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REFORMATION OF THE SURFACE OCEANIC CIRCULATION DURING PALEOGENE: CALCAREOUS NANNOPLANKTONIC, FORAMINIFERAL AND OXYGEN ISOTOPIC EVIDENCES

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Palabras clave: Paleógeno, Nannofósiles calcáreos, Isótopos ^{18}O, Paleoceanografía, Circulación oceánica superficial.

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ABSTRACT: Paleogene calcareous nannoplankton evolution with regard to morphotype changes was analysed. The$^{18}O/^{16}O$ ratio in planktonic foraminifera tests was studied. Conclusions about surface water temperature and salinity changes and about main features of surface circulation based on these data were arrived. Can be seen that the reformation from the mainly halinotypic circulation of the early Paleogene into halotherme one took place in the middle Eocene. In the same time the notable climatic zonation appeared. In connection with the beginning of Antarctic glaciation and climatic cooling during the late Eocene and Oligocene existed mixed halotherme - thermohalinic circulation. Since the middle of Miocene the thermotypic circulation became increase.

RESUMEN: Se analiza la evolución del nannoplancton calcáreo paleógeno, especialmente sus cambios morfotípicos. Se estudia la relación $^{18}O/^{16}O$ en las conchas de foraminíferos planctónicos. Se obtienen conclusiones sobre cambios de temperatura del agua superficial y de salinidad y algunas características de la circulación superficial.

Parece que el cambio, desde la circulación principalmente halinotópica del Paleógeno inferior a la halotérmica, tuvo lugar en el Eoceno medio. En ese tiempo aparece una marcada zonación climática.

Coincidiendo con el comienzo de la glaciación antártica y el enfriamiento climático, durante el Eoceno superior y el Oligoceno, se dio una combinación de circulaciones halotérmica - termohalina.

Hacia la mitad del Mioceno se incrementa la circulación termotípica.

INTRODUCTION

Cenozoic evolution of nanno and microplankton closely connected with the development of oceanic circulation, namely: reformation of the current system, formation of new water masses together with complicating of oceanic climatic zonality.

The planktonic organisms have skeleton constructions allowing floating within optimal ecological nishes. One of the main skeleton function is adaptation to the drift in the water of different density. Skeleton "morphotypes" (their size, shape, form and structural peculiarities) are indicators of certain water masses. Also the oxygen isotopic composition of nanno and microfossils is indirectly connected with water density. Nannoflora provides paleoceanographic information concerning the upper euphotic water layer, while palnktonic microfauna gives information about upper (above pycnocline) and much deeper layers of the surface structural zone.
Study of morphotypes evolution within core sequences and the ^{18}O content of nannofossils and planktonic foraminifera tests have driven us to the following conclusions: 1) about variation in density, temperature and salinity of the surface water masses; 2) about vertical water structure; 3) about main characteristic features of oceanic circulation.

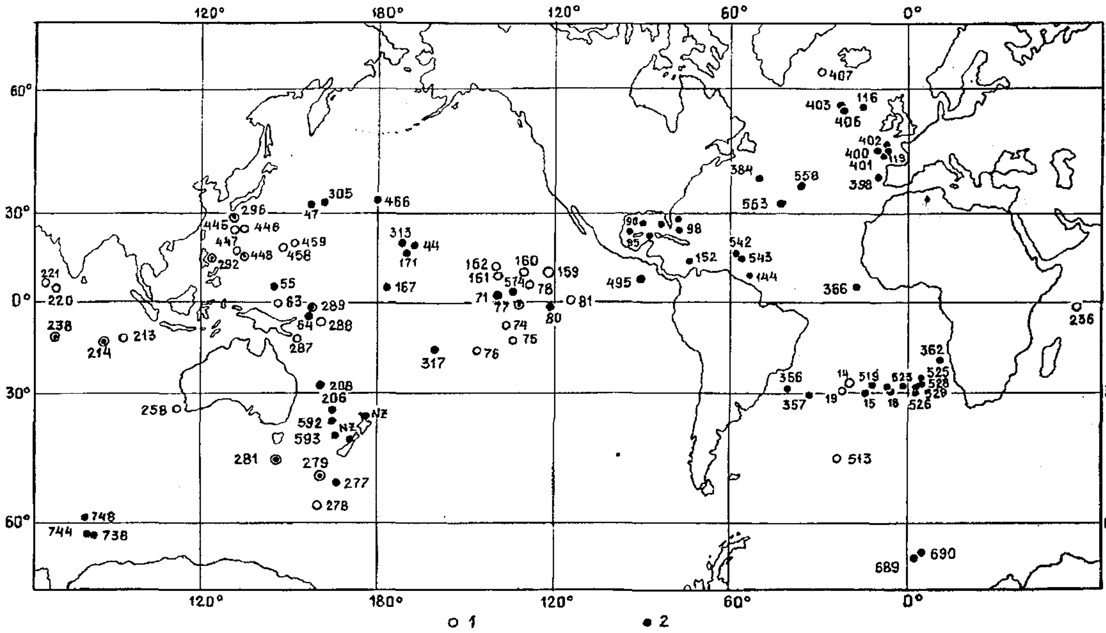

Fig. 1. Recent position of the DSDP and ODP Sites, for which were analyzed the nannoplanktonic and oxygen isotopic data.
1 - own $\delta^{18}O$ measurements; 2 - $\delta^{18}O$ data from the publications.

MATERIAL AND METHODS

Calcareous nannoplankton evolution was studied using the materials obtained during the Deep Sea drilling legs (fig. 1) and the scientific shipboard expeditions of the Institute of Oceanology RAN. We examined 236 Paleogene samples through a light and scanning microscopes (LISITZIN *et al.*, 1983). Beside that the lists of species and quantitative data arranged according to the geochronological subseries (nannoplankton scales by OKADA, 1980; BUKRY,1985 and PERCH-NIELSEN, 1985) from the JRDSDP and PODP volumes have been analyzed.

The following indicators of evolutionary changes were taken into account: the total abundance of nannoplankton, the species diversity and number of species, evolutionary activity (amount of appeared and extinct species), the main nannoplankton events and datum levels used for age control, the dominant morphotypes and their changes. Such peculiarities of nannofossils as a size, general form, mass and degree of calcification, specific surface value of nannoplankton species, their compactness or delicateness and some other features were examined in order to characterize morphotypes.

The morphological peculiarities of planktonic foraminifera tests dependent upon water density, characteristic of their morphotypes together with paleoceanographic and evolutionary interpretation were described in the previous publication (NIKOLAEV *et al.*, 1989).

In the waters of low density nannoplankton and planktonic foraminifera skeletons are usually thin and volumetrical. They have various construction that facilitate sculptural elements. In the waters of high density they have massive, compact, flat or cone-shaped forms with heavy sculptural elements. Large nannoplankton size and great specific surface value reveal relatively warm surface water. But massive and compact highly calcificated nannofossils indicate salinity growth.

Oxygen isotopic research of the early Miocene and Paleogene nannoplankton and planktonic foraminifers was conducted using 170 samples of biogeneous carbonates from 27 DSDP holes (fig. 1). In order analyse $^{18}O/^{16}O$ ratio of nannofossils and foraminifers two sorts of samples were used: 1) nannofossil ooze sediment and sometimes chalk (size fration <50 mk) with $CaCO_3$ preservation check (absence or minimum diagenetic alteration); 2) bulk sediments of nanno-foraminiferal ooze with approximate evaluation of weight contribution of nannofossils and planktonic foraminifera tests and detritus to total sediment composition. When it was possible nannoplankton species and their dominant morphotypes were determined for each sample. ^{18}O of planktonic foraminifera was analysed using juvenile forms (size fraction 50-100 mk), total complex (size fraction >100 mk) or monospecies samples. The species of different morphotypes were taken from the same sample. ^{18}O value measurements were conducted in the Laboratory of recent sediments of Geographical Department of Moscow State University. Numerous published isotopic data were analysed. All these data were interpreted according to our method (NIKOLAEV *et al.*, 1989). This method combines two models. One is the model of depth stratification of calcareous plankton (nannoplankton and foraminifera species) and the other is model of the Cenozoic oxygen isotopic changes of the World Ocean surface water masses, including glacial, latitudional and depth $^{18}O_w$ corrections.

We took into account the change of geographical position of the sites and determined their paleolatitudes according to palynspastic reconstructions (ZONENSHAIN *et al.*, 1984).

RESULTS AND DISCUSSION

Results of the calcareous nannoplankton evolution and nannofossil and foraminifera oxygen isotopic composition study are present in the table and figures 2-9. The data discription and possible interpretation are given below.

In *the early Paleocene* (Pg_1^1) nannoplankton was characterized by monotonous, relatively abundant assemblages which contained oppressed species (*Sphenolitus primius*). They resemble either recent coldwater near-Antarctic

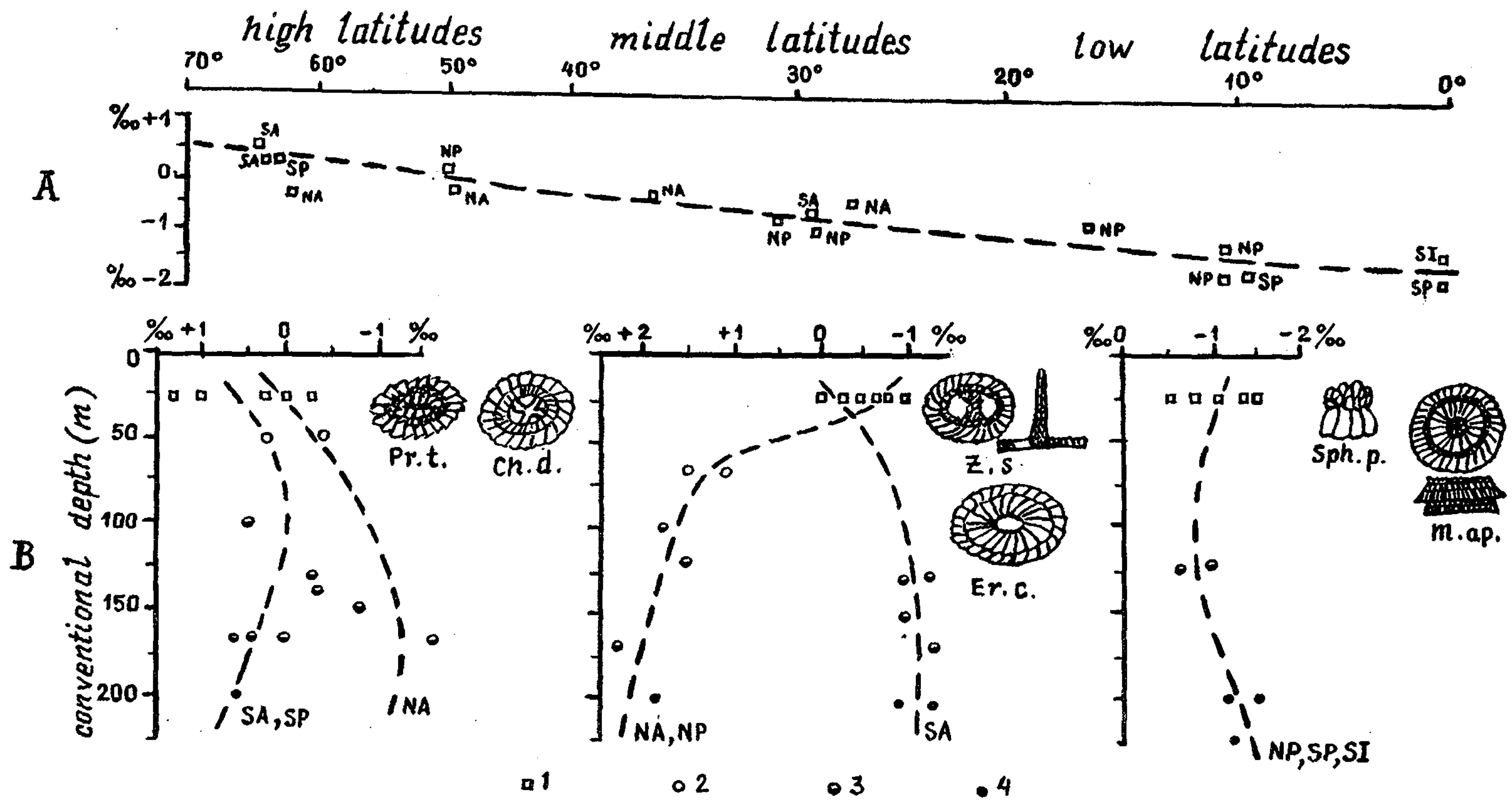

Fig. 2. The early Paleocene oxygen isotopic composition of nannofossils ($\delta^{18}O_n$) and planktonic foraminifers ($\delta^{18}O_f$): A - arranged according to the latitudes (latitudional profile); B - arranged according to the depth (vertical profiles).
1. Predominant morphotypes of nannofossils: *Prinsius tenuiculum (Pr.t.), Chiasmolithus danicus (Ch.d.), Sphenolithus primus (Sph.p.), Ericsonia cava (Er.c.), Zygodiscus sigmoides (Z.s.), Markalius apertus (M.ap.).*
2. Shallow- dwelling planktonic foraminifera: species of genera *Chiloguembellina, Globorotalia.*
3. Middle- dwelling planktonic foraminifera: species of *genera Eoglobigerina, Globigerina, Subbotina;* mixed planktonic foraminifera species.
4. Deep-dwelling planktonic foraminifera: species of *genera Subbotina, Acarinina, Morozovella, Globorotalia.* Regions: NA - North Atlantic, SA - South Atlantic, NP - North Pacific, SP - South Pacific, NI - North Indian, SI - South Indian.

nannoflora, or recent Black Sea one that existing in the waters of low salinity. The whole nannoplankton is represented by one morphotype: small low calcificated with not large specific surface value species of *Cruciplacolithus, Prinsius, Toweius* and *Sphenolithus* genera. These forms indicated relatively cool and not very salty waters. Only by the end of the Pg_1^1 in the near-equatorial region more flattened species with large specific surface (*Ericsonia cava, Chiasmolithus danicus*) appeared.

Oxygen isotopic composition of nannofossils ($\delta^{18}O_n$) varied from +1.3 to -0.3‰ in high latitudes and from -1.6 to -0.5‰ in low ones. Decrease of $\delta^{18}O_n$ values from the poles to the equator was gradual and even (fig. 2A). This phenomen demonstrates rather homogeneous humid conditions in the surface waters. More negative $\delta^{18}O_n$ values were noticed in the North Atlantic. Possibly they indicate narrowness of that part of the ocean at the beginning of Paleogene and powerful fresh water runoff from the surrounding continents. Slight "inversion" of isotopic composition of nannofossils ($\delta^{18}O_n$) and the same of planktonic foraminifers ($\delta^{18}O_f$) at all latitudes was observed. In contradistinction to present situation $\delta^{18}O$ of nannofossils was heavier than $\delta^{18}O$ of planktonic foraminifers, which lived deeper (fig. 2B). It can be explained by predominance of the Tethys isotopic-heavy waters in the uppermost surface water layer.

In *the late Paleocene* (Pg_1^2) small resembling the early Paleocene forms (*Sphenolithus primus, Prinsius sp., Neochiastozygus sp.*) predominated among nannoflora. The peculiarity of this evolutionary stage was development of massive, rough, strongly calcificated, relatively high forms (*Toweius, Heliolithus, Fasciculithus*). The largest rosett-shaped *Discoaster* (*D.multiradiatus, D.gemmius*) appeared for the first time. Dominant morphotype was represented by massive high calcificated forms. By the end of the Pg_1^2 degree of massivity and calcification of nannoplankton decreased and first thin delicate forms appeared. Paleocene - Eocene boundary marks the most distinct evolutionary border. Two thirds of Paleocene flora (*Markalius, Toweius, Ellipsolithus*) became extinct and large species of *Chiasmolithus, Discoaster* and *Coccolithus* evolved.

$\delta^{18}O_n$ varied in the Pg_1^2 from -0.5 to -1.6‰ (fig. 3A), but form of latitudinal profile (fig. 3B) differed greately from that of Pg_1^1. $\delta^{18}O_n$ was significantly heavier in the middle and low latitudes. This probably connected with Tethys closing which resulted in expansion of its isotopically heave waters into these latitudes. Late Paleocene "high-salinity" morphotypes of nannofossils and planktonic foraminifers contradicted with light oxygen isotopic composition of their $CaCO_3$, thus indicating most likely high water temperatures.

In the beginning of early Eocene (Pg_2^1) nannoplankton demonstrated great evolutionary activity. At that time new genera *Helicosphaera, Marthasterites,*

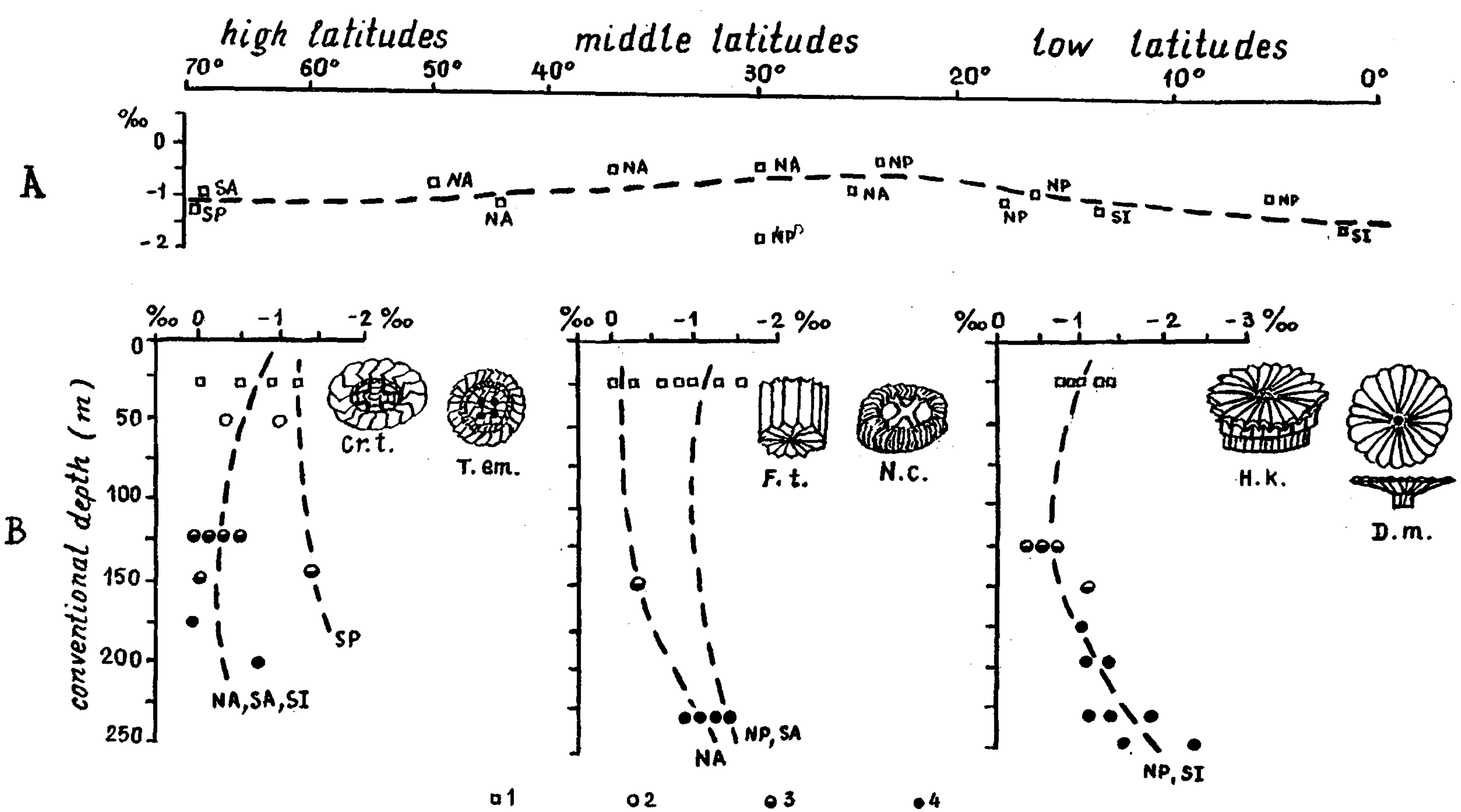

Fig. 3. $\delta^{18}O_n$ and $\delta^{18}O_f$ changes in the late Paleocene:
A - latitudional profile, B - vertical profiles.
1. Predominant morphotypes of nannofossils: *Toweius emineus (T.em.), Cruciplacolithus tenius (Cr.t.), Fasciculithus tympaniformis (F.t.), Neochiastozigus concinnus (N.c.), Heliolithus kleinpellii (H.k.), Discoaster multiradiatus (D.m.).*
2. Species of genus *Chiloguembellina.* 3. Species of genera *Subbotina, Globigerina, Globoanomalina*; mixed planktonic foraminifera species.
4. Species of genera *Acarinina, Subbotina, Globigerina, Morozovella*, mixed kieled species.

Reticulofenestra, Syracosphaera appeared. Uniform assemblages existed through the whole oceanic basin. *Coccolithus formosus, Discoaster lodoensis, D.robustus* predominated. Specific *Discoaster* with rare bent rays (*D.lodoensis*), three-rayed *Marthasterites* and *Sphenolithus* with apical thorns (*Sph.radians, Sph.conspicuus*) was the characteristic feature of this epoch. The main morphotype of nannoflora was represented by rather dense highly calcificated and very large forms of *Chiasmolithus* and *Coccolithus*. But new *Discoaster* species had ray-shaped form and not rosett-shaped like previous (Pg_1^2). Predominance of large, flat delicate nannofossils in the assemblages indicated relatively warm and less salty surface waters than before.

$\delta^{18}O_n$ changed from +0.6‰ in the middle latitudes up to -1.0 - 1.4‰ in the low and high ones (fig. 4A). So, $^{18}O_n$ - enrichment in the northern tropical area (35-15° N) was the same, as in Pg_1^2. Clear $\delta^{18}O_n$ and $\delta^{18}O_f$ inversion is marked in the Northern hemisphera also (fig. 4B).

Evolutionary activity, appearance and development of delicate ray forms with large specific surface and predominant light $\delta^{18}O_n$ values display of low salinity and high temperature of waters. According to numerous oxygen isotopic and paleofloristic data the global climatic optimum occured the end early Eocene and beginning of middle Eocene.

At the *middle Eocene* (Pg_2^2) significant renovation of nannoflora took place. *Reticulofenestra, Chiasmolithus* and *Sphenolithus* became predominant. At that time new genera such as *Pemma, Nannotetrina* appeared. Zonal subdivision of the previously uniform oceanic nannoflora took place. Large flat forms (*Coccolithus pelagicus, Chiasmolithus gigas, Discoaster kuepperi*) predominated in temperate regions. At the low latitudes large light forms (some species of *Reticulofenestra*) and various species of *Sphenolithus* with more stretched in apical direction shape developed. New species of *Discoaster* had less half-free rays. They were greater dissected and had more delicate skeletons than before.

$\delta^{18}O_n$ varied from +0.4 to -0.4‰ in the high latitudes, from +1.0 to 0.0‰ in the middle ones and was about -1,0‰ near the equator (fig. 5A). $\delta^{18}O_n$ latitudional profile was characterized by increase of ^{18}O - content within paleolatitudes of 20 - 30°≠ and its decrease in the equatorial zone. That $\delta^{18}O_n$ distribution indicated existence narrow arid middle latitudional region and humid low latitudional one in f Pg_2^2. Inversion of $\delta^{18}O_n$ and $\delta^{18}O_f$ is well displayed in the high latitudes and less displayed in the low ones (fig. 5B). This marks beginning of reformation of the oceanic surface circulation from mainly halinotypic (high-middle latitudes) to halotherme (low ones).

The *late Eocene* (Pg_2^3) and *early Oligocene* (Pg_3^2) represented the common evolutionary stage of nannoplankton development. Gradual impoverishment of

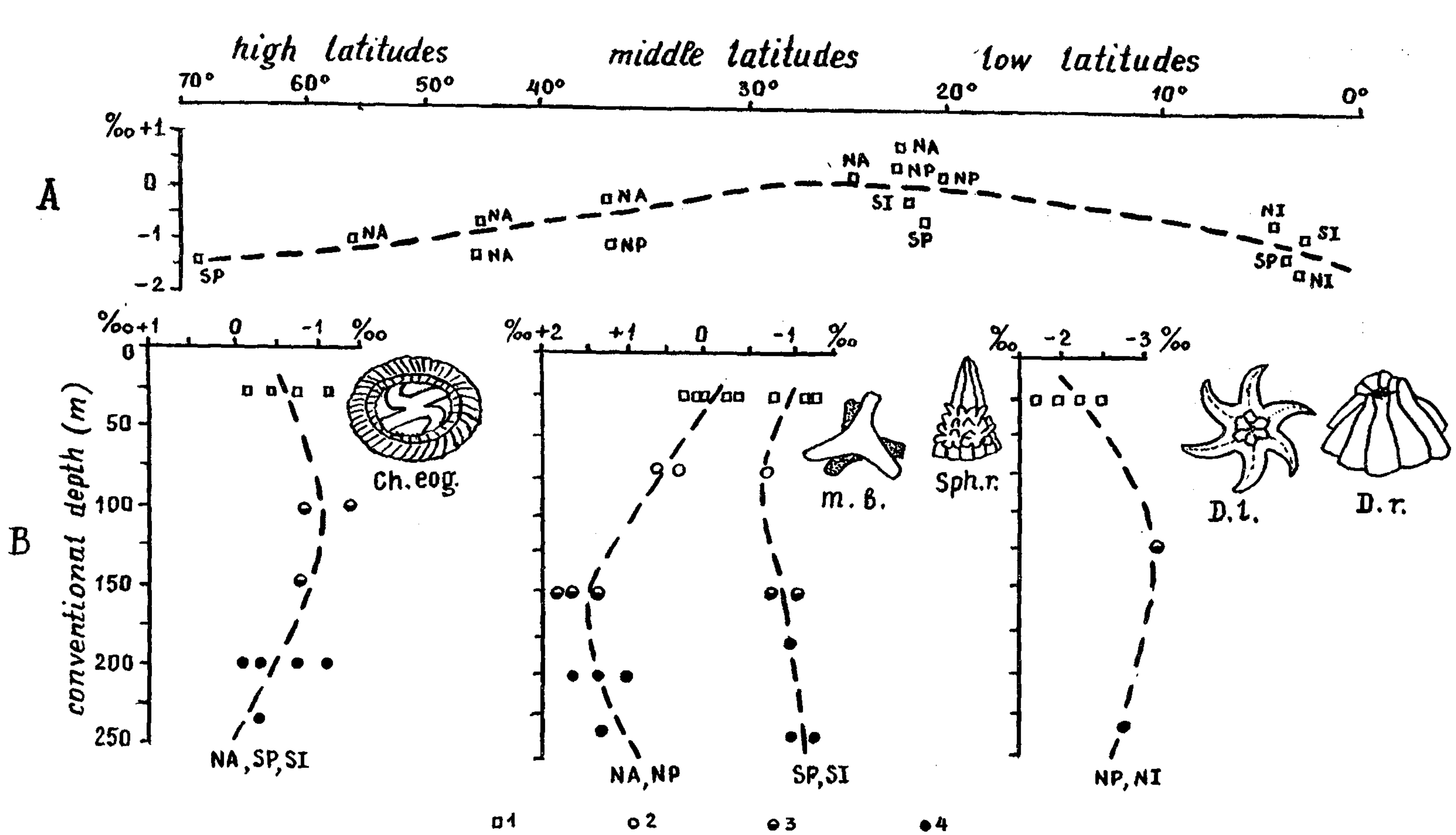

Fig. 4. $\delta^{18}O_n$ and $\delta^{18}O_f$ changes in the early Eocene:
A - latitudional profil; B - vertical profiles.

1. Predominant morphotypes of nannofossils: *Chiasmolithus eograndis* (Ch.eog.), *Mathasterites bramletti* (M.b.), *Sphenolithus radians* (Sph.r.), *Discoaster lodoensis* (D.l.), *D.robustus* (D.r.).
2. no $\delta^{18}O$ data.
3. Species of genus *Subbotina*; unkieled *Globorotalia*, mixed planktonic foraminifera species.
4. Species of genera *Subbotina, Acarinina, Morozovella, Globorotalia*; kieled *Globorotalia*.

assemblages, extinction of nearly all *Chiasmolithus* and some *Sphenolithus* forms went on. Evolutionary activity in Pg_2^3-Pg_3^1 - was low. New species (*Isthmolithus recurvus* and small thin *Chiasmolithus altus, Ch.oamaruensis*) appeared only in the southern high latitudes (notal zone). *Discoaster* became smaller than those of Pg_2^2 and had distinct six-five-rayed simmetry, that subsequently developed (in Neogene).

$\delta^{18}O_n$ values showed significant scattering: during Pg_2^3 (fig. 6A) in the high latitudes (from +1.0 up to -1.2%o) and in Pg_3^2 (fig. 7A) in the low latitudes (from +1.2 up to -1.6%o. That scattering marked unstable distribution of surface water masses in those regions, displaying reformation of oceanic circulation first (Pg_2^3) in the high latitudes and then (Pg_3^1) in the low ones. $\delta^{18}O_n$ latitudional profiles (fig. 6A, 7A) and $\delta^{18}O_n$-$\delta^{18}O_f$ vertical profiles (fig. 6B, 7B) show that the high latitude waters of the North Atlantic in Pg_2^3 were isotopically lighter than in the southern hemisphere. This indicates possible beginning of cooling in the subantarctic area. Formation of Antarctic surface water mass took place in Pg_3^1. This mass was marked by relative diminishing of $\delta^{18}O$ content in nannofossils near Antarctic, that was due to the influence of melted waters, and by specific "polar" type of vertical thermal stratification (STEPANOV, 1983; NIKOLAEV *et al.*, 1989), that first appeared most likely in Pg_2^3. Significant positive values of $\delta^{18}O_n$ indicate that widespread arid areas were formed in the northern middle latitudes in Pg_3^1 (fig. 7A). Only in the middle latitudes there was clear inversion between $\delta^{18}O_n$ and $\delta^{18}O_f$ in Pg_2^3 (fig. 6B). Inversion were in disorder in Pg_3^1 particulary within the low latitudes (fig. 7B).

In *late Oligocene* (Pg_3^2) and *early Miocene* (N_1^1), that were general stage of nannoplankton development, evolutionary activity increased in comparison with the previous stage. The number species of *Discoaster* and *Sphenolithus* extended in the low latitudes. *Discoaster* became slightly smaller and had no bulges on the rays. Long radicle apical thorns appeared in *Sphenolithus* (*Sph.distensus, Sph.ciperoensis*). Stick-shaped *Triquetrorabdulus* (*T.carinatus*) developed only at that time. Nannofossil morphotypes characterized by relatively small forms with facilitated sculptural elements (for example, bifurcation of prolonged apical thorns of *Sphenolithus* and development of distinct-raying *Discoaster*). Further evolution of morphotypes in Neogene included decrease of size, mass and degree of calcification of nannofossils. In subsequent period diminished of species variety took place.

In Pg_3^2 and N_1^1 $\delta^{18}O_n$ widely ranged from +1.3 to -1.9%o. Oxygen isotopic latitudional profiles (fig. 8A, 9A) were similar to early Oligocene one (fig. 7A). $^{18}O_n$-impoverishment was typical for the subpolar regions and low latutudes and $^{18}O_n$-enrichment for the middle ones. Significant negative $\delta^{18}O_n$ values in the equatorial area showed that the conditions seemed to be more humid than in N_1^1.

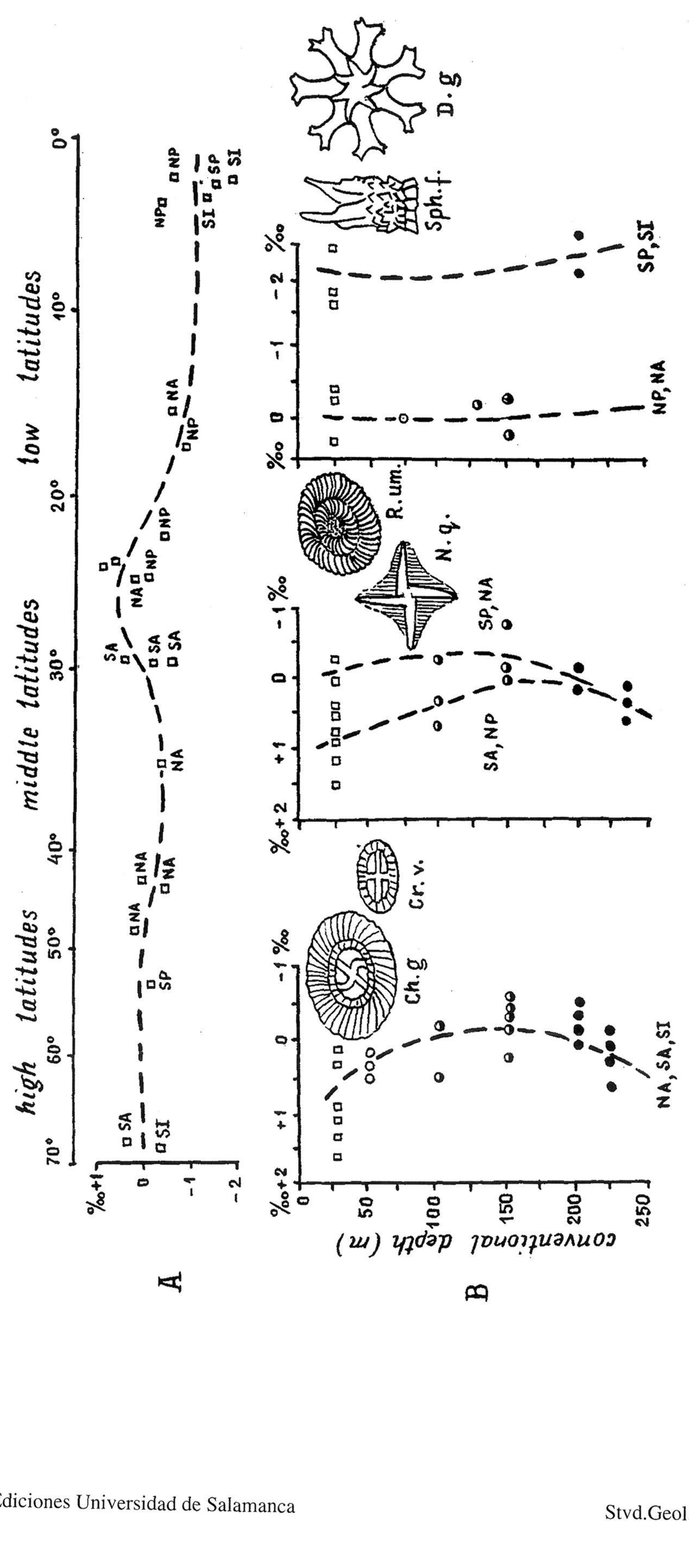

Fig. 5. $\delta^{18}O_n$ and $\delta^{18}O_f$ changes in the middle Eocene:
A - latitudional profile; B - vertical profiles.

1. Predominant morphotypes of nannofossils: *Ch.g.*), *Cruciplacolithus vanheckae* (*Cr.v.*), *Reticulofenestra umbilica* (*R.um.*), *Nannotetrina quadrata* (*N.q.*), *Sphenolithus furcatolithoides* (*Sph.f.*), *Discoaster gemmifer* (*D.g.*).
2. Species of genera *Chiloguembellina*, *Subbotina*, *Orbulinoides*; juvenile planktonic foraminifers.
3. Species of genera *Subbotina*, *Globigerina*, *Globigeapsis*: mixed planktonic foraminifera species.
4. Species of genera *Acarinina*, *Morozovella*.

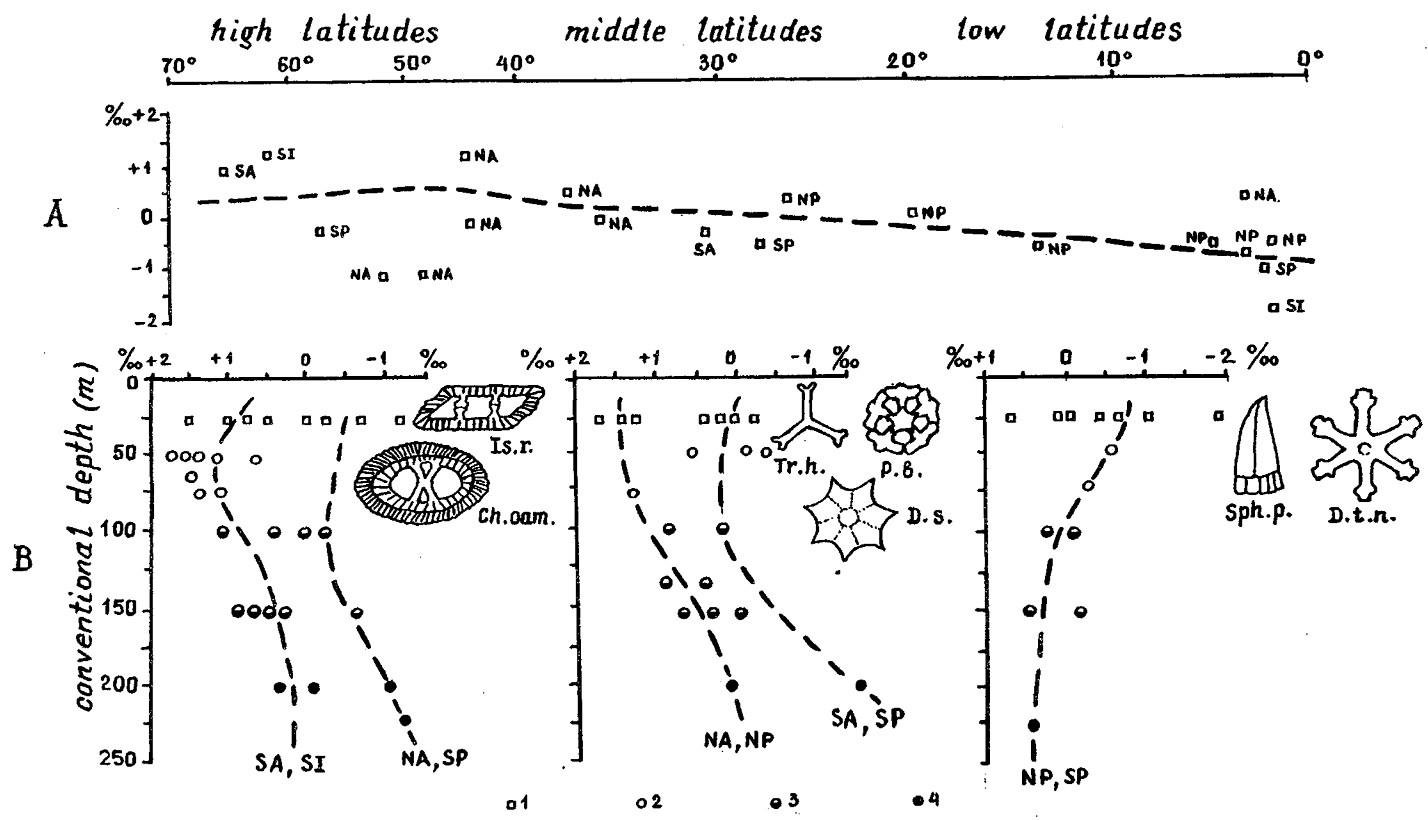

Fig. 6. $\delta^{18}O_n$ and $\delta^{18}O_f$ changes in the late Eocene:
A - latitudional profile; B - vertical profiles.
1. Predominant morphotypes of nannofossils: *Isthmolithus recurvus (Is.r.), Chiasmolithus oamaruensis (Ch.oam.), Trochasterites hornensis (Tr.h.), Pemma basquensis (P.b.), Discoaster saiponensis (D.s.), D.tani nodifer (D.t.n.), Sphenolithus predistentus (Sph.p.).*
2. Species of genera *Globigerina, Chiloguembellina, Globorotalloides, Subbotina, Pseudohastigerina, Globigerinatheka*; juvenile planktonic foraminifers.
3. Species of genera *Subbotina, Catapsidrax, Globigerina, Globigerapsis*; mixed planktonic foraminifera species.
4. Species of genus *Acarinina*.

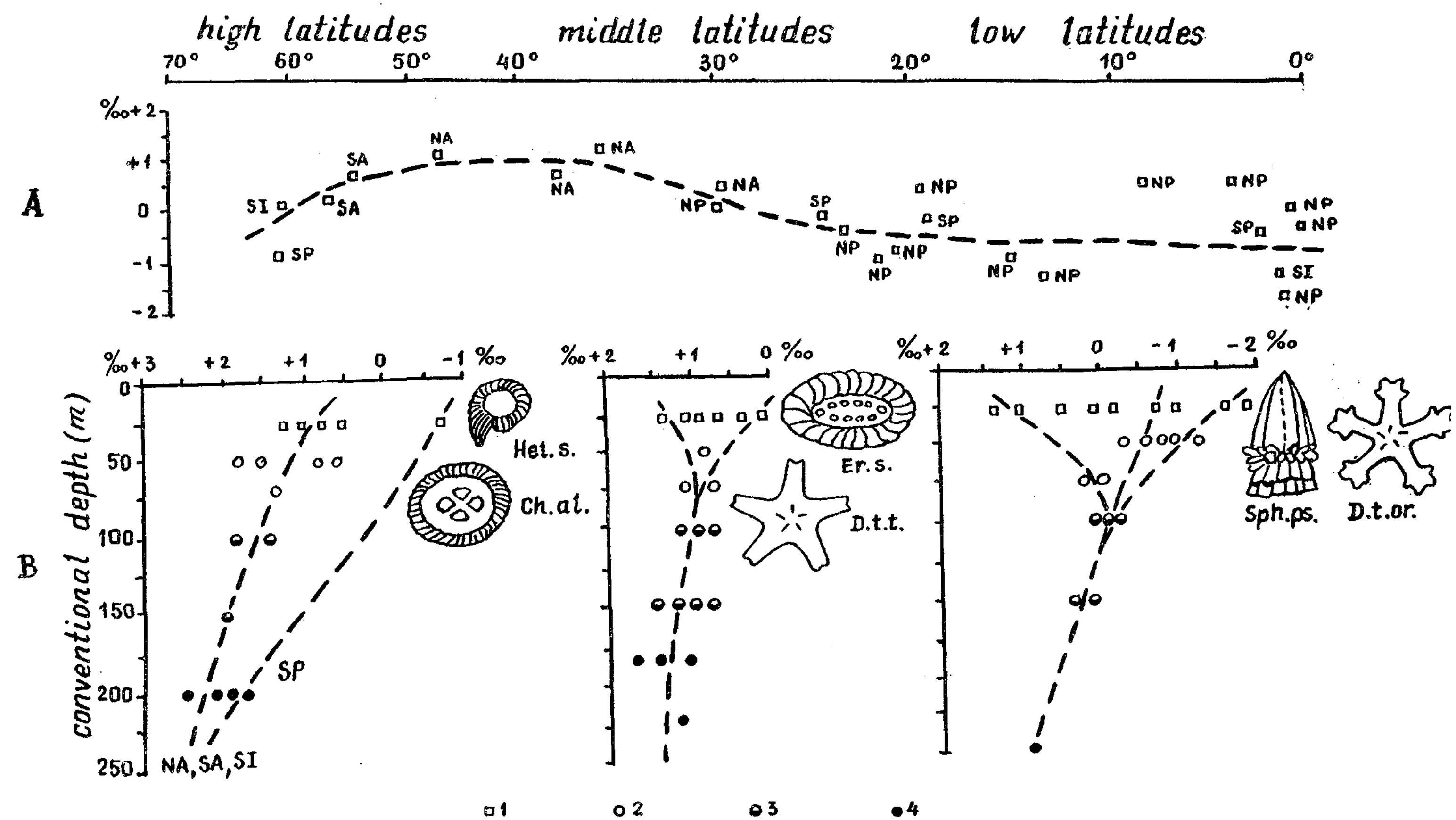

Fig. 7. $\delta^{18}O_n$ and $\neq\delta^{18}O_f$ changes in the early Oligocene:
A - latitudional profile, B - vertical profiles.

1. Predominant morphotypes of nannofossils: *Helicosphaera? subantarctica (Hel.? s.), Chiasmolithus altus (Ch.al.), Ericsonia subdisticha (Er.s.), Sphenolithus pseudoradians (Sph.ps.), Discoaster tani tani (D.t.t.), D.tani ornatus (D.t.or.).*
2. Species of genera *Chiloguembellina, Subbotina, Pseudohastigerina, Hanktenina, Globorotalloides*; juvenile planktonic foraminifers.
3. Species of genera *Globigerina, Catapsidrax, Subbotina*; mixed planktonic foraminifera species.
4. Species of genera *Globigerina, Turborotalia.*

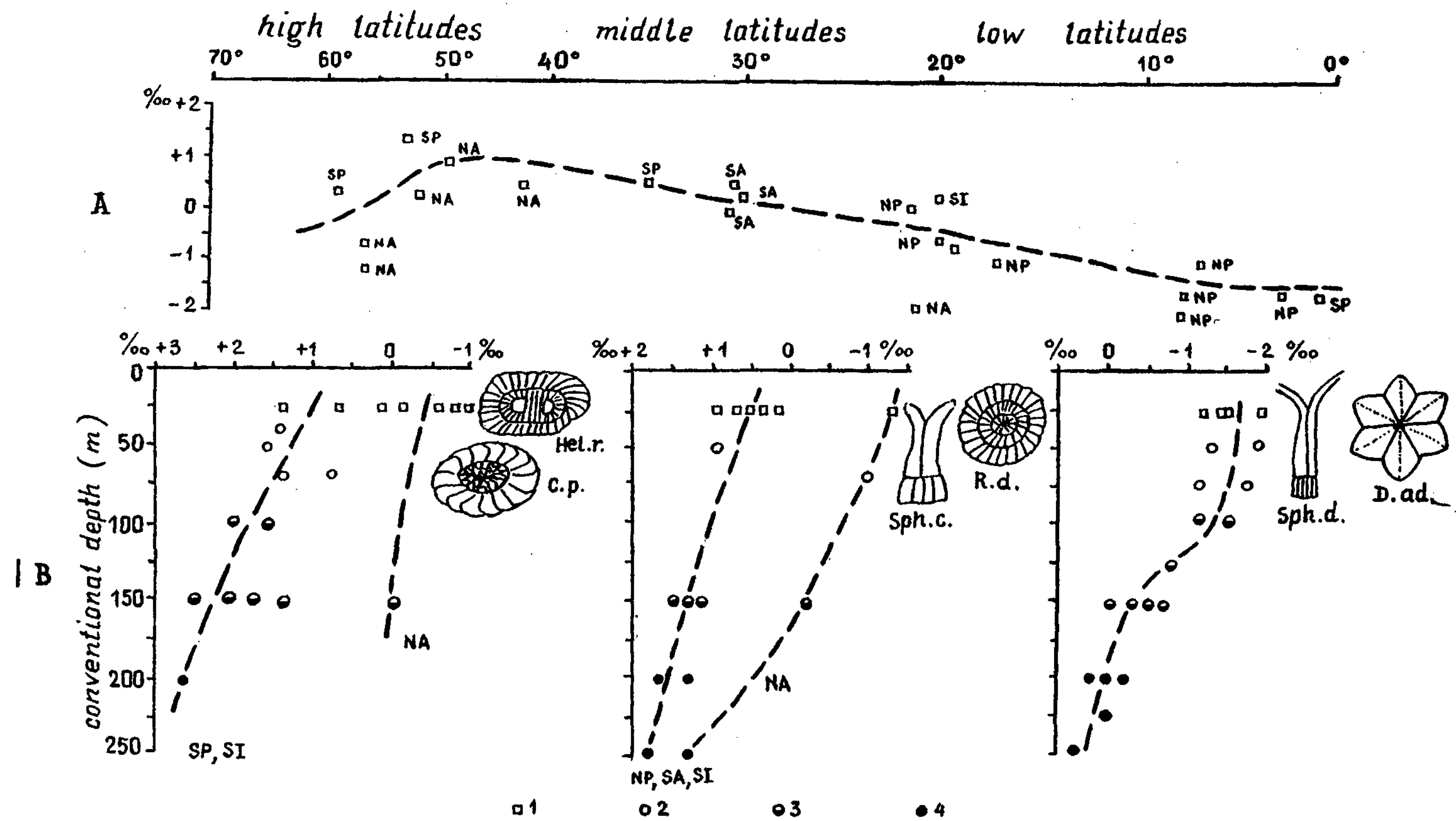

Fig. 8. $\delta^{18}O_n$ and $\delta^{18}O_n$ changes in the late Oligocene:
A - latitudional profile, B - vertical profiles.

1. Predominant morphotypes of nannofossils: *Helicosphaera recta (Hel.r.), Coccolithus pelagicus (C.p.), Reticulofenestra dictyoda (R.d.), Sphenolithus ciperoensis (Sph.c.), Sph.distentus (Sph.d.), Discoaster adamanteus (D.ad.).*
2. Species of genera *Chiloquembellina, Globigerinita, Globorotalloides, Subbotina, Cassigerinella*; juvenile planktonic foraminifers.
3. Species of genera *Subbotina, Globigerina, Catapsidrax, Globoquadrina*; mixed planktonic foraminifera species.
4. Species of genus *Turborotalia.*

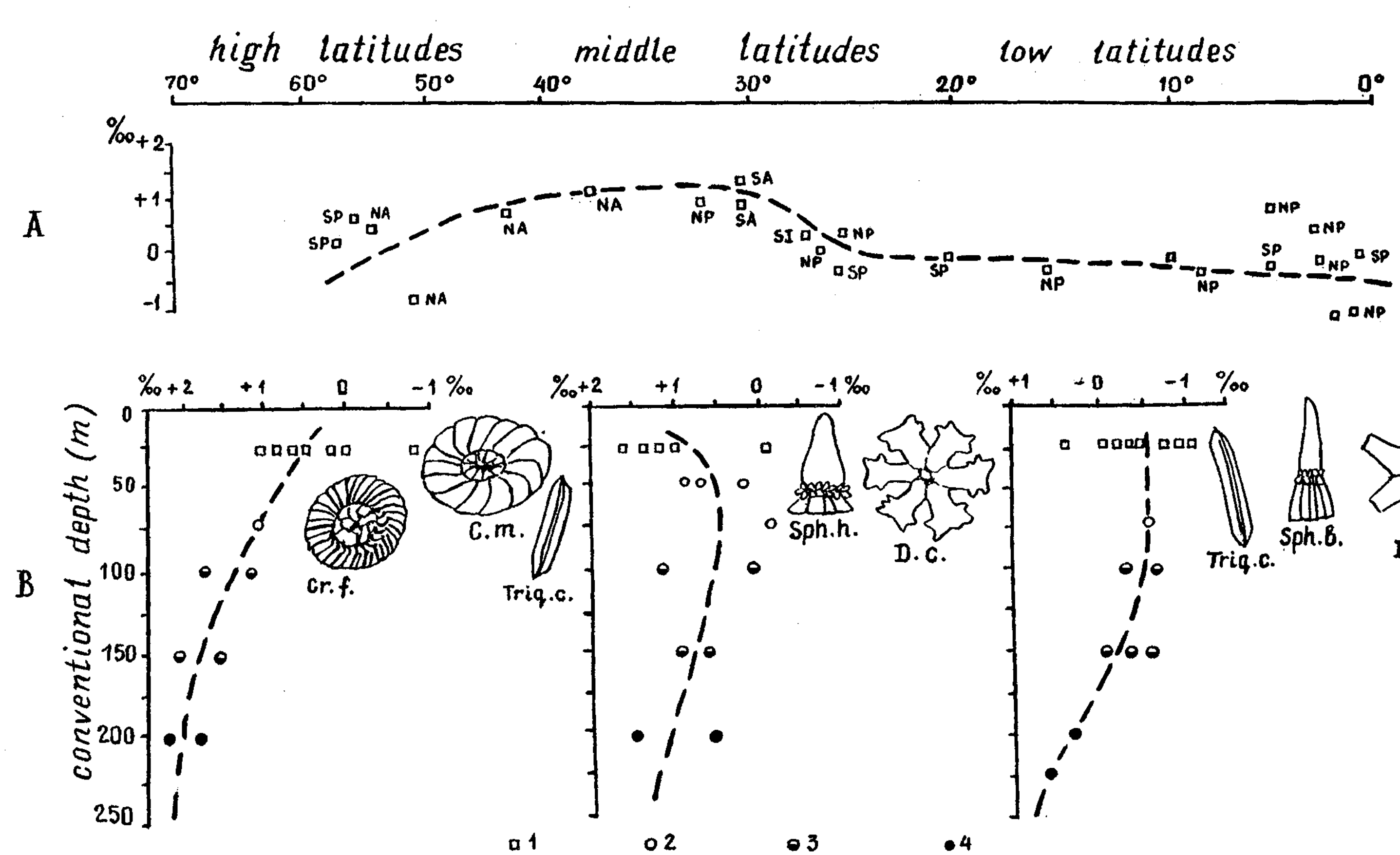

Fig. 9. $\delta^{18}O_n$ and $\delta^{18}O_f$ changes in the early Miocene:
A - latitudional profile, B - vertical profiles.
1. Predomonant morphotypes of nannofossils: *Coccolithus miopelagicus* (C.m.), *Cyclicargolithus floridanus* (Cyc.f.), *Sphenolithus heteromorphus* (Sph.h.), *Sph.belemnos* (Sph.b.), *Discoaster calculosus* (D.c.), *D.druggii* (D.d.), *Triquetrorabdulus carinatus* (Triq.c.).
2. Species of genera *Globigerinoides, Globigerina, Cassigerinella, Globorotalloides*; juvenile planktonic foraminifers.
3. Species of genera *Globigerina, Globoquadrina*, mixed planktonic foraminifera species.
4. Species of genus *Globorotalia, Turborotalia.*

$\delta^{18}O_n$-$\delta^{18}O_f$ vertical profiles for Pg_3^2 and N_1^1 (fig. 8B, 9B) were similar also. Isotopic inversion between nannofossils and planktonic foraminifers existed in the middle latitudes was typical for N_1^1. Probably this inversion can be explained by $\delta^{18}O$-content increase of the upper water layer due to intensive evaporation in these areas.

Single late Oligocene latitudional and vertical isotopic profiles drawn according to the $CaCO_3$ of planktonic microorganisms began to resemble Neogene ones with our paleotemperature interpretation (NIKOLAEV *et al.*, 1989). These profiles display the regions of downwelling of warm but isotopical-heavy (salty?)

Evolution stages	Epochs		Age (my)	Nannoplankton zones (Bukry, 1985)	Evolutionary activity	Abundance	Morphotypes	Nannoplankton events Principal datum-levels (Bukry, 1985)	Paleoceanographic conditions: Oxygen isotopic composition of nannofossils and planktonic foraminifers	Paleoceanographic conditions: Temperature and salinity of surface waters	Paleoceanographic conditions: General circulation
VI	MIOCENE	early	15	NN4	Relative increase of activity in the low latitudes	Common - abundant	Relatively small forms with facilitated sculptural elements	• LAD H.euphratis Distinct dirrerence of the high and low latitudional nannoflora.	Significant $^{18}O_n$ enrichment in the middle latitudes. Distinct $\delta^{18}O_n$ - $\delta^{18}O_f$ inversion only in the middle latitudes.	Temperature contrast between high and low latitudes increased (about 15°C). Arid conditions in the middle latitudes.	Thermohaline
			20	NN1				• FAD D.druggii Discoaster with prolonged rays. Last occurence of Chiasmolithus.			
	OLIGOCENE	late	25	NP25				• LAD D.bisectus Thin Sphenolithus with prolonged and bifurcated apical thorn.	Relatively negative $\delta^{18}O_n$ - values in all latitudes. Slight $^{18}O_n$ enrichment in the temperate regions. Beginning of noted production of subantarctic melf waters. No $\delta^{18}O_n$ - $\delta^{18}O_f$ inversion in all latitudes. Forming of "equatorial-tropical" type of vertical thermal stratification.	Distinct climatic zonality, temperatures changed from 10-12° C (subantarctica) to 23° (equator). Relatively humid conditions in the low latitudes.	
				NP24				• LAD S.distentus Appearance of Triquetrorabdulus.			
			30	NP23				• BAD S.ciperoensis			

Table. The development of Paleogene calcareous nannoplankton and paleoenvironment

V	OLIGOCENE EOCENE	early late	35 40	NP22 NP21 NP20 NP19 NP18	New species in the high latitudes. Cosmopolitic species was typical.	Impoverishment of nannoflora number	Low specialized and simple structural forms. Relatively low calcification.	5-6 raying Discoaster with bulges. Massive unlonged Sphenolithus. . LAD R.umbilica . LAD C.formosus Appearance of Isthmolithus . LAD D.saipanensis . FAD S.pseudoradians . FAD I.recurvus . FAD C.oamaruensis	Significant scattering of $\delta^{18}O_n$ in all latitudes. Gradual decrease of average values from poles to equator. Appearance of "polar" type of vertical thermal stratification near Antarctic. Scatering of $\delta^{18}O_n$ values especially in the low latitudes. Unstable $\delta^{18}O_n$ - $\delta^{18}O_f$ inversion in the middle and low latitudes.	Beginning of cooling and Antarctic glaciation. Forming of the ASW. Humid conditions in the low latitudes. Global cooling continued. Temperature gradient "pole-equator" about 10°C. Middle latitudional arid conditions.	Unstable mixed halothermal-thermohaline
IV	EOCENE	middle	45 50	NP17 NP16	Most high activity. Renovation of nannoflora.	Abundant	Large and flat forms in the high and low latitudes, relatively massive and compact shapes in the middle ones.	. LAD C.grandis Only there Nannotetrina. . LAD C.solitus Reticulofenestra was typical. Appearance of Pemma. Discoaster with half--free rays. Noted difference between nannoflora of high, middle and low latitudes.	More positive values of $\delta^{18}O_n$. Clear $^{18}O_n$ increase in the middle latitudes. $\delta^{18}O_n$ - $\delta^{18}O_f$ inversion in the high and middle latitudes.	Slight decrease of temperatures, relatively high salinity in the middle latitudes.	Halothermal
III	EOCENE	early	55	NP12 NP11		common	Less massive and first delicate forms, calcification decrease.	Discoaster with rare bent rays. Appearance of Helicosphaera, Marthasterites and Neococcolithus. . LAD T.orthostylus Beginning of Sphenolithus diversity, appearance of prolonged forms. . FAD D.lodoensis Two thirds of Paleocene nannoflora became extinct.	Great negative $\delta^{18}O_n$ values. Increase of ^{18}O content in the middle-low latitudional nannofossils. Clear inversion between $\delta^{18}O_n$ and $\delta^{18}O_f$ in the high and low latitudes.	Most high temperatures. Salinity came down a little. Climatic optimum at the early-middle Eocene boundary	Halothermal
II	PALEOCENE	late	60	NP9 NP8 NP5 NP4	High activity	Very abundant	Most massive large, great calcificated forms among small ones.	. LAD F.tympaniformis Development of massive rosett-shaped Discoaster. . FAD D.multiradiatus . FAD H.kleinpellii Toweius was typical. . FAD F.tympaniformis	Relatively negative $\delta^{18}O_n$ values. Slight $^{18}O_n$ enrichment in the middle latitudes.	High temperatures and most high salinity	Mainly halinotypic
I	PALEOCENE	early	65	NP2 NP1	Low activity	Abundant	Small oppressed low calcificated forms.	Appearance of Sphenolithus. Prinsius and Neochiastozygus was typical. . FAD C.danicus	Gradual decrease of $\delta^{18}O_n$ values from poles to equator. Inversion between $\delta^{18}O_n$ and $\delta^{18}O_f$ in the high latitudes and in the southern middle ones.	Relatively cool and low salinity surface waters	Probably halothermal

Table. The development of Paleogene calcareous nannoplankton and paleoenvironment (continued)

waters in the subtropical gyres and regions of upwelling of cold subsurface waters in the equatorial divergence zone. They show that Neogene-Quaternary thermohalinic circulation of the surface waters similar to recent one was formed in the middle of Oligocene. The thermotypic circulation began to strengthen since the middle of Miocene. Since the beginning of Cenozoic glaciation epoch (Pg_2^3 - Pg_3^1) permanent cooling started in high latitudes. According to our data (USHAKOVA & BLYUM, 1992; "Neogene-Quaternary paleoceanography...", 1989) in Neogene low latitudes gradually became warmer.

CONCLUSIONS

The results obtained allow detailing previous ideas on reformation of the total oceanic circulation in the Paleogene - early Neogene (NIKOLAEV *et al.*, 1987; KENNETt & STOTT, 1990).

Analysing the calcareous nannoplankton with regard to morphotype changes and considering $\delta^{18}O$ variation of nannofossils and foraminifers we arrive at following conclusions:

1) Relatively low salinity and cool waters of the early Paleocene ocean conversed into warm and high salinity waters of the late Paleocene. The first assumption confirmed by impoverished assemblages of minor nannoplankton forms at all latitudes and the second assumption - by appearance of warm-water massive *Discoaster*. Slight gradual $\delta^{18}O_n$ decrease from the poles to equator indicates the homogeneity of surface water masses that probably originated from the Tethys waters in the beginning of the Paleocene.

2) At the Paleocene-Eocene boundary the salinity came down a little (the nannoplankton calcification decrease and the beginning of delicate thin *Discoasters* and *Chiasmolithus*). "Pole-equator" temperature gradient in the early Eocene was probably the same as in the late Paleocene. But precipitation value in the high latitudes and near the equator increased in comparison to the late Paleocene (more negative $\neq^{18}O_n$ values in these regions).

3) In the middle Eocene notable climatic zonation appeared at the first time (different nannoplankton morphotypes in the high and low latitudes). Paleolatitudional and vertical profiles of $\delta^{18}O_n$ and $\delta^{18}O_f$ changes indicate the growth of temperature influence upon water circulation in comparison to the early Eocene. Since that the reformation from mainly halinotypic water circulation of the early Paleogene into the halotherme circulation of the Eocene started.

4) In the late Eocene and the early Oligocene the surface waters had similar conditions. It was the period of relatively frequent and contrast temperature and salinity changes of the World ocean waters. That is why this stage was characterized by low evolutionary activity of nannoplankton. The morphotypes well adapted to the changing environmental conditions (low specialized and simple structural forms) evolved. In high latitudes close to modern and steady thermohalinic surface circulation appeared together with the beginning of climatic cooling and Antarctic glacier growth (polar and subpolar types of vertical thermal stratification).

5) In the late Oligocene - early Miocene surface water circulation changed into thermohalinic one in the low latitudes. Subsurface cold water upwelling (tropical and equatorial-tropical types of vertical thermal structure) were formed. This resulted in narrowing of nannoplankton ecological niche in that regions. Some new morphotypes appeared there. This statment is confirmed by relatively poor and scanty assemblages and development of flat thin-rayed *Discoaster* and thinner *Sphenolithus*.

6) During the Neogene directed cooling of the high latitudes and warming of the low ones resulted in existence of mainly thermotypic water circulation patterns.

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BIBLIOGRAPHY

BUKRY, D. (1985): Numerical ages of Cenozoic biostratigraphic datum levels: Results of South Atlantic Leg73 drilling: Discussion and reply, *Geological Society of America Bulletin*, **96**: 813-815.

KENNETt, J.P. & STOTT, L.D. (1990): Proteus and Proto-Oceanus: ancestral Paleogene Oceans as revealed from Antarctic stable isotopic results, ODP Leg 113. *In* BARKER,P.F., KENNETt,J.P. *et al.*, Proc. ODP, Sci. Results, **113**: 865-880;

LISITZIN, A.P., LEVITAN, M.A., MUKHINA, V.V. & USHAKOVA,M.G. (1983): New finds of Pre-Quaternary deposits in the central part of the Indian Ocean, *Reports (Doklady) AN SSSR, Moscow,* **273 (6)**: 1446-1449.

NEOGENE-QUATERNARY PALEOCEANOGRAPHY ACCORDING TO MICROPALEONTOLOGICAL DATA, *(monograph.)*(1989): Barash, M.S. ed. "Nauka", Moscow.

NIKOLAEV, S.D., BLYUM, N.S. & NIKOLAEV, V.I. (1987): Temperature changes of the World Ocean surface water masses during the Eocene, *Reports (Doklady) AN SSSR, Moscow,* **297** (**4**): 967-969.

NIKOLAEV, S.D., BLYUM, N.S. & NIKOLAEV, V.I. (1989): Cenozoic paleogeography of the World Ocean and seas based on isotopic and micropaleontological data, *(monograph), Itogi nauki i tekhniki, seria paleogeographia*, **6**, VINITI, Moscow.

OKADA, H. & BUKRY, D., 1980: Supplementary modification and introduction of code number to the low-latitude Coccolith biostratigraphic zonation (Buckry, 1973; 1975), *Marine Micropaleontology,* **5**: 321-325.

PERCH-NIELSEN, K. (1985): Tertiary calcareous nannoplankton. *In* BOLLI, H.M., SAUNDERS, J.B. & PERCH-NIELSON, K.:, Plankton stratigraphy, *Cambridge Univ. Press. Cambridge*: 427-554.

RESULTS OF THE WORLD OCEAN DEEP SEA DRILLING, 1989: *Gramberg, J.S. ed., "Nedra", Leningrad.*

STEPANOV, V.N. (1983): Okeanosfera, *"Mysli", Moscow.*

USHAKOVA, M.G., BLYUM, N.S., 1992: Neogene-Quaternary climatic changes in the eastern tropical Pacific: Nannoplankton research, *2. Knihovniska zemniho plynu nafta, Hodonin,* **14 b**: 277-291.

ZONENSHAIN, L.P., SAVOSTIN, L.A. & SEDOV, A.P. (1984): Global paleogeodynamic reconstruction for the east 160 m.y., *Geotektonika, Moscow,* **3**: 3-16.
