EVOLUTION OF GEOSYNCLINES ON KAMCHATKA

by

G. P. AVDEIKO

Institute of Volcanology, Pogranichnaya 3, Petropavlovsk-Kamchatsky, USSR

Kamchatka, being one of the youngest regions in tectonic respect, is a good object for revealing regularities of geosynclinal development. Of specific interest are the studies of volcanogenous-siliceous formations which are an indicator of early stages of geosynclinal development. Within the Koryaksko-Kamchatka region of Cenozoic folding three groups of volcanogenic-siliceous formations are distinguished of different age : Late-Jurassic-Valangin, Senonian and Paleogene-Neogene (AVDEIKO, KHRAMOV, 1969). Common peculiarities of composition, structure and similar paleotectonic conditions of formation confirm that these formations are genetically monotype. Volcanogenous formations belong to spilitic-keratophyre group, mainly to spilitic-diabase formation (KUZNETSOV, 1964) with clear petrographic and petrochemical peculiarities allowing to reliably distinguish them from other volcanic formations. Their spatial and paragenetic association with jaspers, silicons, siliceous-argillaceous slates as well as with intrusions of ultrabasic rocks (rarer of basic ones) is observed. They present ophiolite formations together. As know, ophiolite magmatism is the most typical and constant peculiarity of early stages of the development of geosynclinal systems (STILLE,1940 ; SHATSKY,1954 ; AUBOUIN, 1965). Volcanogenous-siliceous formations are connected with facial and gradual vertical transitions with terrigenous deposits thus comprising unique complexes of siliceous-volcanogenous and terrigenous formations up to 8000 m of thickness (AVDEIKOV, KHRAMOV, 1969). In vertical distribution of complexes the following series if usual : terrigenous (aspide)—siliceous volcanogenous-terrigenous (flyshoid) formations, while in horizontal (from continent to ocean) terrigenous-siliceous-volcanogenous formations.

Regular spatial distribution of monotype formations of different age with rejuvenation towards the Pacific allows to distinguish three tectonic zones of different age within the Koryaksko-Kamchatka gegion : Anadyrsko-Koryak, Vetveisko-Kamchatka and East-Kamchatka (Fig. l, 2). The complexes of silica-volcanogenous and terrigenous formations there signify proper geosynclinal stages of development and correspond to the main geosynclinal complex according to M.V. MURATOV (1964). Tectonic zones differ not only by the time of formation of the main geosynclinal complex but by the whole subsequent process of geological development.

Boundaries between the zones mostly pass along the great faults fixed both by geological (EGIAZAROV et al., 1965 ; Geology of the USSR, V. 31, 1964) and by geophysical (RIVOSH, 1963 ; TCHIKOV, IVANOV, 1963) data. These boundaries are often of a clearly expressed arc-like character, and in the places of conjunction of such arcs—as for example within the Central-Koryak plexus of mountains—a whole series of faults is observed mainly of two directions corresponding to the striking of arcs. It is typical also that tectonic zones border upon each other along the intermountain depressions. The Anadyrsko-Koryak zone is separated from the mesozoids of the

Communicated by M. Minato, Feb. 8,1970

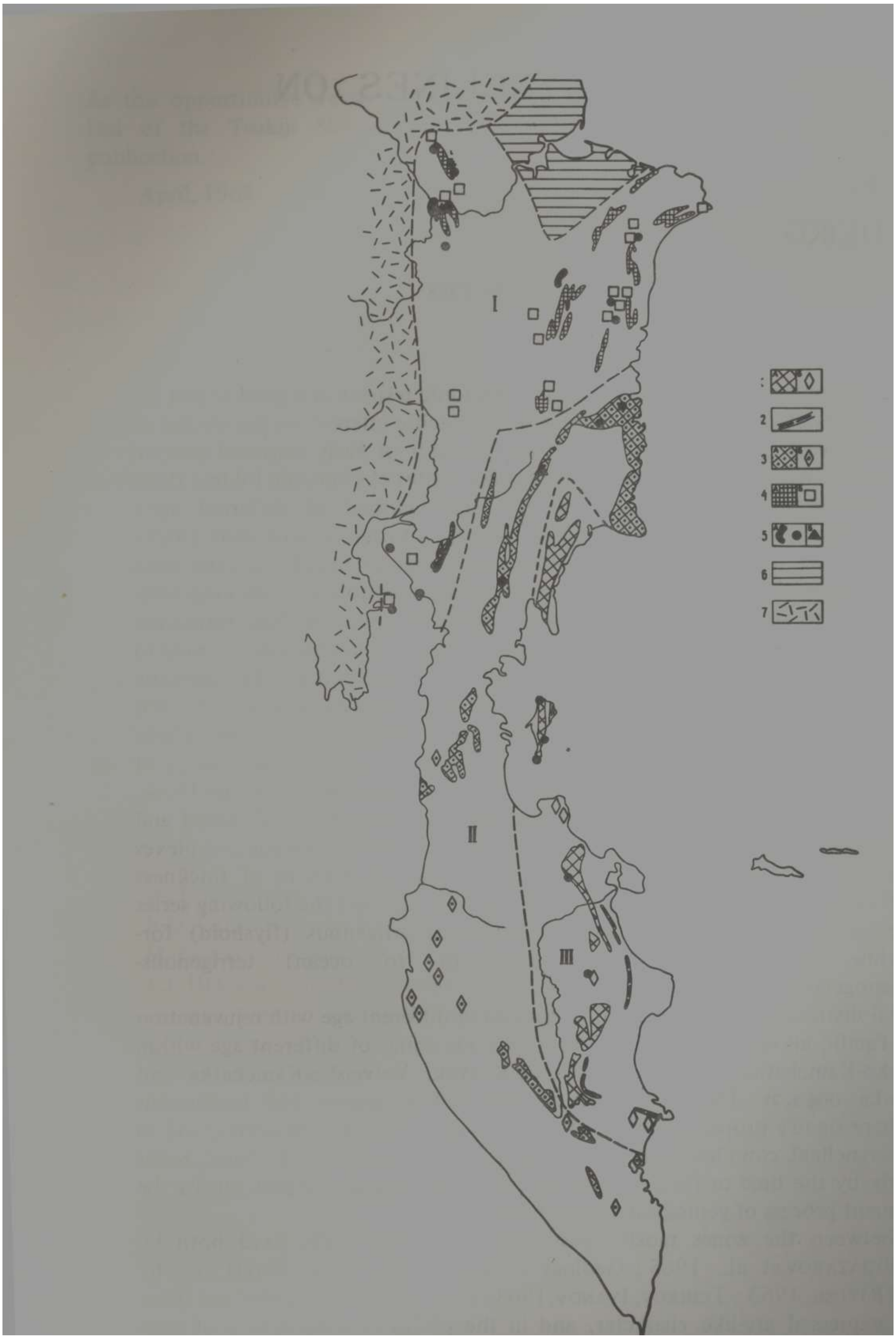


Fig. 1. Scheme of distribution of volcanogenous-siliceous formations in the Koryaksko-Kamchatka area of the Cenozoic folding. 1-4 areas of distribution (a) and certain issues (b) of: 1-upper, 2-lower formations of the Paleogene-Neogene age, 3-upper Cretaceous formation, 4-upper Jurassic-lower Cretaceous formations, 5-ultrabasic (a) and basic (b) intrusions, 6-Eskimo massif; 7-Okhotsko-Chukotsk volcanic belt. Tectonic zones : 1-Anadyrsko-Koryak, II-Vetveisko-Kamchatka, Ill-Eastern Kamchatka.

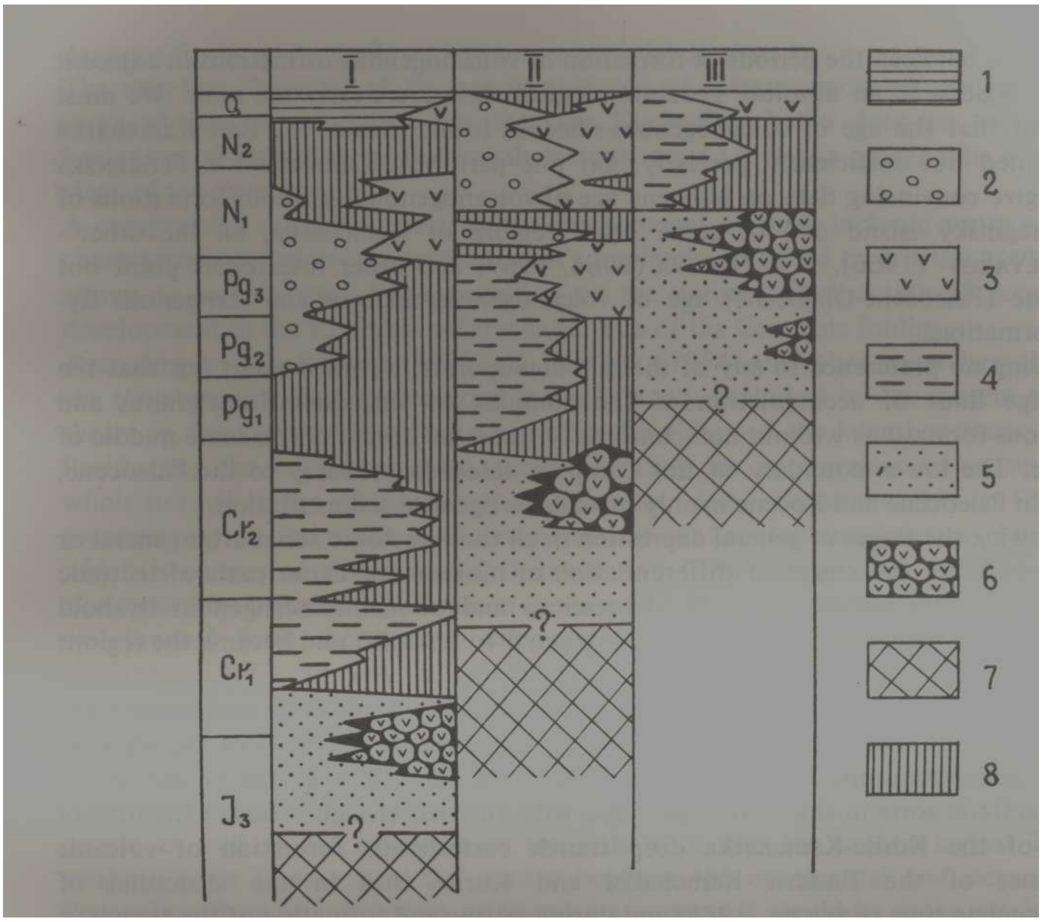


Fig. 2. Scheme of correlation of formations m tectonic zones of the Koryak sko-Kamchatka area of the Cenozoic folding (performed in the absolute geochronological scale) 1-subplatform formations, 2-orogenic molassoid formations ; 3-surface volcanogenous formations, 4-late geosynclinal terrigenous (often flyshoid formations), 5-6-early geosynclinal complex of terrigenous (5) and silica-volcanogenous (6) formations 7-complex of fundamental; 8-intervals in sedimentation.

North-East of the U.S.S.R. by Penzhin depression ; the Vetveisko-Kamchatka from Anadyrsko-Koryak by the depression of Parapolskiy valley going on south-westward in the regions of the Shelekhov bay and the Sea of Okhotsk, the East-Kamchatka from the Vetveisko-Kamchatka by the the Central Kamchatka depression together with the Litke strait. A comparative analysis of formations based on the data of "Geology of the U.S.S.R." v. 1. (1964) and on those of various researchers (AVDEIKO, 1966, 1968 ; BELY *et al*, 1964; EGIAZAROV et al. 1965; ROTMAN, 1961, 1963; KHRAMOV, FLORENSKY, 1969) has shown that the development of all three tectonic zones passed on nearly in the same way. This can be easily seen from the scheme of correlation of formations **(Fig. 2).**

1. The stages of general depression marked by accumulation of complexes of siliceous-volcanogenous and terrigenous formations are typical for geosynclinal development of each of the distinguished zones. Differences between them are displayed only in a relative role^of volcanogenous, siliceous and terrigenous formations and in a correlation between separate component parts of formations. Volcanogenous formations are represented by a group of spilite-keratophyre formations while terrigenous—by aspide and flyshoid ones. The thickness of complex in the Anadyrsko-Koryak zone comprises about 4,000 m. while in the Vetveisko-Kamchatka zone about 6,000 m and in the East-Kamchatka about 8,000 m.

2. Intervals between the periods of formation of volcanogenous formations in adjacent tectonic regions in an absolute geochronological scale are nearly the same. We must point out that the age of volcanogenous-siliceous formations of the East Kamchatka was defined not sufficiently precisely. On one part N.A. KHRAMOV, I.V. FLORENSKY (1969) give convincing data on Miocene age of volcanogenous-siliceous formations of the Karaginsky island and of some other regions of Kamchatka, on the other— V.I.GOLYAKOV (1966), M.Y. SEROVA (1966, 1969) and other researchers point out Paleogene (Paleocene-Oligocene) age of volcanogenous-siliceous and terrigenous fly-shoid formations.

With giving no preference to any of the said standpoints, we must point out that the upper age limit of accumulation of the complex of siliceous-volcanogenous and terrigenous formations without non-conformity traces within it falls on some middle of Miocene. The lower boundary of this complex descends probably to the Paleocene, though in Paleocene and Eocene mainly prevails terrigenous sedimentation.

3. Following the stages of general depression in all three tectonic zones after general or partial uplift are the stages of differentiation of movements. Outer parts of tectonic zones remain the regions of stable depressions and of mainly terrigenous flyshoid sedimentation, while the inner parts are subjected to an uplift and became the regions of removal.

4. To the time of setting of the trough in a younger tectonic zone corresponds the beginning of the surface volcanic activity in the inner (elevated) part of the adjacent tectonic zone, acquiring the character of island volcanic arc with the trough of the young tectonic zone in the frontal part and with the rear trough. Thus to the time of setting of the Kurile-Kamchatka deep trench corresponds formation of volcanic thicknesses of the Eastern Kamchatka and Kurile isles in the structures of grabensyncline type (ERLICH, 1965) and during setting and formation of the trench of the Eastern Kamchatka in oligocene-miocene period within the Median ridge i.e. the elevated part of the Vetveisko-Kamchatka tectonic zone volcanic thicknesses of anavgaiskaya and alneiskaya series are formed close in chemism to the quaternary volcanogenous formations of the Eastern Kamchatka (ERLICH, 1966). However, in formation of the trench of the Vetveisko-Kamchatka tectonic zone within the Anadyrsko-Koryak zone surface volcanic activity of the island-arc type is not observed. It is evidently compensated by the intensification of volcanic activity of the continuously developing Okotsk-Chukotsk volcanic belt.

Alongside with this there is a whole number of data allowing to interpret the troughs of tectonic zones as the analogues of modern deep-sea trenches. Here refers the arc-like character of spatial distribution of volcanogenous-siliceous formations of different age as well as the arc-like character of boundaries between the tectonic zones. These tectonic zones have their continuation in the regions of the Sea of Okhotsk and the Bering Sea which is clearly seen from the analysis of the map of the Earth's crust structure types in the region of Okhotsk (MARKOV et al., 1967, Fig. 37), and the relief of the floor of the Bering Sea. The deep-sea nature of sedimental thicknesses of the lower half of cross-sections is an indirect evidence of the fact that accumulation of complexes of silica-volcanogenous and terrigenous formations took place in the troughs of the deep-sea trench type. Faunal remnanis in terrigenous rocks are as a rule absent and even if they are observed they usually possess the clear traces of roundness and splitting. This is evidently explained by the transportation of fauna from the shelt zone of the trough by turbid streams along the slope down to great depths. The terrigenous rocks are represented by aspide slates, argillites and aleurolites with separate sections of flyshoid interstratification. In siliceous rocks Oligocene-Miocene including the remnants of radiolarians occur rather often and in a great number which are the deep-sea forms while shallow diatoms are completely absent.

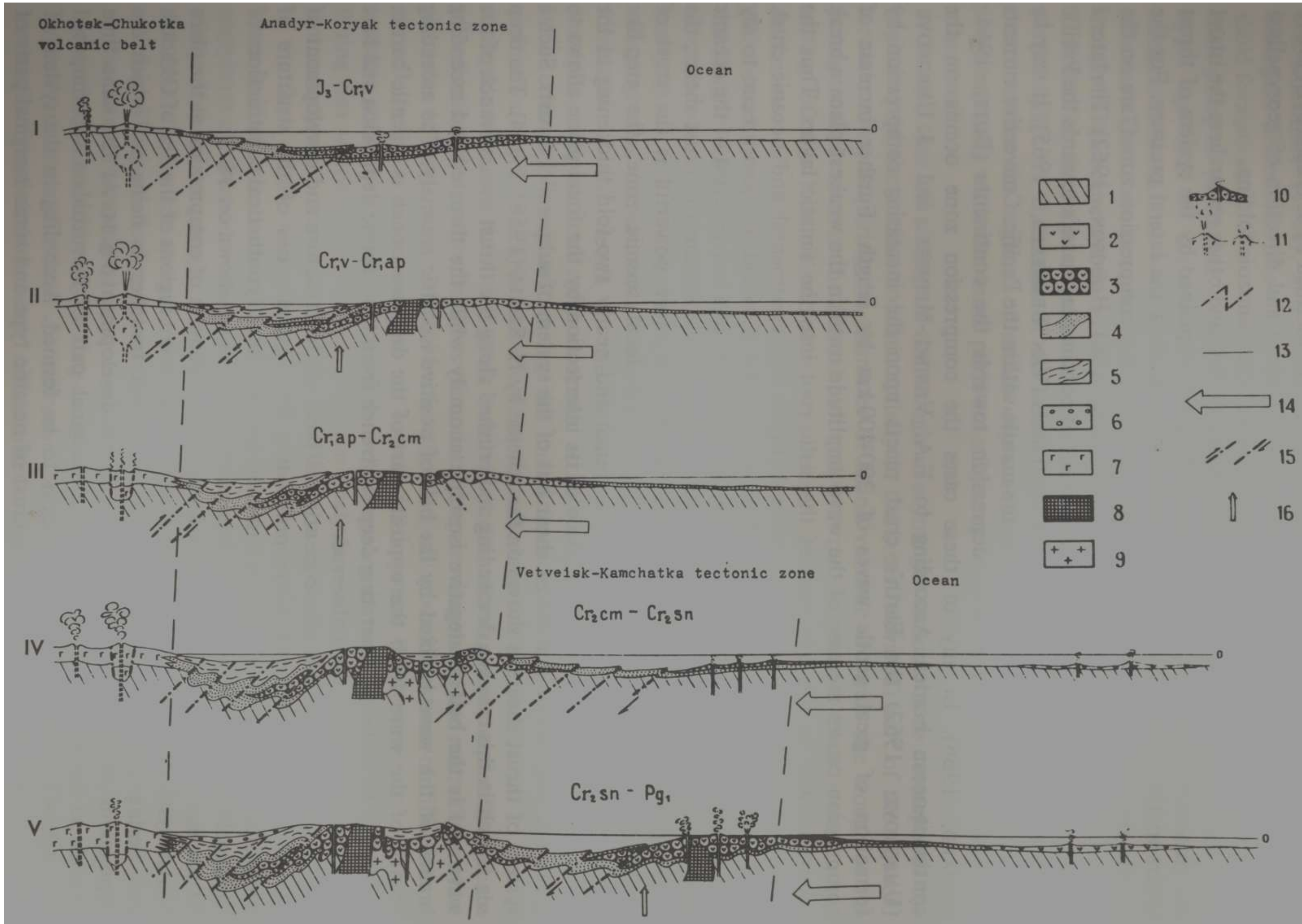
The step-like character of the age juvenization of volcanogenous-siliceous formations (see Fig. 2)brings to mind the idea that the Kurile-Kamchatka deep-sea trench is the beginning of formation of the fourth tectonic zone i.e. it is a geosynclme at an early stage of the development.

A comparative analysis of data on the development of three tectonic zones and main characteristics of island arc systems most completely described by J. UMBGROVE|(1947) allows to put forward the supposition on the nature and direction of geosynclinal development in the Koryaksko-Kamchatka area of the Cenozoic folding.

According to J.D. BERNAL (1961), H. BENIOFF (1954) and other researchers the island arc structure peculiarities are comparatively easily explained by the system of thrust shears in the compression zone i.e. under the effect of the lateral pressure. For the Pacific ring the main horizontal stresses, creating the compression zones, are on the whole normal to the morphostructures (LENSEN, 1961, HODGSON, 1962). The lateral pressure may be the result of the movement of continental massifs towards the Pacific which is connected with the drift of continents (VAN BEMMELEN, 1965). It may be also caused by convective currents in the mantle within the Pacific. Convective currents are directed from the oceanic depression towards the continents (BOTT, 1964; MENARD, 1966). In any of these cases the compression zone occurs on the continent-ocean border. According to F.A. VENING -MEINESZ and J. UMBGROVE (UMBGROVE, 1952) the Earth's crust reacts upon the increasing compression by formation of great gentle waves of 200-400 km by length. Further increase of compression causes increase of the wave amplitude until in the weakest place a break occurs as well as the intrusion of the sialic root into the simatic layers. Thus the weakest place is as a rule the border between the continental and oceanic crust. Proceeding from the structure of island arc systems it would be more precise to say that it is not intrusion which occurs but a movement of a heavier crust of the oceanic type under the crust of continental type following the system of thrust shears, the angle of thrust inclination is the more gentle the more powerful is the crust of continental type. A considerable width of the focal seismic zone, the step-like character of the slope of the deep-sea trench and nearly two-fold thickening of the basaltic layer of the crust in the place of its intersection by the focal plane allows to speak not only about one thrust shear but of the system of subparallel thrusts. Such a system of thrust shears is shown on the scheme by H. STILLE (1958), Fig. 4). The deep sea trench in this case is a descending and crushed along the thrust shears branch of the wave and is the belt of negative isostatic anomaly while the thrusted and ascending branch of the wave is fixed by the belt of positive isostatic anomaly. The ascending branch of the wave from the opposite part of the deep-sea trench is a gentle barrier (swell-like formation), separating deep-sea trench from the oceanic depression and here a weak positive anomaly is observed.

Let us try to explain the above-mentioned facts of the structure and development of the distinguished tectonic zones proceeding from peculiarities of the structure of conjugated systems of island arcs and deep-sea trenches. Hypothetical constructions of the developmenfof tectonic zones in a schematic form are shown on **Fig. 3.**

At the end of the late Jurassic period under the influence of compression at the place of Anadyrsko-Koryak tectonic zone and in the adjacent regions of the Sea of Okhotsk and Bering Sea (see Fig. l) a system of deep-sea trenches is being set which are depressions of an early stage of geosynclinal development,(Fig. 3-i). At the same time though so far in a weak form in the marginal part of mesozoids a superimposed Okhotsko-Chukotsk volcanic belt begin to be formed. According to the system of thrust shears both the parts of the crust of oceanic type and some marginal parts of



Okhotsk-Chukotka volcanic belt
Anadyr-Koryak tectonic zone
Ocean
J3-Cr1v
Cr1v-Cr1ap
Cr1ap-Cr2cm
Vetveisk-Kamchatka tectonic zone
Ocean
Cr2cm - Cr2sn
Cr2sn - Pg1
I
II
III
IV
V
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

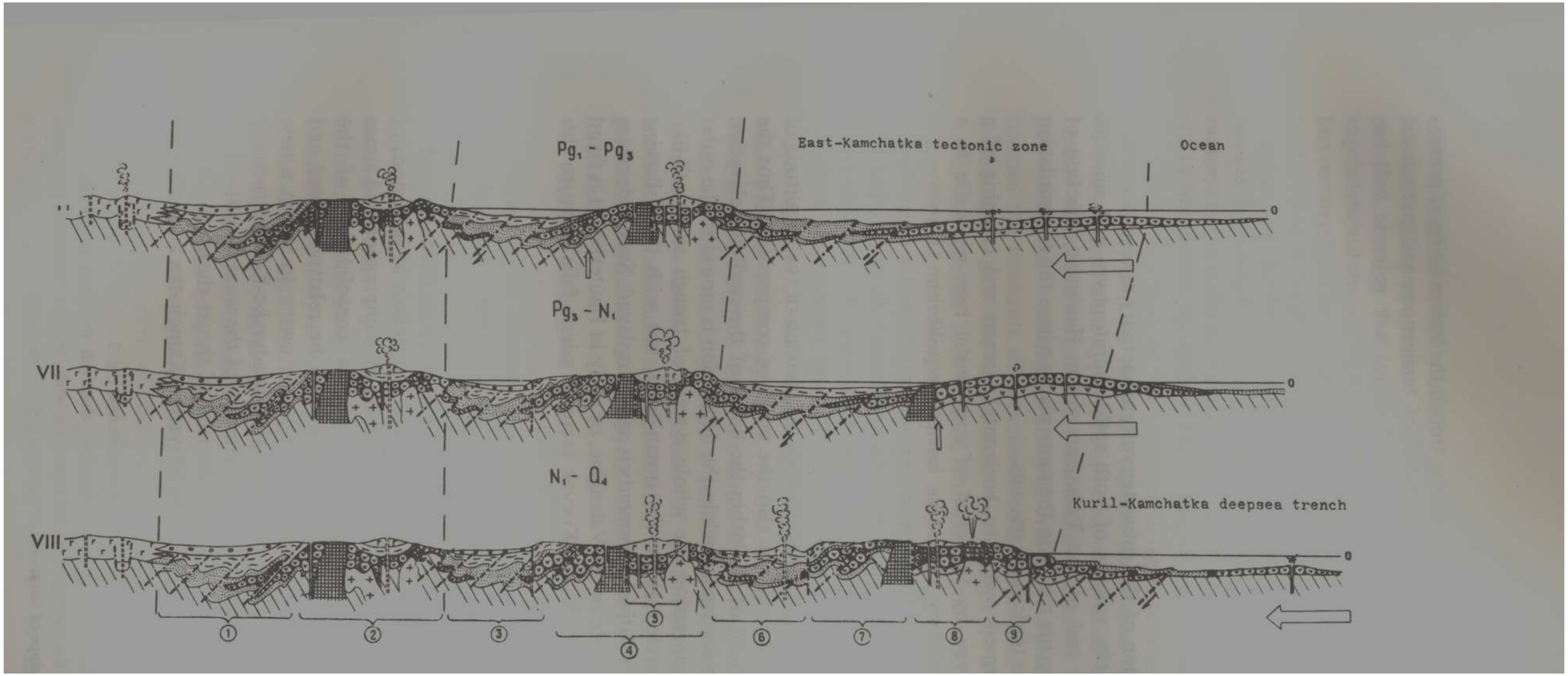


Fig. 3. Scheme of geotectonic development of Koryaksko-Kamchatka area of the Cenozoic folding.

I-heterogenic fundament of geosynclinal systems; 2-volcanic formations of the ocean bed ; 3-4-complexes of volcanogenous-siliceous (3) and terrigenous (4) formations of early stages of geosynclinal development; 5-terrigenous (often flyshoid) formations of the late stages of geosynclinal development; 6-orogenic molassoid formations; 7-volcanogenous formations of the island arc type and superimposed volcanic belts ; 8-basic and ultrabasic intrusions ; 9-granitoid intrusions ; 10-subwater volcanoes ; II-surface volcanoes ; 12-faults of all the types ; 13-ocean level ; 14-lateral pressure ; 15-velocity direction in thrust zones ; 16-elevating power caused by the tendency to restoration of isostatic equilibrium. Modern tectonic structures (figures in circles on the cross-section. VIII) ; 1-the Penzhin depression ; 2-Talovsko-Mainsky anticlinorium ; 3-Parapolsky and Western Kamchatka depressions ; 4-Kamchatsko-Koryak anticlinorium ; 5-graben-syncline of the Median ridge ; 6-Central Kamchatka depression ; 7-Eastern Kamchatka anticlinorium ; 8-graben-syncline of the Eastern Kamchatka ; 9-elevation of the Eastern Kamchatka peninsula.

Mesozoids appeared to be crushed in the basis of the trench the latters being at present elevated in the nuclei of some anticlinoria. Removal of terrigenous and pyroclastic material from the ascending Mesozoids and Okhotsko-Chukotsk volcanic belt has caused formation of mio-geosynclinal terrigenous formations on the continental slopes and on the bottom of deep sea trenches. On the oceanic slopes of the trenches and within the limits of swell-like elevation occurred accumulation of eugeosynclinal spilite-keratophyre and siliceous formations. Between eugeosynclinal and miogeosynclinal formations facial intertransitions are observed so that the boundary between them is not clear. Thus, the formation of the unique complex of silica-volcanogenous and terrigenous formations occurs within the limits of the deep-sea trench and of the swell-like uplift.

In Valangine a gradual attenuation of the subwater volcanic activity takes place which is expressed in a decrease of the volume of both spilito-keratophyre and siliceous formations. Somewhere at the end of the Valangine and in Hauterive injection of ultrabasic and basic intrusions occurs nearly in the same places where the accumulation of spilite-keratophyre formations took place tFig. 3-ii).

Negative isostatic anomaly, formed owing to horizontal stresses and crushing of a heavier crust of the oceanic type by the crust of continental type gives rise to a carrying power caused by a tendency to restore isostatic equilibrium. However the same horizontal stresses do not allow for the carrying power to be realized completely in the zone of thrust shears, i.e. where anomaly is more intensive. In connection with this the amplitude of eleavation is greater on the slope of the trench, conjugated with swell-like elevation **(Fig. 3-й, in).** * In the same direction in the zone of the swell-like elevation the carrying power is acting connected with the increase of the amplitude of the ascending branch of the wave which is also the result of compression. Thus the total carrying effect is marked most of all within the limits of the swell-like elevation and its slope turned to the deep-sea trench while the depression is moved to the outer part. ** With weakening of compression the whole system of trough and swell-like elevation may appear to be elevated above the ocean level, but with the following intensification differentiation of relative movements is again displayed. Such a decrease of compression might have place late in the Valangine, or early in Hauterive. It is fixed by an assumed short interval in Anadyrsko-Koryak tectonic which falls down to this time (AVDEIKO, 1968).

In differentiation of movements the elevated inner part becomes the region of the removal of terrigenous material both into the limits of the depression removed to the outer part and into the limits of the open ocean.

Accumulation of terrigenous volcanogenous and siliceous formations from the end of the late Jurassic to the beginning of the upper Cretaceous, injection of intrusions of basic and ultrabasic composition, folding movements caused by compression and strata sliding from the ascending inner part, led to a relative consolidation of the Anadyrsko-Koryak tectonic zone. Thrust shears appeared to be relatively cured and already could not compensate compression to a full degree owing to which a new compression wave with the descending branch near the Anadyrsko-Koryak tectonic zone occurred from the side of the ocean. A further increase of the wave amplitude led at the beginning of the Senonian period to the formation of thrust shears and to the formation of a new geosynclinal depression of the Vetveisko-Kamchatka zone (Fig. 3-iv).

*** The Roman figure here and further denotes the number of the cross-section on Fig. 3**

**** In accordance with terminology applied to geosynclinal systems we shall call the slope of the depression conjugated with the swell-like elevation-the inner part of the depression while the one conjugated with more ancient tectonic system or zone-the outer slope of the trench or outer part of the depression.**

The rocks of the compley of silica-volcanogenous and terrigenous formations of the late Jurassic-Valangine age partially moved to the funcament of the depression which is fixed by cutting the structures of the Anadyrsko-Koryak zone by those of the Vetveisko-Kamchatka tectonic zone in the region of the Vatyn ridge.

Subwater volcanism on the swell-like elevation and on the inner slope of the trench led to the formation of silica-volcanogenous formations during the Senonian time while the removal of the material from the elevated inner part of the Anadyrsko-Koryak tectonic aone ensured accumulation of terrigenous formations of the same age in the outer part of the depression of Vetveikso-Kamchatka zone. The beginning of accumulation of terrigenous, often aspide formations, underlying silica-volcanogenous formations i.e. those of Lesnov series, hozgon suite and partially of omgon thickness falls evidently still on Hauterive-Aptian time when the inner part of the Anadyrsko-Koryak tectonic zone appeared above the ocean level. Thus we consfder thes of Lesnov series and hozgon suite as oceanic sediments. Practically complete absence of paleontological remnants in them is evidently explained by this, though they must contain the remnants of foraminifers. In the coastal zone a more rough material is accumulated and the connection by means of straits with the though of the Anadyrsko-Koryak zone caused the community of paleontological remnants. The lower part of the community of paleontological remnants. The lower part of the omgon thickness is an example of formation in such conditions. Absence of an interval between oceanic sedimentation and that within the limits of geosynclinal depression makes their separation difficult especially in the outer part of the depression where the composition of sediments is nearly the same. Therefore we combine them into a unique complex of silico-volcanogenous and terrigenous formations.

Inner parts of the Anadyrsko-Koryak tectonic zone in the Senonian are subjected to still a greater elevation along the thrust shears and become a belt of positive isostatic anomalies while the depression is removed still farther to the outer part. A reaction upon this elevation is formation of graben-like depressions where marine and continental formations are accumulated (**Fig.** 3-iv). By the same period are dated the granitoid intrusions of Anadyrsko-Koryak zone. Though they are fine and not numerous.

The Okhotsko-Chukotsk volcanic belt responds to the movements along the thrust shears in the Vetveisko-Kamchatka zone by intensification of volcanic activity.

Late in Cretaceous-early in Paleogene the inner parts of the Vetveisko-Kamchatka tectonic zone are subjected to an uplift under the influence of reasons analysed above for the Anadyrsko-Koryak zone. In most of regions volcanism as a rule attenuates but in a number of regions such as for instance in the basin of the Kirganik river, volcanic apparatus were partially elevated above the sea level which led to the formation of volcanic islands (**Fig. 3-V).** We consider volcanism of the Kirganik period (late Cretaceous-early Paleogene) as residual volcanism of the Senonian.

In Anadyrsko-Koryak tectonic zone further removal of the depression to the outer part at the end of the Cretaceous led nearly to its complete uplift above the sea level and accumulation of coastal-marine and continental orogenic molassoid formations.

In Paleocene and Eocene the elevated inner part of the Vetveisko-Kamchatka zone became an area of a removal of terrigenous material both to the depression moved towards the outer part and to the limits of oceanic depression margins. Apart from that in the adjacent part of the oceanic depression accumulation of volcanogenous thicknesses is possible (**Fig.** 3-iv, **V).**

In Oligocene the Vetveisko-Kamchatka tectonic zone became to a sufficient degree consolidated and compression has caused formation of the depression of the tectonic zone of Eastern Kamchatka (**Fig.** 3-vi) similar to more ancient depressions of the

Vetveisko-Kamchatka and Anadyrsko-Koryak zones. In the Upper Oligocene—lower Miocene in the Eastern Kamchatka zone accumulation of a complex of silico-volcanogenous and terrigenous formations occurs. The beginning of formation of lower horizons of the complex evidently refers to the end of Cretaceous—beginning of Paleogene when the inner part of the Vetveisko-Kamchatka zone was elevated above the ocean level. Being so possible volcanogenous formations of the ocean bed, mentioned above, may also get in the base of the depression. In this case they are difficult to be distinguished from spilite-keratophyre formations of the inner parts of the depression since the volcanogenous formations of oceans, in particular of interoceanic islands are close to spilite-keratophyre formations by chemism (AVDEIKO, KHRAMOV, 1969). Evidently, arguable points of stratigraphy of volcanogenous-siliceous and terrigenous formations of Eastern Kamchatka are caused by this phenomenon.

In the period of formation of the depression of the Eastern Kamchatka zone the inner parts of the Vetveisko-Kamchatka zone are subjected to elevation along thrust shears. In this in the vault parts of elevation as it was mentioned below graben-like depressions or graben-synclines are set up within the limits of which surface volcanic activity of island-arc type is located. The depression of the Vetveisko-Kamchatka zone is moved still further to the outer part, in this case to the Western Kamchatka. Thus, the Eastern Kamchatka and the Vetveisko-Kamchatka zone at the end of Oligocene in the beginning of Miocene acquire the form of a typical island arc. The inner part of the East-Kamchatka zone with the located in its limits subwater volcanism is a swell-like uplift ; the outer part, i.e. the depression itself is a deep-sea trench ; elevated inner part of the Vetveisko-Kamchatka zone is considered as non-volcanic, while volcanic island arcs and the depression of the Vetveisko-Kamchatka zone—as a rear depression. To a great extent the elevated and consolidated Anadyrsko-Koryak zone is a formed to a sufficient degree continent.

In Miocene the development of the Eastern-Kamchatka zone (Fig. 3-vii) follows nearly the same plan as that of the Vetveisko-Kamchatka zone at the end of the Cretaceous—beginning of the Paleogene and of the Anadyrsko-Koryak zone in Hauterive-aptian time. Its inner part under the influence of reasons considered above is subjected to a slow uplift. Injection of hyperbasic intrusions takes place, and the depression is moved to the outer part. Volcanism in the base is damping but sometimes it is displayed as subwater near—the—surface out-flows the tops of some volcanoes being elevated above the sea level (Govena suite). If for deep-sea out-flows effusive activity is prevailing, in this case the leading role is played already by the the explosives.

In the Vetveisko-Kamchatka zone in Miocene a further removal of the depression to the outer part begins, where at this time begins accumulation of molassoid formations and in the elevated inner part surface volcanism is going on of island-arc type with partial accumulation of volcanogenous molassoids.

At the last cross-section (Fig. 3-viii) modern state of the territory under consideration is shown. By this time the East-Kamchatka tectonic zone as a result of volcanism sedimentation, intrusive 'activity and folding movements became already relatively consolidated and could not compensate lateral pressure to a complete extent. As a result of this according to the new system of shears with formation of focal seismic plane the Kurile-Kamchatka deep-sea trench was set up. The thrusted Eastern Kamchatka tectonic zone was subjected to a differentiated elevation and the inner (eastern) part of the zone was separated from the outer part with the less amplitude of elevation with a large fault (the one separating the Eastern Kamchatka from the Central Kamchatka depression). The outer part of the Eastern Kamchatka zone, though preserved as a region of relative subsidence, appeared to be elevated to a large extent above the ocean level, with the exclusion of the Litke strait, Ukinsk bay and Korf bay. Elevation of the Eastern Kamchatka was responded by the formation in the vault part of graben-synclines of the Eastern and Southern Kamchatka with location within their limits of surface volcanism.

In the Vetveisko-Kamchatka zone a certain uplift is being observed with further removal of the depression to the inner part and accumulation of molassoid formations. In the quaternary time in the graben-syncline of the Median ridge by the data of N. V, OGORODOV (1966) mainly basaltoid volcanism was going on. However at present no active volcanoes was marked there.

Conclusions

1. In the Koryaksko-Kamchatka region of the Cenozoic folding discrete migration in space and time is observed of consecutive stages of geosynclinal development in direction from the continent to the ocean. Setting of geosynclinal depression in " younger tectonic zone corresponds approximately to the beginning of orogenic stagf a more ancient zone **(see Fig. 2).**

2. In the development of each tectonic zone migration of sedimentation basins is observed in the direction from the ascending inner part (mountain system) to the continent (foreland) with the formation of molasse foredeep. Such a migration is known from the time of E. HAU,G and is typical for orthogeosynclines (AUBOUIN, 1965).

3. Ophiolite magmatism (spilite-keratophyre volcanism and injection of ultrabasic and basic intrusions) is typical for the stage of isolation of geosynclines i.e. for the stage of deepsea trench stage and is located within the limits of swell-like elevation and inner slope of the deep-sea trench. Terrigenous sedimentation is timed directly to the trench and its continental slope while siliceous sedimentation is typical both for the trench and for the swell-like elevation. In other words within the limits of each analysed elementary geosyncline the inner—eugeosynclinal and outer—miogeosynclinal belts are distinguished. In this case there is no division into eugeosynclinal and miogeosynclinal troughs with an elevation between them.

As is known, J. AUBOUIN (1965) has revealed elementary pairs of geosynclines (eugeosyncline—miogeosyncline) which are located in the following succession from the continental area : continent (foreland)—miogeosynclinal trough—miogeosynclinal elevation—eugeosynclinal trough—eugeosynclinal elevation—oceanic area. If we consider two adjacent tectonic zones for instance, Anadyrsko-Koryak and Vetveisko-Kamchatka in the Cenomanian-Senonian time **(see Fig.** 3-iv), they look together as an elementary pair of J. Aubouin where the depression of the outer part and elevation of the inner part of the Anadyrsko-Koryak zone may be considered respectively as miogeosynclinal depression and miogeosynclinal elevation, the deep-sea trench of the Vetveisko-Kamchatka zone as an eugeosynclinal depression and the swell-like elevation as an eugeosynclinal one. To make certain it is sufficient to compare Fig. 16 from the work of J. AUBOUIN (1965) and the cross-section IV **(Fig. 3).**

4. Modern deep-sea trenches in any case adjacent to the systems of double island arcs are elementary geosynclines in the stage of separation and island arcs are a transition to orogenic stage of development in more ancient geosynclines.

5. Conjugation is observed and age coincidence of surface volcanism of island arc type and of superimposed volcanic belts with formation of deep-sea and of superimposed volcanic belts with formation of deep-sea trenches and ophiolite magmatism. In other words conjugated systems of island arcs and deep-water trenches are a peculiar feature of development of geosynclinal systems of the Koryaksko-Kamchatka area.

These conclusions are drawn from an analysis of the existing material with one rather reliable assumption that geosynclinal depressions at an early stage of the development are equivalent to modern deep-sea trenches.

Basic reasons of directivity of geosynclinal development of considered tectonic zones proceed from the structure of island arc systems and are as follows :

6. Troughs are considered as a result of compression wave formation with the subsequent rupture in the weakest place and crushing of the heavy crust of oceanic type by a lighter crust of the continental type.
7. Uplifts and subsidences are also considered as a result of compression and further tendency to restore isostatic equilibrium.
8. Folding is a discrete-continuous process under the effect of compression and sliding of layers from the ascending territories.

It is necessary to point out that the analysed above hypothetical scheme of development of geosynclines of the Koryaksko-Kamchatka area is applied only in those cases when the crust rupture along the focal zone with formation of the depression occurs either on the border of continental and oceanic crusts or within the limits of not completely formed continental crust. In the latter case the complex of geosynclinal formations of the preceding geosyncline is the fundament of a younger geosyncline (polycyclic development). However it is marked at present that some arcs of separate parts of arcs are strongly moved to the oceanic area. Being so triangle parts with the crust of oceanic type remain in the rear part of the moved arcs limited by the frontal part of articulation of two ancient arcs and the rear part of the young arc. To such triangle parts refer geosynclinal basins of the Bering Sea, Kurile and of the Sea of Japan. It is possible that such triangle geosynclinal basins in the following development will form the fundament of younger geosynclinal systems.

References

AUBOUIN, J. (1965) : Geosynclines. Amsterdam-London-New York.

AVDEIKO, G.P. (1966) : Evolution stages of the Koryaksko-Anadyr folded area in the Early Cretaceous epoch. *Proc. USSR Acad. Sci.,* Geol., Ser., 10 (in Russian).

AVDEIKO, G.P. (1968) : Lower Cretaceous deposits in the North of the Pacific belt. Nauka, Moscow (in Russian).

AVDEIKO, G.P., KHRAMOV N.A. (1969) : Silico-volcanogenic formations of Kamchatka and their petrochemical features. Volcanic facies of Kamchatka. Nauka, Moscow (in Russian)

BELY, W.F., NIKOLAEVSKY, A.A., TILMAN, S.M., SHILO N.A. (1964) : The tectonic map of the USSR (scale 1 : 2 500,000). The tectonics and abyssal structure of the North-East of the USSR, Magadan.

BENIOFF, H. (1954) : *Bull. Geol Soc. Amer.,* 65, 385.

BERNAL, J.D. (1961) : *Nature*, London, 192,123.

BOTT, M.H.P. (1964) : *Nature, 202.*

EGIAZAROV, B.H., DUNDO O.P., ANIKEIEVA, L.T., RUSAKOV, I.M., DEGTJARENKO, J.P. (1965) : Geology and mineral resources of Koryak highland. Nedra, Leningrad (in Russian)

ERLICH, E.N. (1965) : On the structural position of Quaternary volcanisity of Kamchatka. *Geotectonic*, 1 (in Russian).

ERLICH, E.N. (editor) (1966) : Petrochemistry of Kurile-Kamchatka province. Nauka, Moscow (in Russian)

GEOLOGY of the USSR (1964) : 31, Kamchatka and Kurile Islands, I, Geological description (in Russian).

GOLYAKOV, V.I. (1966) : The stratigraphy of paleogenic and neogenic deposits in the eastern part of Kamchatsk neck. *Geology and Geophysics*, 10 (in Russian)

HODGSON, J.H. (1962) : Continental drift. New-York and London.

KHRAMOV, N.A., FLORENSKY, I.V. (1969) : Some facies composition features of silica-volcanogenic series of the East-Kamchatka range and paleogeographical conditions of its formation. Volcanic facies of Kamchatka. Nauka, Moscow (in Russian)

KUZNETZOV, J.A. (1964) : Main types of magmatic rock formations. Nedra, Moscow (in Russian).

LENSEN, G.J. (1961) : *Publ. Dom. Obs., Ottawa,* 20, 395.

MARKOV, M.S., AVERYANOVA, V.N., KARTASHOV, I.P., SOLOVIEVA, I.A., SHUVAEV A.S. (1967) : Mesozoic and Cenozoic history and the structure of the Earth's crust of the Okhotsk region. Nauka, Moscow (in Russian).

MENARD, H.W. (1964) : Marine geology of the Pacific. New York-San Francisco-Toronto-London.

MOURATOV, M.V. (1964) : Stages and stadia in the development of geosynclinal folded areas. iRock deformation and tectonics. Nauka, Moscow (in Russian).

OGORODOV, N.V. (1966) : On recent volcanism of the Kamchatka Sredynny range. *Bull. vole, stations,* 40 (in Russian)

ROTMAN, V.K. (1961) : On certain peculiarities of geosyncline volcanogenic sedimentary formations in the light of up-to-date data. *Dokiadi Akademii Nauk SSSR* (Reports of the USSR Academy of Sciences), 140,2 (in Russian).

ROTMAN, V.K. (1963) : Petrochemical evolution of lavas in the Kamchatka Middle Ridge. Petrochemical features of recent volcanism Nauka, Moscow (in Russian).

RIVOSH, L.A. (1963) : On tectonic structure of Kamchatka peninsula and the bottom of surrounding seas (on geophysical data). *Geology and Geophysics* 6 (in Russian).

SEROVA, M.Y. (1966) : Foraminifera from Paleocene deposits of Eastern Kamchatka. Nauka, Moscow (in Russian).

SEROVA, M.Y. (1969) : Recent data on the age of volcanogenic-sedimentary strata of the South-Western part of the Koriak upland (Govena peninsula). *Dokiadi Akademii Nauk SSSR (Reports of the USSR Academy of Science),* 185, 2 (in Russian).

SHATSKY, N.S. (1954) : On manganiferous formations and metallogeny of manganese. *Proceedings of the USSR Academy of Sciences,* geol. ser., 4 (in Russian).

STILLE, H. (1940) : Einfuhrung in den Bau Nordamerikas. Borntrager, Berlin. 717.

STILLE, H. (1958) : Einiges uber die Weltozeane und ihre Umrahmungsraume. *Geol. Jh.,* Hf. 3-6.

TCH1KOV, B.M., IVANOV V.K. (1963): Magnetic field and some geological structure features of the central part of the Koryak-Kamchatka folded area. Geology of the Koryak highland. Moscow (in Russian).

UMBGROVE, J.H.F. (1947) : The Pulse of the Earth. New York.

VAN BEMMELEN, R.W. (1965): Mega-Undations as cause of continental drift. *Geologie en Mijnbouw,* 44, Jaargang.