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Structure and Age of Mesozoic Sedimentary-Volcanogenic Deposits of the Palana Section (Western Kamchatka)

T. N. Palechek,* A. V. Solov'ev,* and M. N. Shapiro**

**Institute of Lithosphere of Marginal Seas, Russian Academy of Sciences, Staromonetnyi per. 22, Moscow, 119180 Russia*
***Institute of Physics of the Earth, Russian Academy of Sciences, ul. Bol'shaya Gruzinskaya 10, Moscow, 103810 Russia*
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Abstract—It is difficult to reconstruct the pre-Cenozoic history of western Kamchatka, because Mesozoic deposits are fragmentarily exposed here. The Palana section, the most complete one among Mesozoic sections of the region, is described and subdivided into volcanogenic and olistostrome sequences. Based on radiolarians, the volcanogenic sequence is attributed to the Campanian-Maastrichtian. The siliceous olistoliths have been formed in the Late Jurassic to Late Cretaceous time. Data on radiolarians indicate the late Campanian-Maastrichtian age of the olistostrome matrix, but volcanogenic olistoliths suggest that the tectonic imbrication and related olistostrome formation took place after the early Maastrichtian. According to published data, the general deformation of the Palana section, which brought about a sharp unconformity at the base of the Anadyrka Formation, has been finished by the mid-Danian.

Key words: Campanian-Maastrichtian, radiolarians, Upper Maastrichtian olistostrome, Palana section, western Kamchatka.

INTRODUCTION

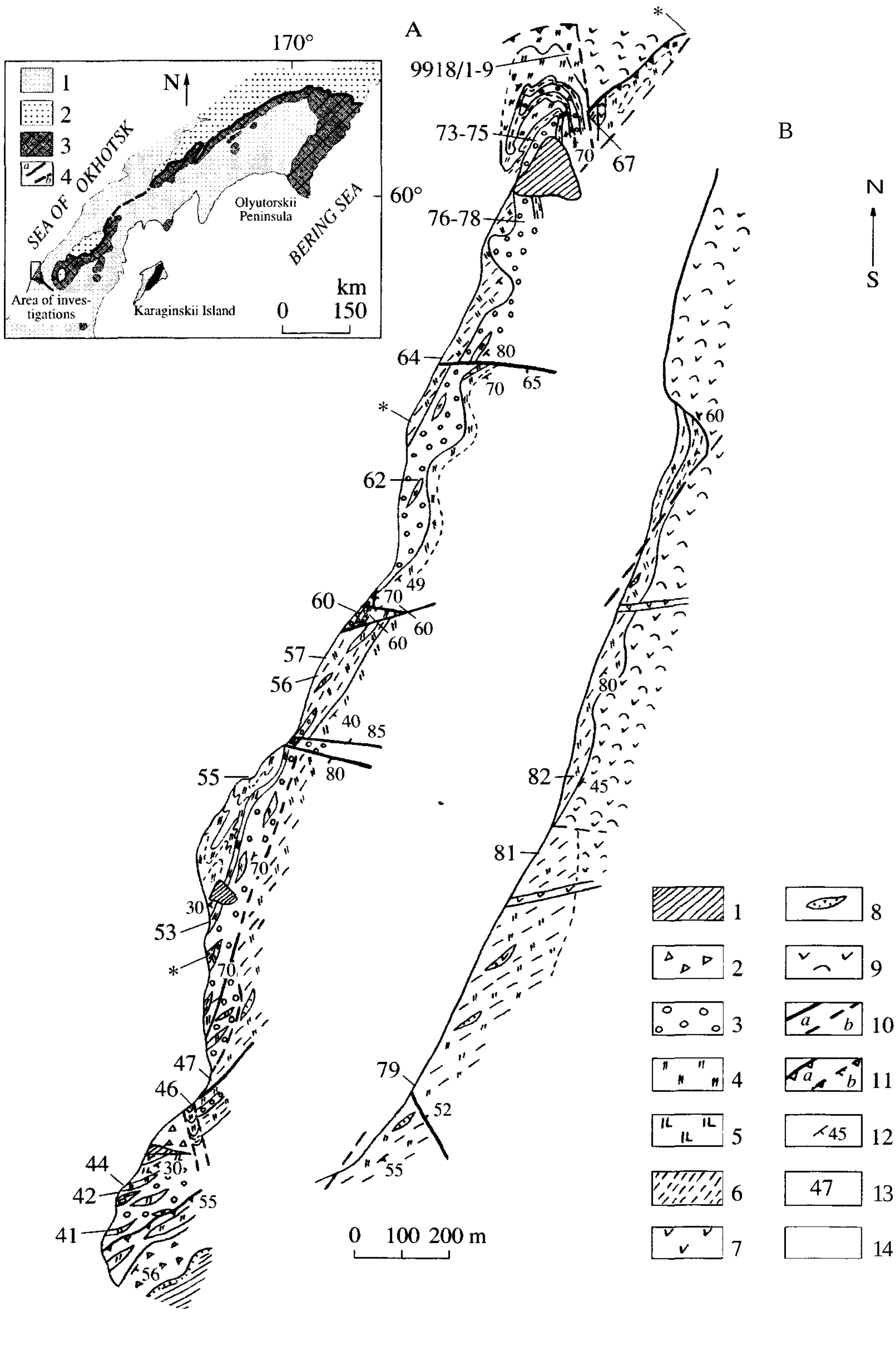
Western Kamchatka is an area of distribution of predominantly Cenozoic deposits with few uplifted blocks composed of pre-Cenozoic deposits, mostly of Upper Cretaceous ones (*Ob'yasnitel'naya...*, 2000). Mesozoic sections, most of which are poorly exposed and incomplete, are unsuitable for understanding of pre-Cenozoic history of the peninsula and the adjacent areas of the Sea of Okhotsk. The Upper Cretaceous rocks exposed in sea cliffs are of particular significance in this situation. The northernmost exposure is located to the north of the Palana River mouth (figure).

Geology of this area was first studied by Dvali (1957), who described the Palana Horizon and tuff-shale sequence of the Cape Palanskii. Later on, in the course of geological mapping, scale 1 : 200000 (Demidov and Sulima, 1982), the Kingiveem, Irunei, Tal'nichnaya and Ust-Palana formations were distinguished. In the geological map, scale 1 : 1000000 (*Geologicheskaya...*, 1989), Cretaceous deposits of the Palana area are divided into the Lower Cretaceous Kingiveem (basalts, dolerites, and siliceous rocks), Campanian Irunei (dolerites, basalts, tuffs, and jaspers), and Maastrichtian Ust-Palana (tuffs, tuff breccias of basalt to trachybasalt composition, sandstones, and conglomerates) formations. In 1991, A.B. Tsukernik who studied the Palana section presented his results in special report of GNPP Aerogeologiya. He established that the northern larger part of seashore exposures southward of the Anadyrka River corresponds to volcanogenic-sedimentary rocks of the Campanian Irunei Formation and distinguished an olistostrome of the Ust-Palana Formation. Geological structure of Cenozoic deposits exposed in sea cliff to the north of the Palana River was described in detail by Gladenkov *et al.* (1977).

THE SECTION STRUCTURE

We divide the pre-Cenozoic Palana section in two, the volcanogenic and olistostrome sequences (figure). Characteristic volcanogenic clasts occurring in the olistostrome suggest that the latter initially overlapped the volcanogenic sequence.

Volcanogenic sequence. In the study area there are no sections where the base of volcanogenic rocks can be observed. These rocks exposed in northern seashore cliffs to the south of the Anadyrka River mouth are mostly represented by massive volcanic breccias (agglomerate) of basaltic and basaltic-andesite composition. Dark gray to black rock clasts in breccias are porphyritic, containing large (up to 3 or 4 mm) isometric phenocrysts of clinopyroxene. Some varieties of basaltic andesites reveal presence of needle-shaped hornblende phenocrysts. Angular basaltic clasts ranging in size from few centimeters to few meters are set, as a rule, in matrix of a similar composition. Some rocks with subangular clasts of different texture can be considered as tuff breccias. The deposits lack any bedding, even the coarse one, and it is impossible to define their attitude, although there are many long multidirectional cracks and fracture zones. Breccias and more massive basalts are intercalated with thin (10–30 m)



Geology of coastal exposures (A and continuation B) to the north of the Palana Settlement (plan view): (1) talus; (2) melange zone; (3) conglomerate, gravelstone, or sandstone; (4) chert; (5) cherts with fragments inoceramid shells; (6) siltstone, siliceous siltstone; (7) basalt; (8) sandstone lens; (9) basaltic breccia (agglomerate), basalt, and basaltic andesites; (10) established *(a)* and presumable *(b)* steep normal faults; (11) established *(a)* and presumable *(b)* thrust faults; (12) altitude; (13) number of sample with microfauna; (14) points of samples dated by Kurilov (2000).

The inset map shows distribution of Cretaceous deposits of the Olyutorskii zone and northern Kamchatka; (1) Cenozoic deposits; (2) Cretaceous-Paleogene deposits of the Ukelayat-Lesnaya depression; (3) Cretaceous siliceous-volcanogenic deposits; (4) Vatyna-Lesnaya thrust fault with established *(a)* and presumable *(b)* segments.

members of mudstones, tuffaceous siltstones and sandstones, siliceous siltstones, and with gray and black cherts having admixture tuffaceous material. Some tuffaceous sandstones and siltstones show indistinct graded bedding. The bedded members are usually in tectonic contacts with enclosing breccias and strongly deformed into tectonic breccias and broken small folds. As a rule, the deposits strike in submeridional direction and dip at steep angles to the east-southeast or west-northwest (in the northernmost outcrops). The strike is parallel to the seashore line and probably corresponds to the attitude of the entire sequence. The bedded members are of a uniform appearance, and some of them may be repeated in the sequence, although the lowest ones are almost entirely composed, in distinction from others, of mudstones with rare chert lenses and fragmented thin prismatic layers of inoceramid shells. It is difficult to precisely estimate the overall apparent thickness of volcanogenic rocks, which may be over one kilometer thick, if they form a monocline extending parallel to the seashore.

Age of volcanogenic rocks. The K/Ar dates of 72.5 ± 3.5 Ma (sample Sh88) and 72.0 ± 3.5 Ma (sample Sh89) have been obtained for amphiboles from two samples of basaltic andesites collected 3 km to the south of the Anadyrka River mouth (age determinations by M.M. Arakelyants).

Five samples of siliceous sediments intercalated with volcanogenic rocks yielded radiolarians, which are satisfactorily preserved (Table 1). The most representative radiolarian assemblages from samples 37 and 79/b indicate the late Campanian-Maastrichtian age of their host rocks. V. S. Vishnevskaya (personal communication) who previously studied a siliceous siltstone from the sequence (sample Ts17/1,2 from the Tsukernik's collection, GNPP Aerogeologiya) identified the Campanian radiolarians *Archaeospongoprunum nishiyamae* Nakaseko et Nishimura, *Orbiculiforma quadrata* Pessagno, *Pseudoaulophacus* sp., *Amphipyndax stocki* (Campbell et Clark), *Eucyrtis carnegiense* Campbell et Clark, and *Lithostrobus* sp.

Olistostrome. To the south of the volcanogenic sequence, in the northern Ust-Palana area, there are cliffs and tidal zone with exposures of olistostrome deposits (figure). The olistostrome is separated from the volcanogenic one by a steep normal fault of submeridional strike. It represents an accumulation, chaotic to poorly structured (oriented), of blocks and size-variable lenses (up to 80 m long) of bedded red, gray-green, and almost black cherts and siliceous mudstones set in the brecciated sandstone matrix. Some large olistoliths and smaller blocks enclose pyroxene basalts with agglomerate texture characteristic of the Palana volcanogenic sequence. Olistoliths of cherts and siliceous mudstones contain, as a rule, the inclusions of fragmented prismatic layers of thick-shell inoceramids. Occasionally these fragments are concentrated in coquina beds with relatively low content of cherty matrix.

The olistostrome matrix is composed of clastic rocks, such as fine-clastic breccia and breccia-conglomerate, gravelstones, and sandstones with rare thin lenticular interbeds of black siliceous mudstones and cherts. Clearly dominating clasts are those of different siliceous rocks, including their varieties with inclusions of fragmented inoceramid shells. The shell fragments frequently occur as separate grains in sandstones. Reworked radiolarians are also present in small clasts of their host rocks. Some sandstone varieties represent a two-component mixture of chert clasts and basaltoid fragments (plagioclases, pyroxenes, and microlitic matrix). In general mineral composition, the latter are analogous to pyroxene basalts of the volcanogenic sequence.

The chaotic complex is intensively dislocated and pierced by mylonitic zones, which frequently bound large blocks and olistoliths. Some blocks of siliceous sediments exhibit small folds, including those with steep hinge lines. The olistoliths are locally sharply bended. We do not consider this chaotic complex as a tectonic melange or megabreccia and identify it, following Tsukernik, as an olistostrome. This is based primarily on the type of matrix composed of peculiar but typical sedimentary deposits, i.e., of breccia–conglomerate, gravelstones, sandstones, and siltstones. Assuming the fragments of these rocks and cherts to be tectonically derived from an original integral sequence, we should admit that the latter represented an alternation of coarse-clastic terrigenous deposits, cherts devoid of terrigenous admixture, and basalts typical of island arcs that is hardly possible. Even if such a sequence existed, clastic material in its terrigenous sediments could not be identical in composition to intercalated siliceous beds, as it recorded in the olistostrome.

Despite the complex inner structure of the olistostrome, structural elements recognizable in the matrix and large olistoliths predominantly have submeridional strike and east-southeast dipping. If they characterize a monocline, the olistostrome thickness should be more than 500 m.

Age of olistostrome. Samples of cherts and siliceous mudstones have been collected from olistoliths and matrix to be dated based on radiolarians.

Dating the olistoliths. The siliceous samples studied yielded radiolarian assemblages of the Campanian-Maastrichtian age, more exactly, the late Campanian-Maastrichtian (samples 42, 55, 60, 9918/2), the Campanian-Maastrichtian (sample 44), the Campanian (samples 46 and 53), the middle Campanian-Maastrichtian (samples 62 and 9918/1), and the late Campanian–early Maastrichtian (sample 9918/7) ones (Tables 2, 5; Plate 3). In addition, Kurilov (2000) macerated some older (early Valanginian, Albian–Cenomanian, and Coniacian–Maastrichtian) radiolarian assemblages from olistoliths of the Palana olistostrome.

Dating the matrix. Ten sandstone and gravelstone samples from the olistostrome matrix yielded abundant

Table 1. Radiolarians from siliceous interbeds of the volcanogenic sequence (shaded boxes denote presence of species)

Species	Sample number				
	37	79b	81a	82a	87b
	1	2	3	4	5
Phaseliforma carinata Pessagno					
Phaseliforma subcarinata Pessagno					
Praestylosphaera pusilla (Campbell et Clark)					
Lithomespilus mendosa (Krasheninnikov)	cf				
Lithomespilus sp.					
Actinomma sp.					
Actinommidae Gen. et sp. indet					
Orbiculiforma renillaeformis (Campbell et Clark)					
Orbiculiforma quadrata Pessagno					
Orbiculiforma sp.					
Spongodiscus impressus Lipman					
Spongodiscus rhabdostylus (Ehrenberg)					
Porodiscus cretaceus Campbell et Clark					
Spongurus sp.					
Spongopyle ? sp.					
Amphibrachium sansalvadorensis Pessagno		aff			
Pseudoaulophacus lenticulatus (White)	cf				
Pseudoaulophacus sp.					
Neosciadiocapsa sp.					
Stichomitra livermorensis (Campbell et Clark)					
Stichomitra sp.					
Amphipyndax stocki (Campbell et Clark)					
Xitus asymbatos (Foreman)					
Lithostrobus rostovzevi Lipman					
Cornutella californica Campbell et Clark					
Theocampe vanderhoofi Campbell et Clark					
Dictyomitra densicostata Pessagno					
Dictyomitra sp.					
Clathrocyclas tintinnaeformis Campbell et Clark					
Sponge spicules					

radiolarians (Tables 3, 5; Plates 1, 2) of the Campanian age. The most representative assemblages have been macerated from samples 75v and 77v (lower-middle Campanian), 76b (Campanian), and 76d (middle-upper Campanian). It is apparent that the majority of the radiolarians of the matrix sandstones and gravelstones are reworked. Accordingly, the late Campanian–Maastrichtian age of radiolarian assemblages mentioned above corresponds to the former thickest part of siliceous deposits, which represented a source for the majority of olistoliths and cherty clasts set in the matrix. Siliceous interbeds of the olistostrome matrix (11 samples) also yielded radiolarians of late Campanian–Maastrichtian age, e.g., samples 76a, 76v, and 77b (Table 4; Plates 1, 2). Although the late Campanian-Maastrichtian age of the olistostrome matrix is evidenced by many radiolarian taxa, the occurrence of *Amphisphaera goruna* (Sanfilippo et Riedel), *Orbiculiforma renillaeformis* (Campbell et Clark), *Spongodiscus alveatus* (Sanfilippo et Riedel), *Spongotrochus polygonatus* (Campbell et Clark), and other forms (Table 5) suggests that the rock unit under consideration was still under formation in the early Paleocene.

Table 2. Radiolarians from siliceous olistoliths of the olistostrome (shaded boxes denote presence of species)

Species	Sample number													
	41	42	44	46	53	55	60	62	67	9918/1	9918/2	9918/6	9918/7	9918/9
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Phaseliforma carinata Pessagno		cf												
Phaseliforma sp.														
Praestylosphaera pusilla (Campbell et Clark)						cf								
Praestylosphaera hastata (Campbell et Clark)													cf	
Praestylosphaera sp.														
Haliomma schucherti Campbell et Clark														
Haliomma sp.														
Actinomma sp.														
Amphisphaera priva (Foreman)														
Actinommidae Gen.et sp. indet														
Lithomespilus mendosa (Krasheninnikov)						cf								
Cromyodruppa concentrica Lipman														
Orbiculiforma renillaeformis (Campbell et Clark)														
Orbiculiforma sp.														
Spongodiscus impressus Lipman														
Spongodiscus alveatus (Sanfilippo et Riedel)														
Spongodiscus rhabdostylus (Ehrenberg)														
Spongodiscus sp.														
Spongotripus morenoensis Campbell et Clark														
Spongotripus sp.														
Spongurus sp.														
Spongosaturnalis spiniferus Campbell et Clark								cf						
Spongosaturnalis sp.														
Archaeospongoprunum hueyi Pessagno														
Archaeospongoprunum sp.														
Pseudoaulophacus lenticulatus (White)		cf	cf											
Pseudoaulophacus sp.														
Histiastrum latum Lipman														
Histiastrum sp.														
Amphibrachium spongiosum Lipman			cf											
Prunobrachium sp.														
Patulibracchium petroleumensis Pessagno			cf											
Patulibracchium sp.														
Spummellaria Gen. et sp. indet														
Crucella sp.														
Praeconocaryomma sp.														
Gongylothorax verbeeki (Tan Sin Hok)		cf												
Kuppelella cayeuxi (Squinabol)				aff										

Table 3. Radiolarians from cherty clasts in the olistostrome matrix (shaded boxes denote presence of species)

Species	Sample number									
	73	75b	75v	76b	76d	77a	77v	78a	78v	78d
	1	2	3	4	5	6	7	8	9	10
Phaseliforma carinata Pessagno					cf					cf
Phaseliforma sp.										
Praestylosphaera pusilla (Campbell et Clark)										
Praestylosphaera hastata (Campbell et Clark)										
Praestylosphaera sp.										
Actinomma sp.										
Cromyosphaera vivenkensis Lipman										
Lithomespilus mendosa (Krasheninnikov)		cf							cf	cf
Lithomespilus sp.										
? *Staurodictya fresnoensis* Foreman										
Orbiculiforma renillaeformis (Campbell et Clark)										
Orbiculiforma quadrata Pessagno				<						
Orbiculiforma sp.										
Spongodiscus impressus Lipman										
Spongodiscus alveatus (Sanfilippo et Riedel)										
Spongodiscus sp.										
Porodiscus cretaceus Campbell et Clark										
Spongurus sp.										
Spongotripus morenoensis Campbell et Clark			cf							
Pseudoaulophacus lenticulatus (White)										cf
Patulibracchium sp.										
Spummellaria. Gen. et sp. indet			*							
Holocryptocapsa sp.										
Novodiacanthocapsa manifesta (Foreman)										
Theocapsomma sp.										
Stichomitra livermorensis (Campbell et Clark)								cf		
Stichomitra shirshovica Vishnevskaya										
Stichomitra campi (Campbell et Clark)							cf			
Stichomitra sp.										
Amphipyndax stocki (Campbell et Clark)										
Amphipyndax streckta (Empson-Morin)										
Amphipyndax tylotus Foreman										
Amphipyndax sp.										
Wildeus punctulatus (Pessagno)										
Lithostrobus rostovzevi Lipman				cf						
Theocampe vanderhoofi Campbell et Clark					cf		cf			cf
Theocampe sp.										
Archaeodictyomitra squinaboli Pessagno										
Archaeodictyomitra regina (Campbell et Clark)										
Dictyomitra andersoni (Campbell et Clark)										
Dictyomitra densicostata Pessagno						cf				cf
Dictyomitra multicostata Zittel										
Dictyomitra sp.										
Clathrocyclas hyronia Foreman										
Clathrocyclas sp.										
Sponge spicules										

Table 3. Radiolarians from cherty clasts in the olistostrome matrix (shaded boxes denote presence of species)

Species	Sample number									
	73	75b	75v	76b	76d	77a	77v	78a	78v	78d
	1	2	3	4	5	6	7	8	9	10
Phaseliforma carinata Pessagno					cf					cf
Phaseliforma sp.										
Praestylosphaera pusilla (Campbell et Clark)										
Praestylosphaera hastata (Campbell et Clark)										
Praestylosphaera sp.										
Actinomma sp.										
Cromyosphaera vivenkensis Lipman										
Lithomespilus mendosa (Krasheninnikov)		cf							cf	cf
Lithomespilus sp.										
? *Staurodictya fresnoensis* Foreman										
Orbiculiforma renillaeformis (Campbell et Clark)										
Orbiculiforma quadrata Pessagno				<						
Orbiculiforma sp.										
Spongodiscus impressus Lipman										
Spongodiscus alveatus (Sanfilippo et Riedel)										
Spongodiscus sp.										
Porodiscus cretaceus Campbell et Clark										
Spongurus sp.										
Spongotripus morenoensis Campbell et Clark			cf							
Pseudoaulophacus lenticulatus (White)										cf
Patulibracchium sp.										
Spummellaria. Gen. et sp. indet			*							
Holocryptocapsa sp.										
Novodiacanthocapsa manifesta (Foreman)										
Theocapsomma sp.										
Stichomitra livermorensis (Campbell et Clark)								cf		
Stichomitra shirshovica Vishnevskaya										
Stichomitra campi (Campbell et Clark)							cf			
Stichomitra sp.										
Amphipyndax stocki (Campbell et Clark)										
Amphipyndax streckta (Empson-Morin)										
Amphipyndax tylotus Foreman										
Amphipyndax sp.										
Wildeus punctulatus (Pessagno)										
Lithostrobus rostovzevi Lipman				cf						
Theocampe vanderhoofi Campbell et Clark					cf		cf			cf
Theocampe sp.										
Archaeodictyomitra squinaboli Pessagno										
Archaeodictyomitra regina (Campbell et Clark)										
Dictyomitra andersoni (Campbell et Clark)										
Dictyomitra densicostata Pessagno						cf				cf
Dictyomitra multicostata Zittel										
Dictyomitra sp.										
Clathrocyclas hyronia Foreman										
Clathrocyclas sp.										
Sponge spicules										

Table 4. Radiolarians from siliceous interbeds in the olistostrome matrix (shaded boxes denote presence of species)

Species	Sample number										
	47	56	57	64	75a	76a	76v	76g	77b	78b	78g
	1	2	3	4	5	6	7	8	9	10	11
Phaseliforma carinata Pessagno											
Phaseliforma laxa Pessagno											
Phaseliforma sp.											
Praestylosphaera pusilla (Campbell et Clark)											
Praestylosphaera hastata (Campbell et Clark)											
Praestylosphaera sp.											
Haliomma minor Campbell et Clark		cf	cf				cf				
Haliomma sp.											
Actinomma sp.											
Acanthosphaera sp.											
Amphishaera goruna (Sanfilippo et Riedel)											
Lithomespilus mendosa (Krasheninnikov)											
Actinommidae Gen. et sp. indet											
Orbiculiforma renillaeformis (Campbell et Clark)			cf								
Orbiculiforma sp.											
Porodiscus cretaceus Campbell et Clark		cf									
Spongodiscus impressus Lipman											
Spongodiscus alveatus (Sanfilippo et Riedel)	cf										
Spongodiscus sp.											
Spongotrochus polygonatus (Campbell et Clark)			*								
Stylotrochus sp.											
Spongurus quadratus Campbell et Clark											
Spongurus sp.											
Spongosaturnalis spiniferus Campbell et Clark											
Protoxiphotractus perplexus Pessagno											
Patulibracchium sp.											
Pseudoaulophacus sp.											
Spummellaria. Gen. et sp. indet.											
Neosciadiocapsa sp.											
Eucyrtis sp.											
Eucyrtidium carnegiense Campbell et Clark											
Stichomitra livermorensis (Campbell et Clark)											
Stichomitra shirshovica Vishnevskaya											
Stichomitra sp.											
Novodiacanthocapsa manifesta (Foreman)											
Theocapsomma erdnussa (Empson-Morin)											
Theocapsomma sp.											
Amphipyndax stocki (Campbell et Clark)											
Amphipyndax stocki var. C Vishnevskaya											
Amphipyndax streckta (Empson-Morin)											
Amphipyndax tylotus Foreman											
Amphipyndax sp.											

Table 4. (Contd.)

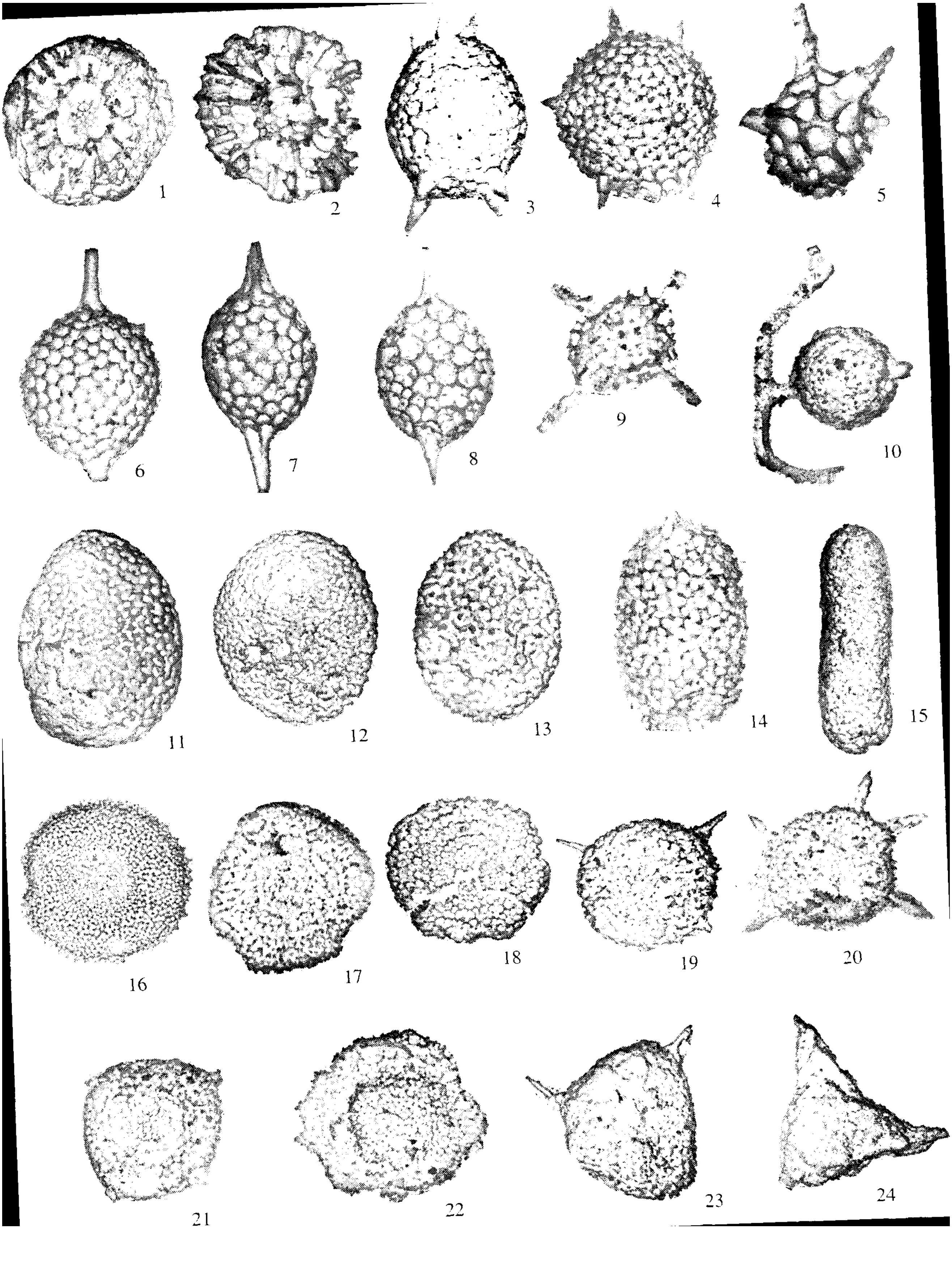
Species	Sample number										
	47	56	57	64	75a	76a	76v	76g	77b	78b	78g
	1	2	3	4	5	6	7	8	9	10	11
Xitus asymbatos (Foreman)											
Lithostrobus rostovzevi Lipman											
Lithostrobus sp.											
Cornutella califomica Campbell et Clark											
Theocampe altamontensis (Campbell et Clark)											
Theocampe vanderhoofi Campbell et Clark											
Theocampe sp.											
Archaeodictyomitra regina (Campbell et Clark)											
Archaeodictyomitra sp.											
Dictyomitra andersoni (Campbell et Clark)											
Dictyomitra densicostata Pessagno											
Dictyomitra multicostata Zittel											
Dictyomitra sp.											
Clathrocyclas hyronia Foreman			cf								
Clathrocyclas diceros Foreman											
Clathrocyclas tintinnaeformis Campbell et Clark											
Clathrocyclas sp.											
Sponge spicules											

RELATIONSHIPS BETWEEN THE CRETACEOUS AND PALEOGENE DEPOSITS

The coastal cliff located 1.5 km to the west-southwest of the Anadyrka River mouth shows a contact between the heavily deformed tuffaceous sediments of the volcanogenic sequence and rocks of the Anadyrka (Khulgun) Formation (conglomerates and sandstones). Gladenkov *et al.* (1997) referred this formation to the Paleocene. However, according to the latest biostratigraphic data, the Anadyrka Formation is of the younger, Eocene age (A.E. Shantser, personal communication). The formation is separated from the volcanogenic sequence by a normal fault oriented at the right angle to the shoreline. To the west of the section interval covered by coastal debris (about 2 m wide), there are exposed volcanic breccias and tuffaceous sediments of the volcanogenic sequence. As far as 200 m to the west, their beds dip to the west-southwest (290°–315°) at the angles of 45°–60° (15 measurements over the distance about 100 m along the shoreline). To the east of the contact between two formations, there are poorly exposed unlithified coarse-grained sandstones. Approximately 30 m to the east, the latter are overlain by conglomerates dipping to the northeast at the angle of about 40°. Farther on, coastal cliffs extending for a distance of 200 m exhibit a lenticular alternation of cross-bedded conglomerate, gravelstone, and sandstone beds with impressions of leaf flora, which gently dip northeastwards. These are the basal beds of the Anadyrka Formation described in detail by Gladenkov *et al.* (1997). According to their description, beds of the Anadyrka Formation have almost horizontal attitude in exposures

Plate 1. Radiolarians from the olistostrome

(1, 2) *Cromyosphaera vivenkensis* Lipman: (1) 1-76/b, ×100; (2) 75/v, ×100; (3) *Lithomespilus mendosa* (Krasheninnikov), 76/v, ×120; (4) *Acanthosphaera* sp., 76/v, ×100; (5) *Amphisphaera goruna* (Sanfilippo et Riedel), 76x, ×200; (6, 7) *Praestylosphaera pusilla* (Campbell et Clark): (6) 76/a, x200, (7) 76/v, ×150; (8) *Protoxiphotractus perplexus* Pessagno, 76/a, ×200; (9) ? *Staurodictya fresnoensis* Foreman, 76/d, x1 10; (10) *Spongosaturnalis siniferus* Campbell et Clark, 76/v, ×150; (11) *Phaseliforma carinata* Pessagno, 75/a, ×100; (12) *Phaseliforma subcarinata* Pessagno, 77/b, x85; (13) *Phaseliforma laxa* Pessagno, 77/b, ×100; (14) *Spongurus quadratus* Campbell et Clark, 75/a, ×200; (15) *Spongurus* sp., 76/v, ×150; (16) *Orbiculiforma renillaeformis* Campbell et Clark, 76/a, x85; (17, 18) *Porodiscus cretaceous* Campbell et Clark: (17) 76/b, ×100, (18) 77/v, ×100; (19) *Spongodiscus* cf. *alveatus* (Sanfilippo et Riedel), 47, x80; (20) *Spongotrochus polygonatus* (Campbell et Clark), 76/a, ×150; (21) *Orbiculiforma quadrata* Pessagno, 77/v, ×100; (22) *Pseudoaulophacus lenticulatus* (White), 76/b, ×120; (23) *Patulibracchium* sp., 77/b, ×100; (24) *Spongotripus* cf. *morenoensis* Campbell et Clark, 75/v, ×120.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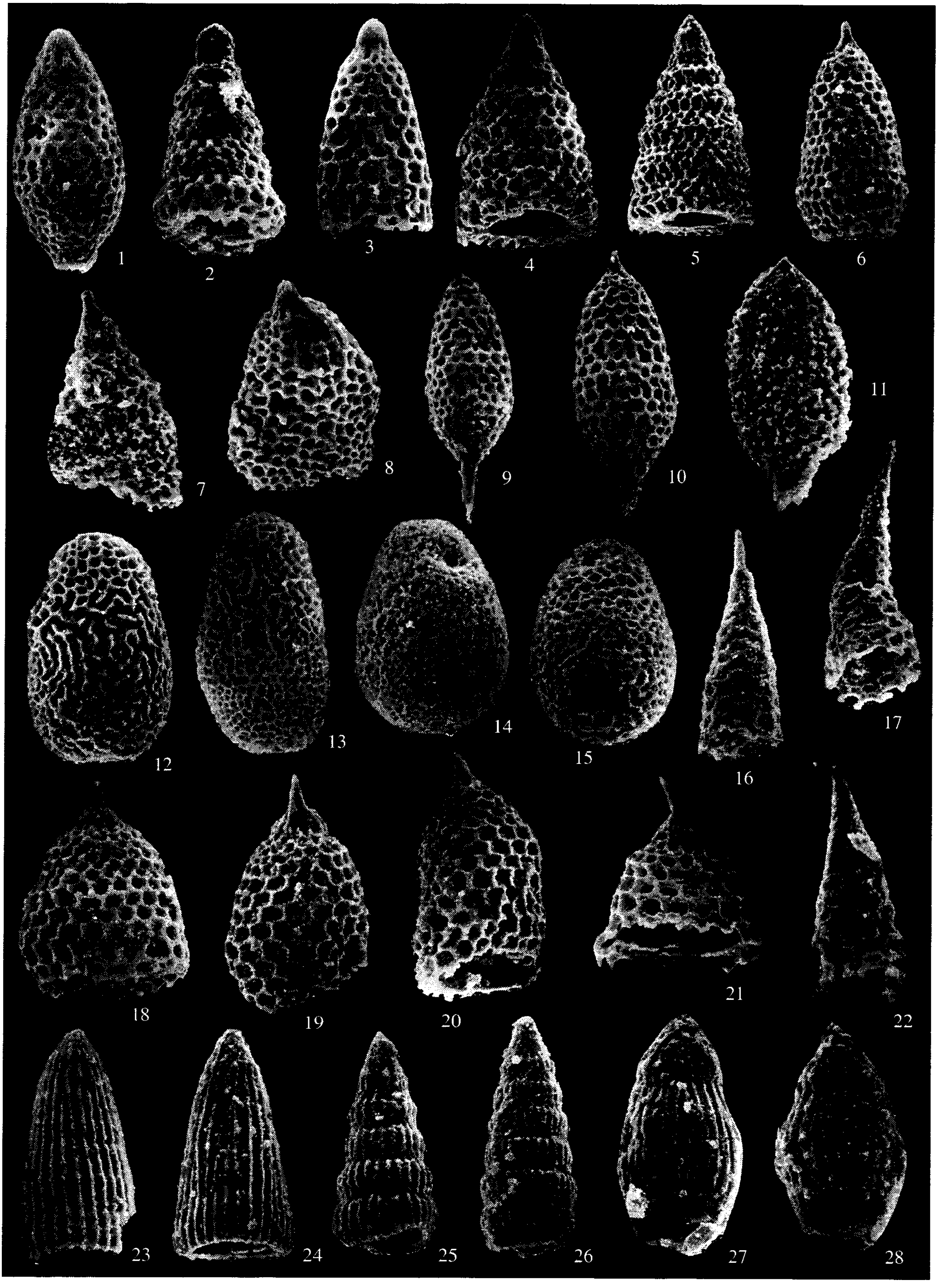
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Plate 2. Radiolarians from the olistostrome.

(1) *Amphipyndax stocki* (Campbell et Clark), 76/a, ×150; (2) *Amphipyndax stocki* var. C Vishnevskaya, 76/a, ×150; (3) *Amphipyndax streckta* (Empson-Morin), 76/d, ×100; (4) *Amphipyndax tylotus* Foreman, 75/a, ×150; (5) *Wildeus punctulatus* (Pessagno), 75/v, ×120; (6) *Lithostrobus rostovzevi* Lipman, 76/v, ×120; (7) *Xitus* cf. *asymbatos* (Foreman), 76/v, x100; (8) *Novodiacanthocapsa manifesta* (Foreman), 76/b, ×150; (9, 10) *Stichomitra livermorensis* (Campbell et Clark): (9) 77/b, ×150, (10) 76/a, x200; (11) *Stichomitra* cf. *shirshovica* Vishnevskaya, 76/v, ×120; (12, 13) *Theocapsomma erdnussa* (Empson-Morin), 75/a, ×100; (14, 15) *Theocapsomma*? sp., 75/a, x100; (16, 17) *Cornutella californica* Campbell et Clark: (16) 76/v, ×150, (17) 76/v, ×180; (18) *Clathrocydas hyronia* Foreman, 76/v, ×150; (19) *Clathrocydas diceros* Foreman, 76/v, ×150; (20) *Clathrocydas tintinnaeformis* Campbell et Clark, 77/b, x110; (21) *Clathrocydas* sp., 76/a, ×200; (22) *Cornutella californica* Campbell et Clark, 77/b, ×200; (23, 24) *Archaeodictyomitra squinaboli* Pessagno: (23) 76/b, x100, (24) 76/d. ×190; (25, 26) *Dictyomitra densicostata* Pessagno: (25) 76/a, x200, (26) 77/v, ×100; (27, 28) *Theocampe vanderhoofi* Campbell et Clark, 77/b, ×200.

extending for the distance over 2 km to the northeast of the river mouth. The basal conglomerate beds of the Anadyrka Formation are predominantly composed of basalts, the pyroxene and hornblende varieties typical of the Palana volcanogenic sequence included. Thus, lithological and structural data indicate a sharp unconformity between the Anadyrka Formation and underlying Cretaceous deposits.

DISCUSSION

Radiolarian assemblages. The radiolarian assemblages from the section studied are unique in terms of abundance and preservation state of species. Practically all of 60 samples collected for micropaleontological analysis contained radiolarians, most of which are well preserved.

Radiolarians were macerated from siliceous interbeds of the volcanogenic sequence and from olistoliths and matrix of the olistostrome. The most representative radiolarian assemblages of the Palana section include up to 31 species of 25 genera. Taxonomic analysis of radiolarian assemblages from the different deposits of the section (Tables 1–4) revealed a great similarity between those characterizing chert interbeds of the volcanogenic sequence, the olistostrome matrix, and some olistoliths. This suggests that all the deposits were formed in the immediate vicinity to each other. In the assemblages, the Campanian and Campanian-Maastrichtian forms are associated with many late Maastrichtian–Paleocene species, such as *Amphisphaera goruna* (Campbell et Clark), *Lithomespilus mendosa* (Krasheninnikov), *Orbiculiforma renillaeformis* (Campbell et Clark), *Spongodiscus alveatus* (Sanfilippo et Riedel), *S. rhabdostylus* (Ehrenberg), and *Spongotrochus polygonatus* (Campbell et Clark). Their presence in the olistostrome matrix (Table 5) suggests that it was still under formation in the early Paleocene.

The late Campanian–Maastrichtian radiolarian assemblages of the Palana section show a high taxonomic diversity. The order Spumellaria is represented by Phaseliformidae, Orbiculiformidae, *Praestylosphaera*, and *Lithomespilus* forms widespread all over the Olyutorskii zone and Kamchatka, by peculiar *Cromyosphaera* and *Actinomma* species, and by abundant representatives of Spongodiscidae (*Spongodiscus alveatus, S. impressus, Porodiscus cretaceus, Spongotrochus polygonatus*, and others) and Sponguridae. Some pseudoaulophacoid forms, such as *Pseudoaulophacus lenticulatus*, also occur. The order Nassellaria is represented by Amphipyndaxidae (*Amphipyndax stocki, A. streckta, A. tylotus, A. pseudoconulus*), Cyrtidae (forms abundant *Archaeodictyomitra, Dictyomitra, Stichomitra*), Theocampidae (*Theocampe altamontensis, T. vanderhoofi, T. yaoi*), and Clathrocyclidae (*Clathrocydas hyronia, Cl. diceros, Cl. tintinnaeformis*). A distinctive feature of the Palana assemblages is abundance of triloculine Nassellaria species, such as *Theocapsomma amphora, T. erdnussa, Hemicryptocapsa conara, Novodiacanthocapsa manifesta, Sciadiocapsa campbelli*, and others.

The assemblages include forms with test walls of different types, i.e., porate (up to 70%), porous-spongy (24%), pseudoaulophacoid (2%) and xitoid (about 4%). This suggests the high-latitude habitat areas of the assemblages. The suggestion is confirmed by data on Campanian radiolarians from different areas of the globe (Empson-Morin, 1984). For instance, she considered the genus *Prunobrachium* whose representatives are present in our collection as a taxon indicative of the

Plate 3. Radiolarians from olistoliths of the olistostrome, (1-20, 25, 26) from Sample 9918/2 and (21-24) from Sample 44.

(1, 2) *Praestylosphaera pusilla* (Campbell et Clark): (1) ×120, (2) ×200; (3) *Amphisphaera priva* (Foreman), ×200; (4) *Lithomespilus mendosa* (Krasheninnikov), x200; (5) *Spongodiscus rhabdostylus* (Ehrenberg), x100; (6) *Cromyodruppa concentrica* Lipman, x90; (7) *Phaseliforma carinata* Pessagno, x100; (8) *Spongodiscus impressus* Lipman, x100; (9) *Spongosaturnalis spiniferus* Campbell et Clark, ×100; (10) *Stichomitra livermorensis* Campbell et Clark), ×100; (11) *Stichomitra campi* (Campbell et Clark), ×120; (12) *Eucyrtidium carnegiense* Campbell et Clark, x100; (13) *Stichopilium teslaense* Campbell et Clark, x100; (14) *Xitus* cf. *asymbatos* (Foreman), x110; (15) *Theocampe altamontensis* (Campbell et Clark), ×200; (16) *Clathrocydas hyronia* Foreman, x200; (17) *Clathrocydas tintinnaeformis* Campbell et Clark, ×180; (18) *Clathrocydas* sp., x100; (19) *Stichomitra* ? sp., ×200; (20) *Cornutella californica* Campbell et Clark, x200; (21) *Hemicryptocapsa* aff. *conara* Foreman, ×200; (22) *Patulibracchium* cf. *petroleumensis* Pessagno, x100; (23) *Histiastrum* sp., x100; (24) *Neosciadiocapsa* cf. *diabloensis* Pessagno, x90; (25) *Dictyomitra multicostata* Zittel, X180; (26) *Archaeodictyomitra regina* (Campbell et Clark), x100.

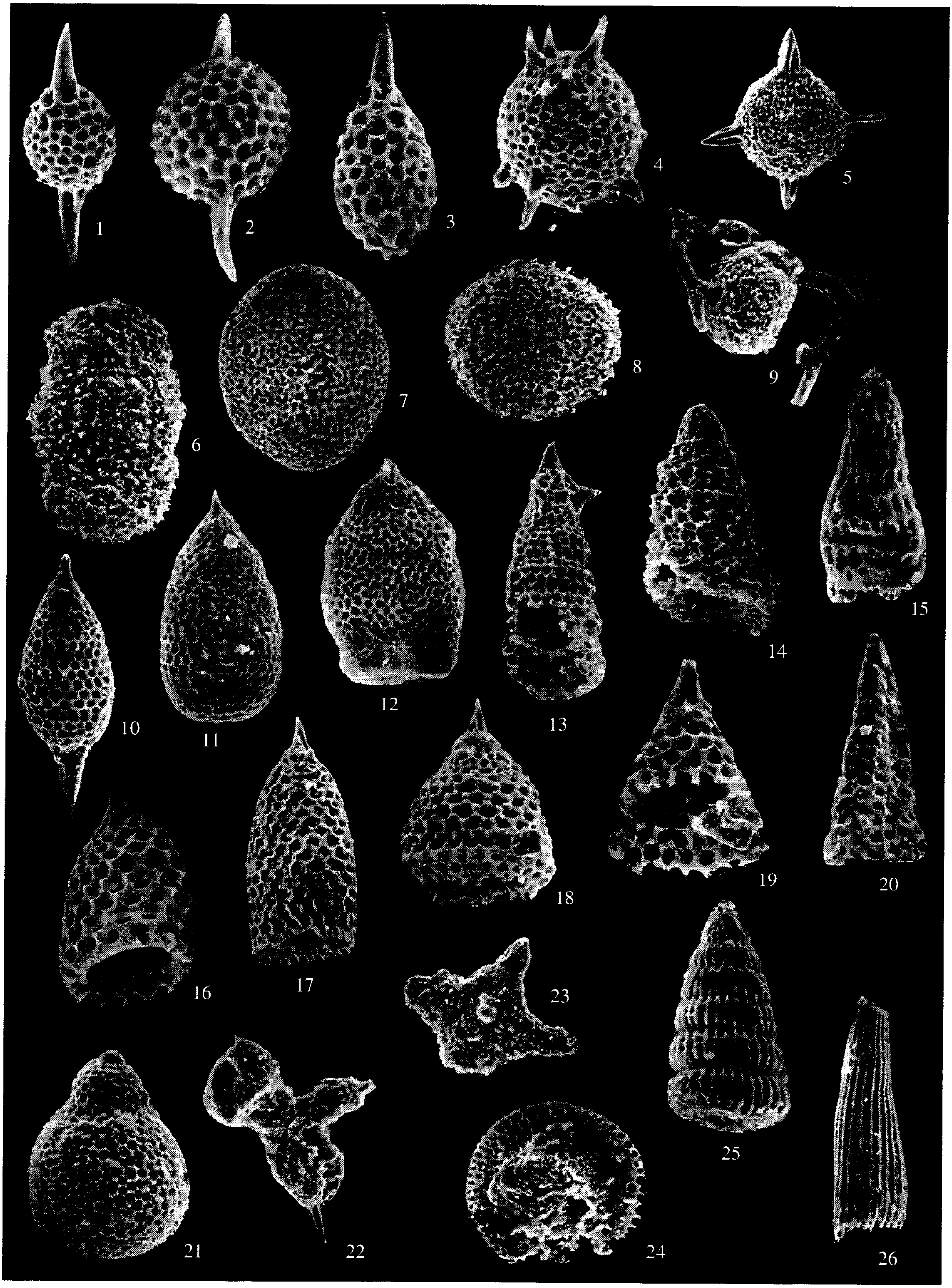
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Table 5. Stratigraphic ranges of identified species according to published data

Species	st	cp			m		d
		cp1	cp2	cp3	m1	m2	
Archaeodictyomitra squinaboli Pessagno	——	——	- - -	- - -			
Dictyomitra densicostata Pessagno	- - -	——	——	- - -			
Orbiculiforma quadrata Pessagno	——	——	——	- - -			
Novodiacanthocapsa manifesta (Foreman)		——	——	——			
Theocapsomma erdnussa (Empson-Morin)		——	——	——			
Lithostrobus rostovzevi Lipman		——	——	——			
Kuppelella cayeuxi (Squinabol)		——	——	——			
Wildeus punctulatus (Pessagno)		——	——	- - -			
Cromyodruppa concentrica Lipman	——	——	——	——			
Pseudoaulophacus lenticulatus (White)	- - -	——	——	——			
Patulibracchium petroleumensis Pessagno		——	- - -	- - -			
Amphibrachium spongiosum Lipman		——	- - -	- - -			
Archaeospongoprunum hueyi Pessagno				——			
Histiastrum latum Lipman		——	——	——			
Haliomma minor Campbell et Clark		——	——	——			
Praestylosphaera hastata (Campbell et Clark)		——	——	——	- - -		
P. pusilla (Campbell et Clark)		- - -	- - -	——	——	- - -	
Prothoxiphotractus perplexus Pessagno		——	——	——	——	——	- - -
Spongosaturnalis spiniferus Campbell et Clark		——	——	——	——	——	
Phaseliforma carinata Pessagno			——	——	——	- - -	
P. subcarinata Pessagno			- - -	——	——	- - -	
P. laxa Pessagno			- - -	——	——	- - -	
Spongurus quadratus Campbell et Clark				——	——		
Amphipyndax streckta (Empson-Morin)			- - -	——	- - -		
A. tylotus Foreman			- - -	——	——		
Clathrocyclas hyronia Foreman			- - -	——	——	- - -	
C. diceros Foreman			- - -	——	——	- - -	
C. tintinnaeformis Campbel et Clark		- - -	- - -	——	——	- - -	
Archaeodictyomitra regina (Campbell et Clark)			- - -	——	——	- - -	- - -
Dictyomitra andersoni (Campbell et Clark)			- - -	——	——	——	
Stichomitra livermorensis (Campbell et Clark)		- - -	- - -	——	——	——	- - -
S. shirshovica Vishnevskaya		- - -	- - -	——	——	——	- - -
S. campi (Campbell et Clark)		- - -	- - -	——	——	——	- - -
Cornutella californica Campbell et Clark		- - -	- - -	——	——	——	- - -
Theocampe altamontensis (Campbell et Clark)		- - -	- - -	——	——	——	- - -
T. yaoi Taketani		- - -	- - -	——	——	——	- - -
T. vanderhoofi Campbell et Clark				——	——	——	
Gongylothorax verbeeki (Tan Sin Hok)		- - -	- - -	——	——	——	
Staurodictya fresnoensis Foreman				——	——	——	
Neosciadiocapsa diabloensis Pessagno					——	——	
Hemicryptocapsa conara Foreman						——	
Amphibrachium sansalvadorensis Pessagno					——	——	——
Amphisphaera priva (Foreman)		- - -	- - -	——	——	——	——
A. goruna (Campbell et Clark)						——	——

Table 5. (Contd.)

Species	st	cp			m		d
		cp1	cp2	cp3	m1	m2	
Orbiculiforma renillaeformis (Campbell et Clark)						—	—
Lithomespilus mendosa (Krasheninnikov)				- - -	- - -	—	—
Spongodiscus alveatus (Sanfilippo et Riedel)						—	—
S. rhabdostylus (Ehrenberg)						—	—
Spongotrochus polygonatus (Campbel et Clark)						—	—
Cromyosphaera vivenkensis Lipman	—	—	—	—	—	—	—
Spongodiscus impressus Lipman	—	—	—	—	- - -	- - -	
Porodiscus cretaceus Campbell et Clark	—	—	—	—	—	—	
Spongotripus morenoensis Campbell et Clark	—	—	—	—	—	—	
Haliomma schucherti Campbell et Clark	—	—	—	—	—	—	
Theocapsomma amphora Campbell et Clark	- - -	—	—	—	—	—	
Sciadiocapsa campbelli Pessagno	- - -	—	—	—	—	—	
Stichopilidium teslaense Campbell et Clark	- - -	—	—	—	—	—	
Eucyrtidium carnegiense Campbell et Clark	—	—	—	—	—	—	
Xitus asymbatos Foreman	—	—	—	—	—	—	
Dictyomitra multicostata Zittel	—	—	—	—	—	—	
Amphipyndax stocki (Campbell et Clark)	—	—	—	—	—	—	—
Amphipyndax stocki var. C Vishnevskaya		- - -	- - -	—	—	—	—

high latitudes. The assemblages also include *Neosciadiocapsa* forms, which inhabited predominantly the high and temperate latitudes (Petrushevskaya, 1981).

Among 62 species radiolarians species from the Palana section, 23 are known from the upper Senonian deposits of California (Campbell and Clark, 1944), and 12 were described from the upper part of the upper Campanian Forbes Formation of northern California (Pessagno, 1976). The latter group includes *Phaseliforma carinata* Pessagno, the index-species of synonymous subzone of the lower part of the upper Campanian of northern California (Pessagno, 1976). Eight of our species are known from the upper Maastrichtian deposits of California (Foreman, 1968), and two, namely *Amphipyndax streckta* (Empson-Morin) and *Theocapsomma erdnussa* (Empson-Morin), are components of the Campanian radiolarian assemblage from DSDP Site 313, the central Pacific Ocean (Empson-Morin, 1984). Some species (for example, *Theocampeyaoi* Taketani) are characteristic of the Campanian deposits in northeastern Hokkaido (Iwata and Tajika, 1986). The majority of identified species are typical of the Campanian–Maastrichtian assemblages from the Olyutorskii zone of Koryakiya (Vishnevskaya, 1985; Palechek, 1997; Solov'ev *et al.*, 1998, 2000), and 13 species are listed in the Campanian–Maastrichtian assemblages of western Sakhalin (Kazintsova, 2000). The assemblages studied show some similarity with the Late Cretaceous–Paleocene radiolarians of New Zealand (Hollis, 1997). All the species mentioned above are characteristic of the circum-Pacific belt. In addition, seven species of the Palana section (*Lithostrobus rostovzevi, Histiastrum latum, Amphibrachium spongiosum*, and others) are known from Upper Cretaceous deposits of the West Siberian lowland (Lipman, 1962), and this may imply that Arctic and Pacific basins were interconnected at that time.

Geological events recorded in the Palana section. Rocks exposed in coastal cliffs between the Palana and Anadyrka rivers recorded a series of successive geological events. These were the accumulation of siliceous deposits now constituting olistoliths of the Ust-Palana Formation, the deposition of volcanogenic rocks and formation of the Ust-Palana olistostrome at the time of deformation of siliceous and volcanogenic sequences. Afterward, the final deformation of the entire Ust-Palana section resulted in elevation and erosion of its rocks followed by accumulation of the continental molasse (the Anadyrka Formation).

Siliceous deposits that represented source material for the most olistoliths and olistostrome matrix accumulated since the Late Jurassic probably to the end of the Cretaceous (Kurilov, 2000; Palechek *et al.*, 2000). Nevertheless, the olistoliths are predominantly of Campanian-Maastrichtian age, and this suggests a low sedimentation rate at the time of pre-Campanian chert deposition. Fragments of inoceramid shells in the Coniacian–lower Campanian olistoliths (Kurilov, 2000) indicate that beginning from the early Coniacian there appeared numerous inoceramid banks at the basin floor, and that the abundant shell detritus was transported by currents. In the Campanian-Maastrichtian time, siliceous deposits accumulated in a basin with a minor influx of tuffaceous and terrigenous material. According to the paleomagnetic data, it was at close to 40°–50° N, i.e., southward of the modern location of the olistostrome in the western Kamchatka (Chernov *et al.*, 2000). This assumption is supported by composition of cherts, which should be deposited far from the northeastern Asia margin supplying abundant terrigenous material into the adjacent basins.

In the second half of the Campanian, submarine basalt eruptions separated by short accumulation periods of bedded tuffaceous-sedimentary members gave rise to formation of the volcanogenic sequence. Composition of volcanic rocks is typical of island arcs and analogous to volcanics of the Kirganik Formation in southern areas of the Median Kamchatka Range (Flerov and Koloskov, 1976).

The age relationships between volcanogenic rocks and Campanian-Maastrichtian siliceous deposits, which produced olistoliths (Kurilov, 2000), cannot be clarified by means of similar results of radiolarian analysis. Because the cherts contain no significant tuffaceous admixture, their accumulation setting should be separated from the provenance of volcanic material either in space or with time. If rocks of both types are contemporaneous, the island arc must be located either nearer to or farther from the continent than the area of siliceous sedimentation. In the first case, it is difficult to explain why the olistostrome with cherty olistoliths is positioned at present closer to the continent than the Upper Cretaceous island-arc sequences of Kamchatka. In the second case, it is difficult to bring into accordance the paleomagnetic data on cherts and on the Median Range and the Karaginskii Island, because the latter structures were located at higher latitudes in the Campanian-Maastrichtian time (Kovalenko, 1990; Levashova and Shapiro, 1999). It seems most probable, therefore, that cherty and volcanic rocks have different ages within the Maastrichtian-Danian time span.

The olistostrome formation implies short-term movements and, probably, thrusting, which caused synchronous destruction of tectonic slices (blocks) of volcanogenic and siliceous deposits in submarine environments. Judging from the age of olistostrome matrix, these events took place in the late Campanian-Maastrichtian. However, the siliceous sedimentation and subsequent volcanic eruptions happened in the same time interval. Thus, the olistostrome was likely formed at the end of the interval. The volcanogenic sequence is dated back to the late Campanian-Maastrichtian based on radiolarians and to the early Maastrichtian based on K/Ar dates for amphiboles from basaltic andesites (72.5 ± 3.5 and 72.0 ± 3.5 Ma). Volcanogenic clasts, which are present in the olistostrome, suggest the post-early Maastrichtian age of the latter. Accordingly, the tectonic imbrication and related olistostrome formation occurred, most probably, after the early Maastrichtian. On the other hand, a sharp unconformity at the base of the Anadyrka Formation is a result of the general deformation of the Palana section. According to available date on the Anadyrka flora (Gladenkov *et al.*, 1997), this event occurred not later than in the mid-Danian time.

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