Upper Pliocene Diatom Complexes and its Significance for Establishing the Lower Boundary of Quarter (South of the Far East)*

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ABSTRACT: Establishing the lower boundary of the Quarter at the level of 2.58 million years was proposed by the International Union of Geological Sciences (Norway, 2009), and adopted on the proposal of the International Commission on Stratigraphy. This decision has caused heated discussion, requiring a serious substantiation of the new position of the stratigraphic boundary, and the inclusion of the Gelasian stage of the Pliocene in the Quarter. This position could significantly affect the development of the structure and hierarchy of stratigraphic units of the Quarter. The issue of the criteria for drawing a new border, its unification in various geographic regions, and regional geological stratotypes is especially considered. This paper considers both the criteria and eligibility of a new Neogene-Quaternary boundary in the Upper Cenozoic continental sediments of the Primorye by utilizing diatoms.

KEY WORDS: Quarter, Pliocene, Gelazian stage, Shufansky Horizon, paleoclimate, Primorye

INTRODUCTION

At present, considerable attention of geologists studying the quaternary deposits is directed at the problem of justification and criteria surrounding the drawing of the lower boundary of the Quarter at the level of 2.58 million years; and therefore, the inclusion of the Gelasian stage in the structure of its units. This decision, following the proposal by the International Commission on Stratigraphy (ICS) was adopted by the International Union of Geological Sciences (IUGS) in 2009, preceded by heated discussion of this problem at the 33rd International Geological Congress (Oslo, Norway, 2008). The stratotype of the lower boundary of the Gelasian age – the Monte San Nikola (Sicily) outcrop – was confirmed in

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1996. At this level, the boundary between the paleomagnetic epoch Gauss-Matuyama, and the lower boundary of the 103rd Oxygen Isotope Stage is situated (Ogg, Pillans, 2008; Pillans, Gibbard, 2012).

In Russia, the lower boundary problem of the Quarter was consistently discussed and, in the spring of 2011, the boundary between the Neogene and the Quarter was adopted at the level of 2.58 million years, upon the recommendation of the Neogene-Quaternary Commission of the Interdepartmental Stratigraphical Committee (ISC) together with the RAS Commission on the study of the Quaternary period (Modern…, 2011). Such adecision has critical consequences as it requires undertaking large-scale geological surveys, and drawing new regional maps of the Quaternary deposits for the exploration of geology. When determining criteria for drawing the boundaries of the regional units of the Quarter, we should also take into consideration the important comments of Svitoch (2016) regarding the ratio of volumes and position of boundaries of the International Stratigraphic Scale (ISS) stages, as well as units of the regional scales. The example of the Big Caspian (BC) showed that the lower boundaries of the ISS stages and regional stages of BC, along with the paleogeographical situations, correlate in different ways. The key reasons for such non-conformities can include a variety of scales, differences and hierarchies of events when comparing – World Ocean and Caspian region. The different criteria for determining the stages in the ISS and regional stages of the BC must also be considered. The interregional correlation of stratigraphic units, especially within the Gelasian stage, is always accompanied by complications caused by different degrees of knowledge and facial heterogeneity in continental strata. Such complications are universal for any region.

In the formally approved Regional stratigraphic scheme of Paleogene and Neogene deposits for the south of the Far East mainland (Turbin, 1994), the Pliocene deposits were included in the stratigraphic volume of the Suifun Horizon (Suifunskaya Formation). It was recognized that the deposits of the Suifunskaya Formation were replaced laterally by the deposits of the Shufanskaya Formation, with more complete outcrops in the vicinity of the Shufan plateau. Later, the stratigraphic volume of the Suifunsky Horizon was reconsidered and its correspondence to the Eopleistocene was proved, therefore, the Shufansky Horizon cannot be the lateral facial analog of the Suifunsky one (Pavlyutkin, Petrenko, 2010). The Shufanskaya Formation as such in the stratotypical outcrop (well bore 415, Fig. 1) was formed in the lower and upper parts by the andesitbasaltic flows, with a thickness of 25 and 13 m respectively. Inter-basaltic clays and sands with interlayers of tuff-diatomite (with a thickness of 48 m) formed under the lake conditions. The Shufanskaya Formation deposits have fairly serious micropaleontological substantiation and radiometric-dating, suggesting their place in the Pliocene (Kovalenko et al., 2010), which renders their transfer to the Eopleistocene level impossible. Such age contradictions have resulted in the reconsideration of the status of Shufanskaya Formation as the facial analog of the

Suifunskaya Formation, and given rise to the identification of the same-name regional Shufansky Horizon in the stratigraphic scheme of Neogene of the Primorye (Pavlyutkin, Petrenko, 2010). The Shufansky Horizon deposits are overlapped by the red series of the Annensky Horizon as proposed by Pavlyutkin, who further associated them with the Gelasian stage (Pavlyutkin, Petrenko, 2010). Above the Annensky Horizon, the deposits of the Suifunskaya Formation are well defined by micro-paleontological data (carpological, spore-and-pollen and diatom analyses) and correspond to the Eopleistocene level. The paleomagnetic investigations have shown that the upper part of the Annensky Horizon deposits are predominantly characterized by the reversed remanent magnetization. Providing the grounds for consideration of the potential time of its accumulation in the course of one the episodes within the Gauss epoch or early period of the Matuyama epoch (Pavlyutkin, Petrenko, 2010).

MATERIALS AND METHODS

The more complete outcrop of the Pliocene (supposed stratotype is outcrop 4131) is situated in the vicinity of the Terekhovka village close to the drilling site of well 415 (Pushkin cavity, coordinates: 43º 20' 25" N and 131º 52' 59" E), and increases the outcrop 4130 of the Ust-Suifun Formation (Fig. 1). The same layers of the Pliocene are traced in the outcrops 4128 and 4129, close to the western fringes of Krasny Yar settlement (43º 41' 40" N and 131º 54' 54" E).

FIG. 1: Location map of the explored Pliocene outcrops in Primorye

The sedimentary stratum of the outcrop 4131 is referred to as the Kedrovskaya Unit (Denisov, 1960). This outcrop is supposedly considered as the stratotype of the horizon as it is fairly complete, characterized by fossil leaf flora, spore-and-pollen data and diatom analyses (Pavlyutkin, Petrenko, 2010; Pushkar et al., 2019).

Deposits of the outcrop 4131 are presented from bottom to top:

1. Clay, hard, bluish-grey, silty clay in some interlayers .... 5.6 m
2. Sand, light-grey, finely grained, good sorting .... 0.65 m
3. Clay, hard, bluish-grey, silty clay in some interlayers .... 0.25 m
4. Aleurolite, light-grey, with tracks of soil in the upper part….......0.55 m
5. Sands, light-grey, finely grained, good sorting,
   silty sand in the upper part ……………………….................3.8 m
6. Buried soil with humic and illuvial horizons ……..................... 0.5 m

Total thickness 11.05 m

The deposits are overlapped by the basaltic sheath (0.7 m thick) and aleurolites (1.1 m thick). Basalts of the upper flow display reversed remanent magnetization corresponding to the paleomagnetic epoch Matuyama (Alekseev, 1978).

RESULTS AND DISCUSSION

The diatom complexes identified in the deposits of the Shufanskaya Formation belong to diatoms *Alveolophora tscheremissinovae* and *Aulacoseira praegranulata* var. *praeislandica* f. *praeislandica* (Fig. 2). The first evolutionary appearances of *Aulacoseira subarctica* (Müller) Haworth, *Pliocaenicus costatus* Loginova, Lupikina, et Khursevich) Flower, Ozornina et Kuzmina, *Stephanodiscus grandis* Khursevich et Loginova, *S. hantzschii* Grun. and *S. nativus* Lupikina, Khursevich, Ozornina were registered at the Miocene-Pliocene. The abundantly present *Alveolophora* (*Miosira*) *tscheremissinovae* Khursevich is a good marker of the Pliocene deposits.

Complex of the *Alveolophora tscheremissinovae* zone (Lower Pliocene, layers 1−3). The top boundary of the zone is drawn according to the extinction of species-index. The age is between 5,3−3,6 million years. The diatom complex is characterized by *Alveolophora tscheremissinovae* Khursevich, *Aulacoseira praegranulata* var. *praeislandica* f. *praeislandica* (Jousé) Moiss., *Melosira undulata* (Ehr.) Kütz, *Ellerbeckia arenaria* f. *teres* (Brun) Crawford, *Fragilariforma bicapitata* (A.Mayer) Williams et Round, *Cymbella* *tumida* (Bréb.) Van Heurck and *Sellaphora americana* (Ehr.) Mann, *Cymbella australica* (A.S.) Cl. The quantity of extinct species reaches 10%. The greater species diversity, as compared with the lower complex((,)) as well as the discovery of warm-water species corresponds to the insignificant climate warming of the Early Pliocene.

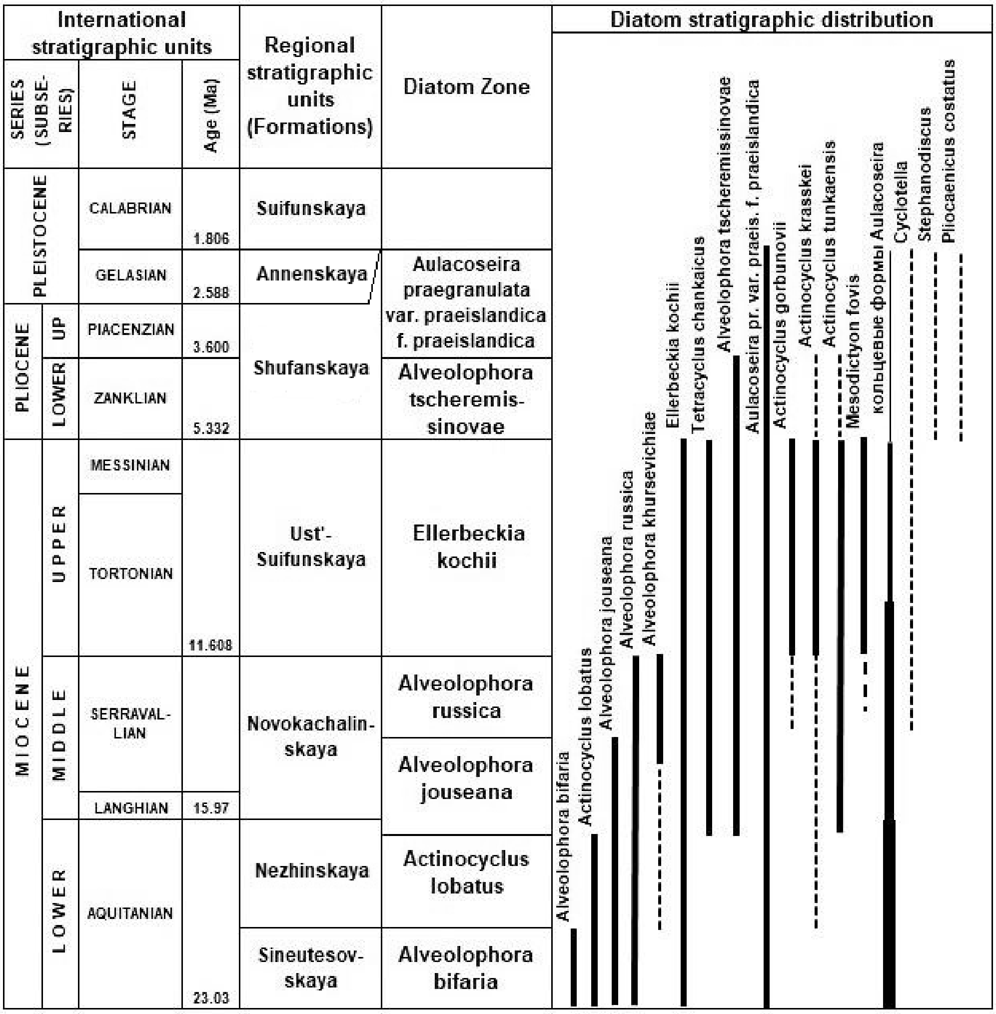

FIG. 2: Zonal diatom scale of the Neogene deposits in Primorye (Pushkar et al., 2019) with slight adjustments

Complex of zone *Aulacoseira praegranulata* var. *praeislandica* f. *praeislandica* (Upper Pliocene, layers 4–6). The top boundary corresponds to the species-index extinction level. The age of the zone corresponds to 3.6–2.58 million years. The diatom complexity is reflective of its evolutionary stage presented by *Aulacoseira praegranulata* var. *praeislandica* f. *praeislandica* (Jousé) Moiss., *A. distans* (Ehr.) Simonsen, *A. praegranulata* var. *praegranulata* (Jousé) Moiss., *A. italica* (Kütz) Simonsen, *Melosira undulata* (Ehr.) Kütz, *Ellerbeckia arenaria* f. *teres* (Brun) Crawford, *Eunotia clevei* Grun., *Tetracyclus ellipticus* var. *lancea* (Ehr.) Hust. Extinct species, apart from diatoms with coarse valves *Aulacoseira praegranulata* (Jousé) Simonsen, are absent. The diatoms with coarse valves *Aulacoseira* are also absent in the Suifun Formation deposits, which assimilates this flora with the recent flora (Pavlyutkin, Petrenko, 2010). Species diversity has considerably decreased and the moderately warm-water element of flora is absent. The benthic diatoms prevail (up to 78%) which is evidenced by the intensification of the alluvial sedimentogenesis as compared with the limnic one. The complexity reflects a new cold wave and cold condition stabilization.

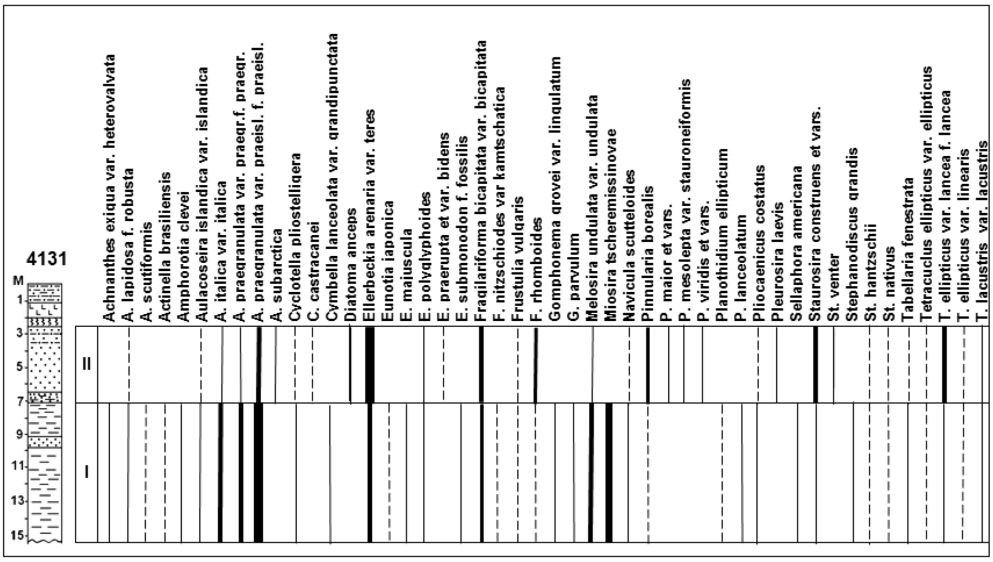

FIG. 3: Diatom diagram of deposits in the key outcrop of the Pliocene deposits (outcrop 4131, lithological description is presented in the text)

From an environmental perspective, the two above-described complexes are contrasting. The lower complex is characteristic of the lakes deep-water facies as is evidenced by the dominance of the benthic *Melosira undulata* var. *undulate* (Ehr.) Kütz. preferring the deep lake biotopes, as well as representatives of planktonic genera of *Ellerbeckia*, *Cyclotella*, *Pliocaenicus* and *Stephanodiscus*. The presence of the warm-water diatoms *Actinella brasiliensis* Grun., *Cymbella tumida* (Bréb.) Van Heurck and *Sellaphora americana* (Ehr.) Mann (up to 41.3%) in the complex is evidenced by the relatively warm climate of the Early Pliocene which is also noted by Pavlyutkin (Pavlyutkin, Petrenko, 2010.

Within the upper complex, representatives of the genus *Aulacoseira* are predominant, inhabiting the shallow waters. The absence of warm-water diatoms is characteristic, suggesting a water level reduction in the lake and the beginning of the strong global cooling in the Late Pliocene reaching maximum phase at 2.58 million years. A dominant position in monsoon circulation is occupied by the winter monsoon. From this moment on, the coexistence and expansion of the polar ice sheets began (transition of the planet from the "Green house" phase to the "Ice house" phase) which determined the formation of the modern climatic system on Earth (Wang et al., 2003).

The diatom complexes of deposits in the outcrop 4129 located on the western fringes of the Krasny Yar settlement (Fig. 1) and increasing, without traces of breaks, ((to)) the outcrop 4128 (Ust-Suifun Formation) are considered as the analogs of the described complexes 4131.

Data from the diatom analysis correspond wholly with the data from the spore-and-pollen analysis (Pavlyutkin, Petrenko, 2010). Two spore-and-pollen complexes are identified in the sedimentary strata of the outcrop 4131.

The spore-and-pollen spectra of the lower part of the outcrop (layers 1–3) are characterized by the predominance of the pollen of *Angiospermae* over *Gymnospermae.* Among *Angiospermae*, the pollen of the broad-leaved species (*Castanea* (up to 4.3%), *Carpinus* (up to 6%), Corylus (up to 3.6%), *Juglans* (up to 5.1%), *Ulmus* (up to 4.3%).) plays a prominent role. *Pinus* subg. *Haploxylon* (4–19.2%) prevails in the composition of *Gymnospermae*. The quantity of *Picea* sect. *Omorica* (1.4–2.3%) and representatives of *Taxodiaceae* (1.2–2.3%) is substantially lower. Among the small-leaved species, the content of *Betula* (2.9%), *Alnus* (up to 19.3%) is appreciable.

Within the upper complex (layers 4–6), the absence of pollen of the broad-leaved species is characteristic. Only rare pollen grains of *Juglans*, *Carpinus*, *Corylus*, *Quercus*, *Fagus*, *Ulmus*, *Acer*, *Tilia*, *Syringa* are encountered and, as a result, the spectrum image turns out to be close to the Eopleistocene ones. This allows us to assume that the sediments of the upper part were formed in the time of the global climatic cooling in the interval between 2.2–3.0 million years, with maximum phase similarity found with the late planet glaciations at the level of 2.58 million years, when comparing intensity (Pavlyutkin, Petrenko, 2010).

Such spectra for the Late Cenozoic reflect the Pliocene climatic oscillations, well-defined within the global palaeotemperature changes (Wang et al., 2003; Pavlyutkin, Petrenko, 2010).

CONCLUSIONS

An analysis of the evolutionary distribution of diatoms in the outcrops of the Late Cenozoic demonstrates that, upon reaching the level of the Annensky Horizon (Gelesian stage), extinct species disappear almost completely. A predominance of the alluvial type of sedimentogenesis and reduction in the lake basin-areas are clearly registered for deposits of the diatom zone *Aulacoseira praegranulata* var. *praeislandica* f. *praeislandica*. A cooling in the Late Pliocene, with the pronounced temperature minimum at 2.58 million years, is reflected in the ecological structures of diatomic associations (upper complex): the benthic arcto- and north-boreal flora predominates.-In that time, a total absence of the pollen of ~~the~~ broad-leaved species is also characteristic and paleo-landscapes become close to ~~the~~ Eopleistocene ones. From this moment on, the coexistence and expansion of the polar ice sheets began (transition of the planet from the "Green house" phase to the "Ice house" phase) determining the formation of the modern climatic system of the Earth, emphasizing the globality of the palaeoclimatic event. From a lithological point of view, the bottom of the red rock strata of the Annensky Horizon, corresponding to the Gelesian stage bottom (2.58 million years) coincides with this boundary in the southern Primorye. The age changes of the Quarter boundary to this chronostratigraphic level is well founded.

REFERENCES

Alekseev M.N. 1978. *Anthropogene of the Eat Asia*. Moscow: Nauka. 108 p. [Rus.]

Turbin M.T. 1994. *Decisions of the Fourth Interdepartment Regional Stratigraphic Meeting on Pre-Cambrian and Phanerozoic of the Southern Far East and Eastern Transbaikalia*. Khabarovsk: Dalgeologiya. 124 p. [Rus.]

Denisov E.P. 1960. To the question of the stratigraphy of the Upper Cenozoic formations of the Southwestern Primorye. *Rep. Far East. Branch Siberian Branch USSR Acad. Sci*. 12: 19–23.

Kovalenko S.V. 1989. In: *The Cenozoic of the Far East*. Vladivostok: FEB RAS. Pp. 64–72. [Rus.]

Modern problems of the Neogene and Quaternary stratigraphy of Russia. 2011. Ed. Yu.B. Gladenkov. Moscow: GEOS. 108 p. [Rus.]

Ogg J., Pillans B. 2008. Establishing Quaternary as a formal international Period/System. *Episodes*. 31(2): 230–233. https://doi.org/10.18814/epiiugs/2008/v31i2/008

Pavliyutkin B.I., Petrenko T.I. 2010. *Stratigraphy of Paleogene-Neogene deposits of the Primorye.* Vladivostok: Dal'nauka. 164 p. [Rus.]

Pillans B., Gibbard P. 2012. In: *The Geological Time Scale*. Amsterdam: Elsevier. Pp. 979–1010. . https://doi.org/10.1127/0078-0421/2012/0020

Pushkar V.S., Likhacheva O.Yu., Usoltseva M.V. 2019. Zonal Diatom Scale of the Continental Neogene in Primorye (Most Southern Territory of the Russian Far East). *Int. J. Algae*. 22(3): 163–176. . https://doi.org/10.1615/InterJAlgae.v21.i2.60

Svitoch A.A. 2016. Position of lower boundaries of the international stratigraphic scale stages of upper Pliocene and Quaternary in succession of Great Caspian Sea and paleogeographical events. *Bull. Mosc. Soc. Nat.* Geol. Ser. 91(2–3): 63–73.

Wang Pinxian, Zhao Quanhong, Jian Zhimin, Cheng Xinrong, Huang Wei, Tian Jun, Wang Jiliang, Li Qianyu, Li Baohua, Su Xin. 2003. Thirty million year deep-sea records in the South China Sea. *Chinese Sci. Bull*. 48(23): 2524–2535.