



PERGAMON

Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

Journal of Asian Earth Sciences 22 (2003) 13–28

Journal of Asian
Earth Sciences

www.elsevier.com/locate/jseas

A pilot model for neogene and paleogene bivalve cenozones of the Northwestern Pacific

Alexander I. Kafanov^{a,*}, Kenshiro Ogasawara^b

^a*Institute of Marine Biology, Far East Branch of the Russian Academy of Sciences, 90 Okeansky Ave., Apt. 242, Vladivostok 690002, Russian Federation*

^b*Institute of Geoscience, University of Tsukuba, Tennodai 1-1-1, Tsukuba 305-8571, Japan*

Received 31 May 2001; revised 28 May 2002; accepted 14 November 2002

Abstract

By means of taxonomically and geochronologically revised species lists (a total of 793 valid species of bivalve molluscs were considered) from 178 formations ('Suites') of Neogene and Paleogene deposits in the Russian Far East and characteristic and index species distinguished on this basis, the molluscan cenozones are established. These allow the construction of a preliminary stratigraphical scheme for the northwestern Pacific (western and eastern Kamchatka, south and north Sakhalin, Koryak Upland). The following cenozones are established: 1—extant species; 2—*Fortipecten takahashii*–*Yoldia* (*Cnesterium*) *kuluntunensis*; 3—*Acila* (*Truncacila*) *marujamensis*–*Lucinoma acutilineata*; 4—*Mya cuneiformis*–*Acila* (*Truncacila*) *gottschei*; 5—*Mytilus* (*Tumidimytilus*) *tichanovitchi*–*Macoma osakaensis*; 6—*Megayoldia* (*Hataiyoldia*) *tokunagai*–*Neilonella* (*Borissia*) *sakhalinensis*; 7—*Periploma* (*Aelga*) *besshoensis*–*Yoldia* (*Yoldia*) *kovatschenensis*; 8—*Papyridea* (*Profulvia*) *harrimani*–*Ciliatocardium asagaiense*; 9—*Megayoldia* (*Portlandella*) *watasei*–*Yoldia* (*Nampiella*) *takaradaiensis*; 10—*Nuculana* (*Saccella*) *gabbii*–*Corbula* (*Cuneocorbula*) *formosa*; 11—*Lucina washingtonensis*–*Nuculana* (*Saccella*) *alaeformis*. On the basis of bivalve distribution patterns, it is assumed that the boundary between the Neogene and the Paleogene lies at the base of the Kuluven Horizon in western Kamchatka, the base of the lower Nevelisk sub-Horizon in south Sakhalin and at the lower part of the Pakhachin Horizon in eastern Kamchatka and Koryak Upland.

© 2003 Elsevier Ltd. All rights reserved.

Keywords: Cenozoic; Northwestern Pacific; Biostratigraphy; Bivalvia; Cenozone; Cluster-analysis

1. Introduction

For Cenozoic deposits of northwestern America and Japan, several regional and interregional biostratigraphic schemes exist at present, based on the distribution of molluscs, mostly Bivalvia (Weaver, 1942; Weaver et al., 1944; Weaver and Kleinpell, 1963; Masuda, 1973a,b; Mizuno, 1964; Adegoke, 1969; Kanno, 1971; Addicott, 1972, 1973, 1974, 1976a,b, 1981; Ikebe et al., 1972; Marincovich, 1984; Tsuchi and Shuto, 1984). It is surprising that there are no unified and approved molluscan stages or zones for the whole of the northwestern Pacific despite the fact that the geochronological distribution of molluscs served as the basis for the International Stratigraphic Scale of the Cenozoic (Lyell, 1830–1833). Prior to the wide introduction of micropaleontological studies, molluscs were the only reliable method for widespread interregional correlations.

The absence of unique and mutually approved molluscan stages for the entire northwestern Pacific is largely due to the poor knowledge of Cenozoic molluscan faunas from regions of the Russian Far East as well as to their inaccessibility for joint research by Russian, American and Japanese scientists because of the language barrier. Nevertheless, Russian paleontologists have distinguished the molluscan zones for Sakhalin and Kamchatka and correlated these zones to the relevant deposits of Japan and the Pacific coast of North America (Krishtofovich, 1964, 1969; Krishtofovich and Ilyina, 1961; Zhidkova et al., 1968, 1972; Gladenkov, 1972; Volobueva, 1976; Zhidkova and Pronina, 1978; Gladenkov and Sinelnikova, 1990; and others). More recently, the correlation of stratigraphic horizons of the North Pacific was mainly done by comparing data from non-molluscan faunas and floras, notably diatoms, foraminifera, pollen, etc. (Menner, 1984; Gladenkov, 1988; Gladenkov et al., 1987, 1991, 1992, 1997, 1999; Arkhipova et al., 1992; Volobueva et al., 1992, 1994), and interest in molluscan zones has diminished. This fact

* Corresponding author.

E-mail address: kafanov@mail.primorye.ru (A.I. Kafanov).

explains the existence of alternative age determination data sets, since the extinction rates and biostratigraphic boundaries determined by different groups are generally different. Thus there is a need to correlate these different schemes to a control group, for which we suggest it would be sensible to use molluscs (mainly bivalves) for the Cenozoic (Lyell, 1830–1833; see Kafanov, 1987 for a short review).

Unfortunately, all the molluscan zones established by Russian researchers are of insufficient practicability, being mainly based on the lists of molluscs presented in numerous handwritten reports, poorly accessible to the scientific community and evoking essential discrepancies in understanding the taxonomic content and the stratigraphic distribution of species (see Kafanov et al., 1999b, 2000). Thus, even in the latest unified stratigraphic scheme of Paleogene and Neogene deposits of Sakhalin and the Kurile Islands (Resolution..., 1998), the 49 ‘characteristic’ species of molluscs particularly include those presented in the open nomenclature—*Acila (Truncacila) sp.*, *Yoldia (Cnesterium) sp.*, *Leionucula ex gr. tenuis*, *Crassatella sp.*, *Spisula sp.*, *Yoldia ex gr. nabiliana*, *Yoldia (Nampiella) sp.*, *Leionucula sp.*, *Viviparus sp.* and *Unio sp.*, *Spisula voyi*—an obvious synonym of *Mactromeris polynyma* (Stimpson, 1860), *Corbicula adamensis*—an obvious synonym of *Corbicula lautenschlaegeri* Zhidkova in Zhidkova et al. (1968), as well as the undescribed, manuscript name *Ostrea ezoense*. It is clear that these species cannot ‘characterize’ anything and this casts some doubts on the taxonomic and stratigraphic status of the remaining ‘characteristic’ species. Such examples are numerous. Therefore the molluscan zones established by Russian researchers lack the main features of scientific study: reproducibility of results and the possibility of their verification. Suffice to say that the molluscan zones

were based on lists of species that had not been formally described in the literature.

To provide a firm basis for reliable zones, it proved necessary to make a complete list of valid taxa, by revising all the described and/or figured Cenozoic marine Bivalvia through reexamination of collections stored at major paleontological and zoological institutions in Russia, Japan and the USA (Kafanov and Amano, 1996, 1997; Kafanov et al., 1999b, 2000, 2001). Certainly, these results are preliminary, and will be refined after more comprehensive comparisons between the geochronological distributions of individual species and related taxa.

The purpose of this work is to recognize bivalve cenozones that can be used as a basis for Cenozoic molluscan biostratigraphy of the northwestern and entire northern Pacific. Considering the proposed scheme as tentative, we do not relate it to the geochronologic scale. Correlation of bivalve cenozones with zonal schemes based on other stratigraphically important groups of organisms and the relationships of the recognized cenozones with the geochronological scale are subjects of future study.

2. Material and methods

The term adopted as the basic stratigraphical division for the Russian Far East is ‘Suite’ (Gladenkov et al., 1990), which is similar in concept to ‘Formation’ of American and Japanese authors. The species lists were compiled for each of 178 suites characterized by bivalve molluscs (Fig. 1; Table 1) on the basis of the data presented by Kafanov et al. (1999b, 2000, 2001). Clusters of associated species for each suite are further named ‘assemblages’. Only valid species

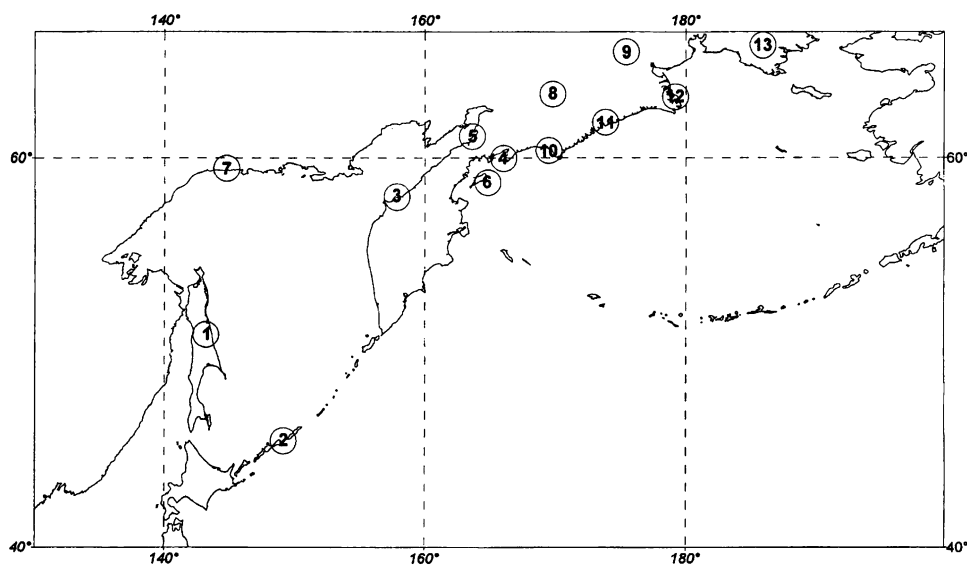


Fig. 1. Index map of the Russian Far East showing areas from which Paleogene and Neogene marine Bivalvia have been recorded or described (after Kafanov et al., 1999b). 1—Sakhalin Island, 2—Kurile Islands, 3—western Kamchatka, 4—Korfa Gulf, 5—eastern coast of Penzhinskaya Bight, 6—Karaginsky Island, 7—region of Okhotsk Town, 8—Penzhina River basin, 9—lower stream of Anadyr' River, 10—Olyutorskaya depression, 11—Khatyrka River basin, 12—Ugol'naya Bight, 13—Chukotka Peninsula.

Table 1
List of suites whose species lists (assemblages) were used for clustering

Numerical code	Suites and other stratigraphic units	Numerical code	Suites and other stratigraphic units	Numerical code	Suites and other stratigraphic units
1	'Etolonskaya' in Eastern Kamchatka	61	Kholmskaya, upper part	121	Ol'khovskaya (Paleogene) ^a
2	'Ezhovyi Horizon' in Eastern Kamchatka	62	Khulginskaya	122	Paleogene Ol'khovskaya, upper part
3	'Il'inskaya' in Eastern Kamchatka	63	Kilakirunnskaya	123	Olen'ya
4	'Kovachinskaya' in Eastern Kamchatka	64	Kitylginskaya Series	124	Ommayskaya
5	'Miocene'	65	Konstantinovskaya Series	125	Ossorskie Layers
6	'Paleogene'	66	Kornovskaya	126	Pakhachinskaya
7	Aglikichskaya formation ('Tolshcha')	67	Kovachinskaya	127	Pakhachinskaya, layer 5
8	Agnevsкая	68	Kovachinskaya Series	128	Pakhachinskaya, lower part
9	Alekhinskaya	69	Kovachinskaya, upper part	129	Parusnaya
10	Alekhinskaya, middle part	70	Kozlovskaya	130	Pestrotsvetnaya
11	Aleksandrovskaya	71	Krasnopol'evskaya	131	Pestovskaya
12	Aluginskaya	72	Krestovskaya	132	Pil'skaya
13	Aluginskaya, member 1	73	Kuluvenskaya	133	Pil'skaya, upper part
14	Aluginskaya, upper part	74	Kurasiyskaya	134	Pilengskaya
15	Amaamskaya	75	Kurasiyskaya, lower part	135	Pinakul'skaya
16	Amaninskaya	76	Kuybyshvskaya	136	Pomyrskaya
17	Amguemskie Layers	77	Kylanskaya	137	Rakitiinskaya
18	Arakayskaya	78	Limimteveyamskaya	138	Rateginskaya
19	Arakayskaya, lower part	79	Lopukhovskaya	139	Rybakovskaya
20	Arakayskaya, upper part	80	Lovtsovskaya	140	Sandstones with <i>Laternula</i>
21	Astronomicheskogo Mysa	81	Lugovskaya	141	Sertunayskaya
22	Attarmanskіe Layers	82	Machigarskaya	142	Shchapinskaya
23	Ausinskaya	83	Machigarskaya, lower part	143	Shumnovskaya
24	Berezovorechenskaya	84	Machigarskaya, upper part	144	Sinegorsk Horizon
25	Borskaya	85	Mallenskaya	145	Snatol'skaya
26	Chazhminskaya	86	Markovskaya	146	Takaradayskaya
27	Chekhovskaya	87	Maruyamskaya	147	Takaradayskaya, lower part
28	Daekhuriinskaya	88	Maruyamskaya, Members II–III	148	Takaradayskaya, upper part
29	Daginskaya	89	Maruyamskaya, Member I	149	Tigil'skaya Series
30	Daginskaya, upper part	90	Maruyamskaya, Member II	150	Tigil'skaya Series, lower part
31	Ekhbinskaya	91	Maruyamskaya, Member III	151	Tkapravayamskaya
32	Enemtenskaya	92	Maruyamskaya, lower part	152	Tochilinskaya
33	Ermanovskaya	93	Maruyamskaya, middle part	153	Tumskaya
34	Etolonskaya	94	Maruyamskaya, upper part	154	Tusatuvayamskie Layers
35	Gailkhavilanskaya	95	Matitukskaya	155	Tyushevskaya
36	Gakkhinskaya	96	Matitukskaya, lower part	156	Uandi
37	Gakkhinskaya, upper part	97	Mayamrafskaya	157	Ukelayatskaya
38	Gastellovskaya	98	Mutnovskaya	158	Undal–Umenskaya
39	Gastellovskaya, lower part	99	Mysa Ploskogo	159	Unel'skaya
40	Gastellovskaya, upper part	100	Mysa Telegraficheskogo	160	Uranayskaya
41	Gastellovskaya, middle part	101	Mysa Tons	161	Ust'–Kamchatskaya Series
42	Gennoyshinskaya	102	Napanskaya	162	Ust'–Limimteveyamskaya
43	Getkilninskaya	103	Nevel'skaya	163	Utkholokskaya
44	Golovninskaya	104	Nevel'skaya, lower part	164	Uvuchinskaya
45	Goryachikh Klyuchey	105	Nevel'skaya, upper part	165	Val'katlenskie Layers
46	Il'inskaya	106	Niklekuyul'skaya	166	Vengeriyskaya
47	Il'khatunskaya	107	Nizhneduyskaya	167	Vengeriyskaya, lower part
48	Il'pinskaya	108	Nizhneduyskaya, upper part	168	Vengeriyskaya, upper part
49	Il'pinskaya, upper part	109	Nutovskaya	169	Vereshchaginskaya
50	Ionayskaya	110	Nutovskaya, lower part	170	Vereshchaginskaya, lower part
51	Kakertskaya	111	Nutovskaya, middle part	171	Verkhneduyskaya
52	Kamchikskaya	112	Nutovskaya, upper part	172	Viventetskaya
53	Kamuyskaya	113	Okeanskaya	173	Voyampol'skaya Series
54	Karaginskіe Layers	114	Okobykayskaya	174	Vychkhyneyskaya
55	Kaskadnaya	115	Okobykayskaya, lower part	175	Yaponskikh Kamney
56	Kaskadnaya, lower part	116	Okobykayskaya, middle part	176	Yun'yun'vayamskaya
57	Kavranskaya Series	117	Okobykayskaya, upper part	177	Yuzhninskaya
58	Khayidinskaya	118	Okruglovskaya	178	Zmeykovskaya
59	Kholmskaya	119	Paleogene Ol'khovskaya, lower part		
60	Kholmskaya, lower part	120	Ol'khovskaya (Neogene) ^a		

^a Vereshchagin (1982) under the same name of 'Ol'khovskaya Suite' mentions two different formations: one referred to Neogene—in eastern Kamchatka and another referred to Paleogene—in Khatyrka River drainage-basin.

and subspecies were considered. The total number of these is 793.

The determination of molluscan cenozones (sensu *International Stratigraphic Guide*, 1994) was made by assemblage clustering using *Ward's method* (1963). This method differs from numerous other methods (giving in our case similar results) in that it uses dispersion analysis for evaluating the distance between clusters, minimizing the intraclass scatter between the objects of clustering. The initial similarity matrix was 178×178 . 'Percent disagreement' between assemblages was calculated. This measure is particularly useful if the data for dimensions included in the analysis are categorical (presence/absence) in nature. The distance is computed as: distance $(x, y) = (\text{number of } x_i \neq y_i) / i$. Species characterizing separate clusters and having wide geographic ranges (north-western or even the entire northern Pacific) were used to distinguish the characteristic and index-species that were used to identify the molluscan cenozones. In any case, the use of the cenozones in biostratigraphy is more reliable than the use of characteristic and/or index species, and this decreases the influence of facies differences in many cases.

3. Results

3.1. Distribution of species number within the bounds of various geological formations

Most species and subspecies occur within only one assemblage (Fig. 2). The distribution of species number $P(n)$ for n assemblages can be sufficiently well approximated by the Pareto–Zipf–Mandelbrot frequency distribution model $P(n) = C/n^z$ with the following numerical parameters: $C = 920.4 \pm 45.9$; $z = 1.788 \pm 0.041$; $C = \sum_{n=1}^{\infty} P(n)$. The residual dispersion of the model accounts for 0.25% of the empirical distribution, confirming the reliability of the approximation.

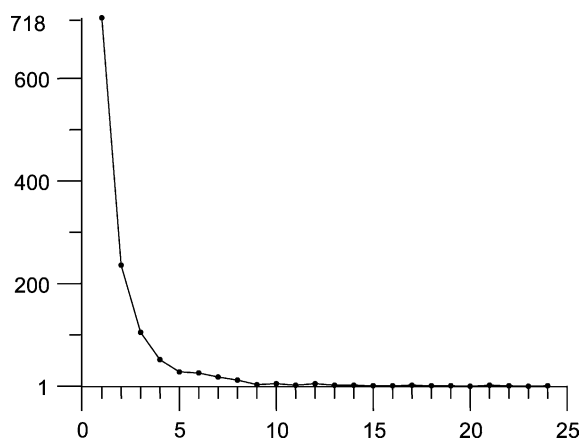


Fig. 2. Distribution of the number of species and subspecies (ordinate) within the bounds of various number of geological formations (abscissa).

In a general way, this agrees with *Zipf's concepts* (1949) on the distribution of species ranges by their size, although in reality a logarithmically normal model would probably prove more adequate (see *Kafanov and Sukhanov*, 1995). Since various species have different time ranges, the distribution of a number of species having different time ranges should also follow the Pareto–Zipf–Mandelbrot model, resulting in Lyellian percentages which, for families, genera and species, correspond well to the Pareto–Zipf–Mandelbrot rank distribution (*Holman*, 1983; *Kafanov*, 1997). The result obtained confirms the conclusion of *Lyell* (1867) who, with reference to Prof. E. Forbes, wrote that few geologists know about a great proportion of known fossil species that are based on a single specimen, while many species are based on few individuals found at one place.

3.2. Clustering of species lists

About 50% of the species are confined to only one assemblage, and a very large number of extant and extinct species with very wide time ranges result in a similar dendrogram. Therefore, the clustering of species lists often gives relatively unstable solutions (Fig. 3). In cluster characterization we limited ourselves to a similarity level exceeding 4%.

Nevertheless, even a preliminary analysis of the species composition similarity dendrogram gives significant results. First, cluster **a** and cluster branch **c1**, pooling assemblages of *Kakertskaya*, *Il'inskaya* and *Etolonskaya* and *Snatol'skaya* Suites in western Kamchatka, respectively, were clearly distinguished (Fig. 3) and characterized by maximum species richness. This reflects the effect of the level of species richness on clustering results (see *Kafanov*, 1994). Second, cluster groups **a** and **b** stand apart from all other clusters and incorporate assemblages, including those of the *Kuluven* Horizon in western Kamchatka, attributed to the Neogene by most recent studies. This substantiates the opinion that at the Paleogene–Neogene boundary, an important change occurred in the composition of the bivalve fauna. Therefore, based on bivalve assemblages, the boundary between the Paleogene and Neogene should be drawn at the bases of the *Kuluven* Horizon in western Kamchatka and possibly of the *Uynin* Horizon in north Sakhalin.

At this stratigraphic level, there is an essential modification of taxonomic structure that is visible at the level of family composition (Table 2). Starting from the base of the *Kuluven* Horizon upward, extant species become common: e.g. *Liocyma fluctuosa* (Gould, 1841), *M. polynyma* (Stimpson, 1860), *Serripes groenlandicus* (Mohr, 1786), *Conchocele bisecta* (Conrad, 1849), *Macoma calcarea* (Gmelin, 1791), *Megayoldia* (*M.*) *thraciaeformis* (Storer, 1838) and *Monia macrochisma* (Deshayes, 1839). The characteristic features of separate clusters are outlined below (Table 3).

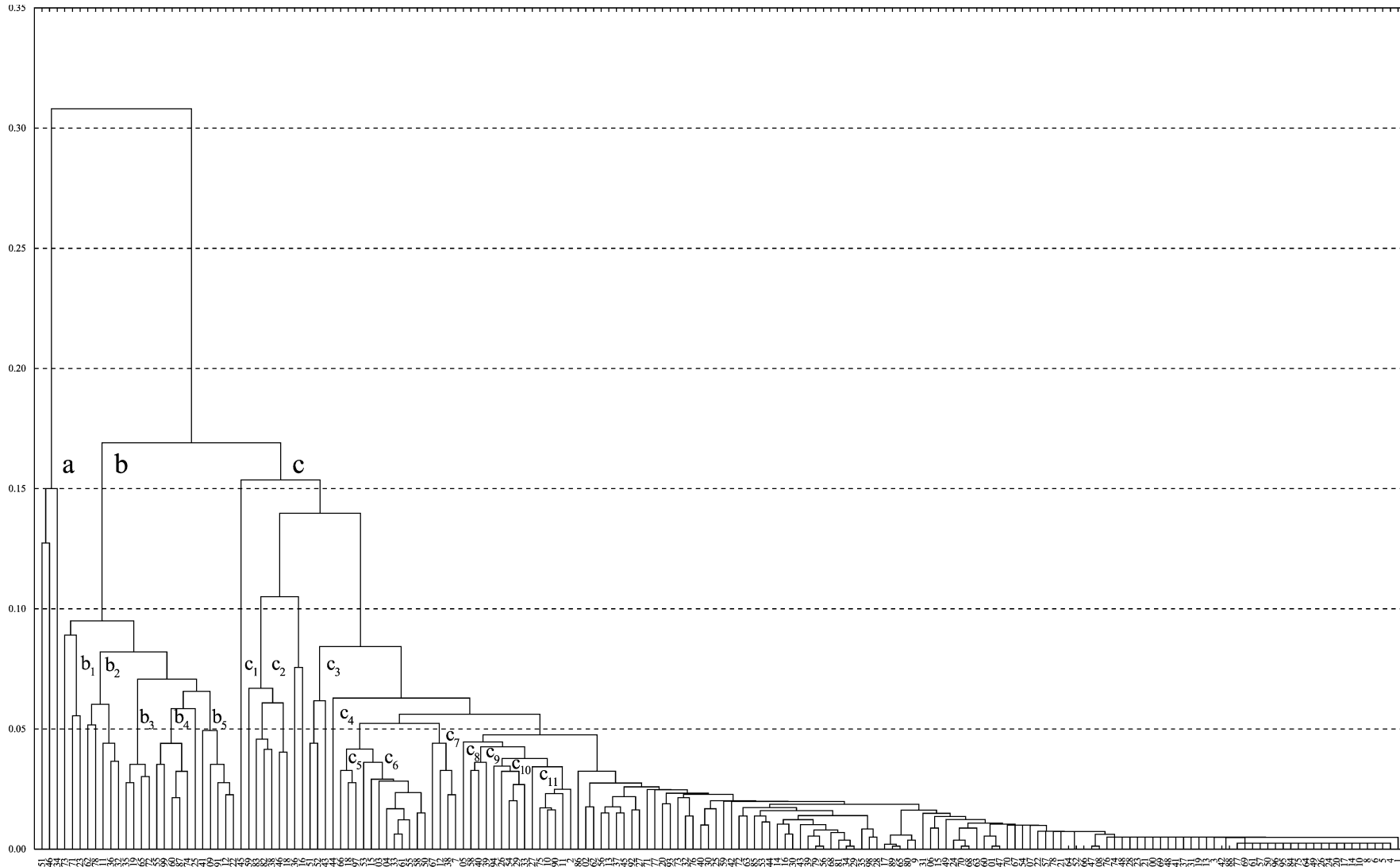


Fig. 3. Similarity dendrogram of molluscan assemblages of the Russian Far East by species composition of Bivalvia. Numerical notation of suite assemblages is given in Table 1.

Table 2
Valid species and subspecies number in various families of Paleogene and Neogene Bivalvia from the Russian Far East

Family	Species and subspecies number	
	Paleogene	Neogene
Anomiidae	3	2
Arcidae	4	8
Astartidae	2	15
Cardiidae	30	47
Carditidae	29	40
Corbiculidae	15	5
Corbulidae	1	1
Crassatellidae	9	6
Cultellidae	–	2
Cuspidariidae	8	2
Glossidae	1	–
Glycymerididae	6	6
Hiatellidae	2	14
Isognomonidae	1	–
Kelliidae	1?	–
Leptonidae	1?	–
Limidae	6	3
Limopsidae	–	1
Lucinidae	8	4
Lyonsiidae	–	1
Mactridae	11	10
Mactromyidae	1	–
Malletiidae	13	8
Mesodesmatidae	1	–
Myidae	7	10
Mytilidae	33	29
Neilonellidae	12	4
Nucinellidae	1	–
Nuculanidae	30	23
Nuculidae	32	15
Ostreidae	8	3
Pandoridae	1?	6
Parallelodontidae	2	–
Pectinidae	6	45
Periplomatidae	16	7
Pholadidae	–	8
Pholadomyidae	3	2
Plicatulidae	1	–
Propeamussidae	4	1
Psammobiidae	7	6
Pteriidae	1	–
Sareptidae	34	51
Semelidae	–	1
Solemyidae	3	2
Solenidae	5	2
Tellinidae	10	22
Thraciidae	4	3
Thyasiridae	8	5
Trapeziidae	1	–
Ungulinidae	3	6
Veneridae	29	29

The boundary between Paleogene and Neogene is accepted herein along the base of Kuluven Horizon in western Kamchatka. Species and subspecies number are bolded for five most numerous families.

Cluster **b2** pools assemblages of the Enemtenskaya Suite in western Kamchatka, Ust'–Limimteveyamskaya and Limimteveyamskaya Suites in Karaginsky Island, eastern Kamchatka, and the Pomyrskaya and middle part of Nutovskaya Suites in Sakhalin. There are no extinct species

common to all five assemblages, but the assemblages are united by the wide distribution of exant species—*L. fluctuosa*, *Hiatellaarctica* (Linnaeus., 1767), *M. polynyma*, *Serripes groenlandicus* and *Siliqua alta* (Broderip and Sowerby, 1829). The first three assemblages are related by the presence of the extinct species *Acila (Truncacila) marujamensis* Ilyina (1957), *Chlamys (Ch.) cosibensis* (Yokoyama, 1911), *Mya (M.) uzenensis* Nomura et Zinbo, 1937 and also the exant species *Crassicardia crassidens* (Broderip and Sowerby, 1829).

Cluster **b3** pools assemblages of the Ol'khovskaya Suite in eastern Kamchatka, and the Pinakul'skaya and Krestovskaya Suites and Val'katlenskie Layers in Chukotka Peninsula. Extinct species are absent, with the exception of *Tridonta borealis invocata* (Merklin et Petrov, 1962), a conventionally treated as a subspecies endemic to the Krestovskaya Suite. The exant species *L. fluctuosa*, *Mya (Arenomya) arenaria* (Linnaeus, 1758), *Serripes groenlandicus* and *Tridonta borealis Schumacher*, 1817 are in common. By the character of their molluscan fauna, all four formations are attributed to the Quaternary (Petrov, 1982).

Cluster **b5** pools assemblages of the Sertunayskaya, Nutovskaya, the lower part of the Maruyamskaya (Member III) and the upper part of the Nutovskaya Suites in Sakhalin, and the Attarmanskies Layers in Eastern Kamchatka. Due to the large number of exant species in common, the two latter assemblages were assigned to this cluster. In this case the upper part of the Nutovskaya Suite is characterized by the presence of the extinct species *Fortipecten takahashii* (Yokoyama, 1930) and *Yoldia (Cnesterium) kuluntunensis* Slodkewitsch, 1936. These two species are absent from the assemblages of the Sertunayskaya, Nutovskaya and the lower part (Member III) of the Maruyamskaya Suites. Species in common to the Sertunayskaya, Nutovskaya and lower part of Maruyamskaya Suites (Member III) are the extinct *Mya (M.) cuneiformis* (Böhm, 1916) and the exant *Keenocardium californiense* (Deshayes, 1839), *L. fluctuosa*, *M. polynyma* and *Megangulus luteus* (Wood, 1828).

To a large extent, cluster **c** appears to be an artificial pool of assemblages of various ages whose common distinction is relatively low species richness. Most distinctly differentiated here are cluster branch **c1**, incorporating only the Snatol'skaya Suite assemblage in western Kamchatka, and cluster branch **c4**, which includes only the assemblage of the Sinegorskie Layers in Sakhalin. As mentioned above, the Snatol'skaya Suite assemblage is characterized by the maximum species richness among all the Paleogene assemblages, and the molluscan fauna of the Sinegorskie Layers consists only of endemic species, permitting no comparison by species composition. From the generic composition of molluscs and complexes of foraminifera and palynoflora, the age of the Sinegorskie Layers is determined as Danian–Paleocene (Kalishevich et al., 1981).

Cluster **c8** pools assemblages of the Undal–Umenskaya Suite in the Koryak Upland and the Gastellovskaya Suite of Sakhalin. There is only one species, *Yoldia (Sachalinella)*

Table 3
Main clusters recognized

Cluster	Suites incorporated	Common extinct species	Proportion of extant species, %
a	W. Kamchatka: Etolonskaya, Kakertskaya, Il'inskaya	<i>Chlamys</i> (Ch.) <i>cosibensis</i> (Yok., 1911); <i>Crassicardia puella</i> Slod., 1938; <i>Glycymeris</i> (G.) <i>snatolensis</i> Slod., 1938; <i>Leporimetis slodkewitschi</i> Kaf. et Ogas., 1999; <i>Lucinoma acutilineata</i> (Conrad, 1849); <i>Macoma optiva</i> (Yok., 1923); <i>Modiolus trigonalis</i> Slod., 1936; <i>Pitar</i> (<i>Neogenella</i>) <i>kavranensis</i> (Slod., 1938)	Up to 20
b1	W. Kamchatka: Kuluvenskaya; S. Sakhalin: Verkhneduyskaya, Ausinskaya	<i>Mya</i> (M.) <i>cuneiformis</i> (Böhm, 1916); <i>Periploma</i> (<i>Aelga</i>) <i>besshoensis</i> (Yok., 1924)	Up to 10–15
b4	E. Kamchatka: Tyushevskaya, Mysa Ploskogo; S. Sakhalin: Maruyamskaya, Kurasiyskaya; N. Sakhalin: Uranayskaya, Borskaya	<i>Mya</i> (M.) <i>cuneiformis</i>	10–30
c2	W. Kamchatka: Amaninskaya, Gakkhinskaya; S. Sakhalin: Kholmskaya, Gastellovskaya, Takaradayskaya, Arakayskaya; N. Sakhalin: Machigarskaya	<i>Delectopecten peckhami</i> (Gabb, 1869), <i>Papyridea</i> (<i>Profulvia</i>) <i>harrimani</i> Dall, 1904; <i>Periploma</i> (<i>Aelga</i>) <i>besshoensis</i>	0
c3	NW. Kamchatka: Tkapravayamskaya, Kamchikskaya, Getkilninskaya	<i>Corbula</i> (<i>Cuneocorbula</i>) <i>formosa</i> Devjat., 1981	0
c5	N. Sakhalin: Vengerriyskaya, Mayamrafskaya; Kurile Islands (Paramushir): Okruglovskaya	<i>Lucinoma acutilineata</i>	0
c6	Koryak Upland: Ionayskaya, Khayidinskaya; N. Sakhalin: Tumskaya, Okobykayskaya (lower part), Pil'skaya, Kaskadnaya; S. Sakhalin: Kholmskaya (upper part), Nevel'skaya (s.l.)	<i>Megayoldia</i> (<i>Hataiyoldia</i>) <i>tokunagai</i> (Yok., 1925)	Up to 5
c7	Koryak Upland: Aglikichskaya Formation; W. Kamchatka: Kovachinskaya; NW. Kamchatka: Rateginskaya; E. Kamchatka: Aluginskaya	<i>Megayoldia</i> (<i>Portlandella</i>) <i>watasei</i> (Kanehara, 1937); <i>Malletia poronaica</i> (Yok., 1890)	0

nairoensis L. [Krishtofovich, 1964](#), which is common for the Undal–Umenskaya Suite and lower part of the Gastellovskaya Suite. The Undal–Umenskaya Suite assemblage includes extinct *Mya* (M.) *cuneiformis* and even extant *Cyclocardia crebricostata*, determining the characteristic features of **b** group clusters, as well as species that never occur in assemblages forming **a** and **b** clusters—*Cyclocardia expansa* (Takeda, 1953), *Liocyma furtiva* (Yokoyama, 1924) and *Modiolus matchgarensis* (Makiyama, 1934). We conclude that the molluscan assemblage of the Undal–Umenskaya Suite occupies a boundary position between Neogene and Paleogene faunas. The adjoining cluster **c9**, the assemblage of the upper part of the Nevel'skaya Suite in South Sakhalin (numerical code 105), stands alone.

Cluster **c10** pools the assemblages of the Ermanovskaya Suite in western Kamchatka, Pakhachinskaya Suite and Tusatuvayamskie Layers in eastern Kamchatka, the upper part of the Maruyamskaya Suite in Sakhalin, and the Parusnaya Suite in the Kurile Islands (Iturup). This cluster does not form a natural group. Despite the presence of some extinct species in each of the assemblages, there are no

extinct species in common. The cluster is mainly formed by extant species of little biostratigraphic value.

Cluster *c11* pools assemblages of the upper part of the Pakhachinskaya (layer 5) and Yaponskikh Kamney Suites in eastern Kamchatka and the lower parts of the Nutovskaya and Maruyamskaya (Member II) Suites in Sakhalin. The assemblages from the upper part of the Pakhachinskaya and Yaponskikh Kamney Suites are united by species in common—*Felaniella sertunayensis* (Slodkewitsch, 1938), the assemblages from the lower parts of the Nutovskaya and Maruyamskaya (Member II) Suites are united by *Macoma optiva* (Yokoyama, 1923).

3.3. Stratigraphic distribution of common bivalve species

With respect to the presence of species characterizing separate clusters and their general time range, the following characteristic and index-species are singled out.

Fortipecten takahashii (Yokoyama, 1930): western Kamchatka: Enemtenskaya Suite; eastern Kamchatka: Shchapinskaya Suite; Sakhalin: Pomyrskaya, upper part of

Nutovskaya, middle part of Maruyamskaya Suites. This species is comparatively widely distributed in Japan: Takikawa, Honbetsu, Atsuga and Yuchi Formations in Hokkaido; Motohata and Yushima Formations in Iwate Prefecture; Togawa Formation in Aomori Prefecture; Tatsunokuchi, Yamada and Kogota Formations in Miyagi Prefecture (Masuda, 1962b) and also Ishiguma Formation in Fukushima Prefecture (Hayasaka and Hangai, 1966) and Gobanshoyama Formation in Miyagi Prefecture (Noda and Masuda, 1968; Noda, 1973). According to Nakashima (2002), fossil occurrences indicate that Fortipecten species lived in Hokkaido from about 7.0–1.2 Ma; the lowermost horizon (about 6–5 Ma) in the Atsuga Formation is correlated with the Astartidae-bearing horizon (5.5–4.8 Ma) in the Bear Lake Formation in southwestern Alaska.

Chlamys (Leochlamys) tanassevitschi (Khomenko, 1934): western Kamchatka: Enemtenskaya and Etolonskaya Suites; Sakhalin: Pomyrskaya, middle part of Nutovskaya and Uandi Suites. This species, as the synonym *Chlamys daishakaensis* Masuda and Sawada, 1961, is known from the Hokkaido–Tomikawa, Nakanokawa and Setana Formations (Kanno, 1962; Sakagami et al., 1966; Sawada, 1962) and from the Honshu–Togawa and Daishaka Formations in Aomori Prefecture (Masuda, 1962a; Iwai, 1965) and Sawane Formation in the Niigata Prefecture (Masuda and Sawada, 1961).

Corbicula matschiensis Lautenschläger in Zhidkova et al. (1968): western Kamchatka: Ermanovskaya Suite; Sakhalin: middle part of Nutovskaya, Sertunayskaya and Verkhneduyskaya Suites.

Yoldia (Cnesterium) kuluntunensis Slodkewitsch, 1936: western Kamchatka: Ermanovskaya and Etolonskaya Suites; eastern Kamchatka: Mysa Ploskogo, Limimte-vayamskaya, Ust'-Limimte-vayamskaya and Yun'yun'vayamskaya Suites in Karaginsky Island; Sakhalin: Nutovskaya and upper part of the Maruyamskaya Suites.

Acila (Truncacila) marujamensis Ilyina, 1957: western Kamchatka: Etolonskaya, Ermanovskaya and Enemtenskaya Suites; eastern Kamchatka: Limimte-vayamskaya Suite in Karaginsky Island; Sakhalin: Nutovskaya (middle and lower parts), Pomyrskaya, Maruyamskaya and Okobykayskaya (upper part) Suites.

Mya (Mya) cuneiformis (Böhm, 1916): western Kamchatka: Kuluvenskaya, Il'inskaya and Kakertskaya Suites; eastern Kamchatka: Pakhachinskaya (member 5) and Rakitinskaya Suites; Karaginsky Island, eastern Kamchatka: sandstones with Laternula, Mysa Ploskogo and Limimte-vayamskaya Suites; Sakhalin: Nevel'skaya, Sertunayskaya, Kurasiyskaya, Borskaya, lower part of Maruyamskaya (member III), Verkhneduyskaya and Uranayskaya Suites; Koryak Upland: Undal–Umenskaya Suite. This species is comparatively widely distributed in Neogene deposits of Japan. Hokkaido: Kawabata, Chikubetsu, Honbetsu, Atsunai, Oiwake, Togeshita and Takinoue Formations (Nagao and Inoue, 1941; Minato et al., 1950;

Fujie, 1957; Kanno and Ogawa, 1964); Honshu: Futatsui Formation in Akita Prefecture (Chinzei, 1973), Nagashino Formation in Aichi Prefecture (Hayashi, 1973), Numanouchi and Nakayama Formations in Fukushima Prefecture (Kamada, 1962), Yamatsuda Formation in Iwate Prefecture (Noda and Tada, 1968), Matsuida Formation in Saitama Prefecture (Watanabe et al., 1950), Nukuta Formation in Nagano Prefecture (Shikama, 1954), Takahoko Formation in Aomori Prefecture (Aoki, 1959). This species also was reported by MacNeil (1965) from the lower part of the Yakataga Formation, Yakataga District, south-central Alaska.

Chlamys (Ch.) cosibensis (Yokoyama, 1911): western Kamchatka: Il'inskaya, Kakertskaya, Etolonskaya and Enemtenskaya Suites; eastern Kamchatka: Rakitinskaya Suite; Karaginsky Island, eastern Kamchatka: Limimte-vayamskaya and Ust'-Limimte-vayamskaya Suites; Sakhalin: Pomyrskaya, middle part of Nutovskaya and Uandi Suites; Kurile Islands: Okeanskaya, Parusnaya and Okruglovskaya Suites. This species has a wide geochronological occurrence in Japan. Hokkaido: Setana (Kanno, 1962; Masuda, 1973a), Kunnui (Sawada, 1962), Tomikawa (Sakagami et al., 1966) and Ainonai (Uozumi et al., 1966) Formations in Hokkaido; Honshu: Hamada (Masuda, 1959; Masuda, 1973a, b), Narusawa (Iwai, 1965), Daishaka (Iwai, 1965; Masuda, 1973a, b) and Narusawa (Iwai, 1965) Formations in Aomori Prefecture; Suenomatsuyama Formation in Iwate Prefecture (Masuda, 1973a); Gobanshoyama (Noda, 1973) and Moniwa (Masuda, 1959, 1962b) Formations in Miyagi Prefecture; Kitaura (Takayasu, 1962) and Sugota (Masuda, 1959, 1962b) Formations in Akita Prefecture; Shigarami Formation in Nagano Prefecture (Masuda, 1959, 1973a); Omma Formation in Ishikawa Prefecture (Kaseno and Matsuura, 1965); Koshiha Formation in Kanagawa Prefecture (Masuda, 1959); Matsuzakatoge Formation in Fukushima Prefecture (Masuda and Shibata, 1971; Masuda, 1973a); Kobana Formation in Tochigi Prefecture (Kanno, 1961) and Nataki Formation in Gifu Prefecture (Itoigawa et al., 1974). It is also reported from 'Middle Miocene to Lower Pliocene' deposits of Saishû Island, Korea (Masuda, 1962b).

Acila (Truncacila) gottschei (Böhm, 1916): western Kamchatka: Il'inskaya Suite; Sakhalin: Maruyamskaya, Sertunayskaya and Kurasiyskaya Suites; Hokkaido: Tomikawa Formation (Sakagami et al., 1966).

Mytilus (Tumidimytilus) tichanovitchi Makiyama, 1934: western Kamchatka: Kakertskaya Suite; Sakhalin: Machigarskaya, Chekhovskaya, Nevel'skaya (upper part) and Borskaya Suites; Hokkaido: Kawabata, Asahi and Horomui Formations (Uozumi, 1953, 1966; Kanno et al., 1968).

Macoma osakaensis L. Krishtofovich [1957]: western Kamchatka: Il'inskaya and Kuluvenskaya Suites; eastern Kamchatka: Pakhachinskaya and Pestrotsvetnaya Suites; Sakhalin: Nevel'skaya (upper part) and Arakayskaya Suites.

Macoma optiva (Yokoyama, 1923): western Kamchatka: Il'inskaya, Kakertskaya and Etolonskaya Suites; eastern

Kamchatka: Yaponskikh Kamney Suite and ‘Ezhovyi Horizon’; Sakhalin: lower part of the Nutovskaya, Aleksandrovskaya, Matitukskaya and lower part of Maruyamskaya (member II) Suites. In Japan this species is known from the Kawabata and Tokomuro Formations of Hokkaido (Uozumi, 1953; Mizuno et al., 1969); Ainaigawa and Sunakose Formations of Aomori Prefecture (Iwai, 1961, 1965); Kaisekizan Formation in Mie Prefecture (Araki, 1960); Nukuta Formation in Nagano Prefecture (Shikama, 1954); Okazaki Formation in Aichi Prefecture (Hayashi and Miura, 1973); Numanouchi, Kokozura and Honya Formations in Fukushima Prefecture, Kokozura Formation in Ibaraki Prefecture (Kamada, 1962); Ushikubitoge Formation in Saitama Prefecture (Kanno, 1960); Itsukaichi Formation in Tokyo Prefecture (Kanno, 1967) and Yamanouchi Formation in Gifu Prefecture (Itoigawa et al., 1974). Moore 1963 (1964) reported this species from the ‘Astoria Formation’ of Newport, Oregon, but this was changed to the upper part of the Nye Mudstone by Snively et al. (1969).

Lucinoma acutilineata (Conrad, 1849): western Kamchatka: Kuluvenskaya, Il’inskaya, Kakertskaya, Etolonskaya, Ermanovskaya and Enemtenskaya Suites; eastern Kamchatka: Goryachikh Klyuchey and Rakitinskaya Suites, ‘Ezhovyi Horizon’; Koryak Upland: Aluginskaya and Undal–Umenskaya Suites; Sakhalin: Machigarskaya, upper part of the Nevel’skaya, Chekhovskaya, Mayamraskaya, Vengeriyskaya, Ausinskaya and lower part of the Maruyamskaya Suites; Kurile Islands: Okruglovskaya Suite. This species has a wide geochronological occurrence in Neogene deposits of Japan: Taiki Formation in Hokkaido (Kanno and Akatsu, 1972); Takahoko and Ainaigawa Formations in Aomori Prefecture (Aoki, 1959; Iwai, 1961); Nukuta and Bessyo Formations in Nagano Prefecture (Shikama, 1954; Tanaka, 1959a); Sasaoka Formation in Akita Prefecture (Takayasu, 1961); Kabeya, Honya and Kokozura Formations in Fukushima Prefecture (Aoki, 1954; Kamada, 1962); Ohno Formation in Aichi Prefecture (Hayashi, 1973); Oidawara, Nataki, Yamanouchi, Maki and Toyoda Formations in Gifu Prefecture (Itoigawa, 1955, 1957; Itoigawa et al., 1974); Kobana Formation in Tochigi Prefecture (Hirayama, 1954); Iioka Formation in Chiba Prefecture (Ozaki, 1958); Tsuzuki Formation in Kyoto Prefecture (Itoigawa, 1956). It is known also from Eocene to Pleistocene deposits in California (Moore, 1988): San Lorenzo Formation; Agua Sandstone Bed of Santos Shale Member, Wygal Sandstone Member, so-called Phacoides Sand Member, Temblor Formation; Santos Shale Member, Temblor Formation, Temblor and Vaqueros Formations; Buttonbed Sandstone Member, Temblor, Castaic, Gould Shale Member, Los Laureles Sandstone Member, McLure Shale Member, Monterey, and Monterey Formations, Olcese Sand, Santa Margarita Formation, Sobrante Sandstone, and Topanga Formation; Etchegoin and Purisima Formations; lower part of Fernando and San Diego Formations; Fernando and Merced Formations and Wildcat Group; Timms Point Silt Member, San

Pedro Formation. This species occurs at many localities in the Astoria Formation (type-locality) in western Washington (Weaver, 1942).

Acila (Truncacila) maruyamensis Ilyina [1957]: western Kamchatka: Etolonskaya, Ermanovskaya and Enemtenskaya Suites; Karaginsky Island, eastern Kamchatka: Limimteveyamskaya Suite; Sakhalin: Nutovskaya, Pomyrskaya, Maruyamskaya and upper part of Okobykayskaya Suites.

Yoldia (Sachalinella) nairoensis Evseev in L. Kristofovich, 1964: Koryak Upland: Aglikichskaya formation (‘Tolshcha’) and Undal–Umenskaya Suite; Sakhalin: Gastellovskaya and Kholmokskaya Suites.

Felaniella sertunayensis (Slodkewitsch, 1938): eastern Kamchatka: ‘Ezovyi Horizon’, upper part of the Pakhachinskaya and Yaponskikh Kamney Suites; Koryak Upland: upper part of the Undal–Umenskaya Suite; Sakhalin: upper part of the Nevel’skaya, Sertunayskaya, Aleksandrovskaya and Verkhneduyskaya Suites.

Nuculana (Nuculana) tatarica Slodkewitsch, 1938: western Kamchatka: Kakertskaya Suite; Sakhalin: Sertunayskaya, Kurasiyskaya, upper part of Dagingkaya, Verkhneduyskaya and middle part of the Okobykayskaya Suites.

Mizuhopecten subyessoensis (Yokoyama, 1930): Sakhalin: Sertunayskaya, Kurasiyskaya, Ausinskaya, lower part of the Maruyamskaya and Verkhneduyskaya Suites. In Japan, the most closely related taxon is *Mizuhopecten kimurai ugoensis* (Hatai et Nisiyama, 1939) which is known from the Chikubetsu Formation in Hokkaido (Masuda, 1962b); Sugota Formation in Akita Prefecture; Tanosawa Formation in Aomori Prefecture; and Shunzaka and Tsunakigawa Formations in Yamagata Prefecture (Zinbo, 1973).

Periploma (Aelga) besshoensis (Yokoyama, 1924): Koryak Upland: Aluginskaya and Khayidinskaya Suites; western Kamchatka: Amaninskaya, Gakkhinskaya and Kuluvenskaya Suites; Sakhalin: Machigarskaya, Arakayskaya, Gastellovskaya, Borskaya, Tumskaya, Ausinskaya, Verkhneduyskaya and Okobykayskaya (lower part) Suites; Hokkaido: Poronai Formation (Uozumi, 1952; Mizuno and Inoue, 1969); Honshu: Shirasaka Formation in Ibaraki Prefecture (Kamada, 1962), Asagai Formation in Fukushima Prefecture (Hirayama, 1955; Kamada, 1962), Hota Formation in Chiba Prefecture (Hatai and Koike, 1957), Oga Formation in Shizuoka Prefecture (Matsumoto, 1964). Kanno and Ogawa (1964) figured very similar forms from the Momijiyama Formation in Hokkaido.

Yoldia (Yoldia) kovatschensis Slodkewitsch, 1938: western Kamchatka: Amaninskaya and Viventekskaya Suites; Sakhalin: Gennoyshinskaya, Gastellovskaya and Takaradayskaya (upper part) Suites.

Periploma (Aelga) yokoyamai Makiyama, 1934: western Kamchatka: Kuluvenskaya and Il’inskaya Suites; Ausinskaya and upper part of the Nevel’skaya Suites in Sakhalin. In Japan this species is reported from the Tokomuro and Toyonigawa Formations in Hokkaido (Mizuno et al., 1969; Kanno and Akatsu, 1972), Nukuta Formation in Nagano

Prefecture (Shikama, 1954), Yukunoura and Kaisekizan Formations in Mie Prefecture (Araki, 1958, 1960).

Modiolus wajampolkensis Slodkewitsch, 1936: western Kamchatka: Amaninskaya, Kuluvenskaya, Il'inskaya and Kakertskaya Suites; eastern Kamchatka: upper part of Pakhachinskaya Suite; Sakhalin: Borskaya Suite.

Megayoldia (Hataiyoldia) tokunagai (Yokoyama, 1925): Koryak Upland: Ionayskaya and Khayidinskaya Suites; Sakhalin: Kholmskaya, Nevel'skaya, Kaskadnaya, Vengeriyskaya upper part of Pil'skaya and lower part of Okobykayskaya Suites; Kurile Islands: Shumnovskaya Suite. Hokkaido: Asahi and Nupinaigawa Formations (Kanno, 1967; Kanno and Akatsu, 1972); Honshu: Ainai-gawa Formation in Aomori Prefecture (Iwai, 1961); Kamenoo Formation in Fukushima Prefecture (Uozumi, 1957; Kamada, 1962); Kadoya Formation in Aichi Prefecture (Hayashi, 1973); Itsukaichi Formation in Tokyo Prefecture (Kanno and Arai, 1964; Kanno, 1967); Oidawara Formation in Gifu Prefecture (Itoigawa et al., 1974); Tottori Formation in Tottori Prefecture (Yamana, 1966).

Neilonella (Borissia) sakhalinensis (L. Krishtofovich, 1964): Kholmskaya and lower part of the Nevel'skaya Suites of Sakhalin. As 'Leda fossa Baird, 1863', this species was cited by Clark (1932) from the lower part of the Yakataga Formation, Yakataga District, south-central Alaska.

Papyridea (Profulvia) harrimani Dall, 1904: western Kamchatka: Amaninskaya and Gakhinskaya Suites; eastern Kamchatka: Alugin'skaya and lowermost part of Pakhachinskaya Suites; Koryak Upland: Ionayskaya Suite; Sakhalin: Machigarskaya, Krasnopol'evskaya, Gastellovskaya and Kholmskaya Suites. Kafanov et al. (1999a) stated that this species occurs only in late Eocene (dated on microfossils) and early Oligocene (dated on molluscs) faunas and is useful for correlating strata from northern Honshu to Alaska: Stepovak Formation, southwestern Alaska; Mallenskaya and Ionayskaya Suites, Koryak Upland; Alugin'skaya Suite and lower part of the Pakhachinskaya Suite, eastern Kamchatka; Amaninskaya, Utkholokskaya and Viventekskaya Suites of western Kamchatka; Machigarskaya, Arakayskaya, Gastellovskaya and Akhsnayskaya Suites, Sakhalin; Nuibetsu, Charo and lower Sankebetsu Formations, Hokkaido; Asagai Formation, Honshu. So, in view of the stratigraphic ranges of *Papyridea harrimani* and other molluscs, strata 3 and 4 of the Pakhachinskaya Suite in eastern Kamchatka may be assigned to the early Oligocene, not to the lower Miocene as stated by Gladenkov et al. (1987).

Ciliatocardium asagaiense (Makiyama, 1934): Sakhalin: Machigarskaya (lower part), Takaradayskaya, Gastellovskaya, Arakayskaya (lower part) and Gennoyshinskaya Suites; Honshu: Asagai Formation in Fukushima Prefecture (Hirayama, 1955; Kamada, 1962).

Megayoldia (Portlandella) watasei (Kanehara, 1937): western Kamchatka: Amaninskaya, Rateginskaya, Snatol'skaya, Gakhinskaya and Kovachinskaya Suites;

eastern Kamchatka: Alugin'skaya, Il'khatunskaya and Mysa Tons Suites; Koryak Upland: Ionayskaya and Khayidinskaya Suites; Sakhalin: Arakayskaya, Takaradayskaya, Nevel'skaya and lower part of Kholmskaya Suites; Hokkaido: Poronai (Mizuno, 1954; Uozumi, 1955a, 1957), Hiragishi (Ogasawara and Kenzo, 1955) and Pepeshiru (Matsui, 1957) Formations; Honshu: Asagai Formation in Fukushima Prefecture (Hirayama, 1955); Aoki Formation in Nagano Prefecture (Tanaka, 1959b); Muro Formation in Wakayama Prefecture (Matsumoto, 1966); Ushikubitoge and Hiranita Formations in Saitama Prefecture (Kanno, 1960; Hirayama, 1973).

Yoldia (Nampiella) takaradaiensis L. Krishtofovich [1957]: western Kamchatka: Kovachinskaya Suite; Sakhalin: Takaradayskaya Suite.

Propeamussium pillarensis (Slodkewitsch, 1936): western Kamchatka: Kovachinskaya and Ommayskaya Suites; eastern Kamchatka: Kylanskaya and Kozlovskaya Suites. This species was established by Slodkewitsch on the basis of a drawing of Pecten (*Propeamussium*) *clallamensis* (Arnold, 1906, pl. 3, Fig. 2), described from the Blakeley Formation in Clallam County, Washington.

Spisula (Pseudocardium) packardi Dickerson, 1917: Niklekuyul'skaya Formation in Koryak Upland. This species is known from the San Emidio and Wheatland Formations in California and the Gries Ranch Beds in southwestern Washington (Dickerson, 1917; Clark and Anderson, 1938; Effinger, 1938).

Eucrassatella yessoensis (Minato and Kumano, 1950): Unel'skaya Suite in northwestern Kamchatka and the Mysa Telegraficheskogo Suite in Anadyr' River drainage-basin. It is known also from the Wakkanabe Formation in Hokkaido (Minato and Kumano, 1950; Uozumi, 1955b; Miyajima, 1959).

Corbicula (Batissa) sitakaraensis Suzuki, 1941: Rateginskaya Suite in northwestern Kamchatka; Krasnopol'evskaya and Nizhneduyskaya Suites in Sakhalin; Shitakara Formation in Hokkaido (Minato, 1950).

Nuculana (Saccella) cowlitzensis (Weaver and Palmer, 1942): western Kamchatka: Snatol'skaya and Getkilninskaya Suites; Paleogene Ol'khovskaya Suite in eastern Kamchatka. In the Pacific North America it is known from the 'Cowlitz Formation' [Coaledo] in southwestern Washington (Weaver, 1942) and San Emidio Formation in southern California (Delise, 1967; Moore, 1983).

Nuculana (Saccella) gabbii (Gabb, 1869): Getkilninskaya and Kamchikskaya Suites in northwestern Kamchatka; Krasnopolyev Horizon in south Sakhalin (Kafanov and Savizky, 1995). In California it is reported from the Las Virgenes Sandstone, Martinez and Meganos Formations, Avenal Sandstone, Domengine and Llajas Formations, Matilija and Muir Sandstones, Tejon Formation, undifferentiated Sacate and Gaviota Formations (Moore, 1983).

Lucina washingtonensis Turner, 1938: Khulgunskaya, Kamchikskaya and Tkapravayamskaya Suites in western

Kamchatka*		Sakhalin*		Ceno- zone
western	northeastern and Koryak Upland	north	south	
				1
Enemten	Limimteveyam	Pomyr Nutov	Pomyr	2
Ermanov Etolona Kakert Ilyin	Mysa Ploskogo Ezhovy	Okobykay	Maruyama Kurasi	3
Kuluven	Pakhachin	Dagi upper	Uglegor	4
		middle		
		lower	Nevelisk	5
		Uynin		
Viventek Utkholok	Upper Alugin	Daekhuriin	Kholmsk	6
Gakkh Amanin	Lower Alugin	Machigar	Arakay	7
Kovachin		coal-bearing layers	Shebunin	8
				9
Snatol			Krasnopoliev	10
			Snezhinkin	11

Fig. 4. Bivalvia cenozones and preliminary correlation scheme for Neogene and Paleogene deposits of the Northern Pacific. Cenozones: 1—extant species; 2—*Fortipecten takahashii*–*Yoldia* (*Cnesterium*) *kuluntunensis*; 3—*Acila* (*Truncacila*) *marujamensis*–*Lucinoma acutilineata*; 4—*Mya cuneiformis*–*Acila* (*Truncacila*) *gottschei*; 5—(*Tumidimytilus*) *tichanovitchi*–*Macoma osakaensis*; 6—*Megayoldia* (*Hataiyoldia*) *tokunagai*–*Neilonella* (*Borissia*) *sakhalinensis*; 7—*Periploma* (*Aelga*) *besshoensis*–*Yoldia* (*Yoldia*) *kovatschensis*; 8—*Papyridea* (*Profulvia*) *harrimani*–*Ciliatocardium asagaiense*; 9—*Megayoldia*

Kamchatka; Cowlitz Formation in southwestern Oregon and southwestern Washington (Weaver, 1942).

Nuculana (*Saccella*) *alaeformis* (Gabb, 1869): Kamchikskaya and Getkilninskaya Suites in northwestern Kamchatka; Las Virgenes Sandstone and Martinez Formation in northern California (Moore, 1983).

Corbula (*Cuneocorbula*) *formosa* Devjatilova in Devjatilova et Volobueva, 1981: Kamchikskaya, Getkilninskaya and Tkpravayamskaya Suites in northwestern Kamchatka.

4. Discussion

The results of comparison of species lists as well as the subregional distribution pattern of characteristic and index-species for the Neogene and Paleogene of the entire northwestern Pacific permit us to recognize the following molluscan cenozones: 1—extant species; 2—*Fortipecten takahashii*–*Yoldia* (*Cnesterium*) *kuluntunensis*; 3—*Acila* (*Truncacila*) *marujamensis*–*L. acutilineata*;

4—*Mya cuneiformis*–*Acila (Truncacila) gottschei*; 5—*Mytilus (Tumidimytilus) tichanovitshi*–*M. osakaensis*; 6—*Megayoldia (Hataiyoldia) tokunagai*–*Neilonella (Boris-sia) sakhalinensis*; 7—*Periploma (Aelga) besshoensis*–*Yoldia (Yoldia) kovatschensis*; 8—*Papyridea (Profulvia) harrimani*–*Ciliatocardium asagaiense*; 9—*Megayoldia (Portlandella) watasei*–*Yoldia (Nampiella) takaradaiensis*; 10—*Nuculana (Saccella) gabbii*–*Corbula (Cuneocorbula) formosa*; 11—*L. washingtonensis*–*Nuculana (Saccella) alaeformis* (Fig. 4). The first five cenozones evidently characterize the Neogene deposits. Cenozone boundaries correspond to the major stages of paleobiogeographic development of the northwestern Pacific.

Our zonal subdivision is very similar to the schemes accepted by Interdepartmental Workshops on Paleogene and Neogene stratigraphy of the Russian Far East (Resolution..., 1998), which are based on the stratigraphic study of diatoms, foraminifers, molluscs, pollen and leaf-floras and are confirmed by absolute dating of geological age. The main difference is in the position of the Paleogene–Neogene boundary.

According to the above-mentioned schemes (Resolution..., 1998), this boundary lies at the bases of the Kuluven Horizon in western Kamchatka, Uynin and Nevelisk Horizons in north and south Sakhalin, and Pakhachin Horizon in eastern Kamchatka and the Koryak Upland. The position of the Paleogene–Neogene boundary at the base of the Kuluven Horizon is well supported by our evidence: 1) clusters **a** and **b** are distinctly differentiated from cluster group **c**; these two clusters include assemblages of the Kuluven Horizon and are located stratigraphically above the horizons; 2) significant changes occur at the level of family composition (Table 2) at the base of the Kuluven Horizon; 3) above the base of the Kuluven Horizon, extant species are widely distributed, whereas they are rare below this level.

At the same time, our data on the distribution of bivalves certainly shows that the lower parts of the Nevelisk and Pakhachin Horizons must be placed in the Oligocene. Thus, the bivalve assemblage of the entire Nevelisk Horizon is very close to that of the Tatsukobu–Tsubetsu fauna in eastern Hokkaido (Morita et al., 1996). Based on the distribution of dinoflagellate cysts and K/Ar-dates Kurita et al. (2000) referred Nevel'skaya Suite in the Makarov and Chekhov areas, southern Sakhalin, to the late Oligocene and early Miocene, respectively. Even earlier Serova (1978), on the basis of planktonic foraminiferal distribution, established the Paleogene–Neogene boundary at the Kholmok–Nevelisk Horizon in Sakhalin, the Kuluven Horizon in western Kamchatka and the Kishima Formation in Kyushu. The last is assigned to the Oligocene by Inoue (1972).

Further work will include a more comprehensive interregional comparison between molluscan cenozones, absolute dating of their boundaries, and correlation with molluscan cenozones to the zones established by diatoms,

foraminifers, radiolarians and calcareous nannoplankton, for a more integrated approach to chronostratigraphy.

Acknowledgements

The first author extends his cordial acknowledgements to Dr Vitaly V. Sukhanov (Institute of Marine Biology, Far East Branch, Russian Academy of Sciences, Vladivostok, Russia) and Dr Igor V. Volvenko (Pacific Scientific-Research Centre of Fisheries and Oceanography, Vladivostok, Russia) for assistance in mathematical treatment and interpretation of the results, Dr Kazutaka Amano (Joetsu University of Education, Joetsu, Niigata Prefecture, Japan) for help in receiving obscure Japanese literature and constant consultancy on taxonomic and stratigraphical issues, Dr John M. Armentrout (Mobil Exploration and Producing Services, Inc., Dallas, Texas, USA), Dr Konstantin B. Barinov (Geological Institute, Russian Academy of Sciences, Moscow, Russia), Dr Elizabeth Nesbitt (Department of Geological Sciences, University of Houston, Houston, Texas, USA) and Dr Louie Marincovich, Jr. (California Academy of Sciences, San Francisco, USA) for very helpful critical comments. We thank to Dr Alan Beu (Institute of Geological and Nuclear Sciences, New Zealand) for helpful suggestions and improve the English.

References

- Addicott, W.O., 1972. Provincial middle and late Tertiary molluscan stages, Temblor Range, California, Proceedings of the Pacific Coast Miocene Biostratigraphic Symposium, Pacific Section, Society Economic Paleontologist and Mineralogist, Pacific Section, Bakersfield, CA, pp. 1–26.
- Addicott, W.O., 1973. Oligocene molluscan biostratigraphy and paleontology of the lower part of the Type Temblor Formation California. US Geological Survey Professional Paper 791, 1–48.
- Addicott, W.O., 1974. Giant pectinids of the eastern North Pacific margin: significance in Neogene zoogeography and chronostratigraphy. Journal of Paleontology 48 (1), 180–194.
- Addicott, W.O., 1976a. New molluscan assemblages from the upper member of the Twin River Formation, Western Washington: significance in Neogene chronostratigraphy. Journal of Research of the US Geological Survey 4 (4), 437–447.
- Addicott, W.O., 1976b. Neogene Molluscan Stages of Oregon and Washington, Neogene Symposium, Pacific Section, Society Economic Paleontologist and Mineralogist, Pacific Section, San Francisco, CA, pp. 95–115.
- Addicott, W.O., 1981. Brief History of Cenozoic Marine Biostratigraphy of the Pacific Northwest, Geological Society of America, Papers, pp. 3–15.
- Adegok, O.S., 1969. Stratigraphy and Paleontology of the Coalinga Region, California, vol. 80. University of California Publications in Geological Sciences, pp. 1–241.
- Aoki, S., 1954. Mollusca from the Miocene Kabeya Formation Joban coalfield, Fukushima Prefecture, Japan. Science Reports of the Tokyo Kyoiku Daigaku, Section C (Geology, Mineralogy and Geography) 3 (17), 23–41.

- Aoki, S., 1959. Miocene Mollusca from the southern part of the Shimokita Peninsula Aomori Prefecture, Japan. Science Reports of the Tokyo Kyoiku Daigaku, Section C (Geology, Mineralogy and Geography) 6 (57), 255–280.
- Araki, Y., 1958. Notes on the Cenozoic deposits in Owase City Mie Prefecture, Japan. Bulletin of the Faculty of Agriculture, Mie University 16, 191–200.
- Araki, Y., 1960. Geology, paleontology and sedimentary structures (including Problematica) of the Tertiary formations developed in the environs of Tsu City, Mie Prefecture, Japan. Bulletin of the Liberal Arts Department, Mie University, Special Volume 1, 3–118.
- Arkhipova, A.D., Brutman, N.Ya., Zhidkova, L.S., Ivan'shina, L.P., Kafanov, A.I., Korobkov, A.I., Kuznetzova, V.N., Moiseeva, A.I., Popova, L.A., Pronina, I.G., Remizovsky, V.I., Runeva, N.P., Savizky, V.O., Sal'nikov, B.A., Utkina, A.I., Shainyan, S.Kh., Schmidt, O.I., 1992. Reference section of Paleogene–Neogene deposits of South–East Sakhalin (Makarov section). All-Russia Petroleum Scientific–Research Geological–Exploration Institute, St-Petersburg, (in Russian).
- Arnold, R., 1906. The Tertiary and Quaternary pectens of California, United States, Department of the Interior, Geological Survey, Professional Paper 47, pp. 1–264.
- Chinzei, K., 1973. Omma-Manganjian molluscan fauna in the Futatsui area of northern Akita Japan. Transactions and Proceedings of the Palaeontological Society of Japan, New series 90, 81–94.
- Clark, B.L., 1932. Fauna of the Poul and Yakataga Formations (upper Oligocene) of southern Alaska. Bulletin of the Geological Society of America 43, 797–846.
- Clark, B.L., Anderson, C.A., 1938. Wheatland Formation and its relation to early Tertiary andesites in the Sierra Nevada. Bulletin of the Geological Society of America 49, 931–956.
- Delise, K.C., 1967. Biostratigraphy of the San Emidio Formation Kern County, California. University of California Publications in Geological Sciences 68, 1–67.
- Dickerson, R.E., 1917. Climate and its influence upon the Oligocene faunas of the Pacific Coast, with descriptions of some new species from the *Molopophorus lincolnensis* zone. Proceedings of the California Academy of Sciences 47 (6), 157–192.
- Effinger, W.L., 1938. The gries ranch fauna (Oligocene) of western Washington. Journal of Paleontology 12, 355–390.
- Fujie, T., 1957. On the myarian pelecypods of Japan. Part 1. Summary of the study of the genus *Mya* from Hokkaido. Journal of the Faculty of Science, Hokkaido University, Series 4 (Geology and Mineralogy) 9 (4), 381–413.
- Gladenkov, Yu.B., 1972. Neogene of Kamchatka (problems of biostratigraphy and paleoecology). Transactions of the Geological Institute, Academy of Sciences of the USSR 214, 1–252.
- Gladenkov, Yu. B., 1988. Marine Neogene stratigraphy of the northern part of the Pacific Belt (Review of the stratigraphical schemes for the Far East of the USSR, North America and Japan). Transactions of the Geological Institute, Academy of Sciences of the USSR 428, 1–213. in Russian.
- Gladenkov, Yu.B., 1990. System of the Neogene regional divisions of Kamchatka and Sakhalin: horizons, zones and beds. Palaeogeography, Palaeoclimatology, Palaeoecology 77 (3/4), 199–201.
- Gladenkov, Yu.B., Sinelnikova, V.N., 1990. Miocene mollusks and climatic optima in Kamchatka. Transactions of the Geological Institute, Academy of Sciences of the USSR 453, 1–175. in Russian.
- Gladenkov, Yu.B., Bratzeva, G.M., Sinelnikova, V.N., 1987. Marine Cenozoic of Korfa Bay in eastern part of Kamchatka. In: Pushcharovskiy, Yu.M., (Ed.), Sketches on Geology of Northwestern Sector of the Pacific Tectonic belt, Nauka, Moscow, pp. 5–73, in Russian.
- Gladenkov, Yu.B., Sinelnikova, V.N., Shants'er, A.E., Tschhelebaeva, A.I., Oleinik, A.E., Titova, L.V., Bratzeva, G.M., Fregatova, N.A., Zyryanov, E.V., Kazakov, K.G., 1991. The Eocene of Western Kamchatka. Transactions of the Geological Institute, Russian Academy of Sciences 467, 1–184. in Russian.
- Gladenkov, Yu.B., Barinov, K.B., Basilian, A.E., Bordunov, S.I., Bratzeva, G.M., Zytyanov, Ye.V., Kuralenko, N.P., Vitukhin, D.I., Oreshkina, T.V., Ganzei, S.S., Kiyashko, S.I., Trubikhin, V.M., 1992. Detailed division of the Neogene of Kamchatka. Transactions of the Geological Institute, Russian Academy of Sciences 478, 1–208. in Russian.
- Gladenkov, Yu.B., Shants'er, A.E., Tschhelebaeva, A.I., Sinelnikova, V.N., Antipov, M.P., Ben'yamovskiy, V.N., Bratzeva, G.M., Polyanskiy, B.V., Stupin, S.I., Fedorov, P.I., 1997. The lower Paleogene of Western Kamchatka (stratigraphy, paleogeography, geological events). Transactions of the Geological Institute, Russian Academy of Sciences 488, 1–368. in Russian.
- Gladenkov, Yu.B., Sal'nikov, B.A., Barinov, K.B., Brutman, N.Ya., Vitukhin, D.I., Grechin, V.I., Ivan'shina, L.P., Margulis, L.S., Oreshkina, T.V., Radchenko, V.G., Stupin, S.I., 1999. Cenozoic Ecosystems of the Okhosk Sea Region, The Paleogene and Neogene Key section of North Sakhalin (Shmidt Peninsula): Stratigraphy, Paleogeography, and Geological Events, GEOS, Moscow.
- Hatai, K., Koike, K., 1957. On some fossil Mollusca from Chiba Prefecture Japan. Japanese Journal of Geology and Geography 28 (1–3), 77–90.
- Hayasaka, S., Hangai, T., 1966. A new locality of *Fortipecten takahashii* (Yokoyama) in Fukushima Prefecture, with reference to its associated fauna. Saito Ho-on Kai Museum, Research Bulletin 34, 29–37.
- Hayashi, T., 1973. Fossils from the environs of Horaiji-san. Bulletin of the Horaijisan Natural Science Museum, 10–17. in Japanese.
- Hayashi, T., Miura, Y., 1973. The Cenozoic sediments in the southern part of Okazaki City, central Japan. The Bulletin of Aichi University of Education, Natural Science 22, 133–149. in Japanese.
- Hirayama, K., 1954. A Miocene Mollusca from the Arakawa Group Tochigi Prefecture, Japan. Part 1 Science Reports of the Tokyo Kyoiku Daigaku, Section C (Geology, Mineralogy and Geography) 3 (18), 43–76.
- Hirayama, K., 1955. The Asagai Formation and its molluscan fossils in the northern region Joban coal-field, Fukushima Prefecture, Japan. Science Reports of the Tokyo Kyoiku Daigaku, Section C (Geology, Mineralogy and Geography) 4 (29), 49–130.
- Hirayama, K., 1973. Molluscan fauna from the Miocene Hiranita Formation Chichibu basin, Saitama Prefecture, Japan. Science Reports of the Tohoku University, 2nd Series (Geology) 6, 163–177.
- Holman, E.W., 1983. Time scales and taxonomic survivorship. Paleobiology 9 (1), 20–25.
- Ikebe, N., Takayanagi, Y., Chiji, M., Chinzei, K., 1972. Neogene biostratigraphy and radiometric scale of Japan. Journal of Pacific Geology 4, 39–79.
- Inoue, E., 1972. Lithofacies, fossil assemblages and sedimentary environment of Oligocene Kishima Formation in Karatsu coal-field, northwest Kyushu, Southwest Japan. Report of the Geological Survey of Japan 245, 1–72. in Japanese.
- International Stratigraphic Guide: A Guide to Stratigraphic Classification, Terminology, and Procedure. Second Ed. Trondheim, Norway: International Union of Geological Sciences; Boulder, CO: Geological Society of America, 1994.
- Itoigawa, J., 1955. Molluscan fauna of the Mizunami Group in the Iwamura basin. Memoirs of the College of College of Science, University of Kyoto, Series B (Geology and Mineralogy) 22 (2), 127–143.
- Itoigawa, J., 1956. Molluscan fauna of the Tsuzuki Group in Kyoto Prefecture Japan. Memoirs of the College of College of Science, University of Kyoto, Series B (Geology and Mineralogy) 23 (2), 179–192.
- Itoigawa, J., 1957. On the Miocene Lucinidae from the Mizunami Group Japan. Transactions and Proceedings of the Palaeontological Society of Japan, New Series 25, 1–6.
- Itoigawa, J., Shibata, H., Nishimoto, H., 1974. Molluscan fossils of the Mizunami Group. Bulletin of the Mizunami Fossil Museum 1, 43–203. in Japanese.

- Iwai, T., 1961. The Miocene molluscan fossils from the area southwest of Hirosaki City, Aomori Prefecture, Japan. Transactions and Proceedings of the Palaeontological Society of Japan, New Series 41, 1–8.
- Iwai, T., 1965. The geological and paleontological studies in the marginal area of the Tsugaru basin, Aomori Prefecture, Japan. The Bulletin of Educational Faculty of Hirosaki University 15, 1–68.
- Kafanov, A.I., 1987. The Willis 'age and area' rule and latitudinal heterochrony of marine biota. Zhurnal obshchey biologii (Journal of General Biology) 48 (1), 105–114. in Russian.
- Kafanov, A.I., 1994. The influence of species richness and abundance on measures of inclusion in the theoretical-and-graph analysis. Izvestiya Akademii Nauk, Seriya biologicheskaya (Proceedings of Russian Academy of Sciences, Series Biological) 3, 428–434. in Russian.
- Kafanov, A.I., 1997. The unity of the empirical and rational in cognition of biodiversity: a reply to I.Ya. Pavlinov et al. (1995). Zhurnal obshchey biologii (Journal of General Biology) 58 (4), 77–91.
- Kafanov, A.I., Amano, K., 1996. Japanese contribution to the Cenozoic marine Bivalvia paleontology of Sakhalin and Kurile Islands. Bulletin of the Russian Far East Malacological Society 1, 13–20.
- Kafanov, A.I., Amano, K., 1997. Check list of Cenozoic marine Bivalvia (Mollusca) of Sakhalin and Kurile Islands described by Japanese paleontologists during 1925–1990. Bulletin of the Mizunami Fossil Museum 24, 11–25.
- Kafanov, A.I., Sukhanov, V.V., 1995. Why there are so few large genera? Zhurnal obshchey biologii (Journal of General Biology) 56 (1), 141–151.
- Kafanov, A.I., Barinov, K.B., Marincovich, L. Jr., 1999a. *Papyridea harrimani* Dall, 1904 (Bivalvia, Cardiidae) as a marker for upper Eocene and lower Oligocene strata of the North Pacific. Paleontological Research 3 (3), 141–150.
- Kafanov, A.I., Ogasawara, K., Amano, K., 1999b. Check list and bibliography of the Cenozoic marine Bivalvia (Mollusca) of North-eastern Asia (Russian Far East) 1893–1938. Bulletin of the Mizunami Fossil Museum 26, 1–76.
- Kafanov, A.I., Ogasawara, K., Marincovich, L. Jr., 2000. Check list and bibliography of the Cenozoic marine Bivalvia (Mollusca) of North-eastern Asia (Russian Far East) 1939–1967. Bulletin of the Mizunami Fossil Museum 27, 13–107.
- Kafanov, A.I., Ogasawara, K., Marincovich, L. Jr., 2001. Check list and bibliography of the Cenozoic marine Bivalvia (Mollusca) of North-eastern Asia (Russian Far East) 1968–1999. Bulletin of the Mizunami Fossil Museum 28, 1–138.
- Kalishевич, T.G., Zaklinskaja, E.D., Serova, M.Ya., 1981. Development of the Organic World of the Pacific Belt on the Mesozoic and Cenozoic Boundary, Foraminifers, Molluscs and Palynoflora of the Northwestern Sector, Nauka, Moscow, in Russian.
- Kamada, Y., 1962. Tertiary marine Mollusca from the Joban coal-field Japan. Palaeontological Society of Japan, Special Papers 8, 1–187.
- Kanno, S., 1960. The Tertiary System of the Chichibu basin, Saitama Prefecture, central Japan. Part II. Palaeontology.: Japan Society of Promotion of Sciences, Tokyo, 123–396.
- Kanno, S., 1961. Miocene *Pleurotomaria* and its associated fauna from Tochigi Prefecture Japan. Japanese Journal of Geology and Geography 32 (1), 111–118.
- Kanno, S., 1962. Molluscan fauna from the so-called Setana Formation, southwestern Hokkaido, Japan. Science Reports of the Tokyo Kyoiku Daigaku, Section C (Geology, Mineralogy and Geography) 8 (73), 49–62.
- Kanno, S., 1967. Molluscan fauna from the Miocene formations in the Itsukaichi basin, Tokyo Prefecture, Professor Hidetaka Shibata Memorial Volume, Tokyo, pp. 396–406.
- Kanno, S., 1971. Tertiary molluscan fauna from the Yakataga District and adjacent areas of southern Alaska. Palaeontological Society of Japan Special Papers 16, 1–154.
- Kanno, S., Arai, J., 1964. Geology of the Tertiary System in the Itsukaichi basin, Tokyo Prefecture. Bulletin of the Chichibu Museum of Natural History 12, 1–15. in Japanese.
- Kanno, S., Ogawa, H., 1964. Molluscan fauna from the Momijiyama and Takinoue districts, Hokkaido, Japan. Science Reports of the Tokyo Kyoiku Daigaku, Section C (Geology, Mineralogy and Geography) 8 (81), 269–294.
- Kanno, S., Akatsu, K., 1972. Tertiary System developed in the Taiki-machi, Biroo-gun, Hokkaido. Memoirs of the National Science Museum, Tokyo 5, 227–238. in Japanese.
- Kanno, S., Ohara, S., Kaiteya, H., 1968. The 'Ashiya Fauna' from the Miocene Formation developed near the Asahi coal-mine, Iwamizawa city, Hokkaido. Science Reports of the Tokyo Kyoiku Daigaku, Section C (Geology, Mineralogy and Geography) 10 (94), 1–14.
- Kaseno, Y., Matsuura, N., 1965. Pliocene shells from the Omma Formation around Kanazawa City. The Science Reports of Kanazawa University 10 (1), 27–62.
- Krishtofovich, L.V., 1964. Molluscs of the Tertiary deposits of Sakhalin. Transactions of the All-Union Petroleum Scientific-Research Geological-Exploration Institute 232, 1–344. in Russian.
- Krishtofovich, L.V., 1969. Provincial stratigraphic scheme of marine Paleogene and Neogene deposits of northwestern part of Pacific Region. In: Fursenko, A.V., (Ed.), Biostratigraphy, fauna and flora of Cenozoic of the northwestern part of Pacific mobile belt, Nauka, Moscow, pp. 26–34, in Russian.
- Krishtofovich, L.V., Ilyina, A.P., 1961. Biostratigraphy of the Paleogene and Neogene deposits of Tigilsky District of Western Kamchatka. The Unified Stratigraphic Schemes of Northeast of the USSR, Gostoptekhizdat, Moscow, 170–180. in Russian.
- Kurita, H., Obuse, A., Ogasawara, K., Hasegawa, S., Amano, K., Hisada, K., 2000. Oligocene and middle Miocene palynostratigraphy (dinoflagellate cysts and pollen) in Sakhalin Island, Far East Russia, and its implications for geochronology and paleoenvironments. Journal of Geography 109 (2/269), 187–202. in Japanese.
- Lyell, Ch., 1830–1833. Principles of geology, or, The modern changes of the earth and its inhabitants considered as Illustrative of geology, three vols. Murray, London.
- Lyell, Ch., 1867. Principles of geology; or, The modern changes of the earth and its inhabitants considered as illustrative of geology, 10th and entirely Revised Ed. vol. 1. Murray London.
- MacNeil, F.S., 1965. Evolution and distribution of the genus *Mya*, and Tertiary migrations of Mollusca. US Geological Survey Professional Paper 483, 1–51.
- Marincovich, L. Jr., 1984. Eastern Pacific molluscan bio-events and their relation to Neogene planktonic datum planes. In: Ikebe, N., Tsuchi, R. (Eds.), Pacific Neogene Datum Planes, Contributions to Biostratigraphy and Chronology, University of Tokyo Press, Tokyo, pp. 69–73.
- Matsui, M., 1957. On the Pepeshiru Formation in the Kanayama coal-field Central Hokkaido. The Journal of the Geological Society of Japan 63 (740), 317–322.
- Matsumoto, E., 1964. The Asagai-Poronai molluscs from Shizuoka Prefecture Central Japan. Memoirs of the College of Science, University of Kyoto, Series B (Geology and Mineralogy) 31 (2), 95–112. art.4.
- Matsumoto, E., 1966. Molluscan fossils from the Muro Group in the southern part of the Kii Peninsula, central Japan. Part 1. Memoirs of the College of Science, University of Kyoto, Series B (Geology and Mineralogy) 32 (4), 369–378. art. 7.
- Masuda, K., 1959. On the Miocene Pectinidae from the environs of Sendai. Part 15. Pecten cosibensis Yokoyama and its related species. Transactions and Proceedings of the Palaeontological Society of Japan, New Series 35, 121–132.
- Masuda, K., 1962a. Pectinid fauna from the Pliocene Sannohe Group Aomori Prefecture, Northeast Honshu, Japan. Ho-on Kai Museum, Research Bulletin 31, 20–26.
- Masuda, K., 1962b. Tertiary Pectinidae of Japan. The Science Reports of the Tohoku University (Geology) 33 (2), 117–238.
- Masuda, K., 1973a. Chlamys cosibensis (Yokoyama) of the northern Pacific. The Science Reports of the Tohoku University, Second Series

- (Geology), Special Volume 6, 109–116. Professor Kotora Hatai Memorial Volume.
- Masuda, K., 1973b. Molluscan biostratigraphy of the Japanese Neogene. The Memoirs of the Geological Society of Japan 8, 107–120. in Japanese.
- Masuda, K., Sawada, Y., 1961. Some new Tertiary pectinids from southwestern Hokkaido. Japanese Journal of Geology and Geography 32 (1), 19–29.
- Masuda, K., Shibata, T., 1971. Molluscan fauna from the Matsuzakatoge Formation Fukushima Prefecture, Japan. Saito Ho-on Kai Museum, Research Bulletin 40, 35–41.
1984. Transactions of the Geological Institute, Academy of Sciences of the USSR vol. 385, 1–336. in Russian.
- Minato, M., 1950. Illustrated Cenozoic fossils of northern Japan 4. The Cenozoic Research (Shin-seidai-no-Kenkyu) 3, 18–19. in Japanese.
- Minato, M., Kumano, S., 1950. Illustrated Cenozoic fossils of northern Japan. 8. Two fossil shells from Wakkanabe Formation, Utashinai district. The Cenozoic Research (Shin-seidai-no-Kenkyu) 5, 80–81. in Japanese.
- Minato, M., Matsui, M., Uozumi, S., 1950. Illustrated Cenozoic fossils of northern Japan. 11. On Mya from Hokkaido. The Cenozoic Research (Shin-seidai-no-Kenkyu) 7, 4–7. in Japanese.
- Miyajima, K., 1959. Illustrated Cenozoic fossils. 29. On some molluscan fossils from the Shiraki Formation, Uryu coal field, Hokkaido. The Cenozoic Research (Shin-seidai-no-Kenkyu) 29, 709–713. in Japanese.
- Mizuno, A., 1954. On *Yoldia laudabilis* (Yokoyama). The Cenozoic Research (Shin-seidai-no-Kenkyu) 20, 13–18. in Japanese.
- Mizuno, A., 1964. Paleogene and early Neogene molluscan faunas in West Japan. Reports of the Geological Survey of Japan 204, 1–72.
- Mizuno, A., Inoue, M., 1969. Some new species of bivalves from the Oligocene Poronai Formation. Bulletin of the Geological Survey of Japan 20 (10), 651–656.
- Mizuno, A., Sumi, Y., Yamaguchi, S., 1969. Miocene stratigraphy of the Kushiro coal-field, eastern Hokkaido, with the special reference to the stratigraphic problem concerning the so-called Chokubetsu Formation. Bulletin of the Geological Survey of Japan 20 (10), 633–649. in Japanese.
- Moore, E.J., 1963. Miocene marine mollusks from the Astoria Formation in Oregon. US Geological Survey Professional Paper 419, 1–109.
- Moore, E.J., 1983. Tertiary marine pelecypods of California and Baja California: Nuculidae through Malleidae. US Geological Survey Professional Paper 1228-A, 1–108.
- Moore, E.J., 1988. Tertiary marine pelecypods of California and Baja California: Lucinidae through Chamidae. US Geological Survey Professional Paper 1228-D, 1–46.
- Morita, R., Titova, L., Akiba, F., 1996. Oligocene-early Miocene molluscs and diatoms from the Kitami-Tsubetsu area, eastern Hokkaido, Japan. Science Reports of the Tohoku University (Geology) 63 (2), 53–213.
- Nagao, T., Inoue, T., 1941. Myarian fossils from the Cenozoic deposits of Hokkaido and Karahuto. Journal of the Faculty of Science, Hokkaido Imperial University, Series 4 (Geology and Mineralogy) 6 (2), 143–158.
- Nakashima, R., 2002. Geographic distribution of the late Cenozoic bivalve *Fortipecten* in the northwestern Pacific. Palaeogeography, Palaeoclimatology, Palaeoecology 186 (3–4), 261–274.
- Noda, H., 1973. Additional notes on the Myagian marine fauna from the Gobanshoyama Formation Ojika Peninsula, Miyagi Prefecture, Japan. Saito Ho-on Kai Museum, Research Bulletin 42, 31–45.
- Noda, H., Masuda, K., 1968. On the Early Miyagian marine fauna from the Ojika Peninsula Miyagi Prefecture, Japan. Saito Ho-on Kai Museum, Research Bulletin 37, 1–9.
- Noda, H., Tada, M., 1968. Anadariids from the Shizukuishi basin Iwate Prefecture, Japan. Transactions and Proceedings of the Palaeontological Society of Japan, New Series 69, 193–206.
- Ogasawara, K., Kenzo, 1955. On some molluscan remains found from the Upper Ishikari Group, representing the leading type of the Poronai Formation. Bulletin of the Geological Committee of Hokkaido (Hokkaido Chishitsu Yo-ho) 29, 28–29. in Japanese.
- Ozaki, H., 1958. Stratigraphical and paleontological studies on the Neogene and Pleistocene formations of the Tyosi district. Bulletin of the National Science Museum, New Series 4 (1;42), 1–182.
- Petrov, O.M., 1982. Marine molluscs of the Anthropogene from the northern region of the Pacific. Transactions of the Geological Institute, Academy of Sciences of the USSR 357, 1–144. in Russian.
- Resolution of the Interdepartmental workshops on Paleogene and Neogene stratigraphy of Russia: Kamchatka, Koryak Upland, Sakhalin, and Kuril Islands. Explanatory note to stratigraphic schemes. Approved by ISC January 28, 1998. GEOS, Moscow (in Russian).
- Sakagami, S., Takano, N., Sasaki, A., Nishikage, T., Ichido, Y., Ozeki, S., Shinohara, H., Tanaka, R., Shimokawabe, H., Takahashi, Y., Takeshita, Y., Hayashi, T., 1966. Fossils from the Tomikawa Formation of Kamiiso, Ohshima Peninsula, Hokkaido. 1. Molluscs, etc. Journal of the Hokkaido University of Education B17 (1), 78–93. in Japanese.
- Sawada, Y., 1962. The geology and paleontology of the Setana and Kuromatsunai areas in southwest Hokkaido Japan. The Memoirs of the Muroan Institute of Technology 4 (1), 1–110.
- Serova, M.Ya., 1978. Stratigraphy and foraminifers of the Neogene of Kamchatka. Transactions of the Geological Institute, Academy of Sciences of the USSR 323, 1–176. in Russian.
- Shikama, T., 1954. On the Tertiary formations of Tomikusa in south Nagano Prefecture. Science Reports of the Yokohama National University, Series 2 (Biological and Geological Science) 3, 71–108. in Japanese.
- Snavely, P.D. Jr., MacLeod, N.S., Rau, W.W., 1969. Geology of the Newport area Oregon (part II, Geologic fieldtrip guide). Ore Bin 31 (3), 49–71.
- Takayasu, T., 1961. On stratigraphy and fossil fauna in the environs of Tofuiwa, northern part of Akita City, Akita Prefecture. Study of Cenozoic fauna in the region of Akita oil field. Part 1. Report of the Research Institute of Underground Resources, Mining College, Akita University 25, 1–14. in Japanese.
- Takayasu, T., 1962. On fossil faunas from the Kitaura and Wakimoto Formations, Oga Peninsula, Akita Prefecture. Study of Cenozoic fauna in the region of Akita oil field. Part 3. Report of the Research Institute of Underground Resources, Mining College, Akita University 27, 43–47. in Japanese.
- Tanaka, K., 1959a. Molluscan fossils from central Shinano Nagano Prefecture, Japan. Part I. Fossils from Akanuda Limestone. Journal of Shinshu University 8, 115–133.
- Tanaka, K., 1959b. Molluscan fossils from central Shinano Nagano Prefecture, Japan. Part II. Family Nuculanidae. Bulletin of the Faculty of Education, Shinshu University 10, 67–79.
- Tsuchi, R., Shuto, T., 1984. Western Pacific molluscan bio-events and their relation to Neogene planktonic datum planes. In: Ikebe, N., Tsuchi, R. (Eds.), Pacific Neogene Datum Planes, Contributions to Biostratigraphy and Chronology, University of Tokyo Press, Tokyo, pp. 75–82.
- Uozumi, S., 1952. Illustrated Cenozoic fossils of northern Japan. 18. On some fossils from Poronai Formation. The Cenozoic Research (Shin-seidai-no-Kenkyu) 12, 212–214. in Japanese.
- Uozumi, S., 1953. Illustrated Cenozoic fossils of northern Japan. 23. Miocene fossils from Hokkaido. Part 1. The Cenozoic Research (Shin-seidai-no-Kenkyu) 18, 356–358. in Japanese.
- Uozumi, S., 1955a. Fossil *Yoldia* and *Portlandia*. Part 1. Characters of the genera and subgenera. The Cenozoic Research (Shin-seidai-no-Kenkyu) 22, 24–30. in Japanese.
- Uozumi, S., 1955b. On some molluscan fossils from the Paleogene Wakkanabe Formation in Hokkaido. Transactions and

- Proceedings of the Palaeontological Society of Japan, New Series 19, 73–80.
- Uozumi, S., 1957. Studies on the molluscan fossils from Hokkaido. Part 2. Genera *Yoldia* and *Portlandia*. Journal of the Faculty of Science, Hokkaido University, Series 4 (Geology and Mineralogy) 9 (4), 539–596.
- Uozumi, S., 1966. Neogene molluscan fauna in Hokkaido. Part I. Description of the Asahi fauna associated with *Mytilus tichanovitchi* Makiyama, from Ikushunbetsu district, central Hokkaido. Journal of the Faculty of Science, Hokkaido University, Series 4 (Geology and Mineralogy) 13 (2), 119–137.
- Uozumi, S., Fujie, T., Matsui, M., 1966. Neogene molluscan fauna in Hokkaido Part III. Description of the Aionai fauna associated with *Desmostylus* cf. *minor* Nagao, from Kitami district, East Hokkaido. Journal of the Faculty of Science, Hokkaido University, Series 4 (Geology and Mineralogy) 13 (2), 165–183.
- Vereshchagin, V.N. (Ed.), 1982. A stratigraphic dictionary of the USSR. Paleogene, Neogene, Quaternary System. Nedra, Leningrad (in Russian).
- Volobueva, V.I., 1976. Paleogene and Miocene deposits of Nizhne-Khatyrka depression. Materials on geology and mineral resources of the North East of the USSR 23 (1), 63–69. in Russian.
- Volobueva, V.I., Belaja, B.V., Dolmatova, L.M., Grevtsev, A.V., Minyuk, P.S., Narkhinova, V.E., Polovova, T.P and Shchiraya, O.A., 1992. Key section of marine Neogene of northeast Asia in Karaginsky Island. Pt. 2. Systematic part. North East Multidisciplinary Scientific-Research Institute, Far East Branch, Russian Academy of Sciences, Magadan (in Russian).
- Volobueva, V.I., Gladenkov Y.B., Ben'yamovskiy V.N., Vitukhin D.I., Minyuk P.S., Muzylev, N.G., Oleinik, A.E., Sinelnikova, V.N., Sokolova, Z. Sh., Titova, L.V., Fregatova, N.A. and Shchiraya, O.A., 1994. Key section of marine Paleogene in the North of the Far East (Il'pinskiy Peninsula). Part 2. Systematical part. North East Multidisciplinary Scientific-Research Institute, Far East Branch, Russian Academy of Sciences, Magadan (in Russian).
- Ward, J.H., 1963. Hierarchical grouping to optimize an objective function. Journal of the American Statistical Association 58 (301), 236–244.
- Watanabe, K., Arai, J., Hayashi, T., 1950. Tertiary geology of the Chichibu basin. Bulletin of the Chichibu Museum of Natural History 1, 29–92.
- Weaver, C., 1942 (1943). Paleontology of the marine Tertiary formations of Oregon and Washington. University of Washington Publications in Geology 5, Part I. Coelenterata, Vermes, Echinodermata, Molluscoidea, Mollusca: Pelecypoda; Scaphopoda, pp. 1–274; part II. Mollusca: Gastropoda; Cephalopoda; Arthropoda, pp. 275–562; part III. Bibliography, faunal localities, correlation chart, faunal tables, plates, new names, index, pp. 563–790.
- Weaver, C., Beek, S., Bramlette, M., 1944. Correlation of the marine Cenozoic formations of Western North America. Bulletin of the Geological Society of America 55 (5), 3–24.
- Weaver, D.W., Kleinpell, R.M., 1963. Oligocene biostratigraphy of the Santa Barbara embayment California. Pt. II. Mollusca from the *Turritella variata* zone. University of California Publications in Geological Sciences 43, 81–161.
- Yamana, I., 1966. Neogene fossil Mollusca from Akenobe Tottori Prefecture Japan. Bulletin of the Japan Museum Association 1, 33–37. in Japanese.
- Zhidkova, L.S., Kuzina, I.N., Lautenschläger, F.G., Popova, L.A., 1968. Atlas of molluscs of upper Miocene and Pliocene of Sakhalin, Nauka, Moscow, in Russian.
- Zhidkova, L.S., Bevez, V.E., Krishtofovich, A.P., Neverova, T.I., Savizky, V.O., Scheremetjeva, G.N., 1972. Atlas of Neogene molluscs of Kurile Islands, Nauka, Moscow, in Russian.
- Zhidkova, L.S., Pronina, I.G., 1978. A correlation of Paleogene and Neogene deposits of the northern part of Pacific Ocean (based on the molluscs). In: Zhidkova, L.S., (Ed.), Cenozoic of Far East region of the USSR, All-Russia Petroleum Scientific-Research Geological-Exploration Institute, Leningrad, pp. 42–80.
- Zinbo, N., 1973. Fossil shells from the Tsunakigawa Formation, Yonezawa City, Yamagata Prefecture. Professor Kuman Haraguchi Memorial Volume, Yamagata, pp. 91–96 (in Japanese).
- Zipf, G.K., 1949. Human behavior and the principle of least effort: An introduction to human ecology, Addison-Wesley Press, Inc, Cambridge, Mass.