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Palynological Characteristics of Miocene Deposits from the Submarine Yamato Rise (Sea of Japan)

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Four heterochronous spore and pollen complexes (SPC) have been identified in the deposits of the submarine Yamato Rise: SPC-1 (Early Miocene), SPC-2 (the end of Early and the beginning of the Middle Miocene), SPC-3 (Middle–Late Miocene), and SPC-4 (Late Miocene). Pollen of various woody plants dominates in SPC-1; the families of gymnosperms (Pinaceae) also prevail in this complex. The climate was moderate and humid because of the proximity to the water area. The complex SPC-2 differs from SPC-1 in the highly increased role of thermophile angiosperms due to the impact of the climatic optimum between the Early and Middle Miocene. The complex SPC-3 is distinguished by the diversity and predominance of broad-leaved woody plants. Gymnosperms are mainly represented by pine families. The composition of palynoflora points to a dissected relief and the burial of pollen not far from the places of its growth. Gymnosperms with a predominance of the Taxodiaceae family are characteristic of SPC-4. The SPC-4 composition is indicative of humid habitat conditions, marshy shoreland, and pollen burial in places of plants growth. The climate was moderate and humid. Palynological investigation suggests the existence of a dry land in the area of the current Yamato Rise throughout the Miocene. The relief was highly dissected and mountainous in the Early and early Middle Miocene; then, the relief roughness and firm-land area reduced dramatically.

Keywords: spore and pollen complex, Miocene, Yamato Rise, Sea of Japan

INTRODUCTION

The Sea of Japan is a marginal sea of the junction zone (JZ) from the Asian continent to the Pacific Ocean. The study of the sedimentary cover of the Far East seas is indispensable for solving the problems of geotectonics and the history of JZ formation. Despite exploration maturity of the Sea of Japan (Bersenev et al., 1987; Tamaki et al., 1992; Jolivet et al., 1994; Isezaki et al., 1996; Lelikov et al., 2007, 2008; and others), there exist a number of important questions and the answer to them could be found through a complex and detailed study of its key structures. One of such issues is the determination of the start of the sedimentation process and opening of deep-sea depressions. Since the duration of the Sea of Japan evolution is important for estimation of its sedimentary basin potential (raw hydrocarbon bearing deposits), the use of new data on the older Paleogene age of the Japan Basin (Ohguchi et al., 2005; Kano et al., 2007; Vashchenkova et al., 2011) gives evidence in favor of secondary stratigraphic studies.

The Yamato Rise is located in the center of the Sea of Japan and appears to be its biggest submarine high (Fig. 1). The rise is oval in shape, elongated to the northwest; it is 360 km long and 250 km wide. Its separate tops are at a depth less than 500 m (244, 283, 287 m), and it rises above the surrounding depressions seafloor at a height up to 2700 m. The rise consists of the North Yamato (Kita-Yamato) and South Yamato (Yamato) ridges separated by the Kita-Yamato Trough and the Takuyo elevation. The deep structure of the rise is similar to continental structures, but at the same time it is separated from the continent by deep-sea depressions (Vasil'ev et al., 1975; Vasil'kovskii et al., 1978; Isezaki et al., 1996). According to geophysical data, the basement outcrops at different depths. The bedded sedimentary Neogene formation lies on the complex heterogeneous basement consisting of pre-Cenozoic consolidated rocks and Cenozoic volcanics. The formation thickness ranges from 0 to 20 m within the basement outcropping between the ridges and reaches up to 1000 m in the Kita-Yamato Trough (Karp et al., 1987; Milanovskii et al., 1987; Barash et al., 2003).

The sedimentary strata mainly deposited between the basement uplifts (Tsoy et al, 1985; Bersenev, 1987). The most ancient sedimentary material gathered in the area of the Yamato Rise (well 302) is presented by zeolite-containing clays, argillites, volcanic silt shales and green tuffs (Karig and Ingle, 1975; Bersenev et al., 1987). The green tuffs are found at the deep-water platform of well 302. They are well correlated with the Lower Miocene green tuffs of northern Honshu underlying the strata of Neogene onshore (Daijima Formation)/offshore (Nishikurosawa Formation)

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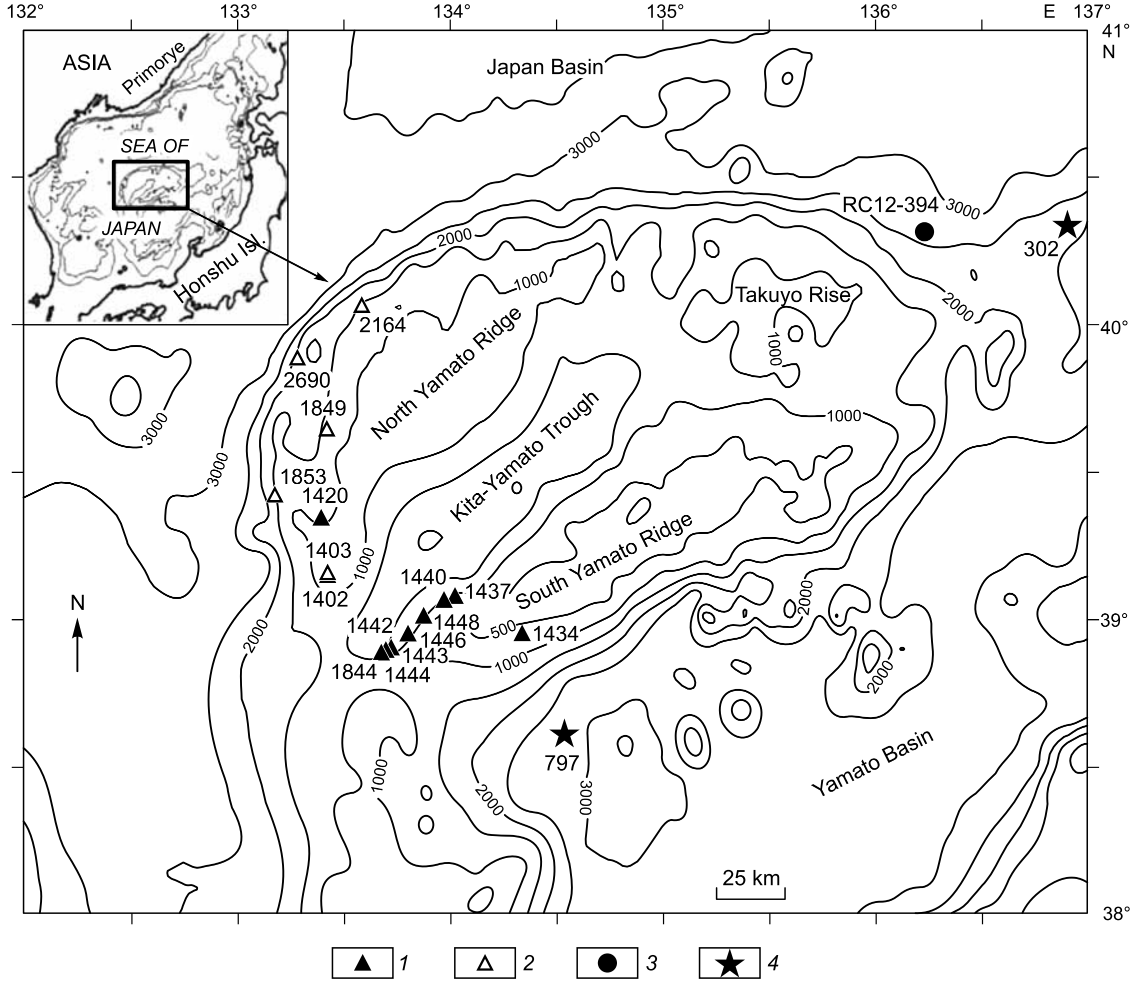


Fig. 1. Location of the identified dredging stations from the Yamato Rise in the Sea of Japan. *1*, stations with pollen-saturated samples; *2*, stations with the samples, where pollen is singular or not found; *3*, RC12-394 column with the detected Miocene palynocomplex (Burckle and Akiba, 1978); *4*, deep-water well 797 containing the determined palynozones (Yamanoi, 1992).

rocks, which are considered to begin the history of the Sea of Japan (Karig and Ingle, 1975; Isezaki et al., 1996). The most ancient deposits we studied are represented by the subaerial complex of tufogenic-sedimentary rocks dredged from the bedrock outcrops in the northwestern part of the South Yamato Ridge.

The first palynological investigations of the Yamato Rise were conducted by the Japanese researchers (Burckle and Akiba, 1978), who detected a Late Miocene spore and pollen complex (SPC) in the sedimentary deposits, which were reached with a RC 12-394 piston corer on the northeastern slope of the rise. Then, an Early Miocene SPC was extracted from sedimentary deposits in the southwestern part of the South Yamato Ridge (Tsoy et al., 1985; Gorovaya, 1987). Three SPCs obtained from the North Yamato Ridge were referred to the Middle Miocene, Late Miocene and Early Miocene (Barash et al., 1987, 2003). Unfortunately, the palynological information of these studies was presented without complete taxonomic composition and indicating the percentage of taxa participation, and also without illustrations that impedes the use of the data for correlation. Later, four palynozones (NP-1, NP-2, NP-3, NP-4) were identified in the deposits drilled in deep-sea wells 794–797 (127th and 128th cruises of the JOIDES Resolution research vessel in the Sea of Japan). These four palynozones cover the age interval from the Early Miocene to the early Pliocene (Yamanoi, 1992). We have used all the palynological data for comparative analyses of the SPCs found in the present study.

The main objective of the research was to obtain additional information on the age and formation conditions of the Yamato Rise sedimentary mantle in accord with palynological data. In this regard, the resampling was carried out, and the results were compared with the published palynological data. Analysis and integration of new data will supplement the findings of the previous research and give a rather comprehensive view on the structure and conditions of the sedimentary mantle formation, and on the geological history of the Yamato Rise and the Sea of Japan overall.

MATERIALS AND METHODS

The deposit samples dredged on the steep slopes of the Yamato Rise were obtained on cruises of the Pervenetz research vessel (1977, 1979) and used as material for the palynological studies. The samples are stored at V.I. Il'ichov Pacific Oceanological Institute, FEB RAS (Fig. 1). The samples were prepared for spore and pollen analysis in accord with the standard technique developed at the Palynological research laboratory of A.P. Karpinsky Russian Geological Research Institute (VSEGEI) (Pokrovskaya, 1966). The technique consists of the following stages: (1) decarbonation: carbonates are dissolved in slightly heated 10% HCl solution; (2) boiling in 10% KOH alkaline solution during 10 min for rock maceration; (3) centrifugation at a speed of 2500 rpm in heavy cadmium liquid ($CdJ_2 + KJ + H_2O$, sp. gr—2.6 g /cm^3) for humus separation; (4) washing of emerged organic particles to clean from the heavy liquid. Then glycerin is added, and the samples are prepared for microscopic observation.

The spore and pollen samples were studied with a LOMO Micmed 6 microscope at 600 times magnification and photographed using a DSM 510 digital camera. Then, the number of 250 grains of pollen and spores of the found taxa was counted per sample. Observations of the samples were continued to find undetected taxa. The percentage of each taxon participation was calculated from the total amount of the counted grains. Moreover, the percentage of pollen (gymnosperms and angiosperms) and spores participation was also calculated in relation to the total amount of counted grains. E.P. Boitsova's indices (1977) were used for interpretation of palynological data. Dominants: dominant/prevailing—40%, plentiful/abundant—20%; subdominants: many/great number—10–20%, prominent—5–10%; associate: a few/few—2–5%; singular—less than 2%. The inversion of paleoenvironment was carried out via ecological aspects interpretation of the SPC taxa. The data on diatoms and radiolarians in the studied deposits were considered for age determination (Isezaki et al., 1996; Tsoy et al., 2017a). The comparative analysis of palynological data on the adjacent areas was conducted, where the age was confirmed by sea fauna, palynoflora, and plant fragments (Yamanoi, 1989, 1992). E.D. Zaklinskaya's interpretation of the notions of spore and pollen complexes (SPC) and palynoflora (PF) is used for discussion of the material (Zaklinskaya and Laukhin, 1979; Nesterov, 1987). Hence, SPC is a taxonomic and quantitative composition of spores and pollen determined at examining the preparation of one sampling material of one species, and PF is fossil flora recovered through inversion of palynological data.

RESULTS AND DISCUSSION

Palynological analysis of ~ 50 samples from 21 stations (Fig. 1, Table 1) was carried out, where only 12 samples contained a sufficient amount of spores and pollen (Table 2). The remaining samples either contained a very small quantity of spores and pollen or palynomorphs were missing. Four sequential SPCs were identified as a result of the present studies.

Table 1. Dredging stations used on the submarine Yamato Rise in the Sea of Japan

Station	Latitude	Longitude	Depth, m
1402	39°08.5′	133°25.2′	1100–1000
1403	39°09.0′	133°25.3′	1100–1000
1420	39°20.5′	133°23.3′	1300–1200
1434	38°56.6′	134°10.6′	320–280
1437	39°03.0′	133°58.5′	1050–950
1439	39°03.5′	133°59.6′	1150–1100
1440	39°03.3′	133°59.0′	1260–1200
1442	38°53.7′	133°42.6′	1200–1100
1443	38°53.2′	133°42.6′	1400–1300
1444	38°53.0′	133°42.5′	1550–1450
1446	38°56.3′	133°48.2′	1260–1200
1448	38°59.8′	133°52.7′	1050–1000
1452	39°04.5′	134°01.5′	1230–1150
1832	39°04.6′	134°02.0′	1400–1300
1833	39°04.3′	134°01.3′	1300–1200
1842	38°53.0′	133°41.9′	1350–1250
1844	38°53.0′	133°40.5′	1500–1400
1849	39°33.3′	133°25.0′	1350–1250
1853	39°24.8′	133°10.3′	1380–1280
2164	40°03.5′	133°34.9′	1550–1400
2690	39°52.7′	133°16.9′	1400–1200

Spore and pollen complex 1 (Early Miocene). Spores and pollen were studied in 22 samples obtained from 7 stations at a depth of 1500–1000 m through dredging of the southern rocks on the northwestern slope of the South Yamato Ridge (Fig. 1). Predominantly fine-grained varieties of rocks are well saturated with spores and pollen (tuff clays, tuff diatomites, ash-stones; samples 1434-2, 1442-1t, 1443-2, 1444-5, 1446, 1448, 1448g, 1448-2a, 1844-4) (Table 2). Only a few or singular grains of pollen are detected in tuff sandstone and equigranular tuffites (Fig. 2).

SPC-1 features in domination and diversity of woody plants pollen. Their composition is distinguished by prevailing families of gymnosperms Pinaceae: *Picea* (*P.* sect. *Eupicea, P.* sect. *Omorica, Picea* sp.), *Tsuga* (*T. diversifolia* (Maxim.) Mast.*, T. canadensis* (L.) Carr.*, T. sieboldii* (L.) Carr.*, Tsuga* sp.*, Pinus* (*P.* subg. *Haploxylon, Pinus* subg. *Diploxylon, Pinus* sp.), a few *Abies* sp., singular *Cedrus* sp., *Podocarpus* sp., Taxodiaceae and Cupressaceae. *Ulmus* sp. is plentiful in the diversified composition of angiosperms; significant content of *Fagus* sp.is frequently detected. Taxa of Juglandaceae family (*Carya* sp.*, Juglans* sp.*, Pterocarya* sp.*, Platycarya* sp.) and of Betulaceae family (*Carpinus* sp., *Betula* sp., *Alnus* sp.*, Corylus* sp.) are more diversified, but small in numbers. Thermophilic *Elaeagnus* sp., *Liquidambar* sp. (deciduous, rare nondeciduous or semideciduous trees) and *Nyssa* sp., *Trapa comitantiboreales* Brutm are singular. Not plentiful cryptograms are represented by

Table 2. Taxonomic composition and quantitative ratios (%) of spore and pollen complexes from the submarine Yamato Rise in the Sea of Japan

Taxa	1434-2	1442-1t	1443 -2	1444 -5	1446	1448	1448 g	1448-2a	1844-4	1440	1420a	1437
Sporophytes	–	–	–	–	–	–	–	–	–	–	–	–
Dicksonia sp.	–	–	–	–	–	0.4	–	–	–	–	–	–
Lycopodium sp.	–	–	0.8	–	–	0.4	–	0.7	–	–	–	0.8
Polypodiaceae gen. indet.	0.8	1.8	–	4.6	2.1	2.2	1.4	2.2	1.2	0.7	–	0.8
Osmunda sp.	–	0.7	–	0.4	–	0.7	0.4	–	0.4	0.7	–	1.5
Lygodium japoniciforme Iv.	–	–	–	–	–	–	–	–	–	0.7	–	–
Ophioglossaceae	–	–	–	–	–	–	0.4	–	–	–	–	0.4
Leiotriletes sp.	–	–	–	0.4	–	0.4	0.4	0.7	0.4	–	–	–
Concavisporites sp.	–	–	–	0.4	–	0.4	–	–	–	–	–	0.4
Gymnosperms	–	–	–	–	–	–	–	–	–	–	–	–
Ephedra sp.	0.4	–	–	–	0.4	0.7	–	–	–	0.7	–	–
Pinaceae gen. indet.	4.3	10.7	11.7	–	–	–	–	–	4.0	0.7	6.0	–
Abies sp.	0.8	1.8	0.4	3.6	7.1	3.6	1.1	4.6	0.4	1.4	0.4	0.8
Tsuga spp.	19.7	1.2	0.4	11.8	12.1	9.6	8.5	7.9	0.4	1.7	3.3	3.4
Picea spp.	27.6	25.0	43.1	35.7	7.9	28.5	35.0	16.1	34.0	6.8	4.9	1.5
Picea sect. *Eupicea*	19.7	3.6	23.5	5.3	4.3	7.1	3.6	6.4	4.0	2.8	–	–
Picea sect. *Omorica*	9.4	–	0.8	4.6	1.4	0.4	2.0	0.7	–	2.1	–	1.5
Cedrus sp.	–	–	–	0.4	–	0.4	–	0.4	–	–	–	–
Pinus spp.	–	2.5	9.4	4.6	3.6	8.9	–	5.4	16.0	1.4	8.8	3.4
Pinus subg. *Haploxylon*	5.2	–	1.6		2.1	5.7	0.7	3.6	4.0	2.8	–	
Pinus subg. *Diploxylon*	2.3	–	1.2	0.4	3.6	1.4	5.0	0.7	4.0	2.1	–	8.9
Taxodiaceae gen. indet.	–	–	–	0.4	0.4	0.4	0.4	1.1	0.4	1.8	–	48.3
Taxodium sp.	–	–	–	–	–	–	–	–	–	–	0.8	5.9
Glyptostrobus sp.	–	–	–	–	–	–	–	–	–	1.4	–	0.4
Sciadopitys sp.	–	–	–	0.4	–	–	–	0.4	–	1.4	–	3.0
Cupressaceae gen. indet.	–	1.8	–	1.1	–	–	–	–	–	0.7	–	–
Angiosperms	–	–	–	–	–	–	–	–	–	–	–	–
Sparganium sp.	–	–	–	–	–	–	0.4	–	–	–	–	–
Liquidambar sp.	–	0.4	–	0.7	2.1	0.4	0.7	0.7	0.8	0.8	4.1	–
Ulmus sp.	3.2	2.8	4.3	7.1	26.1	11.1	20.3	19.6	12.8	3.6	13.0	1.5
Fagus spp.	0.4	1.1	1.2	2.8	3.6	4.5	7.1	9.3	3.2	14.3	12.6	–
Castanea sp.	–	–	–	–	–	–	–	–	–	4.6	–	–
Castanopsis sp.	–	–	–	–	–	–	–	–	–	1.8	–	–
Pasania sp.	–	–	–	–	–	–	–	–	–	3.5	–	–
Quercus (everigreen)	–	–	–	–	–	–	–	–	–	6.1	–	–
Quercus (deciduous)	–	0.4	–	0.7	0.7	0.7	–	1.4	0.4	16.0	7.3	3.7
Betula sp.	2.0	7.4	0.8	1.1	3.6	1.1	3.6	1.1	2.8	2.8	6.5	4.0
Alnus sp.	2.0	16.4	0.8	2.9	1.8	2.1	1.8	2.9	2.4	0.7	4.1	5.6
Carpinus sp.	–	0.4	–	1.1	0.7	1.1	–	3.6	1.2	2.2	8.1	0.4
Corylus sp.	–	0.7	–	0.4	0.4	0.4	–	1.1	–	1.4	1.2	0.4
Myrica sp.	–	0.7	–	0.4	–	0.4	0.4	–	–	–	–	–
Juglans sp.	1.6	7.4	–	2.1	6.4	2.1	2.5	3.6	1.6	2.8	5.6	0.4
Pterocarya sp.	–	–	–	–	1.1	–	–	0.4	0.4	0.7	–	–
Platycarya sp.	–	–	–	–	–	0.4	–	0.7	–	0.4	0.4	–
Carya spp.	–	2.1	–	1.4	7.1	1.4	1.1	3.6	2.0	4.6	12.2	–
Engelhardtia sp.	–	–	–	–	–	–	0.4	–	–	–	–	–
Chenopodiaceae gen. indet.	–	–	–	–	–	–	–	–	0.4	0.7	–	0.4
Ericales	0.4	–	–	0.4	–	0.7	–	–	0.8	0.4	–	–
Tilia sp.	0.4	3.6	–	4.2	1.1	–	0.7	1.1	0.8	1.4	0.8	0.4

(*continued on next page*)

Table 2 (*continued*)

Taxa	1434-2	1442-1t	1443-2	1444-5	1446	1448	1448 g	1448-2a	1844-4	1440	1420a	1437
Trapa comitantiborealis Brutm.	–	–	–	–	–	0.4	–	–	0.4	–	–	–
Acer sp.	–	–	–	–	–	–	–	–	–	0.4	–	–
Nyssa sp.	–	–	–	–	–	–	–	0.4	–	–	–	–
Oleaceae gen. indet	–	–	–	–	–	–	–	–	0.4	0.4	–	–
Diervilla sp.	–	7.4		0.4		–	–	–	–	–	–	–
Lonicera sp.	–	–	–	–	–	0.4	–	–	–	–	–	–
Elaeagnus sp.	–	–	–	–	–	1.1	–	–	–	–	–	0.4
Ilex sp.	–	–	–	–	–	–	–	–	0.4	0.4	–	–
Artemisia sp.	–	–	–	–	–	–	–	–	–	0.4	–	1.5
Cyperaceae gen. indet.	–	–	–	–	–	–	–	–	–	–	–	0.4
Triatriopollenites sp.	–	–	–	–	–	0.4	1.4	0.7	0.4	–	–	–
Gymnosperms	89.4	46.6	92.1	68.7	42.9	66.7	56.3	46.2	67.2	31.2	24.2	77.4
Angiosperms	10.0	50.8	7.1	25.7	54.7	28.7	41.1	50.2	30.8	67.0	75.9	19.1
Sporophytes	0.8	2.5	0.8	5.7	2.5	4.5	2.6	3.6	2.0	2.1	–	3.5

ferns—Polypodiaceae*,* *Osmunda* sp*.,* *Dicksonia* sp. and moss—*Lycopodium* sp. A singular taxon of *Orbiculapollis* (characteristic of Maastrichtian–Paleocene) was found in one of the samples (1448) that indicates erosion of nearby Cretaceous–Paleocene deposits (Phototable 1). Due to domination of *pine* species among gymnosperms and *elm* in composition of angiosperms, SPC-1 from the South Yamato Ridge is compared with the SPC of Lower Miocene deposits of the Fakuyama age. Its composition is associated with moderate, moderately cold macroflora of Aniai-type (Sato, 1963); Early Miocene palynoflora and paleoflora of the upper strata of the Monzen formation deposits from Oga Peninsula of North Honshu (Huzioka, 1964; Wang and Yamanoi, 1996); the Early Miocene SPC of NP-1 zone (Aniai-type flora) determined in the deposits of Japan's coastal areas drilled through deep-water well 797 in the Yamato depression (Yamanoi, 1992). The main difference of the compared SPCs lies in the fact that both *Ulmus* sp. and *Carya* sp. tend to dominate among angiosperms in the Early Miocene spore and pollen complexes, and *Carya* subdominates in the SPC from the South Yamato Ridge. However, the content of *Carya* reaches considerable quantities in some samples.

The SPC identified from the deposits of the Ullyn Plateau of the Sea of Japan is considered to be the most approximated to SPC-1 (Tsoy et al., 2017b). Their similar taxonomic composition, domination of gymnosperms (up to 80%) over angiosperms (up to 40%) and spores (up to 6%) make them closer to each other. Pines are plentiful in the gymnosperms composition of the compared SPCs, but elms are abundant in the composition of angiosperms. The described complex has similar composition and common taxa with the Early Miocene SPC of the argillite foundation on the coastal continental slope (Isezaki et al., 1996; Vashchenkova et al., 2009). Palynoflora of the South Yamato Ridge differs from that of the coastline by a great taxonomic diversity and by a great quantity of thermophile representatives in the composition of Fagaceae, Juglandaceae families and others.

Freshwater diatomic flora (Fig. 2) was found in the same samples containing SPC-1 that points at continental origin of these rocks. Consequently, the area of the South Yamato Ridge was likely to represent island or semi-island dry land with freshwater basins in the Early Miocene (Tsoy et al., 1985; Isezaki et al., 1996; Tsoy and Shastina, 1999; Tsoy, 2017).

The occurrence of taxa with diversified ecology in the composition of the SPC-1 palynoflora (i.e., foreshore-marshy—common bald cypress; valley-growing—elm, wing nut, alder; slope-growing—fir, walnut, beech and others; high-altitude—pine, hemlock, podocarpus, birch; hydrophytes—water chestnut) is indicative of an altitudinal sequence of the plant cover (from coastal to mountainous), and dissected terrain. The occurrence of water chestnut pollen points at the presence of fresh-water basins. The given palynoflora composition is mainly represented by the taxa of present-time plants growing in conditions of the moderate and humid climate of Southwestern Asia (Wolfe, 1979). This is a good reason to assume that in the Early Miocene time when the formation of the sedimentary rock sequence occurred, the climate was humid and moderate because of proximity to the water area.

Spore and pollen complex 2 (end of the Early and beginning of the Middle Miocene). SPC-2 was determined in 2 aleuropelite samples from the southwestern part of the South Yamato Ridge (st. 1440, at a depth of 1260–1200 m). Taxonomic diversity and angiosperms pollen domination (66%) are characteristic of SPC-2. The role of thermophile broad-leaved plants is predominant in this composition. There are numerous various genera and species among them: *Fagus* and *Quercus* (nondeciduous and deciduous species), dominating quantity of *Castanea* sp*., Castanopsis* sp*., Pasania* sp. and *Carya* spp., very few *Liquidambar* sp*., Myrica* sp*., Juglans* sp*., Pterocarya* sp*., Platycarya* sp. Their associates are various moderate and moderately thermophile taxa: *Ulmus* sp., Betulaceae (*Betula* sp*., Alnus* sp*., Carpinus*

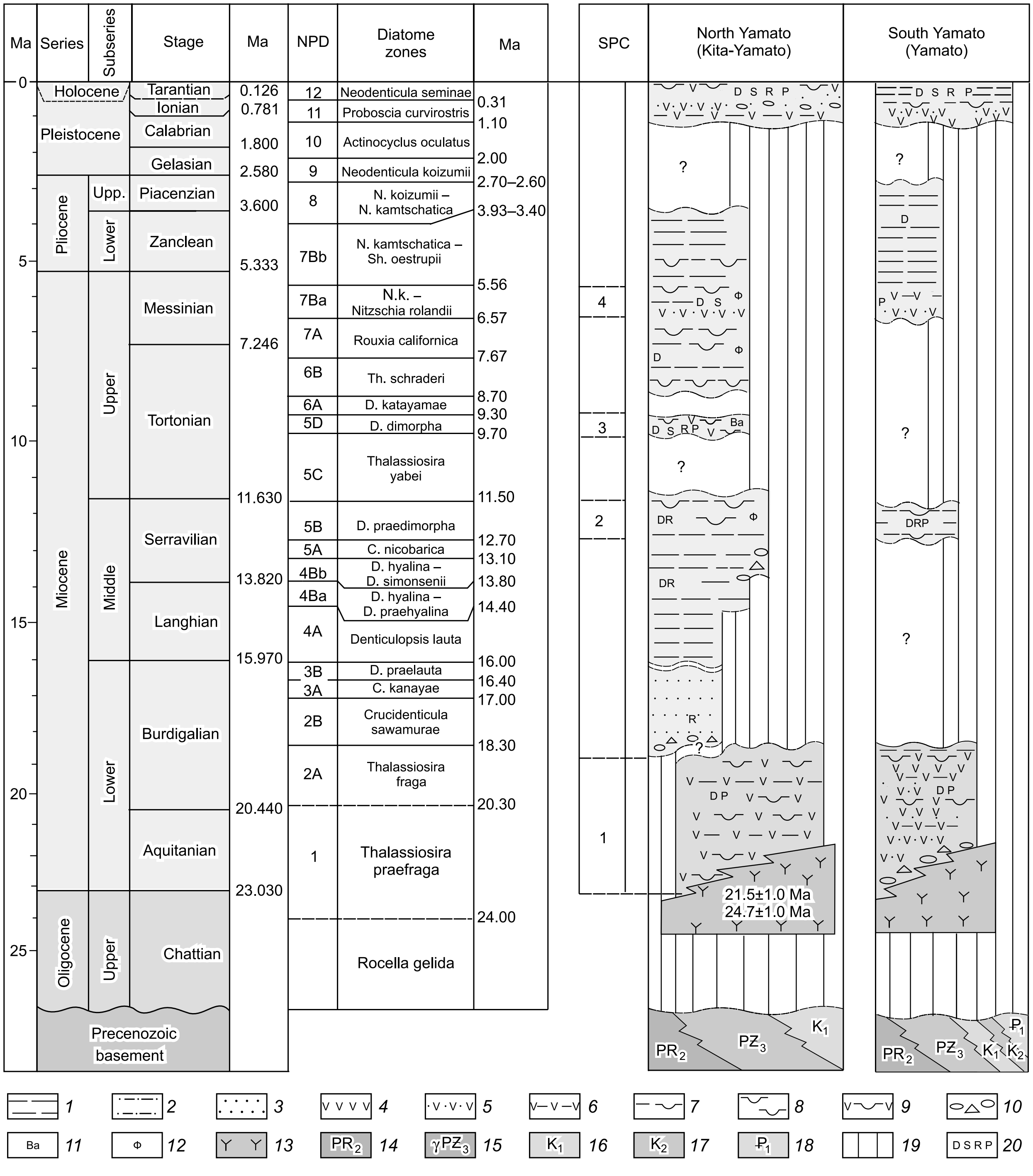
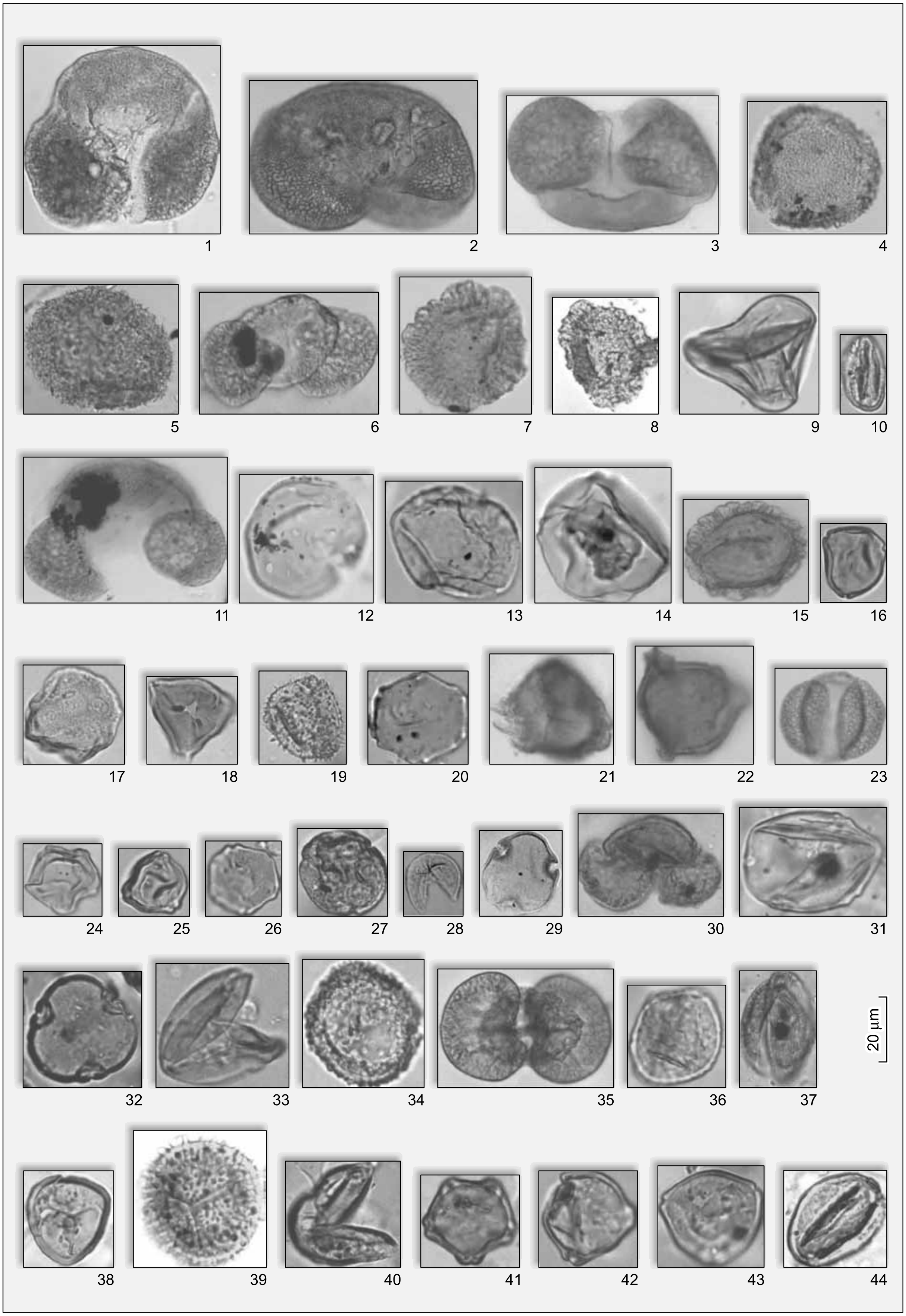


Fig. 2. Sedimentary mantle stratigraphy diagram of the Yamato Rise in the Sea of Japan, according to (Tsoy et al., 2017a), revised and supplemented. *1*, siltstones, silt-rich mudstones, clays; *2*, silty sandstones; *3*, sandstones; *4*, tuffites; *5*, tuff sandstones; *6*, tuff siltstones, tufogenic clays, tuffaceous argillite; *7*, diatomaceous shale; *8*, diatomite; *9*, tuff-diatomite; *10,* tuff conglomerates, gravel-stones; *11*, barite nodules; *12*, phosphorites, phosphatized rocks; *13*, vulcanite of trachyandesite complex in the late Oligocene–Early Miocene; *14*, late Proterozoic amphibolite, gneisses; *15*, late Paleozoic granitoids; *16*, Lower Cretaceous sandstones; *17*, Upper Cretaceous volcanics; *18*, Paleocene silt-rich mudstone; *19*, supposed nonconformities; *20*, micropaleontological groups found in the complexes of sedimentary rocks: D, diatoms; S, silicoflagellates; R, radiolarians; P, spores and pollen. NPD, code number of the Northern Pacific diatom zones (Yanagisawa and Akiba, 1998); SPC, spore and pollen complex.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Phototable 1. Spores and pollen of SPC-1 and SPC-2 from the submarine Yamato Rise in the Sea of Japan. 1, *Picea* sect. *Eupicea* (sample 1844-4); 2, *Picea* sect. *Omorica* sample (1434-2); 3, *Picea* sect. *Eupicea* (sample 1434-2); 4, *Tsuga canadensis* (L.) Carr. (sample 1434-2); 5, *Tsuga sieboldii* (L.) Carr. (sample 1434-2); 6, *Pinus* subg. *Diploxylon* (sample 1446); 7, *Tsuga* sp. (sample 1434-2); 8, *Tsuga parva* Brutm. (sample 1446); 9, *Leiotriletes* sp. (sample 1448-g); 10, *Quercus* sp. (sample 1448-g); 11, *Abies* sp. (sample 1446); 12, *Carya* sp. (sample 1446); 13, *Ulmus* sp. (sample 1446); 14, *Carpinus* sp. (sample 1448-g); 15, *Tsuga diversifolia* (Maxim) Mast. (sample 1434-2); 16, *Corylus* sp. (sample 1442-1t); 17, *Liquidambar* sp. (sample 1448-g); 18, *Elaeagnus* sp. (sample 1448-g); 19, *Diervilla* sp. (sample 1442-1t); 20, *Pterocarya* sp. (sample 1446); 21, *Trapa comitantiboreales* Brutm. (sample 1448-g); 22, *Orbiculapollis* sp. (sample 1448-g); 23, *Pinus* subg. *Haploxylon* (sample 1434-2); 24, *Alnus* sp. (sample 1442-1t); 25, *Betula* sp. (sample 1442-1t); 26, *Juglans* sp. (sample 1442-1t); 27, *Fagus* sp. (sample 1448-g); 28, Cupressaceae gen. indet. (sample 1442-1t); 29, *Tilia* sp. (sample 1444-5); 30, *Pinus* subg. *Diploxylon* (sample 1440); 31, *Carpinus* sp. (sample 1440); 32, *Tilia* sp. (sample 1440); 33, *Glyptostrobus* sp. (sample 1440); 34, *Sciadopitys* sp. (sample 1440); 35, *Podocarpus* sp. (sample 1440); 36, *Ulmus* sp. (sample 1440); 37, *Acer* sp. (sample 1440); 38, *Sphagnum* sp. (sample 1440); 39, *Osmunda* sp. (sample 1440); 40, Taxodiaceae gen. indet. (sample 1440); 41, *Alnus* sp. (sample 1440); 42, *Betula* sp. (sample 1440); 43, *Corylus* sp. (sample 1440); 44, *Quercus* (deciduous type) (sample 1440).

sp., *Corylus* sp.), *Tilia* sp., Oleaceae gen. indet., *Ilex* sp., Chenopodiaceae gen. indet., *Ericales* sp., *Artemisia* sp., *Nuphar* sp. Different species of tsuga are among gymnosperms (31%) actively participating in the SPC (*Tsuga diversifolia, T. canadensis, T. sieboldii*) and fewer species—*Picea* spp., *Pinus* sp., *Abies* sp., Taxodiaceae gen. indet., *Sciadopitys* sp., *Glyptostrobus* sp., *Podocarpus* sp. and *Ephedra* sp. Participance of sporophytes is insignificant: Polypodiaceae gen. indet., *Osmunda* sp., *Sphagnum* sp. and *Leiotriletes* sp. Accordingly, SPC-2 differs from SPC-1 by considerable increase in the role of thermophile angiosperms, such as *Fagus*, nondeciduous *Quercus, Castanea, Castanopsis, Pasania, Carya* and *Liquidambar* (Phototable 1, 2).

SPC-2 is well compared with the SPC of the NP-2 palynozone by the quantitative and taxonomic composition which should be a reflection of the climatic optimum at the end of the Early and the beginning of the Middle Miocene (Daijma type flora) and observed in the Miocene deposits of the coastal areas of NW Japan, the Niigata oil fields, the Oga Peninsula and other regions of Japan (Fuji and Kawai, 1982; Takahashi, 1984; Wang and Yamanoi, 1996), and also in deep-sea wells 794, 797 within the area of the Yamato depression in the Sea of Japan (Yamanoi, 1992). The Japanese Early–Middle Miocene palynoflora of SPC-2 is distinguished by a considerable quantity of *Carya* and *Liquidambar*, which are typical of the climatic optimum (Yamanoi, 1978, 1989; Takahashi, 1984) and referred to the group of subdominants, as in our case. It could be explained by the fact that the explored area is located to the north of Japan. The complexes, which reflect the conditions of the Miocene climatic optimum, were determined on the continental slope of the Peter the Great Bay (Isezaki et al., 1996; Tsoy and Vagina, 2008).

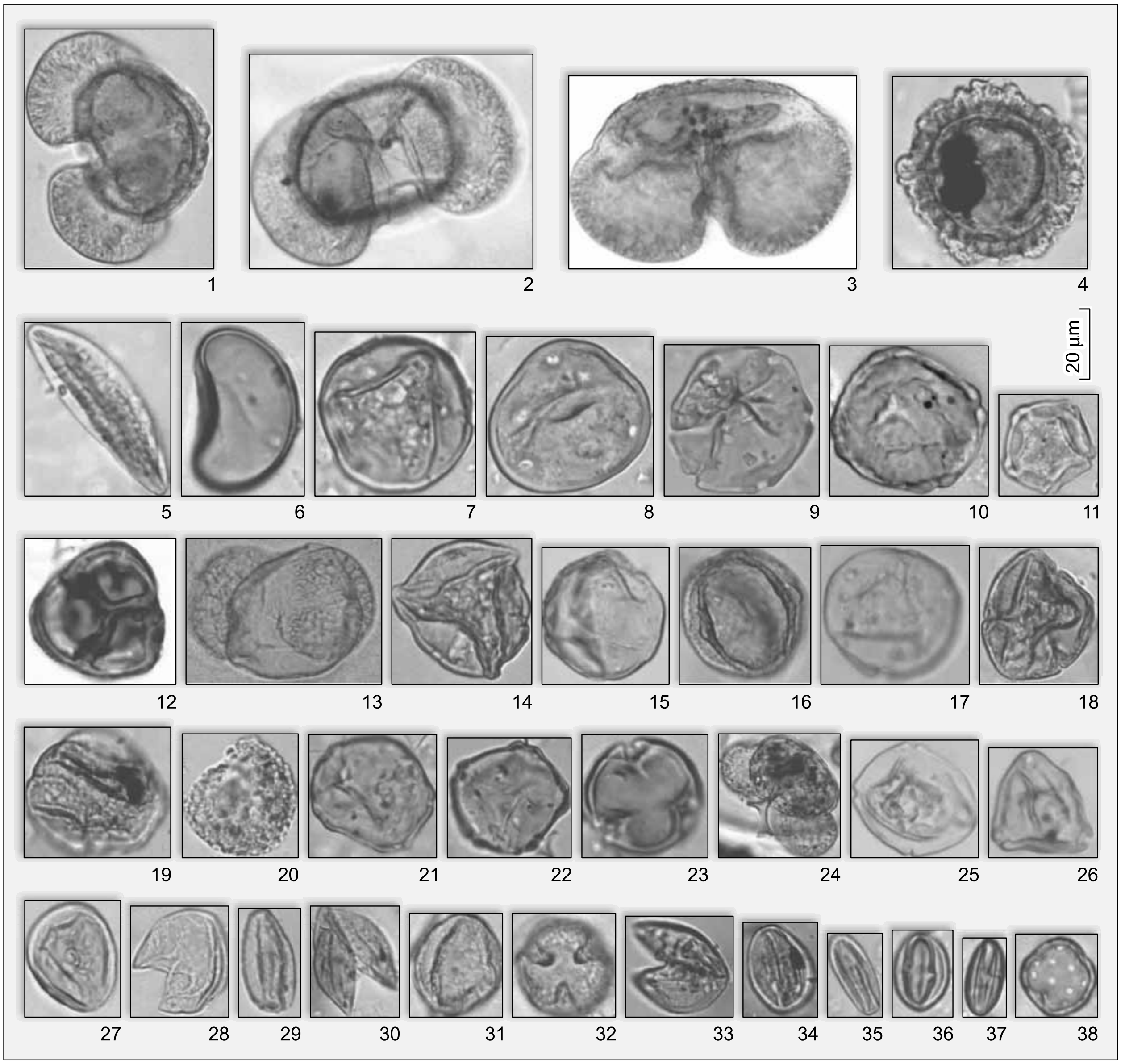
A Middle Miocene radiolarian complex (*Eucyrtidium inflatum*) was identified in deposits of station 1440 (Tsoy and Shastina, 1999) that confirms our data about the deposition age data (Fig. 2).

Pollen of coniferous plants (Barash et al., 2003) dominates in the Middle Miocene composition (the age is determined by radiolarian and diatomite complexes) of the SPC found in the deposits of the North Yamato Ridge (station 3120); therefore, it might be indicative of the cooling period in the investigated Yamato area. That time, the Kita-Yamato trough was likely to be located between the North and South Ridges.

Taxonomic and quantitative composition of SPC-2 gives evidence in favor of coniferous-broad-leaved polydominant forests sedimentation in proximity to the basin. The forests were distinguished by a diversified composition of moderate thermophile broad-leaved plants, both deciduous and nondeciduous. The main forest forming species in the composition were *Fagus*, *Quercus* (deciduous and nondeciduous), *Castanea, Carya, Juglans* (currently growing in conditions of quite warm and humid climate of Eastern Asia (Wolfe, 1979)) and Pinaceae together with different taxa of Betulaceae family. Most researchers relate the enrichment of Miocene flora with thermophile elements to manifestation of the first climatic optimum between the Early and Middle Miocene (Akhmet'ev, 1974; Fat'yanova, 1987; Velichko, 1999; and others). Ecological aspects of taxa (mountain, slope and valley-growing plants associations) indicate that the sedimentation basin was surrounded by a mountainous terrain. The quality of pollen preservation and the occurrence of significant quantity of taxa whose pollen is carried at small distances (for e.g., beech, chestnut, birch family, walnut family) point at pollen burial in places of plants growth.

Spore and pollen complex 3 (Middle–Late Miocene). SPC-3 was determined in diatomite (sample 1420) and tuff-diatomite (sample 1420a) from the North Yamato Ridge (Fig. 1, 2). There is a little pollen in sample 1420, but its taxonomic composition is similar to the palynospectrum composition determined in sample 1420-a. Diversity and predominance of broad-leaved woody species pollen (76.4%) are characteristic of the designated class. The following flora species are the most prevailing—*Ulmus* sp., *Fagus* sp. and *Carya* sp.; prominent quantity of *Quercus* sp. (deciduous), *Carpinus* sp., *Betula* sp.; a few *Juglans* sp., *Liquidambar* sp. and *Alnus* sp.; singular *Quercus* (nondeciduous), *Tilia* sp., *Platycarya* sp., *Corylus* sp. Gymnosperms are included into the group of associates and mainly represented by pine-family species (*Pinus* sp., *Picea* sp., *Tsuga* sp., *Abies* sp.) and singular *Podocarpus* sp. and *Taxodium* sp. (Phototable 2).

SPC-3 and SPC-2 have similar taxonomic composition, but quantitative ratios of taxa groups tend to vary dramatically. For instance, the number of SPC-3 nondeciduous spe-



Phototable 2. SPC-2, SPC-3, SPC-4 spores and pollen from the submarine Yamato Rise in the Sea of Japan. 1, Pinaceae gen. indet. (sample 1437); 2, *Abies* sp. (sample 1440); 3, *Picea* sect*. Omorica* (sample 1440); 4*, Tsuga diversifolia* (Maxim) Mast. (sample 1440); 5, *Ephedra* sp. (sample 1440); 6, Polypodiaceae (sample 1440); 7, 8, 14, *Carya* sp. (sample 1440); 9, *Juglans* sp*.* (sample 1440); 10, *Ulmus* sp. (sample 1420-a); 11, *Alnus sp.* (sample 1420-a); 12, *Ericales* (sample 1440); 13, *Pinus* sp*.* (sample 1420-a);15, *Fagus* sp. (sample 1420-a); 16, 18, 19, *Fagus* sp. (sample 1440); 17, *Carya* sp. (sample 1420-a); 20, *Sciadopitys* sp. (sample 1437); 21, *Juglans* sp. (sample 1440); 22, *Pterocarya* sp. (sample 1440); 23*, Rhus* sp. (sample 1437); 24, *Pinus* subg*. Diploxylon* (sample 1437); 25*, Carpinus* sp. (sample 1420-a); 26, *Corylus* sp. (sample 1420-a); 27, 33, *Taxodium* sp. (sample 1437); 28, Cupressaceae gen. indet. (sample 1437); 29, 34, 35, *Quercus* (nondeciduous type) (sample 1420-a); 30, *Glyptostrobus* sp. (sample 1437); 31, 32, Q*uercus* (type) (sample 1420-a); 36, *Pasania* sp. (sample 1440); 37, *Castanea* sp. (sample 1440); *38*, Chenopodiaceae gen. indet. (sample 1437).

cies reduces sharply, such as *Quercus* and *Castanea* presently growing in the subtropical zone of southwestern part of Honshu Island, in China and Taiwan; but at the same time the role of moderately thermophile species tends to increase (*Fagus, Carpinus*).

Judging by taxonomic composition and prominence of *Carya, Fagus, Ulmus, Quercus* (deciduous), SPC-3 has much in common with PF from the *Carya* subzone (*Carya–Liquidambar* zone) of the Oga Peninsula in Japan (end of the Early and the beginning of the Middle Miocene) (Yamanoi, 1978; Takahashi, 1984), and with Late Miocene PF (Mitoku-type flora) from the deposits of the northeastern slope unsealed with a RC 12-394 piston corer (Burckle and Akiba, 1978).

The diatomite complex of Denticulopsis dimorpha (Late Miocene) zone and the radiolarian complex of *Lychnocano-*

ma nipponica magnacornuta (Middle–Late Miocene) zone were determined in the same samples selected for SPC-3 (Tsoy and Shastina, 1999).

The designated SPC-3 composition is an indicative of a sylvan type of flora in the sedimentation area. Forests were broadleaved-pine-small-leaved. Broadleaved plants were represented by elm, beech, wing nut, oak (deciduous), fewer horn-beech species, hazel and sweet palm, and not numerous lime tree species, hickory and others.

The taxonomic complex composition points at moderate, moderate-warm climate being typical of the second warming between the Middle and Late Miocene (Fat'yanova, 1987). Ecological characteristics of taxa (valley-growing—common bald cypress, elm, alder, wing nut; slope-growing—beech family trees, elm, various walnut family species, lime tree and others; high-altitude—pine, hemlock, fir) included in the palynoflora composition are indicatives of the dissected terrain and an altitudinal sequence of the plant cover in the vicinity of the sedimentation basin. Diversity of taxonomic composition and good pollen preservation give evidence in favor of pollen burial near the places of their growth (Koreneva, 1983).

Spore and pollen complex 4 (end of the Late Miocene). SPC-4 was determined in tuff sandstones (sample 1437, depth: 1050–950 m), raised from the northeastern slope of the South Yamato Ridge (Fig. 1, 2). Pollen of gymnosperms dominates in the SPC-4 composition with the prevalence of Taxodiaceae family (dominant *Taxodium* sp., *Sciadopitys* sp. and a few *Glyptostrobus* sp.). Pine family species (not numerous *Pinus* sp*.*, *Tsuga* sp.; singular *Abies* sp., *Picea* spp.) and *Ephedra* sp. appear to be subdominant in this complex. The group of subdominants comprises angiosperms. The following species are represented in small quantities in their composition and in the order of decreasing: *Alnus* sp*.*, *Betula* sp*.*, *Quercus* (deciduous), *Ulmus* sp., *Corylus* sp., *Carpinus* sp., *Juglans* sp., *Tilia* sp*.*, *Elaeagnus* sp. Herbaceous plants are singular: Chenopodiaceae, Cyperaceae, *Artemisia* sp. Spore composition is not numerous and less representative: Polypodiaceae, *Lycopodium* sp., *Osmunda* sp. (Phototable 2).

A similar Late Miocene complex with dominating Taxodiaceae and Pinaceae families was designated in the deposits of the northeastern part of the Okusiri Ridge in the northwestern area of the Sea of Japan (stations 1711, 1713) (Vashchenkova et al., 2011), on the northeastern slope of the Okusiri Ridge (D-258, RC-19 stations) (Geological…, 1978), and also in the deposits drilled in deep-sea well 796 (NP-3 palynozone) (Yamanoi, 1992). Japanese Late Miocene palynoflora—Mitoku-type flora (Tanai, 1961; Sato, 1963; Fuji, 1969) and NP-3 zone palynoflora (Yamanoi, 1978; Takahashi, 1984; Yamanoi, 1992; and other) are distinguished not only by plentiful species of taxodium/pine families, but also by diversity and the great number of beech family (*Fagus, Quercus*-deciduous, *Castanea*) and walnut family species, i.e., this paleoflora is more thermophile than that of the Sea of Japan.

SPC-4 taxonomic composition allows us to suppose that flora was represented by slope- and valley-growing associations in the area of sedimentation. Predominance of *Taxodium* producing little pollen, which is badly carried, and occurrence of *Glyptostrobus* in the SPC composition give evidence in favor of humid habitat conditions, marshy coastlines within the sedimentation basin and the burial of pollen in places of pollen-producing plants growth (Koreneva, 1983; Petros'yants et al., 1990). Predominance of plants pollen of valley-growing associations in the SPC composition points at less dissected terrain compared with the previous conditions. The climate was moderate and humid.

CONCLUSIONS

The outcome of the conducted investigation of the deep-sea Yamato Rise deposits has been the determination of four heterochronous spore and pollen complexes: SPC-1 (Early Miocene), SPC-2 (end of the Early and the beginning of the Middle Miocene), SPC-3—(Middle-Late Miocene), SPC-4 (Late Miocene). The analysis of the taxonomic pollen composition, quantitative and ecological complex characteristics has enabled us to follow the variation of flora complexes in the area of the submarine Yamato Rise during the Miocene.

The palynoflora of SPC-1 is distinguished by the predominance and diversity of angiosperms taxa existing in conditions of the moderate and humid climate of the Early Miocene. The SPC-2 palynoflora with the diversified taxonomic composition, significant participation of both thermophile and deciduous plants reflects the climatic optimum between the Early and Middle Miocene, while the SPC-3 palynoflora of reflects the second climate warming between the Middle and Late Miocene. The most thermophile taxa have been withdrawn from the PF composition, and the number of moderately thermophile plants tends to increase, that is indicative of a mild-warm climate. The SPC-4 composition points at a climatic cooling at the end of the Late Miocene. Thermophile broad-leaved taxa drop out of the composition, and the role of boreal taxa tends to increase, indicating moderate climate conditions. In general, the sequence of spore and pollen complexes reflects the common trend towards climatic cooling in the Miocene with few periods of relative warming.

Although the sediments containing SPC-1 appear to be continental lake deposits, for they contain fresh-water diatoms, palynological studies allow supposing the occurrence of dry land in the area of the current Yamato Rise location during the Miocene. Diversity of the taxonomic composition and good pollen preservation give evidence in favor of pollen burial in proximity to places of pollen-producing plants growth. In the Early and at the beginning of the Late Miocene, the terrain was severely dissected and mountainous. It is indicated by the presence of the most pollen taxa with different ecology in the complexes composition, such as fir, pine, hemlock, elm, beech, birch. In the Late Miocene, the severity of topography reduced, and the dry land area was likely to decrease. The SPC-4 composition is distinguished not only by predominance of valley-growing plants pollen, which is badly carried, but the pollen of plants growing on marshy coasts. Only in the Pliocene, the rise might have gone completely into the sea.

Similarity of the studied Miocene spore and pollen complexes from the South Yamato Ridge with coeval spore and pollen complexes of Japan gives evidence in favor of supposition that in those times the rise was rather far from Asia, and probably, the Yamato Depression wasn't wide enough.

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