, silver-fir, pine) took place, which bears evidence of the developing quasi-interglacial forests. In deposits of the time interval between 2.7–2.65 million years ago, an increase in the role of grasses took place, as seen in the pollen spectra. The vast areas of the

Vankarem Lowland were occupied by swamps (Andreev et al., 2013). At the turn of the period, 2.61 million years ago (Gauss-Matuyama boundary), the abrupt transition from interglacial to glacial conditions (the emergence of dry and cold tundra-steppes) is fixed; followed by the expansion of open shrub tundra, registered between 2.5–2.34 million years ago (Andreev et al., 2013).

CONCLUSIONS

The Zhuravliny moraine was deposited under coastal-marine conditions when the climate in the Vankarem Lowland was close to that of recent times but wetter, which promoted the development of the Late Pliocene glaciations. Meanwhile, about 3.2 million years ago, sections of the larch forests were preserved at the Anadyr plateau. The Pliocene analogs of the glacial tundra-steppes – vegetation of the treeless tundra similar to the steppe one – first appeared in the vicinity of the Lake Elgygytgyn in the interval between 3.14–3.05 million years ago and, mainly, during the Kaena Subchron, i.e. 3.116–3.032 million years ago. Around 2.97 million years ago, in the tundra near Lake Elgygytgyn, sections of the silver-fir forests reemerged. Thus, the Zhuravliny glacier terminus to the plain, at the interval between 3.2–3.1 million years ago is most probable.

The grey moraine appeared in the plain, most likely, during the sea regression, as marine diatoms were not found in the lower layers of the Unit 5. The main part of the moraine was deposited under coastal-marine conditions during the formation of the deposits of complex II. As deduced from the thickness of the moraine (about 30 m), and the bedding of two interlayers (aleuritic, thin-laminated and sorted, apparently fluvioglacial sand) in its middle, the glacier came to the plain prior to the sea transgression, i.e. prior to 2.2 million years ago.

The remains of the cold tundra-steppe in the section of the Lake Elgygytgyn were dated as 2.65–2.5 million years ago. In the interval of 2.5–2.3 million years ago, the larch forest-tundra expanded and, in the layers of 2.26 million years ago, pine pollen has been registered (Laukhin et al., 1999; Andreev et al., 2013). The significant cooling 2.6–2.5 million years ago is comparable in scales and intensity to the maximum of the Late Neo-Pleistocene global glaciation. This glaciation, with a pronounced temperature minimum at ~ 2.58 million years ago was briefly reflected in the ecological structures of diatom associations of complex II (lower part Zone *Thalassiosira convexa* (2.58–2.3(2.2) million years ago).

From this moment, under conditions of sudden climatic changes, the phenotypic modifications in the morphogenesis of diatom valves and their phenotypic selection in evolution begins (Cherepanova et al., 2010. A total absence of pollen from broad-leaved species is characteristic of that time. From this moment forward, the coexistence and expansion of the polar ice sheets (transition of the planet from the “Green house” mode to the "Ice house" mode), defining the formation of the current climatic system of the Earth, began, stressing the significance of this event as the climate-stratigraphic border between the Pliocene and Quarter.

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