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Tectonostratigraphy of the Northern Olyutor Zone (Anastasiya Bay area of Koryak Highland)

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

Institute of the Lithosphere, Russian Academy of Sciences, Staromonetnyi per. 22, Moscow, 109180 Russia

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Abstract—Volcanogenic-siliceous and sedimentary–volcanogenic rock complexes are distinguished in the Anastasiya Bay area (the Koryak Highland) in the western coast of the Aleutian Basin. The age of siliceous beds in these complexes was inferred from radiolarian finds. The volcanogenic–sedimentary complex incorporates layers of the Campanian–Maastrichtian age. By lithology, it is correlated with the "Vatyna" Group, which previously was attributed to the Albian–Campanian. According to our data, the stratigraphic range of these deposits should also include the Maastrichtian. The sedimentary-volcanogenic rock complex is subdivided into three units: the volcanogenic (lower), volcanogenic–terrigenous (middle or transitional), and siliceous-terrigenous (upper) subcomplexes. The siliceous-terrigenous subcomplex contains radiolarians, which allow the host rocks to be dated as the Campanian-Maastrichtian. The sedimentary-volcanogenic complex is correlated with the Machevna complex or "Achaivayam Formation." The volcanogenic–siliceous complex was probably formed within a marginal sea basin and the sedimentary-volcanogenic complex in an island-arc and its slope settings. The data obtained allow us to reconstruct the hypothetical lateral succession of the Campanian-Maastrichtian paleogeographic settings: the continental margin-marginal sea-island arc–oceanic basin.

Key words: *tectonostratigraphy, radiolarians, Late Cretaceous, paleotectonic reconstructions, Olyutor zone, Koryak Highland.*

INTRODUCTION

Several objective obstacles complicate the stratigraphic subdivision and correlation of deposits composing the thrust-and-fold accretionary systems framing the Bering Sea. First, volcanogenic–siliceous–terrigenous deposits that are widespread there lack determinable macrofossil remains therefore stratigraphic subdivision is based on microfaunal remnants, extraction and determination of which is a time-consuming process, which does not always bring the desirable results. Second, these deposits are characterized by a significant facial variability. Third, their natural sections are too fragmented and disjointed for an easy reconstruction of paleoenvironments. When studying deposits in the intricate accretion zones, researchers should keep in mind that they are dealing with tectonostratigraphic rock successions formed under tectonic accretion of deposits rather than with normal stratigraphic sections (*Tektonicheskaya rassloennost'*..., 1990). Tectonostratigraphic sections composed of tectonic nappes are bounded by thrust surfaces that may stretch from dozens of meters to several kilometers.

In the methodical respect, the study of tectonostratigraphic rock successions requires the detailed sampling of each tectonostratigraphic unit for the micropaleontological investigations, the careful analysis of relationships between beds, and accurate description of lithological properties of rocks. This paper deals with results on tectonostratigraphic sequences composed of Upper Cretaceous volcanogenic-siliceous terrigenous deposits outcropping in the Anastasiya Bay area of the western coast of the Aleutian basin.

The material was obtained in summer 1994. Rock samples from the distinguished tectonostratigraphic units were subjected to petrographic and lithologic analyses. The fluoric (2-10%) or acetic (10–30%) acid etching was used to extract the volumetric radiolarian skeletons from these rocks. Acid concentration and etching exposure time were experimentally defined. Radiolarian microphotographs were made using the scanning electron microscope.

As a result of our study, the primary relationships between deposits now composing the thrust sheets were reconstructed. The principal possibility of such reconstructions is shown in the paper using the thrust-and-fold structures of the Koryak Highland as an example.

GEOLOGY OF THE REGION

The area in question is located in the Anastasiya Bay on the western coast of the Aleutian Basin of the Bering Sea (Fig. 1). The tectonic structure of the area is determined by its position between the Olyutor and Ukelayat zones. The Olyutor zone, which is characterized by the intricate thrust-and-fold structure was investigated by many scientists from different geological organizations: A.A. Aleksandrov and others from the Northeast Complex Geological Research Institute; E.S. Alekseev from "Aerogeologiya;" N.P. Mitrofanov from the All-Russia Institute of Mineral Resources; A.D. Kazimirov, O.V. Astrakhantsev, and others from Geological Institute, Russian Academy of Sciences; and scientists from the Institute of the Lithosphere, Russian Academy of Sciences (Bogdanov, 1970; Bogdanov *et al.*, 1982; *Geologiya yuga...*, 1987). The frontal part of the Olyutor zone includes a series of Cretaceous oceanic and island-arc complexes composing large allochthonous nappes (Astrakhantsev *et al.*, 1987; Chekhovich, 1993), which were obducted onto deposits of the Ukelayat trough along the Vatyna-Vyvenka thrust (Mitrofanov, 1977). Astrakhantsev *et al.* (1987) distinguished the following structural units in the northern part of the Olyutor zone: (1) relative autochthon represented by tuffaceous–terrigenous deposits of the Upper Cretaceous-lower Paleogene Koryak Group (the Ukelayat zone); (2) paraautochthon composed of the Maastrichtian olistostrome sequence; the matrix of the latter is represented by flysch facies, and olistoliths are mainly composed of rocks of the Vatyna Group affinity; (3) the allochthon represented by volcanogenic-siliceous deposits of the Albian–Campanian Vatyna Group; and (4) neoautochthon composed of lavas and tuffs of the andesite–dacite and dacite–liparite series, and of plateau basalts of the Neogene–Quaternary age. In this paper, tectonostratigraphy of the allochthonous rock complexes is considered.

GEOLOGICAL STRUCTURE

The geological structure of the peninsula located between the Anastasiya Bay and Nerpich'e Ozero Lagoon was investigated (Fig. 1). As a result, the volcanogenic-siliceous and sedimentary–volcanogenic rock complexes were distinguished using differences in their lithologic characteristics and composition. The lower structural boundary of the volcanogenic-siliceous complex is represented by the Vatyna-Vyvenka thrust, along which these deposits were obducted onto the flyschoid deposits of the Ukelayat zone. Upward the sequence, rocks of the sedimentary-siliceous complex are replaced by the volcanogenic-siliceous complex. The contact between these two complexes in the region is of the subhorizontal thrust type in some areas and of the steep upthrow fault type in others.

THE VOLCANOGENIC-SILICEOUS COMPLEX

Deposits of the volcanogenic-siliceous complex outcropping only in coastal sections of the peninsula occupy the lowest hypsometric position (Fig. 2). In this case, we deal with the tectonostratigraphic, but not stratigraphic section. The volcanogenic-siliceous complex is composed of pillow basalts, hyaloclastites, and dolerites intercalated with subordinate siliceous rocks and aleuropelites. Different tectonic slices are characterized by different paragenetic rock associations: (a) pillow basalts, hyaloclastites, and red-brown jaspers; and (b) black aleuropelites and green to gray siliciliths.

The red-brown jasper member with clasts of the inoceram shells represents a good marker horizon and is a characteristic feature of the first association. The jaspers have baking contacts with basalt flows, and both rock types compose tectonic slices. The jaspers show turbidite textures and a disharmonic folding in some layers. The latter is a result of synsedimentary deformations, most likely of the slumping origin.

The second association occurs in tectonic slices bounded by thrust surfaces at both sides. Black aleuropelites incorporate strongly deformed lenses and interbeds of green and gray siliceous rocks. Black aleuropelites are characterized by thin platy jointing.

Radiolarians from Siliceous Rocks of the Complex

Samples for the radiolarian analysis were collected from siliceous and terrigenous rocks of different tectonostratigraphic units (Fig. 2). About 100 samples from the volcanogenic–terrigenous complex were studied, and only nine of them collected from red-brown jasper (samples 4, 12, 29, 43/a, 44/c, A10, A12, A14, T28) yielded the determinable radiolarians. Radiolarian assemblages are of a low taxonomic diversity and abundance (Table 1). The maximum diversity amounts to 10-13 species whose abundance is as high as a few dozens of specimens per sample. Most common among radiolarians are *Praestylosphaera pusilla* (Campbell et Clark), *Amphipyndax stocki* (Campbell et Clark), *Stichomitra livermorensis* (Campbell et Clark), *Dictyomitra densicostata* Pessagno, *D. multicostata* Zittel, *Clathrocyclas tintinnaeformis* Campbell et Clark, and various species of the *Phaseliforma* genus (*P.* ex gr. *carinata*, *P.* cf. *subcarinata*). In addition, single specimens of *Cornutella californica* Campbell et Clark, *Stichomitra* cf. *shirshovica* Vishnevskaya, *Xitus* cf. *asymbatos* (Foreman), and *Phaseliforma* cf. *meganosensis* Pessagno are also present. Such composition of the radoiolarian assemblage (Table 1, Plates 1, 2) allows the volcanogenic-siliceous complex of the Anastasiya Bay to be attributed to the Campanian–Maastrichtian (Table 2). The radiolarian assemblage of sample 29 from the upper tectonic slice of section I (Fig. 2) indicates the middle Campanian–early Maastrichtian age of red-brown jaspers baked by overlying pillow basalts. This fact is important because it suggests that basalt eruption occurred in submarine environments at that time.

The Sedimentary–Volcanogenic Complex

The main part of the peninsula between the Anastasiya Bay and Nerpich'e Ozero Lagoon is composed of rocks of the sedimentary-volcanogenic complex (Fig. 1).

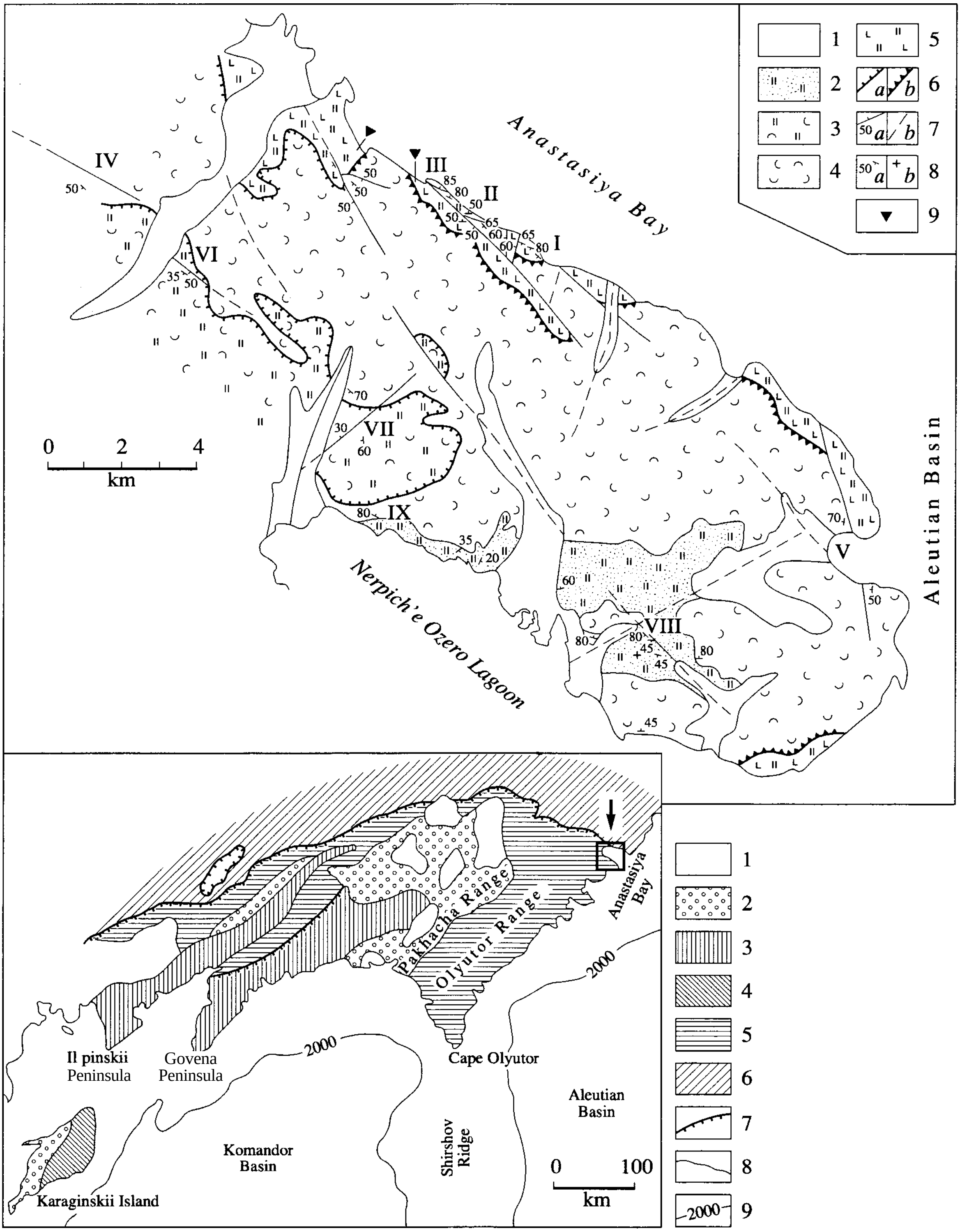

Fig. 1. Schematic geological structure of the Anastasiya Bay area (including data from the appendix to *Tektonicheskaya rassloennost'*..., 1990): (1) Quaternary loose deposits; (2–4) sedimentary–volcanogenic complex: (2) siliceous-terrigenous subcomplex (Campanian–Maastrichtian), (3) volcanogenic–terrigenous subcomplex, (4) volcanogenic subcomplex; (5) volcanogenic–siliceous complex (late Turonian–Maastrichtian); (6) reversed fault: (6*a*) subhorizontal thrust, (6*b*) steep reversed fault; (7) nonclassified faults: (7*a*) proven, (7*b*) assumed; (8) occurrence of bedding surface: (8*a*) slopping, (8*b*) vertical; (9) location of samples from collection of N.A. Bogdanov and K.A. Savel'ev; determination of radiolarians by V.S. Vishnevskaya (Table 3). Roman number indicate location of studied sections shown in Figs. 2, 3. Inset map shows the study area and schematic geological structure of the southwestern framing of the Bering Sea: (1) Pliocene–Quaternary volcanics; (2-6) complexes: (2) Neogene, (3) Paleogene, flyschoid and volcanogenic, (4) Upper Cretaceous, undivided, (5) Cretaceous, siliceous–volcanogenic, (6) Cretaceous–Paleogene, flyschoid, the Ukelayat trough; (7) thrusts; (8) stratigraphic contacts; (9) isobaths, m.

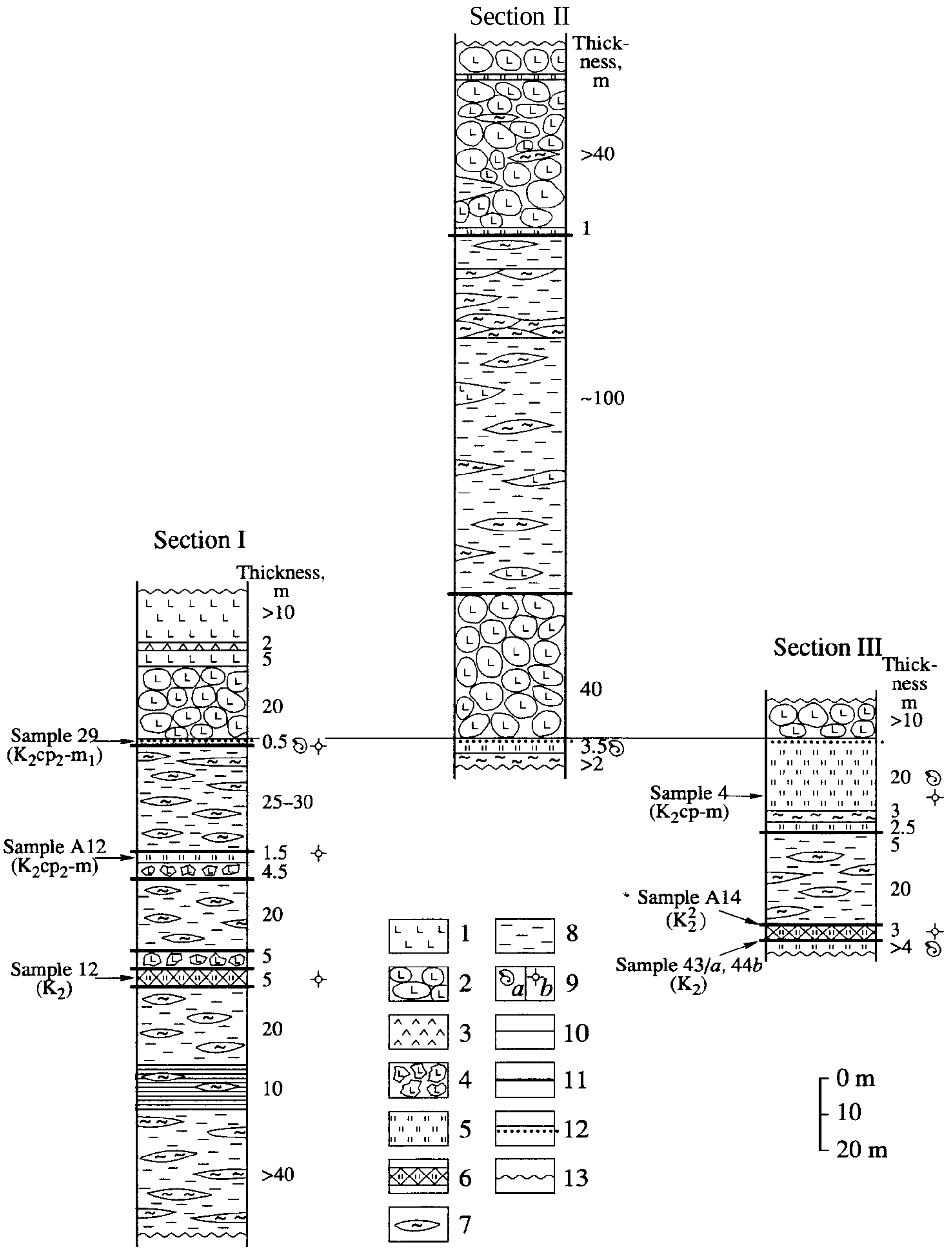

Fig. 2. Tectonostratigraphic sections of the volcanogenic-siliceous complex: (1) massive basalt; (2) pillow-basalts; (3) hyaloclastites of the basaltic composition; (4) red jaspers; (6) fractured zones; (7) red and gray siliceous rocks (beds and lenses); (8) black aleuropelites; (9) fossils: *(9a)* inocerams (indeterminable), *(9b)* radiolarians; (10) stratigraphic contact; (11) tectonic contact; (12) quenched contacts; (13) boundary of exposed section.

Fragmentary sections of the sedimentary–volcanogenic complex were studied along trubutaries of the Ushchel'nyi, Obkhodnoi, and Bolotnyi creeks, in the northern coast of the Nerpich'e Ozero Lagoon, on the southwestern slope of Mt. Krutaya, and in coastal outcrops of the Malaya Bight (Fig. 3). Tectonostratigraphic units are bounded by thrust surfaces. Columns in the figure show the hypsometric position of thrust sheets and stratigraphic contacts within the distinguished units.

The sedimentary-volcanogenic complex is somewhat arbitrarily subdivided into three units: (1) volcanogenic (lower); (2) volcanogenic–terigenous (middle or transitional), and (3) siliceous-terrigenous (upper) subcomplexes.

The volcanogenic subcomplex is composed of porphyry amygdaloid basalts, volcanic breccia basaltic in composition, and subordinate lavaclastites with the graywacke matrix, as well as interbeds and lenses of

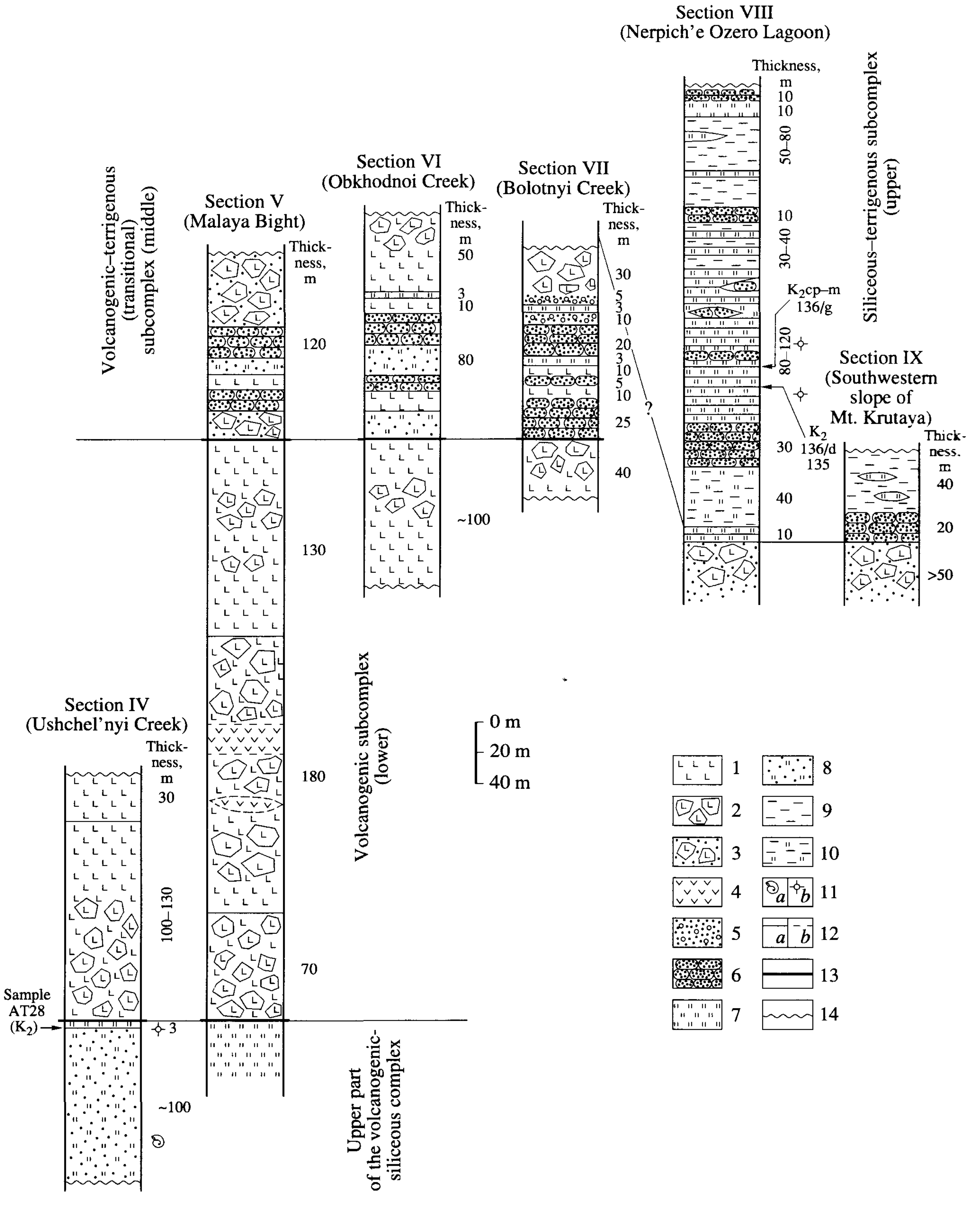

Fig. 3. **Tectonostratigraphic** sections of the **sedimentary–volcanogenic** complex: (1) massive amygdaloid porphyry basalt; (2) volcanic basaltic breccia; (3) basaltic blocks in the graywacke matrix; (4) basaltic **andesites**; (5) volcanomictic **lithocrystalline** graywacke; (6) volcanomictic graywacke sandstone with a **tuffaceous**admixture; (7) siliceous rocks; (8) siliceous rocks with an admixture of terrigenous material; *(9)* **aleuroprlite**; (10) siliceous **aleuropelite**; (11) fossils: (1*1a*) **inocerams** (indeterminable), (1*1b*)**radiolarians**; (12) **stratigraphic** contact: (12*a*) proven, (12*b*) assumed; (13) tectonic contact; (14) boundary of visible section.

basaltic andesites (Fig. 3). The characteristic constituents of the subcomplex are the amygdaloid basalts with large clinopyroxene phenocrysts (to 2 cm) and volcanic breccias with the ataxic (brecciated–taxic) texture (*Strukturagornykh...*, 1948). The ataxic texture is characterized by inclusions (to 10-50 cm across) of both rounded and irregular forms submerged into matrix with the fine-porphyry texture. The matrix and inclusions are identical in composition. The volcanogenic subcomplex overlies with the tectonic contact the volcanogenic–siliceous complex. The tectonic contact was observed along the Ushchel'nyi Creek tributaries and in coastal outcrops of the Malaya Bight. Structurally higher, the volcanogenic–terrigenous complex is thrust along the low-angled plane over the volcanogenic subcomplex of the southwestern part of the peninsula and represents an autonomous tectonic nappe.

The volcanogenic-terrigenous subcomplex is locally exposed and composed of graywacke sandstones, monovolcanic lithocrystalloclastic basaltic breccia, basalts, lavabreccia, and siliceous rocks with a substantial admixture of terrigenous material (Fig. 3). Its upper horizons include submarine slump deposits: large (to 10 m) blocks of basalts and lavabreccia submerged into the graywacke sandy matrix. The position of this subcomplex in the structure of the peninsula is unclear because it was detected only in isolated allochthonous thrust sheats (Fig. 1). The transitional character of the volcanogenic-terrigenous subcomplex is evident from its composition: it includes both the volcanic rocks typical of the volcanogenic subcomplex (lower) and terrigenous deposits characteristic of the siliceous-terrigenous (upper) subcomplex.

The siliceous–terrigenous subcomplex is widespread in the southern part of the peninsula and consists of grawacke sandstones, aleuropelites, silicified siltstones, and green to black cherts. The subcomplex conformably rests upon the rocks of the volcanogenic subcomplex. The gradual transition from volcanic breccia to fine-grained sandstones was observed on the southwestern slope of Mt. Krutaya and the conformable contact between black cherts and underlying volcanic breccia was described in the Nerpich'e Ozero Lagoon area.

Radiolarians from Siliceous Rocks of the Complex

Over 50 samples from the siliceous-terrigenous subcomplex were subjected to the radiolarian analysis. Three samples yielded radiolarian assemblages that were sufficiently well preserved and diverse in the sample 136/g only (Fig. 3, Table 1, Plate III). The assemblage includes *Praestylosphaera pusilla* (Campbell et Clark), *Cornutella califomica* Campbell et Clark, *Clathrocyclas* cf. *tintinnaeformis* Campbell et Clark, *C.* cf. *hyronia* Foreman, *Theocampe* cf. *altamontensis* (Campbell et Clark), *Lithostrobus* cf. *rostovzevi* Lipman, *Phaseliforma* sp., *Stichomitra* sp., *Dictyomitra* sp., and prevalent *Theocampe yaoi* Taketani. This assemblage suggests the Campanian–Maastrichtian age of host rocks of the siliceous-terrigenous subcomplex (Table 2).

DISCUSSION

The frontal part of the Olyutor zone in the Anastasiya Bay area is chracterized by the thrust-and-fold structure and comprises two units: the volcanogenic–siliceous and sedimentary volcanogenic complexes.

The volcanogenic-siliceous complex is composed of oceanic *(sensu lato)* pillow basalts, as well as of pelagic and hemipelagic siliciliths and aleuropelites. Volcanics of the volcanogenic–siliceous complex are represented by aphyric and plagioclase–clinopyroxene–porphyry basalts and dolerites. All the rocks are variably spilitizied. The prevalence of lavas and absence of pyroclastic rocks indicate that eruptive centers were of the fracture or central types located below the pressure compensation level (Fisher, 1987). According to estimates, this level is 200 m and deeper below sea level for basic lavas. Siliceous rocks and aleuropelites contain an admixture of the graywacke material derived by erosion from the ensimatic crust. The presence of turbidity and slump textures testifies to the existence of the differentiated relief during the formation of the complex.

Siliciliths from tectonic slices of the tectonostratigraphic section of the volcanogenic-siliceous complex are dated back to the Campanian-Maastrichtian. Correlation of radiolarian assemblages from these deposits with radiolarian zonation elaborated for the Bering Sea region (Vishnevskaya, 1985) shows that they appear to be coeval with the late Vatyna and early Innetyvayam assemblages.

Previously, deposits of the volcanogenic-siliceous complex of the Anastasiya Bay area were studied by N.A. Bogdanov and K.A. Savel'ev. From samples collected by these reasearchers, Vishnevskaya (1985) determined radiolarian assemblages of the late Turonian–early Campanian and Coniacian–middle Campanian ages (Table 3), which were correlated with the early-middle Vatyna assemblages. L.G. Bragina determined radiolarians of the Santonian–Campanian age correlative with the middle-late Vatyna assemblages from jaspers of the Snegovaya nappe (Astrakhantsev *et al.,* 1987) probably representing rocks of the volcanogenic-siliceous complex.

The history of stratigraphic studies of volcanogenic-siliceous deposits in the Koryak Highland was considered earlier *(Geologiya yuga...,* 1987). The "Vatyna Group" was attributed to the Cretaceous at the end of the 1950s (Lipman, 1959), to the Late Cretaceous at the beginning of the 1970s (Zhamoida, 1972), and to the Albian–Campanian in the mid-1980s (Vishnevskaya, 1985). In lithologic and petrographic properties, the volcanogenic-siliceous complex of the Anastasiya Bay area is identical to deposits previously included in the "Vatyna Group." Based on the latter evi-

Plate I

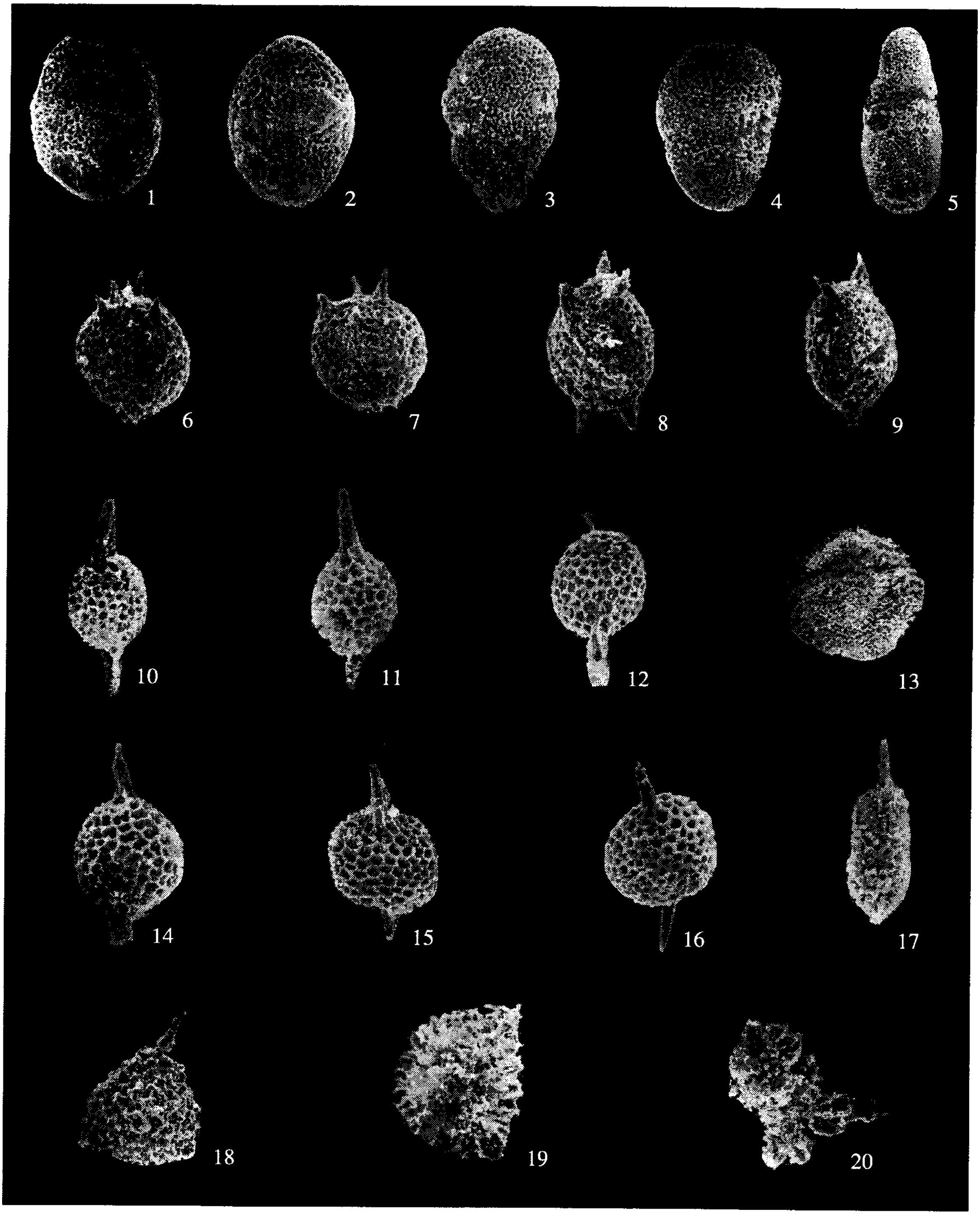

Plate 1. Radiolarians from rocks of the volcanogenic–siliceous complex.

(1, 2) *Phaseliforma* ex gr. *carinata* Pessgno, ×100, Sample A12 (1), Sample 12 (2); (3, 4) *Phaseliforma* cf. *sucarinata* Pessagno, ×100, Sample 29; (5) *Phaseliforma* cf. *meganosensis* Pessagno, x50, Sample 29; (6-9) *Lithomespilus mendosa* (Krasheninnikov) ×150 (6, 8, 9), x120 (7), Sample A12; (10–12) ***Praestylosphaera pusilla*** (Campbell et Clark), xlOO, Sample 29; (13) *Orbiculiforma* sp., x90, Sample 4; (14-16) Praestylosphaera hastata (Campbell et Clark), xlOO, Sample 29 (14), ×110, Sample A12 (15, 16); (17) ***Archaeospongoprunum*** sp., ×150, Sample 4; (18–20) ***Alievium*** sp., x90 (218), XlOO (19, 20), Sample 4.

Plate II

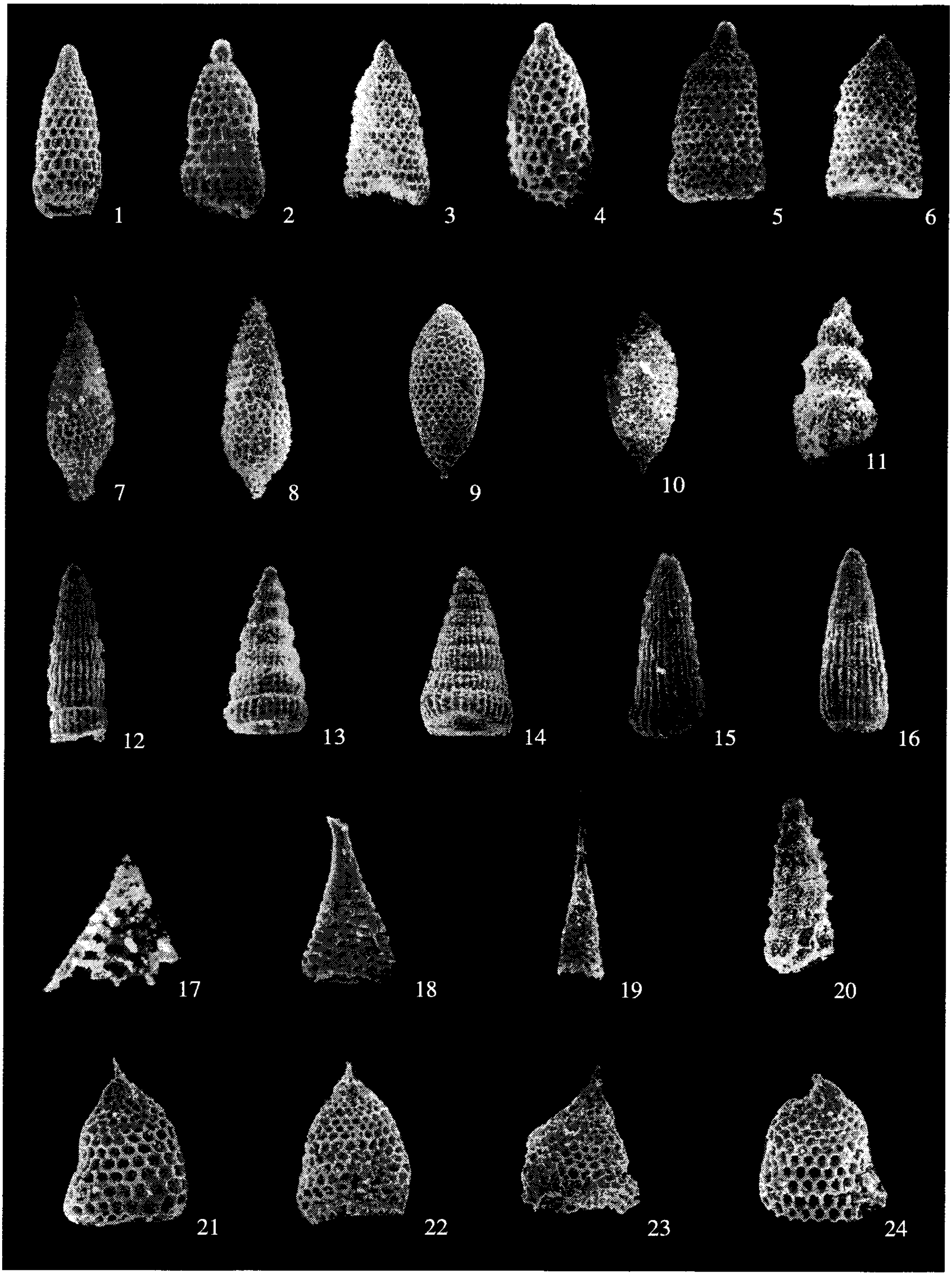

Plate II. Radiolarians from rocks of the volcanogenic-siliceous complex.

(1, 2) ***Amphipyndaxstreckta*** **Empson-Morin, ×100,** Sample A12 (1), Sample 29 (2); (3) ***Amphipyndax****stocki* (Campbell et Clark), ×100, Sample 29; (4) *Amphipyndax stocki* var. B Vishnevskaya, xlOO, Sample 29; (5, 6) *Amphipyndax? stocki* (Campbell et Clark), xlOO, Sample 29; (7, 8) ***Stichomitra livermorensis?*** **(Campbell** et Clark), xlOO, Sample 4; (9, 10) ***Stichomitra*** cf. ***shirshovica*** Vishnevskaya, xlOO, Sample 29; (11) *Stichomitra* **sp.**, xl 10, Sample 4; (12) ***Archaeodictyomitra regina*** (Campbell et Clark), xlOO, Sample 29; (13, 14) *Dictyomitra densicostata* Pessagno, xlOO, Sample 29 (13), Sample 4 (14); (15, 16) ***Dictyiomitramulticostata*** **Zittel,** xlOO, Sample A12; (17) *Bathropyramis* **sp.,** xlOO, Sample 4; (18) *Cornutella* cf. *califomica* Campbell et Clark, xl 10, Sample A12; (19) *Cornutella califomica* Campbell et Clark, xlOO, Sample 4; (20) ***Xitus*** cf. *asymbatos* (Foreman), xlOO, Sample 4; **(21, 22)** ***Clathrocyclas hyronia*** **Foreman, ×120** (21), xl 10 (22), Sample A12; (23, 24) ***Clathrocyclas*** **ex** gr. ***hyronia*** **Foreman,** xl 10 (23), xlOO (24), **Sample** A12.

Plate III

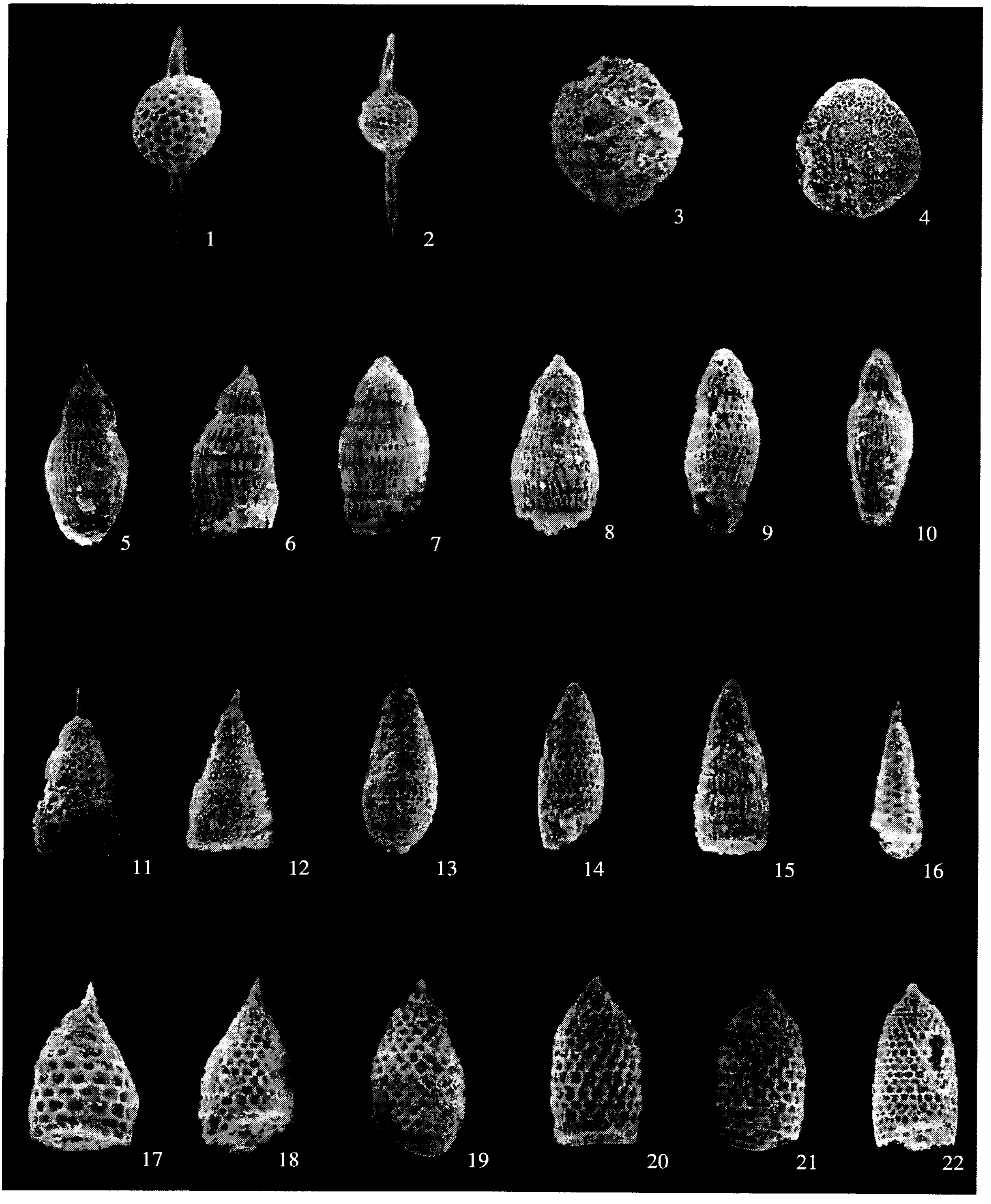

Plate 3. Radiolarians from rocks of the siliceous-terrigenous subcomplex of the sedimentary-volcanogenic complex (Sample 136/g). (1, 2) *Praestylosphaera pusilla* (Campbell et Clark), ×150 (1), ×100 (2); (3, 4) *Orbiculiforma* ? sp., ×100; (5-8) *Theocampe* cf. *yaoi* Taketani, x100; (9, 10) *Theocampe* cf. *altamontensis* (Campbell et Clark), ×110; (11, 12) *Lithostrobus* cf. *rostovzevi* Lipman, x100; (13, 14) *Stichomitra* sp., x100; (15) *Dictyomitra* sp., ×110; (16) *Cornutella californica* Campbell et Clark, ×150; (17-19) *Clathrocyclas* cf. *hyronia* Foreman, X100; (20–22) *Clathrocyclas* cf. *tintinnaeformis* Campbell et Clark, x100.

Table 2. Stratigraphic range of radiolarian species

Radiolarians	K_2							P_1^1
	cn	st	cp			m		
			e	m	l	e	l	
Phaselifroma ex gr. *carinata* Pessagno			– –	– –	—	?		
Phaseliforma cf. *subcarinata* Pessagno			– –	– –	—			
Phaseliforma cf. *meganosensis* Pessagno		–	– –	– –	—			
Orbiculiforma quadrata Pessagno	—	—	—	– –				
Praestylosphaera pusilla (Campbell & Clark)			?	– –	—	—	–	
Praestylopshaera hastata (Campbell & Clark)			—	—	—	–		
Ltihomespilus mendosa (Krasheninnikov)							—	—
Cornutella californica (Cambell & Clark)			– –	– –	—	—	–	– –
Stichomitra livermorensis Campbell & Clark	–	– –	–	–	—	—	–	– –
Stichomitra cf. *shirchovica* Vishnevskaya					—	—		
Amphipyndax stocki (Campbell & Clark)	—	—	—	—	—	—	—	—
Amphipyndax stocki var. B. Vishnevskaya		—	—	—	–	–		
Amphipyndax streckta Empson–Morin				–	—	–		
Archaeodictyomitra regina (Campbell & Clark)				–	—	—	–	– –
Dictyomitra densicostata Pessagno	–	– –	—	– –	–			
Dictyomitra cf. *multicostata* Zittel	—	—	—	—	—	—	—	—
Clathrocyclas tintinnaeformis Campbell & Clark			–	–	—	—	–	
Clathrocyclas cf. *hyronia* Foreman					—	—	–	
Xitus cf. *asymbatos* (Foreman)	—	—	—	—	—	—	—	—
Theocampe yaoi Taketani					—	—	—	—
Theocampe cf. *altamontensis* (Campbell & Clark)					—	—	—	—
Lithostrobus cf. *rostovzevi* Lipman		—	—	—	—			

dence and our dating, we believe that the "Vatyna Group" incorporates also younger Maastrichtian horizons.

Rocks of the "Vatyna Group" were previously interpreted as representing: (1) deposits of the eugeosynclinal Late Cretaceous depression on the oceanic crust (Alekseev, 1979); (2) deposits of a deepwater basin (Bogdanov *et al.,* 1982); (3) a fragment of the upper oceanic crust (Astrakhantsev *et al.,* 1987); (4) the basaltic layer of the oceanic crust detached from the basement or fragments of oceanic volcanic plateaus (Kazimirov *et al.,* 1987); (5) heterogenous complex of deposits originated in the mid-ocean ridge and abyssal plains (the Albian–Turonian), intraoceanic undersea rises (the Coniacian–Campanian), and marginal seas (Campanian) (Sokolov, 1992); and (6) deposits of a marginal sea (Chekhovich, 1993).

The sedimentary–volcanogenic complex is subdivided into three units: volcanogenic, volcanogenic–terrigenous (transitional), and siliceous-terrigenous subcomplexes. Some inferences concerning formation environments of the complex can be based on classification of volcanoclastic sedimentation setting proposed by Fisher (1987) in accordance with lithologic properties of sections. The volcanogenic subcomplex is composed of thick flows of massive basalt and basaltic andesite with subordinate beds of coarse tuffs and explosive breccia. These features allows us to suggest that the volcanogenic subcomplex was formed in subaerial environments. The volcanogenic–terrigenous subcomplex is represented by basalts, volcanic breccias, and thick poorly sorted terrigenous deposits with obscure bedding that were most probably formed in shallow submarine environments as a result of reworking of subaerial volcanics with subsequent transportation of the reworked material by gravity flows. The siliceous-terrigenous subcomplex incorporates thin layers of fine-grained sorted material displaying the graded bedding that indicates their accumulation in sufficiently deep submarine settings. According to the model of volcanogenic sedimentation (Cary and Sigurdsson, 1987), two latter subcomplexes probably rep-

Table 3. Age of some siliceous rocks from the Anastasiya Bay area (collection by N.A. Bogdanov and K.A. Savel'ev, 1985; determinations by V.S. Vishnevskaya)

Sample number	Relative abundance \ Age	al	cm	t	cn	st	cp_1	cp_2	m
8/6, 8/7	*Acanthocircus* cf. *ichikawai* (Foreman)								
	Euchitonia triradiata Lipman								
	Dictyomitra ex gr. *multicostata* Zittel								
	Archaeodictyomitra regina (Campbell & Clark)								
	Stichomitra? *livermorensis* (Campbell & Clark)								
	Lithostrobus rostovzevi Lipman								
	Theocapsomma ex gr. *comys* Foreman								
	Amphipyndax stocki var. A Vishnevskaya								
	A. stocki var. B. Vishnevskaya								
7/2	*Pseudoaulophacus floresensis* Pessagno								
	Orbiculiforma quadrata Pessagno								
	Amphipyndax stocki var. A. Vichnevskaya								
	Archaeodictyomitra squinaboli Pessagno								
3/6	*Phaseliforma carinata* Pessagno								
	P. concentrica (Lipman)								
	Stylodruppa bifascicula Kazintsova								
	Amphipyndax stocki var. A. Vishnevskaya								
	Lithostrobus zhamoidae Kazintsova								
1/1	*Cromyosphaera vivenkensis* Lipman								
	Orbiculiforma quadrata Pessagno								
	Alievium superbum (Squinabol)								
	Theocapsomma? *amphora* Campbell & Clark								
	Neosciadiocapsa diabloensis Pessagno								
	Amphipyndax stocki var. A Vishnevskaya								
	A. stocki var. B. Vishnevskaya								
	A. conicus Nakaseko & Nishimura								
	Archaeodictyomitra squinaboli Pessagno								

resenting different facies of the volcanoclastic apron on the slope of an island arc with subaerial volcanic eruptions.

Siliciliths from the siliceous-terrigenous subcomplex are dated as the Campanian–Maastrichtian. The radiolarian assemblages from these deposits are correlative with the late Vatyna and early Inetyvayam assemblages (Vishnevskaya, 1985). In lithology and structure, the sedimentary–volcanogenic complex can be correlated with three units: with the “Achaivayam Formation" (Zhamoida, 1972; Astrakhantsev *et al.*, 1987), volcanogenic complex (Bogdanov *et al.*, 1982), and Machevna complex (Sukhov, 1983; *Geologiya yuga...*, 1987).

The "Achaivayam Formation" was considered as representing deposits of an island-arc system (Bogdanov *et al.*, 1982; Astrakhantsev *et al.*, 1987; Kazimirov *et al.*, 1987). The Machevna complex was interpreted to be a relict of the incipient or remnant island arc of a westward orientation in its frontal part (Sukhov, 1983; *Geologiya yuga...*, 1987).

Thus, three main structural–formational complexes formed in different geodynamic settings can by recognized in the Anastasiya Bay area: flysch deposits of the continental rise or deep-sea trench (the Ukelayat zone; Kazimirov *et al.*, 1987; Chekhovich, 1993); volcanogenic–siliceous deposits of the marginal sea (the "Vatyna Group" of the Olyutor zone; Chekhovich, 1993); and sedimentary-volcanogenic deposits of the ensimatic island-arc system and its slope (the Machevna complex or "Achaivayam Formation"; *Geologiya yuga...*, 1987). As was shown above, some horizons of volcanogenic–siliceous and sedimentary-volcanogenic complexes were formed simultaneously, in the Campanian-Maastrichtian. Deposits of the Cam-

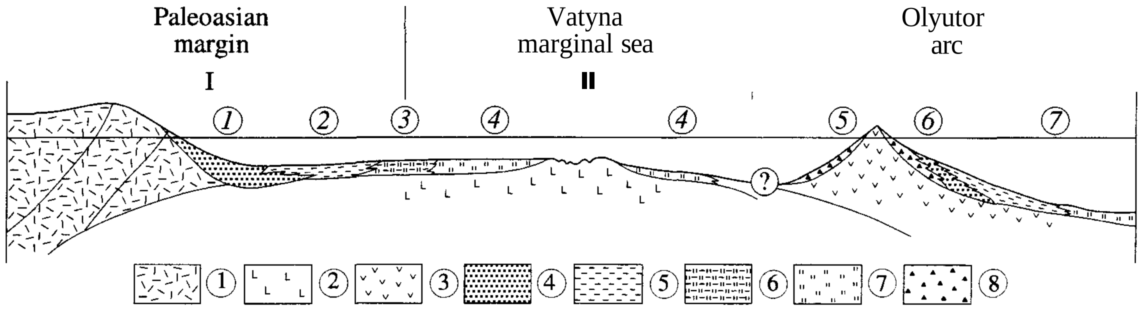

Fig. 4. Hypothetical lateral succession of the Campanian–Maastrichtian settings inferred from the analysis of tectonostratigraphic sections of the Anastasiya Bay area and published data (Chekhovich, 1993): (I) Ukelayat flysch complex with *(1)* proximal and (2) distal fan facies; (II) volcanogenic–siliceous complex (the "Vatyna Group") with *(3)* transitional facies (aleuropelites and siliceous rocks) and *(4)* basalts with siliceous rocks; (III) sedimentary–volcanogenic complexes (the "Achaivayam Formation") with (5) volcanogenic, (6) volcanogenic–terrigenous, (7) siliceous-terrigenous subcomplexes. Symbols in boxes: (1) accretion complexes of the Koryak Highland; (2) marginal-sea crust, (3) island-arc crust; (4) terrigenous and volcanogenic psammites; (5) aleuropelites of a variable genesis; (6) clayey-siliceous facies; (7) siliceous facies; (8) coarse volcanogenic rocks.

panian–Maastrichtian age were also recorded in the flyschoid complex of the Ukelayat zone (Kazimirov *et al.,* 1987). All these structural–formational complexes are close in the formation time and tectonically juxtaposed in the modern structure. Accordingly, we reconstruct the following lateral succession of depositional settings during the Campanian-Maastrichtian: the continental slope-marginal sea basin-island arc–deepwater oceanic basin (Fig. 4). Presence of aleuropelites in the tectonostratigraphic sections of the volcanogenic-siliceous complex allows the latter to be referred to transitional facies between the continental rise (Ukelayat facies) and marginal sea basin (the "Vatyna Group" of the Olyutor zone). Transitional facies were also described in sections of the Ukelayat zone, where siliceous–clayey rocks and high-titanium basalts occur among flysch deposits (Sokolov, 1992).

The Analysis of Radiolarian Assemblages

The presence of cancellate radiolarian skeletons, along with cyrtoid forms, in radiolarian assemblages and sponge remains in rocks of the volcanogenic-siliceous complex (Samples 12, 29) suggest that this community inhabited waters of a marginal sea. The burial of the assemblage most likely occurred in relatively shallow environments, which is evident indirectly from a rather high percentage of sponge forms, almost complete absence of spines, and strong fragmentation of skeletons.

The radiolarian assemblage from the siliceous-terrigenous subcomplex is dominated by cyrtoid forms (sponge/cyrtoid forms ratio is 1 : 10). Most common are representatives of the *Theocampe* genus typical of basins with a depth close to the abyssal one (Empson-Morin, 1984). The above-described assemblage probably inhabited an open sea basin, where the burial depth was greater as compared with that of radiolarians from the volcanogenic-siliceous complex.

Radiolarians from tectonostratigraphic sections of the Anastasiya Bay area are akin to those from Upper Cretaceous deposits of California (Campbell and Clark, 1944; Pessagno, 1976) and Japan (Taketani, 1982), as well as to assemblages from DSDP Site 275 in the southern high-latitude Pacific (Pessagno, 1975). Empson-Morin (1984) noted that the high-latitude radiolarian assemblages are characterized by presence of orbiculiformids and phaseliformids with the reduced height/width ratio of skeletons. This value in phaseliformids from our collection is 1.42–1.59.

The low diversity, smoothed forms, presence of massive thick-walled shells, low percentage of spiny forms, and small dimensions allow the described radiolarians to be referred to the high-latitude assemblage.

CONCLUSION

(1) Two structural-formational complexes are established in the Anastasiya Bay area: volcanogenic-siliceous and sedimentary-volcanogenic. In the modern structure, deposits of these complexes occur in tectonostratigraphic sections.

(2) The volcanogenic-siliceous complex incorporates rock members dated as the late Turonian–early Campanian and Coniacian–middle Campanian (determinations by V.S. Vishnevskaya). The Campanian-Maastrichtian members are established in the complex for the first time. By lithology, the complex is correlative with the "Vatyna Group" *(Geologiya yuga...,* 1987; Astrakhantsev *et al.,* 1987). Previously, it was believed that the "Vatyna Group" was formed in the Albian–Campanian *(Geologiya yuga...,* 1987). According our data, it also includes Maastrichtian rocks.

(3) The sedimentary-volcanogenic complex is subdivided into three units: the volcanogenic (lower), volcanogenic-terrigenous (middle or transitional), and siliceous-terrigenous (upper) subcomplexes. The siliceous-terrigenous subcomplex contains radiolarians,

which allow the host deposits to be dated as the Campanian–Maastrichtian. The sedimentary–volcanogenic complex is correlated with the Machevna complex (*Geologiyayuga...*, 1987) or "Achaivayam Formation" (Astrakhantsev *et al.,* 1987).

(4) The volcanogenic–siliceous complex was likely formed in a marginal sea basin, whereas the sedimentary-volcanogenic complex was accumulated in an island arc and its slope setting. The data obtained allow the succession of paleosettings to be reconstructed as follows: continental slope-marginal sea basin-island arc–oceanic basin.

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Fission-track study of the Omgon accretionary complex on Western Kamchatka (Russian Far Eeast): Possible northern continuation of the Shimanto belt (Japan)

A.V. Soloviev[1], J.I. Garver[2]

[1] Institute of the Lithosphere of Marginal Seas RAS, 22 Staromonetny per., Moscow 109180, Russia, e-mail: solov@ilran.ru
[2] Union College, Geology Department, Schenectady, NY 12308, USA, e-mail: garverj@union.edu

ABSTRACT

Detrital zircon fission-track ages from sedimentary rocks of the Omgon accretionary complex (Western Kamchatka) suggest deposition and deformation of this wedge resulted from Cretaceous subduction of Pacific oceanic plates under the Eurasian continental margin. The Omgon accretionary wedge was originated in very similar geodynamic setting and same time as Cretaceous Shimanto Belt much farther to the south (older part of the belt). The similarity of ages, lithologic similarity, and tectonic setting may suggest the Omgon is the northern continuation of Shimanto. If the Omgon is a northern continuation, and if it is in place, this suggestion has important implications for the evolution of the Sea of Okhotsk to the east.

Key words. *fission-track, zircon, accretionary wedge, Kamchatka*

INTRODUCTION.

A detailed understanding of accretionary complexes can provide important insight into the formation and development of continental crust in subduction zones. On-land fission-track investigations on accretionary wedge were carried out in a number of places including in southwest Japan (Shimanto belt (Hasebe, Tagami, 2001)), western coast of North America (Franciscan Complex (Dumitru, 1989) and Olympic Subduction Complex (Brandon and Vance, 1992; Stewart, Brandon, in press)). An ancient accretionary complex exposed on the eastern coast of the Sea of Okhotsk in the Omgon Range (Western Kamchatka) has only recently been discovered by our mapping. Map relations, lithological, structural and detrital fission-track studies indicate that the Omgon represents an accretionary complex (Fig. 1 B, C) formed in Cretaceous as result of offscraping and underplating of the upper part of the oceanic crust during subduction of Pacific oceanic plates under the Eurasian continental margin. The Cretaceous Omgon belt is similar in age, structure and tectonic position to Shimanto belt in southwest Japan (Fig. 1 C).

GEOLOGICAL OVERVIEW

The oldest unmetamorphosed sedimentary sequence in Kamchatka is exposed on the eastern coast of the Sea of Okhotsk in the Omgon Range. The Omgon Range is made up of southeast-verging imbricated tectonic units (Fig. 1d). The imbricated sequences are dominated by sandstones, mudstones, conglomerates (flysch complex), as well as a number of slices and blocks of pillow and massive basalts with radiolarian cherts (volcanogenic-siliceous complex). The Omgon Flysch is mainly highly deformed turbidites, with macrofossils and flora indicating an Albian-Coniacian (c. 113 to 87 Ma) age (Geologiya USSR, 1964). Sandstones are uniform in composition and the sediment is inferred to have been derived from a continental arc. The slices and blocks have the oceanic affinity based on their geochemistry (Soloviev et al., 2000). Radiolarian assemblages and Buchias ranging in age from Jurassic to Early Cretaceous are reported from volcanogenic-siliceous slices and blocks (Vishnevskaya et al., 1999). Available paleomagnetic data indicate that complexes of Omgon Range are located in more-or-less their modern position definitely since the beginning of Paleocene and probably since Cretaceous (Chernov and Kovalenko, 2001).

Detrital fission-track (FT) thermochronology. Detrital FT thermochronology involves using FT ages of single grains for stratigraphic correlation, provenance analysis, dating unfossiliferous sediments, and exhumation studies (e.g. Garver et al., 1999). Detritus shed off an active arc tends to retain a good record of the timing of volcanic and high-level intrusive events. In this case, a population of detrital grains is derived from contemporaneous volcanics and therefore the age of the young population can serve as a proxy for depositional age, or a limiting age on the timing of deposition. Detritus from contemporaneous volcanic sources is transported very quickly into adjacent flanking basins.

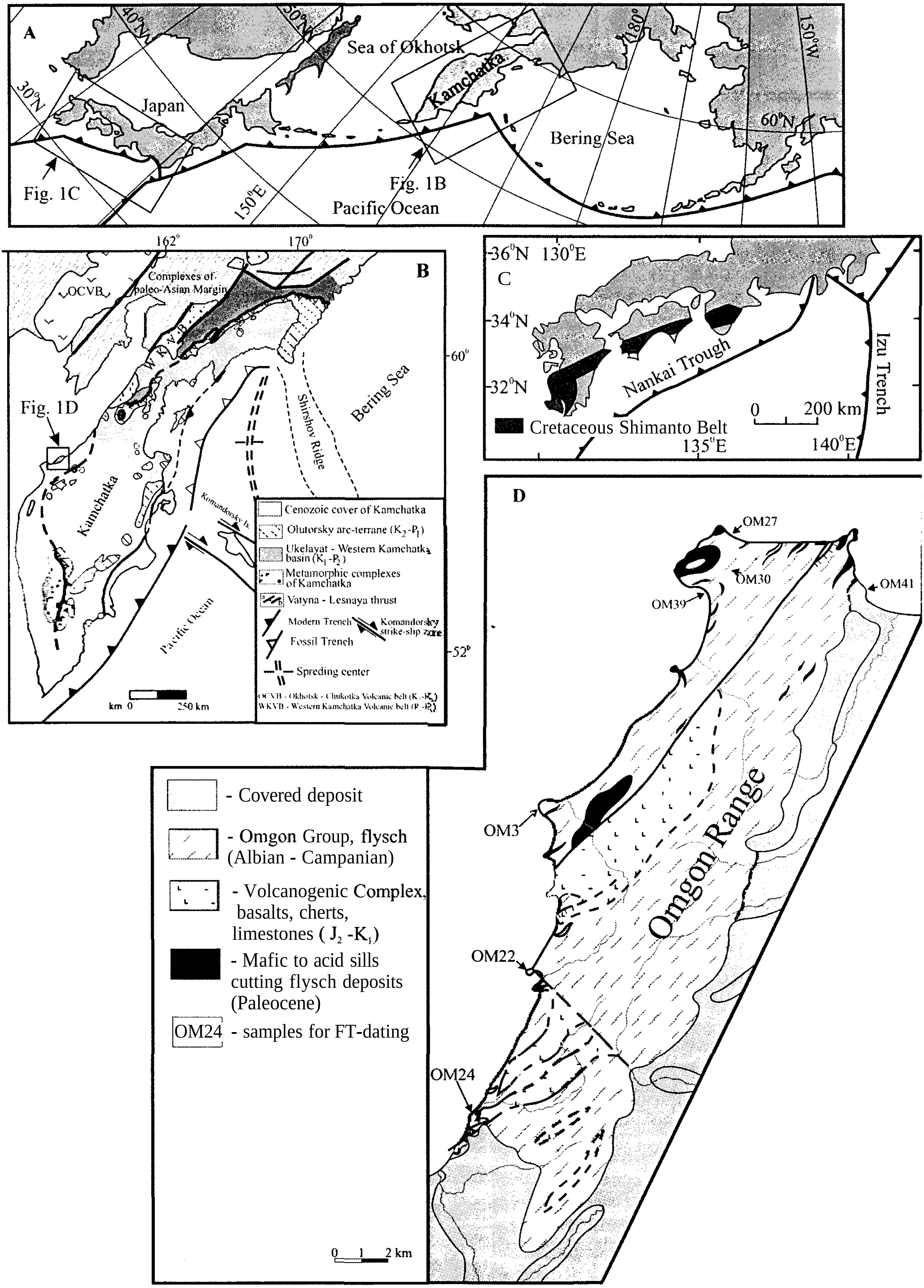

Fig. 1. (A) Regional setting of the western margin of the Pacific Ocean. (B) General geological setting of Kamchatka. (C) Distribution of the Shimanto Belt in Japan. (D) Simplified geological map of the Omgon accretionary complex.

Table 1: Summary of detrital zircon fission-track data from Omgon accretionary complex

No sample	Nt	Age of zircon population		
		P1 (Ma)	P2 (Ma)	P3 (Ma)
OM3	75	80.0±4.1 (95%)	175.7150.5 (5%)	-
OM39	74	85.3±4.2 (95%)	167.8±33.6 (5%)	-
OM30	46	90.6±9.0 (53%)	151.3+17.3 (47%)	-
OM27	75	99.8±5.8 (83%)	187.0127.9 (17%)	-
OM24	75	102.0±18.9 (19%)	142.2±12.0 (68%)	248.2+28.8 (13%)
OM22	60	114.5±7.2 (70%)	-	237.1+25.3 (30%)

Note: Nt = number of grains; percentage of grains calculated in a specific peak; uncertainties cited at ±1 se. Zircons were dated using standard methods for FT dating using an external detector. Mounts were etched in a NaOH-KOH at 228°C for 15 and 30 hr and then irradiated at Oregon State with a fluence of 2 x 10" n/cm^2, along with zircon standards and dosimeter CN-5. Tracks were counted on an Olympus BX60 at 1600x, and a ζ-factor of 348.2±11.02 was used.

Sandstones from Omgon Flysch have a population of colorless, euhedral zircons, ascribed to active magmatism in the source. This young population can be used to constrain the maximum age of the units. Populations of fission-track ages of unreset detrital zircon grains from 6 sandstone samples from Omgon Flysch are between 78 to 250 Ma and represent cooling ages in the source (see Table 1). The youngest population of grain ages may be ascribed to syn-depositional volcanic sources. The zircon FT minimum ages range from 114.5±7.2 Ma to 80.0±4.1 Ma and may approximate depositional age of these rocks.

CONCLUSIONS.

The Omgon Range (Western Kamchatka) is made up of southeast-verging imbricated tectonic units that were likely imbricated in a subduction setting. Sandstones are uniform in composition and the sediment is inferred to have been derived from a continental arc, and the FT depositional ages of detrital zircons from the Omgon flysch are Albian-Campanian. It is likely that this arc was the contemporaneous Okhotsk-Chukotka volcanic belt (to the west, Fig. 1 B) as the main phase of volcanism and plutonism in this belt is mid Cretaceous. The younger flysch is clearly imbricated with older elements of oceanic rock. The basalts are tholeiites similar to those of spreading centers of oceanic and marginal basins. The overlying siliceous rocks are dated as the Middle Jurassic to Early Cretaceous. The Albian-Campanian continent-derived flysch with the exotic Middle Jurassic to Early Cretaceous ocean-derived blocks is a fragment of the accretionary wedge related to the Cretaceous subduction under the Eurasian margin. The Cretaceous Shimanto belt in Japan is similar to Omgon belt in age. structure and tectonic position. We are struck by the similarity of lithology and timing of these two units that occur in outboard positions. It is possible that the Omgon is essentially a northern continuation of the Shimanto. but the oceanic plates involved are not clear.

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