UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE CALDERAS OF KAMCHATKA AND KURILE ISLANDS WITH COMPARISON TO CALDERAS OF JAPAN AND THE ALEUTIANS, ALASKA

By

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This report was prepared under contract to the U.S. Geological Survey and has not been reviewed for conformity with USGS editorial standards and stratigraphic nomenclature. Opinions and conclusions expressed herein do not necessarily represent those of the USGS.

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Denver, Colorado

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FOREWORD

This report represents the results of a year-long USGS contract with Dr. Edward Erlich, a Soviet volcanologist and petrologist, who emigrated to the United States from the Soviet Union in 1984. Before leaving the Soviet Union, Dr. Erlich was a senior volcanologist in Kamchatka, where he spent more than ten years working at the Institute of Volcanology on Quaternary volcanism and tectonics of Kamchatka. This contract provided a unique opportunity to have the author's first-hand field experiences and interpretations summarized in English for the first time, and to have him assemble and translate the major scientific papers and current ideas of Soviet scientists working with calderas of Kamchatka and the Kurile Islands. Thus, this report represents a rare opportunity to augment our knowledge of volcanoes of the Northwest Pacific margin that are not accessible to western volcanologists.

This report consists primarily of descriptive data on Quaternary calderas of the Kurile Islands and Kamchatka; details about their physical characteristics, chemistry, age, and origin are discussed in the context of their island arc setting. Because of its length, and complexity, the technical content has not been reviewed in typical USGS fashion. Some chapters have been edited to improve the style of the English; others have not been edited. Although the report is preliminary in form and does not conform to USGS style or standards, it is being made available in its present form in order to expedite it for readers who may be interested in the information that it contains.

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ABSTRACT

The body of the report is composed of files of data on all Quaternary calderas of Kuriles and Kamchatka. This enormous set of data for the first time provides Western geologists with up-to-date information about data and ideas of Russian volcanologists on various aspects of caldera formation.

Data about calderas of these regions are discussed in the context of the broad background of island arc geology. Differences in calderas size/type in normal island arc and geotectonic systems of the Kamchatka type are discussed. Evidence suggests that structural position of calderas is controlled by fissures subsidary to deep-seated strike-slip faults.

Calderas and volcano-tectonic depressions are divided into two genetically-opposite groups: one is connected with decreasing magma pressure within the magma-generation zone in the Upper Mantle, and another is related to increasing magma pressure during the process of the emplacement of magma intrusions in the upper horizons of the Crust. The first group of processes produces great volcano-tectonic depressions, that are connected either with great basaltic volcanoes (Fudji, Etna, Tolbachik, Veniaminoff, Big Island of Hawaii), or with bi-modal basalt-dacite/rhyolite rock series (Zhupanovsky, Semiachik, Ichinsky). Calderas of the second group are divided mainly by composition of volcanic rocks on structures connected with silicic and basaltic volcanism.

Among silicic calderas, several types are recognized based on types of caldera-forming eruptions:

1. Calderas without any significant eruptions during the caldera-forming stage (Khangar, Aniakchak, ancient Hakone caldera);

2. Calderas connected with emplacement of ring complexes of extrusive domes (Bolshe-Banny, Haroharo type);

3. Calderas associated with ignimbrite eruptions (Uzon - Long Valley type);

4. Calderas associated with pumice airfalls (Mashu-Karymsky or Crater Lake type);

5. Calderas at which the first phase of eruptions consisted of dacitic pumice and the last stage consisted of basaltic scoria (Ksudach-Oshima type).

No lateral blasts are known in connection with all these types of calderas; lateral blasts with subsequent small collapses and landslides normally occur at andesitic strato-volcanoes.

Basaltic (Hawaiian) calderas are associated with drainage of central magma chambers into regional en-echelon systems of fissures (rift zones). As a result of refraction of regional faults, the strike of these rift zones changes on the constant angle after intersection with the central magma chamber.

Two petrological aspects of the caldera problem are discussed: the Mantle origin of silicic volcanic rocks and the influence of the trend of the calc-alkaline volcanism on the composition of the magma-generation zone.

Greatest Quaternary silicic calderas in the Circum Pacific were formed during a series of short episodes that coincided with sharp intensification of the rate of mountain-growing process and different stages of glaciation.

Due to its complex character the report proposes new concepts of caldera origin and classification, and permits to assessment of different types of calderas and volcano-tectonic depressions for different types of ore deposits, and geothermal fields and allows the possibility of improving methods of volcanic and seismic hazards assessment.

INTRODUCTION

Presented work is prepared on the contract granted by USGS through Geoexplorers International Inc. (Dr. J. Krason, President). By the terms of the contract the following tasks are to be performed:

1. Preparation of a bibliography, in English, of pertinent literature on calderas of the Kuriles and Kamchatka, with a supplement containing Russian-language literature about calderas of Japan and the Aleutians.
2. Review information about Kamchatka and Kruile calderas that is presently in the Smithsonian Volcano Reference File, checking for accuracy and completeness.
3. Preparation of a dossier on each caldera of the Kuriles and Kamchatka. A geologicl map should be included in each dossier, if available. Each caldera should be considered as a volcanic center, and information about volcanoes within and on the rim of a caldera should be included in the discussion of tha caldera.
4. Preparation of a report that summarizes information from the dossiers, and draws comparisons between calderas within the Kuriles and Kamchatka and calderas in Japan and the Aleutians. This comparison is not intended as a comprehensive review of calderas in Japan and the Aleutians, but rather as a means to identify significant similarities and differences between calderas in these four regions. Special attention should be given to differences in calderas within volcanic arcs, across transitions from oceanic to continental crust, and in different tectonic settings.
5. Visit USGS centers in Menlo Park, Denver, Reston, Flagstaff, Vancouver, Hawaii, and Anchorage, as appropriate to discuss this study with scientists in those centers and to give lectures on volcanism in the Kuriles and Kamchatka.

Due to these demands the main part of the presented report consists of descriptions of all calderas within both regions—Kuriles and Kamchatka. In the same time author wanted not only to compile all existing data, but also to introduce to readers leading ideas, connected with Quaternary calderas, their structure and origin, developed in process of study in Kurile-Kamchatka area in order to give to readers existing approach to some problems, connected with tectonic setting, deep structure, evolution of volcanism, petrology of caldera complexes and so on.

By this means systematic description of calderas is preceded by discussion of structural setting of calderas (combined with some, necessary for discussion, geodynamic aspects of normal island arcs (Kuriles, Aleutians) and Kamchatka-type geotectonic systems (Kamchatka, Japan, Alaska). Chapter IV is devoted to some regularities of temporal distribution of Quaternary calderas and associated with them volcanism. Chapter V—to some petrological problems, connected with caldera volcanism. In conclusive Chapter VI, an attempt to analyse types of calderas in the Northwest Circum-Pacific, mode of their origin and regularities of spatial distribution in dependance with geotectonic positon is made. Bibliography to Chapter II and III pertinent literature on calderas of the Kamchatka and Kuriles form appendix of the report.

By the terms of the contract, author visited USGS National Center, Reston, Virginia, USGS centers in Menlo Park, California, Hawaii, Anchorage, Alaska, Cascade Volcano Observatory in Vancouver, Washington. In all these centers and also in USGS center in Denver, Colorado, has given lectures about specific features of Quaternary volcanism in Kuriles and Kamchatka in comparison with other regions of Circum-Pacific and discussed the main problems of caldera geology. Author participated in the USGS workshop on geothermal resources in the Cascade Range (Menlo Park, May 22-23, 1985). Visit to USGS center in Flagstaff, Arizona, was rejected by Dr. Krason in order to preserve money to complete report.

Report was prepared with the close cooperation of U.S. Geological Survey. Content and leading ideas of each chapter of the final report have been discussed with USGS personnel in Denver.

One of the greatest difficulties in compiling this was the absence of topographic maps. Due to existing regulations regarding the publication of topographic materials in the USSR, scale and geographical coordinates are absent for the most part on the maps and schemes. Even by combining the materials of different published maps, author was unable to compile any new maps. In all cases, where possible, author put an approximate scale on existing maps.

Main stages of caldera study in Kuriles and Kamchatka.

For the first time all material regarding calderas in the Kuriles and Kamchatka were compiled during the preparation of a catalogue of active volcanoes of these regions (Vlodavets and Piip, 1959; Gorshkov, 1958). Specific features of all materials available at this time were used and each volcano has been studied separately. Any special studies of a group of volcanoes, their structures, and evolution of volcanism, are rare.

A new stage of study was started at the end of the 1950s and the beginning of the 1960s. It is connected with two events - 1) The active geothermal exploration in the regions and; 2) the organization of the Intitute of Volcanology, Petropavlovsk in Kamchatka, and Sakhalin Complex Research Institute, Yuzhno-Sakhalinsk (both associated with the Academy of Sci., USSR).

In the first years of the Institute of Volcanology existence, a series of works were produced in the fields of Quaternary volcanic belts geology: work on regional stratigraphic scheme, based on the correlation between volcanic and glacial processes (Braitseva and others, 1968), works on tectonic setting of Quaternary volcanic belts, evolution of the Quaternary volcanic process, descriptions of volcano-tectonic structures, development of great volcanic groups, and specific descriptive features of petrochemistry and the evolution of caldera volcanism (Erlich, 1965, 1966, 1966a).

At the same time at least two very important works were produced in the field of caldera studies: 1) Complex geophysical study of Avacha volcano (Steinberg and others, 1966) and; 2) Gravimetrical studies of different calderas, resulting in several papers written by principal investigator in this field, M. I. Zubin with different coauthors.

All works were submitted to the Oxford conference on "The roots of volcanoes" in 1969, a report on Quaternary calderas in Kamchatka, published in 1972 (Erlich and others, 1972).

The next step in the study of calderas in Kamchatka was the complex study of the Uzon - Geyzernaya caldera (Naboko, ed., 1974). This work was started due to the interest in geothermal potential of this region and the findings of a series of recently formed ore minerals in geotherms.

The tendency to produce complex descriptions has continued through the 1970s, when materials about volcano-tectonic structures (Pauzhetka, volcano-tectonic depression; and Karymsky ring volcano-tectonic structure) were published (Masurenkov, ed., 1980, 1980a).

The quantity of works produced on the Kurile calderas were small due to the lack of transportation into the region. Practically all data for the Kruiles were summarized in monograph of Gorshkov, published in English in 1970

(Gorshkov, 1970). Descriptions listed below are mainly on this monograph with some additions on stratigraphy or Quaternary volcanic sequences made by Melekestsev (Luchitsky, ed., 1974), and additional geophysical and petrological data of scientists from Sakhalin Complex Research Institute.

Terminology accepted

Terminology used in the caldera study of the Kurile-Kamchatka region is very uncertain. In the beginning the term "caldera" was applied to structures of different origin, mainly as a geomorphological term, which means any kind of depression in relief created under the influence of a volcanic process. The distinction between the terms "crater," "caldera," and "volcano-tectonic depression" is undefined. The basic difference between the terms "caldera" and "volcano-tectonic depression" is mainly the size of the structure and the character of its association with certain volcanic edifices. The inherited structures, located on the summit of a single volcano, are termed "caldera," and for large ring depressions which cut the formations different in age and nature the term "volcano-tectonic depression" is used.

The distinction between the terms "caldera" and "crater" were made by Russian volcanologists based on the size of the structures. Structures with a diameter of more than 2 km are labeled calderas, and less than 2 km are considered craters. Japanese authors (Aramaki, 1977) also adhered to this definition. Although some authors emphasized genetic differences between craters and calderas (Markhinin, 1964; Luchitsky, 1971), they do not indicate just how this distinction was made. Due to all the uncertainities, the author has followed the terminology accepted in publications regarding each caldera.

Main ideas about calderas classification and origin

The first Russian classification of calderas was published by V. I. Vlodavets (1944) and was mainly a geomorphological classification. The most influential ideas about genesis and classification of calderas accepted in the USSR were produced in the works of H. Williams (1941). Later the main ideas of this work was rewritten in Russian by E. K. Markhinin (1964). In the mid-1950s significant influence on caldera studies were produced by descriptions of ignimbrites and welded tuffs around a series of calderas in Kamchatka and the Kuriles. These works were published in English and edited by C. S. Ross (1964). In the mid-1960s papers by R. L. Smith (1960), C. S. Ross and R. L. Smith (1961), became very popular among Russian volcanologists. Constant association of silicic calderas with ignimbrites and pyroclastic covers and ideas developed from a study of the Bezimianny volcano eruption in 1956 (Gorshkov and Bogoyavlenskaya, 1965), lead to overestimation of the role of blasts and outflow of pyroclastic material, and the role of tectonics was underestimated for the Kurile calderas (Gorshkov, 1970).

It should be noted that landslides are not widely accepted among Russian geologists. Landslides on certain volcanoes are described as sectorial grabens on volcanic edifices.

The ideas of R. L. Smith and R. A. Bailey (1968) regarding resurgent calderas have become widely recognized.

In this work, the author tries to exclude all structures of uncertain origin. That is why descriptions of structures on Bezimianny and Sheveluch volcanoes, formed by a combination of blasts and landslides, are excluded. Calderas on some volcanoes (Anaun, Bakening), have not been described because their existence has not been confirmed by following works.

Basis for volcano stratigraphy

Potential readers of this report must bare in mind that stratigraphic studies in volcanic regions up to the present time, were based on correlation of volcanic process with two stages of Upper Pleistocene glaciations. Traces of so-called "maximal" Middle Pleistocene glaciation are very rare and uncertain. Quantity of paleomagnetic studies is limited. The same is true of the quantity of radiometric, K-Ar in particular, data of Quaternary and even Neogene volcanics available in both regions. Volcanic rock dating was started in the mid-1970s by a series of tephrochronological works in Kamchatka (Braitseva and others in different combinations), but quantity of radiocarbon dates existing up to now is still insufficient.

ACKNOWLEDGEMENTS

This work could not have been produced without the cooperation, support, and help of collaborators of the Igneous and Geothermal Processes Branch of the U.S. Geological Survey, Dr. P. W. Lipman, Dr. C. Dan Miller, Dr. R. P. Hoblitt, Dr. C. A. Newhall, Dr. J. S. Pallister, and Dr. W. E. Scott. Help in the final preparation of this report was provided by Mrs. M. Simpkins and Mrs. R. Kolpanen. The main part of the drafting was produced by M. Krason. Great help in correction of the final report was provided by my wife, R. Erlich. Compiling of the bibliography could not have been done without the assistance of the U.S. Geological Survey Library in Denver: Ms. H. King, S. Powers, J. Bonn and others. Airborne radar images of some Alaskan volcanoes are provided through the courtesy of Dr. J. Friedman (USGS, Denver), shuttle-photos of volcanoes are provided by Dr. C. A. Wood (NASA, Lyndon Johnson Space Center).

CHAPTER 1

SOME ASPECTS OF GEODYNAMICS OF THE KURILES AND KAMCHATKA AND STRUCTURAL POSITION OF CALDERAS

Speaking about structural position of calderas within the region under consideration we have to discuss separately two different types of tectonic systems: normal island arcs (Kuriles, Aleutians) and tectonic systems of Kamchatka type (Kamchatka, Alaska, Japan). General features of these two types of tectonic systems have been discussed by the author previously (Erlich, 1973; Erlich and Gorshkov, 1979). Terms "normal island arcs" and "Kamchatka-type geotectonic systems" in some ways correspond with terms "intra-oceanic" and "Andean type" island arcs; but in defining "normal island arcs" and "Kamchatka-type geotectonic systems" not only the type of the crust is considered, but also geological features such as height of tectonic relief, zonality of structural elements, seismicity, volcanism, etc. There is now too much speculation about the nature of these systems. I do not want either to go too far in discussion about different opinions on the structure or to create any new speculative theories, but rather to make an attempt to discuss from the very beginning (if it is still possible) the simplest geological facts and connections between the most obvious features.

Now practically all types of connections between volcanic belts and different structural elements have been discussed. On this subject, in the Kurile - Kamchatka regions, different types of structural elements--deep seated structure by geophysical data (Steinberg, 1966), on opposite--morphostructure (Erlich, 1965), have been examined. And none of them give a universal decision of the problem.

In this situation the main attention has to be put on an attempt to reconstruct geodynamic conditions of localization of great volcanic centers. These can be reconstructed mainly on the base of analysis of spatial distribution of different types of structural elements. Besides this in specific conditions of recent island arcs and tectonic systems of the Kamchatka type, great advantage in discussion of this problem is provided by now existing tectonic activity, in particular earthquakes.

NORMAL ISLAND ARCS

Kuriles - transversal and longitudinal zoning.

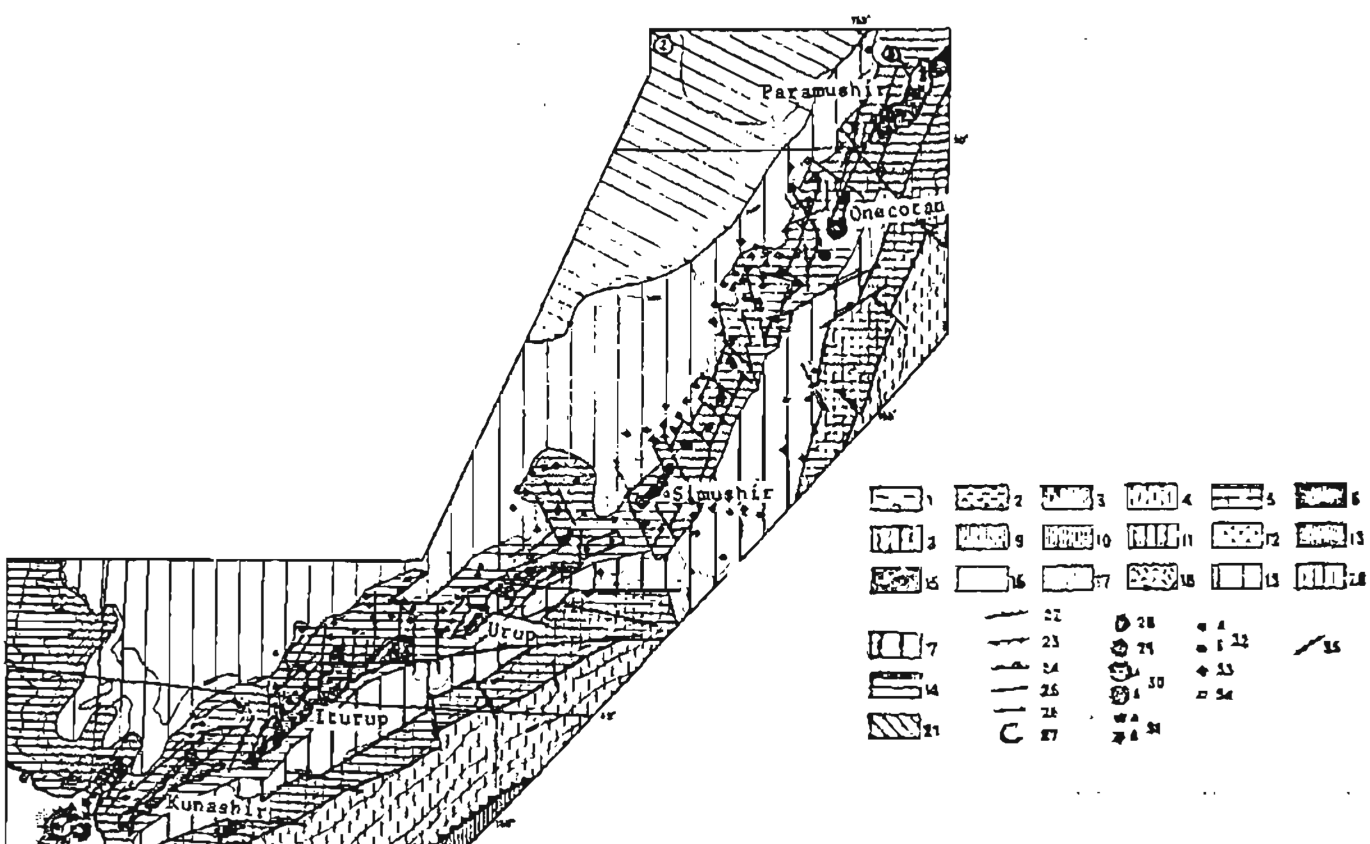
The most characteristic feature of the structure for all normal island arcs, such as the Kuriles, is a transversal zoning in the distribution of the main structural elements: i.e., oceanic trench - linear uplifted belt of the outer non-volcanic arc (Lesser Kurile Chain of Islands, submarine Vityaz Ridge), linear uplifted belt of the inner, volcanic arc (Great Kurile Chain of Islands) and rear deep-water basin of the marginal sea (Kurile depression of the Okhotsk Sea) (Fig. 1). Contact between inner and outer arcs is along the so-called Mid-Kurile deep-seated fault which coincides with the rear Benioff zone boundary. Along it is observed as a narrow (15-30 km) depression in which recent accumulation of sedimentary and volcano-sedimentary rocks is found.

Besides the transversal zoning for the Kuriles is also very characteristic longitudinal zoning in the distribution of structural elements. Intensity of the recent uplift reflected in the height of recent tectonic reflief changes, for example. In the central islands of the arc, no

Fig. 1 - Map showing the recent structure of the Kurile Islands Arc - from Erlich and Gorshkov (1979).

1 - Ocean floor - thalassocraton; 2 - rampart-like uplift of the ocean floor along the outside of oceanic trenches; 3 - oceanic trenches; 4 - zone of development of fault dislocations in the area of downwarp of M discontinuity on the continental slope; 5 - Horst-anticlinal uplift zones of Preneogene complexes in submarine topography; 6 - subaerial horst-anticlinal zones. Troughs between the volcanic belt and the geanticlinal belt of the external arc; 7 - Recent, reflected topography; 8 - Neogene. Sites of advancing troughs of Oligocene-Neogene age, analogues of recent trenches; 9 - drawn into the uplifts of Quaternary time; 10 - zone of continental sedimentation of Quaternary time; 11 - being a zone of marine (shelf) sedimentation of Quaternary time. 12 - relics of central massifs composed of metamorphic terrains; 13 - anticlinal basement folds. Sites of Oligocene-Neogene volcanic belts drawn into the process of uplift in Quaternary time; 14 - in submarine topography; 15 - subaerial zones of arched uplifts.

Sites of grabens and graben-synclines composed predominately of: 16 - Quaternary volcanic rocks; 17 - complexes of loose Quaternary sediments; 18 - pumices and ignimbrites; 19 - recent rear troughs of marginal seas; 20 - peneplaned zones of rear troughs of Neogene time; 21 - area of shelf seas; 22 - surface trace of seismofocal zone; 23 - crustal flexure at the ocean-continent contact in regions where the trench is absent; 24 - strike-slip faults with considerable shear component in Upper Pleistocene-Holocene; 25 - faults, active in Upper Pleistocene-Holocene; 26 - faults of unknown displacement; 27 - volcano-tectonic fault zones; 28 - shield-like volcanoes of basalt-andesitic composition without calderas: a) active, b) extinct; 29 - caldera-volcanoes: a) active, b) extinct; 31 - shield volcanoes and stratovolcanoes of basaltic compositions: a) active, b) extinct; 32 - submarine volcanoes; 33 - coral reefs; 34 - zones of flood basaltic volcanism; 35 - vent alignments.



outer arc is present. As a result, this part of the system resembles a normal single-arc structure, which to the north and to the south is replaced by typical structure of double-arc system. The level of elevation of part of the central Kuriles, which corresponds with outer arc, coincides by absolute height with surrounding continental slope. Horst uplifts of the Neogene basement in the central Kuriles (excluding Simushir Island) are practically absent. The southern part of the Great Kurile Chain is probably the most uplifted part of the arc. Here are located the longest and in the same time--highest block uplifts of the Neogene basement. Along the southern group of the islands is located the most elevated part of the outer arc--Lesser Kurile Chain of Islands. On the northern group of islands, horst uplifts of the Neogene basement are also developed, but in a lesser degree in comparison with the southern group.

In accordance with varying degree of uplift, thickness of the crust also changes. In the northern and southern island groups the crust is 18-25 km thick, but in the central group it is only 13-15 km thick and of transitional, suboceanic type.

Very important also are changes in strike of different parts of the arc: southern and central parts of it are elongated N45°E and continue directly structures of the north-east Hokkaido. The northern group of the islands form rows of north-south strike, which continue directly structures of southern and central Kamchatka. Both differently-oriented parts of the arc are broken by system of faults and strike-slip faults with north-west and east-west strike. As a result, there is a complex configuration of the block of the arc along the strike. At the same time, strike of the trench changes continuously giving to the whole system arc-like shape.

Geoanticline of the outer belt by geophysical data is characterized by very uniform types of fields--increased anomalies of magnetic field ΔT and high positive gravity anomalies in the Bouguer reduction. Thickness of the Earth's crust is also increased and in general belongs to the continental types (Kosminskaya and others, 1963). Uniformity of geophysical characteristics indicate probable uniformity of geological structure. Lesser Kuriles Islands are composed of sedimentary-volcanogenic terranes of the Upper Cretaceous-Paleogene time, so it is very probable that the same deposits were developed over all of the outer arc geoanticline system. Any traces of recent or even Neogene volcanic activity are absent.

Some features of Benioff zone structure.

All territory between the trench and the geoanticline of the outer arc is characterized by the presence of shallow earthquakes foci (not more than 50 km), which represents the intersection between Benioff's zone and the Earth's surface. Speaking about earthquakes distribution within this belt, it is important to emphasize several specific features:

a. The outer boundary of the Benioff zone does not coincide with boundary of the oceanic trench, but rather lies parallel to it at a distance of 20-30 km (Fedotov and others, 1966);

b. Inner (rear) boundary of the Benioff zone is very sharp and coincides with the Mid-Kurile deep-seated fault, the boundary between the geoanticline of the outer arc and linear depression which divides it from the inner, are geoanticline;

c. By seismological data of Averianova (1968) the strip between the trench and linear uplifted belt of the outer arc is characterized by right-lateral strike-slip faults. In western strip, which coincides with the outer arc geoanticline (Lesser Kurile Chain and Vityaz Ridge) left-lateral strike-slip faults prevailed. The main horizontal vector of compression within earthquakes foci is of east-west strike.

Data about longitudinal zoning of the Kurile arc tectonic system coincides with data of Averianova (1968) that maximal depth of earthquakes foci increased from Kamchatka southward to the north and central Kuriles (depth of earthquakes foci in this block changes from 100 km up to 600 km), and another block, from Hokkaido northward to the south and central Kuriles (depth of earthquakes foci changes in this block from 300 km up to 600 km) (Fig. 2). The same study shows difference in strike of vectors of compression within earthquakes foci near the south and the north Kuriles: rear boundary of the northern block is cut by faults, which dip to north-northeast, and rear boundary of the southern block is cut by faults with the same strike, which dips to the southwest, i.e., in the opposite directions.

Shallow earthquakes foci to the west of the Mid-Kurile deep-seated strike-slip fault are rare or absent (Fig. 3). Earthquakes foci with intermediate depth are distributed in the form of strips on mainly east-west strikes.

Recent structure of volcanic belt.

Inner, Great Kurile Arc, has subsided since the Oligocene, interrupted by short impulses of uplift. Total thickness of rocks accumulated during this time interval is about 8,000 m. Sedimentation has place in environment of comparatively shallow sea. About 80% of this sequence is of volcanogenic origin. Quantity of lavas reach 30% of the total thickness. Volcanism was accompanied by formation of series of small granitoid intrusion with radiometric age 4 to 6 million years (Firsov, 1964). Zone of the Great Kurile arc is characterized by lesser in comparison with outer arc, thickness of the crust, lesser meanings of anomalies of magnetic and gravity field (Kosminskaya and others, 1963). For the recent structure of the Great Kurile Arc is characteristic en-echelon distribution of elevated blocks or folds, formed by Neogene volcanogenic calc-alkaline rocks, and comparatively subsided areas, occupied by chains of Ouaternary volcanoes. Amplitude of uplift in such elevated blocks within the Great Kurile Arc is equal 200-700 meters. Average elevation of the roof of pre-Quaternary basement in subsided blocks is around sea level. Streltsov (1970) shows that elevated blocks within the Great Kurile Arc are represented by a kind of drag-folds. Axis of these folds are regularily oriented under the angle 30° to the strike of Mid-Kuriles deep-seated fault. Streltsov connected what appeared to be regularity of horizontal movements along this fault zone, which in his opinion represents a kind of strike-slip fault. Continuing with his idea it is possible to state, that echelons of Quaternary volcanoes, which divide these folds, occupy place of subsidiary open (or at least with tendency to opening) fissures, origin of which is also connected with horizontal movements along the main zone of the strike-slip fault. Subsidiary character of these fissures lead to very regular changes in the degree of opening along the strike of these fissures, which influence strongly the type of magma evolution, especially in the behavior of volatiles.

Fig. 2 - The longitudinal section of the Kurile-Kamchatka seismofocal zone (after Averianova, 1968). The areas within which the total energy released in the earthquake foci in 1911-1963 with $M \geq 5$ in the area of 900 km^2 is 10^{19} erg:

1 - $\Sigma E > 550$; 2 - $400 \leq \Sigma E < 530$; 3 - $200 \leq \Sigma E < 400$; 4 - $90 \leq \Sigma E < 200$; 5 - $40 \leq \Sigma E < 90$; 6 - $10 \leq \Sigma < 40$; 7 - $4 \leq \Sigma < 10$; 8 - $\Sigma E < 4$ erg.
from Erlich and Gorshkov (1979).

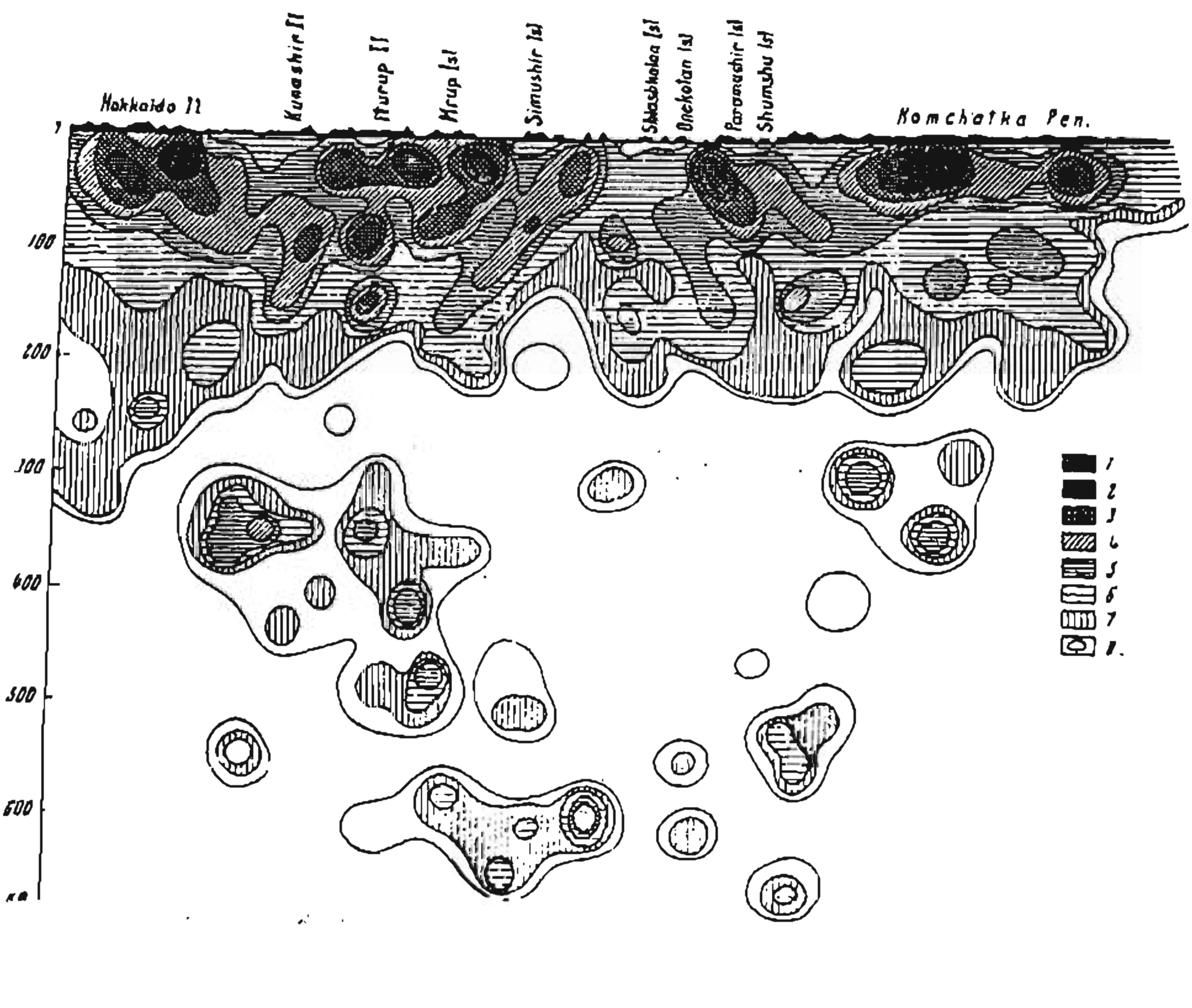
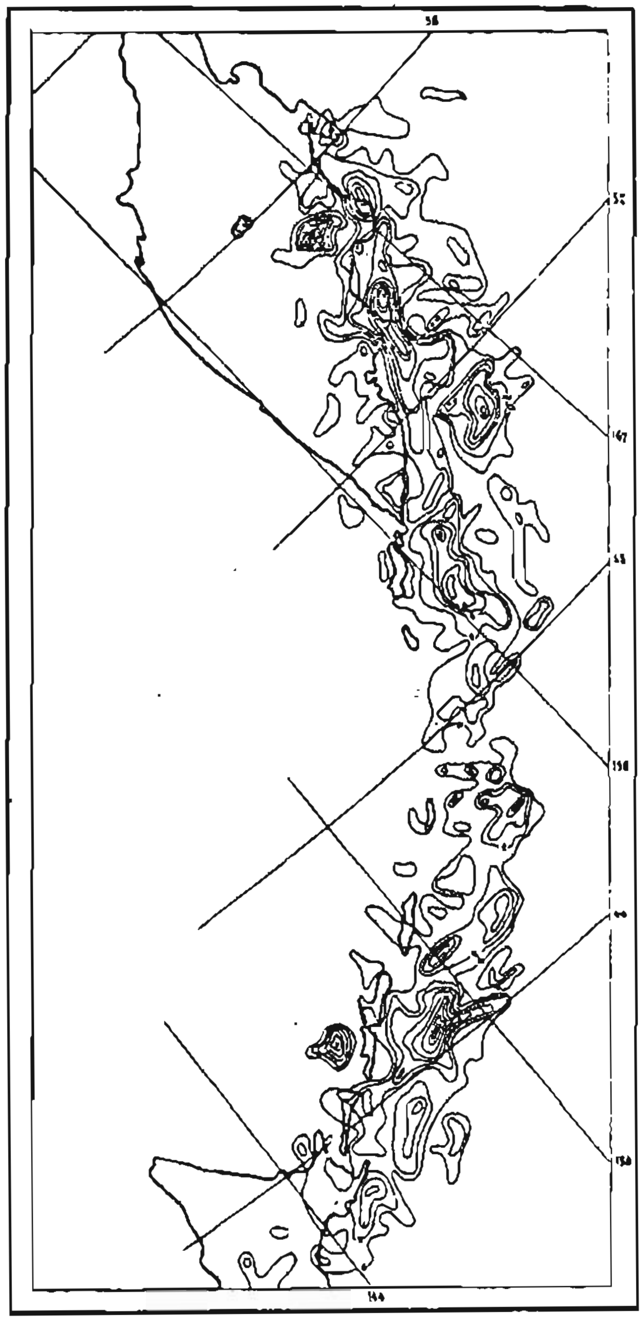


Fig. 3 - Map of the density of earthquake epicenters in the Kurile-Kamchatka zone - from Erlich and Gorshkov (1979).



From all these data follow, that Mid-Kurile deep-seated strike-slip fault is the main structural line within this tectonic system - line, which divide the strips absolutely different in geological history, deep structure and dynamic conditions. General scheme of geodynamics of the southern and central Kuriles, inferred by these data is shown on Figure 4.

As mentioned above, to the west of the Great Kurile Arc is located deep-water (depth more than 3,000 m) basin of the marginal sea--so-called Kurile basin of the Okhotsk sea. Sedimentation here has place in uncompensated form, which is fixed by the sudden increasing of the depth of the Okhotsk sea. From deep seismic refraction data, thickness of the Earth's crust here is decreased and does not exceed 13-15 km (Kosminskaya and others, 1963).

All these connections and facts can be explained if it will be inferred an idea, that the tectonic system of the Kurile Island Arc is not uniform, but rather was formed as a result of developing along the strike of two independent tectonic systems: one, which includes southern and central groups of islands as a result of expanding along the strike of the geotectonic system, connected with north-eastern Hokkaido, another, which includes northern and partly central group of islands is probably the result of expanding along the strike of the Kamchatka tectonic system. The central group of islands probably was formed on the late stage of development of these two tectonic systems.

Absolutely the same features of structure are characteristic for the Aleutian Island arc and other island arcs of normal type (Erlich and Gorshkov, 1979).

Structural distribution of the Quaternary voclanoes.

Belt of Quaternary volcanoes inherits its position from the Neogene volcanic belt. Chains of volcanoes are distributed in en-echelon manner and are divided by uplifted blocks composed by Neogene volcanics.

Now it is known (Gorshkov, 1970; Markhinin, 1967) that development of Quaternary volcanoes in Kuriles took place in the form of three or more cycles of activity. By idea of D. S. Stratula (1969) (Fig. 5) following from the "base" to the "summit" of each volcanic echelons, i.e., in dependence with distance from the Mid-Kurile deep-seated fault, it is possible to observe decreasing of the volcanic process intensity in time, however it is approximately equal during each certain cycle. In parallel, age and chemical composition of volcanic rocks changed. This regularity has no connection with the thickness of the Earth's crust. Stratula indicates that: a. All volcanoes which started their development in the Holocene time are located on "summits" of the echelons, i.e., on the longest distance from the Mid-Kurile deep-seated fault; b. Among known 20 volcanic centers which stopped their development in Pleistocene, only one is located on the summit of an echelon; c. Among Holocene volcanoes about 40-50% are located on the "summits" of echelons, and only 1-5% on the "base" of it.

Among 37 historically active volcanoes of Kuriles 18 (about 50%) are located on "summits" of echelons and only 7 (25%) on the "bases" of it.

In order to illustrate changing of the average chemical composition along echelons, Statula indicates that following the chain Golovnin - Mendeleev - Tiatia volcanoes from base to summit, the average silica content changes from 61.4 to 57.6% and at last to 52.2% accordingly. At the same time along the chain Ushishir-Rasshua-Matua-Raikoke the same figures are: 60.4 - 56.3 - 53.1 - 51.5% accordingly. Structures of volcanoes along echelons become more and more complicated with distance from Mid-Kurile deep-seated fault. So chain Zavaritsky Caldera-Prevo Peak consist of three volcanoes. Among them

Fig. 4 - Scheme of the dynamics of formation of structure of the southern and central part of the Kurile Arc.

1. The plate of the crust where stress is released generated during relative motions of oceanic and continental plates: a) Zone of mainly upthrust movements; b) Zone of mainly fault movements. 2. Zone of stress release, generated during strike-slip fault movements along the rear boundary of thrusted plate. 3. Rear basins of marginal seas. 4. Oceanic plates. 5. a) frontal boundaries of thrusted blocks (teeth cogs indicate direction of compression); b) rear boundary of the thru sted plate (cogs indicate subsided wing). 6. Faults. 7. Subsidary fissures on the wing of the strike-slip fault. 8. Drag folds. 9. Direction of movement thrusted plate. 10. Direction of displacement along strike-slip faults. 11. Orientation of compression: a) and extension; b) on the wings of the main fault zones. 12 The main volcanoes.

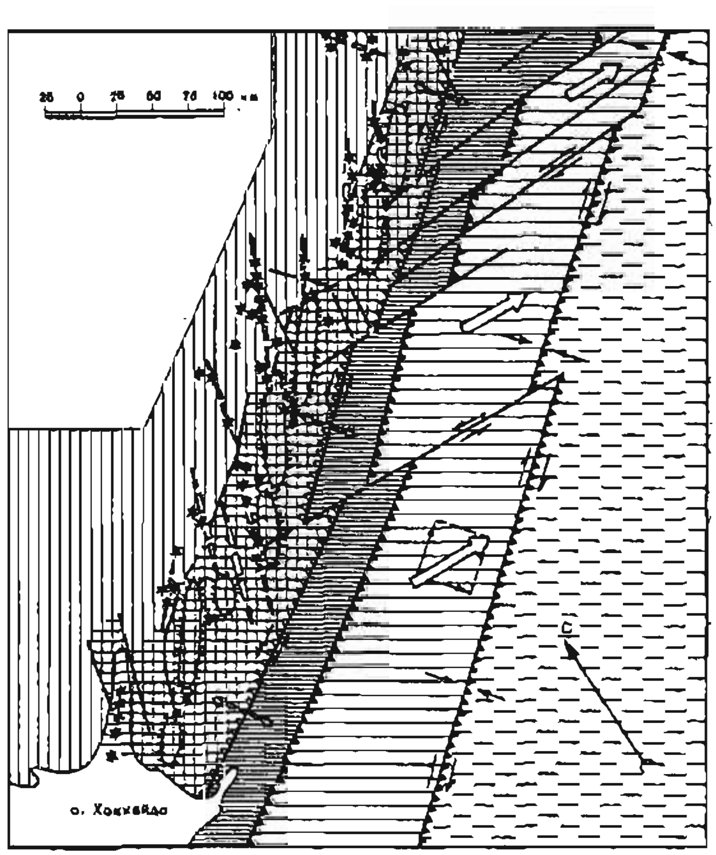
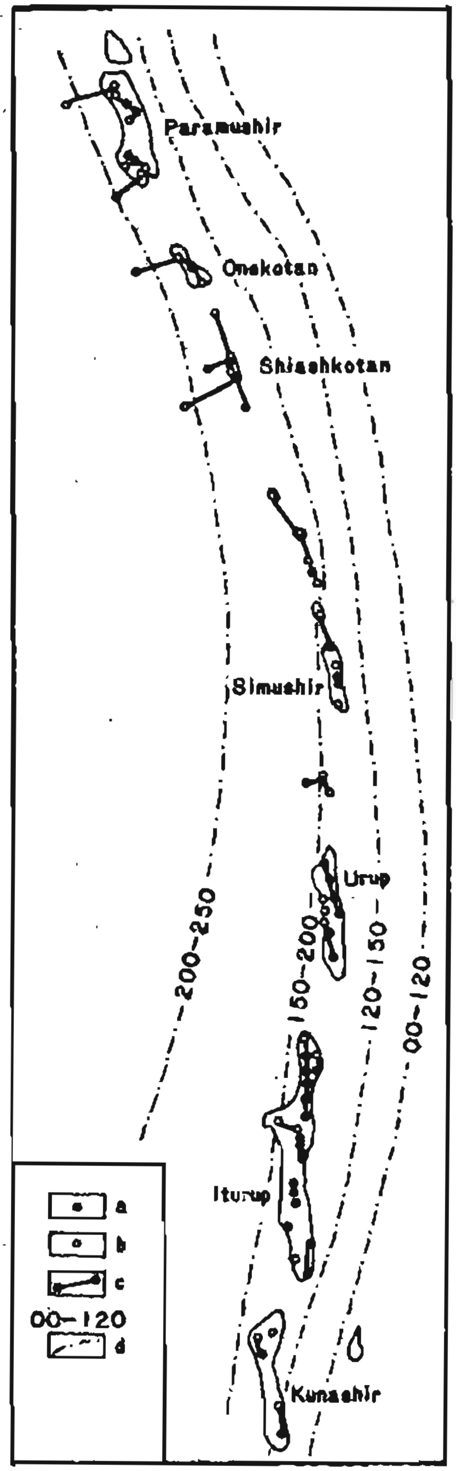


Fig. 5 - Subaerial volcanoes of Kuriles (by Stratula, 1969).

a - active volcanoes; b - extinct volcanoes; c - rows of volcanoes (by Gorshkov, 1969, 1967 with some connections); d - isolines of the earthquakes depth in km.

Volcanoes:

1.	Alaid	2.	Vetrovoy	3.	Ebeko
4.	Bordanovich	5.	Vernadsky	6.	Fersman
7.	Chikurachky	8.	Tatarinov	9.	Lomonosov
10.	Arkhangelsky	11.	Karpinsky	12.	Fussa
13.	Antsiferova	14.	Makanru shi	15.	Nemo
16.	Shestakova	17.	Tao-Rusir	18.	Harimkotan
19.	Sinarka	20.	Kuntomintar	21.	Lovushki
22.	Ekarma	23.	Chirinkotan	24.	Raikoke
25.	Matua	26.	Russhua	27.	Sredny
28.	Ushishir	29.	Ketoi	30.	Uratman
31.	Peak Prevout	32.	Ikanmikot	33.	Zavaritsky Caldera
34.	Milne	35.	Gory-aschaya Sopka	36.	Broutona
37.	Cherny	38.	Brat Chirpoev	39.	Desantny
40.	Volcanoes of the northern part of the Shokalsky ridge				
41.	Volcanoes of the southern part of Shokalsky ridge				
42.	Volcanoes of the Petr Shmidt ridge				
43.	Kolokol	44.	Tri Sestry	45.	Rudakova
46.	Volcanoes of the Krishtofovich ridge				
47.	Volcanoes of the group of Medvezhya Caldera				
48.	Tsirk Caldera	49.	Demon	50.	Kamuy
51.	Sibetoro	52.	Group of cones - Torny-Golets		
53.	Vetrovoy Isthmus caldera				
54.	Volcanoes of the Grozny ridge				
55.	Chirip	56.	Baransky	57.	Tebenkov
58.	Machekha	59.	Grozny	60.	Motonopuri
61.	Burevestnik	62.	Bogatyr	63.	Stokap
64.	Atsonupuri	65.	L'vinaya Past'	66.	Urbich
67.	Beraturaba	68.	Tyatya	69.	Mendeleev
70.	Golovnin	71.	Ruruy	72.	Smirnov



Paramushir
Onekotan
Shiashkotan
Simushir
Urup
Iturup
Kunashir
200-250
150-200
120-150
00-120
a
b
c
00-120
d

Zavaritsky caldera consists of three nested sommas. Within inner caldera there are present small extrusive domes. The first somma is of pre-glacial age. The second was formed during inter-glacial time, and the third one is Holocene in age. The second volcano of this chain--Ikanminkot was founded during inter-glacial time. Data about its structure are absent. The third volcano of this echelon--Prevo Peak is a single cone of Holocene age. Within echelon Grozny group of cones--Demon volcano, several volcanic massifs are known: Group of cones of Grozny Ridge which was founded in pre-glacial time and probably continued weak activity during inter-glacial time, Vetrovoy Isthmus Caldera, which was formed during inter-glacial time, group of cones Torny and Golets are Late Pleistocene volcanoes.

The same increasing complexity of volcanic structure is observed along chain Golovnin caldera-Tiatia volcano. In the structure of Golovnina caldera there are two nested Pleistocene sommas and several Holocene extrusive domes. Mendeleev volcano has two sommas, one formed during pre-glacial time and another formed during interglacial time, and the internal Holocene cone. Tiatia was formed in Holocene and has simple edifice, which is composed of a somma and inner cone.

The same type of changings are observed in other rows (Milne-Goryaschaya Sopka and others).

So calderas - the complex and long-lived volcanic centers are located in the bases of echelons - in dependence with degree of subsidary fissures openings on the wing of deep-seated strike-slip faults. In the case of the Kuriles, it is the Mid-Kurile deep-seated strike-slip fault.

Structural position of caldera-volcanoes on the Aleutian Island arc is similar as in the Kuriles--they are located mainly in the bases of echelons.

KAMCHATKA AND GEOTECTONIC SYSTEMS OF KAMCHATKA TYPE

General tectonic zoning.

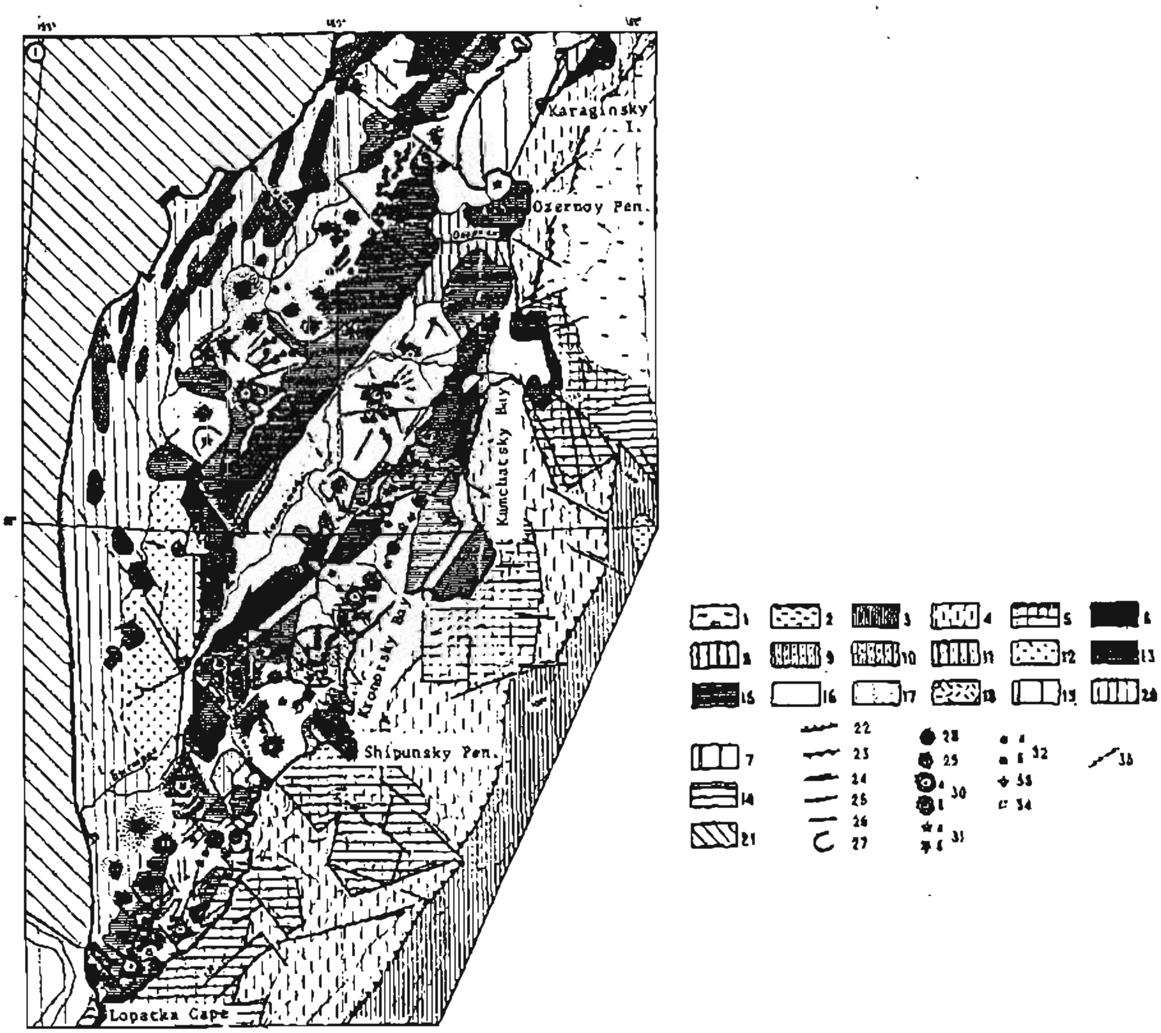
Kamchatka and similar geotectonic systems, have several contrasting features in comparison with normal island arcs (Erlich, 1973; Erlich and Gorshkov, 1979):

1. Earth's crust in general belongs to normal continental type, as by its thickness (40-45 km), so by development of normal granitic layer.
2. Height of pre-Quaternary tectonic relief averages 1000-1500 m, i.e. one order more than within normal island arcs.
3. Usual for normal island arcs zonality of structural elements here become more complex. There appear several zones of horst-anticlines, divided by graben-synclinal belts, where pre-Quaternary basement is subsided below existing erosional level, and as a rule, below sea level. About 70% of all Quaternary volcanoes are located within these graben-synclines (Fig. 6).
4. In the frontal and rear zone of the system are located linear depressions, filled by thick (8-10 km) sequences of sedimentary (not volcanic) rocks. Environment of sedimentation in these sediments changes upward the sequence from deep water (probably oceanic) to sub-aerial, practically continental. Age of sediments range from Paleogene up to Pliocene. Based on all these features these depressions are considered as filled by sedimentary sequences oceanic trench (frontal depression) and deep-water basin of the marginal sea (rear basin). This interpretation is supported by the fact that marginal basin, now existed in the rear zone of Kurile island arc (Kurile depression of the Okhotsk Sea) disappeared just near southern Kamchatka.

Fig. 6 - Map showing the recent structure of Kamchatka - from Erlich and Gorshkov (1979).

1 - Ocean floor - thalassocraton; 2 - rampart-like uplift of the ocean floor along the outside of oceanic trenches; 3 - oceanic trenches; 4 - zone of development of fault dislocations in the area of downwarp of M discontinuity on the continental slope; 5 - Horst-anticlinal uplift zones of Preneogene complexes in submarine topography; 6 - subaerial horst-anticlinal zones. Troughs between the volcanic belt and the geanticlinal belt of the external arc; 7 - Recent, reflected topography; 8 - Neogene. Sites of advancing troughs of Oligocene-Neogene age, analogues of recent trenches; 9 - drawn into the uplifts of Quaternary time; 10 - zone of continental sedimentation of Quaternary time; 11 - being a zone of marine (shelf) sedimentation of Quaternary time. 12 - relics of central massifs composed of metamorphic terrains; 13 - anticlinal basement folds. Sites of Oligocene-Neogene volcanic belts drawn into the process of uplift in Quaternary time; 14 - in submarine topography; 15 - subaerial zones of arched uplifts.

Sites of grabens and graben-synclines composed predominately of: 16 - Quaternary volcanic rocks; 17 - complexes of loose Quaternary sediments; 18 - pumices and ignimbrites; 19 - recent rear troughs of marginal seas; 20 - peneplaned zones of rear troughs of Neogene time; 21 - area of shelf seas; 22 - surface trace of seismofocal zone; 23 - crustal flexure at the ocean-continent contact in regions where the trench is absent; 24 - strike-slip faults with considerable shear component in Upper Pleistocene-Holocene; 25 - faults, active in Upper Pleistocene-Holocene; 26 - faults of unknown displacement; 27 - volcano-tectonic fault zones; 28 - shield-like volcanoes of basalt-andesitic composition without calderas: a) active, b) extinct; 29 - caldera-volcanoes: a) active, b) extinct; 31 - shield volcanoes and stratovolcanoes of basaltic compositions: a) active, b) extinct; 32 - submarine volcanoes; 33 - coral reefs; 34 - zones of flood basaltic volcanism; 35 - vent alignments.



5. For Neogene structure of these tectonic systems is characteristic tectonic zonality which is usual for normal island arcs (Fig. 7). But in Quaternary time the situation was changed and there appeared a new type of tectonic system similar by some important features with normal island arcs (calc-alkaline volcanism, presence of the Benioff zone) but at the same time different by other important characteristics listed above.

Elements of deep-seated structure.

Important feature of deep structure of eastern Kamchatka by gravity data is that frontal zone of linear horst-anticlinal, which coincide with system of peninsulas on the eastern coast of Kamchatka - Shipunsky, Kronotsky, mchatsky Mys and Beregovoy ridge in southern Kamchatka is expressed in gravity field in the same way as horst-anticlinal belt of the outer arc of Kuriles (Lesser Kurile chain - submarine Vitiaz Ridge), i.e., as a zone of very high gravity anomalies and increasing thickness of the Earth's crust. The rear boundary of this zone expressed in gravity field as a narrow linear high-gradient zone coincide with geologically expressed fault zone on the boundary between graben-synclinal which control structural position of Quaternary volcanic belt and linear uplift of horst-anticlinal uplift. As in Kuriles, so in Kamchatka this zone coincides with Benioff zone rear boundary, expressed as rear boundary of the field of high-density of shallow earthquakes foci distribution. So, as in the Kurile's case, this zone can be called the main rear deep-seated strike-slip fault zone. This deep-seated fault zone has the same position and nature as the Mid-Kurile deep-seated strike-slip fault described above. It is possible to give to this fault in Kamchatka specific name--eastern Kamchatka deep-seated strike-slip fault.

Frontal deep-seated strike-slip fault zone, which coincides with frontal boundary of Benioff zone lay on the distance about 30 km from the inner boundary of oceanic trench (Fedotov and others, 1966).

Simultaneously also changes geological nature of different geoanticlinal belts. If in Kuriles, geoanticlinal belt has the single nature--it is composed of the Upper Cretaceous-Paleogene volcano-sedimentary sequence, in Kamchatka only one geoanticlinal belt - geoanticline of the eastern ridge is of the same nature. The outer geoanticlinal belt is formed as a result of inversion of the frontal linear depression--previously existed oceanic trench, filled by sediments. Due to inversion and uneven uplift along the strike in some places appear anticlinal folds with the Upper Cretaceous deposits in the core. And the westernmost among these geoanticlinal belts along the northern part of the Sredinny Ridge appear on the place of Neogene volcanic belt.

As in many geotectonic systems of these type within Kamchatka peninsula there is a rigid block, composed of metamorphic terranes and granitic intrusions, so-called Median Massif, transformed during youngest stages of development of recently active mobile belt in which it is involved in characteristic Z-like form (Fig. 8).

For Neogene volcanic belts it is characteristic development along the strike. As a result the age of the youngest and oldest volcanic rocks changes along the strike of volcanic belts. So along the single east Kamchatka volcanic belt the oldest volcanic rocks within the southern Kamchatka graben-syncline belong to Oligocene, in the eastern Kamchatka graben-syncline the oldest rocks belong to Pliocene.

Fig. 7 - Scheme of the Kamchatka tectonic zonation (after G. C. Vlasov, 1964).
1. - boundaries of tectonic regions;
2. - boundaries of structural-facies zones;
3. - assumed Central-Kamchatka deep fault;
4. - profiles of DSS (I - 1969, II - 1970-1971).

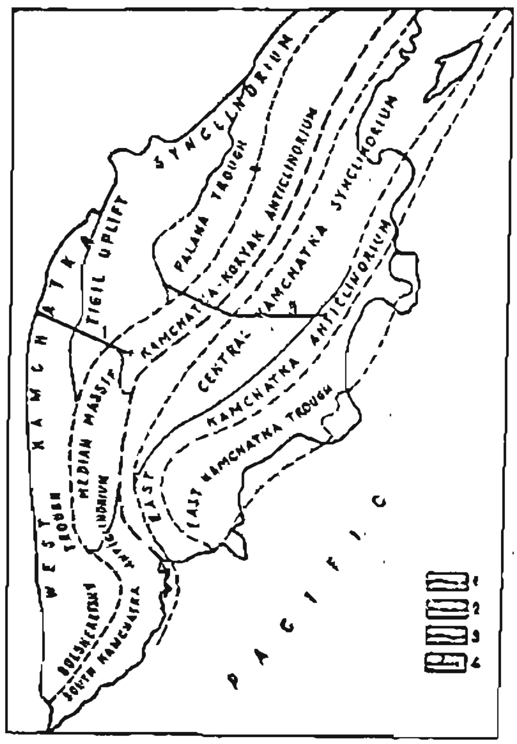
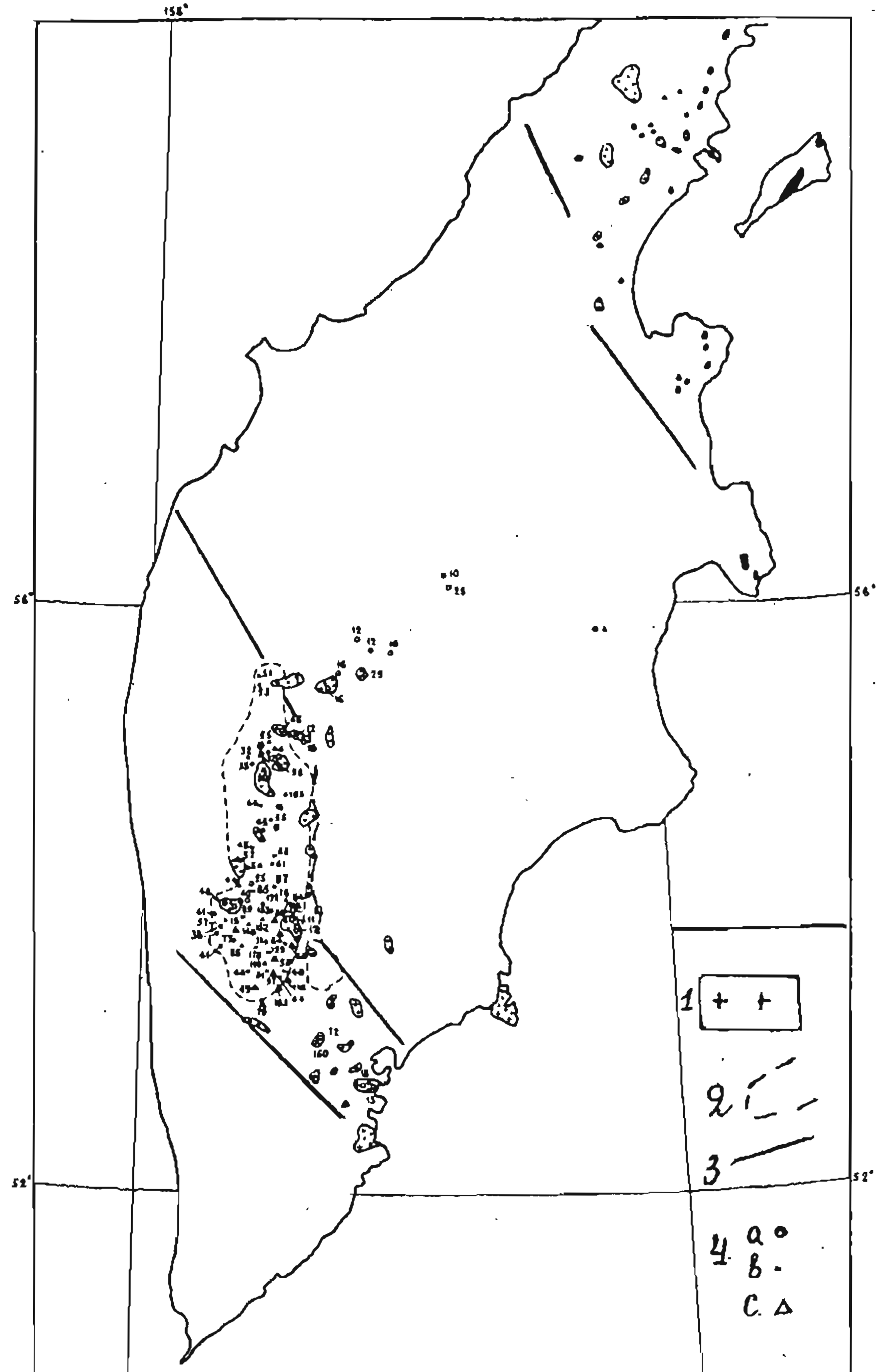


Fig. 8 - Z-like deformation of the rigid block in Central Kamchatka (Z structure).



All these characteristic features including complex structural zoning appears only in Pleistocene time. During Neogene Kamchatka belonged to normal island arcs with single non-volcanic geoanticlinal and volcanic belt. The last stretched from southern Kamchatka along the eastern boundary of the Median Massif and which follow the Sredinny Ridge. Part of this volcanic zone, which stretches along Sredinny Ridge is called central Kamchatka volcanic zone (Vlasov, ed., 1964).

Changing of the character and scale of volcanism.

It has been shown previously, that within geotectonic system of Kamchatka type the type of volcanism is changed—instead of andesitic volcanism of normal island arc systems here appear bi-modal volcanism with widespread basaltic volcanism in different forms (shield volcanoes, stratovolcanoes and fissure basaltic volcanism) and silicic volcanism—ignimbritic and pumice covers, dacitic and rhyolitic extrusive domes. Andesites are present here in subordinate quantities.

At the same time changes the rate of magma generation: volume of synchronous volcanoes of the same type in Kamchatka is in order more than in Kuriles. Comparison between diameter of volcanoes in Kuriles (and normal island arcs in general) from one side, and Kamchatka-type geotectonic systems from another side show, that within systems of the last type rate of magma production for the certain time intervals increases in order (Erlich, 1973; Erlich and Gorshkov, 1979).

Changings of type/rate of magma production of the same type are observed in all places, where normal island arcs enter uplifted blocks of Kamchatka-type geotectonic systems.

If one, for example, will trace Ouaternary volcanism along the strike of Sunda island arc, the first place, where great amount of dacitic pyroclastics will appear is the strait between Java and Sumatra, where the famous Krakatau volcano is located. And on the Sumatra there appear from one side great fields of silicic ignimbrites on southern Sumatra and around volcano-tectonic depression of the Toba Lake, and from another side—large fields of Soekadana basalts. When Tonga-Kermadek island arc system enter the North Island of New Zealand, there appear great Taupo fields of silicic ignimbrites and at the same time linear zones of basaltic volcanism in Tarawera region. When Aleutians enter uplifted block of Alaska, there appear from one side such great basaltic volcano as Veniaminof, and from another side such centers of silicic volcanism as Aniakchak and Ugashik calderas. The greatest on the Aleutians Vsevidof caldera appears on the Umnak island which in the recent structure belongs rather to Alaska, not to the normal island arc system.

General distribution of Quaternary silicic volcanism on Kamchatka-type geotectonic systems.

In general the distribution of centers of Quaternary silicic volcanism in Kamchatka-type geotectonic systems have two important general regularities:
1. General tendency to location in frontal parts of volcanic belts or in frontal volcanic belt (in case if a pair of volcanic belts is present in the region).

In Kamchatka centers of Ouaternary silicic volcanism are located in the frontal part of south Kamchatka graben-sycline, or in eastern Kamchatka graben-syncline (frontal volcanic belt). In central Kamchatka depression silicic volcanism is represented by acid andesites and any Quaternary silicic calderas are absent, excluding small calderas on Zarechny volcano. Here present great volcano-tectonic structures, connected with basaltic volcanism -

Tolbachik volcano-tectonic depression and Hawaiian calderas of Plosky Tolbachik and Plosky volcano. In rear Quaternary volcanic zone - Sredinny Ridge centers of silicic volcanism are rare and of a specific type - with them are not connected any great fields of silicic pyroclastic products. Here also present calderas and volcano-tectonic depression connected with basaltic volcanism.

In north-eastern Japan there are two parallel volcanic zones and all centers of Quaternary silicic volcanism are located in frontal, Nasu zone, but they are practically absent in rear Chokai volcanic zone (Kawano, Yagi, Aoki, 1961).

Quaternary volcanoes on north-eastern Hokkaido are located in two en-echelon distributed chains, which continue volcanic belt of the Kurile arc and distribution of different types of volcanoes remind regularities marked in previous section of this chapter for normal island arcs. Caldera-volcanoes are located in the base of both chains. So, Shiretoko-Akan chain nearest to Kuriles volcanoes are represented by noraml strato-cones and in the south-west part of the chain are located series of great calderas Kutcharo, Akan, Mashu and all stratovolcanoes are located inside calderas (Atsonupuri, Me-Akan, O-Akan). The same distribution is characteristic for another, Tokachi-Daisetsu chain, located in parallel with Shiretoko-Akan chain, but displaced to north-west in en-echelon manner. North-eastern part of the chain consist of series stratovolcanoes and in south-west part of it great Tokachi caldera is located (Katsui, 1963).

Manifestations of Quaternary silicic volcanism on the extenion of two other normal island arcs which enter Japan, are distributed in the same manner.

In Kyushu calderas are located in two linear zones - Kirishima, with three great calderas which overlap each other - Ata, Aira and Kakuto. In parallel is located Unzen - Kudju volcanic zone in which at least three centers of silicic volcanism are located: Unzen volcano, Aso caldera and Kudju ring complex of extrusive domes. On the extention of this zone in south-western Honshu, group of silicic extrusive domes.

In central Japan on the continuation of Izu island arc, Quaternary volcanoes are located in two zones - northern Fuji and Norikura zones. And the greatest center of silicic volcanism-Hakone volcano is located in the frontal part of the northern Fuji zone. In the rear part of this zone, basaltic Fuji volcano is located in great volcano-tectonic depression, connected with basaltic volcanism. And in rear - northern zone calderas are absent (Minato and others, eds., 1965).

Regularities of distribution of silicic calderas in Alaska also combine regularities described for normal island arcs and Kamchatka-type geotectonic systems.

Regions of silicic volcanism are distributed along recent volcanic belts in a dotted-line manner. So, in eastern Kamchatka, all centers of silicic volcanism are concentrated within central part of the graben-syncline. In the same time for the southern and northern part of the graben—syncline linear chains of stratovolcanoes are characteristic (Erlich and Gorshkov, 1979). In north-eastern Japan, within Nasu volcanic zone, two subzones - northern and southern, different in scale of silicic volcanism are divided. Within southern subzone calderas and associated with them fields of silicic pyroclastic rocks are absent. In the same time in the northern Honshu and southern Hokkaido, within northern Nasu subzone are located series of large Quaternary calderas such as Towada, Toya, Kutcharo and others with formation of which great outbursts of silicic volcanic activity is connected (Kawano, Yagi, Aoki, 1961). In south-western Japan all centers of silicic volcanism are concentrated on Kyushu (Minato and others, eds., 1965).

In New Zealand the central volcanic region is divided in two equal in lengths, continued each other along the strike: the part from the Bay of Plenty to Taupo Lake (Taupo-Rotorua zone) where all manifestations of silicic volcanism are located, and the part of the Tongariro National Park within which andesitic stratovolcanoes are located (Grindley, Harrington, and Wood, 1959).

Now it is still difficult to explain the reason of such character of distribution. Partly it is the result of some specific tectonic conditions. But it is possible to mark, that in all cases, when Quaternary volcanic belt inherit position of the region of previous great outbursts of silicic volcanism, Quaternary silicic volcanism is insignificant or absent.

The strongest outburst of Neogene silicic volcanism in Kamchatka is observed within the Sredinny Ridge volcanic zone--so-called central Kamchatka Neogene volcanic belt, and any great manifestations of Quaternary silicic volcanism are absent there. In southern Kamchatka it is marked displacement of the centers of Quaternary siicic volcanic centers eastward in connection with centers of Neogene silicic volcanism.

The same picture is observed in Japan. In south-western Honshu after strong ignimbritic and welded tuffs eruptive activity in Upper Cretaceous time silicic volcanism have place neither in Neogene nor in Quaternary time. In north-eastern Japan episode of intensive silicic volcanism and granitoids of the same age have place exactly in the southern part of Nasu zone, where Quaternary silicic volcanism is small in scale. On opposite, centers of silicic volcanism in northern Honshu and Hokkaido superimposed Neogene andesitic sequences or series of sedimentary rocks of the same age. In New Zealand Neogene zone of silicic volcanism in the Koromandel peninsula extinct after an epoch of strong outbursts of silicic pyroclastics. Regions of Quaternary silicic volcanism are displaced here along the strike in southeast direction, within recently existed Taupo-Rotorua zone.

So it is possible to mark, that the main catastrophic outbursts of silicic volcanism occurs only once during one cycle of tectonic development. It is probable, that this outburst is the reflection of the crust transformation and it transition to the stable crust of continental type. After this process of silicic volcanism (and caldera formation) is displaced to another part of the volcanic zone.

Features which govern structural position of certain calderas in Kamchatka.

As it has been mentioned above, structural position of all Quaternary volcanic belts also is changed in Kamchatka in comparison with normal island arcs. Instead of series of en-echelon distributed rows of volcanoes, characteristic for Kuriles, here appear series of linear graben-synclinal zones within which about 70% of all Quaternary volcanoes and all caldera-volcanoes (excluding Khangar caldera and volcano) are located.

In order to understand structural position of calderas in Kamchatka one needs to put in attention two characteristic features of the structures.

The first is specific feature of distribution of earthquakes foci of different depth in connection with graben-synclinal structures.

Benioff zone of Kamchatka is the direct continuation of the same zone of Kuriles. And for its structure the same characteristic features are typical as we saw above. Here it is important to emphaize that earthquakes foci with depth more than 50 km are distributed in form of east-west strips, which coincide within horst-anticlinal belts with known strike-slip faults (Fig. 9). Amplitude of horizontal displacement along these zones is equal 3-8 km. Within volcanic belts on the continuation of such strike-slip faults lay practically all long-lived volcanic centers of southern and eastern Kamchatka. On the territory of Quaternary volcanic belts such zones are not expressed in surficial geology of volcanic rocks cover, where are observed only systems of fissures without displacement, or there is seen displacement of magma chambers in time along these zones (as in the case of Pauzhetka volcano-tectonic depression), or deformation of ring complexes of extrusive domes (as in case of Ichinsky volcano) is observed.

Another important specific feature of spatial distribution of silicic calderas in Kamchatka is that within graben-synclinals distribution there are located around large (20-50 km in diameter) negative Bouguer gravity anomalies with concentric contour lines (Erlich and others, 1972).

In the distribution of silicic calderas and volcano-tectonic depressions with respect of such anomalies can be distinguished two cases (Fig. 10): In the first group, e.g., the Pauzhetka, Great Semiachik, Karymsky and Khangar coincide with gravity anomalies. Depth of gravity centers of the anomaly-causing bodies for this group is equal 8-15 km. The mass deficiency which determines these anomalies is around 12×10^{16}g for Karymsky anomaly and 15×10^{16}g for the Pauzheka and Great Semiachinsky anomalies. The depth of the top margin of the anomaly-causing body appears in all cases to be about 5-6 km. Therefore the computed parameters of the anomalies of the group under discussion are almost identical which itself indicates the identity of their nature.

Gravity anomalies of the second group have no correspondence with surface structures. It is characteristic, however, that complex volcanic structures with a highly differentiated lava composition are located around such anomalies in areas of high horizontal gravity gradients of gravity field. Moreover such location is also characteristic of the largest silicic calderas and other types of centers of silicic volcanism. So Taunshits, Unana volcanos and Uzon are located around periphery of Uzon negative gravity anomaly, while Opala, Gorely calderas and Asacha volcano are located along the periphery of the Tolmachev gravity anomaly.

The Uzon anomaly occupies an area of 50x45 km and is characterized by high intensity and considerable peripheric gradient. The depth of the body, that caused Uzon anomaly has been determined to be 14-18 km and the mass deficiency is about $200\text{-}250 \times 10^{16}$g.

For the Tolmachev negative gravity anomaly the depth of the top margin of the anomaly-forming body exceeds 12 km. A characteristic feature of magnetic field is the presence of a positive magnetic anomaly that connects the Gorely, Opala and Asacha volcanoes forming a closed polygon. The silicic calderas— Opala and Gorely are located on the corners of the polygon and are associated with intense magnetic anomalies.

The similar characteristics of the negative gravity anomalies, their general connection with areas of silicic volcanism, the substantial depths of the gravity-causing bodies and their relatively low density with absence of any connection with surficial geological features lead Erlich and his coauthors (1972) to the conclusion that such anomalies are due to the presence within the crust of magmatic masses mainly silicic in composition. Such a conclusion is confirmed by the negative magnetic anomaly of secular duration in the area of Pauzhetka gravity minimum. The eastern branch of this anomaly coincides exactly with the negative gravity minimum and according to Pudovkin can be explained by the presence of a high-temperature mass of the depth of about 10 km.

Fig. 9 - Density of earthquakes foci with depth more than 50 km (Erlich, 1973).
By the data of Tokarey and others (1968, 1970), Fedotov and others (1967, 1970), and Averianova (1968). Isolines of earthquakes foci density for quadrangles with side 25 km, where have been marked: 1 - one; 2 - three; 3 - five and more foci. Vectors of compression within earthquakes foci by data of Zobin: 4 - with depth 60-70 km; 5 - with depth 70-100 km; 6 - with depth more than 100 km; 7 - inferred strike-slip faults on the boundary between blocks with different seismicity; 8 - supposed direction of compression; 9 - calderas (a); and volcano-tectonic depressions (b).

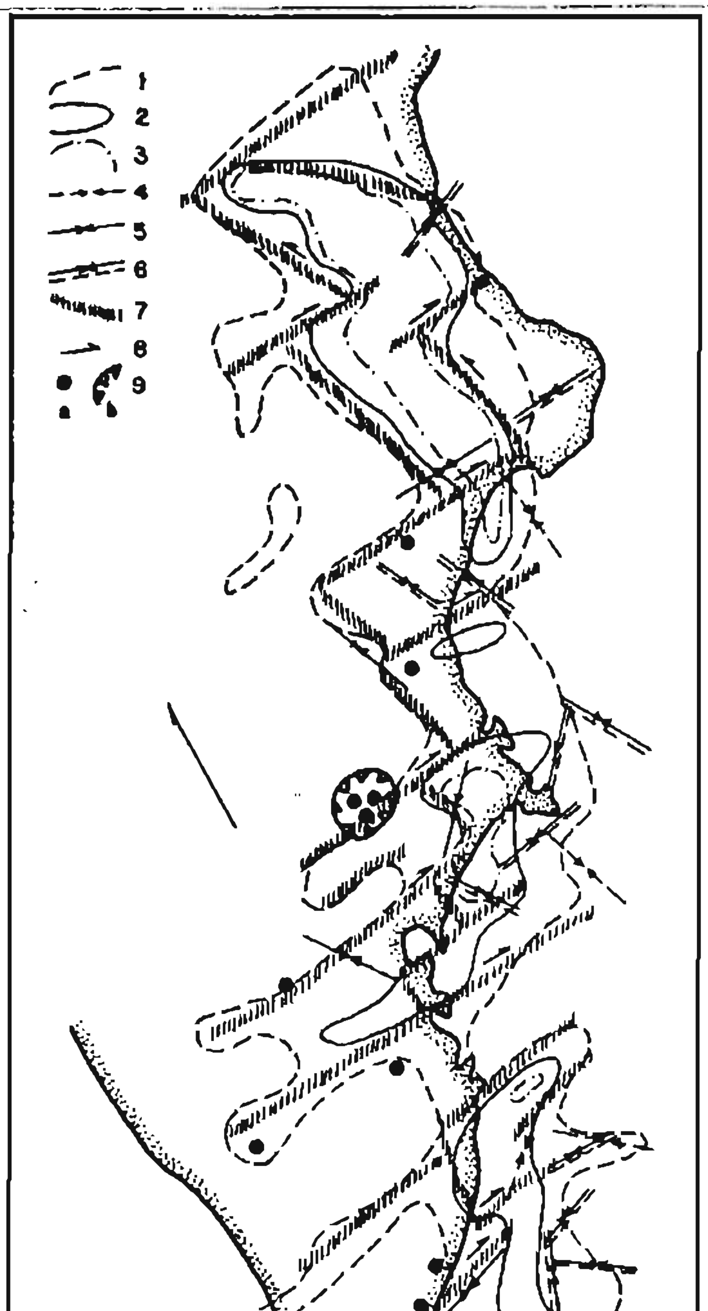


Fig. 10 - Distribution of Quaternary calderas and volcano-tectonic depressions in Kamchatka - from Erlich and others, 1972.

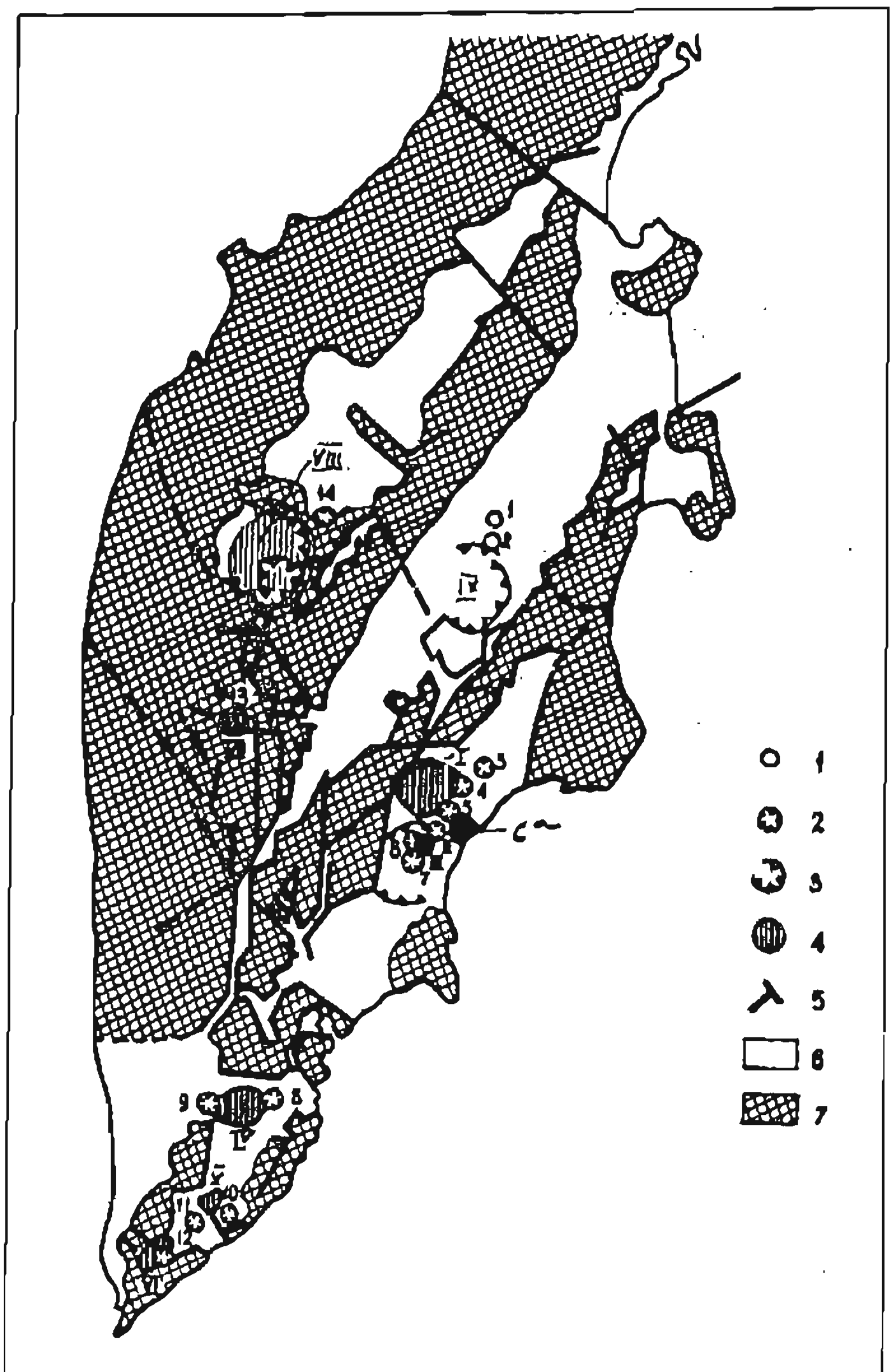
Key: 1: Hawaiian-type calderas; 2: Krakatau-type calderas; 3: Main volcano-tectonic disjunctive dislocations; 4: Zones of negative gravity anomalies; 5: Tectonic disjunctive dislocations; 6: Areas of continuous development of Quaternary volcanic and volcano-sedimentary rocks; 7: Pre-Quaternary rocks.

Arabic numerals: Calderas

Latin numberals: Large negative gravity anomalies

Calderas: 1 - Dalnaya Ploskaya sopka; 2 - Plosky Tolbachik; 3 - Krasheninnikov; 4 - Uzon-Geyser valley; 5 - Semiachik; 6a - Maly Semiachik; 6 - Karymsky volcano; 7 - Karymsky lake; 8 - Gorely; 9 - Opala; 10 - Ksudach (Stubel caldera); 11 - Prizrak; 12 - Kurile lake; 13 - Khangar; 14 - Uksichan.

Negative Gravity Anomalies: I - Uzon; II - Bolshe-Semiachik coinciding with the same name ring-structure; III - Karymsky anomaly inside the Zhupanov ring-structure; IV - Tolmachev; V - Golygin; VI - Pauzhetka; VII - Khangar; VIII - Ichinsky; IX - Tolbachik volcano-tectonic depression.



In the same time calderas are absent at any other types of volcanic centers along active faults, which bound graben-synclinal structures. Structural position of calderas and volcano-tectonic depressions in southern and eastern Kamchatka is shown on Figures 11 and 12, respectively.

Structural position of calderas in connection with tectonic lines, which cut volcanic zone is also very typical for other geotectonic systems of Kamchatka type. So, great centers of silicic volcanism on Kyushu island (southern Japan) - Unzen volcano and Aso volcano are located on the intersection of northeast trending volcanic zone and east-west fault zone. Similar position is characteristic for the Hakone caldera in central Honshu Island, which is located on the continuation of axes of east-west fold system of Kwanto basin with north-west trending volcanic zone of Fossa Magna (Geological Map of Japan in scale 1:5000,000, 1982). Greatest caldera of Hokkaido - Akan, is located on the intersection of north-east trending volcanic zone with north-south trending Hidaka folded belt (Minato and others, eds., 1965).

Calderas of the Nasu volcanic zone in north-eastern Honshu which in general has north-south strike are located on the eastern edges of the east-west lines of volcanoes (Kawano, Yagi, Aoki, 1961). So, structural localization of calderas in Nasu volcanic zone combine featues, characteristic for both types of geotectonic systems--Kuriles and Kamchatka. The same is typical also for silicic calderas in Alaska, which also are located mainly in the summits of the volcanic echelons.

GENERAL GEODYNAMIC FEATURES OF TECTONIC SYSTEMS UNDER CONSIDERATION

All geological, geophysical and petrological materials now available for geotectonic systems under consideration permit to revise some points of views on important features of geodynamics of island arcs and connected with them geotectonic systems of Kamchatka type.

Types of geotectonic systems and general connection between tectonics and rate/type of the magma production.

It has been shown above, that within Western Circum-Pacific there presents at least two different types of geotectonic systems: normal island arcs (Kurile type) and Kamchatka type of geotectonic systems, different either by the type of volcanism (andesite on normal island arcs and bi-modal in Kamchatka type of geotectonic systems) or rate of magma production for the certain periods of geological time (volume of the single volcanoes increase in order in Kamchatka-type geotectonic systems in comparison with normal island arcs).

Comparison of volcanism with different features of geological structure of different regions show, that the most sensitive indicator on which react composition and intensity of volcanism is intensity of the modern (Quaternary ?) uplift, expressed in the height of recent tectonic relief. So in such island arcs, where absolute height of tectonic relief is less than sea level, intensity of volcanism decreased and the main type of volcanic rocks are represented by basalts, mainly low-potassium tholeiites similar to normal oceanic tholeiites (Izu, Bonin, Tonga, Kermadec, western part of the Sunda Arc). Within island are systems, which in Quaternary time undergo general subsidence, volcanism and Benioff zone disappear (Yap, Palau, East Melanesian uplift).

Fig. 11 - Geology and Structure of South Kamchatka.
1 - rises formed on dislocated Prepliocene deposits; 2 - fields of Pliocene-Lower Quaternary effusives (the additional oblique shading depicts the uplifted blocks of Golyginskie and Detinka Mountains, Nachikinskaya transverse zone of dislocations and the stabilized blocks along the eastern graben-synclinal margin); 3 - basaltic shield and shield-like volcanoes (Q_{1-2}); 4 - large, composite strato-volcanoes of central type of andesitic, andesite-basaltic and basaltic composition (Q_{3-4}); 5 - ignimbrite and pumice sheets (Q_2-Q_4); 6 - extrusive domes (Q_2-Q_4): a) large groups, b) single domes; 7 - flows of viscous acid lava; 8 - flows of basalt lava (Q_{3-4}); 9 - basaltic scoria cones and small shield volcanoes (Q_{3-4}); 10 - zones of accumulation of loose Quaternary deposits; 11 - deep-seated faults (from gravimetric data): a) flexure of M discontinuity, b) other faults, including deep-seated strike-slip faults; 12 - observed faults; 13 - large calderas and volcano-tectonic depressions; 14 - lines of equal quantity of earthquake epicenters with focal depth of more than 50 km, calculated in squares of 25 km side (according to data of seismic stations network for 1963-1970).

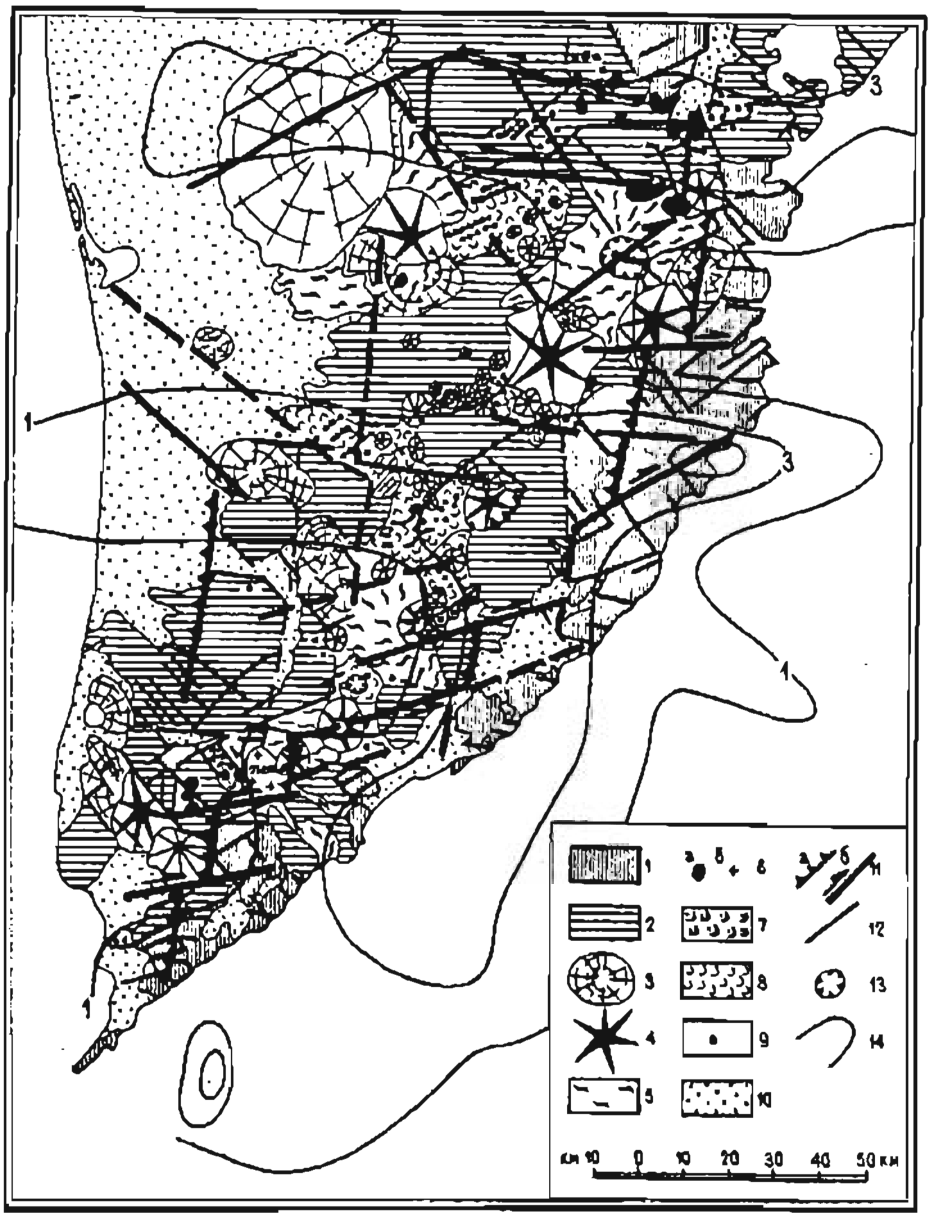
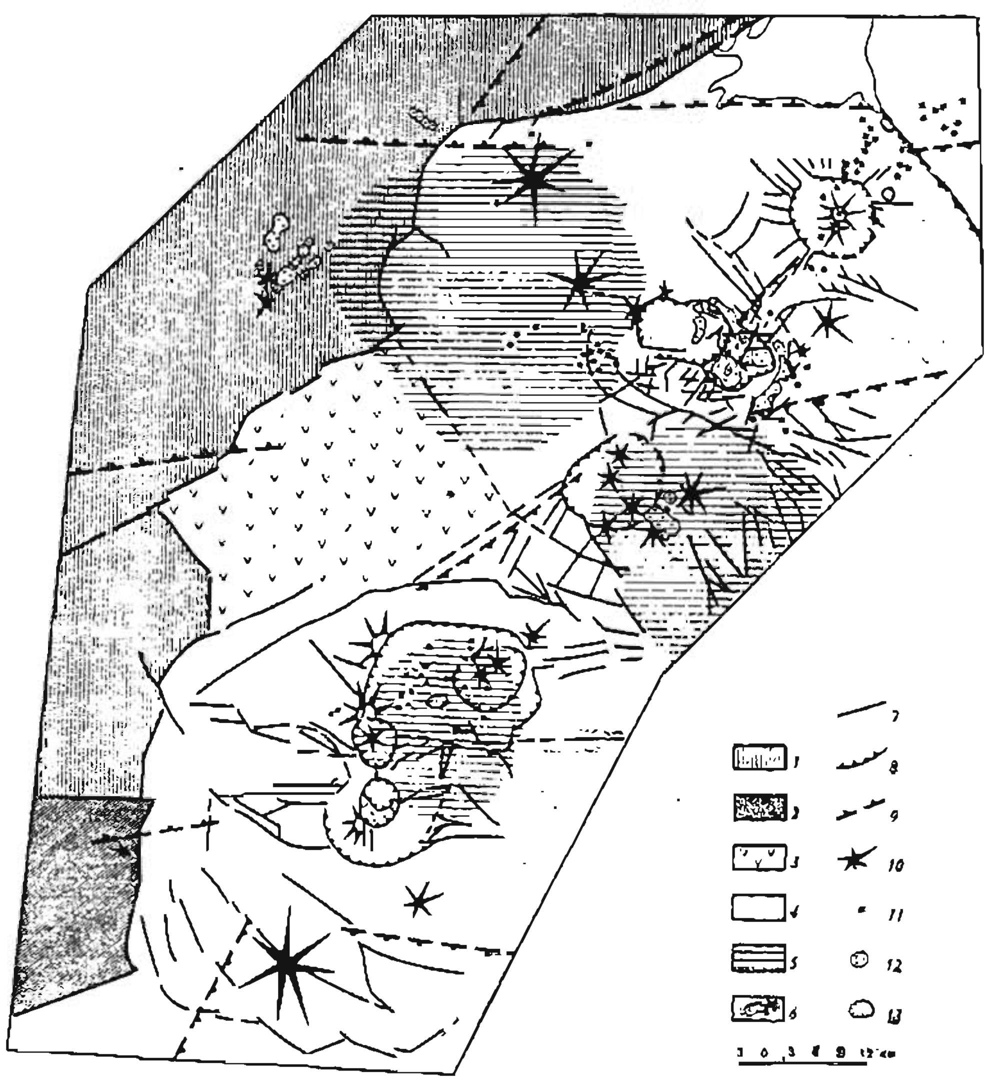


Fig. 12 - Structural scheme of the Uzon-Karymsky part of the Eastern Kamchatka graben-syncline (from Luchitsky, ed., 1974).
1 - horst-anticlinals, formed by dislocated pre-Pliocene deposits; 2 - uplifts, formed by the combinaton of tectonics and volcanic accumulation; 3 - stable blocks on the margins of graben-synclines; 4 - Eastern Kamchatka graben-syncline; 5 - large negative gravity anomalies; 6 - linear zones of shallow earthquakes (depth less than 50 km); 7 - faults, inferred by geophysical data; 8 - ring faults on the boundaries of calderas and volcano-tectonic depressions; 9 - faults, inferred along high-gradient zones in gravity field, 10 - largest central volcanoes; 11 - cinder cones and small basaltic lava volcanoes; 12 - extrusive domes; 13 - maars and blast funnels.



In the same time, when tectonic relief of geotectonic systems exceed some critical level (about 2000 meters in average) volcanism decreased abruptly or even disappear at all. This can be seen within north Kamchatka-Olyutorsky block, south-western Japan (excluding Kyushu island), Taiwan, north Luson block of Phillipines, New Guinea, South Island of New Zealand. Within all these regions normal for island arcs zonal system of Neogene structures superimpose different in age and nature pre-Neogene folded systems. In Quaternary time these systems were involved in intensive uplift. Benioff zones and trenches here are absent. Quaternary volcanoes do not form independent belts, connected with any kind of specific structure, but are or connected with development of adjacent geotectonic systems (for example--normal island arcs) or are located in the tectonically weak zones, or on domal uplifts, of tectonic relief of pre-Quaternary dislocated rocks, or within circular in plan volcano-tectonic depressions (as Khangar within Meidan Massif of Kamchatka).

Benioff zone - characteristic features.

The main specific feature of geodynamics of island arcs and tectonic systems of Kamchatka type is presence of Benioff zone. So, for understanding of any kind of processes within these systems it is extremely important to put in attention some specific features of movements within this Benioff zone.

Speaking about movements within Benioff zone it is necessary to mark in the very beginning, that this zone not necessary divide plates with oceanic and continental crust. There exist probably any possible combinations of the type of the crust within two zones, divided by Benioff zone. Moreover among these different type of combinations presence of continental crust in upthrusted plate and oceanic in downgoing plate is quite rare. Even in Kuriles in the rear zone there present basin of marginal sea with oceanic type of the crust, and for example on Marianas, Izu, Yap and several others on the both wing of the Benioff zone there present identical oceanic plates. In Eolian Islands in the front of island arc there lay the Sicilian plate with normal continental crust, and behind the island arc, on opposite, Tirrenian plate with typical oceanic crust.

The eastern part of the Sunda island arc lay between two plates of continental shelf—edge of the south-eastern Asian plate and Australian plate. And it is important to note, that in the front of island arc there lay also the plate of continental nature.

Further, it is well known, thrust (or probably more correctly-reverse fault by the reason of steep angle of the dip of Benioff zone) character of these zones. Such character explains very well one among the most characteristic features of the structure of these systems—zonal distribution of the linear belts with different types of movements and presence here pair system of belts—tectonic (non-volcanic) geoanticlinal belts and adjacent to it subsided belt of Quaternary volcanism.

Besides all diversity of geological structure of individual regions, presence of the pair system of belts is proved to be the single feature, which is present everywhere. Two belts, which compose this zonal system are: outer zone of high compression, which correspond to belt of shallow earthquakes, connected with Benioff zone. As we saw this belt is everywhere characterized by increased thickness of the crust, high positive gravity (and magnetic) anomalies. In the rear part of this belt lay non-volcanic geoanticline. The rear belt corresponds with volcanic zone and is characterized by general extension. Despite some difference in structure in different geotectonic systems it is represented mainly by linear zone of subsidence, cut by linear zones of increased density of intermediate earthquakes foci, characterized by compression. Thickness of the crust, magnetic and gravity anomalies within this belt are decreased.

It is important to note, that geological terranes, exposed in the outer belt in different regions are different by all means (age, composition, degree of metamorphism). So, as we saw, in outer belt of Kuriles they are of Upper Cretaceous-Paleogene age, in Kamchatka they belong to mainly Tertiary sedimentary sequence, in north east Japan mainly Paleozoic rocks are exposed in such structural position. In south-west Japan in the same belt mainly Jurassic rocks are developed. In Phillipines there present Pre-Cambrian terrains.

Geologically common for all these belts is only presence in parallel to them Neogene-Quaternary volcanic belts. So, it is possible to conclude, that all previously mentioned uniformity of geophysical characteristics appear as a result of crust transformation during very short period of time and have place in connection with generation of the Neogene-Quaternary volcanic belt.

In the development of such pair belts decisive role play, as we have seen for geotectonic systems of Kuriles and Kamchatka, deep-seated fault, which divide this pair belts. It is Mid-Kurile and Eastern Kamchatka deep-seated strike-slip faults. The same deep-seated systems of strike-slip faults are observed in other island arcs and similar with to geotectonic systems of Kamchatka type.

For understanding of the nature of island arcs and Kamchatka geotectonic systems very important are observations on the nature of such lines in uplifted regions, where geological study is possible. In this connection at least two regions are important: Volcanic belt of Ryukyu islands (normal island arc) is continued on Kyushu island (geotectonic system of Kamchatka type). And the line, which divide outer belt of non-volcanic geoanticline and volcanic zone is immediately continued in Shikoku by so-called Median Line of south-western Japan. The same situation is observed in New Zealand. Here Taupo volcanic zone in North Island (geotectonic system of Kamchatka type) continue Tonga-Kermadek island arc system. In turn the line which divides Taupo volcanic zone and outer geoanticlinal belt of Ruahine-Rimutake Ridge is continued in Alpine fault of the South Island. In both mentioned cases, deep-seated faults (Median Line and Alpine Fault) divide paired metamorphic belts. Outer belt is characterized by high pressure-low temperature, and inner by high temperature-low pressure, facies of metamorphism. For both these faults strike-slip nature is characteristic.

Speaking about nature of the trench and deep-seated fault on its inner boundary, it is important to mark, that northern edge of the central America trench practically enters the mouth of the Bay of California, and the last in turn is directly continued by San Andreas deep-seated strike-slip fault. Along San Andreas Fault series narrow linear depressions, filled by very thick (up to 10,000 meters] sequence of Neogene sediments are located. Such connections indicate probably that these depressions represent itself trench, which superimpose marginal part of the north American continent. As we have seen above, strike-slip fault movements are the most characteristic for the deep-seated fault, which go in parallel to the inner trench boundary.

Putting into attention all these data it is possible to suggest, that Benioff zone is represented by series of upthrust-overfault faults, dip of each separate fault among them is rather vertical by seismological data. But the depth on which they appear increased backward the island arc geotectonic system.

Frontal boundary of the Benioff zone by seismological data do not coincide with boundary of the oceanic trench, but rather is located in parallel to it, between oceanic trench and shore line (Fedotov and others, 1964, 1966, Minato and others, eds., 1965). This is probably indication that the trench itself is not connected with process of thrusting (or upthrusting-overfaulting) within Benioff zone but rather is a kind of independent structure.

It is very important for discussion about regularities of spatial distribution of different types of geological structures, that the main vector of compression within earthquake's foci is not normal to the strike of the system, but rather is oriented under an acute angle to it. So, for example, in the Komandor branch of Aleutian Islands this vector has north-south strike (Zobin, 1969, 1970) in southern Kuriles it is of east-west strike (Averianova, 1968).

These deviations lead to important consequences for the structures. To understand it let us look at the effect of the forces in one of the points of the intersection of the frontal part of Benioff zone with Earth's surface. In all cases compression along the vector going under some angle to the strike of Benioff zone can be divided on two componets, one--oriented along normal to the strike and another along tangent of the arc's strike, or, in the case of linear strike of the structure, in normal and along the strike of tectonic system. There follow from it very important consequence: movements along Benioff zone has a component, oriented along the strike of island arcs. Direction of the action of this component in case of oriented in the single direction movements, will change in dependance of the strike of the tectonic system (Fig. 13A). So within Aleutian arc in case of uniform north-south direction of the compression, direction of the strike-slip fault movements will be different in Komandor (of northwest strike) and Aleutian (of northeast strike) branches of the arc.

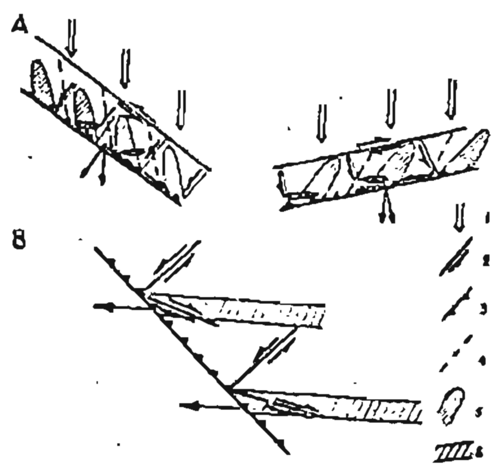
General uneveness of the movements along Benioff zone lead to the formation of the system of left-lateral strike-slip faults, normal to the strike of tectonic system as a whole (Fig. 13B).

This is the way of origin of east-west faults along which has place displacement of the shelf blocks between Andreanof and Fox islands and blocks of Komandor and Rat islands in Komandor branch in Aleutian branch of the Aleutian island arc. Similar type of displacements are observed also within Kurile island arc system.

Another important feature of the movements along Benioff zone is that they appear within the plate with finite thickness. Due to this there have to exist fault zone, which bound the rear part of the thrusted plate. The role of such rear deep-seated faults play described above zones between outer, non-volcanic geoanticlinal belt and inner volcanic zone. Great vertical displacement along both types of deep-seated faults are out of any doubts. It is interesting, however, to discuss presence of horizontal displacement along these zones. To check presence of this kind of movements we have to put in attention, that if there exist horizontal displacement along deep-seated fault in the front of the Benioff zone, such displacement have to exist also along deep-seated fault in the rear part of this zone. Direction of the displacement along "rear" deep-seated fault will change on the opposite in

Fig. 13 - Scheme of dynamic movements within Benioff's zone and its influence of the crust structures:

A - Generation of strike-slip faults under the influence of the oriented in single direction compression within Benioff's zone. B. Generation of strike-slip faults in connection with different degree of seismicity in different parts of Benioff's zone: 1) vector of compression is oriented under an angle to the horizon; 2) direction of the vector of horizontal compression; 3) strike-slip faults. C. Line of intersection of the Benioff's zone frontal boundary with Earth's surface: 4) subsidary fissures on the ridge of the strike-slip fault with tendency to opening; 5) drag folds; 6) zone of increased seismicity.



comparison with direction of the movement along the frontal deep-seated fault. So, for example if along frontal zone have place right-lateral displacement, along rear zone left-lateral displacement will be observed (Fig. 13A).

Strike-slip character of horizontal displacements along the rear deep-seated fault zones lead to appearance along it typical en-echelon type of structure - systems of drag folds and divided them complementary fissures of extension, which control position of the Quaternary volcanoes.

In some regions, which pass in their development through the stage of normal island arc and now are involved in process of active uplift and by this means are accessible for geologic observations. It is such regions as Japan, New Zealand, Phillipines. In south-western Japan the rear deep-seated fault zone coincides with the Median Line, in north-eastern Japan - with so-called Shirakawa-Morioka zone, which divide uplifted blocks Kitakami and Abakumi from the Neogene-Quaternary volcanic belt. In New Zealand the same nature has Alpine Fault in the South Island. In Phillipines - The Great Phillipine Fault Zone. In Sumutra - Semangko Fault System. In all of these cases, presence of the horizontal displacement is obvious--it is discussed only how great it is—on several tens or on several hundreds km. Faults of such type in general can be called deep-seated faults of Median Line type.

Horizontal displacement along rear deep-seated zone generate in adjacent structures system of dislocations-drag folds and divided them complementary fissures, along which Quaternary volcanoes are located. These structures (drag folds and fissures) are distributed under regular acute angle to the strike of the rear deep-seated fault zone; which, as we have seen, coincide with regularities of distribution of normal subsidary structures on the wing of the strike-slip faults. As a consequence of the development of such structures along rear deep-seated fault zone, tectonic system is expanded not only in the frontal direction, toward the ocean, but also toward the rear part of tectonic system. This tendency can explain why Quaternary volcanic zone of the Sredinny Ridge overlaps linear western Kamchatka rear basin, why in Kuriles volcanoes as Alaid or Makanrushi are developed within Kurile depression of Okhotsk Sea (marginal sea). By the same reason volcanoes of Bogoslof island appear in the rear of the Aleutian island arc and volcanoes of the Banda Sea in the rear of Sunda arc.

General compression in the direction of the main vector can generate formation of structures oriented in normal to it. This explains appearance on the Aleutian arc elevated blocks of east-west strike such as islands Atka, Amlya, Attu. It is characteristic, that on these islands are located outcrops of the most ancient complexes for all Aleutians up to Paleozoic rocks. This indicates, that in formation of these structures the role of vertical movements is the most important.

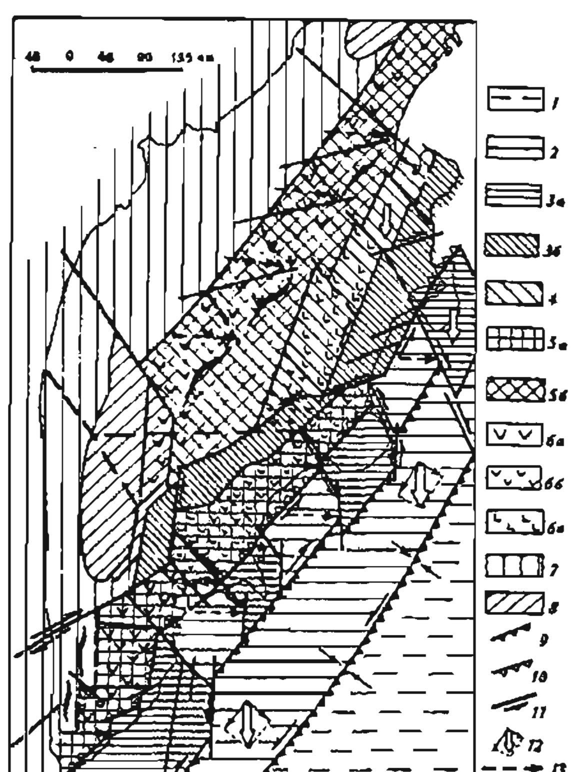
Due to all these features of structural development geotectonic systems of island arcs and similar with them—Kamchatka-type geotectonic systems can be defined as tectonic systems connected with strike-slip fault style of tectonics.

Ability of geotectonic systems, similar with island arcs, for development along the strike is resulted in their tendency to expand along the strike. It is this ability due to which stable areas of ancient platforms (Canadian and Antarctic) become involved in recent intensive tectonic and magmatic activization. Due to same process during Quaternary time, Kamchatka-type geotectonic system was developed in the North Island of New Zealand and Taupo volcanic zone appear on the continuation of Tonga-Kermadek island arc system.

This ability also is used by author in order to explain specific features of the Kamchatka geotectonic system itself. By this model this specific feature appears in the result of development of two similar in nature but expanding in different direction along the strike geotectonic systems: north Kamchatka-Olyutorsky system, expanding southwestward, and Hokkaido-Kurile system, expanding northeastward (Fig. 14).

It is also possible to note that widespread opinion about this type of geotectonic systems, as about areas of development of exclusively compression tectonics, is not correct. It is possible to say, that extension type of tectonics in the area of volcanic belt, connected with island arcs and Kamchatka type geotectonic systems is of the same scale as in other areas of grabens development (stable cratons or mid-ocean ridges). Scale of extension which have been developed here during Quaternary is not less and style is absolutely the same. As we have seen, compression in such geotectonic systems is concentrated within narrow belts between Benioff zone frontal boundary is parallel to the trench and Median Line deep-seated strike-slip fault zones. And within volcanic zone, which are mainly areas of extension, zones of compression are located along narrow deep-seated transverse strike-slip faults, on which central volcanoes and calderas are located.

Fig. 14 - Scheme of dynamic of formation of Kamchatka structures. It is seen forming of specific features of Central Kamchatka due to development along the strike of two similar but displaced en-echelon tectonic systems: Northern Kamchatka-Olyutorsky and Northern Kurile - Southern Kamchatka and:
1. Oceanic plate. 2. Zone of prevailing of fault dislocations within thrusted plate (continental slope and part of the shelf). 3. Zone of prevailing of upthrow-overfault dislocations within: a) horst-anticlinal systems connected with Northern Kurile-Southern Kamchatka tectonic system and; b) Northern Kamchatka Olyutorsky tectonic systems. 4. Parts of horst-anticlinal belts of Northern Kamchatka-Olyutorsky tectonic system, involved in subsidence in recent time. 5. Zone of manifestation of stress in rear wing of thrusted plates connected with: a) Northern Kurile-Southern Kamchatka tectonic system; b) Northern Kamchatka-Olyutorsky tectonic system. 6. Territory of volcanic zones developed from: a) Oligocene, partly Miocene; b) Pliocene; c) Lower Quaternary time. 7. Tectonically stable zone of Western Kamchatka rear linear depression. 8. Domal uplifts. 9. Frontal boundaries of thrusted plates (teeth turned in the side of thrusting). 10. Rear boundary of the thrusted plate (teeth turned in the direction of subsided wing. 11. Faults. 12. Direction of the movements of thrusted plates correspond to prevailing direction of compression in shallow earthquakes foci. 13. Prevailing direction of movements along zones of deep-seated strike-slip faults (it is seen, that to in the places of appearances of these strike-slip faults on the surface there appear dislocations of North-West and North-East strike). 14. Axes of linear arches.



CHAPTER II

DESCRIPTION OF KURILE CALDERAS

Description of Kurile calderas is arranged in accordance with their geographical distribution (Fig. 15).

SOUTHERN KURILE ISLANDS

1.1. Golovnin volcano and caldera.

Location and general geology.

Golovnin volcano is located in the southern part of Kunashir Island. The volcano is a wide, flat cone more than 10 km in diameter (Gorshkov, 1970). It is surrounded by several hills, which probably represent a ring of extrusive domes around the volcano. On the top of the cone is located a caldera 4.0-4.5 km in diameter (Fig. 16a, b), with caldera walls 300-400 m high. Outcrops on the somma walls and inside the caldera are mainly tuffs of hypersthene and two-pyroxene andesites. Blocks of andesitic lava (56-58% SiO_2) also occur. Golovnin volcano is built largely of pyroclastics. Probably this volcano is characterized mainly by explosive activity. Gorshkov (1970) suggested that two calderas formed, but it is possible that the outer ring is a result of emplacement series of extrusive domes along the ring fissure. The northern part of the caldera is occupied by a lake 1 x 2.5 km in diameter. The southwestern part of the caldera is an uplifted bench 7-12 m (or above the lake 70-80 m over the bottom of the lake). On the edge of uplifted part is a steep radial dip of lacustrine gravel, and radial and concentric fissures indicating the presence of a resurgent dome.

Post-caldera activity.

Two dacitic domes (64-65% SiO_2) lie on the boundary between the lake and the uplifted part of the caldera bottom, along an east-west line. The western dome is cut by small explosion crater in which are located active solfataras. Near the foothills of the eastern extrusive dome but from the southern side is another explosion crater (350 m diameter) which partly cuts the slope of the dome and partly cuts the caldera bottom. The bottom of that crater is occupied by a hot lake with temperatures between 36-65°C. Nearby solfataras reach temperatures of about 100°C.

Markhinin (1959), also described two other domes--one near the west bank of the lake and the other near the south edge of the caldera bottom. Lavas of the first are andesites, characterized by increased content of quartz phenocrysts. Hypersthene is replaced by chlorite, which might indicate an underwater formation of this dome. Active fumaroles occur on the submerged slope of this dome. Another andesitic extrusive dome is located on the outer slope of the cone.

Deep structure.

The deep structure of Golovnin caldera was studied by seismic reflection of the earthquake waves (Zlobin and Fedorchenko, 1982). A series of deep-seated boundaries were identified (Fig. 16c). The top boundary (1) is located at a depth of 0.6-2.8 km, forming a low dome at the center of the caldera. Another boundary (2) has a complicated configuration. Throughout most of the caldera it is depressed to a depth of 6 km, but in it forms a dome-like uplift to a depth of 2.6 km, coincident with the intra-caldera extrusive domes.

Fig. 15. Scheme of location of Kurile calderas.
1.1. Golovnin volcano and caldera; 1.2. Mendeleev caldera volcano; 1.3. Tiatia volcano; 1.4. L'vinaya Past'Caldera; 1.5. Urbich caldera; 1.6. Atsonupuri volcano; 1.7. Calderas of Grozny group of volcanoes; 1.8. Volcano-tectonic depression of Chirip Peninsula; 1.9. Vetrovoi Isthmus caldera; 1.10. Tsirk caldera; 1.11. Kamuy caldera; 1.12. Medvezhya caldera; 1.13. Volcano-tectonic depression of Krishtofovich Ridge; 1.14. Berg and Trezubets volcanoes; 1.15. Caldera of Chirpoy and Brat Chirpoyev Islands; 2.1. Goriaschaya Sopka volcano; 2.2. Milne volcano; 2.3. Zavaritsky caldera; 2.4. Uratman volcano; 2.5. Ketoi caldera volcano (Pallas Peak); 2.6. Ushishir volcano and caldera; 2.7. Rasshua caldera volcano; 2.8. Matua caldera (Sarychev Peak volcano); 3.1. Kuntomintar caldera volcano; 3.2. Sinarka caldera volcano; 3.3. Tao-Rusyr caldera; 3.4. Caldera of Kryzhanovsky volcano; 3.5. Nemo Peak caldera; 3.6. Karpinsky caldera.

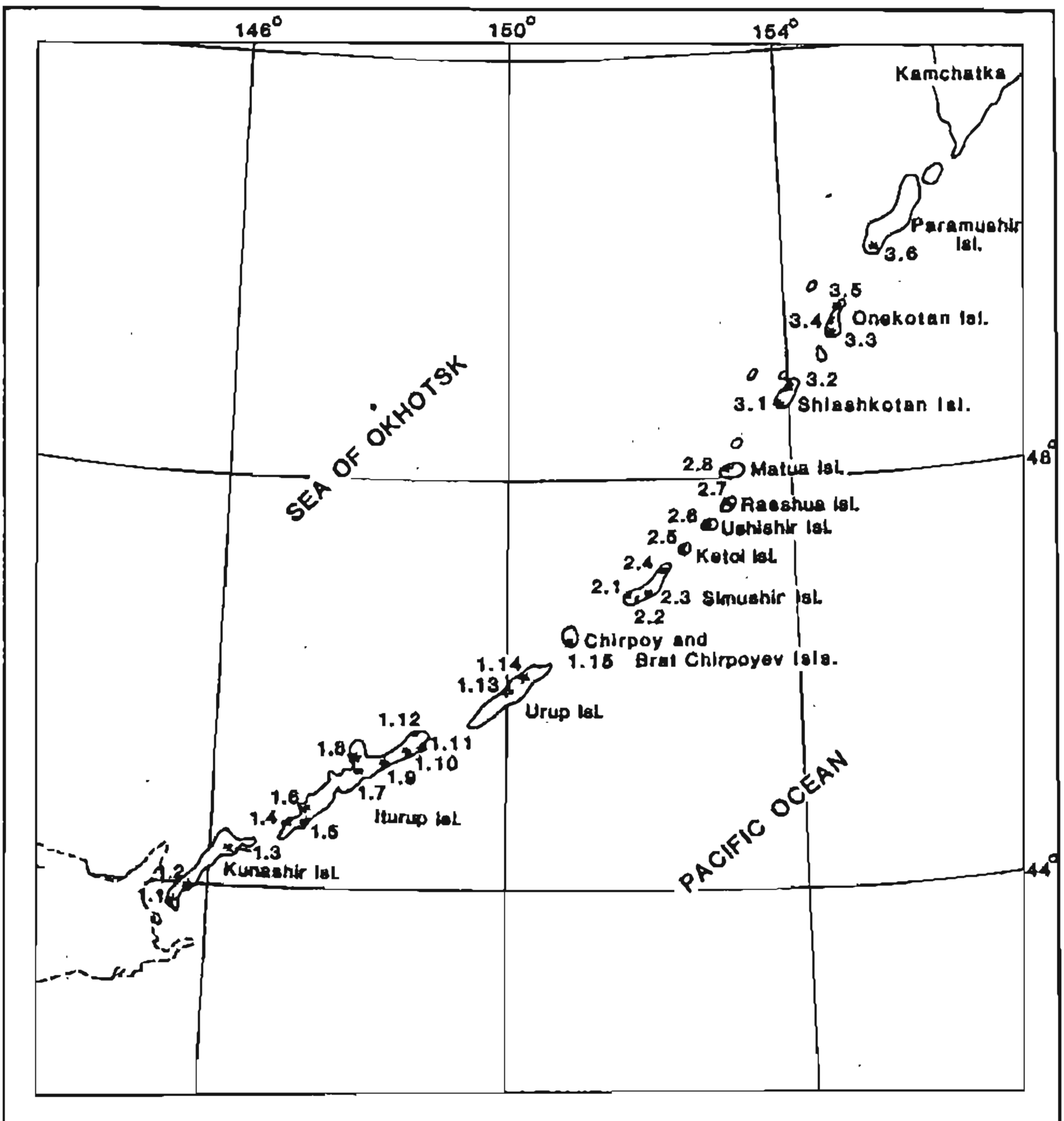


Fig. 16a. Scheme of the Golovnin caldera (after Gorshkov, 1958).

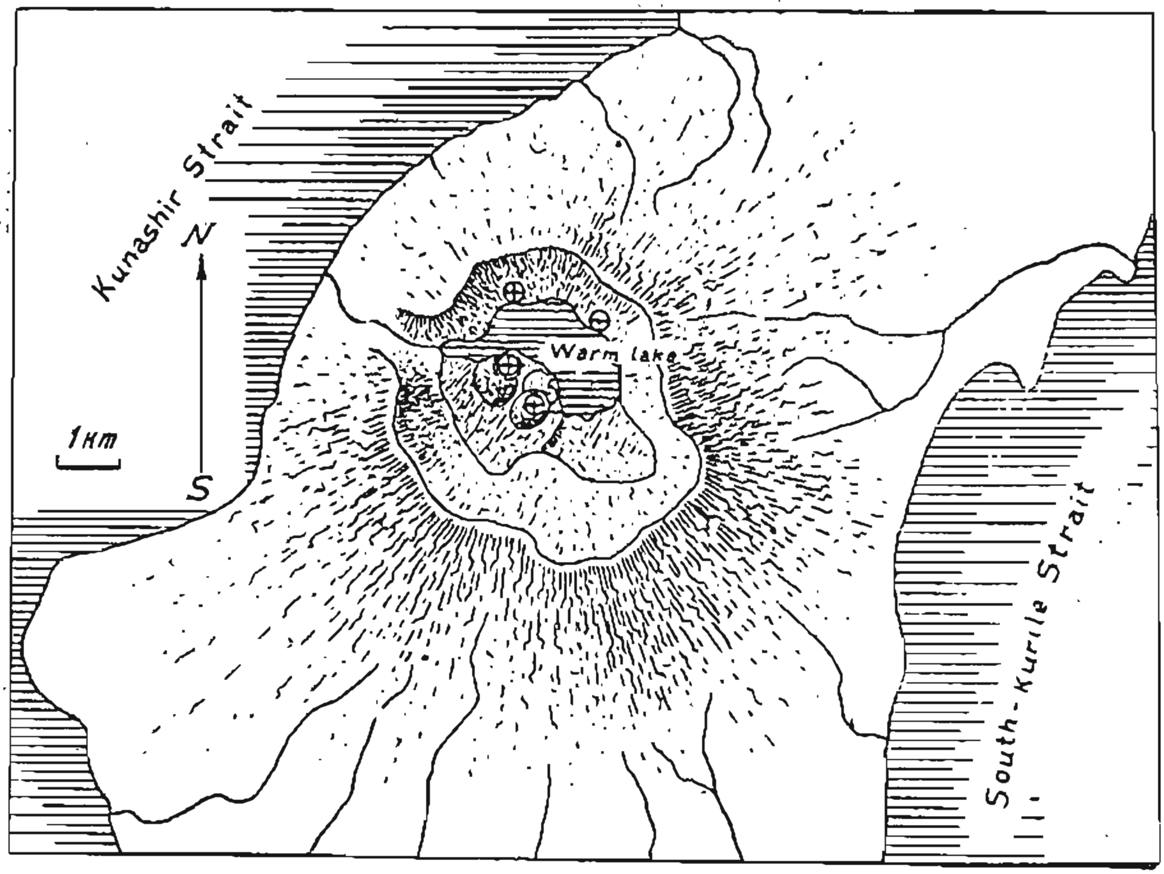


Fig. 16b. Scheme of the Golovnin caldera structure (after Gorshkov, 1970). 1 - inner somma; 2 - outer somma.

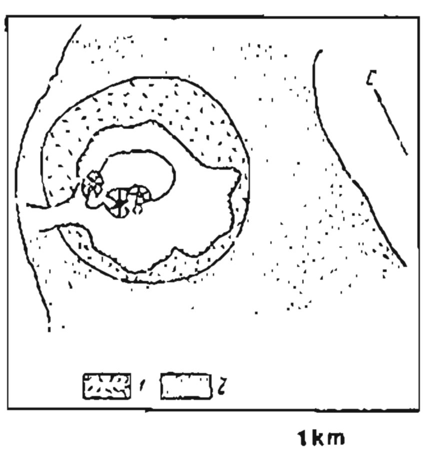


Fig. 16c. I. Time section of delaying of exchanged seismic waves from earthquakes (after Zlobin and Fedrochenko, 1982).
1 - seismic station locations; 2 - regions of sparceness of time of exchanges seismic waves from the single boundary; 3 - inferred boundary of exchange (I-V); 4 - points on the section single meanings of time delay.

I

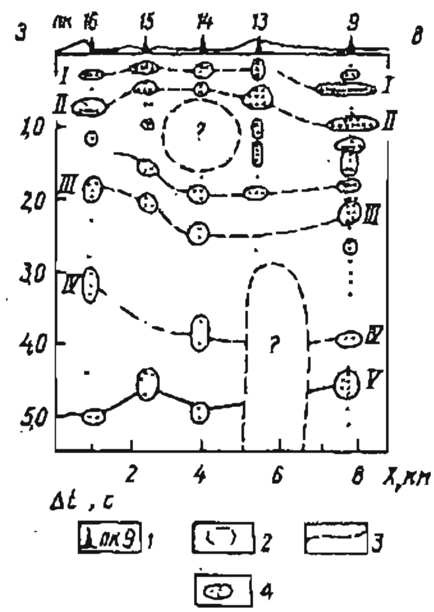
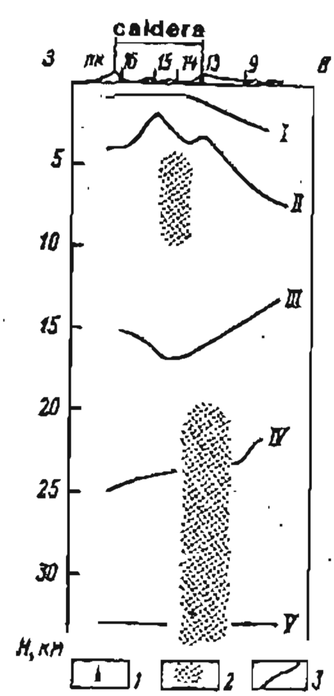


Fig. 16c. II. Scheme of Earth's crust structure in the region of Golovnin caldera by data of method of reflected earthquake's waves.
1 - seismic station locations; 2 - inferred regions of the absence of seismic waves change; 3 - boundaries of the exchange (I-V). Horizontal and vertical scales are equal.

II



Boundary (3) lays at a depth of 14-17 km. It is depressed in the region of the dome structure formed by boundary (2) and confirms general subsidence of the crust beneath the volcano. Boundary (4) lays at a depth of 22-25 km, is flat and forms a flexure-like rise to the east from the volcano. In the region of calderas it forms a general depression.

Recent geothermal activity.

The volcano presently shows constant fumarolic activity at 6 points—in two explosive craters, two places on the northern bank of the lake, on the submarine slope of an internal dome and on the shore of Kunashir strait near the youngest dome.

1.2. Mendeleev caldera volcano.

Location and general geology.

Mendeleev volcano is located on Kunashir Island north of the Golovnin volcano. The most ancient part of Mendeleev volcano is a large caldera about 6-7 km in diameter (Fig. 17a, b). Its rims are strongly dissected and are preserved only on the northwest side; its eastern side is completely destroyed and the southern side is overlapped by a younger second generation somma. On the southern side some lavas of the ancient caldera rim are exposed beneath lavas of the second generation cone. Lava flows exposed in the ancient caldera rim are mostly of two-pyroxene andesite (sometimes with olivine) and basaltic anesites. Practically everywhere the oldest cone is overlapped by loose pyroclastics (Golovnin suite of Markhinin, 1956). These pyroclastic deposits are andesitic to dacitic, and include a thick sequence of dacitic pumice. Gorshkov (1970) thought that these pyroclastic deposits were associated with formation of the large caldera.

The northern part of the second generation cone partially fills the bottom of the first caldera. Now only eroded relicts of this second cone's slopes are preserved. A 3.0 x 3.5 km caldera of this second cone is marked by a series of topographic high points and fumarolic fields. In the northern part of the first caldera are located two topographic highs--probably excentric domes. The second caldera was probably formed by a blast directed to the north (Gorshkov, 1970).

The second cone is composed of monotonous pyroxene-olivine basalts and basaltic andesites. Pyroclastic deposits of two-pyroxene andesite, found in the first caldera, are probably connected with the blast and the second caldera.

Inside the second caldera with some shift to the north is a central cone. Four fumarolic fields are located between the second somma and the central cone . The northeastern of these fumarolic fields is obviously connected with an excentric explosive crater. It is probable that other fields are also connected with some excentric explosive funnels. The highest point of the central cone reaches about 850 m above sea level and about 300-500 m above the bottom of the second caldera. The based diameter of the cone about 3 km diameter, and the diameter of the crater is more than 1 km. Formation of so wide a crater is probably connected with strong blast directed westward, which destroyed western part of the edifice (Gorshkov, 1970). The breach contains pyroclastic flow deposits, and the destroyed crater of the central cone contains a well-preserved extrusive dome. The central cone is composed of two-pyroxene andesites and basaltic andesites. The young dome is dacitic in composition (SiO_2 65.5%).

Fig. 17a. Structure of the Mendeleev caldera volcano (after Gorshkov 1958).

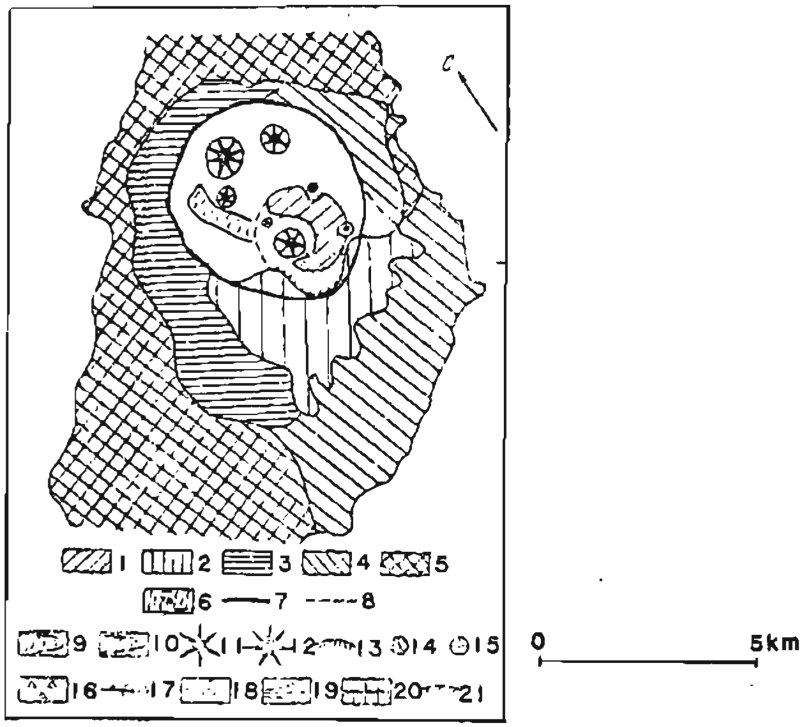
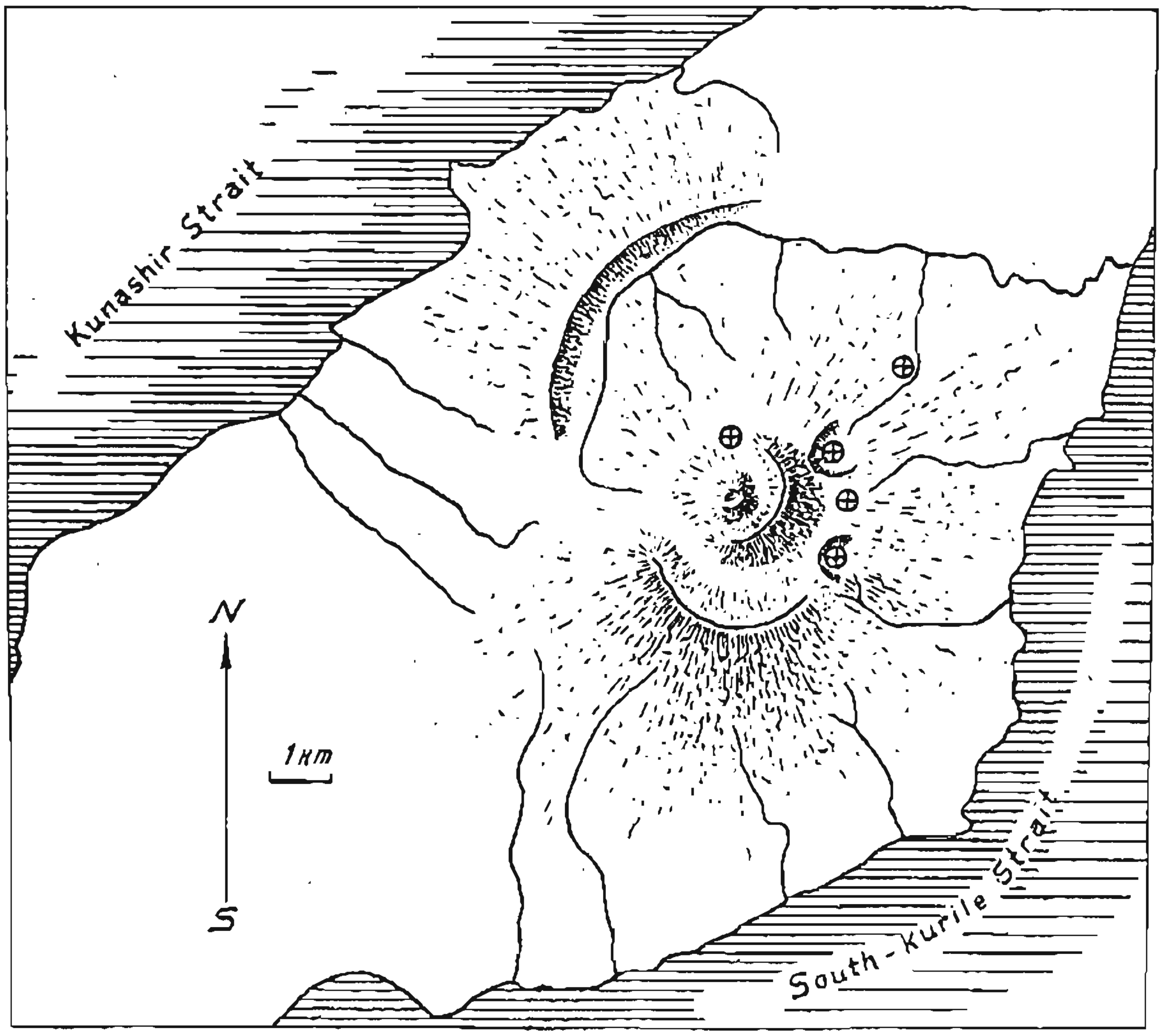


Fig. 17b. Structure of the Mendeleev caldera volcano (after Gorshkov, 1970). 1 - central cone; 2 - the second somma; 3 - the first somma; 4 - non-divided sequence (partly Tertiary); 5 - basement; 6 - pyroclastic flow; 7 - boundary of the ancient caldera; 8 - boundary of the young caldera; 9 - young lava flows; 10 - more ancient lava flows; 11 - cone with the crater; 12 - dome; 13 - scarps (mainly tectonic in origin); 14 - adventive craters; 15 - fumarolic fields; 16 - moraine; 17 - ridge; 18 - pyroclastic deposits; 19 - slopes; 20 - basement; 21 - slopes of glacial valleys (troughs).
Signs 9 - 21 are the same for Figures 18 - 44.



History of volcanic activity.

Eruptions forming the first cone were of andesites and basaltic andesites, later joined by silicic rocks. A gigantic explosive eruption of silicic pumice occurred and a large caldera was formed. All of these events were in pre-glacial time. Radiocarbon dates indicate that lavas of the first somma overlap terraces with relicts of plants the radiocarbon age of which is equal.

Eruptions of the second cone also started by outpourings of mafic lavas but finished by a northward directed blast of acid andesite. Conditionally this second edifice grew during interglacial time (39,000-Wurm interstadial).

The central cone is composed of comparatively mafic rocks and practically fills all of the second caldera. Around the boundaries of the second caldera, a series of explosions took place and a dacitic dome grew up in one of the explosion craters. Age of this last dome by radiocarbon data is 4200 years B.P (Gorshkov, 1970).

Historic eruptive and geothermal activity.

The only known historical eruption of Mendeleev volcano occurred in 1880 (Milne, 1880). It occurred near the northeast solfatara field and probably consisted of pure gas emission and weak explosions. The volcano shows constant fumarolic activity in four fumarolic fields around the central dome. Goriachy Pliazh, a geothermal field, is located on the eastern flanks of the Mendeleev complex, along the ocean shore.

1.3. Tiatia volcano.

Tectonic setting.

Located on the northern part of the Kunashir Island (Fig. 18a), the volcano is surrounded by an arcuate arrangement of topographic highs composed of Tertiary and Lower Pleistocene volcanic rocks. Lava of Tiatia volcano flowed over escarpments several hundreds of meters in height, and composed by the ancient volcanic formations. It is possible that this circular escarpment reflects the boundary of a volcano-tectonic depression within which Tiatia grew.

General geology.

Tiatia Volcano belongs to the Somma-Vesuvius type (Fig. 18b) with a regular cone within a somma. The somma rim is 2.1-2.4 km in diameter, and has a height of 50-80 m. The somma rim is best defined in the southern part, but some relicts of it are observed also in the western and northwestern sides of the flat topped summit. On the east and north the rim of the caldera is absent and a flat caldera bottom passes directly onto outer slopes of the somma. Eroded relicts of an ancient volcanic edifice occur on the northeast slope of volcano, part of a narrow belt which extends up to the Okhotsk Sea shore. Relicts of three small adventive cones are located on the flanks of Tiatia, including two with lava flows near the western foot of the volcano, along a supposed ring fault. Several others are located along the southern flanks of Tiatia.

The somma walls expose layered rocks in which lava predominates over pyroclastics. Rocks in the lower part of the somma are mainly olivene basalts and those in the upper part are mafic andesites. Gorshkov (1970) found no traces of glacial activity on the slopes of the somma, indicating that at least the outer surface of Tiatia was constructed in Holocene time.

Fig. 18a. The scheme of Tiatia volcano (after Gorshkov, 1970). Fault around the volcano added by the author.
1 - fumarolic field of Ruruy volcano; 2 - pyroclastic deposits of Tiatia volcano; 3 - adventive craters; 4 - relicts of the ancient edifice of Tiatia volcano; 5 - massif of Ruruy volcano; 6 - massif of Smirnoff volcano; 7 - basement. Other signs are the same as Fig. 17.

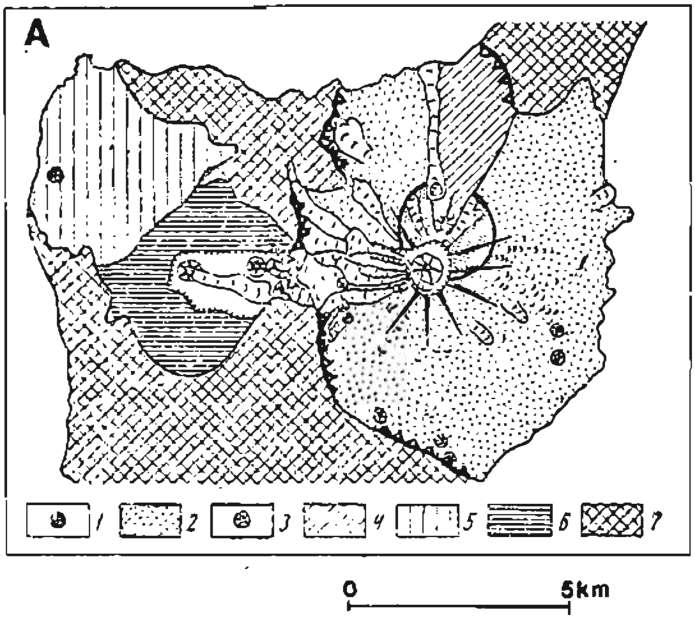
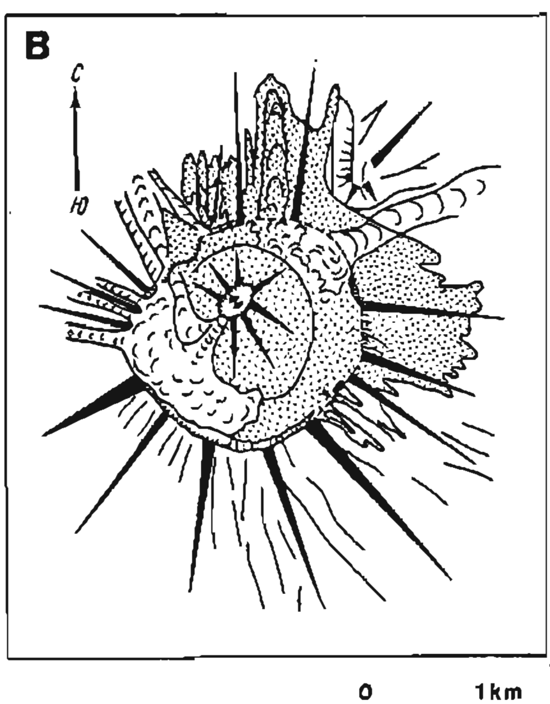


Fig. 18b. Scheme of the structure of the summit of Tiatia volcano (after Gorshkov, 1970). Signs are the same as Fig. 17.



Central cone is located in the center of the somma. Two explosive funnels are located on its summit. Lavas and pyroclastics of the central cone are olivine basalts.

Eruptive activity of Tiatia volcano is characterized by strombolian explosions with a prevalence of fluid basalts and basaltic andesites. Toward the end of volcanic activity two-pyroxene andesites joined mafic composition rocks. Then after a pause in eruptions, a blast cleaned out the previously existed feeding channel and the summit of the cone collapsed. Summit craters and adventive cones occurred after the blast.

Historic activity.

Before the 20th century only an eruption in 1812 is known (Gorshkov, 1958). By personal communication with C. Newhall In Japanese Bulletin of Volcanic eruptions N21 there is indication of a small eruption of Tiatia in June 1981, which is not mentioned in Russian literature. Another eruption started July 14, 1973. In the beginning two maars were formed on the northern slope of the cone, and a maar and a crater were formed on the the southeast slope. Through the upper maar, 40 m in diameter mainly gases were emitted, through the lower crater 250-300 m in diameter, gas-saturated pyroclastics were erupted. Eruption continued to July 28. On July 27, pressure of gases decreased abruptly and lava fountains began. As a result, truncated adventive cone with crater 400 m in diameter and 100 m in depth was formed.

1.4. L'vinaya Past'Caldera.

L'vinaya Past'Caldera is located in the southern part of Iturup Island (Fig. 19) on a tectonic line striking N20°E through Atsonupuri and Beraturabe volcanoes (Figs. 19, 20). The caldera is located within a typical lava stratovolcano, composed mainly of mafic rocks. The basal diameter of the stratovolcano is 12-13 km; the caldera is elongated in south-north direction and is 7 x 9 km in diameter. The height of caldera walls is about 1000 m and the inner part of the caldera is occupied by waters of the Okhotsk Sea. Caldera Bay is divided from the sea by threshold only 50 m below sea level.

An absence of traces of glacial activity on the slopes of pre-caldera cone, suggests that the cone was formed after the first glaciation. The caldera probably formed in Holocene time. About 20 km^3 of dacitic pumice from the caldera forming eruption surrounds the caldera and fills lows between it and adjacent volcanic massives (Melekestsev-in Luchitsky, ed., 1974). Maximum thickness of pumice reaches 100 m. On the base of interconnection with terraces, Melekestsev determined age of caldera formation as approximately 9400 years B.P.

The thick pyroclastic cover includes about 5 pyroclastic units different in color, degree of density, and size of fragments. Absence of any other deposits and any traces of reworking between these horizons suggests that these were formed within a short time interval.

1.5. Urbich caldera.

The Urbich Caldera is located in the southern part of Iturup Island, just north of the L'vinaya Past caldera. The caldera walls expose the pre-glacial volcanic Rocco Massif. Diameter of caldera along the rim is about 6 km. The height of the caldera walls is about 500 m. Inner walls of caldera have no traces of glacial activity, so it is defined as post-glacial. There is no indication of volcanic activity in this caldera in Holocene time. Dacitic pumice erupted during the caldera-forming stage. Pre-caldera volcanic complex remind forms of linear-cluster group of small volcanoes so widely developed in

Fig. 19. Active volcanoes of the Iturup Island (after Gorshkov, 1958). Numbers on the figure indicate position of calderas shown on other figures.

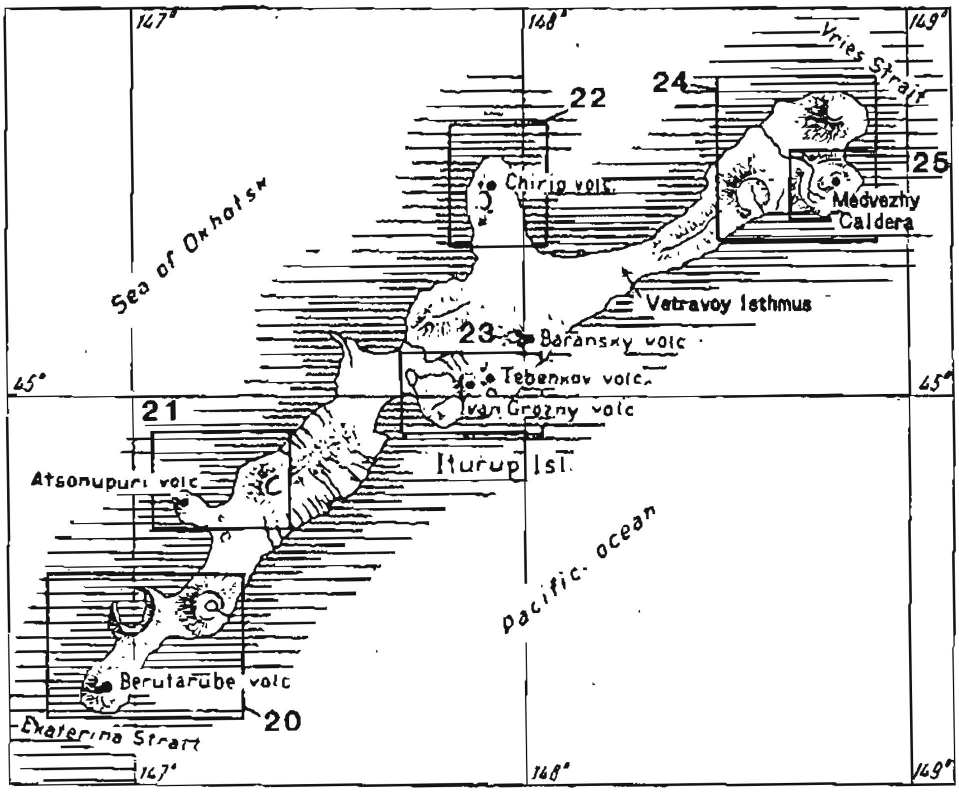
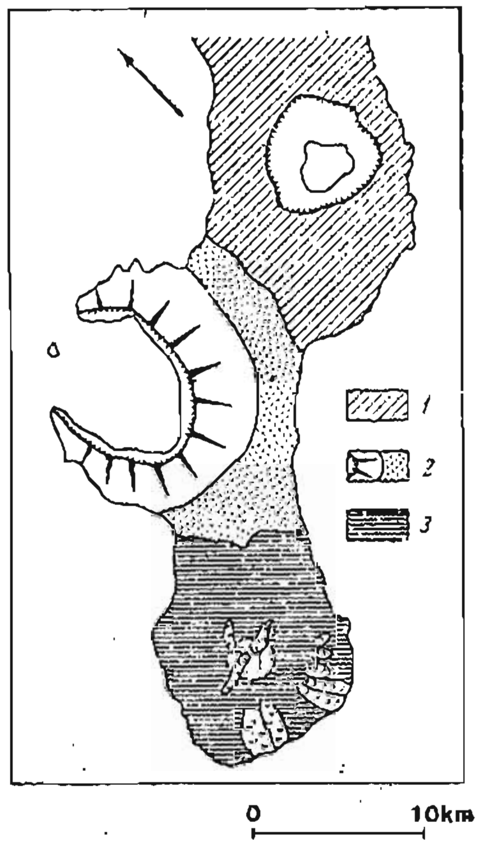


Fig. 20. Scheme of location of volcanoes in the southern part of Iturup Island (after Gorshkov, 1970).
1 - Rocco massif and Urbich caldera; 2 - L'vinaya Past' caldera; 3 - Beraturabe volcano. All other figures are the same as on Fig. 17.



Kuriles. Pumice is replaced from the caldera slopes by erosion and accumulates at a distance from the caldera. The lake inside the caldera is about 3 km in diameter. Melekestsev (in Luchitsky, ed., 1974) dated this caldera at the beginning of the second part of the Upper Pleistocene.

1.6. Atsonupuri volcano.

Atsonupuri Volcano is located in the southern part of Iturup Island on the Okhotsk shore, on a north-south tectonic line. Gorshkov (1970) shows a circular scarp (Fig. 21) around the volcano, which reflects existence of circular in plan volcano-tectonic depression. Composition and structure of volcano is unknown. The volcano is of the Somma-Vesuvius type, and composed of andesites and basaltic andesites. Remains of the somma are preserved in the eastern half of the cone. The western part of the rim is overlapped by volcanic products of the young cone. The diameter of the somma is about 2 km, and the height of its walls is only 20-30 m. Smooth, undissected slopes of the cone indicate a young age. From the morphology of adjacent shores it seems that lavas of the volcano overlap a 140 m deep submarine terrace, so the somma volcano is not older than Upper Pleistocene. The northwest part of the somma is broken by a major fault. Gorshkov (1970) related formation of the caldera and movements along this fault, but direct evidence of this relation is lacking. He spoke also about explosive origin of caldera.

Volcanic activity

There exist uncertain indications of eruptions in 1812 and 1932. Now the volcano is dormant.

1.7. Calderas of Grozny group of volcanoes.

Location and general geology.

The Grozny group of volcanoes is located in the central part of Iturup Island, and spans 45 km along the Pacific coast of the island. The basement of the group is formed by pre-glacial volcanoes. In the southwestern part of Gorzny chain are the Teben'kov and the Grozny volcanoes (Fig. 22).

The cone of Teben'kov volcano is located in the southeast part of a 2 km-wide caldera-like depression that is open to the east. Lavas of Teben'kov cone are two-pyroxene andesites. To the south of Teben'kov cone is the north-south trending depression of Machekha volcano. Lavas of Machekha volcano are andesites and basaltic andesites; its depression was formed by the erosion of a large explosion crater. To the southwest from Teben'kov cone is the Grozny volcano group. A caldera rim is preserved in the northwest part of the Grozny group; other parts of the caldera rim are destroyed or overlapped by young volcanoes. The height of northwestern wall of the caldera reaches 200-240 meters, and the diameter of the caldera is about 3.0-3.5 km. The Grozny caldera was formed during the Upper Pleistocene or Holocene. In the northern part of the caldera probably was located a great lake. On the southern edge of the caldera extrusive dome Grozny. To northeast from Grozny dome is Drakon dome. To the west of Grozny adjoin effusive dome Yermak, to the west of which Yermak volcano is located.

Fig. 21. Scheme of location of Atsonupuri volcano (after Gorshkov, 1970).
1 - Pleistocene lavas. Other signs are the same as on Fig. 17.

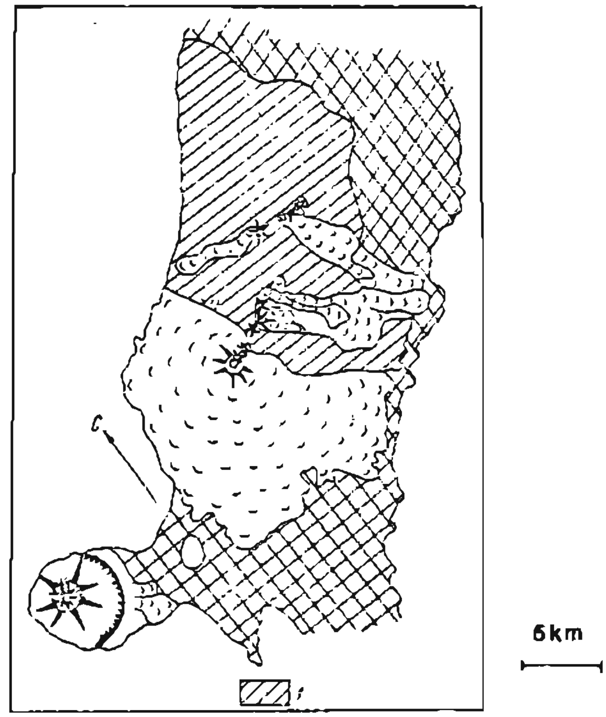
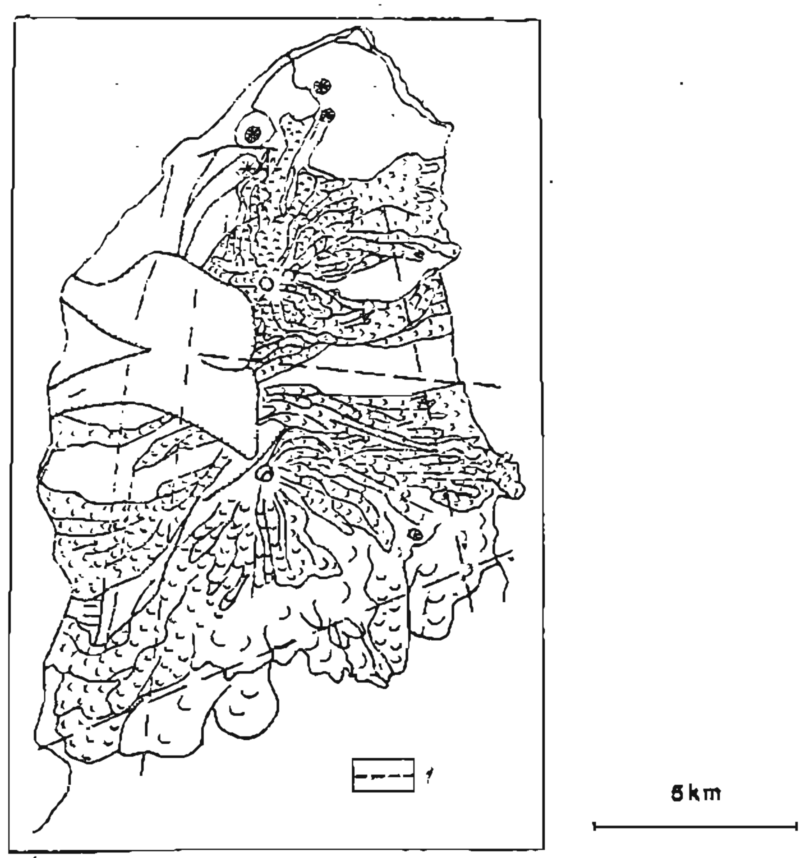


Fig. 22 Scheme of the structure of Chirip peninsula (after Gorshkov, 1970).
1 - Tectonic faults. Other signs are the same as on Fig. 17.



Historical activity.

The last eruption on Ivan Grozny formed an extrusive dome. The volcano now shows constant fumarolic activity. The last prehistoric eruption on Teben'kov was of the Bandai-san type, a purely phreatric laterally directed blast. Now there is constant solfataric activity in the Machekha crater.

1.8. Volcano-tectonic depression of Chirip Peninsula.

The Chirip peninsula is located in the center of Okhotsk shore of the Iturup Island. Pre-glacial Quaternary rocks are exposed mainly along the west coast (Fig. 23), but a narrow ridge of pre-glacial rocks is located in the central part of peninsula. Tertiary rocks are exposed in the southern and western parts of the peninsula.

The central part of the peninsula is cut from the west by a 4 km wide, 500 m deep depression. This depression cuts not only pre-glacial forms, but also post-glacial relief, and so is probably of Holocene age. But Gorshkov (1970) does not exclude the possibility that Holocene movements only renewed previously existing structure. Relicts of an old cone and a ridge composed of two partial extrusive domes divides the depression into two parts.

According to Gorshkov, this depression was formed mainly by tectonic movements. But he did not exclude also role of great explosions. In his opinion, these explosions deposited a thick layer of welded tuff exposed in the northern part of the depression.

Historical activity.

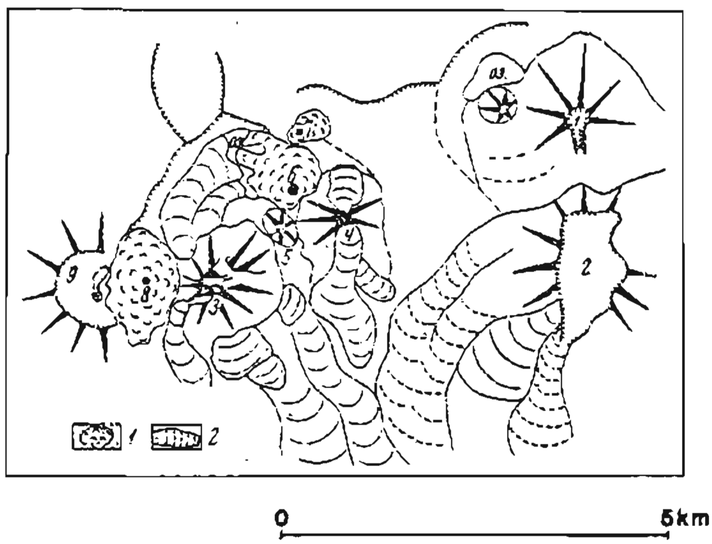
There are uncertain indications of explosions in 1843 and 1860. At present only weak solfataric activity exists.

1.9. Vetrovoi Isthmus caldera.

The Vetrovoi Isthmus Caldera is located south of the Medvezhy peninsula of Iturup Island (see Fig. 19). Here, bounded by a north-south graben, are relicts of a caldera rim with a diameter of about 6-7 km. This rim is open to southeast, and on the northwest it joins the north-south fault and is partly buried by pumice. Gorshkov (1970) speaks about caldera-volcano, but what he described is a pumice cone, formed during or just before the caldera-forming eruption. Thick pumice deposits in the region of Vetrovoi Isthmus are probably from the maar of Tayny Lake. Tephra of this eruption lies in the upper part of the soil-pyroclastic cover of all Upper Pleistocene terraces, including the youngest 35-40 m high terrace. Tephra horizons in the region immediately adjacent to the Vetrovoi Isthmus are 1.0-1.5 m thick. The caldera appears to be the result of strong submarine eruption in inter-glacial time. The total thickness of pyroclastics in the region of Vetrovoi Isthmus is not less than 200 m. These thick pyroclastic deposits older topography over in great areas. Center of eruption is not expressed in relief. Pyroclastic material is represented by dacitic pumices about 65-67.1/5 SiO_2. Total volume is equal to 30-40 km^3 (Bent, 1962). Welded rocks are absent in spite of the fact that temperature in the moment of eruption were much higher than Curie point (Melekestsev and others, 1970).

The graben is an average of about 10 km wide. It was formed during the first glaciation (Gorshkov, 1970). With interpretation of air-photo, it is possible to see a large caldera.

Fig. 23. Scheme of the structure of Grozny volcanic group (after Gorshkov, 1970).
1 - effusive domes; 2 - pyroclastic and mud flows. Other signs are the same as on Fig. 17.



1.10. Tsirk caldera.

The Tsirk Caldera lies to the west of Medvezhy caldera in the northern part of Iturup Island (Fig. 24). The caldera is well-expressed in relief, but pyroclastic deposits connected with it are not preserved. The caldera cuts volcanic edifices of Middle-Upper Pleistocene age and is overlapped by small lava volcanoes of Upper Pleistocene age. The diameter of the caldera rim is about 6 km. It is possible that the caldera was formed at the end of the first glaciation, or in the interglacial time. On the inner walls there are traces of the second glaciation activity. The caldera cuts a shield-like volcano of probable Lower Pleistocene age. At the end of the Pleistocene time two small post-caldera lava cones Torny and Golets were formed on the southern slope of pre-caldera edifice.

1.11. Kamuy caldera.

The Kamuy Caldera is located on the northern edge of Iturup Island (see Fig. 24). It is formed on the top of a shield-like Lower Pleistocene volcano 10x18 km in diameter. Now it is preserved only in the form of a arcuate ridge or scarp along the east and northeast side of the caldera. According to Gorshkov it was formed in pre-glacial time. In the inter-glacial time a series of volcanic cones formed inside the caldera. Some of these cones (in particular the highest among them--Kamuy) were still active at the time of the second glaciation (Gorshkov, 1970). In the Holocene volcanic lavas filled a trough of the second glaciation, and built a new large cone Demon was formed on the last stages of development and was destroyed by a directed blast.

1.12. Medvezhya caldera.

The Medvezhya caldera is located in the northern part of Iturup Island east-southeast of Kamuy caldera. The caldera is 8 km in diameter and the caldera walls are about 300 m in height (Fig. 25). Inside the caldera are a series of post-caldera cones and domes, formed along an east-west line during Holocene time. Lavas of these cones are basalts, basaltic andesites and andesites. Around the caldera is a lot of dacitic pumice.

There are no significant changes in composition between pre-caldera and post-caldera volcanoes. The caldera was destroyed by erosion, including glaciation (the first glaciation). Clear traces of the second glaciation are absent. It is possible that two small extrusive domes in the southern part of the caldera belong to interglacial time. Ostapenko (1969) likened the pre-caldera edifice of Medvezhya to Hawaiian type volcanoes. In the western part of line formed by post-caldera domes is located a kind of effusive dome with which are connected series of large lava flow.

Historical activity.

Gorshkov (1958) indicates explosions in summit crater of Kudriavy cone took place in 1778 or 1779, and May-June 1883. A preheatic explosion was observed in 1946. Now there is intense solfataric activity in both summit crater and Kudriavy cone.

1.13. Volcano-tectonic depression of Krishtofovich Ridge.

Fig. 24. Scheme of location of volcanoes on Medvezhy peninsula (after Gorshkov, 1970).
1 - Kamuy massif; 2 - Demon volcano; 3 - Medvezhy volcano; 4 - Tsirk caldera; 5 - Torny cone. I - Quaternary lavas. Other signs are the same as on Fig. 17.

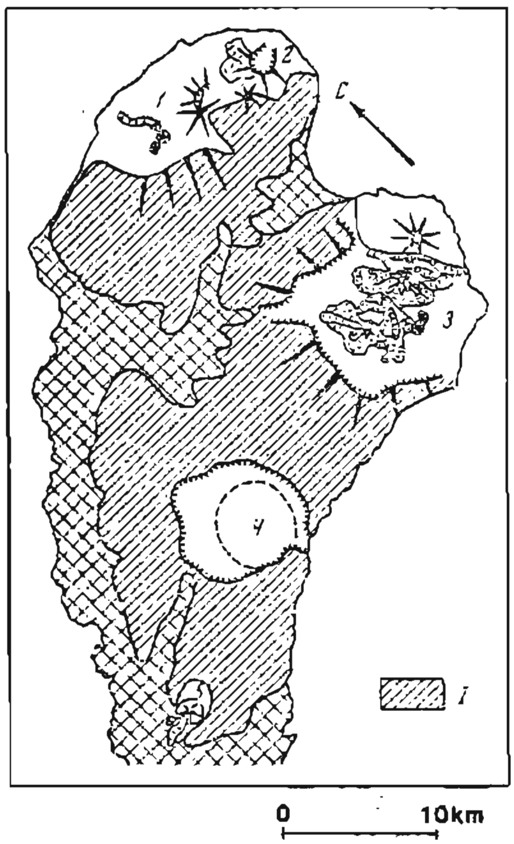
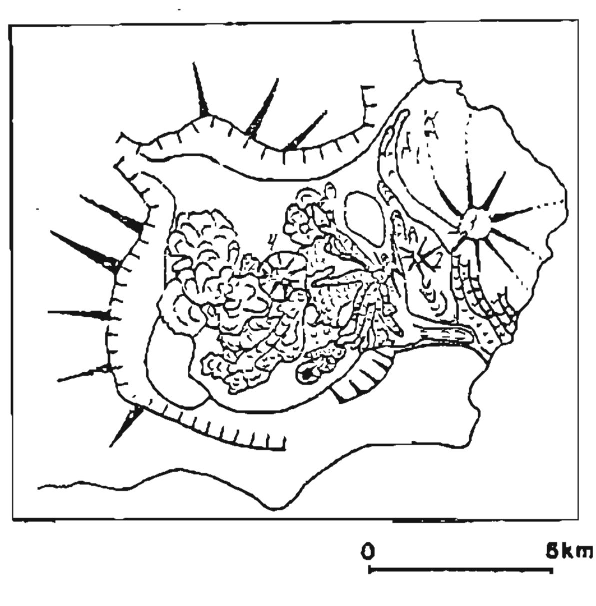


Fig. 25. Scheme of the structure of Medvezhy caldera (after Gorshkov, 1970).
1 - Medvezhy cone; 2 - Sredny cone; Men'Shoy Brat dome; 5 - effusive dome.
Other signs are the same as on Fig. 17.



Position and general geology.

An unnamed volcano-tectonic depression occurs in the central part of Urup Island in the region of Krishtofovich Ridge (Fig. 26). It is located in area of most contrast relief. This is about 9 km in length, and is covered by lavas overlain by landslide deposits and moraines. Presence of lavas in the southern part is uncertain.

The walls of the depression expose pre-glacial lava flows and cones. Inside the depression series of post-glacial lava cones grew inside the depression (Fig. 27). Height of scarps on the boundaries is about 600 m. No recent volcanic activity has occurred inside the depression.

1.14. Berg and Trezubets volcanoes.

Location and geology.

Berg Volcano is located within a group of volcanoes, together with Trezubets and Kolokol volcanoes, on the southern end of Shokalsky Ridge, Urup Island (Fig. 28). A 600 m high somma rim, 2 km in diameter, is located on a cone composed of two pyroxene andesites. An extrusive dome is located inside the caldera above the crater floor, or above sea level.

Both volcanoes are strato-cones composed by two-pyroxene andesites. The crater diameters are about 2 km and inside are located extrusive domes.

Historical activity.

One of the volcanoes in this group erupted in 1770-1780, and in 1845. Gorshkov (1958) mentioned eruptions of Berg volcano in 1894, 1924, and in the winter of 1951-1952. Now both volcanoes show strong fumarolic activity.

1.15. Caldera of Chirpoy and Brat Chirpoyev Islands.

Subaerial and submarine relief around the Cherniye Brat'ya Islands indicate two large overlapping calderas 8-9 km in diameter. Central part of the calderas is occupied by the complex volcanic edifice of Chirpoy Island (Fig. 29). Another volcanic island - Brat Chirpoyev is located southwest of Chirpoy Island.

Chirpoy is the largest of 6 volcanic edifices on Chirpoy Island. It appeared in the first half of the Holocene, as did another cone immediately southwest of it. The other four edifices were formed in the second half of Holocene. Lavas of the youngest cones - Snow and Cherny are two-pyroxene andesites with 59-60% SiO_2. Brat Chirpoyev is a fragment of Early Holocene (probably Late Pleistocene) volcano and is composed of olivine-pyroxene basalts.

CENTRAL KURILE ISLANDS

General distribution of volcanoes within this region is indicated on Fig. 30. Volcanoes of the Simushi Island are shown on Fig. 31.

2.1. Goriaschaya Sopka volcano.

Location and general structure.

Goriaschaya Spoka is located just to the northwest of Milne volcano on the continuation of a northeast fault which cuts both volcanoes. It is a volcano of the Somma-Vesuvius type. The older cone is a typical stratovolcano. In the northwestern part of the amphitheater the somma is a

Fig. 26. General location of volcanoes on Urup Island (after Gorshkov, 1970). Position of calderas indicated on separate figures is shown by quadrangles and figures.
I. Mt. Desantnaya massif; II. northern part of the Shokalsky Ridge; III. southern part of the Shokalsky Ridge; IV. Petr Schmidt Ridge; V. Krishtofovich Ridge. 1 - Holocene lavas; 2 inter-glacial lavas; 3 - eroded part of Quaternary (mainly pre-glacial) edifices; 4 - the basement. Other signs are the same as on Fig. 17. Number of insertions coincide with numbers of figures.

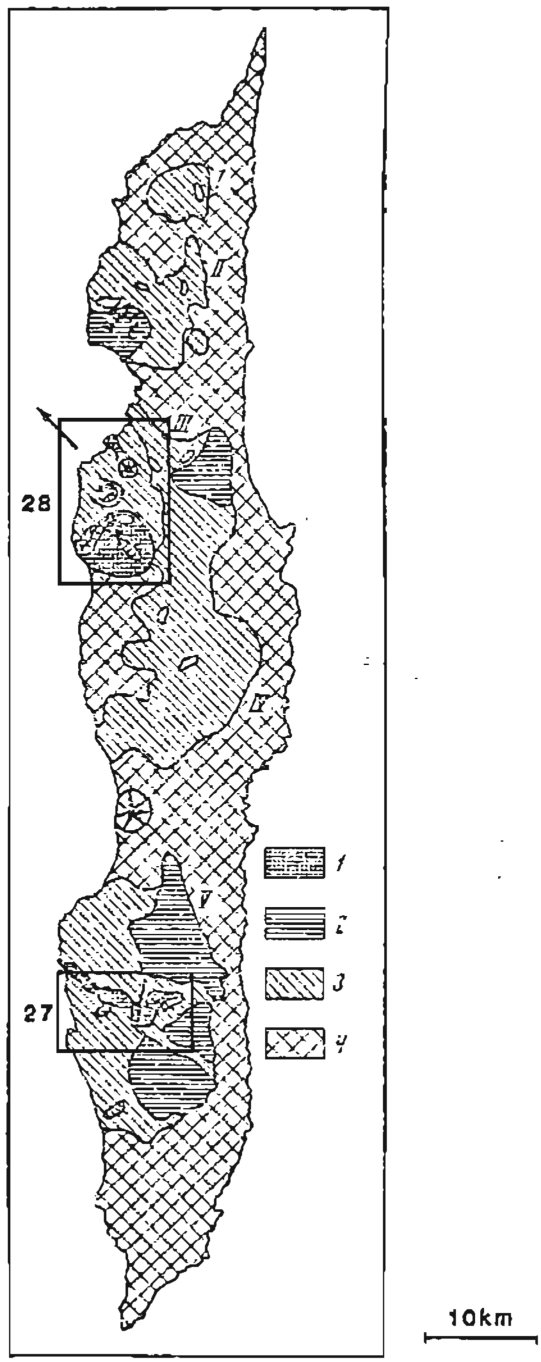


Fig. 27. Scheme of the Ivao volcanic group - part of Krishtofovich Ridge volcano-tectonic depression (after Gorshkov, 1970). Other signs are the same as on Fig. 17.

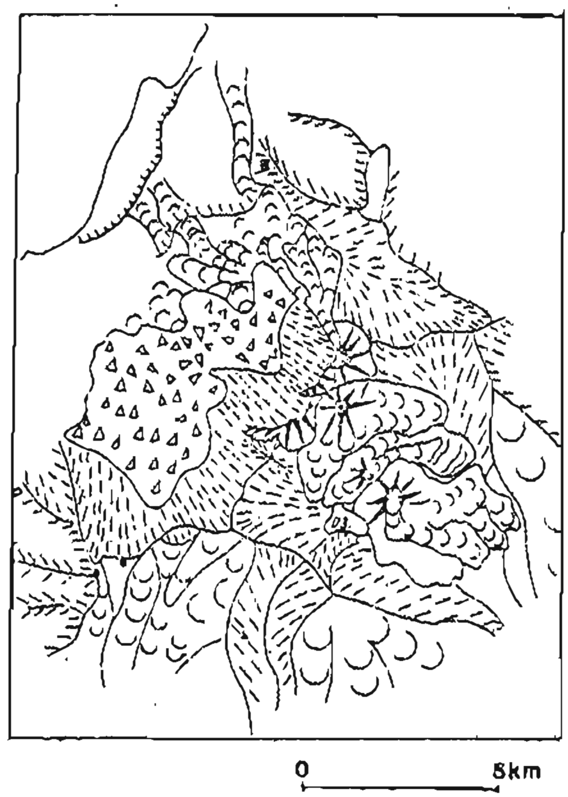


Fig. 28. Scheme of the Kolokol volcanic group structure (after Gorshkov, 1970).
1 - Berg volcano; 2 - Trezubets volcano; 3 - Kolokol volcano. Other signs are the same as on Fig. 17.

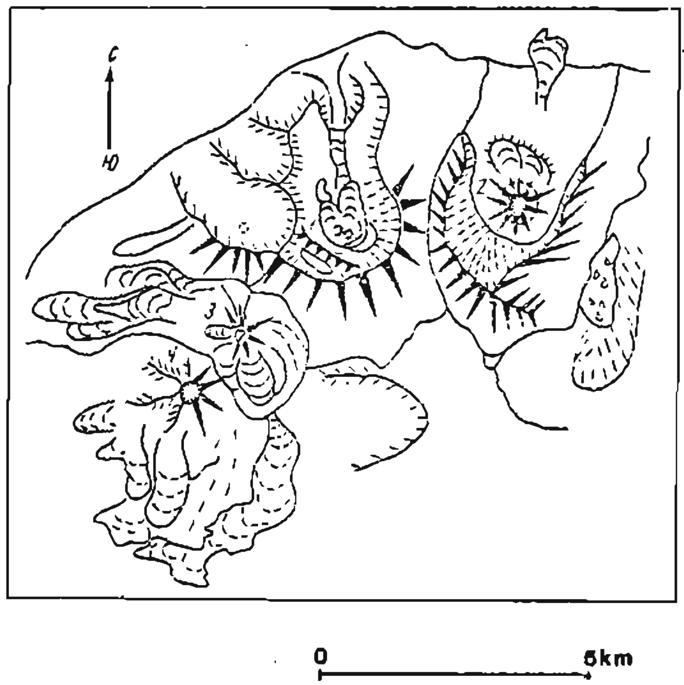


Fig. 29. Scheme of the structure of Chirpoy (I) and Brat Chirpoyev (II) Islands (after Gorshkov, 1970, with small additions).

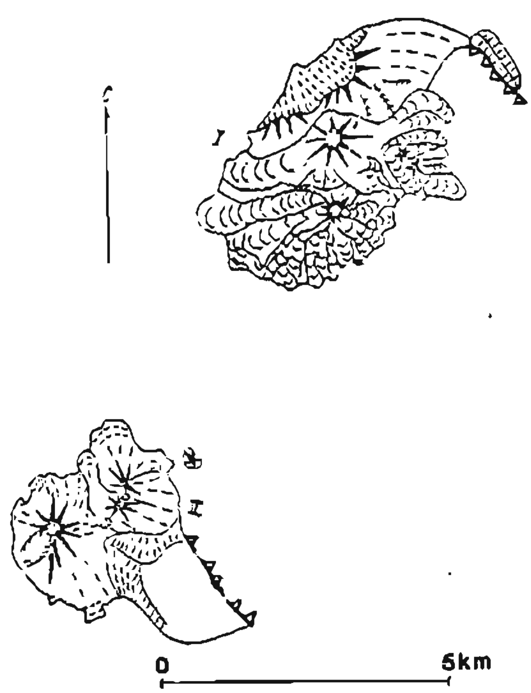
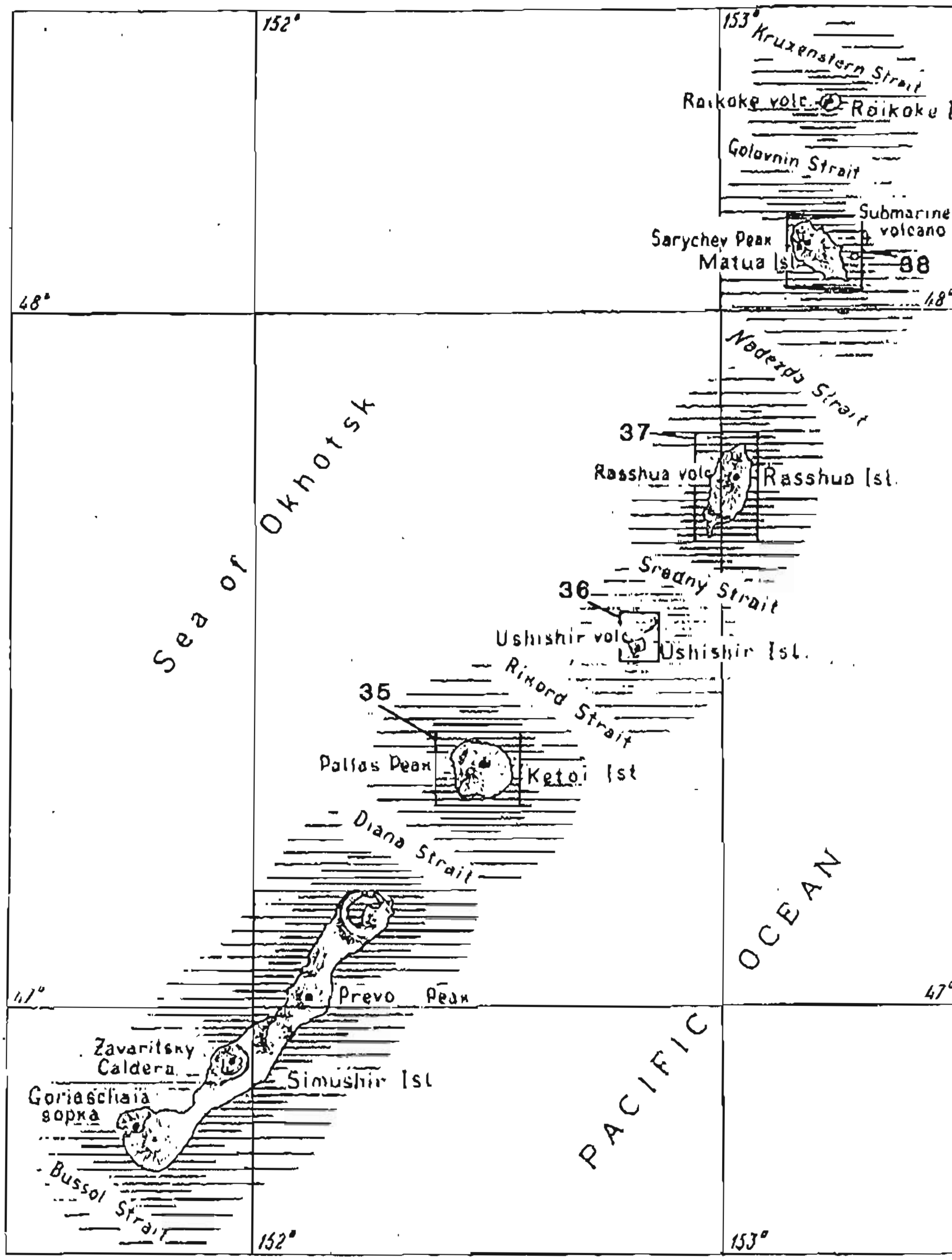


Fig. 30. Scheme of the southern part of Central Kurile group of Islands (after Gorshkov, 1958). Position of calderas, located on separate figures is shown by quadrangles and figures.



dome with a diameter of about 1 km (Fig. 32). Numerous lava flows are exposed beneath the dome, they are probably from a pre-dome vent in the crater. The dome is composed of two-pyroxene andesites.

Historical activity.

Data regarding eruptions of the volcano before the middle of the 19th century are absent. An eruption in 1842 marked the beginning of a new cycle of activity. Another eruption took place in 1849 and in September 1881, outpouring of numerous lava flows was observed. Gorshkov (1970) suggested that the present-day dome did not yet exist in this period. It probably formed during eruptions of 1883, as the final stage of an eruption started in 1881. Formation of the last lava flow and explosive crater on the summit of the dome took place at an unknown time. Weak explosive eruptions took place in 1914 and 1944. Now on the summit of the dome and near its foot there continues weak fumarolic activity.

2.2. Milne volcano.

Milne Volcano forms southwestern part of Simushir Island. It is a typical Somma-Vesuvius type volcano. Milne is a typical stratovolcano with basal diameter of about 10 km. On the summit of volcano is a caldera with a diameter of about 3 km, and 250-300 m high walls. The northwestern part of somma is broken by a fault which extends to the Zavaritsky caldera. Inside the caldera a small cone is located. Lavas of somma and the young cone are very similar--both are pyroxene andesites and basaltic andesites.

The basement of volcano is altered leucocratic lavas with reversed magnetic polarity. The caldera, according to Gorshkov (1970), was formed during the second glaciation (Upper Pleistocene). The caldera itself became a center of strong glaciation. The volcano is now dormant.

2.3. Zavaritsky caldera.

Location and general geology.

Zavaritsky Caldera is located in the southern part of the Simushir Island. The volcano has a complex edifice with two nested calderas, a partial blasted central cone, and a caldera filled by the lake (Fig. 33).

The first caldera does not signify a single volcano, but rather a series of merged lava stratovolcanoes. By the data of Bernstein (1952), lavas of the first stratovolcano are reversely polarized and belong partially to Upper Pliocene time. The southern part of the first caldera is preserved; its northern portion is not preserved. The rim of the first caldera on the northeast joins the rim of the second caldera. The diameter of the first caldera reaches 10 km.

The second caldera is almost a complete ring 7-8 km in diameter, broken only in the northwest. The height of the caldera walls is 375-400 m. The second caldera exposes a typical stratovolcano with lavas in the lower part of the sequence and pyroclastics in the upper part. Lava samples from the walls of the second caldera are pyroxene andesites (Gorshkov, 1970), and pyroclastics in the upper part of the sequence are dacitic pumice. A"roof" of strongly welded tuffs covers the caldera rim. Formation of the second caldera belongs to interglacial time. In the beginning of post-glacial time the northwest part of edifice subsided below sea level along a fault and a bay was formed inside the second caldera.

Fig. 31. Scheme of location of volcanoes on Simushir Island (after Gorshkov, 1970).
1 - Uratman volcano; 2 - Prevo Peak; 3 - Ikanmikot volcano; 4- Zavaritsky caldera; 5 - Milne volcano; 6 - Goriaschaya Sopka volcano. Other signs are the same as on Fig. 17.

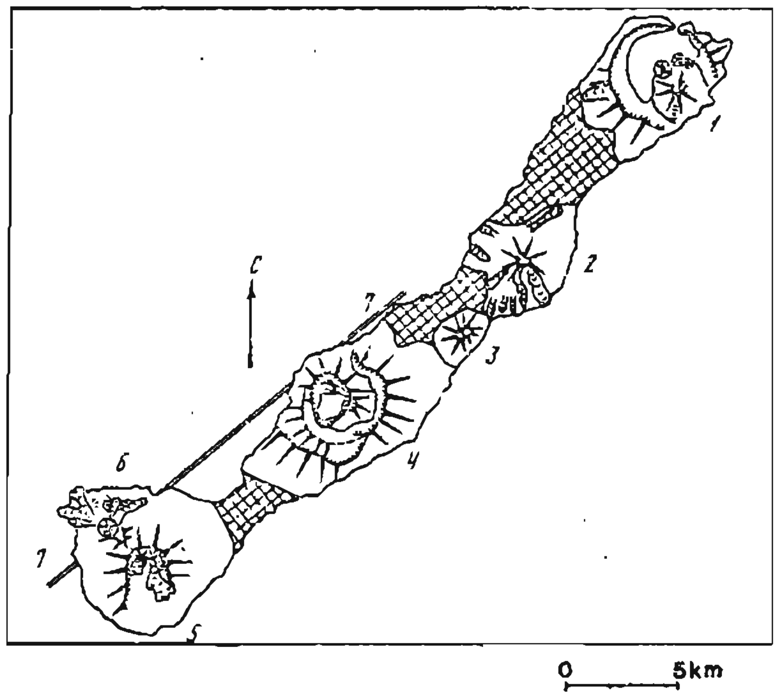


Fig. 32. Scheme of Milne (I) and Goriaschaya Sopka (II) volcano (after Gorshkov, 1970). Other signs are the same as on Fig. 17.

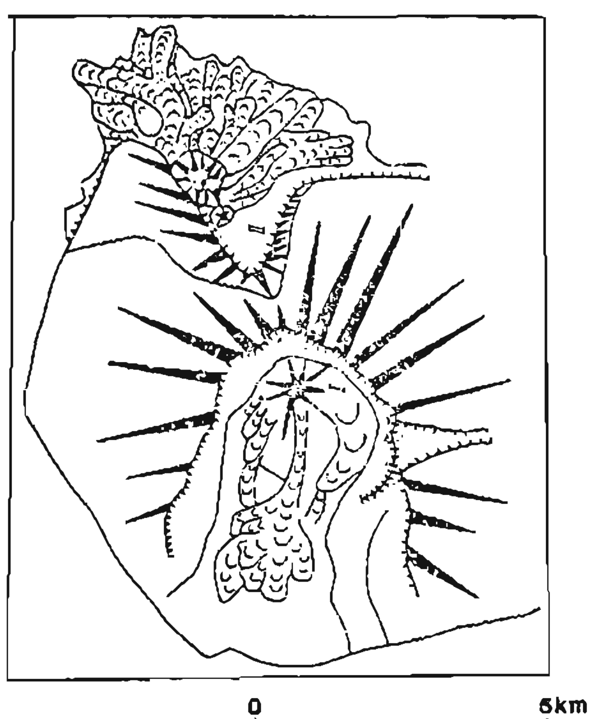


Fig. 33. Scheme of Zavaritsky caldera (after Gorshkov, 1970).
I. the first caldera; II. the second caldera; III. the central cone with recent third caldera. Other signs are the same as on Fig. 17.

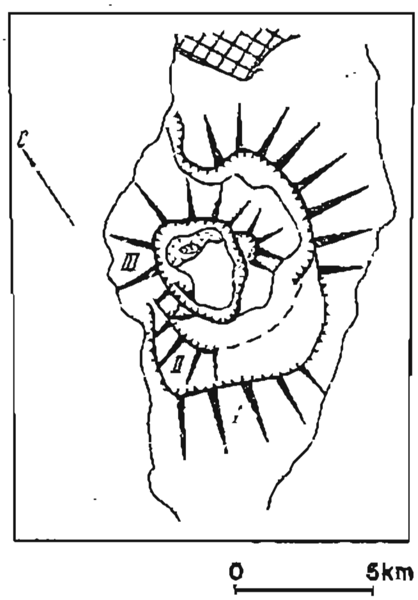
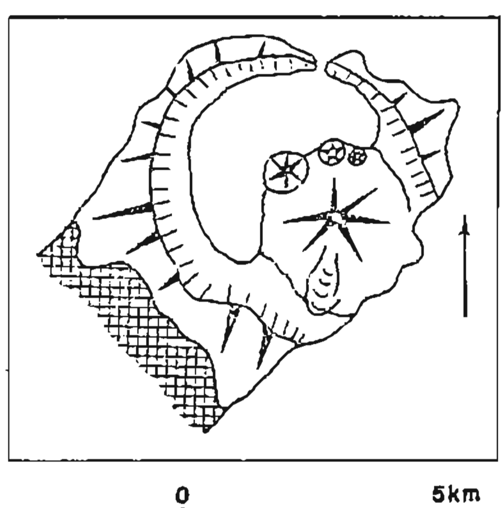


Fig. 34. Scheme of the structure of the Uratman volcano (after Gorshkov, 1970). Other signs are the same as on Fig. 17.



A central cone inside the second caldera contains yet a third caldera. The central cone is typical stratovolcano with a dominance of pyroclastic material, cut by numerous vertical dikes. Its rocks vary from basalts through to dacites. The upper walls of the third caldera exposed a layer of strongly welded tuffs which in places grade into to rheoignimbrites. The third inner caldera is 3.5 km from north to south, and between 1 and 2.5 km west to east.

Post-caldera stage of activity.

Post-caldera products are mainly dacitic pumice. Along the western rim of caldera, blocks about 1 km in length and 0.1 km in width have slipped or subsided about 150 m. On one of the stage of existence of caldera inside it there constantly exists inter-caldera lake, level of which has been considerably higher in comparison with level of now existed lake. Over layers of pumice pyroclastics on the height 190 m over recent level of the lake there lay suite of lacustine tuffites, which adjoin pumices. In the upper part these layers lay horizontally but aftrerward dip under the angle about 60°. Level on which lay lacustrine sediments and character of their laying indicate on resurgent doming processes which took place inside caldera.

Historical activity.

Based upon Japanese topographic works, Gorshkov (1970) speaks about eruptions which probably took place between 1916 and 1931, when a new effusive dome formed inside the inner caldera. An explosion took place inside the caldera in 1957. During this eruption, an extrusive dome of Santorini type with lava flows developed inside the lake. Since 1957, strong fumarolic activity continues in the northern part of the caldera.

2.4. Uratman volcano.

Uratman Volcano is located on the northeast edge of the Simushir Island. It is similar to Somma-Vesuvius. A narrow arc-like somma ridge bounds the large caldera, 7.5 km in diameter. Wall of the caldera is broken in the northern part in the direction of the Diana strait, and between central cone and walls of caldera there is a narrow atrio, filled by the sea. In the southeast part the rim of caldera is overlapped by the central cone. In the southwestern part lavas of Uratman volcano come to the scarp of Oleny Ridge, composed of Tertiary volcanic rocks. From the other sides it is surrounded by the sea. The central cone—Uratman—is a stratovolcano that is covered by dense vegetation. Diameter of its base is about 4 km.

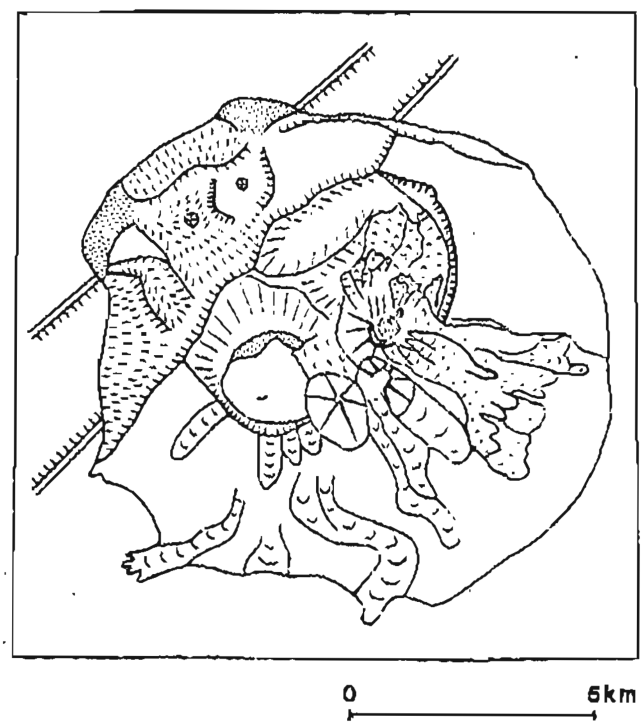
To the north of the central cone are three adventive edifices: the western among them is an extrusive dome, and two others are cinder cones (Fig. 34). Lavas of the somma are two-pyroxene and hypersthene andesites and basaltic andesites. The central cone and adventive craters are two-pyroxene andesites, and the extrusive domes are amphibole-pyroxene andesite. The pre-somma edifice is pre-glacial; the central cone is Holocene.

2.5. Ketoi caldera volcano (Pallas Peak).

Ketoi Volcano forms an island in the central group of Kurile Island Arc, located just to the north of Ushishir Island.

Most of the island consits of relicts of an ancient caldera-volcano (Fig. 35). The rim of a 5 km diameter caldera is preserved only in the northeastern part of the volcano, where its height reaches 720 m. A flat slope of the ancient volcano is bounded on the sea side by 100 m scarps. Fragments of ignimbrites suggest that the caldera formed by an ignimbrite eruption.

Fig. 35. Scheme of the structure of Ketoy volcano (after Gorshkov, 1970). Other signs are the same as on Fig. 17.



The northwestern part of Ketoi island is a young central edifice with a height of 1172 m. The eastern part of the island has been intensively glaciated and no volcanic forms have been preserved.

The northwestern part of Ketoi, together with the ancient edifice, is broken by northeast trending faults that form a graben and adjacent horst. In the base of the horst are exposed horizontally-banded tuff-conglomerates formed in shallow-sea conditions, overlain by lavas and pyroclastic rocks emplaced under subaerial conditions.

Northwest of the island the sea floor is faulted to great depth but on other sides it is a submarine terrace. Inside the graben there are two solfatara fields and relicts of a pyroclastic cone. In the central part of the island is a comparatively large depression occupied by a lake 1.5 km in diameter. According to Gorshkov (1970) it is explosive caldera formed probably by explosion of one of several young intra-caldera cones.

The southern rim of the young caldera practically coincides with the rim of the old caldera and partly cuts an adjacent part of the old volcanic edifice. This ancient edifice partly overlaps rim of ancient caldera, but in the eastern part there exists a large atrio in which, due to character of deposits, there existed a lake. In this atrio is located a young central cone - Pallas Peak. In miniature its structure is similar to Somma-Vesuvius type volcanoes. Southwestern, older part with height about 1000 m is open to the southeast amphitheater in which the young less high cone is located. The northeastern slopes of the young cone come to the atrio of ancient caldera and its southeastern slope is poorly expressed. In both the ancient volcanic edifice and the central cone basalts and basaltic andesites prevailed; recent lavas are two-pyroxene andesite.

A young extrusive dome is located on the eastern edge of Ketoi Lake. Beside it are relicts of the second intra-caldera cone with great lava flows which flowed to the southeast.

<u>History of formation.</u>

In the lower Pleistocene time an eroded Tertiary basement shield volcano was formed by a gigantic blast accompanied by pyroclastic flows and ignimbrite formation. A result of this explosion was a large (5-6 km) caldera eccentrical in connection with volcano with shift to northwest. The first glaciation do not form any significant traces. During inter-glacial time the central edifice was formed in the northwestern part of the caldera, overlapping the northwestern caldera wall. In the eastern part of the caldera a lake was formed.

The second glaciation strongly eroded this central edifice. In the beginning of post-glacial time the northwest part of the island was broken by faults. Cinder cones filled a graben, but the main activity was concentrated east of the central edifice approximately along the boundary of the ancient caldera. A large cone formed near the southern rim of the caldera, and its formation was finished by an explosion. Pumice from this explosion covered lacustine deposits in the atrio. After formation of the inner caldera, a large extrusive dome formed on the eastern edge of the caldera. Adjacent to it Pallas Peak grew and erupted a series of lava flows with lengths up to 2.5-3 km. Lava flowed to the ocean shore and in the north overlapped remaining part of the atrio and pumice of the inner caldera.

<u>Historical volcanic activity.</u>

In the first half of the 18th century the volcano showed no traces of fumarolic activity. The first reported eruptions were in 1843, when Perrey

(1864) saw a strong eruption with outpouring of lava. This eruption continued up to 1846. An eruption occurred in 1924, but no details are known. On September 27, 1960, ash falls were noted. At the present time weak fumarolic activity is marked on outer slope. Fumaroles are present inside the crater lake.

2.6. Ushishir volcano and caldera.

Ushishir Volcano occupies an island with the same name in the central part of the Kurile Island Arc (Fig. 36). It is of the Somma-Vesuvius type in which a 10 km in diameter somma is strongly eroded from previously-existed shield like volcano, and preserved only as two small islands. The Ushishir caldera is about 1.6 km in diameter. Its southern wall is cut and an inlet is formed about 1 km in width and up to 58 m in depth. Its walls in northern and western part reaches 250 m above sea level, and the highest point reaches 400 m. Around the islands is a great submarine terrace indicating the age of the pre-somma edifice is pre-glacial. Relicts of Tertiary basement are present on both islands (Markhinin, Stratula, 1966).

In the center of caldera bay there exist two flat extrusive domes, which together with two other domes on a peninsula define a ring with diameter about 0.5 km. They reflect the position of submarine feeding channel. All four domes are composed of amphibole andesites. By Markhinin and Stratula (1966) the somma edifice is composed by augite andesites and basaltic andesites. Nemoto (1938) described two-pyroxene andesites and andesites with a mixture of olivine. Gorshkov (1970) described one sample of amphibole dacite from Ushishir somma.

Near the southwest walls of the caldera a nest of strong fumaroles and hot springs are active. Gorshkov (1970) inferred from a journal by Cherny, that weak volcanic eruptions took place at the beginning of the 18th century. It is possible, that two of the four domes inside the caldera were formed after Cherny's visit, or after 1769.

2.7. Rasshua caldera volcano.

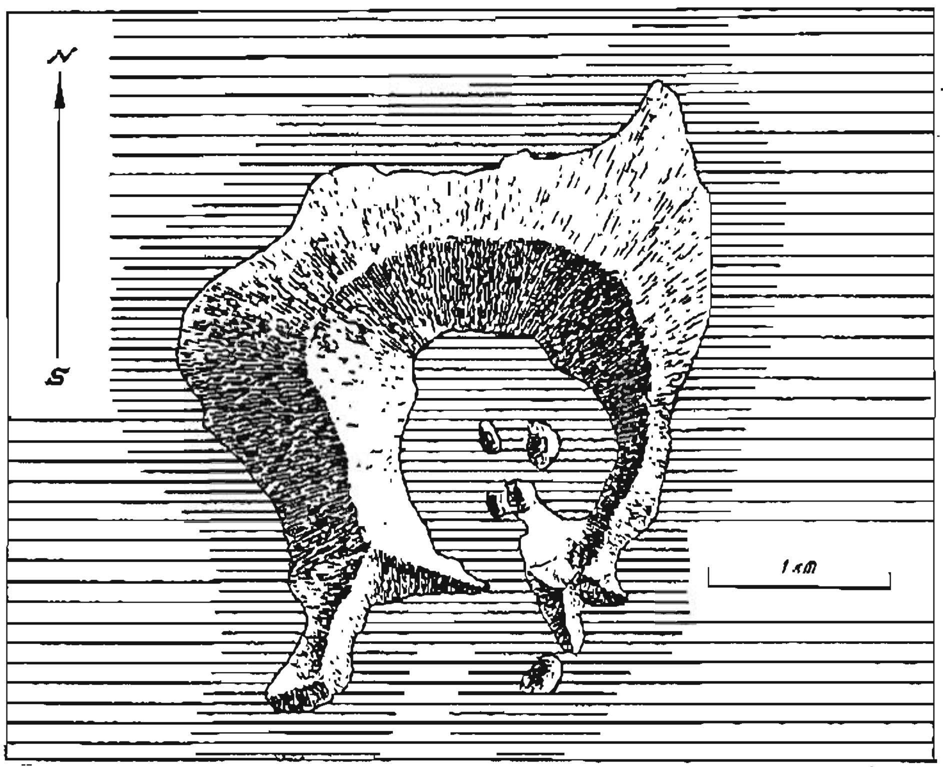
Location and general geology.

Rasshua Volcano occupies an island with the same name, located 28 km to the south of Matua Island in the northern part of the central Kuriles.

The volcano is of Somma-Vesuvius type. Relicts of the 6 km diameter somma rim form the northern and southern end of the island (Fig. 37). On the southern edge of the island Tertiary rocks crop out. The somma underwent strong glacial erosion. The western rim of the caldera was located along the shore of the island, eastern was located east of the present island. The older edifice is composed of two-pyroxene basaltic andesites and andesites.

In the middle of the island a complex central cone almost completely fills the caldera. The cone is eccentric inside the caldera - it is shifting northward. Main part of the central cone is strongly eroded. Some valleys resemble cirque and are probably connected with the second glaciation. In the southern part of the volcano is seen the rim of large crater about 2 km across. On the northwest shore is located another isolated young cone probably of the same age. It is composed mainly of two-pyroxene andesites.

Fig. 36. Scheme of the structure of Ushishir caldera (after Gorshkov, 1958).



Sketch showing the structure of Ushishir caldera.

Fig. 37. Scheme of the Rasshua caldera-volcano (after Gorshkov, 1979). Other signs are the same as on Fig. 17.

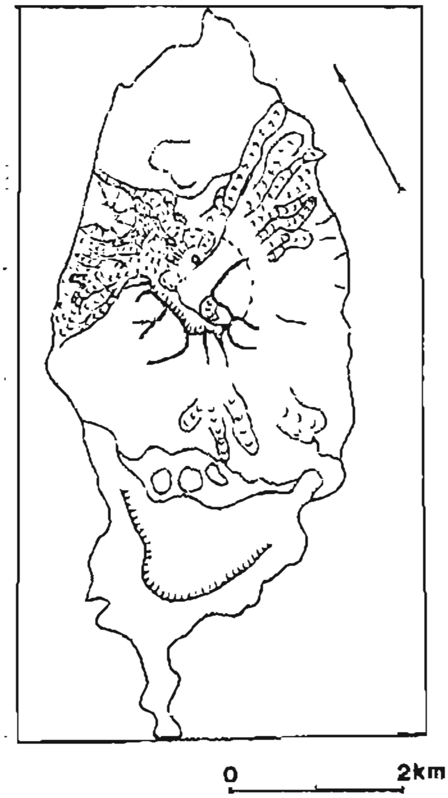


Fig. 38. Scheme of the structure of Sarychev Peak volcano (after Gorshkov, 1970).
1 - nuee ardente deposits; 2 - fault line. Other signs are the same as on Fig. 17.

Historical activity.

A strong eruption of the volcano occurred in 1846. Probably during this eruption the eastern cone was destroyed. On November 4, 1946, just before eruption on adjacent Sarychev Peak, Rasshua volcano increased its fumarolic activity. In October, 1957, increased fumarolic activity was marked, possibly with weak explosions. The volcano now exhibits constant fumarolic activity in eastern crater and in the saddle between the eastern and western cones.

In atrio amphibole dacitic pumice is found.

2.8. Matua caldera (Sarychev Peak volcano).

Location and general geology.

Sarychev Peak Volcano is located on Matua Island in the northern part of the central Kurile Islands. The southeastern part of the island contains relicts of Matua volcano (Fig. 38), now the somma for the Sarychev Peak vólcano. Tertiary volcanogenic rocks lie beneath Matua volcano. Matua volcano was a typical stratovolcano with abundant lava flows, formed in pre-glacial times. The eastern part of Matua joins a 140 m deep submarine terrace formed during the second glaciation; this terrace disappears beyond the relicts of the somma. The northwest part of the island is subsided along the fault of a great amplitude, which cuts the caldera (Gorshkov, 1970). At the beginning of Holocene a series of faults appeared on the western side of the Central Kuriles. Gorshkov (1970) associated the formation of the caldera with movements along these faults.

Boundaries of the Matua caldera can be traced only in a small area in the southwest part of the island. All other parts of the caldera are hidden under rocks of a young cone, Sarychev Peak. The diameter of caldera is 3-3.5 km. The northern part of the island subsided and a preserved part of the caldera appeared in the central cone. In the northwestern part of the island, Sarychev Peak, completely fills the caldera depression and partially overlaps its rim. That cone is typical strato-cone composed of two-pyroxene andesites and basaltic andesites. An old adventive cone to the south of Sarychev Peak is composed by aphyric basalts. Upper parts of the strato-cone slopes are armoured by well preserved lava flows: lower parts of slopes are composed of nuee ardente deposits

Historical activity.

An eruption in 1760 was described as an explosion of unknown character and duration. A lava flow occurred in the winter of 1878-79. Explosions of strombolian and Saint-Vincent types took place on February 14, 1928, February 13, 1930 (lasting 13 hours), November 9-19, 1946, and in August-October 1954. At the time of the last eruption, the extrusive dome inside the crater grew. Since 1954, constant fumarolic activity has taken place in the summit crater.

NORTHERN KURILE ISLANDS

3.1. Kuntomintar caldera volcano.

Kuntomintar Volcano is located in the southern part of Shiashkotan Island and is a double volcano of Somma-Vesusius type (Fig. 39). The older edifice composes the eastern part of the massif. Its southeastern part has clear traces of glacial activity. In northeastern part of the massif are relicts of an ancient caldera with diameter 4-4.5 km. An older caldera in this massif is

Fig. 39. Scheme of the structure of the Kuntomintar volcano (after Gorshkov, 1970).
I. pre-glacial edifice; II. inner cone; III. ignimbrites. Other signs are the same as on Fig. 17.

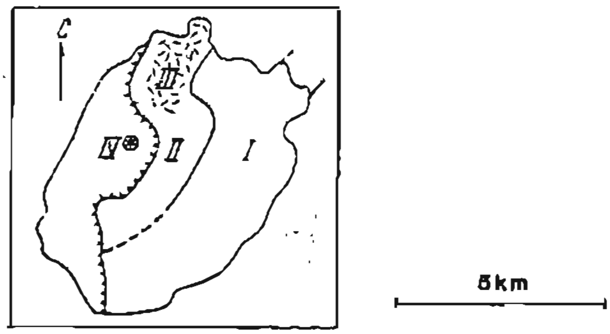
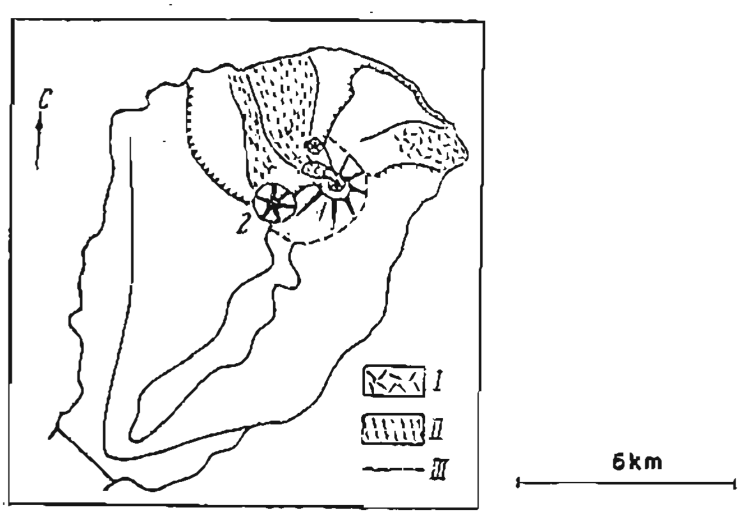


Fig. 40. Scheme of the structure of Sinarka volcano massif (after Gorshkov, 1970).
I. ignimbrites; II. nuee ardente deposits; III. inferted contour of the ancient crater. 1 - Sinarka volcano; 2 - Zheltokamenny dome. Other signs are the same as on Fig. 17.



almost filled by an inner cone and so it is not seen in its southeastern part. On the western edge of the massif, another caldera 2-2.5 km in diameter is open to the west. Gorshkov (1970) thought that the latter caldera was the center of the second glaciation. However, the northern part of the massif is covered by ignimbrites obviously connected with formation of the inner caldera. Along the western coast of Kuntomintar volcano the western part of volcano has subsided along a linear fault.

Great scarps expose the structure of the Kuntomintar stratovolcano, with prevalence of pyroclastics, mainly of two-pyroxene andesites. No eruptions are known to have occurred in post-glacial time, but the volcano shows constant fumarolic activity along the eastern wall of caldera.

3.2. Sinarka caldera volcano.

Location and general geology.

Sinarka Volcano is located in the northern massif of Shiashkotan Island, in the southern part of the Northern Kuriles group. The volcanic massif (Fig. 40) formed as the result of pre-glacial eruption of two-pyroxene basaltic andesite. Its development was completed by formation of the crater (or caldera? - note of Gorshkov, 1970) 2 km in diameter which is completely hidden under the young cone and is reconstructed on the basis of relief analysis. Deposits of welded tuffs in north eastern part of massif are connected with the formation of this crater. A central cone of post-glacial age completely filled the caldera and upper parts of nearby valleys. The northeastern slope of the cone have since been destroyed by explosion (or landslides - not clear). In the young crater is located an extrusive dome surrounded by an agglomerate mantle. Another well-preserved extrusive dome is located 1.5 km from this dome. The young cone and both extrusive domes are composed of two-pyroxene andesites.

Historical activity.

Eruptions of Sinarka volcano took place in the first half of 18th century, in 1846 and in 1855. In 1872 a directed blast which destroyed the northwest part of the young cone and buried a village. Then a thick lava flow formed and an extrusive dome started to grow. These eruptions continued up to 1878. Now only fumarolic activity is observed on volcano.

3.3. Tao-Rusyr caldera.

Is located in the southern part of Onekotan Island of the Northern Kuriles (Figs. 41 and 42). The pre-caldera edifice is a flat shield volcano with basal diameter of 16-17 km. On the summit is located a caldera, 7.5 km in diameter, 400 m above sea level, in which is located a lake with a depth of more than 150 m.

Geology of somma.

The pre-glacial edifice has clear traces of glacial activity in its southern and western parts. In contrast, its east and north western slopes lack any traces of glacial activity. Numerous lava flows have preserved the surface structure and one lava flow came across the trough of the axis valley. It is possible to conclude, the shield volcano appeared in inter-glacial time on the relicts of a pre-glacial volcano edifice. Tao-Rusyr

Fig. 41. Location of volcanoes on Onekotan Island (after Gorshkov, 1970). 1 - dome of eruption of 1952; 2 - pyroclastic deposits connected with formation of the Tao Rusyr caldera; 3 - ignimbrites of the Nemo caldera; 4 - inferred rim of the Nemo Peak inner caldera; 5 - inferred rim of the ancient Nemo Peak caldera; 6 - ancient (partly Tertiary) rocks of the outer Nemo Peak edifice; 7 - Mt. Shestakov massif; 8 - relicts of the ancient Medny volcano. Figure 1 shows Kryzhanovsky caldera volcano. Other signs are the same as on Fig. 17.

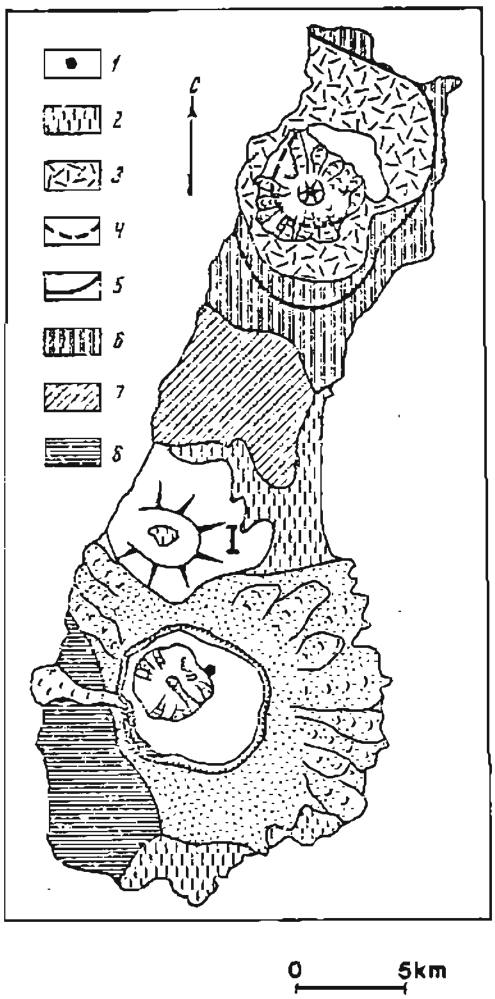
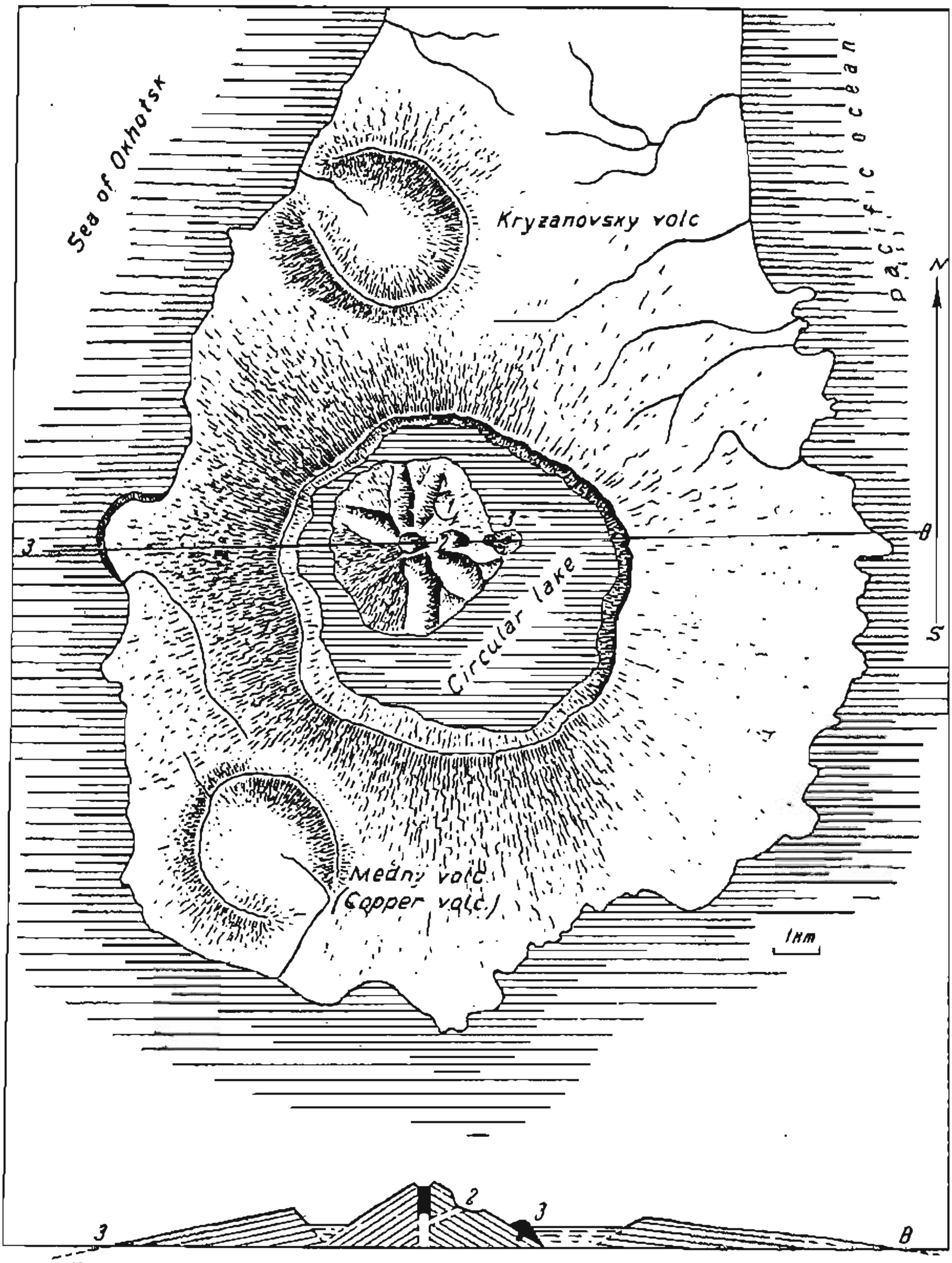


Fig. 42. Scheme of the structure of Tao-Rusyr caldera (after Gorshkov, 1958).



Sketch showing the structure and a section of Krenitzyn peak and Tao-rusyr caldera.

(1 - old lateral crater, 2 - lateral crater of 1952, 3 - dome of 1952, ⊕- solfataras).

volcano continued its activity in post-glacial time. Pre-caldera rocks are olivine basalts and subordinate quantity of two-pyroxene basaltic andesites interbedded with pyroclastics of the same composition, capped by a layer of dacitic pumice, and filling thin flows of basalts.

Caldera forming eruption.

Development of the volcano was finished by a gigantic explosion which destroyed the summit and formed the caldera. The explosion was accompanied by pyroclastic flows which cover a considerable part of the eastern coast. Their thickness continuously decreases northward. Material of these flows is andesitic (58.7% SiO_2). By radiocarbon data, this eruption took place 7040 years B.P. (Gorshkov, 1970).

Post-caldera volcanic activity.

In the northern part of caldera the central cone Krenitsyn Peak rises above a caldera lake. Its diameter at the level of the lake is 3.5-4 km. It is composed by monotonous pyroxene andesites. A summit extrusive dome is characterized by a more acid composition of plagioclase.

Historical activity.

Krenitsyn Peak showed weak solfatara field activity in 1846 and 1879, and in 1952 a strong eruption took place and formed an explosive crater on the eastern slope of the volcano. The place of the explosion was near to the base of the volcano, and afterward an extrusive dome was formed. After this eruption, the volcano renewed its fumarolic activity in three places: on the rim of summit crater, in an adventive crater, and in the new submarine crater.

3.4. Caldera of Kryzhanovsky volcano.

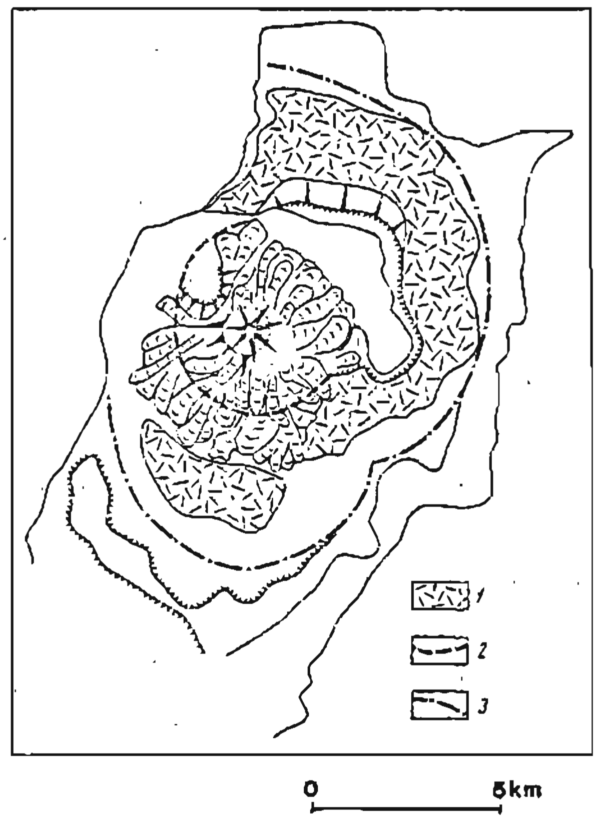
Kryzhanovsky volcano is located to the northwest from Tao-Rusyr Caldera, on Onekotan Island in the northern group of the Kuriles. The volcano has a well-preserved summit caldera with a diameter of 3 km open to the west. Slopes of the volcano have clear traces of glacial activity. The bottom of the caldera, as noted by Gorshkov (1970), is covered by pyroclastics, of the caldera-forming eruptions. The volcano is composed mainly of basalts. The rim of the caldera reaches 550 m high above sea level. No detailed data about geology of volcano and caldera is available.

3.5. Nemo Peak caldera.

Nemo Peak caldera is located in the northern part of Onekotan Island, in the northern group of the Kuriles. Here a great depression about 11.5 km in diameter is open to the west. Mountains around it suggest that two calderas are present (Fig. 43). All the ridges have traces of glacial erosion and the small height of these ridges suggests that they were eroded by the first, stronger glaciation. On the bottom of the depression, to the northeast from Nemo Peak, are relicts of another younger edifice at about the place where the two calderas overlap. This younger edifice has been destroyed by explosions and only relicts of the caldera rim remain, with the form of half a moon. That rim is overlapped partly by lavas of Nemo Peak. Lake Nemo fills part of this caldera.

A flat bottom of the depression to the north and east from the lake is covered by uniform layer of ignimbrites supposedly Holocene in age, which overlie moraines. To the south, ignimbrites are overlapped by lavas of the

Fig. 43. Scheme of the structure of the Nemo Peak caldera (after Gorshkov, 1970).
1 - ignimbrite deposits; 2 - rim of the inner caldera; 3 - contour of the ancient caldera. Other signs are the same as on Fig. 17.



Nemo Peak. These ignimbrites are silicic andesites or andesite-dacite (64% SiO_2). Rocks of pre-caldera edifice are basaltic andesites; the central cone is composed of basaltic andesites and andesites. Short, young flows are composed of augite andesite (59.3% SiO_2).

History of the volcano.

In pre-glacial time a double nested caldera was formed on some ancient volcanoes. Then the island underwent glaciation. A new volcanic edifice formed in interglacial times. Its cone overlaps glacial relief. Eventually a strong explosion destroyed the cone, accompanied by an outpouring of pyroclastic flows. The caldera formed during this event has a diameter of about 5 km.

In post-glacial time a central cone was formed. At first this cone had two summits, but now eruptions continue through only one crater - Nemo Peak. The most recent eruptions have fed numerous lava flows, interrupted by strong strombolian-type explosions. Nemo Peak fills almost all of the caldera in the south, and in the west it overlaps the caldera rim. The atrio is preserved only to the north from the central cone. On the final stage, an extrusive dome was formed in the summit crater.

Historical activity.

Eruptions of Nemo Peak took place in the 18th century. The dome might have formed during the eruption of 1906. Fumarolic activity persists through explosion funnels located on the rim of the summit crater.

3.6. Karpinsky caldera.

Karpinsky caldera is located in the southern part of Paramushir Island and is usually not described as a separate structure. Gorshkov (1970) divided its description into two separate parts - an inter-glacial volcanic edifice and post-glacial centers of Karpinsky group.

Gorshkov (1970) concludes that the depression previously described by him as Karpinsky caldera was formed mainly by glacial erosion processes. The structure has rhomb-like form, its walls were formed at various times from Lower Pleistocene up to Holocene.

The inter-glacial edifice has three volcanic centers (Fig. 44). Post-glacial activity within Karpinsky caldera is represented by three independent small cones with extensive lava flows. These cones are composed mainly by lavas but several funnel shaped craters with strong fumarolic activity are located on or around the cones. After the earthquake in 1952, there was a sharp intensification of fumarolic activity.

Fig. 44. Scheme of Karpinsky caldera (after Gorshkov, 1958).

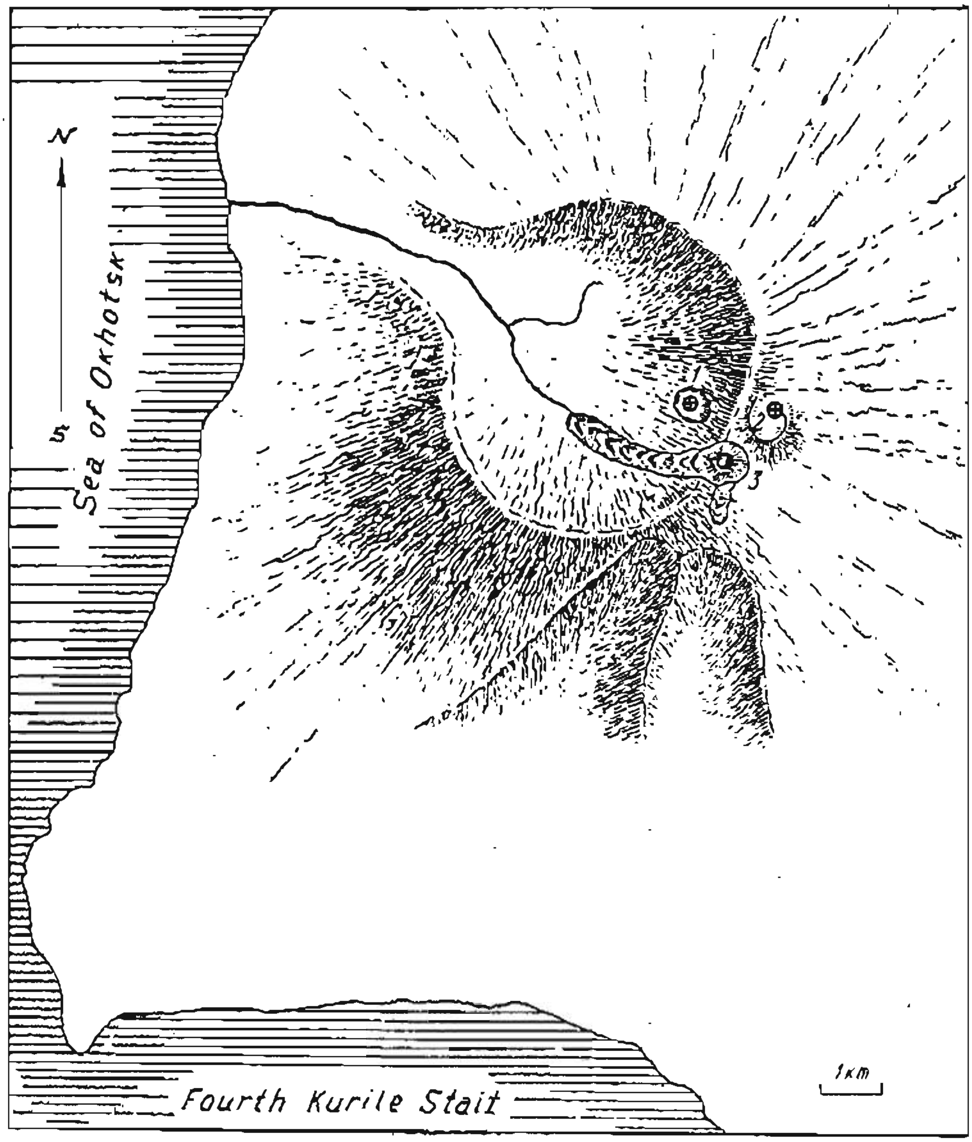
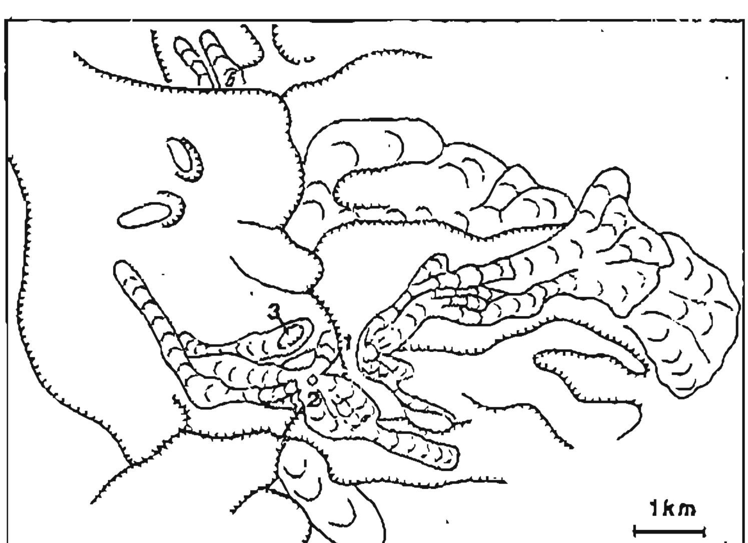


Fig. 44a. Scheme of the Karpinsky caldera (after Gorshkov, 1970). Numbers on the figure indicate position of post-caldera cones.



CHAPTER III

DESCRIPTION OF KAMCHATKA CALDERAS

Description of Kamchatka calderas is arranged in accordance with their geographical/geological distribution (Fig. 45).

SOUTHERN KAMCHATKA

4.1. Pauzhetka Volcano-Tectonic Depression (Kurile Lake caldera, Il'insky caldera volcano).

The Pauzhetka depression in southermost Kamchatka is among the largest, and perhaps the best studied, structure of this type in Kamchatka.

Published studies.

Study of the western part of the depression has been mainly due to exploration for geothermal resources. In contrast, the eastern portion, which includes the Kurile Lake caldera, has been studied mainly as an example of volcanism and structure related to a Krakatau-type caldera.

The Pauzhetka depression was first described by Aver'ev and Sviatlovsky (1961), although subsequent work has greatly modified their ideas. The currently prefered boundaries of the depression were defined by Melekestsev (in Luchitsky, ed., 1974), who emphasized a volcano-tectonic origin. Sheimovichy (1974) related formation of the depression to eruption of the Golygin ignimbrite sheets, which were deposited over a large region around the depression. The boundaries defined by Melekestsev were accepted by Kozhemyaka and Ogorodov (1977), who interpreted the genesis of the depression dominantly as the result of volcanic process and played down any relation to regional tectonics. In contrast, Leonov (1981) interpreted the depression as related to the main extensional faults of southern Kamchatka, without considering the role of volcanic processes at all.

Regional setting.

The Pauzhetka depression is at the intersection of several major fault systems (Fig. 46). North-south faults define the eastern borders of the Kamchatka Median massif with the graben-syncline of south Kamchatka. Near the Pauzhetka depression, N-S faults bound the uplifted volcanic rocks of the Golygin Mountains with displacements down more than 1,000 m to the east. At the southern margin of the Golygin Mountains, a N-S fault is cut by the E-W Ozernovsky strike-slip fault. Lesser faults with NW and NE strike occur in the same region.

Morphology and structure.

The Pauzhetka depression is an E-W-elongate subsided block, 20 by 25 km across; northeast-striking linear grabens join the subsided block on its eastern and western sides (Fig. 47). The depression is bounded by faults with total displacement exceeding 1,000 m, and is filled by the "Pauzhetka suite" of terrigenous volcanic deposits, of upper Pliocene to middle Quaternary age.

Fig. 45. Quaternary calderas and great volcano-tectonic depressions in Kamchatka. 1 - contours of great Quaternary volcano-tectonic depressions; 2 - Quaternary calderas. Roman numerals/volcano-tectonic depressions: I. Pauzhetka; II. Karymshinsky; III. Zhupanovsky (Karymsky); IV. Great Semiachik; V. Tolbachik; VI. Khangar; VII. Ichinsky; VIII. Alney Chashokondzha.

Arabic numberals denote to: 4.1 - Pauzhetka volcano-tectonic depression (Kurile Lake caldera, Il'insky caldera volcano); 4.2 - Inkaniush volcano-tectonic depression (Zheltovsky caldera volcano); 4.3 - Prizrak caldera (Kell' caldera volcano); 4.4 - Ksudach caldera volcano; 4.5 - Gorely caldera volcano; 4.6 - Opala caldera volcano; 4.7 - Bolshe-Banny (Karymshinskaya) ring structure; 5.1 - Avacha caldera volcano; 5.2 - Caldera group of Zhupanovsky (Karymsky) volcano-tectonic depression; 5.2.1 - Polovinka caldera volcanoes Odnoboky and Akademii Nauk); 5.2.2 - Stena-Soboliny caldera (Maly Semiachik caldera volcano); 5.2.3 - Caldera of the Karymsky volcano; 5.3 - Great Semiachik volcano-tectonic depression; 5.4 - Uzon-Geyzernaya volcano-tectopnic depression; 5.5 - Krasheninnikov caldera volcano; 6.0 - Tolbachik volcano-tectonic depression; 6.1 - Plosky Tolbachik caldera volcano; 6.2 - Dal'ny caldera volcano; 6.3 - Zarechny caldera volcano; 7.1 - Khangar volcano-tectonic depression; 7.2 - Ichinsky volcano-tectonic depression; 7.3 - Uksichan caldera volcano; 7.4 - Bolshoy caldera volcano; 7.5 - Kekuknaisky (Leningradets) caldera volcano; 7.6 - Bolshoy Chekchebonay caldera volcano; 7.7 - Maly Chekchebonay caldera volcano; 7.8 - Tigilsky caldera volcano; 7.9 - Perevalovy caldera volcano; 7.10 - Alney-Chashokondzha volcano-tectonic depression.

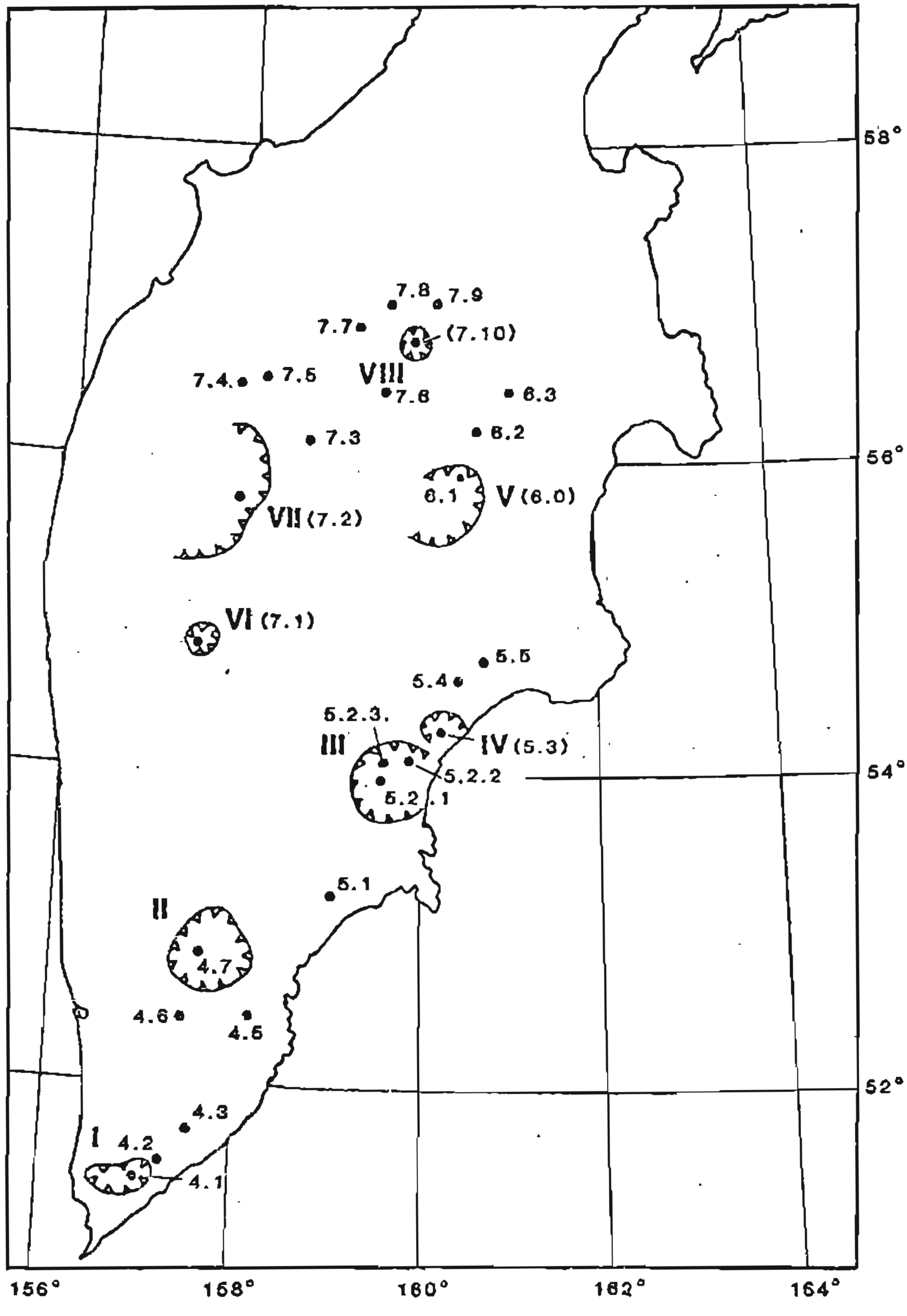

58°
56°
54°
52°
156°
158°
160°
162°
164°
7.8
7.9
7.7
(7.10)
7.4
7.5
VIII
7.6
6.3
7.3
6.2
6.1
V (6.0)
VII (7.2)
VI (7.1)
5.5
5.4
5.2.3.
III
IV (5.3)
5.2.2
5.2
.1
5.1
II
4.7
4.6
4.5
4.3
I
4.2
4.1
1
I
2
6.2

Fig. 46. - Scheme of southern and eastern Kamchatka faults active in Neogene-Quaternary time (by Leonov, 1981). 1 - System of faults of Nachiki-Kumroch strike slip fault, connected with grabens of Pauzhetka volcano-tectonic depression including: (a) faults without considerable vertical components; (b) Faults with amplitude more than 100 m; (c) Thrusts; 2 - Faults bordering supposed zone of extension; 3 - Faults of NW (a) and sublatitudinal; (b) strike; 4 - Faults of latitudinal strike; 5 - Kamchatka Median massif; 6 - Volcanoes (a) and calderas (b); 7 - Hot springs.

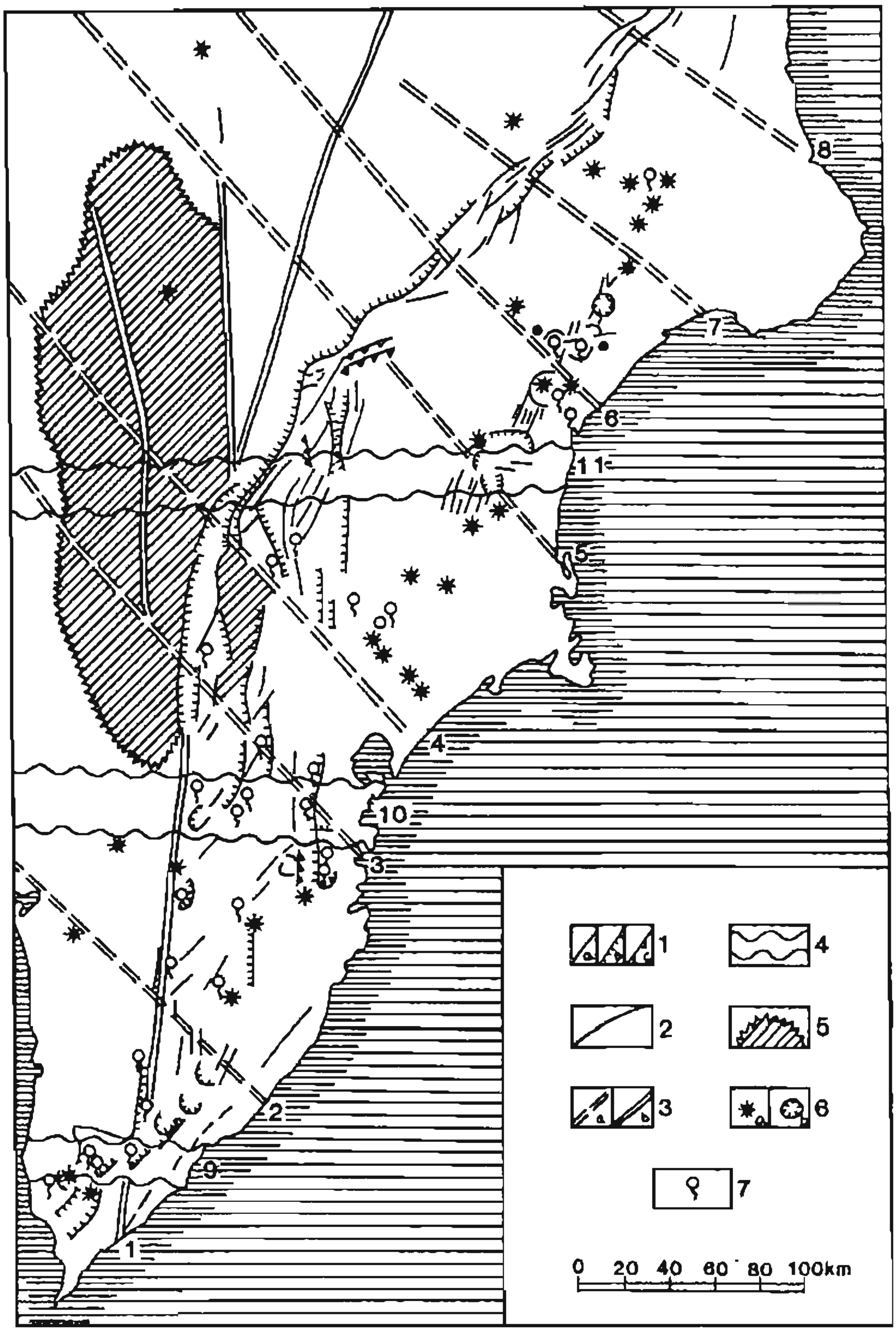


Fig. 47. - Geology of the Pauzhetka volcano-tectonic depression (Kozhemyaka and Ogorodov, 1977).

I. Quaternary deposits:

1. Blast deposits, Q_4;
2. Scoria, Q_4;
3. Blast pumice - scoria deposits, Q_4;
4. Thick pumiceous pyroclastic flows, Q_4;
5. Redeposited pumices, Q_4;
6. Glacial deposits of the second stage of Upper Pleistocene glaciation, Q_3^4;
7. Glacial deposits of the first stage of Upper Pleistocene glaciaton, Q_3^2;
8. Undivided loose deposits, Q_3^4;
9. Rhyodacite tuff ignimbrites, Q_2;
10. Sedimentary tuffs of the Pauzhetka suite, $N_2^3 - Q_3^1$ (?).

II. Miocene, Pliocene and Lower Pleistocene deposits:

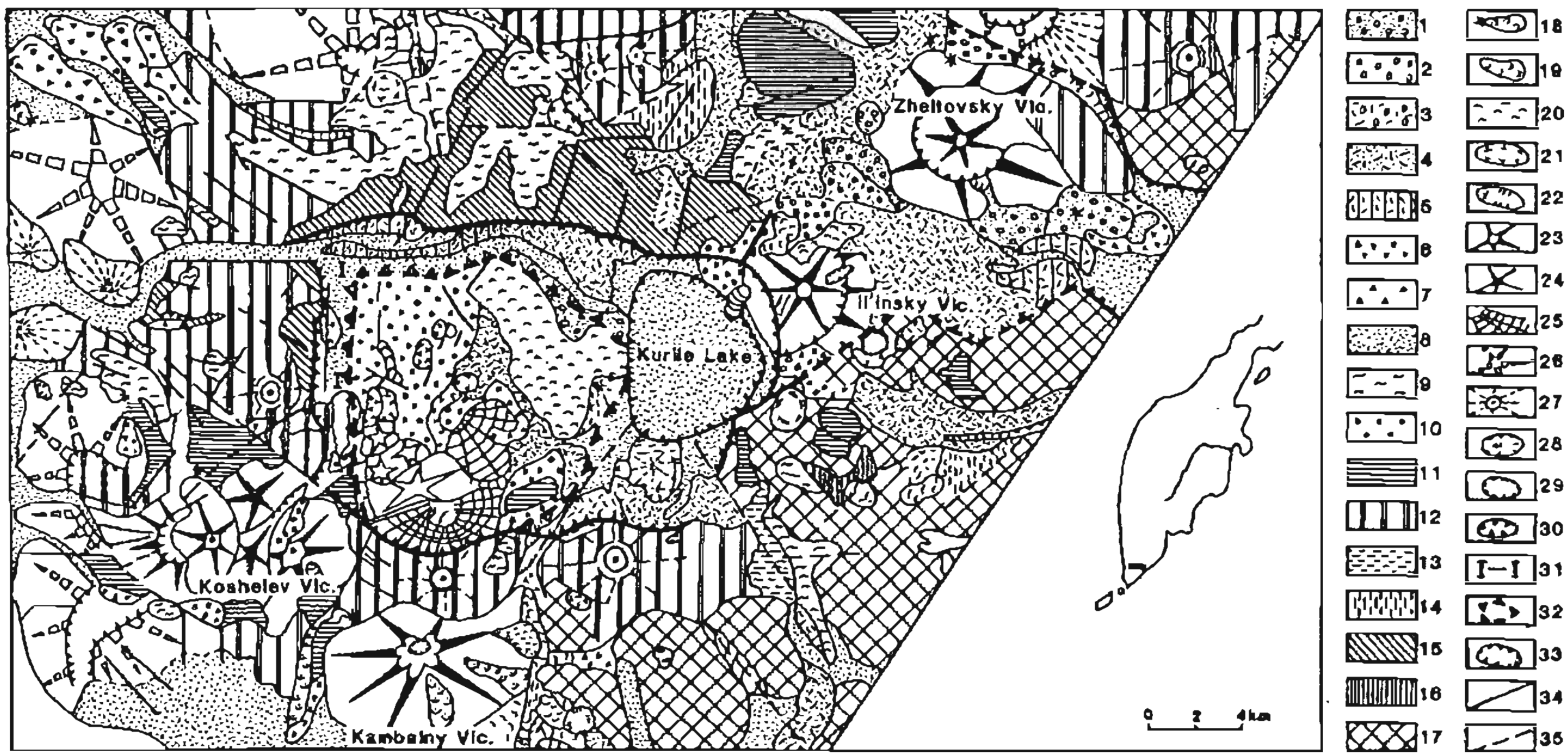
11. Plateau-like relicts of strongly eroded shield-like volcanoes, Q_1;
12. Effusive-pyroclastic complexes of large Pliocene centers of volcanism;
13. Volcanogenic sedimentary deposits of Middle-Lake Pliocene, N_2^{2-3};
14. Large intrusive bodies, N_2 (?);
15. Volcasnogenic, mainly lava, complexes of Lower and Middle Miocene, N_1^{1-2}
16. Tuffogenic sandstones and gravellites of Late Paleogene-Lower Miocene, $P_3 - N_1^1$;
17. Undivided deposits of Late Paleogene - Lower Middle Miocene, $P_3 - N_1^{1-2}$ (?);

III. Genetic types of volcanoes and their morphology:

18. Basaltic scoria cones, Q_4;
19. Basaltic lava cones, Q_4;
20. Large poly-phase extensive complex Diky Graben, Q_4;
21. Small extrusive domes of dacites,. $Q_3 - Q_4$;
22. Subintrusive formations;
23. Mainly lava strato-volcanoes;
24. Large lava-pyroclastic strato-volcanoes;
25. Mainly pyroclastic strato-volcanoes, $Q_1 - Q_2$;
26. Shield-like mainly lava volcanoes, $Q_1 - Q_2$;
27. Large Pliocene centers of volcanism;
28. Strongly eroded relicts of pliocene volcanoes;
29. Craters of strato-volcanoes;
30. Fault of bounding of the Pauzhetka depression;
31. Graben of the Pauzhetka river valley;
32. Horst of the Kambalny ridge;
33. Calderas with which are connected pumice pyroclastic covers.

IV. Disjunctive tectonic faults;

34. States;
35. Inferred
36. Fissures of pumice eruption, Q_4.


Zheltovsky Vlc.
Il'insky Vlc.
Kurile Lake
Koshelev Vlc.
Kambalny Vlc.
0 2 4 km
1
2
3
4
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Boundary structures of the depression truncate older desposits of varying age and origin. The western boundaries truncate Miocene-Pliocene sediments of the "western Kamchatka rear linear depression"; south of Kurile Lake, Miocene terrigenous volcanic deposits are cut. North of the depression and uplifted Golygin Mountains are composed of Miocene-upper Pliocene to lower Quaternary volcanics, overlapped by ignimbreite cover (so called Golygin horizon). To the southwest are the lower-middle Quaternary volcanic edifices of the Koshelev group.

The Pauzhetka depression coincides with the "Golygin" negative gravity anomaly. The mass deficiency is 1.5×10^{17} grams; modelling, based on an assumed density contract of 0.28 cm^3, indicates that the top of the low-density material is at a depth of 5-6 km, with its center at a depth of 10-15 km. The low-density material is interpreted as a still partly molten magma chamber (Erlich and others, 1972).

The inner structure of the Pauzhetka depression is divisable into three main features (W to E): Pauzhetka Graben, Kambalyny Ridge Horst, and Kurile Lake caldera. The active Il'insky Volcano, on the northeast side of Kurile Lake, covers the caldera boundary fault; this volcano in turn has a summit caldera.

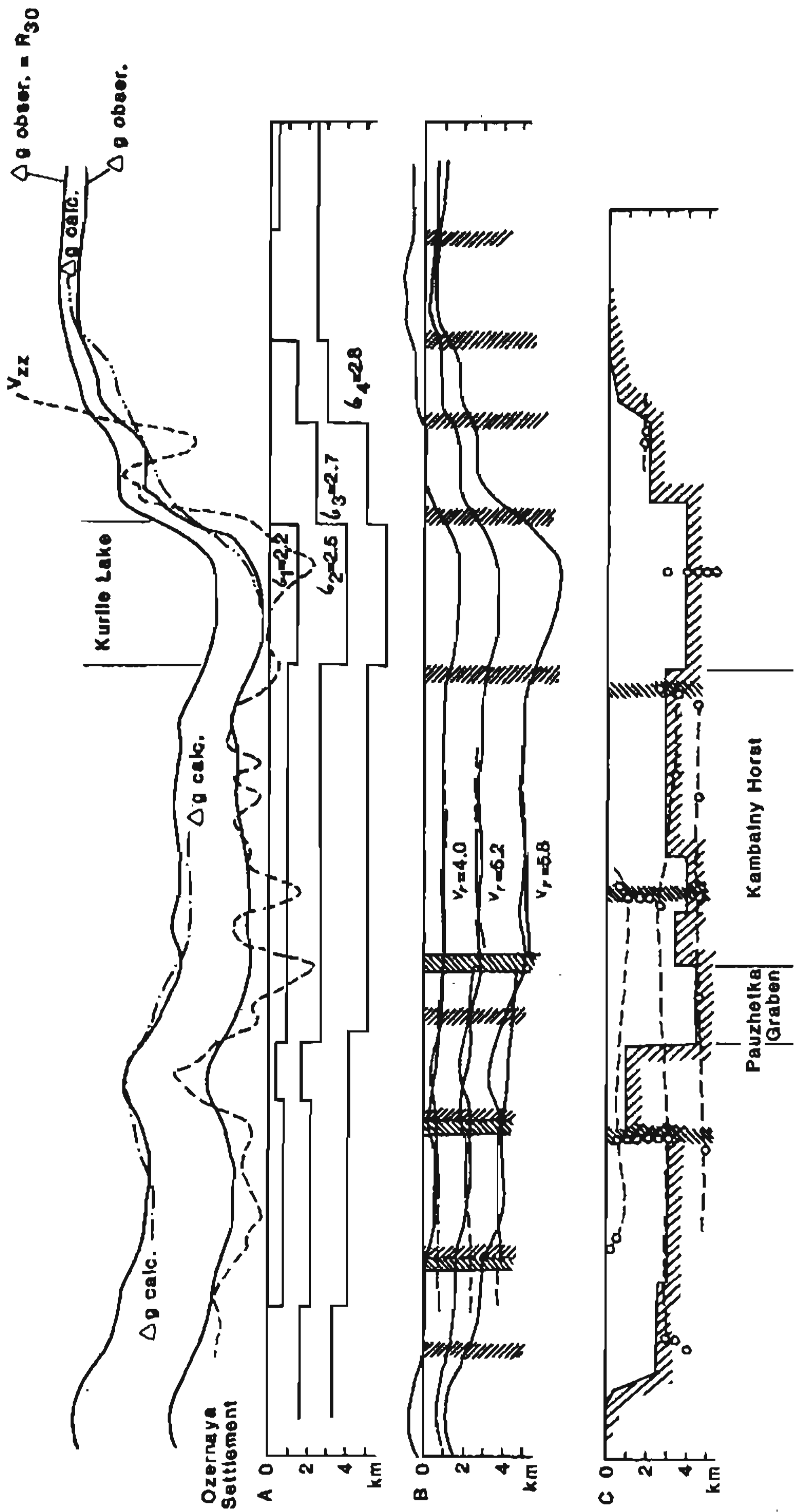
Pauzhetka Graben.

Downstepping of the basement along the western margin of the depression is complicated by a graben occupied by the Pauzhetka River (Figs. 48-49). In this description as everywhere, author preserved terms used in Russian literature. But in author's opinion, Panzhetka graben represents itself as a kind of "caldera moat" - topographic and structural low between caldera wall and resurgent central uplift. The graben is several kilometers wide, strikes NNE, and has bounding displacements of 250-400 m (Masurenkov, ed., 1980). The basement consists of slightly deformed and metamorphosed sandstone and siltstone, interbedded with andesitic lavas (the Kurile complex of middle-upper Miocene age) (Fig. 47). Within the graben, the top of the basement dips a few degrees NE and is overlapped by several volcanic suites of upper Pliocene-middle Quaternary age: (1) a lava-pyroclastic suite 80-150 m thick, mainly lava in its lower part, overlain by tuff and conglomerate containing clasts of silicic tuff, diorite porphyry, and andesite; (2) an ignimbrite horizon 125-190 m thick; and (3) terrigenous volcanic rocks of the Pauzhetka suite as much as 800 m thick. The Pauzhetka suite changes upward from mafic tuff breccia (lower subunit), to coarse tuff of intermediate to silicic composition (middle subunit), to silicic pumiceous tuff (upper subunit).

Kambalny Ridge Horst.

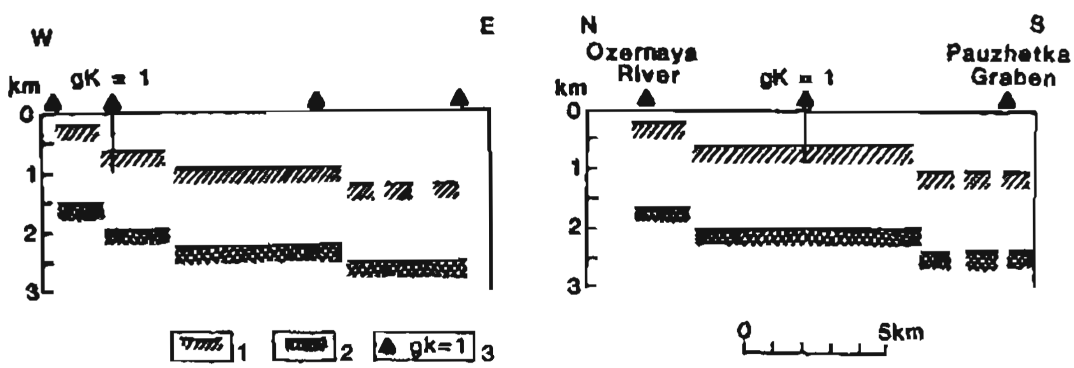
Between the Pauzhetka Graben and the Kurile Lake caldera is a elliptical horst, exposing sedimentary deposits of the Pauzhetka suite, and with structural relief of 800-1,000 m, formed at the end of the Middle Pleistocene (Fig. 49). Formation of the Kambalny Horst coincides with intrusion and extrusion of about 50 km^3 of silicic magma as tuff and lava (Kozhemyaka and Ogorodov, 1977). Related intrusions permeate strata of the Pauzhetka suite. Only small parts of the extrusions and intrusions are exposed in deep erosional cuts. The largest extrusion is a complex dome called the Diky

Fig. 48. - Observed and calculated Δg along profile: settlement Ozernovsky-Kurile Lake-Pacific Ocean, along the axis of Pauzhetka volcano-tectonic depression (by Masurenkov, ed., 1980). a-Model constructed by working of direct task by paletka method; b-Model by correlative equation (faults - by seismic and gravimetric data); c-Model by method of Berezkin and second derivatives.



Δg obser. = R_{30}
Δg obser.
Δg calc.
V_{zz}
Kurile Lake
σ_1=2.2
σ_2=2.5
σ_3=2.7
σ_4=2.8
Δg calc.
Δg calc.
Ozernaya Settlement
A 0 2 4 km
B 0 2 4 km
V_r=4.0
V_r=5.2
V_r=5.8
C 0 2 4 km
Kambalny Horst
Pauzhetka Graben

Fig. 49. - Character of laying of roof of sandstones and rocks of the Cretaceous basement within the Pauzhetka volcano-tectonic depression by gravimetric data (by Masurenkov, ed., 1980). 1-Roof of volcanogenic sandstones of the Kurile complex; 2-Roof of the Cretaceous basement; 3-Deep drill-holes.



Graben, that formed contemporaneous with postcollapse activity at the Kurile Lake caldera. Obviously this horst represents a kind of typical, large resurgent dome.

4.1.1. Kurile Lake Caldera.

The Kurile Lake caldera is one of the most impressive in Kamchatka. Dacitic pumiceous flows extend 20 km or more from the lake (Fig. 50b), as shown by satellite photography. The pyroclastic flows have yielded ^{14}C of 8,000± 30 and 8,340±40 years (Luchitsky, ed., 1974).

Echo-sounder data permits the lake to be divided into: (1) a flat-bottomed saucer-like northern part 5 km across, with a maximum depth of 300 m; and (2) a southern part about 10 km across, characterized by straight short-line segments and an irregular rectangular form (Figs. 50-51). The two parts are divided by a narrow ridge about 150 m across. Slopes in the southern part are steep, up to 60° and with a stepped profile, down to 300 m depth. The lake floor is greater than 300 m deep and is 4-5 km in diameter, with a relatively flat bottom. Several small islands within the lake are rhyolitic lava domes.

The Kurile Lake caldera is characterized by a gravity minimum within the general gravity low of the Pauzhetka depression. Values are low on the rhyolite islands in the lake. The low gravity field at Kurile Lake is interpreted as related to a low-density body (probably magma chamber) about 10 km across, at a depth of about 4 km (Zubin and others, 1982).

The magnetic field is complex but generally low over the lake. Within the generally low values, the magnetic field is lowest in the northern part of the lake, and another area of low values occurs in the southern part of the lake. In form, these anomalies are similar to the topography of the lake bottom (Fig. 50c-50d). Distinct anomalies also occur at the Diky Graben extrusive complex in the adjacent Kambalny Horst, and on a small island at the foot of Il'insky Volcano, both probably related to magnetic lava flows.

The northern part of the lake has been interpreted as a blast funnel, filled by breccia of silicic igneous rocks (Zubin and others, 1982). Interpreted energy of the blast is 10^{25} ergs, assuming a source depth of 1.5 km. in case of density contrast $0.49/cm^3$. The southern part of the lake is considered a typical caldera (Fig. 50e). All authors describing the lake, indicate a great amount of dacitic pumice around it, decreasing in thickness outward from the lake. On air-photos there are traces of flowing pumice from the direction of the lake.

4.1.2. Il'insky Volcano.

Il'insky Volcano covers the caldera boundary fault on the northeast side of Kurile Lake. It is a typical stratovolcano about 8 km across at its base, with its summit 1,578 m above sea level and 1,470 m above lake level. A summit caldera contains a young nested cone (Fig. 52).

The precaldera cone is composed of basalt and basaltic andesite flows and interbedded pyroclastic material; the ratio of lava to pyroclastics is about 1:1. The summit cone consists of lava flows and pyroclastic material: basaltic agglutinate, scoria, and tuff; pyroclastic material is most voluminous except low on the cone. Compositions change with time: basaltic andesite, andesite, andesitic dacite. The youngest flows in the southwestern flank of the volcano, near Kurile Lake, are silicic andesitic dacite ($63\% SiO_2$). Scoria cones on the southwestern flanks are sources of lava flows and effusive domes; some of these form small islands in Kurile Lake.

Fig. 50. - Geological, geophysical schemes of Kurile Lake and vicinity (Zubin, Nikolaev and Sheimovich, 1982). a-Scheme of geological structure; b-distribution of pumice-pytoclastic flows (from space-photo interpretation); c-Bathymetric scheme; d-Scheme of magnetic field; e-Elements of geological interpretaion of the lake's bottom by geophysical and bathymetric data. 1-Miocene-Pliocen volcanogenic formation; 2-Quaternary volcanites: a-Lower Quaternary basalts; b-Il'insky strato-volcano; 3-Holocen pumice pyroclastic flows; 4-Holocene rhyolite extrusive domes: a-stated; b-supposed; 5-Holocene lake deposits; 6-Faults; 7-Zones of increased jointing; 8-Position meanings of magnetic field; 9-Borders of collapse caldera; 10-Positive meanings of magnetif field; 11-Negative meanings of magnetic field; 12-Isolines of magnetic field, hundreds; 13-Borders of the blast crater.

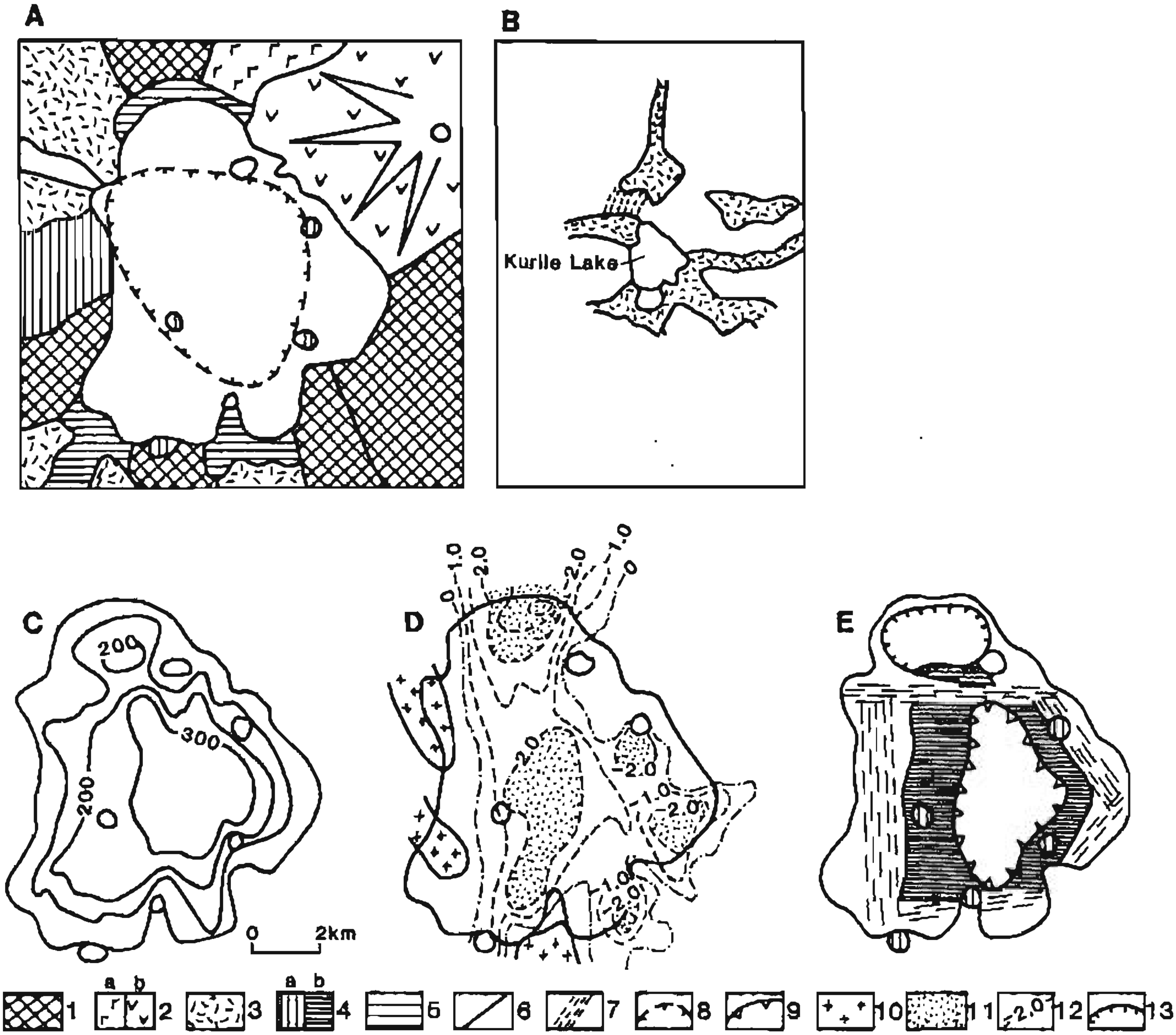


Fig. 51. - Bathymetric profiles across Kurile Lake (Zubin, Nikolaev, Sheimovich, 1982).

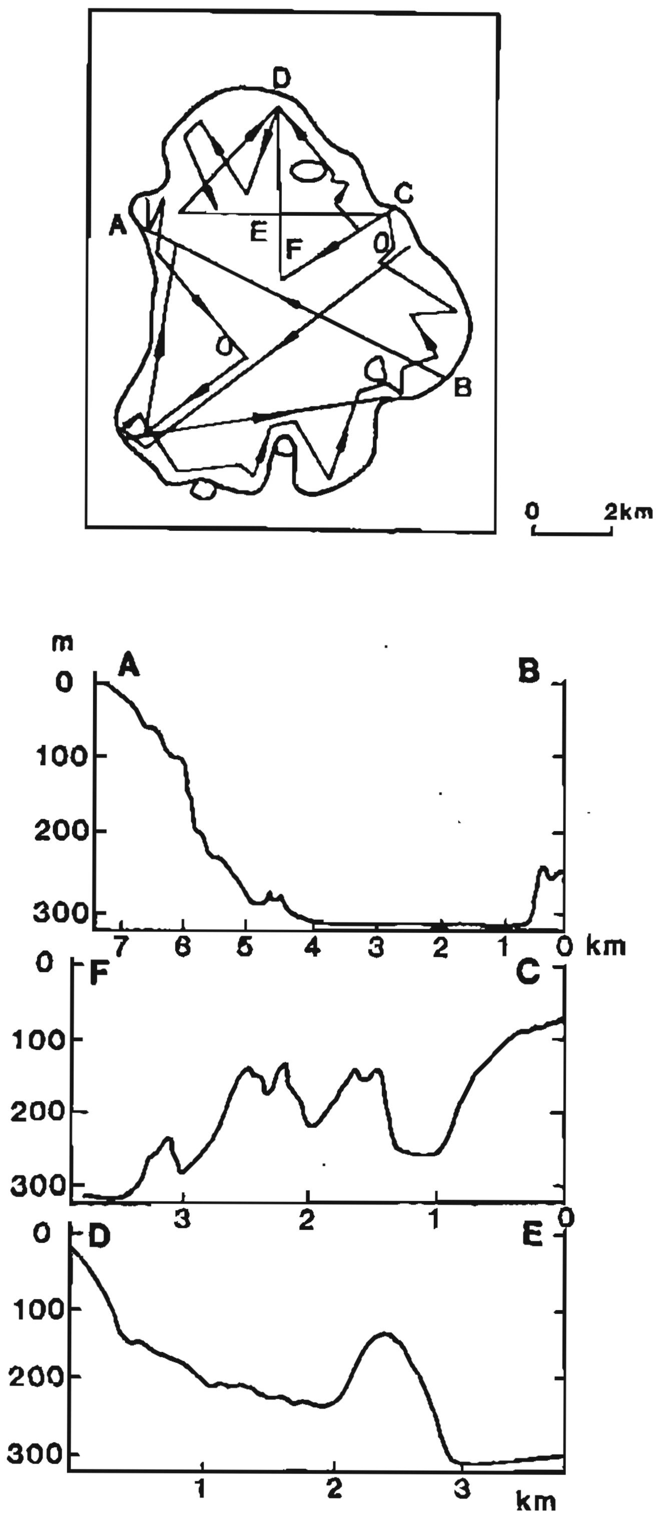
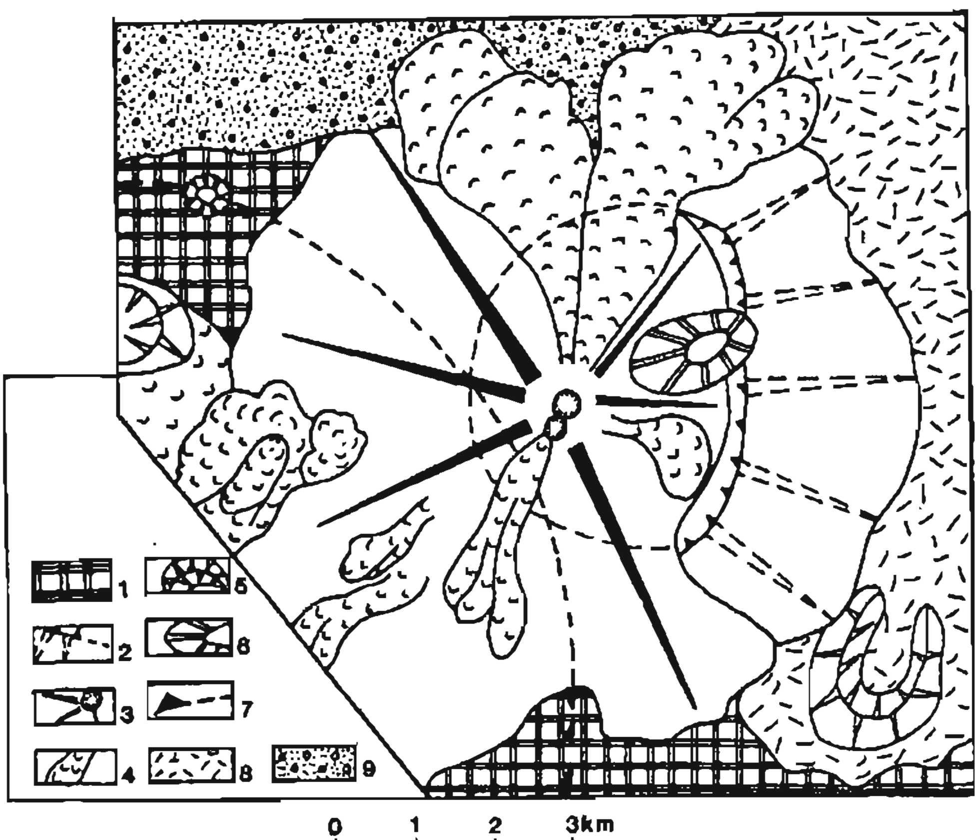


Fig. 52. - Scheme of the geological structure of Il'insky volcano (by Masurenkov, 1980). 1-Basement of the volcano (Miocene-Pliocene deposits); 2-pre-caldera edifice; 3-summit cone; 4-separate lava flows; 5-scoria cones; 6-blast funnel; 7-boundary of the Kurile Lake caldera; 8-pumice-pyroclastic deposits; 9-undivided Quaternary deposits.



A blast funnel, 1,000 x 800 m across and 450 m deep, is located on the east side of the summit cone. The blast removed part of the precaldera edifice and part of the summit cone. Pumice, related to this funnel, thickly blankets the northeast slopes of the volcano and has a volume of 10-11 km^3. Pumice compositons are similar to the youngest andesitic dacite flows of the summit cone (63-65% SiO_2). Abundant anorthositic blocks 0.1-1.0 m in size are present on the northeast slope, between caldera wall and the summit cone. Well-rounded vein quartz boulders of uncertain origin, but presumably related to the blast occur on the upper slopes of the volcano.

Geothermal activity.

Geothermal springs are present at several of the volcanic structures. For example, surface hot springs occur along the northeastern shore of Kurile Lake, and underwater springs may be present along faults which border the southern part of the lake and bound the inferred caldera (Zubin and others, 1982). Pauzhetka is the only geothermal field in the USSR on which a geothermal plant has been constructed.

The major springs of the Pauzhetka geothermal field are within the Pauzhetka River Graben and adjacent parts of the Kambalny Horst. A northern group of springs form a thermal zone with a northwest strike. The direction of hydrotherms coincides with the strike of the zone, as indicated by changes of temperature (Fig. 53), piezometric levels and concentrations of chemical components (Fig. 54). Hydrothermal fluids from this zone flow into the Pauzhetka River along the border of the depression, where Palogene-Neogene basalt and tuff breccia form a natural barrier which causes underground water to surface. Total present surface heat loss from this hydrothermal system is 25 kcal/sec; assuming a heat content of 170 kcal/kg, the inferred total heat capacity is 178,000 kcal/sec.

Recent volcanic activity.

Because of the distance from populated areas and transportation facilities, settlement in the region of the Pauzhetka depression began only in the 1950s and historic observations of eruptions are limited. Strong, apparently phreatic, eruptions occurred in the laternal northwest crater of Il'insky Volcano in 1901, and tephra were dispersed widely (Vlodavets and Pipp, 1959).

Seismicity.

Seismic data are also limited and nature of earthquakes is uncertain. Although seismicity was weak during 1973-1977, seasonal swarms tended to occur March-April and July-August (Levina and others, 1980). Pauzhetka earthquakes are characterized by increased seismic moment in comparison with average world data, a feature typical of volcanic earthquakes.

The epicentral region of local earthquakes (Levina and others, 1980) appears to coincide with a system of NE-striking tectonic faults (Fig. 55). Focal-mechanism solutions for two earthquakes are left-lateral strike-slip, with steep dips. Extensional strain is prevailed, what documents the rift character of the regional structure (Levina and others, 1980). One possible reason for activation of the regional tectonic structures is the exploitation of the geothermal field; another is the influence of volcanism.

Fig. 53. - Connection between the temperature field and relief of the roof of the basement (by Masurenkov, 1980).

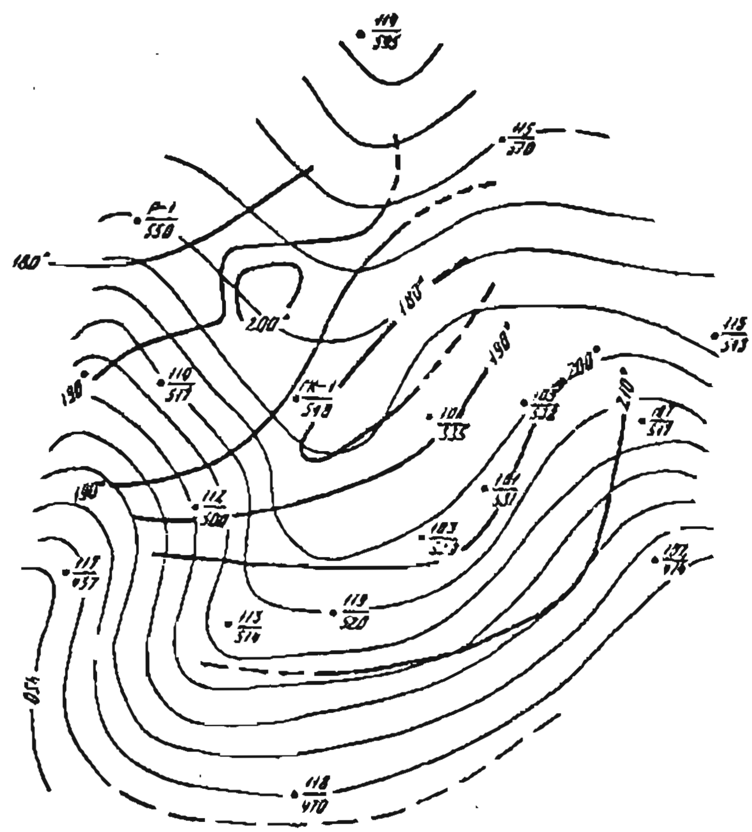


Fig. 54. - Trends of concentrations of the Pauzhetka deposit thermal water components (by Masurenkov, 1980).

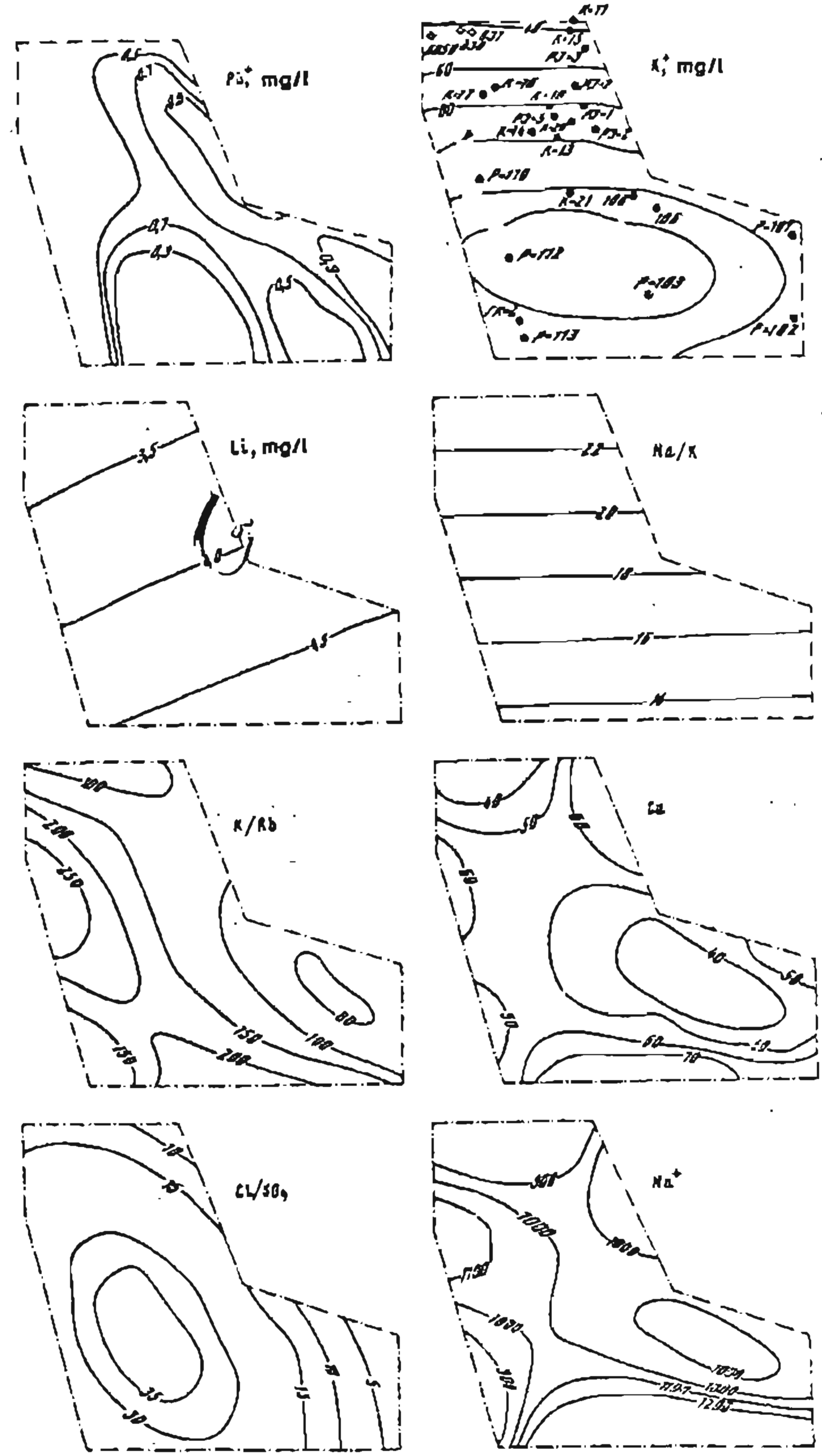
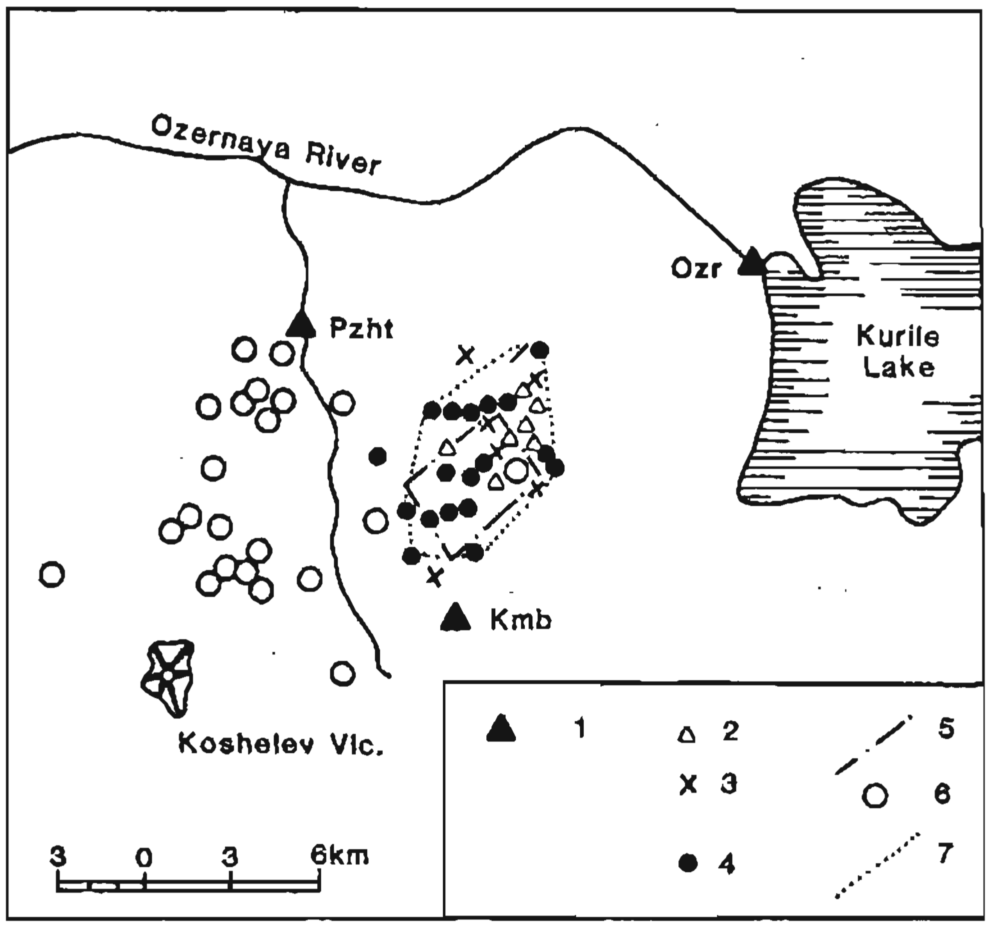


Fig. 55. - Scheme epicenters of earthquakes within Pauzhetka geothermal field (Levina, Firstov, Zobin, 1980). 1-Seismic stations: Pauzhetka (Pzht), Kambalny (Kmb), Ozernaya (Ozr); Epicenters of earthquakes, defined by records of seismo-stations; 2-Pauzhetka, Ozernaya, Kambalny stations; 3-Pauzhetka, Kambalny; 4-Pauzhetka, Ozernaya; 5-Region of epicenters defined by average statistical Sp and parameters; 6-Region of epicenters of strongest earthquakes defined by regional network data; 7-Region in which more than 70% of epicenters are concentrated by data of field stations.



Origin of structure.

In the most part of papers which discuss the origin of Pauzhetka volcano-tectonic depression, its subsidence is connected with the eruption of ignimbrites of Golygin horizon. Slight difference in interpretation depends on the determination of the age of these ignimbrites. Aprelkov (1962) date is as Pliocene, now are available radiometric dates of the same ignimbrites from drill holes within the Pauzhetka River Graben (0.22-0.01 Ma, in Masurenkov, ed., 1980). Volcanism of post-caldera stage in this depression is represented by numerous extrusive bodies in Kambalny Ridge Horst, which caused resurgent doming in this area. Simultaneously the Pauzhetka River Graben was formed. Later (about 8,000 years B.P. by radiocarbon data) in the easternmost part of the depression, Kurile Lake caldera was formed and great amount of pumice, connected with this caldera was erupted.

Post-caldera stage of development of the last caldera is represented from one side by a series of silicic extrusive domes inside the Kurile Lake and great Diky Graben extrusive dome in Kambalny Ridge, and from another side by basaltic Il'insky volcano with a caldera on the summit with which a lot of pumice flows are associated. So it is obvious that magma chambers (or maybe a series of magma chambers) beneath Pauzhetka volcano-tectonic depression constantly migrated eastward during Ouaternary time. Another point of view has been presented by Ogorodov and Kozhemiaka (1977) and in Masurenkov, ed., (1980). They deny any connection between ignimbrites of Golygin horizon and subsidence of Pauzhetka volcano-tectonic depression. Their arguments against these connections are: (1) absence of coincidence between volume of silicic volcanic material, which they estimate in 45 km^3 and volume of depression (about 400 km^3 by their estimation); (2) on opposite - astonished coincidence between volume of depression and volume of Pliocene volcanites; (3) presence of the centers of ignimbrites eruption outside Pauzhetka volcano-tectonic depression in Golygin Mountains.

This point of view was developed due to misunderstanding of some important stratigraphic problems. In particular Ogorodov and Kozhemiaka thought, that ignimbrites of Golygin horizon are widespread only to the north from the depression and do not correspond with the ignimbrites in the drill hole inside the Pauzhetka River Graben. So, they follow the idea that Pliocene age of these ignimbrites and that is why neglect their own data on radiometric age of ignimbrites, indicates on the Upper part of the Middle Pleistocene.

4.2. Inkaniush volcano-tectonic depression (Zheltovsky caldera volcano).

For the first time under this name has been described by Aprelkov and others (1977). It is also indicated without description on the structural scheme in the paper of Ogorodov and Kozhemyaka (1977).

General structure and possible mode of origin.

Strucutre is represented by subsided block elongated in N 45° E direction 12 km in diameter (Aprelkov and others, 1977) infer subsidence of two nested segments. The more elevated outer segment consist mainly of andesitic flows and tuff cut by diorite porphyry, and associated with it wide zones of polymetalic ores. The inner segment, bounded by acurate faults associated with intrusions and barren veins, consists mainly of silicic tuff cut by diorite porphyry. Within the most subsided area of the structure, Zheltovsky volcano is located. Most of the volcano-tectonic depression's bottom is covered by dacitic pumice connected with the eruption of the Zheltovsky volcano's summit crater.

Mode of the origin of the depression is unclear. Aprelkov and others (1977) without any kind of discussion of the facts postulate that it was formed in Miocene time. But on the structural scheme, presented by Ogorodov and Kozhemyake (1977) is seen that its boundaries cut different in age volcanogenic complexes the youngest among which belongs to the Middle Pleistocene (Fig. 47). Absence of any kind of silicic pyroclastics specifically timed to the moment of volcano-tectonic depression generation and normal fault on its boundary indicate on gradual subsidence of the block of depression bottom. Author thinks, that depression probably was formed as a result of subsidence caused by decreasing pressure within magma generation zone during outpouring of basaltic magma of Zheltovsky volcano.

Zheltovsky caldera volcano.

According to Khrenov and Ogorodov (1973), Zheltovsky volcano was formed in three stages (Fig. 56): (1) An upper Pleistocene shield volcano, composed of olivine basalt and containing a summit caldera 3 km across. (2) Formation of a younger cone within the caldera, composed of basaltic andesite. Explosive eruptions increased during this stage, but without observed differentiation of magmatic material. Lava flows 3-5 m thick, 2.5-3.0 km long, and up to 800 m wide, are interbedded with layers of scoria, pumice, and tuff up to 1 m thick. Late in this stage basaltic dikes were emplaced centrally within the cone. (3) At the end of the Holocene, after a long quiescent period, a paroxizmal blast destroyed the upper cone and created summit caldera 1.6 km across. Associated with the blast, and agglomerate flow formed on the southeast slope, followed by extrusion of four andesitic domes within the crater. The largest, in the southern part of the crater, forms the summit of the present volcano. A flow associated with this dome may have erupted in 1923 (Novograblenov, 1932).

Rounded blocks of diorite and anorthosite, 0.5-1.0 m in size, are present on the slopes of the volcano. Many appear to be xenoliths, but some inclusions are texturally transitional to the host lavas. They are composed of anorthite, olivine, pyroxenes, and glass, and are similar in composition, size, and position to similar inclusions on the slopes of Il'insky volcano.

Historical activity.

Vlodavets and Piip (1958) mentioned a strong explosive eruption lasting two months during February-April 1923, ejected ash and incadescent gases. The possible lava flow associated with this eruption has already been noted (Novograblenov, 1932).

4.3. Prizrak caldera (Kell' volcano).

The Prizrak caldera is located immediately north of Zheltovsky volcano on the continuation of the strike-slip fault which cuts (with horizontal displacement) the deepseated fault on the eastern boundary of the southern Kamchatka graben-syncline (see Chapter 1. Fig. 11). This caldera is located in a remote region that is almost inaccessible and therefore, most geological data about this region have been obtained by air-photo interpretation. According to Melekestsev (in Luchitsky, ed., 1973), this caldera consists of at least three large (3 to 5 km in diameter) depressions, at least partially nested (see photo, Fig. 57). The innermost structure is complicated by the presence of small stratovolcanoes composed mainly of lava. The largest of these is called Kell' volcano. Extrusive domes are also present. The age of this depression is thought to be upper Pleistocene, and there are no traces of recent volcanic or hydrothermal activity within this caldera.

Fig. 56. - Geological map of the Zheltovsky volcano (Khrenov and Gorodov, 1973). 1-Deluvial deposits; 3-agglomerate deposits; 3-basalts; 4-dacites; 5-andesites; 6-pumices; 7-scoria; 8-welded scoria; 9-basement; 10-scoria cones; 11-crater of the volcano; 12-dikes; 13-ancient crater; 14-boundary of lava flows; 15-boundary of the pyroclsstic material development; 16-extrusive domes.

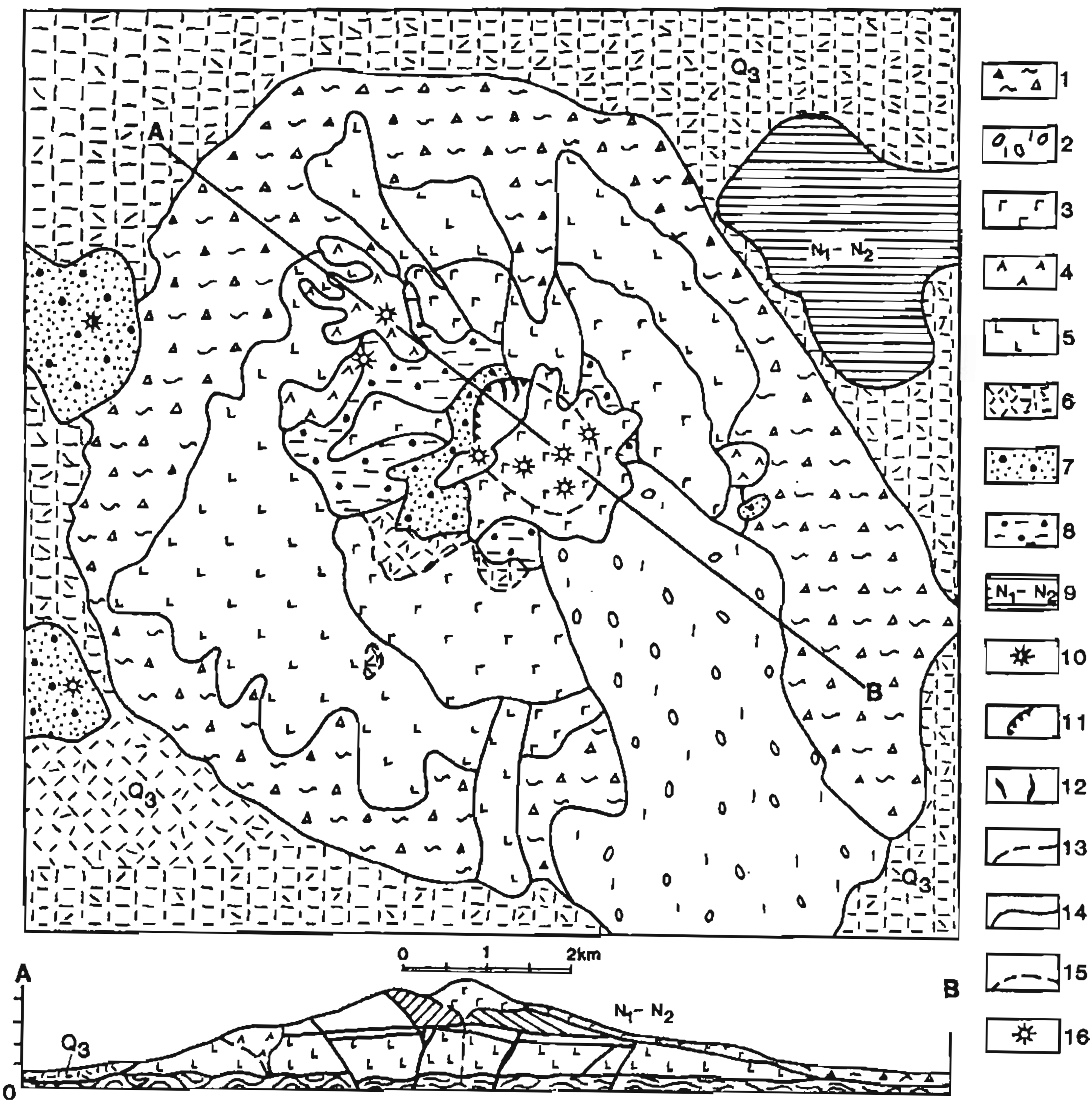


Fig. 57. - Oblique airphoto of Prizrak caldera (Sviatlovsky, 1959).

4.4. Ksudach caldera volcano.

Structural Position.

Ksudach caldera volcano is well known for its great eruption in 1907, which was observed from a great distance at Petropavlosk, Kamchatka, and from ships. Because of its location, there has been limited studies of the Ksudach caldera except for a few expeditions.

The caldera lies within the eastern part of the southern Kamchatka graben-syncline at the intersection with a major strike-slip fault. This fault, which trends N45°E, offsets the graben-syncline. The caldera is located on the summit of a shield-like, pre-caldera edifice, which reaches altitudes of 950-1080 m. The pre-caldera shield is composed of alternating layers of basalt lavas and dacitic pyroclastic deposits. On the basis of interpretation of satellite imagery, Aprelkov and others (1979) described an arcuate fault southeast of the shield that displaces volcanogenic deposits of Pliocene to early Pleistocene age. The vertical displacement along this fault exceeds 1000 m. These authors conclude that the pre-caldera shield of Ksudach caldera itself lies within a huge ancient caldera.

Melekestsev and others (in Luchitsky, ed., 1974) find Ksudach caldera was formed of several nested calderas of a successively smaller size. The older calderas are of late Pleistocene age, the youngest is Holocene. Only the southwest part of the oldest caldera is preserved. Other parts were destroyed during the formation of a younger calderas. The main Ksudach caldera is circular, has a diameter of about 7 km, and has walls from 0-200 m high. Several calderas (3-5 km across) are nested in the northern part of Ksudach caldera (Fig. 58b). A small, gently sloping stratocone with an active crater, so-called Stübel cone, lies in the northernmost caldera.

In contrast to the ring-like pattern of subsidence during caldera formation, post-caldera deformation has been dominated by subsidence along north-northeast-trending faults. Holocene and historic volcanic phenomena are associated with this fault zone. These include extrusion of black vitreous dacites into the loose deposits of the caldera floor, hot springs, and the formation of Stübel cone, which last erupted in 1907.

A positive gravity anomaly, located somewhat eccentric to the caldera, extends far beyond the caldera (Erlich and others, 1972). Direct methods of interpretation define a depth of 5-7 km for the upper margin of the anomaly-causing body.

A linear chain of small basaltic lava volcanoes and cinder cones cut the northern part of the pre-caldera shield. Similar volcanoes are located around the margin of the pre-caldera edifice. These are thought to mark a system of ring fractures associated with a huge ancient caldera within which the pre-caldera edifice was built.

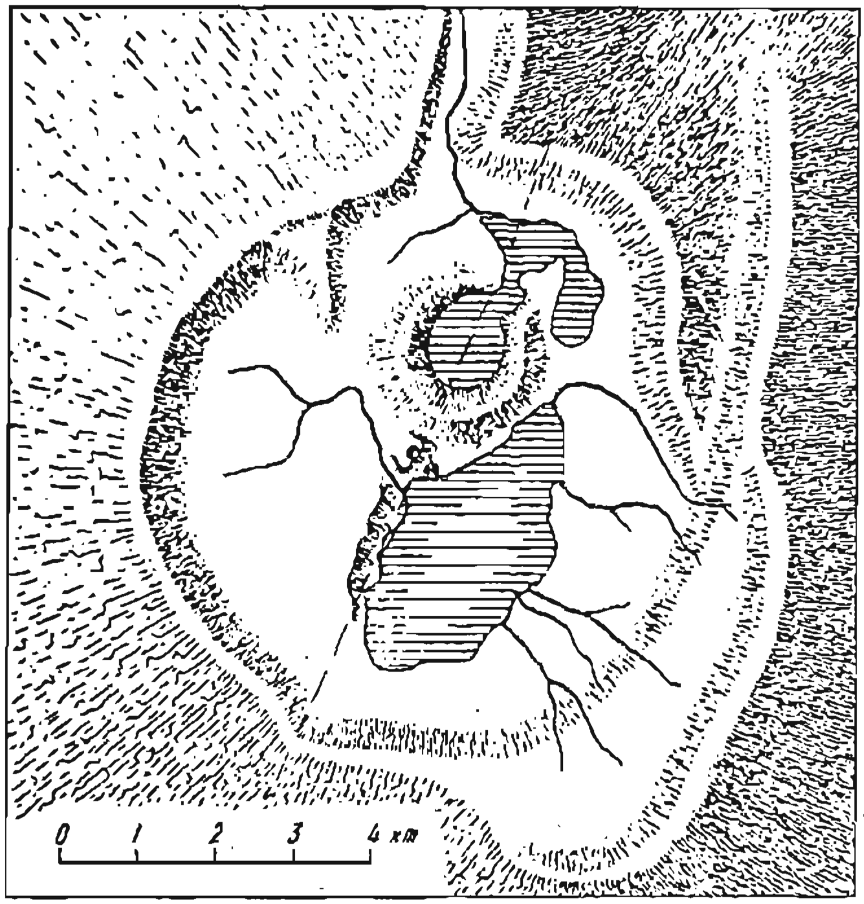
The formation of the Holocene caldera was associated with a great outburst of dacite pumice. This pumice covers a broad area around the volcano, but is most abundant on the north slope where is fills a depression that was probably formed by sector collapse. A system of basaltic ring dikes surrounding the caldera rim were probably emplaced late in the caldera-forming stage.

Eruptive Activity and Geothermal Manifestations.

The great eruption of 1907, during which Stübel cone formed, has not been studied sufficiently. Vlodavets and Piip (1959) describe it as a phreatic eruption; however, it is obvious from observations that it probably began with

Fig. 58a. - Oblique air-photo of Ksudach caldera (Sviatlovsky, 1959). On the background is seen wall of volcano-tectonic depression in which Ksudach volcano is located.

Fig. 58b. - Sketch of the summit of Ksudach volcano (from Vlodavets and Piip, 1958).



Sketch of the top of Ksudach volcano.

Hot springs are indicated by dots, the fault by a dashed line.

eruption of juvenile dacitic pumice. The pumice contains many anorthositic inclusions of the same type as have been mentioned previously in description of Il'insky and Zheltovsky volcanoes. These inclusions range in size from 1-3 cm to blocks more than 1 m across. Stübel cone, by the recent data of Solovieva (personal communication), is composed of basaltic(?) scoria and lava, and was probably formed after the dacitic pumice eruption. Therefore this single eruption was characteristic of the entire history of the Ksudach volcano, showing an abrupt change in eruptive products from dacitic tuff and pumice to basaltic lava and scoria.

At present, Stübel cone is still the main focus of activity. The cone is low and gently sloping with a steep funnel-shaped crater with a diameter of 1.5 km that is open to the northeast. Fumaroles of the mofette type with temperatures up to 80° C lie at the southern base of the Stübel cone.

4.5. Gorely caldera volcano.

Structural position and inner structure.

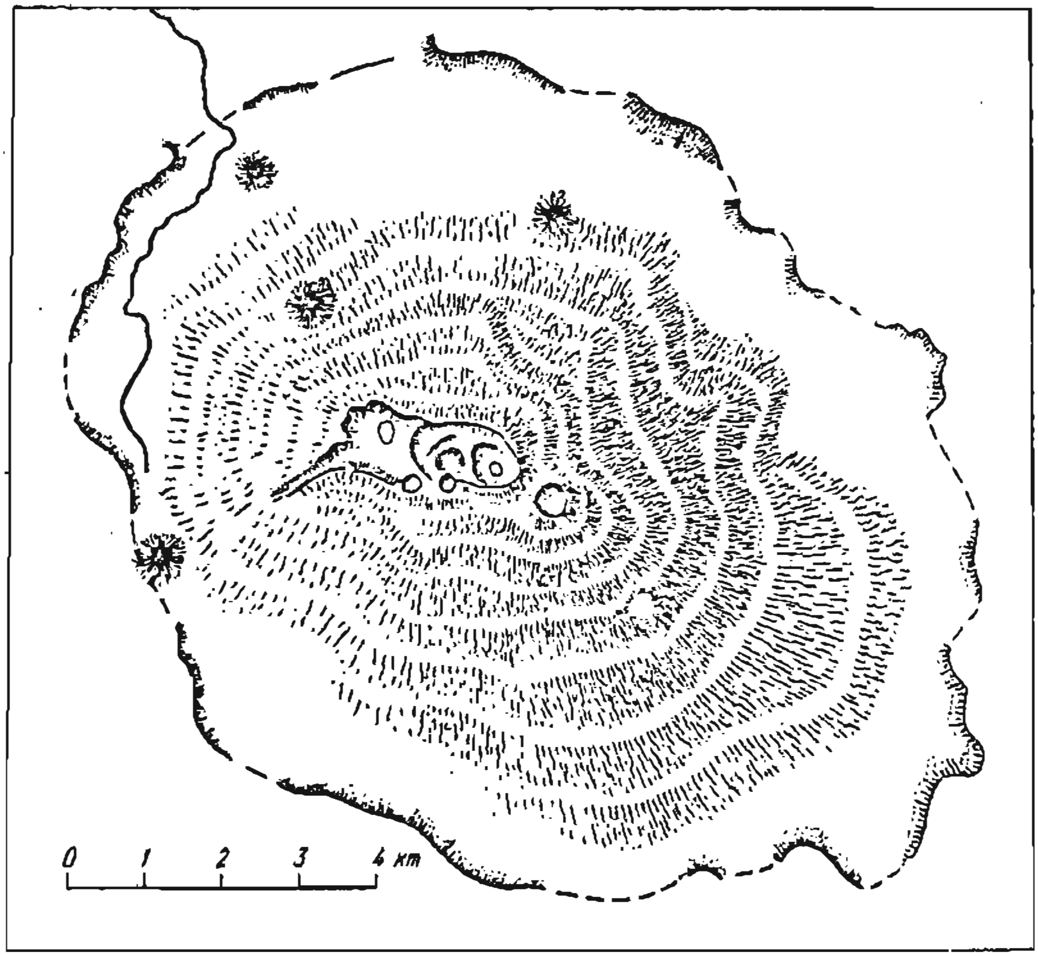
The Gorely caldera is located in the northeast corner of the southern Kamchatka graben-syncline at the intersection of several deepseated faults (see Chapter 1, Fig. 11).

The Gorely caldera is located in a characteristic location of the margin of the great negative gravity anomaly known as the "Tolmachev gravity anomaly". Several major centers of acid volcanism are located around the periphery of this anomaly including the Gorely and Opala calderas, and the Asacha volcano, with its vast volume of acid extrusive domes. The depth of the upper margin of the anomalous mass responsible for this anomaly is about 12 km. The characteristic feature of the magnetic field in the vicinity of the Tolmachev gravity anomaly is the presence of a single positive anomaly with a polygonal form, which apparently is related to the Gorely, Opala, and Asacha volcanoes. The linear character of the sides of this polygon, the coincidence of the positive magnetic anomalies with high gradient zones in the gravity, and the high intensity of the magnetic anomalies suggest that the marginal faults are deepseated, and that the depression is filled with highly magnetic magmatic rocks. Krakatau-type calderas are characteristically located in the apexes of the polygon, at the intersection of linear zones of magnetic anomalies.

The Gorely caldera has an elliptical form, is about 13.5 by 9 km in diameter, and has an area of about 100 km^2. In the center of the caldera is an uplifted area known as Gorely volcano which is also elongated in plan, with the long axis oriented in a north-northwest direction (Fig. 59). The height of the scallop-shaped caldera wall ranges from 150-200 m down to 0 m in places, where it is buried under younger lava flows. Around the margins of the caldera remnants of an extensive ignimbrite sheet of upper Pleistocene age is preserved. The area of this ignimbrite plain is about 600 km^2 and it has a volume of about 120 km^3 (not including pyroclastics removed by erosion) (in Luchitsky, ed., 1974).

The gravity anomaly associated with the Gorely caldera is generally a negative one, but it has a complicated structure. These structures may be explained by different elevations of the roof of basement blocks within the caldera. The depth to the upper margins of the anomalous blocks is about 2 km. The volume of the caldera is greater than the volume calculated from the mass deficiency suggested by the gravity anomaly (200-250 km^3 and 160 km^3, respectively).

Fig. 59. - Sketch of the Gorely caldera (Gorely Khrebet) (Vlodavets and Piip, 1959).



Sketch of the caldera of Gorely Khrebet.

Historic eruptive activity.

The Gorely volcanic cone, located within the caldera, is a shield volcano of the Hekla type, composed of basaltic-andesite and augite, hypersthene andesite. The volume of pyroclastics in the section is subordinate to lava flows, and represents only about 10-20%. As a rule, eruptions of Gorely volcano have been observed from Petropavlovsk, Kamchatka at a distance of about 150 km away. Vlodavets and Piip (1959) have described a series of normal Vulcanian explosions in 1828, 1832, 1855, 1929-1930, and 1931, and strong solphataric activity in 1947.

4.6. Opala caldera volcano.

Structural position.

The Opala caldera volcano is located in the northwest part of the southern Kamchatka graben-syncline (see Chapter 1, Fig. 11). The position of the caldera is defined by two deep-seated faults. The first major fault is the nearby east-west fault of the northern boundary of the southern Kamchatka graben-syncline. The second deepseated fault is the northward continuation of the north-trending fault along the eastern boundary of the Golygin Mountain block. It must also be emphasized that the Opala caldera is located on the margin of the great Tolmachev negative gravity anomaly, a feature which is circular in plan view (see Chapter 1, Fig. 10).

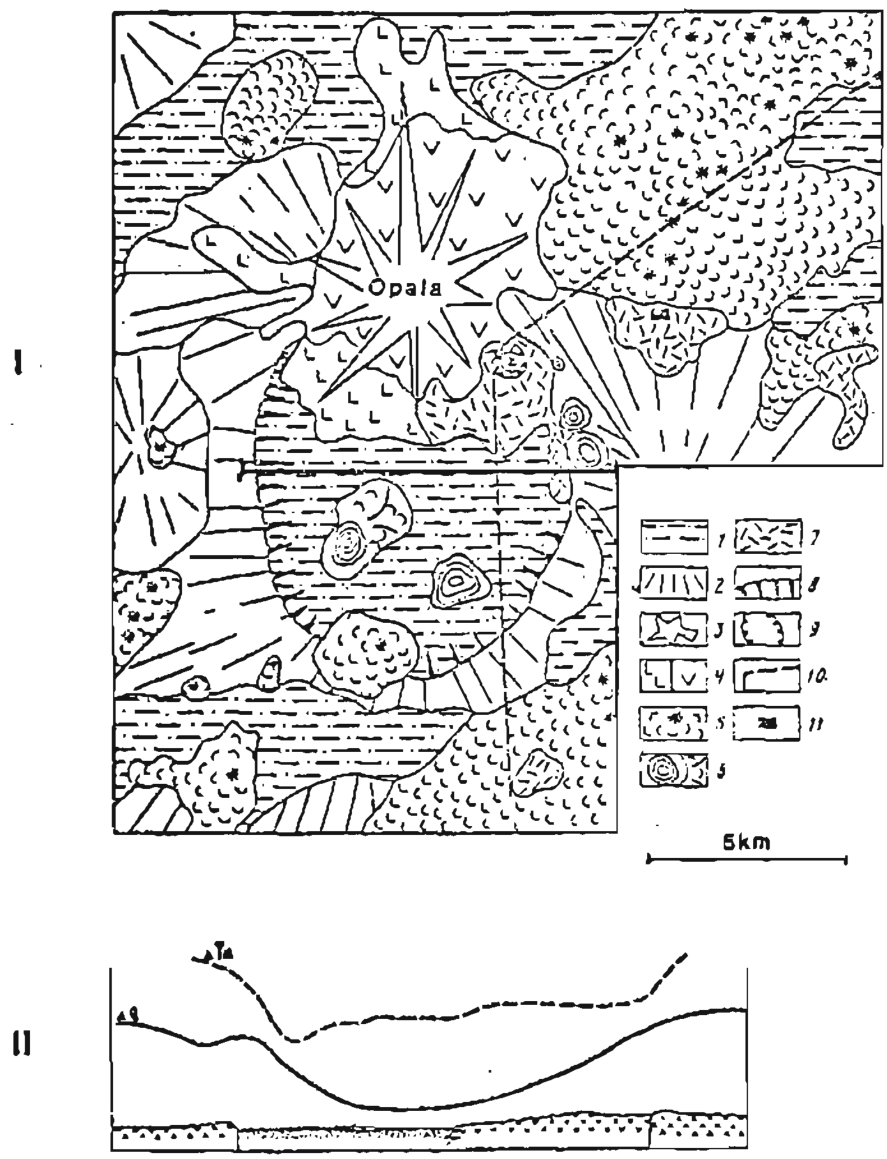
Caldera structure.

The caldera is 10-12 km in diameter (Fig. 60-I), and cuts a group of shield volcanoes that are Middle Pleistocene in age. The caldera walls range between 200 and 250 meters high and the floor of the caldera is covered by lacustrine and alluvium-colluvial deposits. Formation of the caldera was associated with the eruption of pumiceous ashflows, which with their associated fluvial deposits, covered an area of about 1500 km^2. The maximum thickness of these deposits is 30 to 60 m. Assuming that the average thickness of the ashflows from this eruption is about 50 m, the estimated volume of pumice is about 90 km^3. Stratigraphic data suggest that the caldera formed near the end of late-Pleistocene time. Melekestev (in Luchitsky, 1974) suggested, based on the radiocarbon age of organic fossils in deposits covered by tuffs associated with the caldera-forming eruption, that formation of the Opala caldera took place between about 31 and 39 thousand yrs BP, during an upper-Pleistocene interstadial. The Opala caldera is characterized by a negative gravity anomaly (Fig. 60-II), which has been interpreted as a consequence of the low-density caldera fill.

Postcaldera volcanic activity.

During Holocene time, Opala stratovolcano, with a height of 2475 m, a diameter of 8.5 km, and a volume of about 35 km^3 formed within the Opala caldera, overlapping the north wall. The early stage of formation of the stratovolcano is represented mainly by basalts; later stages in its development were characterized by eruption of andesites and dacites. The summit of the volcano consists of a dacite neck, with associated dikes that are connected directly with lava flows. Other volcanic activity associated with this late stage of development are a series of small extrusive andesitic volcanoes and a series of rhyolite extrusions on the eastern rim of the caldera.

Fig. 60. - Geologic structure of the region of Opala caldera (Sheimovich and Patoka, 1979). I. 1-Quaternary fluvioglacial deposits; 2-lower-middle Pleistocene volcanics:basalts, andesites; 3-Holocene Opala volcano; 4-andesite-dacite lavas of Opala volcano; 5-Holocene basalts and scoria cones connected with areal volcanism; 6-Holocene andesitic and rhyolitic extrusive domes and associated lava flows; 7-Directed blast deposits and rhyolite pyroclastic flows connected with the Amphitheatre of Barany crater; 8-scarps of the caldera; 9-scarps of the Barany Amphitheatre crater; 10-approximate boundaries of the sector of spreading of the pyroclastic formations of the Barany Amphitheater crater; 11-the buried charcoal locality. II. Gravity profiles across Opala caldera is added from work of Erlich, Melekestsev, Tarakanovsky and Zubin (1972).



Near the southeast foothills of the Opala stratovolcano is a large crater, known as the Barany Amphitheater. The diameter of this "blast funnel" is 1.3 by 2 km. The height of the inner walls relative to the bottom is about 200 m. The funnel is filled by a series of small rhyolite domes. An eruption of pumice with a volume of about one to ten km^3 is associated with formation of the Barany Amphitheater crater. The eruption has been radiocarbon dated at 1490±70 yrs BP (GIN 1034). Indirect data suggest that pyroclastic eruptions have occurred at this crater very recently. Lavas from the Opala volcano are characterized by numerous inclusions of partly remelted granitic xenoliths.

Historic volcanic eruptions.

Eruptions of Opala volcano have been observed from Ust' Bolsheretsk on the western shore of Kamchatka, a distance of about 100 km from the volcano. An explosive eruption in 1776, and strong solfataric activity in 1827, 1854, and 1894 have been described by Vlodavets and Piip (1959).

4.7. Bolshe-Banny (Karymshinskayaskaya) ring structure.

Previous studies.

Initial studies of this ring structure were associated with exploration for the Bolshe-Banny geothermal field, one of the largest in Kamchatka. This ring structure, first described by Erlich and Trukhin (1969), has now become widely recognized. More recently, Lonshakov (1979) proposed that the Bolshe-Banny ring structure is a part of the much larger Karymshinskaya volcano-tectonic structure (Fig. 61).

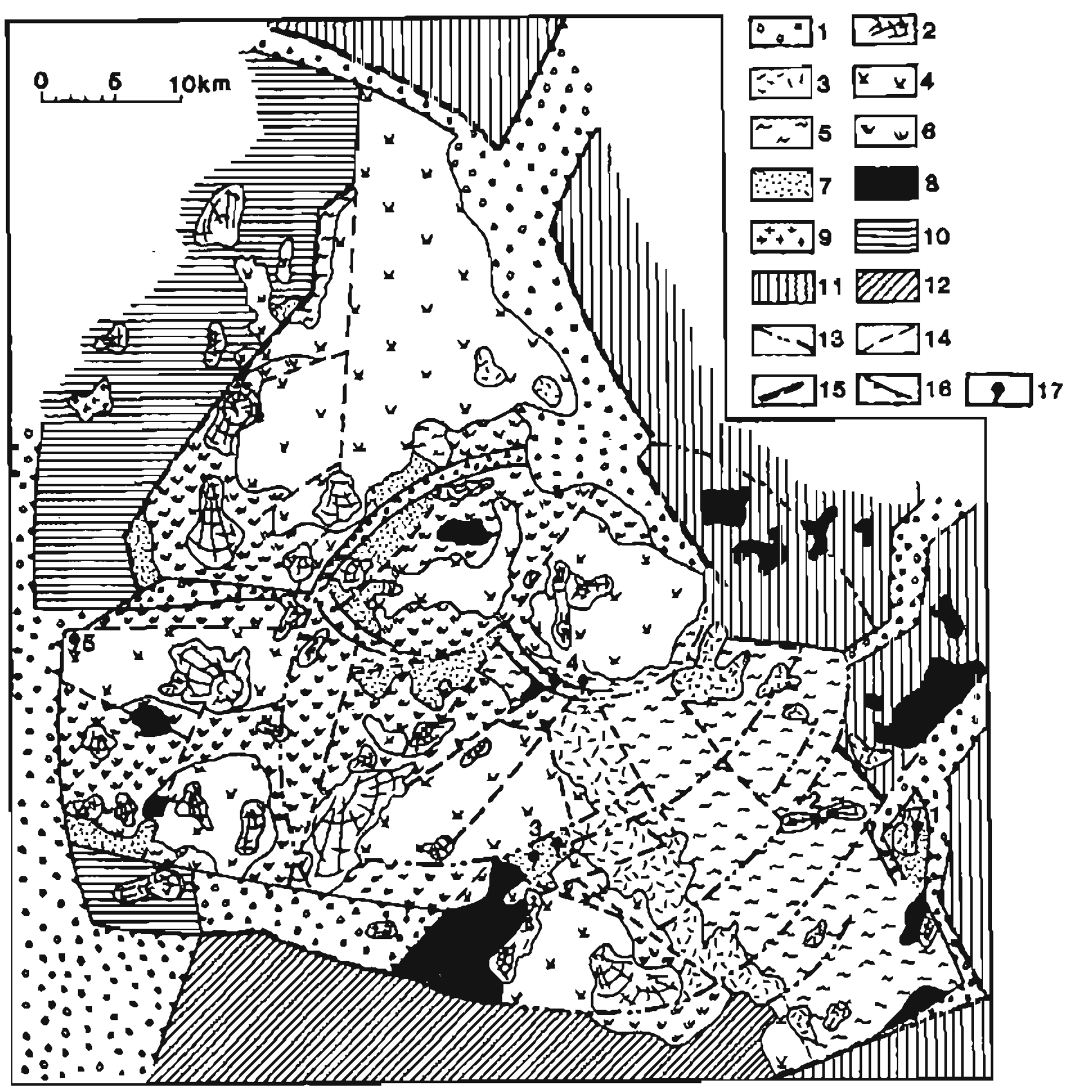
Structural position and internal structure.

This ring structure is located north of the northern boundary of the southern Kamchatka graben-syncline (see Chapter I, Fig. 11). The position of the structure is controlled by the intersection of a series of differently oriented deep-seated faults along the boundaries of adjacent structures. On the northeast is the Nachickinskaya folded-block zone which has a general SE-NW strike. On the west of the volcano-tectonic structure, is the southeast edge of the central Kamchatka anticlinorium. The southern boundary of the structure coincides with the east-west oriented, deep-seated fault system along the northern boundary of the south Kamchatka graben-syncline. Narrow grabens filled with unconsolidated Quaternary sediments are located along the margins of the volcano-tectonic structure which is bounded by vertical faults with observed displacements of about 1000 m.

The basement of the depression is composed of terrain that is Oligocene to lower Miocene in age. The basement can be divided into two suites: The lower sequence has a thickness of about 800 m and is composed of tuffs of basic to intermediate composition, siltstones, and tuffaceous sandstones; these units are intruded by dikes and sills of porphyry. The upper sequence is about 700 m thick and is composed mainly of black argillites interbedded with siltstones. The upper part of this sequence contains layers of dacitic tuffs.

The contact between these two suites of rocks is not sharp and is expressed by a gradual upward disappearance of tuffs and the appearance of argillites in the section. Both the upper and lower sequences in this structural complex are cut by intrusions of diorite-granodiorite. Rocks of this complex are characterized by intense block dislocations that sometimes dip at angles that are less than 30 to 40 degrees.

Fig. 61. - Karymshynskaya volcano-tectonic structure (Lonshakov, 1979, with additon). 1-unconsolidated Quaternary deposits; 2-Quarternary basaltic cones; 3-rhyolite extrusive domes and associated lava flows; 4-upper Miocene-Pliocene volcanics of mixed composition; 5-6-middle-Miocene rhyolite-dacite formation: a-ignimbrites; b-lavas and tuffs of intermediate and intermediate-silicic composition; 7-lower Miocene tuffaqous sediments; 8-Miocene intrusions; 9-upper Miocene instrusions; 10-12-framing structures: a-southeastern edge of the Central Kamchatka anticlinorium; b-Nachikinskaya folded block zone; c-part of Quaternary overlapped volcanic belt; 13-ring fault systems; 14-linear tectonic faults; 15-the main structure-forming faults; 16-fault bounded depressions, filled by unconsolidated Quaternary deposits; 17-hot springs (upper Paratunka, Karymchinsky, Karymshinky, Banniye, Bolshie and Malie).



Rocks of the upper structural complex, which fill the volcano-tectonic depression (Lonshakov, 1979), belong to middle Miocene and upper Miocene-Pliocene volcanic complexes.

The lower part of this complex is composed of thick tuffs that are silicic to intermediate in composition, interbedded with layers of andesite lavas. The upper part is composed of andesite, basalts-andesitic, and dacite, and a subordinate volume of pyroclastic debris. Both units are cut by small rhyolite bodies with characteristic flow banding.

The Quaternary volcanic complexes are represented by remnants of olivine bearing plateau basalt effusives that are associated with small volcanoes and scoria cones dispersed over the area. Relicts of the plateau basalts have been extensively eroded by glacial processes. These basalts are thought to be lower Quaternary in age. A younger complex of compositionally monotonous large extrusive domes with short flows of viscous lava are also present; they form ring complexes that are 5-12 km in diameter (e.g. the region of Barkhatnaya sopka, Goryachaya sopka in the Paratunka River graben, Babiy Kamen, and finally, the Bolshe-Banny ring complex). In some places, these domes are connected with ignimbrites. These domes crosscut the plateau basalts, but their eroded fragments are common in upper Pleistocene glacial moraines. The youngest volcanoes within the structure are represented by small basaltic scoria cones and flows of olivine basalt. These young basalts sometimes overlie rhyolitic extrusions, and they are absolutely undisected and are very well preserved.

The inner structure of the depression is not homogenous. According to Lonshakov (1979), it is characterized by a combination of linear and ring-shaped elements (Fig. 61). In combination they form a ring structure about 25 km across. Large upper Miocene-Pliocene volcanic centers are located in the northern part of the structure. On the opposite side of the structure, on its southern border. is a horst-like block composed primarily of middle Miocene volcanics. The total thickness of deposits filling the depression reaches 2000 m.

Middle Pleistocene extrusive domes in the region of the Banny River form a ring structure that is 12 km in diameter. Shemedogan volcano is located on its west boundary (Fig. 62). On the east it is bounded by Nachikinsky Lake graben. On the south and south-east it is bounded by an arcuate graben which contains Nachikinsky Creek and Bannaya River. The strike of the faults on the sides of the graben changes from northeast in the region of Nachikinsky Creek to east-west in the region of Bolsh-Banny Hotsprings and from there to the northwest. Absolutely no displacement has been observed along the zones that control the locations of acid extrusive domes. Basaltic volcanoes and scoria cones are located along the same joint system. The amplitude of displacement on faults on the boundaries of the arcuate graben ranges from 50-100 m up to 250-400 m (Krayevoy, Kovalenko, and Evtukhov, 1971).

<u>Geothermal activity.</u>

In the region of Bolshe-Banny Springs superheated waters with temperatures of 137-171.5° C. are located along part of the valley for a distance of 2.5 km. Hot springs can be found along 1.8 km of the valley. At depths of 25-500 m, drill holes have reached thermal waters with temperatures of 68 to 90° C.

Fig. 62. Bolshe-Bannaya volcano-tectonic structure (Erlich, Trukhin, 1969). 1-unconsolidated Quaternary deposits in recent river valleys (Nachikinsky Creek Valley, Bannaya River Valley); 2-Holocene basaltic scoria cones; 3-olivine basalt lava flows, connected with scoria cones; 4-rhyolite and obsidian extrusive domes; 5-pyroclastic flows, connected with these domes; 6-lower Quaternary scoria cones and small basaltic shield volcanoes; 7-lava flows, connected with them; 8-field of development of Upper Miocene - Pliocene lavas and pyroclastic deposits; 9-extrusive domes of andesite and andesite-dacite; 10-edifice Shemedogan central volcano of Pliocene age; 11-Lower Miocene volcanogenic deposits; 12-Upper Oligocene, Lower Miocene volcanogenic, and sedimentary deposits; 13-series of Quaternary deposits; 14-granodiorite intrusion; 15-faults: a-with uncertain direction of displacement; b-with stated direction of displacement; 16-thermal springs (Bolhiye Banniye, Maliye Banniye).

The positions of springs are controlled by the presence of shields in the form of massive granodiorite intrusions (e.g. Bolshe-Banniye Springs). Heatflow for Bolshe-Banniye Springs (considering underground and surface flow) is equal to 8400 kcal/sec; for Maly Banniye Springs heatflow is 118 kcal/sec; for Karymshinsky geothermal heatflow is 11000 kcal/sec (Krayevoy, Kovalenko, and Evtukhov, 1971).

EASTERN KAMCHATKA

5.1. Avacha caldera volcano.

Previous studies.

Avacha volcano is located close to Petropavlovsk, the largest city on the Kamchatka peninsula. Because of its location, it was described by the earliest travellers and first geologists to visit the penninsula, Krasheninnikov (1775) and Bogdanowitsch (1904). The detailed petrography of the Avacha rocks was first described by one of the earliest Soviet volcanologists, Zavaritsky (1935, and based on this description, published in 1977). The first director of the Institute of Volcanology, Academy of Science, USSR, B. I. Piip, organized a geophysical group to investigate Avacha volcano and to predict its eruptions. This group produced the first complex geophysical investigaton of the volcano (Steinberg and others, 1966). Because of its convenient location and access, Avacha volcano has been very well studied by seismological methods (Fedotov and Farberov, 1966). Avacha volvano is also the first volcano in Kamchatka where plans have been made to drill for geothermal energy from its magma chamber, based on the results of geological and geophysical investigations (Fedotov, and others, 1977). Based on all these investigative techniques, Avacha volcano has become the most intensively studied volcano of the somma-vesuvius type in all of the Kurile-Kamchatka region.

Structural position.

Avacha volcano is located in a linear row of stratovolcanoes that has a northwest trending strike (Chapter 1, Fig. 11). According to Steinberg and others, (1966), this row of volcanoes is located along a sharp flexure of the Moho discontinuity. Deep seismic sounding data suggest that the Earth's crust under Avacha volcano has anomalous structure (Figs. 63, 63a). The thickness of the crust in comparison with adjacent areas is thin and is estimated to be only 20-22 km. The thickness of the granitic layer is also thin, and is estimated at about 6 km. The basaltic layer has an estimated velocity of 7.2 km/sec and is located at a shallow depth of 9-10 km. The basement of the volcano is composed of a highly disrupted upper Cretaceous volcanic-terrigenous complex that is metamorphosed to greenschist facies. Seismic and gravity data suggest that the basement forms a linear graben with a northwest trend that coincides with the trend of the overlying volcanic chain. Geophysical data suggest that the displacement of the basement ranges from 300 m up to as much as 2.5 km (Fig. 64). On average, the roof of the basement is located at a depth of 1600-2000 m below sea level. A fault bounded graben is located about 15 km southwest of, and parallel to, the volcanic chain. A zone of weak positive gravity anomalies is located along the central part of the graben (Fig. 65); seismic data indicate that these anomalies are not connected with any recognizeable basement uplift. The coincidence of these positive anomalies with zones of extrusive domes suggests that these gravity anomalies

Fig. 63. - Map of the geologic structures of the Koriaka-Avacha volcanic region (Fedotov and others, 1977). 1-flood plains of rivers; 2-glaciers; 3-loose volcanogenic-terrigenic deposits; 4-andesite - basalt lava flows of Koriaka volcano and cone of the Avacha volcano; 5-scoria cones of basalt and andesite-basalt; 6-extrusive domes of andesite and dacite; 7-scarps of somma and craters; 8-dacite, andesite and basalt of lower part of volcanic cones; 9-cover of andesite and basalt of Upper Pliocene age; 10-sandstone, phyllite, siltstone, flinty slate, tuff and porphyry of the Upper Cretaceous complex, 11-contour line of the roof of the Upper Cretaceous basement.

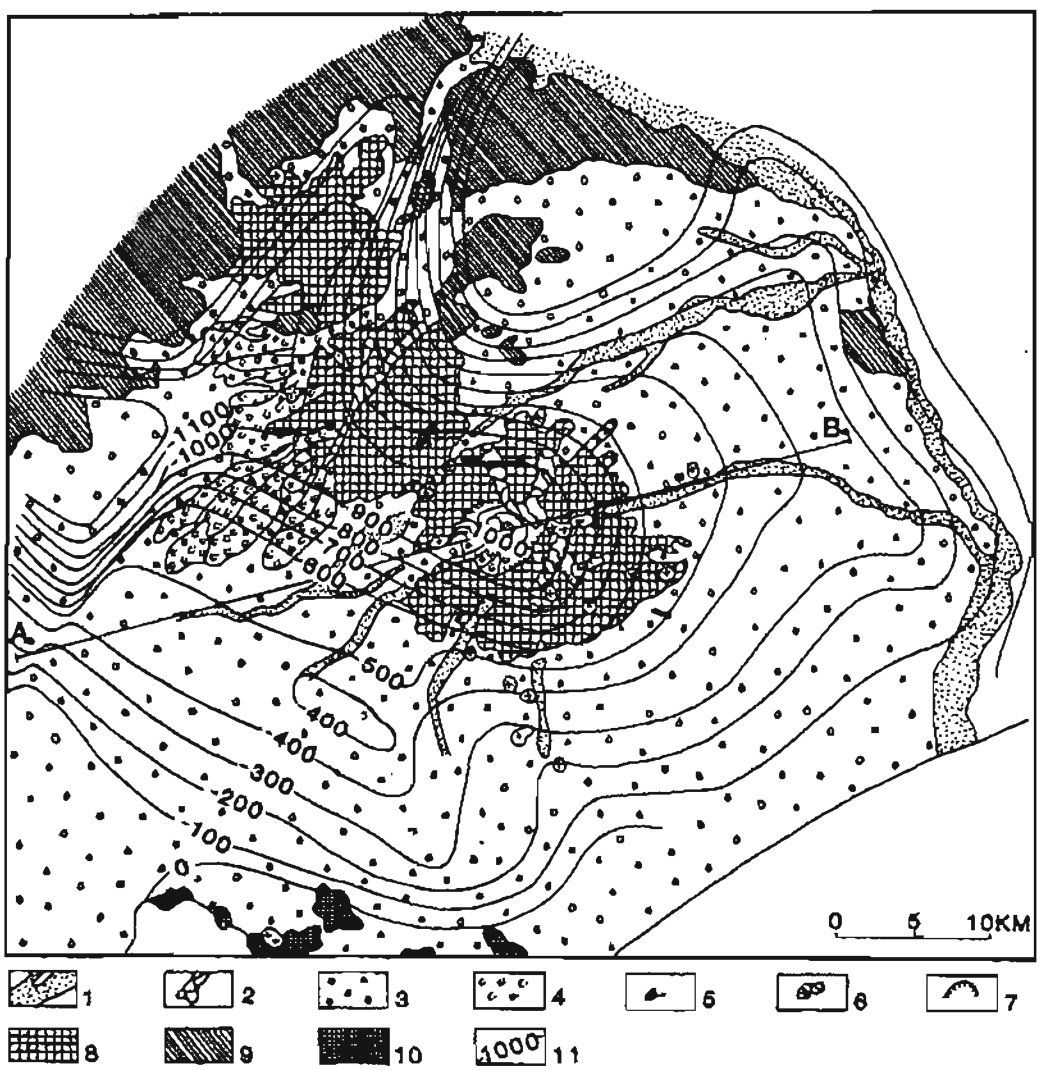


Fig. 63a. Geogological-geophysical profiles of the region of the Avacha volcano (by Fedotov and others, 1977).
1 - volcanoclastic deposits; 2 - crystalline rocks of the Cretaceous basement; 3 - "granitic" layer; 4 - "basaltic" layer; 5 - feeding channels of extrusive domes; 6 - reflecting horizons; 7 - axis of the shallow magma chamber in its widest part; 8 - center of gravity of the anomalous masses; 9 - suggested form of the magma chamber; 10 - feeding magmatic zone beneath the Avacha volcano.

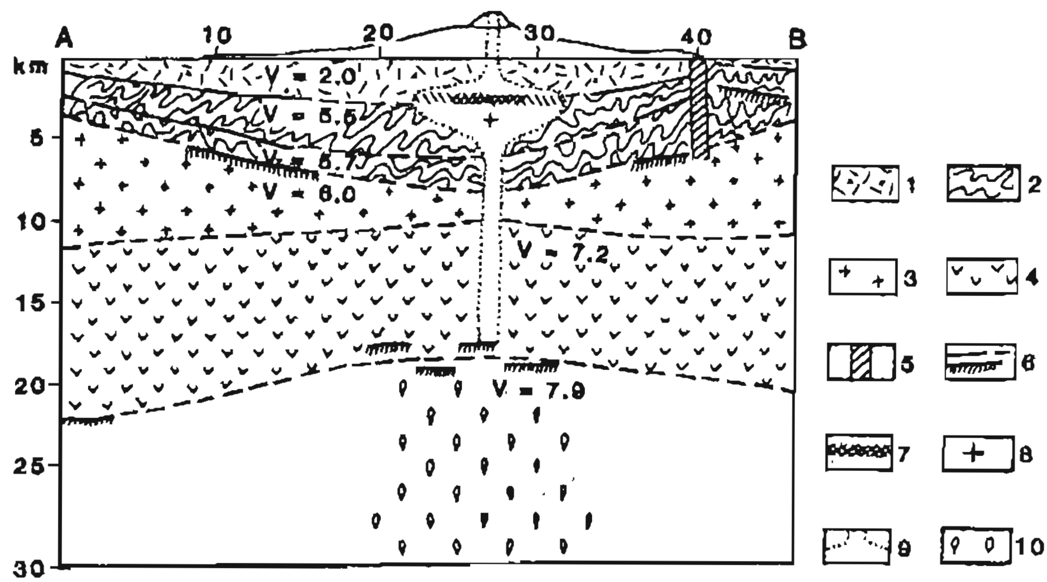


Fig. 64. - Position of the peripheric magma chamber under Avacha volcano based on geophysical data (Steinberg and others, 1966).
1 - basement with density 2.65 g/cm^3; 2 - magma chamber where density is 2.85 g/cm^3; 3 - magma chamber where rock density is 3.15.

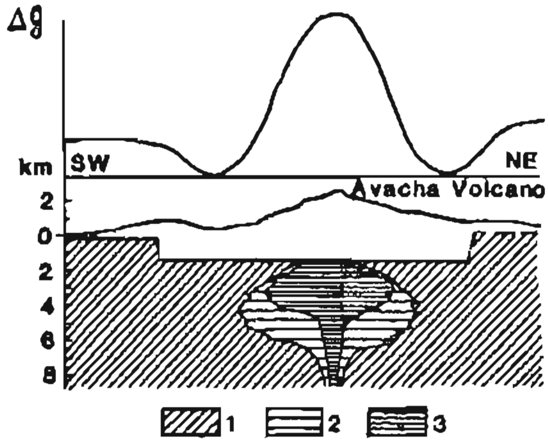
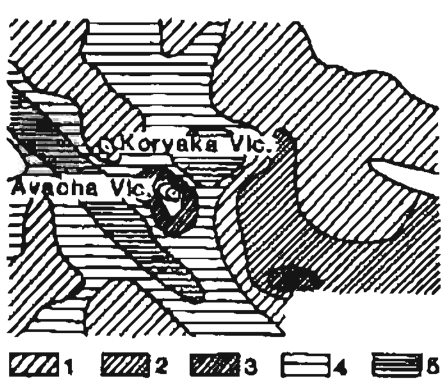


Fig. 65. - Map of the local gravity anomalies near Avacha volcanic group (Steinberg and others, 1966).
Positive anomalies: 1 - weak; 2 - intermediate; 3 - intensive. Negative anomalies: 4 - weak; 5 - intensive.



can be explained by the presence of a large volume of extrusive lava with a density of 2.5-2.56 g/cm^3, which is more dense than the unconsolidated fragmental host deposits. Fedotov and others, (1977) suggested that within the roof of the upper Cretaceous deposits, concentric ring-like depressions change into an uplifted region toward the center of the structure. According to these authors, Avacha volcano is located above the deepest part of the depression (Fig. 64, 65). The core of the ring-shaped depression is composed of Miocene volcanic and intrusive rocks. In the region of the Avacha volcanic group, the Miocene rocks are buried under a sequence of younger Pliocene-lower Pleistocene andesites, andesitic-basalts, and basalts, which form the immediate basement of the Quaternary volcanoes.

Structure of the volcano.

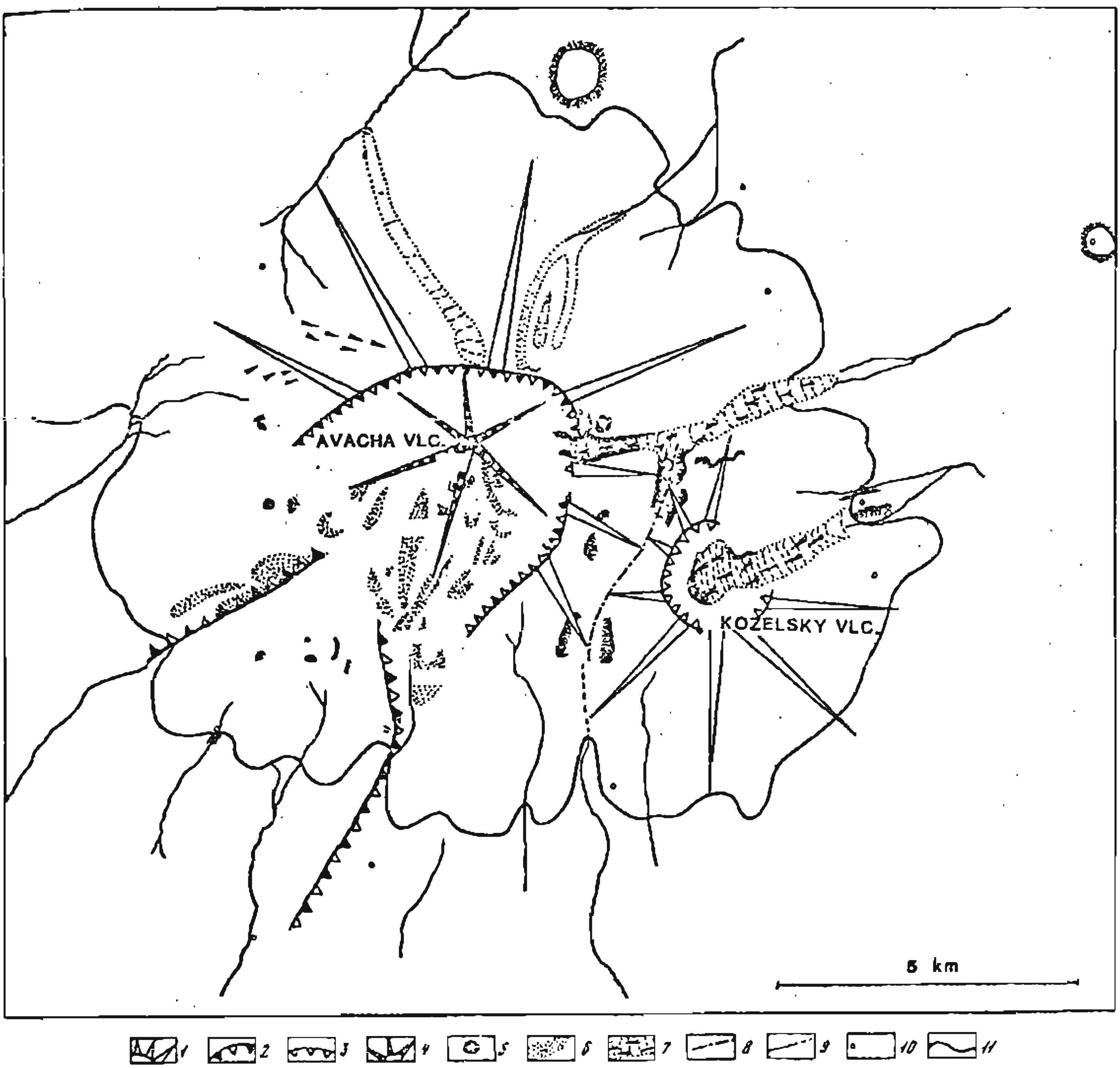
Avacha volcano is a typical volcano of the Somma-Vesuvius type, with a height of 2751 m. The volcano has a summit caldera that is about 4 km across. A young cone with a relative height of about 500 m is located off center within the crater. The somma is composed of interbedded andesites and andesitic-basalts and their agglutinates. The uppermost part of the somma section is represented by basalts. Rocks of the somma are cut by basaltic and andesitic dikes. Kozelsky volcano is located on the eastern slope of the somma (Fig. 66) which is partly comparable in age to the upper part of the somma. The somma is also cut by a series of young extrusive domes composed mainly of andesite: Mounts Odinokaya, Bulka, Dvugorbaya, Mesa, and Perevalnia. The northwest part of the somma is broken by a series of northeast striking faults. The somma is open to the southwest; it is interpreted as a down-dropped block which forms a depressed sector with a central angle of about 120°. The subsided block is bounded by radial faults and has a dip reversal toward the center of the caldera.

The early somma eruptions occurred in the upper Pleistocene epoch during the last major glaciation. Formation of the caldera was associated with a strong directed blast toward the southeast. The resulting blast deposits formed a vast plain with an area of about 400 km^2. The thickness of these deposits reaches about 300 m. Based on the relationship between blast deposits and marine terraces the blast took place during the second half of the upper Pleistocene interstadial at a time interval between deposition of terraces that are 50-60 and 28-30 m high respectively. Melekestsev (in Luchitsky, 1974) suggested that the blast probably occurred about 30 to 35 thousand years ago.

The radiocarbon age of pyroclastic flows that immediately preceded formation of the young cone is between 5480±70 yrs BP (GIN- 122), and 5455±48 yrs BP (GIN 119). Pyroclastic deposits related to the earliest eruptions of the young cone have a radiocarbon age of 3300±35 (GIN-120) and 3110±25 (GIN-121).

The young cone is composed of lava flows of pryoxene andesite, covered by pyroclastic flows of andesitic lapilli and ash. The length of most lava flows does not exceed 4-5 km; their thickness is about 10-15 m. There are at least 15 known lava flows on the slopes of the young cone. One of the pyroclastic flows on the slopes of the young cone contains large angular blocks of peridotite and pyroxenite up to one meter in size, that have sharp contacts with the host rocks.

Fig, 66. - Geologic structures of Avacha volcano (Zavaritsky, 1977 with additions).
1 - somma of volcanoes Avacha and Kozel´sky; 2 - volcanic and volcano-tectonic scarps (caldera of Avacha volcano, boundaries of landslide block); 3 - crater of the Kozel´sky volcano; 4 - recent cone of the Avacha volcano; 5 - crater; 6 - lava flows; 7 - glaciers; 8 - boundaries of volcanoes Avacha and Kozel´sky; 9 - channels of dry rivers; 10 - summits of single rocks (mainly on extrusive domes); 11 - contours of the volcanic group.



Structure of the volcano root zone.

In the region of the Avacha volcano there is a positive gravity anomaly with an intensity of several milligals that is circular in plan. This anomaly greatly exceeds the anomaly associated with the upper Cretaceous basement. The anomaly is apparently associated with a body of material under the volcano that is dense (more than 2.65 g/cm^3) relative to the density of the upper Cretaceous basement. Assuming density contrasts of 0.2 and 0.5 g/cm^3, this body can be modeled as a biaxial ellipsoid with axes: a= 5.2 km, b= 2.5 km and a= 3.5 km, b= 1.5 km respectively. The upper boundary of this body is located at a depth of 1.5-2.0 km below sealevel for both cases, i.e. practically at the level of the upper Cretaceous basement. Assuming a density of $2.85 < G < 3.15$, this body could correspond to basalt or to ultrabasic rocks, but both of these rocks types are characterized by high magnetic susceptibility. The aeromagnetic survey flown at a height of 3000 m shows a positive anomaly over the volcano which can be completely explained by the influence of the volcanic edifice (Fig. 67, 68). Thus, a residual anomaly caused by a deep-seated source was not found. The nature of the body which is responsible for this gravity high under the volcano could be interpreted as a magmatic mass with a temperature higher than the curie point for ferromagnetic minerals (> 600° C.) (Steinberg and others. 1966). A study of the distribution of seismic waves from nearby earthquakes in the region of Avacha volcano (Fig. 69; Fedotov and Farberov, 1966) shows that shear wave amplitudes are diminished (absorbed) in the region of the lower crust (20-35 km) under Avacha volcano by the value 0.039 ± 0.014 km^{-1} (based on the data from 22 earthquakes) and by a value of 0.039 ± 0.012 km^{-1} (based on data from 21 earthquakes) for the upper mantle at depths of 35-80 km. This exceeds by approximately four times the absorption of shear waves in the upper mantle under the southern Kuriles. At the same time, however, complete absorption of shear waves does not occur, i. e. there is no great liquid filled magma chamber under Avacha volcano within the depth interval between 20-80 km. The observed increase in absorption of shear waves can be explained by dissipation of elastic energy in small pockets of liquid magma. Such pockets could form up to 20% of the volume of a vertical column up to 25 km in diameter in the depth range of 20-80 km.

Volcanic eruptions

Vlodavets and Piip (1959) noted in their literature complete descriptions of volcanic eruptions at Avacha volcano in 1737, 1779, 1827, 1855, 1894-95, 1901, 1909, 1926, 1938, and 1945. In three cases, (1772, 1878, and 1881) dates of eruptions are indicated without full descriptions. Eruptions were either too weak to be of interest, or they were noted as eruptions by mistake. Eruptions are mainly of the explosive type and are always accompanied by small avalanches of loose material and often are followed by an eruption of short andesitic to basaltic-andesite lava flows whose lengths rarely exceed 5 km. As a rule, the eruptions are short in length, lasting for several hours to several days. Occasionally, several paroxysms have occurred within a single year. In these instances, the duration of individual eruptions is increased to several months.

The activity of Avacha volcano is episodic, with 1 to 3 century-long periods of intensive eruptive activity separated by 2 to 15 century long periods of relative quiescence (Melekestsev and Kiryanov, 1984). Holocene activity of Avacha volcano was characterized by violent pyroclastic eruptions of relatively silicic composition (andesite to dacite). Following a repose

Fig. 67. - Isolines of ΔT in the region of Avacha volcanic group, aeromagnetic survey at an altitude of 3,000 meters (Steinberg and others, 1966).

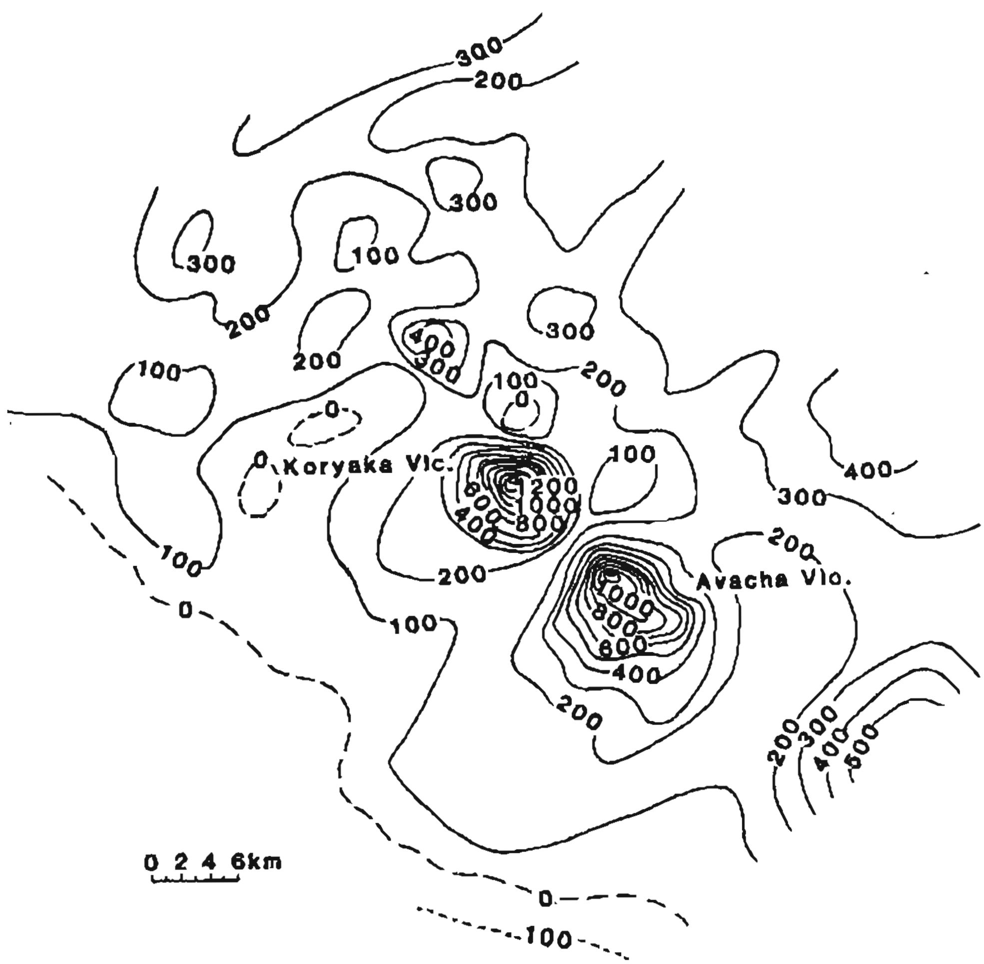


Fig. 68. - Distribution of magnetic field ΔT in the vertical plane (Steinberg and others, 1966).

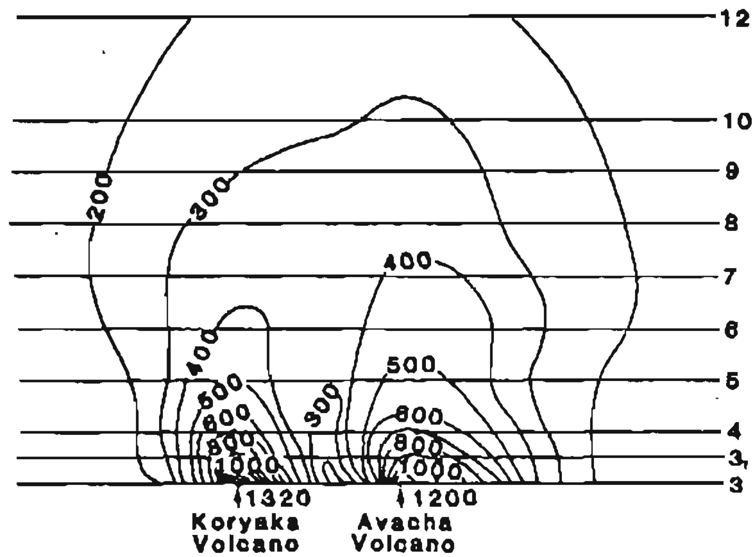
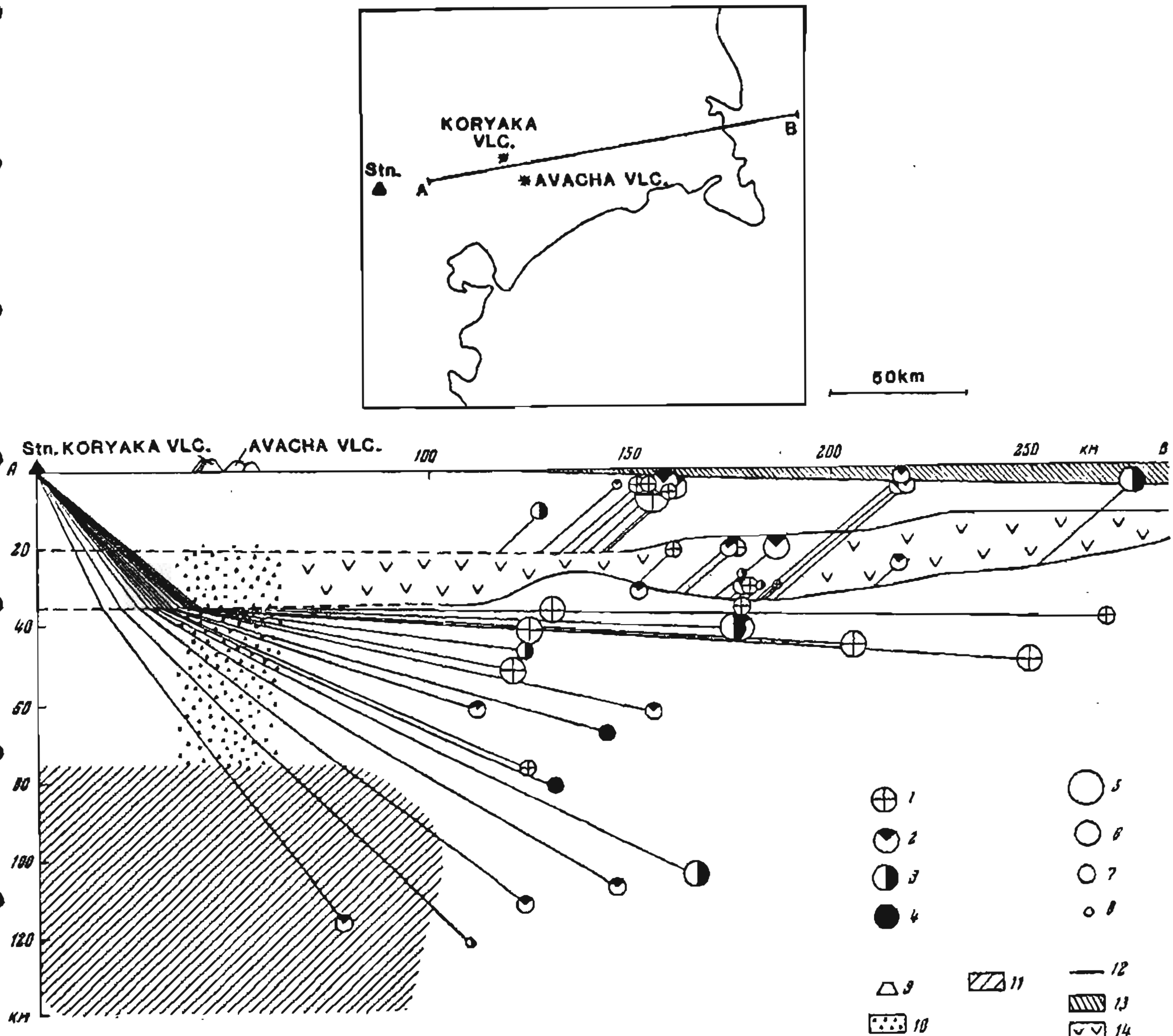


Fig. 69. - Generalized vertical section along cross section AB (Fedotov, Farberov, 1966). Earthquake foci with different meanings of K :1 = 0.73 - 0.50; 2 = 0.50 - 0.30; 3 = 0.30 - 0.10; 4 = less than 0.6. Earthquake foci of different energy classes K (energy within earthquake foci E jowles 10^K): % - K=12; 6 - K=11; 7 - K=10; 8 - K=9; 9 - volcanoes; 10. region of the magma upwelling; 11. probable region of the magma generation, 12. earthquake ray paths, 13. water; 14. basalt, lower layers of the Earth's Crust.



interval lasting 1 to 1.5 thousand years, Avacha volcano entered a new stage of intensive volcanism about 6.7 to 7 thousand years ago (cycle 1, Table 1). This cycle had a duration of 3 to 4 centuries and ended about 6370 radiocarbon years ago. This eruption began with a blast, followed by an huge (about 5 km^3) outburst of andesitic pyroclastics. The next 2 to 2.5 thousand years of Avacha's activity were characterised by relative quiescence; during the first thousand years after the blast, probably no eruptions occurred at all. Medium and strong eruptions characterized the second half of this period, layers of tephra (andesite and basaltic-andesite) with an age probably younger than 3970 yr B.P (II and III eruptive cycles). Light colored juvenile material, which was characteristic of the first half of the Holocene, is absent in the eruption products younger than 2000 yrs B.P.

The next period of intense activity of Avacha volcano began about 3600 yrs. B.P. when a series of 6 eruptions occurred, culminating with a strong blast and outburst of juvenile andesitic pyroclastics. Part of the latter form a considerable pyroclastic cover in the southern sector of the foothills (eruptive cycle IV). Within the deepest river valleys, the thickness of this cover reaches 50-6- meters. The approximate volume of juvenile pyroclastics of this stage (pyroclastic flows plus tephra) is 1.5 km^3. The average radiocarbon age of this catasrophic eruption is 3200 yrs. B.P. One of these eruptions ejected a great quantity of olivinite and peridotite blocks with a K/Ar age of about 1×10^8 years (Skripko, Farberov, Shanin, 1969).

From 4900 yrs B.P. until the present (eruptive cycles II to X), the chemical composition (pyroxene andesites and basaltic andesites) and the shapes of the pyroclasts have not changed. The similarity between the products of these eruptions and rocks of the younger cone suggest that the young cone did not start to grow earlier than 4500-6000 yrs. B.P. Construction of this cone after a period of long (about 1500 yrs.) quiescence after a catastrophic eruption of the final phase of Holocene stage of silicic volcanism and more composition of its volcanic rocks witness about beginning about 4500-500 yrs. B.P. a new stage of Avacha volcano activity.

The ninth eruptive cycle of Avacha volcano lasted from about 1100 to 1200 yrs. B.P.; the tenth (last) cycle started in A.D. 1737. The latter coinceded in time with the strongest historical earthquakes, which Krasheninnikov (1949) said continued throughout Kamchatka from the end of A.D. 1738, and were accompanied by destructive tsunamis with waves up to 65 m high. In all there were 12 or 13 eruptions, the strongest of which was in A.D. 1737, 1779, and 1945. Most of these eruptions were explosive, only in 3 or 4 cases were there also small-volume lava flows. Based on the thicknesses and distributions of the tephra deposits, the maximum tephra volume was erupted during the eruption of February 25, 1945 (about 0.25 km^3). The volumes of tephra erupted in 1737 and 1779 were around 0.05 to 0.1 km^3; all other eruptions yielded around 0.05 km^3. The total volume of all solid products erupted during the last cycle do not exceed 0.6-0.7 km^3; their weight is about 10^9 tonnes. The average intensity of volcanic products discharged for the last 800 years have been equal to only about 1.2×10^6 tonnes per year. This is less than the rate of discharge for the young cone: about 2.2×10^6 tonnes per year for the period 3000 - 5000 yrs. B.P. and about 2.5×10^6 tonnes per year for the first half of the Holocene. Avacha volcano's decreasing discharge rate may be related to its increasing age. This may also explain (?) the long repose between eruption cycles IX and X. With such discharge rates, the next eruption should occur within 30 to 400 years, or perhaps more. Each eruptive cycle culminated with a strong eruption. The same was observed during the last historical cycle of activity (1737-1945).

TABLE I

ERUPTIVE CYCLES OF AVACHA VOLCANO IN HOLOCENE TIME*

Cycle	Age of activity interval (yrs.)	Repose duration (yrs.)	C^{14}-age data
X	A.D. 1945-1737		
		550	
IX	A.D.(?)1200-1100		
		200	
VIII	A.D.(?)900-700		1240±100, IVAN 4000 1490±70, GIN 1039 1420±250 GIN 2911
		300	
VII	400±**		
		300	
VI	100±		
		300	
V	3300 B.P.±		
		1400	
IV	3500-3700 B.P.		3300±35 GIN 120 3110±20 GIN 121
		500	
III	4900 B.P.±		
		700	
	4900 B.P.±		5555±45 GIN 119 5480±70 GIN 122
		1500	
	6400-6700 B		

** Indicates exact interval is unknown
* Modified from Melekestsev and Kiryanov, 1984

Constant volcanological monitoring of Avacha since 1945 has shown no significant changes. In the present repose the heat capacity of the volcano is estimated as 75 thousand kilowatts (Fedotov and others, 1977) on the basis of heat discharge in the crater and as 60 thousand kilowatts on the basis of the height to which a plume ascends from the crater. This value coincides with the value for the last 800 years (about 60 thousand kilowatts), calculated on the basis of the heat discharge by eruptive rocks.

Geothermal manifestations.

Thermal hotsprings are absent in the vicinity of Avacha volcano. Nevertheless, there is a marked increase in the temperatures in drill holes that is thought to be connected with the presence of a magma chamber at comparitively shallow structural levels. Based on these data and the distribution of temperatures within the crater of the volcano (Fig. 70), Fedotov and his collaborators (1977) calculated heat resources within the host rocks and proposed construction of a geothermal power station.

5.2. Caldera Group of the Zhupanovsky (Karymsky) volcano-tectonic depression.

History of study.

Study of the calderas of this group have been concerned mainly with the most active volcano on Kamchatka, i.e., Karymsky volcano, and geothermal manifestations of another active volcano, i.e., Maly Semiachik.

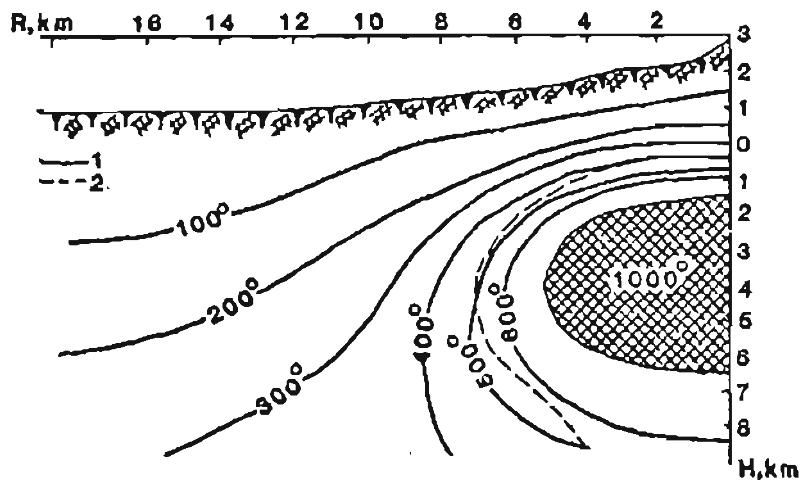
The impressiveness of these volcanic features, and their relative accessibility, have made them among the most studied volcano-tectonic structures in Kamchatka.

The first description of volcanoes of this region was made by Vlodavets (1947). Ivanov (1970) produced a monograph concerning Karymsky volcano. Steinberg and Zubin with the same Ivanov (1971) described geophysical data from the Karymsky volcano caldera. Chirkov (1970) studied the radon content in geothermal waters of the region; in later work (1971) he correlates radon contents with volcanic activity.

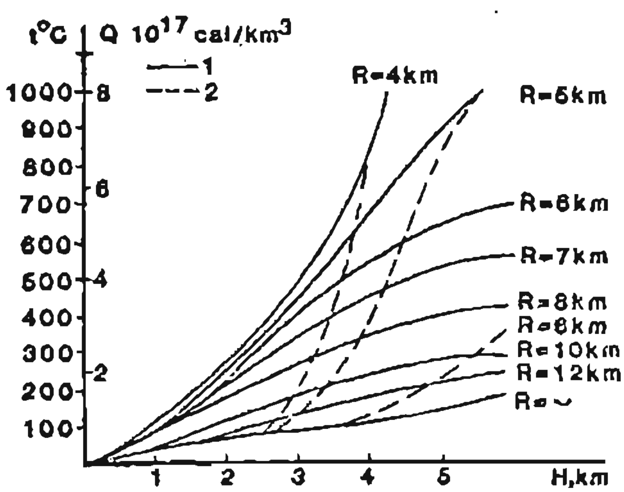
A volcano observatory was constructed in the late 1960's for the purpose of continuously monitoring the activity of Karymsky volcano. A series of studies were conducted from the late 1960's until the early 1970's on Maly Semiachik volcano: a complex geological-petrological study by Seliangin (1977), a geophysical study by A.P. Gorshkov (1976). Detailed tephrochronological studies were first conducted in this region in the mid-1970's (Seliangin and others, 1979; Braitseva and others, 1978). These studies really opened a new page in the study of Quaternary volcanism in Kamchatka. Because of aerial photo interpretations and regional structural analysis, Erlich (1966), it was first suggested that the calderas of this region are elements of nesting volcano-tectonic ring structures. Because of this work, the name Zhupanovsky volcano-tectonic depression has been inferred. In the late 1970's a monograph was compiled concerning the volcanoes of this region (Masurenkov, ed., 1980a). Following the previously developed ideas of Erlich (1966), the authors of this monograph considered the entire group of volcanoes and volcano-tectonic structures to reflect a single great center.

Fig. 70. - A. Distribution of temperature under Avacha volcano (Fedotov and others, 1977): stationary distribution temperatures; isotherms 250° C after 20,000 years. B. Resources of heat in the region of Avacha volcano as function of the depth and distance from volcano: under stationary heat flow conditions, 2-20,000 years after magma chamber generation.

A



B



Terminology accepted.

Details of geological development, names of some certain structures in the region and even their quantity are still unclear and are described in different ways in works of different authors.

Here we follow mainly the most recent collective monography on the subject (Masurenkov, ed., 1980a).

By the data of this monograph, within Zhupanovsky (Karymsky) volcano-tectonic depression on the background of a dome (or shield) two great nested calderas are developed: (1) Polovinka caldera (with Odnoboky and Akademii Nauk caldera-volcano inside) and (2) Stena-Soboliny caldera (with Maly Semiachik caldera volcano inside). By the data of Seliangin (1977) here also present Krayny caldera-volcano. These two calderas are divided by stable blocks within which the caldera volcanoes Dvor and Karymsky are located (Fig. 71). Of the many calderas in the region, only the caldera of the Karymsky volcano is comparatively well described.

The name Zhupanovsky was proposed by Erlich (1966). In collective monography edited by Masurenkov (1980a) the name has been changed to Karymsky. Here we follow the first given name because the name Karymsky is too often used for different structures and volcanoes and could produce undesirable confusion.

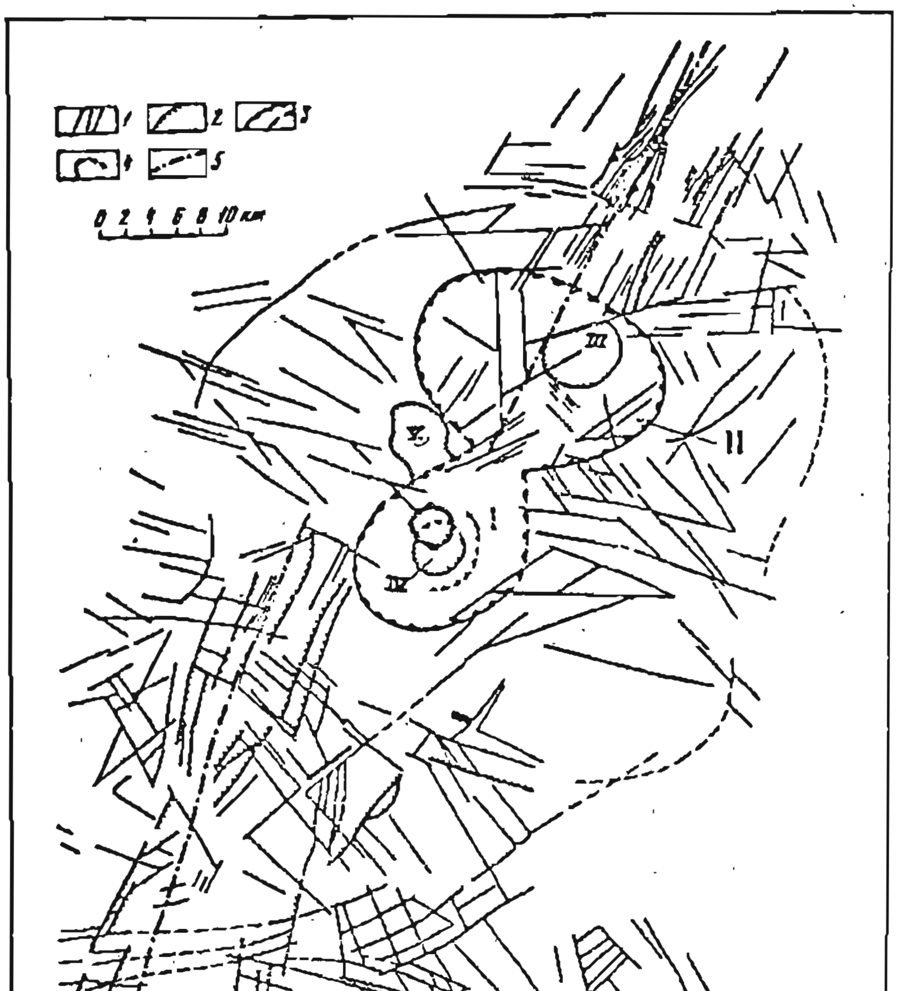
Structural position.

The Zhupanovosky (Karymsky) ring structure is located within the Eastern Kamchatka graben-syncline, immediately to the north of the Avachinsky-Zhupanovsky groups of volcanoes. The exact position of the Karymsky ring structure within the graben-syncline is determined by two factors. First, it coincides with a large ring-shaped (about 40 km in diameter) negative gravity anomaly (see Chapter 1, Fig. 10). This anomaly is exactly the same--in size, shape, intensity, and correlation with different geological structures--as anomalies in Southern Kamchatka. Second, deep-seated east-west strike-slip faults cut across the central part of the Zhupanovosky (Karymsky) ring structure. This system of deep-seated faults coincides with a zone of earthquake foci with depths of more than 50 km (Erlich, Melekestsev in Luchitsky, ed., 1974) (see Chapter 1, Fig. 12). The highest gradients of the gravity field coincide with the zone earthquake foci. A system of east-west faults, with lengths of up to 20 km (average length 8 km), is visible at the ground surface above the zone of earthquake foci. Along this 6 to 8 kilometer-wide zone, structural elements of the northern part of the ring structure have undergone right-lateral displacement about 5 km to the east. This fault zone marks the contact between sectors in which two different volcano-tectonic processes are operative: volcano-tectonic depressions of the Stena-Soboliny volcanoes to the north and Polovinka caldera to the south. Masurenkov states that this zone divides the Akademical and Semiachik sectors of the structure slightly different in geological history. The Dvor and Pra-Karymsky and the caldera of Karymsky volcano are located within relatively stable blocks which follow the fault zone.

General internal structure.

Inside outer boundaries of Zhupanovsky (Karymsky) volcano-tectonic depression is located on a flat shield about 40-60 km across. The genesis of this shield is still unclear; different authors have interpreted it in different ways. Erlich (1966) and Seliangin (1977) suggested that it is mainly the product of volcanic accumulation. Masurenkov (1980) thought that most of the shield formation was due to tectonic processes and, therefore,

Fig. 71. Scheme of faults and internal structure of Zhupanovsky (Karymysky) volcano-tectonic depression (Masurenkov, ed., 1980a).
Linear Faults: 1 - without visible displacement; 2 - ring faults of caldera boundaries with visible displacement; 3 - Middle--Pleistocene faults; 4 - Upper Pleistocene--Holocene faults; 5 - axis of longitudinal rift (in process of formation). I. Polovinka caldera; II. Stena-Soboliny caldera; III. Caldera of volcanoes Karmysky and Dvor; IV. Calderas of Odnoboky and Akademii Nauk (Karymsky Lake) volcanoes; V. Caldera of Maly Semiachnik volcano.



that the shield is a kind of tectonic or volcano-tectonic dome. In any case, the dome (or shield) is composed of volcanic rocks of Upper Pliocene-Lower Quaternary age, which form the basement of the Quaternary volcanic centers. Rocks of the shield are mainly lavas of basalt and basalt andesite and dacitic ignimbrites of different ages. All of these rocks show reversed magnetic polarity. Two concentric fault systems are present on the shield. One of these is along the outer border of the shield, along the Zhupanova and Semiachik rivers. Locally, recent river valleys follow narrow grabens in this outer system. The second concentric ring-fault system is formed by boundary faults of the two greatest volcano-tectonic depressions, nested calderas, within the Zhupanovsky (Karymsky) ring system--Stena and Soboliny to the north and Polovinka to the south. The depressions are separated by narrow linear stable blocks which coincide with the previously mentioned east-west system of deep-seated strike-slip faults. Inside these two large volcano-tectonic depressions are the calderas of Maly Semiachik, Karymsky, and Akademii Nauk (Karymsky Lake) volcanoes. The displacement along the concentric fault system bounding Polovinka and Stena-Soboliny calderas is not less than 300-400 m, but probably not more than 500-600 m (Masurenkov, ed., 1980a). In addition to concentric fault systems, the shield is broken by a series of linear faults. Quaternary volcanoes are located along some of the linear faults. Faults of a north-south trending system are not very well expressed in surface fissures or faults. Nevertheless, Quaternary volcanoes inside volcano-tectonic depressions are located along north-south trends. Narrow (2-3 km wide) northeast and northwest striking grabens (Fig. 71) are located just north of the east-west system of deep-seated strike-slip faults. A system of northeast-trending faults define the position of Maly Semiachik volcano and a linear chain of volcanic centers within it caldera. Especially intense faulting has occurred in a narrow strip trending 25-30° east to north. These faults typically exhibit vertical displacements of 100-200 m. The width of this strip is about 10-20 km (it averages 12 km). In the southern part of the ring structure, along the main east-west system of deep-seated strike-slip faults, this strip is shifted approximately 5 km westward. As is evident from Fig. 71, the faults of this system are younger than faults of the concentric systems. In general this linear system of faults which bounds the largest calderas is directly analogous to faults which cut many other calderas; for example, Krasheninnikov and Ksudach. This pattern reflects intense extensional processes in Holocene time in eastern Kamchatka. In each case it the faulting was developed after caldera formation.

Volcanism and structural development.

Early stages of volcanism development within Zhupanovsky (Karymsky) volcano-tectonic depression is unlcear. By the data, described in Masurenkov, ed., (1980a), Upper Pliocene volcanic rocks are represented by several suites. Marine sedimentation in this time gradually gave way to subaerial continental sedimentation, including some coal deposition. The uppermost part of this sequence contains up to 45% volcanogenic material, including trachybasalt flows. These flows yield a radiometric age 3.8 - 4.2 million years B.P. The upper part of the sequence is composed silicic pyroclastic rocks that cover an area about 3000 km^2. The age of this ranges from Uppermost Pliocene to Lower Pleistocene time. Ignimbrites of this complex are characterized by stable reversed magnetic polarity.

According to Seliangin (1977) and Masurenkov, ed., (1980a) volcanic process is developed in the form of several great rhythms, divided by paroxismal eruptions of silicic volcanic rocks and caldera-forming processes.

Eruptive centers of this complex are probably located in the region of the Maly Semiachik, Soboliny, Dvor and Karymsky volcanoes, i.e., in the northern part of Zhupanovsky (Karymsky) volcano-tectonic depression. This location is indirectly confirmed by the presence of limnic deposits in the basin of Zhupanova river. Diatomic flora from these deposits indicate fresh-water sedimentation, so this paleo-basin was isolated from the ocean (Fig. 72). The visible thickness of silicic pyroclastics, including ignimbrites, totals 70-100m. This composition ranges from andesites to rhyodacites (58-68% SiO_2). All the rocks of this pyroclastic blanket belong to one of two discrete groups: rhyodacites and andesites. A gap on SiO_2 content of 6% consistently separates these two groups. It is thought to be results of synchronous eruption of heterogenous melt composed of two unmixed magmas-andesites and rhyodacitic. Volcanic rocks of intermediate and mafic composition occur to the east from the Zhupanova river, near Razlaty and Dvor volcanoes. According to Masurenkov, ed., (1980a) the completion of this stage of silicic volcanism and the simultaneous sedimentation of the limnic environment was accompanied by formation of a series of stratovolcanoes composed of basalt andesite (48-55% SiO_2) at the beginning of Lower Pleistocene. This rhythm of volcanism was supposedly complete by the end of Pliocene-beginning of Lower Pleistocene time. Volcanic rocks of this rhythm have been leveled by eroision resulting in a great flat plain that is slightly inclined toward the ocean. It is supposed that, between the end of the first and the beginning of the second rhythm, there existed a short repose interval during which this plain was formed. The surface of this plain is overlain by lavas of Zhupanovskiye Vostriaky volcano and loose glacial deposits.

During the second rhythm basalts and the basaltic andesites with total volume of about 375 km^3 were emplaced. These eruptions were characterized by the construction of strato- and shielf volcanoes and, to a lesser extent, by fissure-zone eruptions. The ring complex of central volcanoes was formed during this stage (Fig. 73). Characteristically, the average composition of rocks in this complex vary systematically outward from dacitic at the center to basaltic at the margin (Fig. 74, 74a). On this basis, it was suggested that this pattern reflects the compositional zonation of magma body located within an underlying basement structure (Masurenkov, ed., 1980a). The end of the second rhythm was marked by the period of repose during which erosion of Early-Middle Pleistocene volcanics occurred.

After this repose period, the formation of two great calderas - Polovinka and Stena-Soboliny occurred, associated with an eruption (about 280 km^3) containing ignimbrites and pyroclastic material.

The next rhythm of volcanism began at the end of the Middle Pleistocene. It is characterized by the formation of basalt and basaltic andesite volcanoes: Odnoboky, Beliankina, Pra-Semiachik, Dvor, Akademii Nauk. Cyclicity is characteristic of the evolution of these volcanoes. Typically the chemistry of the volcanic rocks varies from basalts and basaltic andesites to dacites and rhyodacites. Development of all of these volcanoes was completed by the next stage of silicic volcanism when three young calderas formed: Akademii Nauk (Karymsky Lake), Maly Semiachik and calderas of volcanoes Dvor and Karymsky. This stage of the caldera formation took place at the end of Upper Pleistocene and beginning of Holocene time. Unwelded pyroclastic deposits, pumice and agglomerate tuffs, are associated with each of these calderas.

Fig. 72. Facies of Upper Pliocene volcanogenic and volcano-sedimentary rocks in the region of Zhupanovsky (Karymsky) volcano-tectonic depression (after Masurenkov, ed., 1980a).
1 - the first pyroclastic cover (tuffs and ignimbrites); 2 - lacustrine deposits; 3 - more (a) and less (b) probable contours of volcano-tectonic depression; 4 - lava facies of Upper Pliocene volcanogenic complexes.

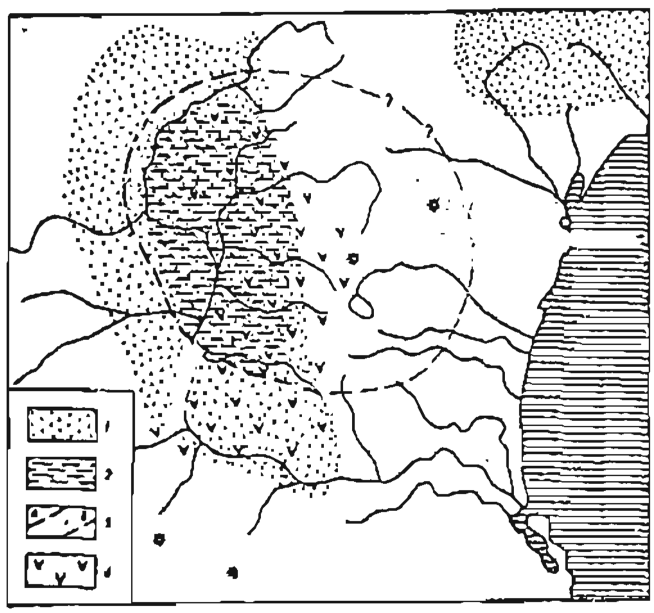


Fig. 73. Reconstruction of the domal surface of Early Pleistocene and strato-volcanoes located on it (after Masurenkov, ed., 1980a).
1 - Isolines of the Upper Pliocene roof surface; 2 - strato-volcanoes.

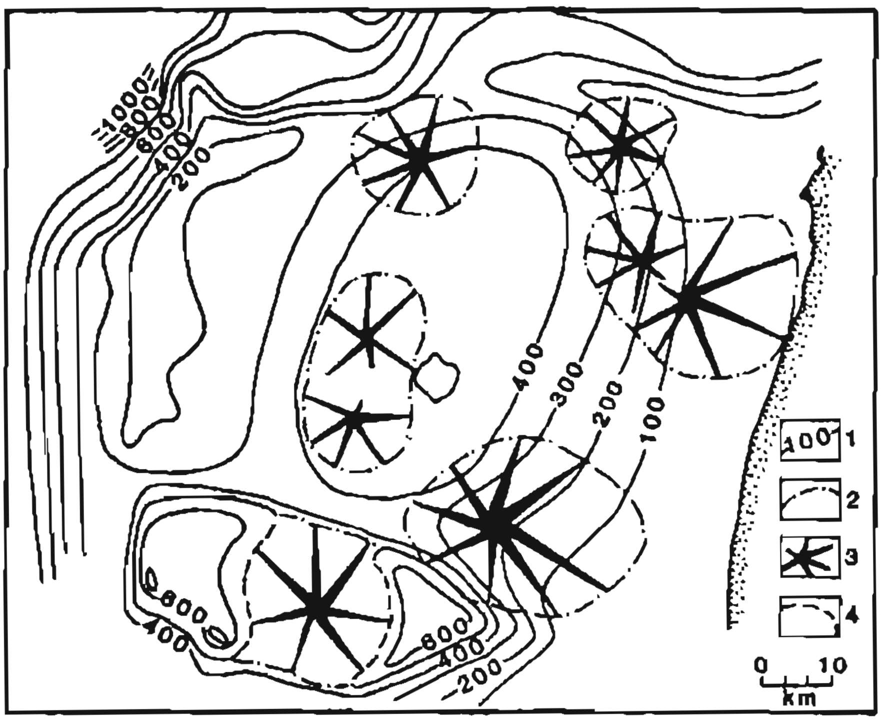


Fig. 74. Concentric zonal distribution of average chemical composition of strato-volcanoes in connection with intensity of vertical movements deformation of the domal surface (after Masurenkov, ed., 1980a). Deformation of the domal surface is shown in plan, distribution of oxides on profiles: 1 - lines of equal uplift, drawn on the basis of the difference between basal surfaces IV-V (A) and V-VI (B) (constructed as surface of equal downcutting of valleys for rivers of IV, V, and VI order); 2 - distribution of average concentration of iron oxides (A) and and silica (B); 3 - distribution of the sum of alkalies; 4 - strato-volcanoes.

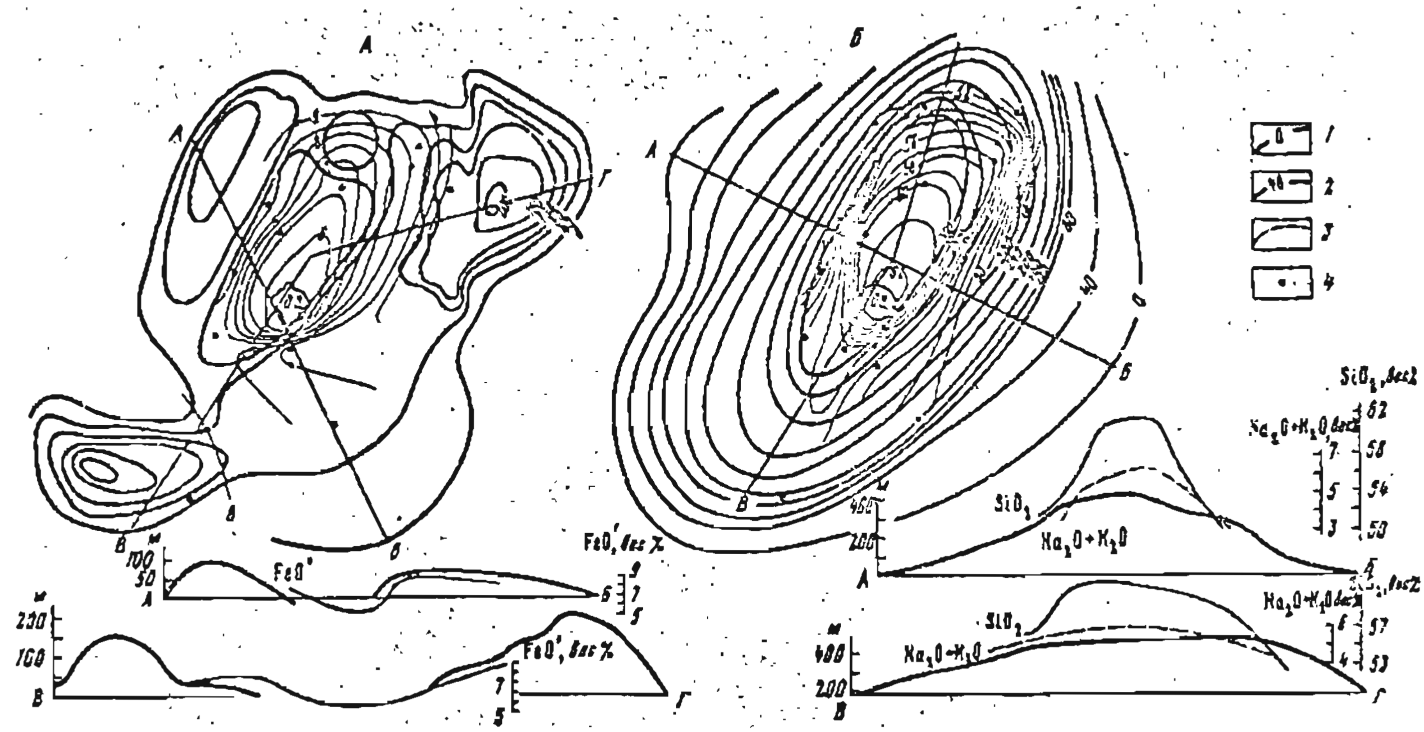
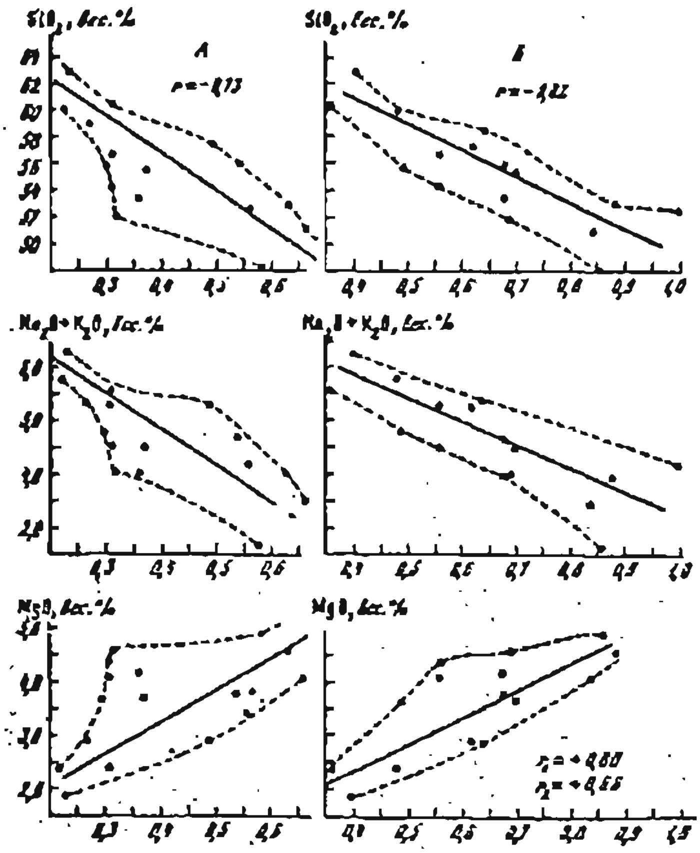


Fig. 74a. Correlation between average content of some oxides in stratovolcanoes and the distance from the center of the structure (after Masurenkov, ed., 1980a). A - for average contours of domal structure (on the basis of whole set data of morphometric analysis); B - for depression on the summit of the dome for Middle Pleistocene time (on the basis of difference between IV and V basic surface).



5.2.1. Polovinka Caldera (caldera volcanoes Odnoboky and Akademii Nauk).

Subsided block of Polovinka caldera is located to the south of east-west fault system, divided Zhupanovsky (Karymsky) volcano-tectonic structure (Fig. 71).

Formation of this caldera is accompanied by formation of a cover of tuffs and agglomerates andesitic and dacitic in composition, mixed with some amount of resurgent material (not more than 5-10% of their total volume). They completely fill the caldera and form a cover south-southeast from it.

Composition of products of caldera forming eruptions and their time are about the same on Polovinka and Stena-Soboliny calderas. Both structures were formed simultaneously in the second half of the Middle Pleistocene. These facts support the idea regarding the close genetic connection and single source of their magmas. Total volume of silicic volcanic products, connected with both calderas is estimated at about 280 km^3.

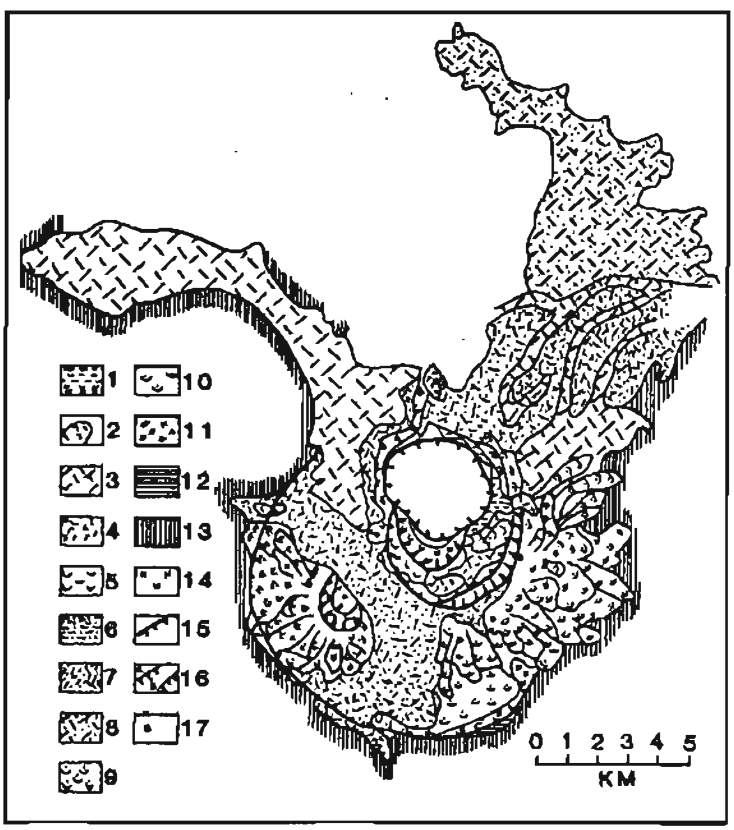
Post-caldera stage of activity.

Inside Polovinka caldera are located three post-caldera volcanoes composed by basalts and basaltic andesites, stratovolcano Beliankina, strato-cone composed by andesites and basaltic andesites and caldera volcanoes Odnoboky and Akademii Nauk (Fig. 75). These volcanoes overlap litificated tuffogenic sequence represented by dacitic and andesitic tuffs in which some layers of sedimentary (lacustrine?) deposits are present. Due to a variety of differences in the genesis and composition of the rocks present in these tuffs, they are named "dikiye" (wild) tuffs. Odnoboky volcano is composed mainly by basalts and basaltic andesites. Akademii Nauk volcano is formed by sequence of interbedded andesitic lava flows 13-15 m thick and 300-400 m in length and agglomerate tuffs of the same composition 5-35 m thick. The upper part of the sequence on this volcano is composed by roughly-stratified gravelitic tuffs and grey pumice with a mixture of volcanic ash. The final stage of volcano development is characterized by the emplacement of a series (not less than four) dacitic extrusive domes located along arcuate fissure. Probably along this fissure a series of blocks are subsided during the caldera forming stage. As a result of this development, Odnoboky caldera volcano which is 5 x 4 km in diameter and Akademii Nauk (Karymsky Lake) caldera which is 3 x 5 km in diameter were the last volcanic centers formed. The emplacement of extrusive domes and the formation of Akademii Nauk caldera were accompanied by an eruption of pyroclastic flows, which filled a trio between Odnoboky and Akademii Nauk volcanoes. Silicic volcanic rocks, associated with Akademii Nauk caldera have been dated by different radiometric methods at 80 thousand to 17.8 thousand years B.P. (Masurenkov, ed., 1980a). In the upper part of the sequence, pumice associated with Akademii Nauk caldera are overlapped by the Holocene pumice and lapilli. At this time the caldera of Akademii Nauk volcano is filled by Karmysky Lake. Around the lake low-temperature geothermal activity has taken place.

5.2.2. Stena-Soboliny caldera (caldera of the Maly Semiachik volcano).

This structure is represented by a subsided block 20 x 15 km across, located in the northern part of Zhupanovsky (Karymsky) volcano-tectonic depression. It has an irregular oval shape with a long axis stretched northwest-southwest-southeast. Faults bounding this structrure are cut over parts of a volcanic plateau which is partially overlapped by ignimbrites and

Fig. 75. Geological map of Polovinka caldera (after Masurenkov, ed., 1980e). 1 - recent lacustrine deposits; 2 - Holocene lava flows from Lagerny cone - Holocene; 3 - Holocene pumiceous tuffs; 4 - tuffs and pyroclastic flows from Akademii Nauk volcano - Uppermost Pleistocene; 5 - lava flows and edifices of Akademii Nauk volcano - Upper Pleistocene; 6 - lacustrine deposits - Upper Pleistocene; 7 - pumiceous tuff from Odnoboky caldera, fourth pyroclastic cover-lower part of Upper Pleistocene; 8 - pumiceous tuffs-Upper Pleistocene and Holocene (undivided probably from caldera-forming stage of Akademii Nauk caldera); 9 - lava flows and edifices of Beliankin volcano - Middle and Upper Pleistocene; 10 - lava flows and edifices of Odnoboky volcano - Middle and Upper Pleistocene; 11 - lacustrine deposits of the first stage of sedimentation - upper part of the Middle Pleistocene; 12 - "Dikiye" (wild) tuffs - Middle Pleistocene; 13 - pre-caldera formations; 14 - landslide deposits; 15 - ring faults, observed; 16 - scarps along caldera boundaries (a) and along explosive forms on strato-volcanoes (b); 17 - center of eruptions.



central volcanoes of a pre-caldera complex. Amplitude of displacement along these faults near Stena volcano is not less than 400 m, northern and western boundaries of the caldera are overlapped by younger volcanic formations. The southern boundary is hidden under lava flows and partially by pyroclastics of the younger stages of the caldera formation and is inferred conditionally along east-west faults in the central part of Zhupanovsky (Karymsky) volcano-tectonic depression. Tuff-ignimbrites cover connected with formation of this caldera is up to 200 m thick. It was formed at the end of Middle Pleistocene time during several strong eruptions, started after a period of erosion of the ring volcano-tectonic complex.

Caldera of Maly Semiachik volcano.

This caldera is located in the northeastern part of Stena-Soboliny caldera. Agglomerates associated with Maly Semiachik caldera overlap moraines of Upper Pleistocene glaciation. By uranium-thorium method they have a radiometric age of 10-12 thousand years B.P. (Masurenkov, ed., 1980a). The time surface of the area was leveled and relief was represented by a flat plain with low hills. Walls of the Stena-Soboliny caldera were strongly eroded at this time.

Products of caldera forming eruption.

Agglomerates connected with the caldera forming eruption of the Maly Semiachik volcano covers an area about 300 km^2, which filled the depression of the Stena-Soboliny caldera and spread north and eastward from it. Thickness of agglomerates in some places reach 100 m, but as a rule is equal 10-20 m. Their total volume is estimated at 6 km^3. In the northern walls of Maly Semiachik caldera a sequence of rocks connected with the caldera forming eruption looking upward is as follows:

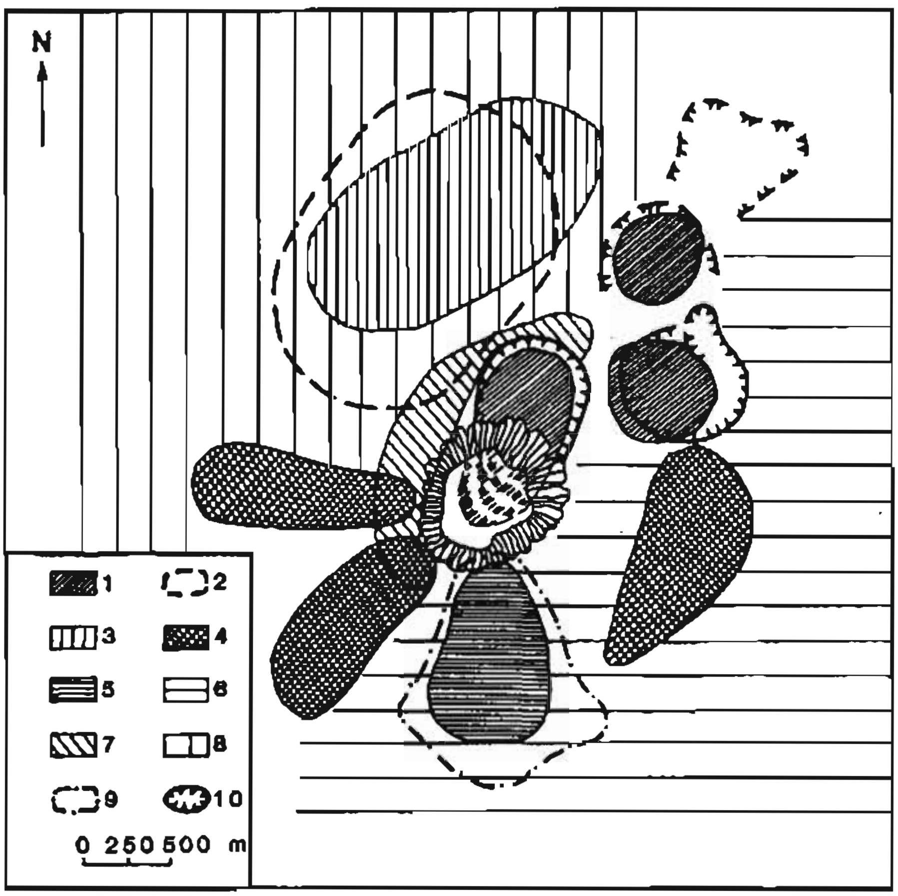
1. Horizon of weakly welded red scoria and pumice (63.5% SiO_2), 2 m thick;
2. Layer of red obsidan (60.8% SiO_2), 1 m thick;
3. Layer of black obsidian (61.9% SiO_2), 1-2 m thick;
4. Lilac-grey stratified ignimbrites 15 m thick;
5. Loose agglomerates about 12 m thick.

The caldera connected with the eruption of these rocks is located supposedly on the site of the previously existing Pra-Semiachik volcano. Then practically all traces of this volcano collapsed and was overlapped by agglomerates. The following accumulation completely hide part of the caldera boundaries. Consequently its size is stated at approximately 7x6 km and the area of a subsided block is estimated as 35 km^2.

Post-caldera stage of volcanism.

Inside the caldera Maly Semiachik a volcano is located. It is represented by a volcanic ridge composed by basalts and consisting of three cones, composed by basalts and basaltic andesites. Cones consistently become younger in a southwestward direction (Paleo-, Meso- and Kaino-Semiachiks). The youngest among them has a Hawaiian-type caldera on the summit (Seliangin, 1977). According to Gorshkov (1976) this caldera is characterized by positive gravity and magnetic anomalies, caused by the presence of basaltic intrusion inside the volcanic edifice (Fig. 76). Vlodavets and Piip (1959) noted the changing of the character of the lava streams on the volcano. Ancient lava streams were ropy, the younger ones are blocky.

Fig. 76. Scheme of location of gravity and magnetic anomalies on the Maly Semiachik volcano (Gorshkov, 1976).
Gravity maximums: 1 - intensive; 2 - intermediate, gravity minimums; 3 - intensive; 4 - intermediate, magnetic anomalies; 5 - intensive; 6 - intermediate; 7 - magnetic minimums; 8 - decreased gravity field; 9 - relatively increased gravity field; 10 - craters.
Areas of intensive gravity anomalies are interpreted by A. P. Gorshkov as reflection of magma chambers inside volcanic edifice.



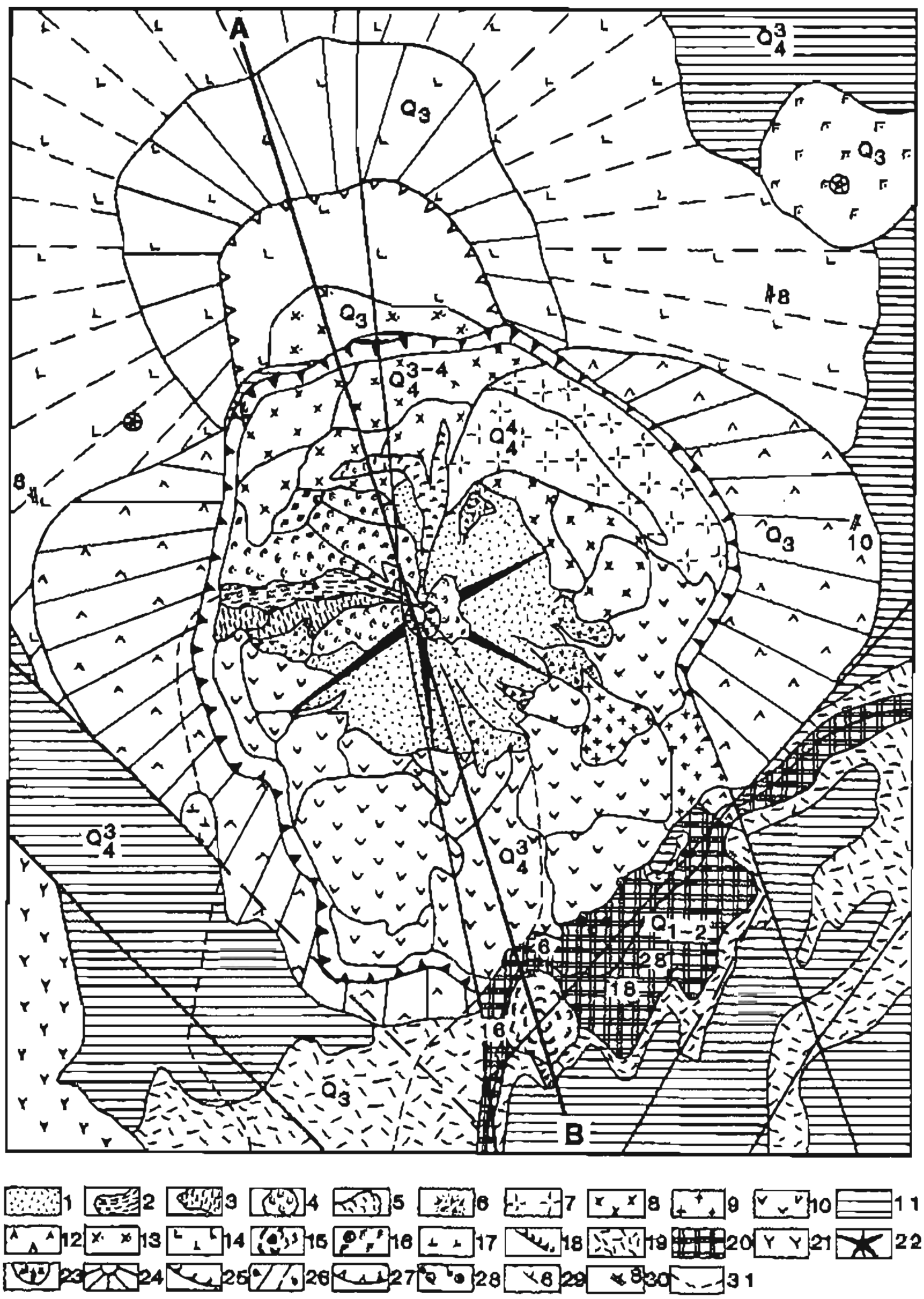
Historic activity of Maly Semiachik volcano.

Vlodavets and Piip (1959) described the series of eruptions as mainly volcanian type. The strongest took place in 1804 and was accompanied by the collapse of the volcano summit. Another eruption took place in September 1851, spring and July of 1852, autumn 1945, spring 1946 and the latest in December 1952. Fore runnings of these eruptions were early melting of snow in the southern part of edifice, and local earthquakes. In the active crater with a diameter of 500 m and 170 m in depth, a hot lake with an area 0.25 km^2 is located. On the banks of the lake and on the inner walls of the crater, fumaroles with temperatures of up to 90°C (in 1946) are present.

5.2.3. Caldera of the Karmysky volcano.

The caldera of the Karymsky volcano (5 km in diameter) is approximately located in the central part of the Zhupanovsky (Karymsky) ring structure. This location coincides with the crest of the shield that underlies the Karymsky ring structure. Its position is controlled by the strip of east-west deep-seated strike-slip faults that cut the Zhupanovsky (Karymsky) structure. The walls of the caldera expose relicts of the ancient volcanic edifice (Pra-Karymsky volcano) (Fig. 77). This complex edifice had an absolute height estimation of about 1800-2200 m (Ivanov, 1969), and covered an area of about 25 km^2. The best preserved outcrops were located in the western, northern and eastern caldera walls; exposures ranged in height from 10-15 m in the southern part of the caldera and up to 250 m in the northern part. The slope of the walls ranged from 30° to nearly vertical in the northern part. The caldera occupies an area of about 12 km^2. In the northern, western and eastern caldera walls the lava flows dip to the north, west, and east respectively. This proves (Ivanov, 1970) that the lavas belong to the ancient Karymsky volcano rather than Dvor volcano, as was suggested by Vlodavets (1947). The western and eastern slopes of the caldera are covered by pyroclastic deposits from the most recent eruptions. These deposits mantle the flanks of the volcano. The ancient Karymsky volcano was a typical stratovolcano that formed at the beginning of the Upper Pleistocene. The caldera of Karymsky volcano formed at the beginning of the Holocene, after a series of catastrophic explosions. The lower part of the ancestral Karymsky volcano is mainly composed of lavas that are dominantly andesitic in composition. The characteristic feature of rocks of the ancestral Karymsky volcano is the absence of olivine phenocrysts, which allows them to differentiated from lavas of the adjacent Dvor volcano. The terrain adjacent to the caldera of Karymsky volcano is mantled with light-yellow, fibrous dacitic pumice. The area covered by these pumice total about 60 km^2; thickness range from 100-165 m within 1-3 km from the western caldera rim to 1-1.5 m 10 km northeast of the caldera rim. Thus, tephra thicknesses regularly decrease outward from the caldera. This deposit was produced at the moment of the caldera formation. Within the caldera, the modern Karymsky volcano is a typical stratovolcano with a height of 1530 m. It consists of interbedded two-pyroxene andesites and andesite-dacites and associated pyroclastics. The total volume of the young cone and the lavas which fill the bottom of the caldera is about 2 km^3.

Fig. 77. Geology of the Karmysky volcano (after Ivanov, 1970). 1 - recent loose Quaternary deposits on the slopes of the cone; 2 - two-pyroxene andesite-dacitic flows of 1964; 3 - two-pyroxene adnesite-dacitic flows of 1963; 4 - two-pyroxene andesite dacite flows of 1962; 5 - agglomerate flows of 1962 - 1963; 6 - dacite lava flow of 1908; 7 - two-pyroxene andesites of the northern lava complex (Q_4^{3-4}); 8 - two pyroxene dacites of the southern lava complex (Q_4^3); 9 - two-pyroxene andesite dacites of the southern complex (Q_4^3).



Geophysical data concerning the deep structure of the caldera.

The caldera of Karymsky volcano is expressed in the gravity field by a flat maximum about 15 km across, and by steep gradients over the caldera rims (Zubin, Ivanov, and Steinberg, 1971). According to geophysical data the maximum lava thickness within the caldera is about 300 m. If we assume that the gravity anomaly is a consequence of the lava sequence in the inner part of the caldera, the total lava thickness must be at least 3 km (70-82% of the section composed of pyroclastic materials). However, the probability of such a thickness is very small. Calculations show that the center of gravity of the anomaly-forming mass lies at a depth of 4.5 km. Zubin and others (1971) consider this mass to be a significant silicic (dacitic) magma chamber (Fig. 78). The density contrast between this mass and the host tuff-lava complex ranges from 0 to 0.3 g/cm^3. The volume of such a magma chamber could be from 50 to 170 km^3. If the chamber was spherical, it would have a radius of from about 2.3 to 3.5 km; the depth of the upper margin would be 1 to 2 km below sea level.

Considered together, gravity and magnetic data lead to the conclusion that a considerable part of the magma chamber must have a temperature below the Currie point, because of the observed magnetic anomaly. Marginal parts of the shallow magma chamber have already crystallized.

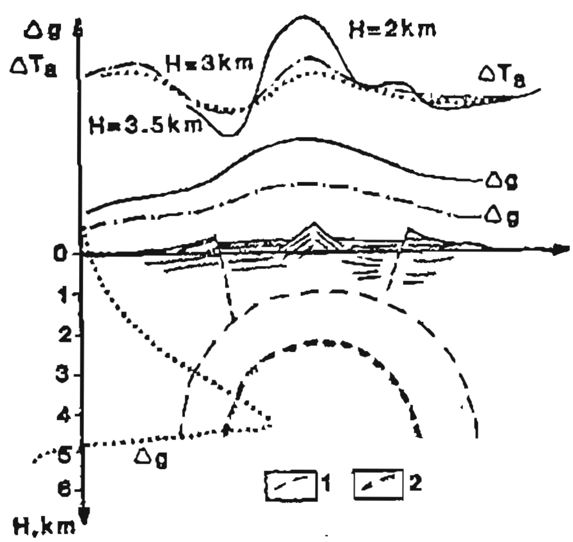
Two explanations have been suggested for the genesis of the Karymsky volcano caldera. Vlodavets (1944) thought that it was purely the result of a collapse. Gorshkov (1962) thought that blasts played a considerable role in the caldera formation. According to Zubin and others (1971) the caldera is the product of both processes, explosion and collapse. Zubin and others (1971) think that the Karymsky volcano caldera is not associated with the development of Dvor volcano, as has been suggested by Vlodavets (1944) and Svistlovsky (1959), but rather is a consequence of the development of an independent ancestral Pra-Karymsky volcano. This point of view is supported by structural and mineralogical evidence.

Volcanic activity.

A radiocarbon age of 7800-7900 B.P. was obtained from the soil that underlies pumice from the caldera-forming stage of Karymsky volcano. This age is in agreement with the age data obtained from pumice lapilli from basal deposits of the caldera forming eruption. A somewhat older age was obtained from charcoal - bearing deposits (8400-8000 years B.P.), perhaps due to contamination by carbonic acid. The caldera formation stage on Karymsky volcano coincided with a period of quiescence on Maly Semiachik volcano. The duration of the whole caldera forming process on Karymsky caldera was extremely short, not more than 200-300 years. In reality the duration probably did not exceed several tens of years.

On the basis of radiocarbon data and detailed tephrochrological studies, the first eruptions of the post-caldera cone of Karymsky volcano occurred about 5300 yrs. B.P. Karymsky volcano reached its modern height about 2200 yrs. B.P. (Masurenkov, ed., 1980a). Within the time interval 2200-500 years B.P., a few minor eruptions occurred. After 500 yrs. B.P. Karymsky volcano entered a regime of short-period pulsations (Masurenkov, ed., 1980a). Masurenkov thought that it was probable that a large crater or summit caldera would form in the near future, perhaps during the next pulsation. A drastic decrease in the height of the volcano would accompany the crater or caldera formation.

Fig. 78. Latitudinal gravimetric and magnetic profiles across caldera of the Karmysky volcano (Zubin and others, 1971).
1 - 2 inferred contours of magma chamber in case of density excess 0.1 and 0.3 g/cm^3.



Recent volcanic activity.

The first uncertain reports about eruptions of Karymsky volcano are from 1771, 1830, and 1852. Data for the period 1852 to 1908 are absent. During the 110 years from 1852 and 1962 two effusive-explosive eruptive periods occurred on Karymsky volcano. The first started approximately in 1908, when a dacitic lava flow was erupted on the eastern slopes of the volcano. This flow had a volume of 3 X 10^8 m^3. The second peroid began on October 17, 1962.

Ivanov (1970) reviewed all of the historical activity of Karymsky volcano up to 1965, and divided its activity into two stages: explosive and effusive-explosive. Both stages consisted of several eruptive cycles. Each eruptive cycle continued for several days to 5 years, and the duration of the entire explosive stage was 40-60 years. Periods of repose between different eruptive cycles lasted from 1 to 6 years or more. These periods were characterized by fumarolic activity. The effusive-explosive stage was always shorter than the explosive stage. After the eruptive cycles reach its limit of intensity, the paroxysmal (effusive-explosive) stage began; this was characterized by the extrusion of lava flows accompanied by moderate explosive activity. The duration of the effusive-explosive cycles on Karymsky volcano were not more than 3-7 years. Twenty-two eruptions occurred during the 110 years from 1852 to 1962. Ivanov (1970) combined the eruptions in the time interval from 1909 to 1962 into the following eruptive cycles: (I) 1909-1915; (II) 1921-1925; (III) 1929-1932; (IV) 1934-1935; (V) 1943-1947; (VI) 1952-1962; (VII) growth of the inter-crater extrusive dome, from August until October 17, 1962.

Ivanov (1970) divided the eruptions that occurred within the period 1962 to 1965 into nine cycles:

(I) paroxysmal vulcanian eruptions on October 17-20 and 27-28, 1962;
(II) moderate vulcanian eruptions from November 10, 1962 to January 1, 1963;
(III) paroxysmal eruptions on January 1-30, 1963;
(IV) moderate to strong vulcanian eruptions and, on May 11, 1963, a culminate explosion;
(V) paroxysmal vulcanian eruptions on May 11-19, 1963;
(VI) moderate vulcanian eruptions from May 20, 1963 to January 20, 1964;
(VII) paroxysmal vulcanian eruptions from January 21 to May 20, 1964;
(VIII) moderate to strong mixed vulcanian-strombolian eruptions from May, 1964 to January 1965;
(IX) paroxysmal mixed vulcanian-strombolian eruptions from January 10-15, 1965.

After January 15, 1965, only moderate vulcanian eruptions have occurred.

The period between 1965 and 1970 was mainly quiet; weak eruptive activity might have occurred in 1967 (data from Smithsonian volcano file). Starting in 1970 a new cycle of volcanic activity began. Activity for the 1970 to 1980 period has been divided into nine stages:

(I) paroxysmal vulcanian and mixed vulcanian-strombolian eruptions on May 11, 1970, lava flows with volume of 6 X 10^6 m^3 were extruded;
(II) moderate vulcanian eruptions from May 20, 1970 to January 25, 1971;
(III) paroxysmal vulcanian eruption on January 26, 1971;
(IV) moderate to strong vulcanian eruptions from January 26 to July 16, 1971;
(V) paroxysmal eruptions from July 16 to October 26, 1971, accompanied by extrusion of lava flow with a volume of 8 X 10^6 m^3;
(VI) weak explosive activity from October 26, 1971 to March 16, 1976;
(VII) paroxysmal mixed vulcanian-strombolian eruption at the end of March, 1976
(VIII) moderate to strong mixed vulcanian-strombolian eruptions from August,

1976 to August, 1979 and, from the middle of August, 1979, small lava flows;

(IX) paroxysmal eruptions from August, 1979 to December, 1980, accompanied by lava flows of unknown size.

Repeated geodetic surveys on Karymsky volcano from 1972 to 1981 have revealed a general subsidence of the volcano relative to the stable block between the calderas of Karymsky volcano and Akademii Nauk (Magus'kin, and others, 1982). Subsidence has been symmetrical relative to the volcano crater, and has been restricted to within 3-4 km of crater. At a distance of 1.5 km from the crater, subsidence totals 3-4 cm. The subsidence is probably related to effusive activity. The subsidence over the entire nine year period produced a volume change of 0.038 km^3; i.e., approximately three times more than the volume of the lava discharged in the same period.

Impulses of uplift occurred within this period of general subsidence and was related to explosive activity on the volcano.

Horizontal displacements around Karymsky volcano occurred during swarms of volcano-tectonic earthquakes and during stress changes within the magma supply system. After some earthquake swarms, sudden horizontal displacements of 5-10 cm occurred in a southeast-northwest direction. Vertical displacements near the Karymsky volcano were satisfactorily explained by an isometric or axial-symmetric pressure source, the upper limit of which was no closer to the surface than 1-1.5 km.

Periodic sampling of spontaneous volcanic gas emissions from the hot springs near the foothills of Karymsky volcano begun in 1966 (Chirkov, 1973; Firstov and Chirkov, 1978). The Rn concentration in the gas emissions fluctuate and increase in direct proportion to the volcano activity. Six to seven months before the strong eruption of May, 1970, pressure in the magma chamber/volcanic conduit increased leading to the destruction of crystal lattices in minerals, and consequent release of Rn. The same mechanism may have caused the Rn concentration to increase during the growth of an inter-crater extrusive dome in September, 1970. That extrusion was preceded by frequent volcanic earthquakes in July-August, 1970.

During the period of lava extrusions in July-August, 1971, the concentrations of Rn in spontaneous gas emissions from hot springs was unstable. As a rule, increasing Rn concentrations have been observed 1-2 days before an increase of volcanic activity. The Rn content in spontaneous gas emissions reached a maxima during the period of miximum lava discharge (Firstov and others, 1978).

5.3. Great Semiachik Volcano-tectonic Depression.

History of the study.

Interest in this structure is motivated by the extensive geothermal activity within it, which is associated with Bol'shoy Semiachik and Burliastchy volcanoes. The existence of a great volcano-tectonic depression in this region was first suggested by Erlich (1966), mainly on the basis of aerial-photograph interpretation and regional structural analysis. Some authors, while not denying the existence of a volcano-tectonic depression in this region, reinterpreted its boundaries (Melekestsev in Luchitsky, ed., 1974). Possible boundaries were inferred on the basis of airborne radar images as shown in Figures 79 and 79a.

Fig. 79. Geological-Geomorphological scheme of Great Semiachik volcano-tectonic depression (from Luchitsky, ed., 1974).

Volcanic formation of post-caldera complex: 1 - basaltic stratovolcanoes, Holocene; 2 - basaltic scoria cones and connected with them lava flows, Holocene; 3 - basaltic andesites extrusive domes and connected with them lava flows, Holocene; 4 - basaltic stratovolcanoes and their lava flows: (a) preserved parts, (b) destroyed parts--Upper Plesitocene - Holocene; 5 - andesitic stratovolcanoes and their lava flows: (a) preserved parts, (b) destroyed parts, Upper Plesitocene - Holocene; 6 - dacitic stratovolcanoes - Upper Plesitocene; 7 - dacita-rhyolite extrusive domes, Upper Pleistocene--Holocene; 8 - andesite-dacite extrusive domes, Upper Pleistocene; 9 - pumice cones, Upper Pleistocene--Holocene; 10 - andesitic and basaltic effisive domes, Upper Pleistocene; 11 - small andesitic lava volcanoes (a), and connected with them lava covers (b)--Upper Pleistocene; 12 - basaltic lava plains--Upper Pleistocene; 13 - pumice covers--Upper Pleistocene; 14 - ignimbrite covers, connected with Great Semiachik--Upper Plesitocene; 15 - layered tuffs, deposits of the Uzon's III intra-caldera lake, middle part of the Upper Pleistocene; 16 - layered tuffs, deposits of I and II Uzon's intra-caldera lakes, lower part of the Upper Pleistocene; 17 - dacitic and rhyolithic extrusive domes, Middle--Upper Pleistocene.

Volcanic formations of the caldera-forming stage: 18 - Ignimbrite covers, connected with Uzon-Geyzernaya volcano-tectonic depression, Middle Lower Upper Pleistocene; 19 - ignimbrites of the Semiachik river valley, Middle - Upper Pleistocene; 20 - ignimbrite covers, connected with Great Semiachik volcano-tectonic depression, Middle Pleistocene.

Volcanic formations.of the pre-caldera complex: 21 - basaltic stratovolcanoes (a) preserved, (b) destroyed, Middle Pleistocene; 22 - basaltic lava and cinder cones, Middle Pleistocene; 23 - basaltic lava plateau, Middle Pleistocene; 24 - lava plateau and relicts of volcanic edifices (shield and mainly lava stratovolcanoes) composed by mainly mafic volcanic rocks, Upper Pliocxene--Lower Pleistocene; 25 - lava plateau and underlied it tuff-lava sequences mainly solicic in composition - Upper Pliocen--Lower Pleistocene; 26 - lava plateau and underlied it tuff-lava complexes of the mix compositon.

Other signs: 27 - alluvial deposits, Holocene; 28 - deluvial proluvium fanglomcrate deposits, Upper Pleistocene--Holocene; 29 - morains of the second stage of the Upper Pleistocene glaciation; 30 - blast's funnels; 31 - ring faults of caldera rims; 32 - faults; 33 - tectonic fissures without displacement; 34 - fault zones, marked by rows of volcanoes; 35 - faults drawn by geophysical data; 36 - recent thermal manifestations; 37 - zones of hydrothermally altered rocks.

NOTE: Signs 15 and 16 belong to the Uzon-Geyzernaya caldera, located just to the north of the figure's northern boundary.

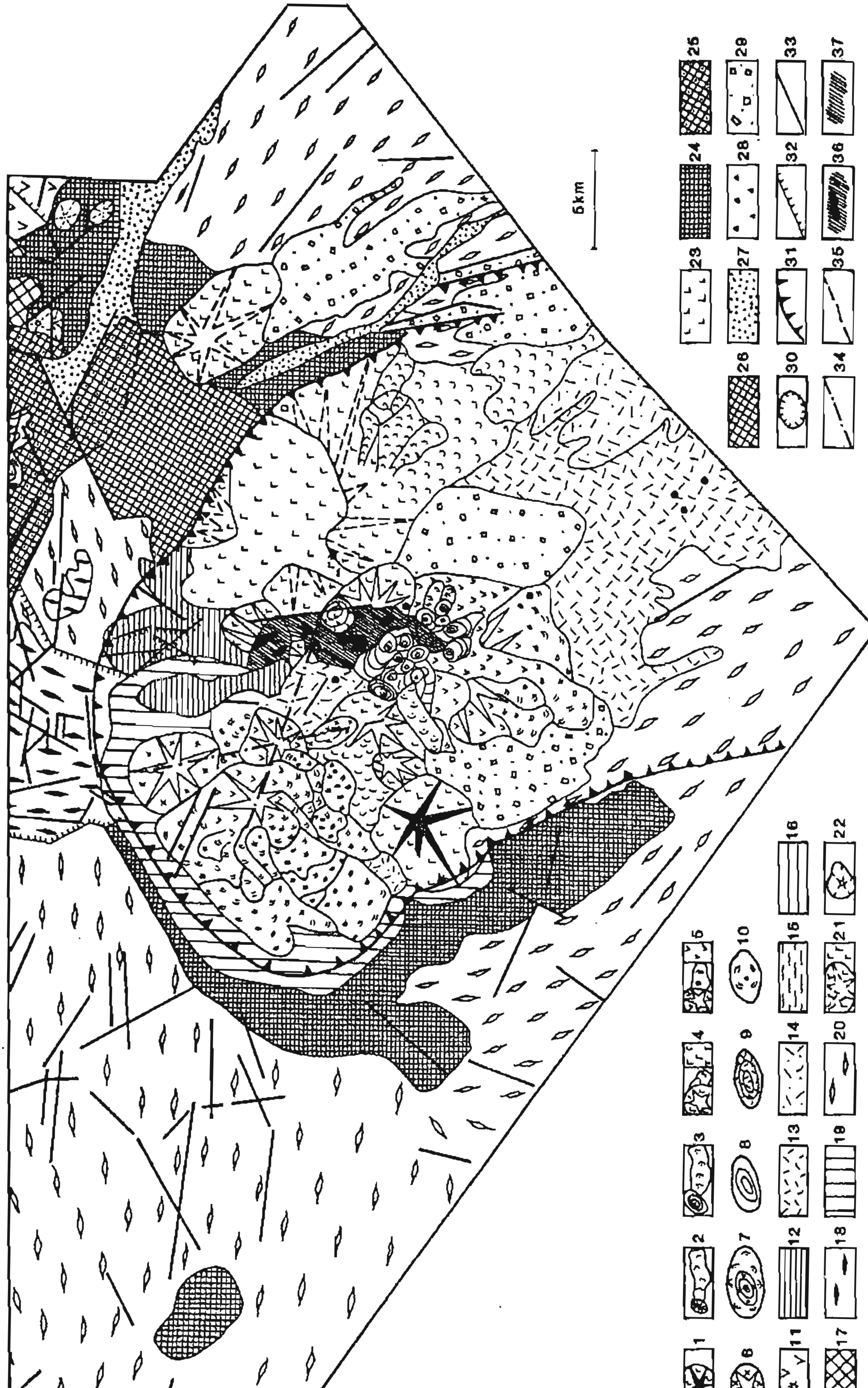

5km

Fig. 79a. Airborne radar image of the Great Semiachik volcano-tectonic depression (Eastern Kamchatka).

Structural position.

The Great Semiachik volcano-tectonic depression is located between the Zhupanovosky (Karymsky) ring structure and the Uzon-Geyzernaya volcano-tectonic depression, within the eastern Kamchatka graben-syncline. The specific position of the Great Semiachik volcano-tectonic depression is defined by two factors: (1) a pronounced gravity anomaly which coincides with this depression and (2) an east-west zone of deep-seated strike-slip faults, which goes practically through the center of the depression. This fault is also expressed by a series of earthquake foci with depths of more than 50 km (Luchitsky, ed., 1974).

General structure.

Bounding ring faults cut a complex volcanic plateau composed of basalts and silicic volcanic products of Upper Pliocene and Lower Pleistocene age, and some relicts of Lower to Middle Pleistocene basaltic and basaltic-andesite volcanoes. The total displacement along these bounding faults is 300-400 m.

Ignimbrite covers.

Pumice and ignimbrite sheets associated with the Great Semiachik volcano-tectonic depression are exposed along the shore of the ocean--in the so-called coastal section. These deposits overlie unwelded airfall pumice, fluvial deposits and buried soils. This sequence overlies plateau-ignimbrites. Thus, the Great Semiachik depression formed significantly later than the main phase of ignimbrite formation in the region. Soil which divides two ignimbrite horizons in this section is of the same age as soil that divides moraines of two stages of Upper Pleistocene glaciation. Ignimbrites are also overlapped by moraines of the second stage of the same glaciation. These facts suggest that ignimbrites were formed during the interstadial time of the Upper Pleistocene glaciation.

Post-caldera stage of volcanism.

Data concerning the internal structure of the volcano-tectonic depression and the stages of its post-caldera volcanic activity are sparse. But it is important to mention that Melekestsev (in Luchitsky, ed., 1974) described the outcrops of pre-caldera rocks (Upper Pliocene-Lower Pleistocene) in the central part of the depression. The reason for their occurrence within the central part of the caldera is unclear and could be an indication of the presence of a resurgent dome. Post-caldera volcanoes inside the depression are of diverse types and sizes--ranging from mainly basaltic stratovolcanoes to complexes of extrusive domes of silicic andesite to rhyodacite.

5.4. Uzon-Geyzernaya Volcano-Tectonic Depression.

Previous Studies.

The Uzon-Geyzernaya volcano-tectonic depression is composed of two calderas, Uzon and Geyzernaya, and is well known for its fields of ignimbrites and impressive geothermal features. As access is comparatively difficult, it has been studied only during occassional expeditions. The Uzon hot springs were described first by Piip (1937). The hot springs in the middle of the Geyzer Valley were described by Ustinova (1946).

Piip (1961) first speculated on the existence of the Uzon caldera. He thought that the caldera occupied the summit of a large stratovolcano, called Uzon Volcano, and that the caldera was the source of all the ignimbrites in the Kronotsky region. The Geyzer Valley was not included within the caldera limits. After this time, other authors denied the existence of a caldera. Belousov and Ivanov, (1967) considered the region to be a series of different types of volcanic centers located along a ring fault. Fine-grained lacustrine deposits exposed in the center of the caldera were thought to be the most ancient rocks in the region, and were thought to underlie the lavas and pyroclastic deposits exposed in the walls of the caldera. Without any supporting evidence, they considered the fine-grained deposits to be marine. From their marine origin and their maximum altitude they concluded that the region had been uplifted 1000 m. On the basis of aerial-photographic interpretation and structural analysis, Erlich (1966) and Melekestsev (1967) worked out the concept of a large volcano-tectonic depression in which they included the Geyzer Valley. Later works confirmed this view allowing the establishment of a reasonably complete geologic history for this depression.

In the mid-1960's, an indepth study of the Uzon hot springs was begun mainly for geothermal-energy purposes under the leadership of V. V. Averiev. Highlights of this work included a complete description of the volcanic history of the region and a description of interesting assemblages of ore minerals and hydrocarbons associated with the hot springs. The results of these studies were published in a monograph edited by Naboko (1974).

Structural Position.

The Uzon-Geyzernaya volcano-tectonic depression is located in the Uzon-Semiachinsky part of the eastern Kamchatka graben-syncline at the intersection with a deep-seated, east-west fault zone (see Chapter 1, Fig. 12). The east-west zone is reflected by a steep gravity gradient. The volcano-tectonic depression is offset 3-5 km in a left-lateral sense along the fault zone, and there is marked evidence of strike-slip displacements on east-west surface faults. A marked series of earthquake foci also occur along the zone at depths of 100-120 km (Naboko, 1974).

Another important aspect of the structural setting of the depression is its location on the margin of a large (45-50 km across) negative gravity anomaly that is characterized by a high intensity and by steep gradients on its margins. The depth of the center of gravity of the anomaly-forming body is 14-18 km. In addition to the Uzon-Geyzernaya depression, other volcanoes including Taunshits and Great Semiachik lie on the margin of this gravity low. Mass deficiency of this anomaly is 200-250 X 10^{16} g.

Structure of the Volcano-Tectonic Depression.

The Uzon-Geyzernaya volcano-tectonic depression measures 18 X 7 km and contains two large calderas (Fig. 80). The Uzon caldera lies in the northwest part of the depression and the Geyzernaya caldera lies in the southeast part of the depression. The unity of the entire structure is defined by a ring fault that is mapped around its margin. Geophysical data suggest the fault has steep inward dips. The marginal ring fault is expressed by scarps 300-400 m high. Considering the thickness of the fill in the depression, the displacement on the ring faults is probably twice their height. The ring faults cut volcanic sequences of different ages and compositions: (1) an early and middle Pleistocene tuff and lava complex of basic through silicic composition, (2) Uzon Volcano, a basaltic volcano of middle Pleistocene age, and (3) younger extrusive domes that are probably coeval with ignimbrites of the caldera-forming eruptions.

The western part of the depression, the Uzon caldera, is formed in pre-caldera rocks of mostly basaltic composition. It has good topographic expression and is partly filled by lacustrine deposits. The comparatively small amount of post-caldera volcanism is represented by a single extrusive dome and the basaltic maar of Dal'nyeye Lake.

The structure of Uzon caldera is complicated by a young explosion-funnel, which is the focus of a considerable amount of the present hydrothermal activity. This explosion-funnel is superimposed on part of the pre-existing ring structure of Uzon caldera and was formed by a large explosion and subsequent collapse. The upper part of the funnel is partly filled by lacustrine deposits. Gravity data suggest that Uzon caldera consists of several fault blocks that differentially displace basement rocks. These faults have east-west and northwest strikes and are expressed by steep gradients in the gravity field (Fig. 81). The arcuate zone of positive gravity anomalies around Uzon caldera (Fig. 82) reflects the presence of relicts of the pre-caldera shield-like volcano.

The explosion-funnel within the caldera is expresses by a marked gravity low. In the south part of the funnel a local minimum in the gravity field is thought to reflect the position of a buried block of the pre-caldera complex. The gravity low associated with the explosion-funnel is almost equidimensional in plan and has a considerable amplitude. Recalculation of Zubin's (in Naboko, 1974) model of the anomaly provides a mass deficiency of about 3.2×10^{15} g. The depth to its center of gravity using the formula of Afanasiev (ref?) is about 1.3 km. In the case that its horizontal dimension exceeds its vertical one, it's possible to conclude that the depth to its center of gravity does not exceed 1 km. This is small in comparison with its diameter (6 km) at the surface. The form of the gravity plot permits the assumption that the gravity low is caused by a funnel-shaped depression that is filled by low-density material. Calculations made by Zubin (in Naboko, 1974) assuming a density contrast of 0.2 g/cm^3 show a cone with a radius of 3 km, a height of 2 km, and a volume of 18 km^3. The resulting mass deficiency is 3.6×10^{15} g and is consistent with other calculations. This funnel was probably formed by a single large explosion superposed on a ring structure. The funnel accumulated a low-density fill composed of brecciated basement

Fig. 80. Generalized geologic map of the Uzon-Geyzernaya volcano-tectonic depression. Post-caldera complex: 1 - basaltic scoria cones and lava flows; 2 - pumice deposits; 3 - pumice cones; 4 - dacitic and rhyolitic extrusive domes and lava flows; 5 - small andesitic lava volcanoes and lava fields; 6 -layered tuffs, deposits of the third lake; 7 - layered tuffs, deposits of the first and second lakes. Deposits of the caldera-forming stage: 8 - dacitic and rhyolitic extrusive domes and lava flows; 9 - ignimbrites of the Uzon and Geyzernaya calderas; 10 - ignimbrites of the Semiachik volcano-tectonic depression. Pre-caldera volcanic complex: 11 - basaltic strato-volcanoes, a-preserved, b-destroyed; 12 - basaltic lava and scoria cones; 13 - basaltic deposits; 14 - tuff and lava deposits of mainly basaltic composition; 15 - tuff and lava complexes mainly of dacitic composition. Other deposits and structures: 16 - sandy, pebble-bearing alluvial deposits; 17 - blocky rock debris of alluvial and colluvial deposits; 18 - moraine of the second stage of late Pleistocene glaciation; 19 - maar of Dalnyee Lake; 20 - ring fault of the caldera margin; 21 - fault that bounds the blast funnel; 22 - faults and strike-slip faults; 23 - tectonic fissures with no displacement; 24 - faults drawn on geophysical data; 25 - areas of modern geothermal activity; 26 - groups of hot springs and single springs; 27 - zones of hydrothermally altered rocks.

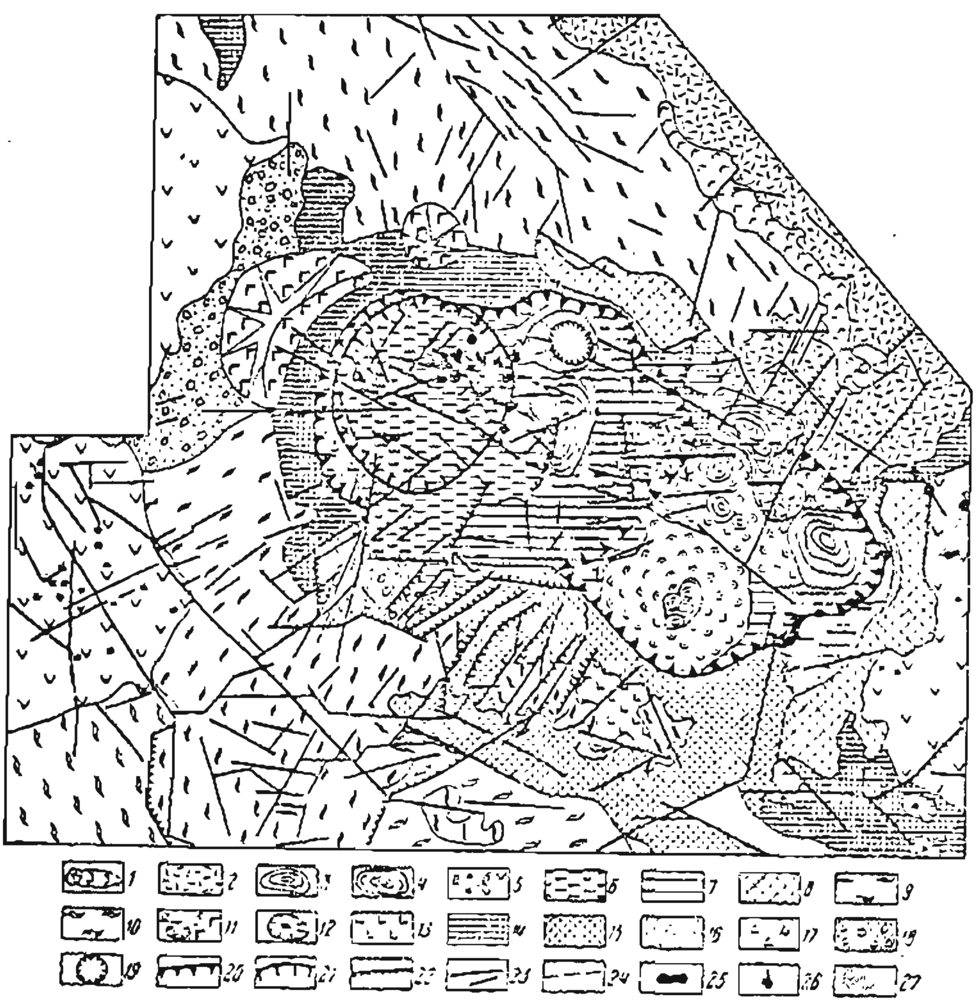


Fig. 81. Generalized gravity anomalies of the Uzon-Geyzernaya volcano-tectonic depression (after Naboko, ed., 1974). 1 - zones of positive gravity anomalies; 2 - zones of negative gravity anomalies; 3 - zones of steep gradients; 4 - ring faults of caldera margin, (a) observed, (b) inferred. Increased density of map pattern corresponds with greater intensity of anomalies.

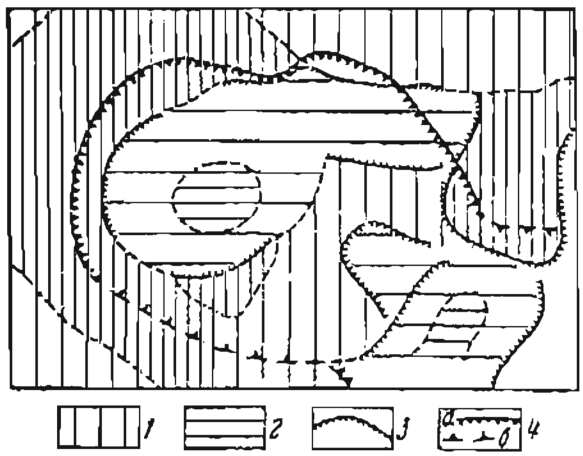
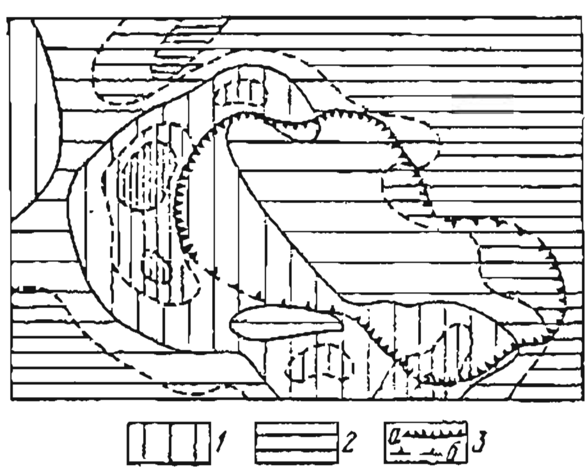


Fig. 82. Generalized magnetic-field anomalies of Uzon-Geyzernaya volcano-tectonic depression (after Naboko, ed., 1974). 1 - zones of positive magnetic anomalies; 2 - zones of negative magnetic anomalies; 3-ring faults of caldera margin, (a) observed, (b) inferred. Increased density of map pattern corresponds with greater intensity of anomalies.



rocks, pumice, lacustrine deposits, and so forth. This model explains the gravity minimum very well. If the blast that formed the funnel occurred at a depth of 2 km, the total energy of the blast would be 10^{25} to 10^{26} ergs (Steinberg, 1960).

Geyzernaya caldera lies in the southeast part of the volcano-tectonic depression and occupies a pre-caldera site of silicic volcanism (Fig. 80). Dacites of this center are exposed in the Shirokoye Plateau and Geyzers Valley east and southeast of the caldera. The caldera is not well expressed morphologically because it is nearly filled with deposits of the post-caldera complex. The boundary of the caldera is accentuated by the valleys of the Shumnaya and Geyzernaya Rivers, which follow the faults along the caldera boundary.

Geyzernaya caldera is characterized by a negative gravity anomaly having a steep gradient on the north side which is interpreted as an east-west fault. Beyond the north boundary of the caldera, the gravity field becomes slightly positive.

The boundary between the two calderas is not well located because of widespread volcanic and sedimentary deposits that obscure the boundary. Geophysical and remote-sensing data suggest that both the Uzon and Geyzernaya calderas have been displaced along a system of east-west faults. One of these systems follows the upper part of the Geyzers Valley, another cuts the northern part of the Shirokoye Plateau. Both fault systems are located on the boundaries of the silicic and basaltic fields that form the pre-caldera complex. A post-caldera pumice cone, called Okrglaya sopka, lies on the northern of these fault systems and its deposits bury the fault scarp. These relations suggest that the east-west fault systems have had a long history of activity. They were formed in pre-caldera time and continue to be active during the post-caldera stage of development of the volcano-tectonic depression.

These east-west faults have little horizontal displacement and are not traceable beyond the boundaries of the depression. The faults cut and in places merge with the caldera-rim faults.

The volcano-tectonic depression is cut by two narrow grabens. One stretches southward to the Great-Semiachik volcano-tectonic depression. It is about 4 km wide and is formed of fault segments with strikes of north to northeast. As a result, the graben is elbow-shaped. The vertical displacement on the graben faults is about 150-200 m. The graben is filled with unconsolidated sediments and pyroclastic deposits of the post-caldera stage. The graben faults continue into the western part of the Uzon caldera in the form of fissures and faults with small displacements.

The other graben trends northeast from the Uzon-Geyzernaya volcano-tectonic depression toward Krasheninnikov caldera. The graben is formed by a system of northeast-striking faults with displacements of 10-35 m. Near Krasheninnikov caldera, this fault zone merges with a zone of cinder cones and monogenetic basaltic volcanoes.

The inner part of the depression is cut by a series of east-west faults and fissures with branching fissures of northwest strike. This northwest system of fissures controls the position of the main part of the geothermal fields within the caldera.

Eruptions of the caldera-forming stage.

The caldera-forming stage is recorded in a complex sequence of plateau-forming ignimbrites that lie north and south of the calderas. The direction of movement of the ignimbrites can be reconstructed from the 3-7° primary slopes of the plateaus. This analysis suggests that the source of the ignimbrites lies in the position of the present calderas. Total thickness of the Uzon-Geyzernaya ignimbrites reaches 100 m. A great variety of ignimbrite types is represented, from gray and pinkish-gray weakly welded tuffs with lenses of black and white pumice, to gray and red densely welded tuffs with fiamme and black glass. Prevalent varieties of fiamme range from black, highly inflated pumice to dense obsidian. The following are the most abundant forms of Uzon ignimbrites.

1. Ignimbrite breccia often lies at the base of the sequence. It consists of a layer of black glassy lapilli and bombs that grades upward into light-brown, weakly welded ignimbrites with crude platy jointing.

2. Porous to dense, gray and brown, ignimbrites rich in fiamme contain a large quantity of black dacitic glassy lenses. The base of each cooling unit consists of dense, massive, lava-like ignimbrite that has traces of vapor-phase alteration and crystallization.

3. Light-gray ignimbrite composed of welded particles of light-brown dacitic and rhyolitic glass (68% SiO_2) with rare, thin ($\leq$ 5 mm) lenses of glass. This and variety (2) contain as much as 10% of small fragments of andesite and basalt.

The ignimbrite sequence north of the Uzon caldera consists of several cooling units separated by thin, unwelded pyroclastic deposits of airfall ash, lapilli and pyroclastic-flow deposits. In neither this nor the southern field are there any intercalated fluvial deposits or soils which indicates that the ignimbrites erupted over a relatively short interval of time.

Two types of volcanic complexes belong to the caldera-forming stage: (1) ignimbrites surrounding the depression and (2) silicic domes and related lava flows.

The ignimbrites are unevenly distributed around the depression. They form two fields, one north and the other south of the depression. The northern field stretches to the shore of Kronotsky Lake, a distance of 30 km, and is oval in shape with a maximum width of 6-8 km. Its exposed thickness ranges from 10 to 100-120 m. The southern field of ignimbrites covers the area between the Uzon and Geyzernaya calderas and the Great Semiachik volcano-tectonic depression, a distance of 15 km. The field ranges in thickness from several meters to several tens of meters, but its mean thickness does not exceed 10-15 m. Only small relicts of ignimbrites occur east and west of the calderas. This distribution of ignimbrites is controlled mainly by direction of the flows and partly by topography.

The stratigraphic position of the Uzon ignimbrites is very clear. They lie on deposits of the pre-caldera stage, the youngest of which dates from a middle Pleistocene interglacial age. Lacustrine deposits, which partly fill the Uzon-Geyzernaya depression date from the upper Pleistocene interglacial age. Thus, the time of formation of the Uzon ignimbrites dates from the second half of the middle Pleistocene. Temporally and genetically related to the ignimbrites are dacite to rhyolite extrusive domes and short lava flows that lie along the northern and eastern margin of the depression. Their precise relation to the ignimbrites is unknown; however, it is possible that the domes along the caldera rim were extruded during the last stage of the ignimbrite eruptions, because some of the domes are displaced by the caldera-rim faults.

Post-Caldera Volcanic Activity.

Post-caldera volcanic activity within the caldera is represented by (1) typical dacite (65-68% SiO_2) that forms extrusive domes, some with short lava flows and (2) rhyolite (70-71% SiO_2) that forms small volcanoes composed of extrusive domes and lava flows. Groups of these short lava flows form small lava plateaus. The activity of these rhyolitic volcanoes ended with the emplacement of summit spines.

All of the post-caldera volcanic forms have fresh morphology and have no trace of glacial sculpture, whereas at similar altitudes cirques are present along the caldera walls. Therefore the post-caldera activity cannot pre-date late Pleistocene glaciation. However, Belousov (1967) and Melekestsev (1967) think that certain features of these post-caldera forms point to their eruption under thick ice cover, which suggests that some of the extrusions may date from the late Pleistocene glaciation. Explosive eruptions associated with the growth of the post-caldera domes formed a cover of pyroclastic deposits that overlies the ignimbrites. This cover is up to 40 m thick and is composed of unsorted pyroclastic material with thin interbeds of stream-reworked material.

The final stage of post-caldera silicic activity in the Uzon-Geyzernaya depression was the formation of the explosion-funnel described earlier. A thick (up to 40 m) layer of airfall pumice lapilli was deposited on the west rim of Uzon caldera during the explosions. There is no evidence of reworking of the material by water during deposition of the pumice layer. Apparently the pumice was deposited by successive explosive eruptions. This explosive activity was also accompanied by subsidence.

The youngest eruptive activity was the formation of the maar now filled by Dal'nyeye Lake. The maar has a diameter of 1 km. The steep inner walls of the maar extend 40-60 m above the lake. The ejecta ring is composed of scoriaceous blocks, bombs, lapilli, and ash of basaltic andesite (54-56% SiO_2).

Much of the floor of the Uzon-Geyzernaya volcano-tectonic depression is covered with lacustrine deposits as thick as several hundred meters. The site of the lakes in which these sediments were deposited has migrated from southeast to northwest, or toward younger parts of the structure. The major component of the lacustrine fill is airfall pumice that was mostly reworked by water. Pumiceous pyroclastic flows of considerable thickness were buried without significant reworking.

Geothermal Activity.

There are three areas within and near the Uzon-Geyzernaya volcano-tectonic depression that have evidence of recent geothermal activity.

1. Numerous hot springs are located along northwest-striking fissures that lie north of the main east-west fault in Uzon caldera. The fissures are readily seen on aerial photographs. These fissures displace the caldera wall 100-150 m horizontally. The rectilinear pattern of the northwest-trending fissures indicates the dip of the east-west fault is vertical. These fissures aren't traceable south of the east-west fault. On these and other northwest-striking fissures and faults are located volcanic centers of different ages, such as the pre-caldera Uzon Volcano and the maar of Daln'yeye Lake. This indicates that northwest-striking faults have been active both prior to and following caldera formation. Northeast-striking fissures and faults of small displacement cause an en echelon offset of the northwest-striking fissures that feed the hot-springs.

2. A strip of hyrdothermally altered rocks is located along the eastern end of the east-west fault zone, beyond the limits of the Uzon-Geyzernaya depression and south of Kikhpynich Volcano. Intense discharge of sulfurous gases occurs in this strip. Both this strip and area (1) above are located on the ends of the east-west fault zone.

3. The third area of hydrothermal activity is localized along the portion of the depression-bounding ring fault that lies between the mouth and the middle part of the Geyzernaya Valley. All the geysers and most of the hot springs in the Geyzernaya Valley area are concentrated here. All of these thermal features lie south of the main east-west fault, which cuts the depression and controls the location of the main zones of hydrothermal activity and hydrothermally altered rocks. The location of thermal springs in this part of the Geyzernaya Valley is probably controlled by the ring-fault zone draining hot water from the east-west fault zone; the hot water then emerges from the hot springs. This hypothesis is supported by the chemistry of the hot water and by the types of hydrothermal alteration of the host rocks (Naboko, 1974). This hypothesis also explains the absence of geothermal features in the large area along the caldera-rim fault north of the main east-west fault zone.

5.5. Krasheninnikov Caldera Volcano.

Previous Studies.

Krasheninnikov caldera volcano is located in the remote, northernmost part of the Karymsky-Semiachinsky region of the eastern Kamchatka graben-syncline. Because of poor access the caldera has been studied mainly by aerial-photographic and airborne-geophysical methods. The first brief descriptions of the caldera have been published by Sviatlovsky (1959) on the basis of aerial-photographic reconnaissance of Kamchatka volcanoes undertaken during the late 1940's, and by Ustinova (1955) as a part of her work in the Kronotsky reservation. Vlodavets and Piip (1959) regarded Krasheninnikov Volcano, which lies within the caldera, as an active volcano because of its freshness of form and some signs of fumarolic activity. Subsequently, the caldera has been studied using airborne geophysics (Steinberg, 1964) and aerial-photographic interpretation (Melekestsev and Erlich in Luchitsky, ed., 1974). Zubin produced a gravity profile across the caldera (Erlich and others, 1972, 1973). Compilations of the caldera's geology were made by Skorokhodov (1979) and Frolova (1974). Florensky (1984) has determined the age of the caldera-forming eruption. Unfortunately, chemical analyses and descriptions of rocks collected in Krasheninnikov caldera by Yu. M. Dubik are unpublished.

Structural Position.

Krasheninnikov caldera is located at the intersection of the Eastern Kamchatka graben-syncline and a deep-seated, east-west fault (see Chapter 1, Fig. 12). This fault is expressed at the surface as a zone of short linear fissures which have small vertical displacements. The fault zone trends along the northern margin of the caldera. Seismic data for the period 1964-1969 indicate that earthquakes with focal depths >100 km lie along this fault zone. In addition, the caldera is intersected by a north-south zone of fissures and small grabens that extend from Kikhpynich Volcano, 12 km south of the caldera, cuts part of the floor of the caldera, and stretches more than 9 km further north. Geophysical data (Steinberg, 1964) indicate that this zone continues beneath Kronotsky Lake as linear fault scarps along the lakeshore and as a chain of small island volcanoes that are coincident with positive magnetic anomalies.

Inner Structure and Volcanic History.

The caldera forms a circular depression about 9 X 11 km that is slightly elongated an east-west direction. Geophysical data indicate that the caldera-bounding fault is nearly vertical (Fig. 83). The height of the caldera walls varies from 400-600 m and the altitude of the highest part of the caldera rim is about 900 m above sea level.

The pre-caldera complex forms a shield-like structure about 30 km in diameter. Variations of rock type within the shield suggest that it is composed of several volcanic edifices. Melekestsev (in Luchitsky, ed., 1974) described a large stratovolcano on the northern margin of the caldera and smaller andesite and basalt volcanoes, extrusive domes, and scoria cones exposed in other parts of the caldera walls. All of the pre-caldera complex is of late Pliocene to middle Pleistocene age. Within the section of pre-caldera rocks are horizons with reversed magnetic polarity, which probably date from the Matuyama epoch of 0.7 to 2.5 m.y. ago.

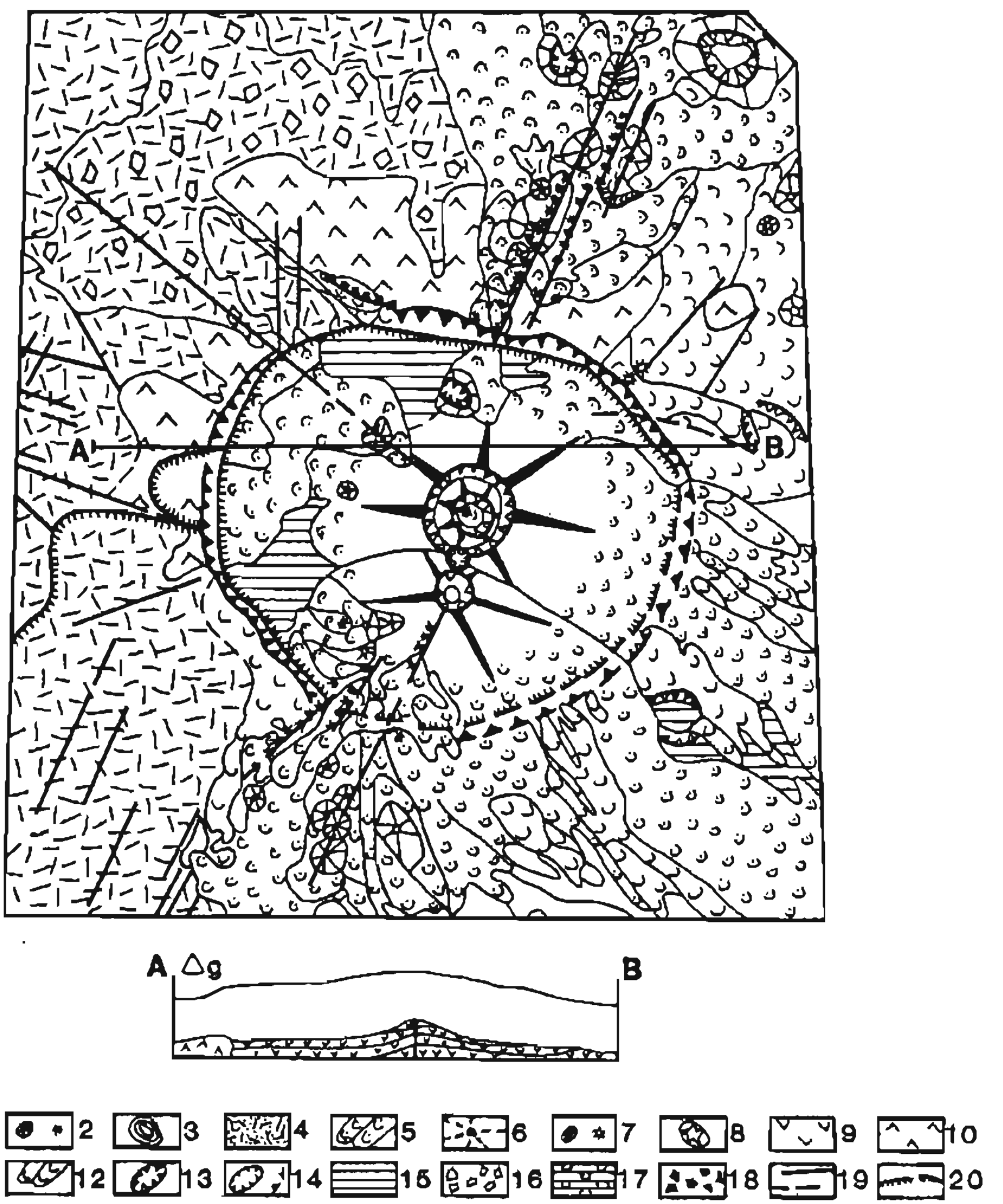
Frolova (1974) describes two types of sections that are characteristic of the pre-caldera complex—one is found distant from the caldera along the foothills of the Kronotsky River valley and the second is found exposed in the caldera walls. The rocks distant from the caldera are dominantly lava flows of high-alumina basalt that range from 12 to 50 m thick. In contrast, the rocks of the caldera walls are lava flows, tuffs, and agglutinates; the quantity of lavas and pyroclastic material is about equal. These are also dominantly high-alumina basalts, but Frolova (1974) shows they are enriched in alkalies in comparison with basalts of the Kronotsky valley foothills. SiO_2 and Al_2O_3 contents of both suites of rocks are approximately equal.

The pre-caldera complex is broken by a system of radial faults that form a series of differentially subsided blocks. Blocks on the northwest and southeast margins of the pre-caldera complex are especially deeply subsided.

Systems of radial and concentric dikes of basalt and basaltic andesite are a characterisitic feature of the caldera. One element of the concentric dike system, a great arcuate dike called the Dvuglavy Zubets, forms the northern and highest part of the caldera wall.

The pre-caldera complex is overlain by dacite pumice of the caldera-forming eruption. The pumice forms weakly welded ignimbrites (so-called tuff-ignimbrites) and unwelded airfall pumice that occur mostly in the deeply

Fig. 83. Geologic map of Krasheninnikov caldera (from Erlich and others., 1972). 1 - Holocene stratovolcanoes; 2 - Holocene cinder and lava cones, (a) shown in scale of map, (b) out of scale; 3 - Holocene and late Pleistocene extrusive domes; 4 - Holocene pumiceous pyroclastic-flow deposits; 5 - Holocene lava flows; 6 - late Pleistocene and Holocene stratovolcanoes; 7 - late Pleistocene volcanic cones, a-shown in scale of map, b-out of scale; 8 - middle Pleistocene scoria cones; 9 - fragments of middle Pleistocene partly destroyed and buried volcanic edifices; 10 - fragments of late Pliocene-middle Pleistocene volcanic edifices; 11 - late Pleistocene pumice deposits; 12 - late Pleistocene lava flows; 13 - Faults scarps of caldera, (a) have topographic relief, (b) destroyed and partly buried; 14 - late Pleistocene and Holocene alluvial plains; 15 - volcano-tectonic faults with small displacements, solid line-observed, dotted line-inferred; 16 - main volcano-tectonic faults. Below-gravity profile across the caldera.



subsided blocks in the northwest and southeast parts of the pre-caldera complex. The volume of the pumice is estimated by Dubik (ref?) to be 6 km^3. Stratigraphic relationships show that the pumice of the climactic eruption of Krasheninnikov caldera overlaps ignimbrites from Uzon caldera and is the youngest widespread pyroclastic unit in the Karymsko-Semiachinsky part of the eastern Kamchatka graben-syncline.

Within the caldera (Fig. 84). lies Krasheninnikov volcano of late Pleistocene to Holocene age. It is composed of two overlapping volcanoes whose lavas are interbedded. The highest point of this edifice (1857 m) towers about 900-1000 m above the caldera wall. Both of these volcanoes are basalt to basaltic andesite in composition and both are crowned by collapse calderas of the Hawaiian type. The caldera of the south cone is 800 m in diameter and 140 m in depth. The structure of the caldera of the north cone is more complex (Figs. 84 and 85). An outer caldera with a diameter of 2000 m encloses an inner crater with a diameter of 800 m. Within the inner crater lies the lava cone called Pauk, which is composed of short flows of blocky lava. Aeromagnetic data indicate that both the north and south cones are composed mainly of lava (Steinberg, 1964). Several young monogenetic lava volcanoes and cinder cones of the same composition as Pauk are located along the rim and also inside Krasheninnikov caldera. Lavas flows erupted from these vents fill the inner part of the caldera.

More than 15 lava volcanoes and cinder cones lie along two parallel north-northeast-trending fissure zones that cut the pre-caldera complex. Distances between vents along this zone are locally as great as 300-500 m, but typically range from 50-200 m. Scattered along both chains of vents are large cones with craters as large as 400 m in diameter. The characteristic structure of this zone is *en echelon* grabens and chains of vents.

The gravity field within Krasheninnikov caldera is characterized by a weak positive anomaly that is bounded by the caldera rim (Fig. 84B). Zubin (*in* Erlich and others, 1972,1973) thinks that this anomaly is caused by lava flows that fill the caldera.

Volcanic and Geothermal Activity.

There are no known historic eruptions of volcanoes in or immediately around Krasheninnikov caldera. Steinberg (1964) noted some fumarolic activity.

CENTRAL KAMCHATKA DEPRESSION

6.0. Tolbachik volcano-tectonic depression.

The lava plateau that forms the basement of the young volcanoes in the southwest part of the Kliuchevskaya volcanic group is cut by a series of faults. The faults are expressed as scarps that are partly overlapped (buried) by lavas of the young volcanoes of the group and outline a subsided area about 40 km across--the Tolbachik volcano-tectonic depression. Amounts of vertical displacement on the faults range from 400-700 m. As a result, the surface of the volcanic plateau within the stable blocks on the southern and

Fig. 84. Shuttle photo of the Krasheninnikov volcano, eastern Kamchatka (courtesy of C. A. Wood). It shows a series of cones one with summit Hawaiian-type caldera nested inside Krashininnikov caldera, and linear zone of small basaltic cinder cone and lava volcanoes which cuts across the caldera. Dark black indicates Kronotsky Lake. Located northeast of Krasheninnikov caldera volcano is the regular cone of Kronotsky. The wall of the Uzon-Geyzernaya caldera is located to the southwest.

southwestern margins of the Kliuchevskaya volcanic group lies at an altitude of about 1,000 m and the top of the subsided block within the volcano-tectonic depression is at an altitude of 300-600 m. Outcrops of these plateau lavas are exposed along river valleys around the periphery of the subsided block. All of the central part of this depression is occupied by numerous scoria and lava cones of the zone of volcanism to the south of the Tolbachik volcano.

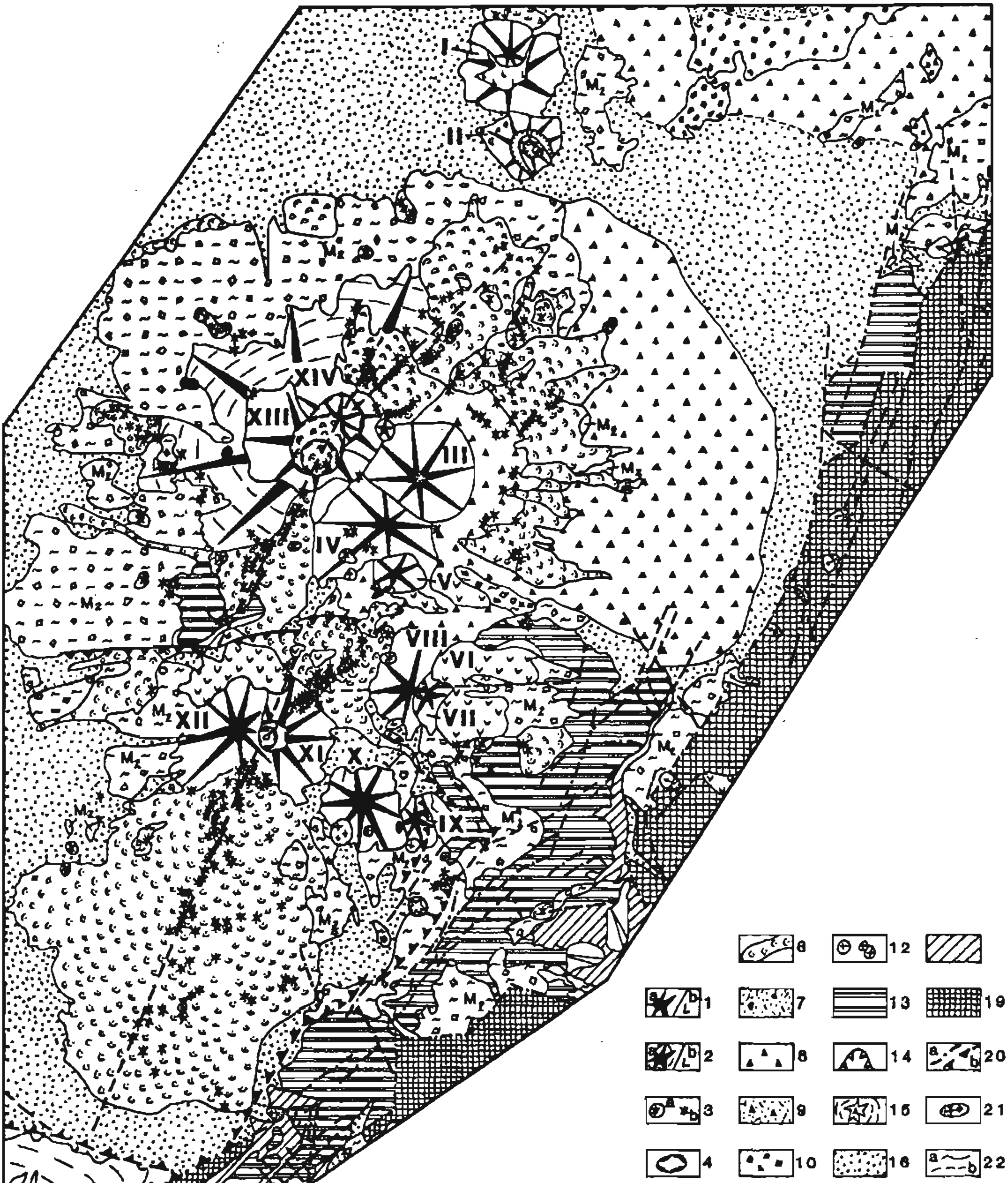
On the north margin of the depression lay the groups of Udiny volcanoes (Bolshaya and Malaya Udiny sopky) and Tolbachiks volcanoes (Ostry and Plosky Tolbachiks volcanoes) (Fig. 85). Both groups are elongated in a northwest direction. Lava complexes of similar age and composition on the north and northwestern slopes of Bolshaya and Malaya Udina volcanoes overlap the basement lavas at an altitude of about 1,000 m, the same altitude as the basement lavas within stable blocks. In contrast, the lavas on the south and southwestern slopes overlap basement lavas at an altitude of about 600 m, the characteristic altitude of the basement lavas in the inner part of the depression. This same relationship is characteristic for the lower horizons of the lavas of Tolbachik volcano in the eastern part of Plosky Tolbachik volcano. The reason for this difference in the altitude of the basement lavas is that Malaya Udina volcano lies on a fault scarp of northwest strike, along which the basement lavas are displaced the same amount as beneath the lavas of the young volcanoes. It is clear that the comparatively young volcanic edifices of volcanoes Udiny' and Tolbachik's volcanoes are also located on a fault scarp of northwest strike, which they mask with their lavas. This buried scarp is well expressed in the magnetic field by a steep gradient of northwest strike along the southern foothills of the Udini volcanoes.

This zone continues along the valley and north bank of the Studenaya River, where it is represented by faults with large (up to 700 m) vertical displacements along which the southern block is subsided. They form a broad arc, open to the south. The amount of displacement along these faults dies out gradually to the west. To the east, these fault scarps are buried by young lavas from numerous scoria cones in the upper part of the Studenaya valley. These scarps are possibly extensions of the faults of the depression boundary.

Consequently, the depression is bounded by a crescentic zone of faults open to the west, which can be traced from the northern edge of Askhachny Uval to Khapischinsky Dol, under Udiny volcanoes, and finally to the system of faults along the north bank of the Studenaya River.

Fig. 85. Schematic geomorphic map of the Kliuchevskaya volcanic group (Melekestsev, taken from Fedotov, ed., 1984). 1 - Strato-volcanoes of late Pleistocene to Holocene age, (a) preserved parts, (b) destroyed parts; 2 - shield volcano of the basement of Plosky volcano: (a) preserved parts, (b) destroyed parts; 3 - cinder and lava cones of Late Pleistocene to Holocene age: (a) shown to scale, (b) not shown to scale; 4 - Hawaiian-type calderas; 5 - craters; 6 - lava flows and plains of Late Pleistocene to Holocene age; 7 - deposits of directed blasts and pyroclastic flows of Holocene age; 8 - Holocene volcanogenic proluvial (alluvial) plains; 9 - Holocene volcanogenic-proluvial and pyroclastic plains, undivided; 10 - Upper Pleistocene directed-blast deposits; 11 - strato-volcano of Middle to Late Pleistocene age, in different degree destroyed, (a) preserved parts, (b) destroyed parts; 12 - extrusive domes; 13 - lava plateau; 14 - ancient caldera of the Shiveluch volcano; 15 - Upper Pleiocene--Lower Pleistocene shield-like volcanoes; 16 - Upper Pleistocene to Holocene accumulative plains; 17 - moraines of the second phase of late Pleistocene glaciation; 18 - area with volcanogenic-tectonic relief; 19 - area with denudative-tectonic relief; 20 - faults, (a) expressed by topographic relief, (b) inferred under cover of unconsolidated deposits; 21 - earthquake-generated landslides; 22 - contacts between units: (a) mapped, (b) aproximately located.

Volcanoes identified by Roman numerals: I. Kharchinsky; II. Zarechny; III. Kliuchevskaya; IV. Kamen; V. Bezymianny; VI. Gorny Zub; VII. Ovalnaya Zimina; VIII. Ostraya Zimina; IX. Malaya Udina; X. Bol'shaya Udina; XI. Plosky Tolbachik; XII. Ostry Tolbachik; XIII. Dal'ny Plosky; XIV. Blizhny Plosky.



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The depression is also bounded by lava complexes of uniform age that dip radially outward from the depression boundaries except on the west from Kinchokla volcano to the Studenaya River. It is possible to conclude that formation of the depression preceded the formation of the young central volcanoes—Udinys and Tolbachiks. Around the depression no traces are found of any silicic pyroclastic material that can be related to the time of its formation.

6.1. Caldera of Plosky Tolbachik Volcano.

General position.

Plosky Tolbachik volcano, which has an Hawaiian-type caldera at its summit, is located in the southwest part of the Kliuchevakaya volcanic group (Fig. 86). Plosky Tolbachik volcano forms part of Tolbachik massif and consists of two volcanoes—Ostry and Plosky Tolbachik, which are located in the northern part of the Tolbachik volcano-tectonic depression (see fig. 1). These volcanoes are aligned parallel to the east-west fault that forms the depression's northern boundary.

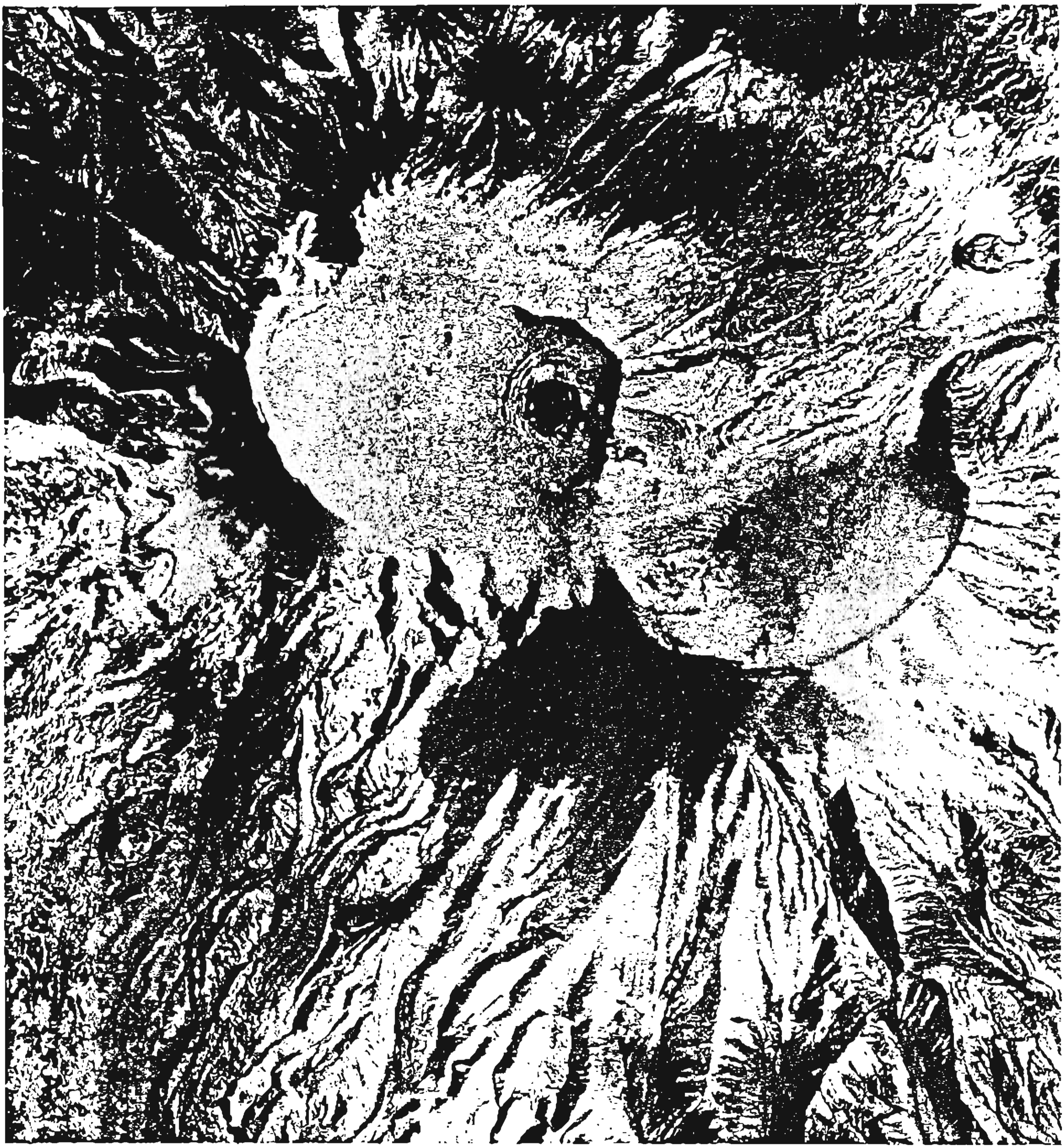
History of volcanic activity.

The first stage of volcanic activity in the Tolbachik massif is represented by lavas that form a common platform for both Ostry and Plosky Tolbachik. Pyroclastic rocks are rare and occur as lenses up to 100 m thick. On the basis of overlying moraines of the Upper Pleistocene glaciation, the age of this platform is thought to be as Middle Pleistocene. The lower lavas are olivine-pyroxene and augite basalts, replaced upward by plagiophiric basalts and basaltic andesites. Their total thickness is 300-400 m; the thickness of the latter group is about 100 m. The thickness of the individual flows of augite basalt is 8-12 m and those of plagiobasalt up to 25 m. The lava flows dip at angles of 3-5^{o}. The volcanic center reconstructed from these flows is a shield volcano with an axial thickness of about 1,000 m and a diameter of about 11 km.

Alluvial-fan deposits lie everywhere on this platform up to an altitude of 1,800-2,000 m. The thickness of these deposits reaches 800-900 m on the Plosky Tolbachik volcano. Pyroclastic rocks in the upper part of this sequence compose 60-70% of the total thickness. This sequence is overlain by the stratovolcanoes. The stratovolcano parts of the Ostry and Plosky Tolbachik edifices were formed simultaneously in the Upper Pleistocene, probably before the first phase of the Upper Pleistocene glaciation. But it is also possible that the stratovolcanoes were formed partly during the first phase of the Upper Pleistocene glaciation. The ratio of volcanic versus alluvial and glacial deposits near the foothills of the stratovolcanoes is 10:1 and in the upper parts of the volcanoes is 1:1 - 1:2. The lavas of both Ostry and Plosky Tolbachik stratovolcanoes are similar and are interbedded.

The stratovolcanoes were formed during the second half of the Upper Pleistocene. The distribution of pyroclastic material within the strato volcanoes is uneven. On Plosky Tolbachik pyroclastic rocks compose 40-45% of the total thickness. The thickness of individual lava flows is typically 1.5-7 m and sometimes up to 10 m. The thickness of pyroclastic layers is from

Fig. 86. Air-photo of the Tolbachik caldera (after Sviatlovsky, 1959). Ostry Tolbachik strato-cone is seen east of the Tolbachik caldera.



0.2–0.3 m up to 1.5 m, rarely more. In the lower parts of the sequence plagiobasalts and basalts without visible plagioclase phenocrysts are interbedded. In the upper part of the sequence, plagiobasalts and basaltic andesites are prevalent.

The summit part of Plosky Tolbachik volcano is formed almost exclusively of lava flows of megaplagiophiric basalts. They form low lava cone about 200–400 m thick. The height:diamter ratio of this cone is about 0.08. The thickness of the individual lava flows ranges from 1–1.5 up to 7m.

An arcuate wall of a blast funnel open to northeast is located on the northeastern slope of Plosky Tolbachik volcano. V. A. Ermakov (Ermakov and Vazheevskaya, 1973) described blast deposits composed of coarse blocks of Plosky Tolbachik volcanic rocks lying on the volcanic plateau near the foothills of Bolshaya Udina volcano. Lavas of Bolshaya Udina are not present among the fragments and blocks in these deposits. A dike swarm having a strike is present in the wall of the arcuate funnel. The funnel is cut by a linear zone of small monogenetic basaltic volcanoes and cinder cones with a strike of N45°E.

Two extensive zones composed of numerous cinder cones and monogenetic basaltic volcanoes with great lava flows join from the southwest and the northeast at the caldera of Plosky Tolbachik. The total length of both these zones is about 65 km; the length of the southwest part is about 40 km. The angle between the strikes of these two zones is about 150°. The southwestern zone is composed of a series of small volcanic centers distributed in en-echelon pattern. In the opinion of Ermakov and Vazheevskaya (1973) the angle between the two zones indicates that the feeder dike that underlies this zone is inclined at an angle of 70–75° toward the east-southeast.

Structure of the caldera.

A circular collapse caldera is located in the summit part of Plosky Tolbachik volcano. The caldera has a telescope-type structure. Nested inside the 3-km-diameter outer caldera is a small caldera about 1.8–2.0 km in diameter and 20–150 m deep. A crater inside the inner caldera was 350–400 m across and 150–200 m deep just before the eruption of 1975.

As discussed in Fedotov, ed., (1984), the summit of Plosky Tolbachik volcano was destroyed and the first caldera was formed in early Holocene time. It is still preserved even though it is almost completely filled by ice. Formation of the caldera was accompained by the first appearance of subalkaline high-alumina basalt, which are similar to lavas of the basement of the Kliuchevskaya volcanic group. The same type of lava also appeared at the same time along the linear zone of basaltic volcanism to the south and northeast of Plosky Tolbachik volcano.

By tephrochronology, the date of formation of the first caldera is 10,000 yr B.P. During the second half of the Holocene the second and smaller caldera was formed inside the large caldera. Since that time it has been filled by ice, sporadically erupted megaplagiophiric lavas and pyroclastics, and collapsed without significantly changing in size and shape. The composition of lavas erupted during this period has remained constant.

Evolution of volcanism in linear zone connected with Plosky Tolbachik caldera.

Volcanism in linear zones connected with Plosky Tolbachik caldera occurred in two main stages according to data compiled by Fedotov, ed., (1984). The first stage of volcanism embraces the time interval from 10,000 up to 2,000 yr B.P. It began with outpourings of subalkaline high-alumina basalt of the same type as is found in the summit caldera. The first radiocarbon dates connected to this stage are as old as 7,000 yr B.P., but it is possible that the first eruptions started about 10,000 yr B.P. Eruptions connected with the first stage occurred within the entire volcanic area south of Plosky Tolbachik. The total volume of magma evacuated during this stage from the summit part of the volcano is about 6-7 km^3 (Fedotov, ed., 1984). If pyroclastic rocks compose about 10%, the total volume of lavas and pyroclastics would have been about 8-9 km^3. During the first stage of activity there was some textural differences in the lavas from different lava fields. South of Plosky Tolbachik, megaplagiophiric basalts erupted at the same time that porphyritic, aphiric, and subporphyritic lavas erupted from vents northeast and south-southwest of the volcano. This probably reflects the difference in temperature conditions of the magmas in the different areas.

Composition of the volcanic rocks erupted during the first stage was comparatively stable. In the beginning of this stage the width of the zone of vents was 12-13 km and progressively narrowed until the vents late in the stage were concentrated within a strip only 4-5 km wide. Slight changes in the composition of the lavas occurred during this stage. Beginning about 4,000 yr B.P. basalts of the so-called intermediate alumina type (Fedotov, 1984) were erupted. By the end of the first stage, the total volume of eruptive products in the area reached 50-56 km^3.

The second stage of volcanism began about 2,000 yr B.P. and continues up to the present. During this stage volcanism was localized in a narrow strip 3 km wide and about 45 km long. The length of the active part of the zone was progressively shortened during this stage. This general shortening of the vent region was accompanied by deepening of the feeder fractures through which the magnesium-rich basalts with moderate alkalinity came to the surface. During this stage there were contrasts in the composition of the basalts and a great variety of volcanic products. Basaltic magmas with moderate alkalinity erupted at the same time as subalkaline high alumina basalts and intermediate varieties. The last eruptions took place in 1975-76 and are represented by megaplagiophiric lavas.

Activity of the summit crater during eruption 1975-76.

On July 2-3, 1975 in the southern part of the summit crater of Plosky Tolbachik, a strong flow of gas 6-8 m in diameter was observed coming from a crater about 30-40 m in dimater. A glow seen above the crater was probably due to the presence of fresh lava in the crater. By the end of July gas emission stopped. Increasing of the gas emission was accompanied by an underground roar. The glow in the crater disappeared. In addition to juvenile pyroclastics on the crater floor there were large fragments of accidental material. From air-photos taken at the end of August, 1975, the volume of the crater had increased to 0.269 km^3 and its depth was 385 m. This was probably witnessed about the time that collapsing of the crater began. In the latter part of August, 1975, the entire crater floor was covered by a mass of mud and rock with a horizontal surface. The next stage of the great collapse in the crater of Plosky Tolbachik occurred at the end of September, 1975. Gusev et al. (1979) thinks it was connected with the eruption of a large volume of volcanic material from the south breakthrough within the linear zone of volcanism to the south of the volcano. In the beginning of September, 1975, a spot of melted ice that was soon a small steaming lake appeared on the floor of the crater near the north wall. From photogrammetric studies, the volume of the crater at the end of September, 1976, was 0.338 km^3 and the depth to the surface of the lake in the crater was 380 m. In December, 1975, the entire floor of the crater was occupied by this lake. The following observations show that the lake's level continued to rise until the middle of 1976, at which time the fumaroles appeared. By the end of September, 1977, when volcanic activity in the breakthrough zone to the south of the volcano ended, the lake in the summit crater disappeared and the crater was up to 404 m deep. The increase in volume of the crater during the last year was small, growing to 0.347 km^3 mainly by increasing its depth.

Problems of the caldera genesis.

There are two points of view on the genesis of Plosky Tolbachik caldera. One recognized practically by everybody was developed by Piip (1956), who thought it is a typical caldera of the Hawaiian type. In contrast, Ermakov and Vazheevkaya (1976) hypothesize that it was formed by a great blast. However, if we consider that Plosky Tolbachik is a basaltic shield volcano which is connected to linear zones of volcanism it appears likely that the caldera is of the Hawaiian type.

Similarities between Hawaiian-type calderas and Plosky Tolbachik caldera include (1) both occur on shield volcanoes, (2) the position and size of the calderas are similar, (3) both types have linear zones of volcanism connected with the calderas, and (4) the angles between the strikes of these zones are the same (150°). Also, both types have a connection between caldera formation and eruptions within the adjacent rift zones.

6.2. Caldera of Plosky volcano.

General description of the central volcano and its calderas.

The great massif of the Plosky volcano is composed of two overlapping volcanic cones (Fig. 86). The summit of the southwestern cone (so-called Dal'ny Plosky volcano) is a large caldera about 5.5-6 km across. In the southern part of the caldera is located a low shield-like volcano about 4.5 km in diameter and 400 m high. On the top of this volcano on air photos is seen a crater-like depression 3.5 km across, in southern part of which two scoria cones are located. In the northeastern part of the massif, Blizhny Plosky volcano is located in another, but older, caldera about 5 km in diameter. The north and northeast rim of this caldera can be observed, but the southern part of it can only be reconstructed on air photos. On the top of Blizhny Plosky volcano lies a crater about 2 km across with an extrusive dome in its center. The southwestern part of Blizhny Plosky volcano collapsed during formation of the crater.

Linear zones of basaltic volcanism connected with the volcano.

A characteristic feature of the massif of Plosky volcano as a whole is the presence of series of small monogenetic basaltic lava and cinder cones. By the data of Sirin (1968), they are located along short radial fissure zones. The two main series are distributed along a linear zone that cuts the summit caldera. These series of cones typically change strike after intersecting the caldera. The linear zone to the south of caldera has a N20°E strike; after intersecting the caldera the strike of the zone changes to

N45°E. Both parts are not formed as a single continuous fissure, but rather are distributed in en-echelon zones of numerous small volcanic centers. As we will see later, these two structural features also characterize an adjacent caldera of the same type—the caldera of the Plosky Tolbachik volcano.

Structural position and basement of the volcano.

Plosky volcano is located in the western part of the Kliuchevskaya volcanic group, supposedly on a flexure on the slope of the central uplift formed by lavas of the basement of the whole volcanic group (Erlich and Gorshkov, eds., 1979). By the data of Sirin (1968), Plosky volcano inherited its position from the large pre-glacial shield volcano, which is composed of a thick lava sequence practically without any pyroclastics. This lava complex is conditionally divided into two sequences—a lower megaplagiophiric and an upper mesoplagiophiric. Within each of these sequences lava compositions change upward from basaltic andesites to basalts. The thickness of single lava flows is about 1-7 m. Their surfaces show no trace of erosion, so the outpouring of these flows probably occurred in a comparatively short time interval. Outcrops of rocks belonging to the lower sequence are observed up to an altitude of 1,400 m. The length of the flows in the lower part of the lower sequence reaches about 25 km; the upper flows are much shorter. The upper sequence occurs up to altitudes of 1,600-1,700 m. The maximum thickness of the sequence is 800 m. The flows dip radially outward around the summit of the volcano, which indicates that the present Plosky volcano inherited the position of the ancient one that erupted the two lava sequences.

History of development of Plosky volcano.

Plosky volcano, which overlaps the basement described above, can be divided into seven sequences (Sirin, 1968). From oldest to youngest they are:

1. An andesitic sequence is developed in the southern sector of the Plosky volcano. Rocks of this sequence are represented mainly by hypersthene andesites. Its thickness reaches 150 m.

2. A lava-pyroclastic sequence formed by interbedding of thin (1-8 m) lava flows and agglomerates (0.5-3 m). Its visible thickness is 300 m; its total thickness is assumed to be 600-700 m. The rocks dip radially outward from the volcano summit.

3. A pyroclastic sequence is located only in the north and northwest sectors of the volcano. Its total thickness is about 200 m. It is composed of layers and lenses of tuffs and tuff-breccia of two-pyroxene and hyperstene basaltic andesites.

4. The upper mega-plagiophiric sequence composes the lower part of the summit cone of Dal'nyaya Ploskaya sopka volcano. It is composed practically only of lavas. The thickness of single lava flows is 2-7 m; agglomerates between lava flows are rare and thin. These lavas everywhere lie on the strongly eroded surface of the lava-pyroclastic sequence (unit 3). The visible thickness of this sequence is 300 m; its total thickness may be about 500 m.

5. A basaltic sequence is developed only in the summit part of the volcano, where it fills a caldera. Its thickness within the caldera is about 100 m.

6. Lavas of the inter-caldera mega-plagiophiric sequence forms the low inter-caldera lava cone. Pyroclastics are absent. Its total thickness is about 200-250 m.

7. An extrusive dome of amphibole andesite fills the crater of Blizhnyaya Ploskaya volcano.

6.3. Zarechny Caldera Volcano.

The caldera of Zarechny volcano is located within the Central Kamchatka Depression (graben-syncline), just across the Kamchatka River from Kliuchi settlement.

Specific features of its position.

Zarechny volcano together with Kharchinsky volcano and a group of small, monogenetic basaltic volcanoes and lava flows form the so-called Karchinsky volcanic group (Fig. 85). This volcanic group is located in the gap between two great active volcanic centers within the central Kamchatka depression--Shiveluch on the north and the Kliuchevskaya volcanic group on the south. Position of the volcano is defined by deepseated east-west fault going along Kamchatka river valley on its east-west part. This deepseated east-west zone from the northern boundary of the central uplift of the basement is in the central part of Kliuchevskaya volcanic group. On the extension of the same east-west deepseated fault zone in the Sredinny Ridge is located Alney-Chashskshaya volcano-tectonic depression.

Structure and composition of the volcano and caldera.

Zarechny volcano is a cone about 8 km in diameter which is nested within the 4.5-6-km-diameter caldera of a larger cone about 4 km in diameter. There is no information about the structure of the caldera or the composition of the lavas of either cone because the area is covered by thick vegetation and no outcrops are known. The cone of Zarechny volcano is essentially uneroded and both it and the caldera in which it lies are dated as Holocene Melekestsev (*in* Luchitsky, eds., 1974). The summit of Zarechny contains a small caldera about 2-2.4-km in diameter.

SREDINNY RIDGE VOLCANIC ZONE

7.1. Khangar Volcano-tectonic Depression.

Khangar volcano-tectonic depression, named for the Khangar Volcano, which lies within it, is the southernmost volcano in the Sredinny Ridge volcanic zone and is separated from the other Quaternary volcanoes in the zone. Due to its isolated and remote location, it has been studied during several special scientific expeditions.

Structural Position.

Khangar volcano-tectonic depression is located in a metamorphic terrane that is conditionally dated as Paleozoic-Mesozoic, although reset potassium-argon dates of these rocks ranges from 40 to 200 my. The structural block that this terrane occupies is called Median Massif of Kamchatka. The position of the volcano-tectonic depression is controlled by two structures:

1. It is located at the center of a domal uplift, which is evident on a topographic map that removes the unconsolidated Quaternary deposits and effects of Quaternary erosion (Fig. 87). The altitude of the uplift around the volcanic area is 1500-1700 meters. The volcanic area forms a circular volcano-tectonic depression 12-16 km in diameter. It is slightly elongated in a north-south direction Several outcrops of the same granodiorites observed around the depression are found at the bottom of the depression, which lies about 1000 meters above sea level. Therefore the amount of subsidence along the circular outer system of faults that bound the depression, is about 500-700 m. The topographically high area to the northeast is composed of a tight fold in metamorphic and intrusive rocks; the core of the fold is displaced to the NE by a fault. According to Kutiyev, Lebedev and Maximovsky (1976), this domal uplift coincides with a metamorphic dome that has metamorphic facies zoned concentrically around the core of the structure (Fig. 88).

2. The volcano-tectonic depression is located at the intersection of the domal uplift and an east-west, deep-seated, strike-slip fault zone, which can be traced across the entire Kamchatka Peninsula to the east coast.

The gravity field in the depression is similar in size, shape, and intensity to that around the main centers of silicic volcanism in southern and eastern Kamchatka, where such anomalies are considered to reflect the presence of a magma chamber beneath the volcano-tectonic depressions. At Khangar we see Tertiary granodiorites on the surface. This probably confirms the conclusion regarding the connection between negative gravity anomalies and presently existing magma chambers.

Distribution of Volcanic Centers.

Most of the volcano-tectonic depression is occupied by Khangar volcano (Figs. 89 and 90). An arcuate zone of extrusive domes is located around the flank of the volcano in the northern part of the depression. The southern part of the depression is occupied by a structural block, called the Vodopadny block, that is composed of a series of obsidian domes overlapped by a small scoria cone with lava flows of olivine basalt.

Fig. 87. Morphostructure of the Khangar volcano-tectonic depression (after Kutiyev, Lebedev, and Maximovsky, 1976). 1 - Generalized contours (in meters above sea level) that ignore Quaternary unconsolidated deposits and erosion; 2 - areas with altitudes of 1400-1500 m; 3 - areas with altitudes of 1600-1700 m; 4 - areas with altitudes of 1800-2000 m; 5 - The main arcuate faults of the caldera boundaries; 6 - faults of the Vodopadny uplift; 7 - gravity contours over caldera (all values are calculated in reference to an artificial zero level); 8 - minimum of the gravity field of the caldera; 9 - crater lake, maar, and strato-volcano within the caldera.

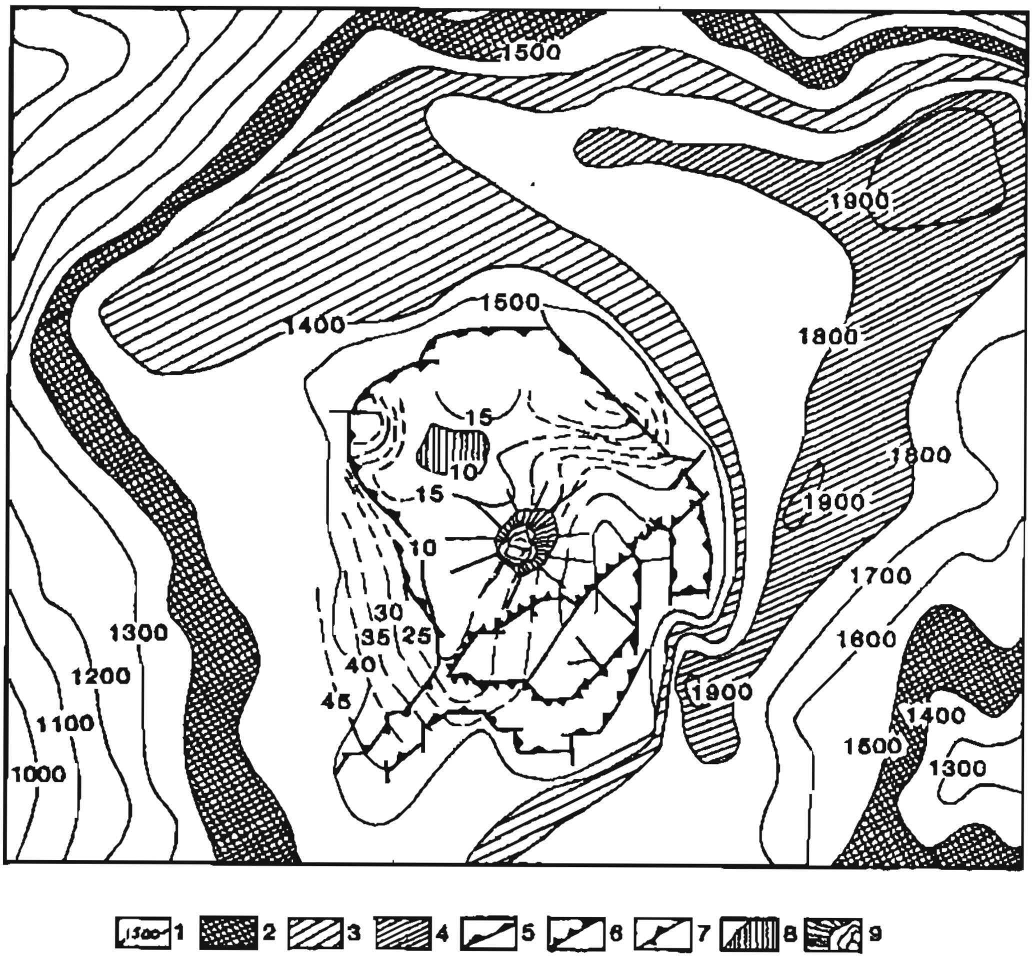


Fig. 88. Schematic geologic map of the granite-gneiss dome, on which the Khangar volcano-tectonic depression is formed (after Kutiyev, Lebedev, and Maximovsky, 1976). 1-5. Rocks of Khangar Volcano. 1 - Intra-caldera pumice covers; 2 - olivine basalts; 3 - the main extrusive dome; 4 - extrusive domes emplaced along inner arcuate faults; 5 - intra-caldera effusive and pyroclastic deposits.
6-9. Intrusive rocks of the Khangar granite-gneiss dome. 6 - porphyritic granodiorites, Neogene; 7 - biotite-amphibole granodiorites, Neogene; 8 - basic and ultrabasic intrusions, Upper Cretaceous; 9 - two-mica plagiogranites, Upper Cretaceous; 10 - Oligocene-Miocene unmetamorphosed terrigenous and volcanogenic deposits; 11 - volcanic rocks metamorphosed to greenschist facies; 12 - schistose sandstones; 13 - schistose porphyry metamorphosed to greenschist facies; 14 - mica-bearing sandstones and phyllite-like schists; 15 - phyllite schists; 16 - phyllites; 17 - amphibolites and amphibole-chlorite schists; 18 - crystalline, meta-pelite schists; 19 - granite-gneisses and gneissic plagiogranites; 20 - migmatites; 21 - zones of mylonitization and retrograde metamorphism; 22 - zones and fields of migmatites; 23 - faults in the granite-gneiss dome; 24 - the main volcano-tectonic faults of the volcano-tectonic depression; 25 - faults of the Vodopadny uplift; 26 - maar and crater lake on the summit of the main stratovolcano in the caldera.

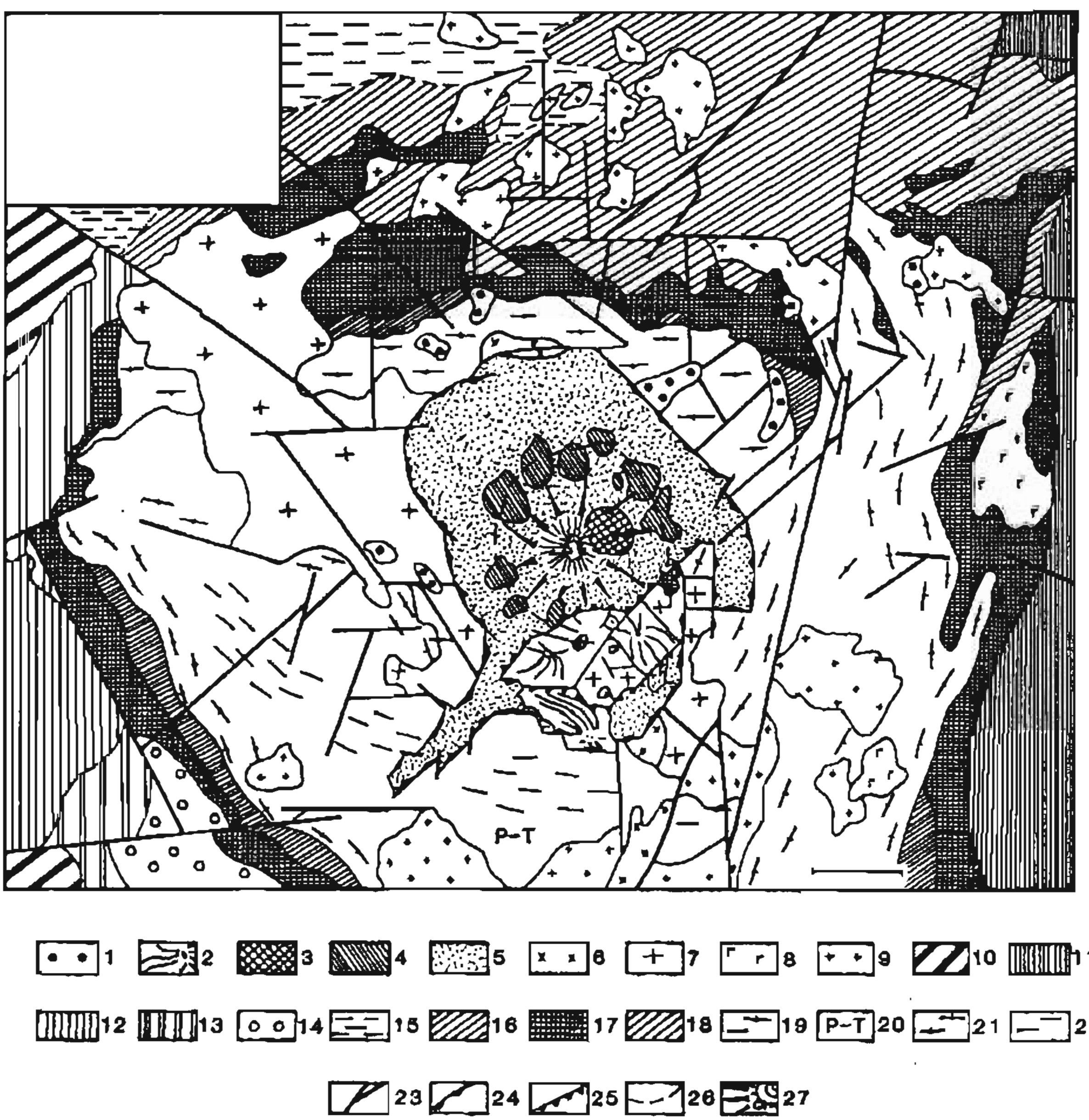


Fig. 89. Geologic map of Khangar volcano-tectonic depression (after Kutiyev, Lebedev, Maximovsky, 1976).
1 - Migmatites, gneisses, plagiogranites, and granodiorites of the basement of the volcano. 2-4. Rocks of the first stage of volcanism; 2 - lava flows of amphibole-pyroxene andesite; 3 - lava flows of biotite-amphibole dacite; 4 - extrusvie domes of plagioclase andesite.
5-7, 15. Rocks of the second stage of volcanism; 5 - extrusive domes of biotite-amphibole-pyroxene andesite; 6 - extrusive domes of biotite-amphibole dacite; 7 - extrusive domes of biotite rhyolite; 15. dike of biotite rhyolite.
9-13. Rocks of the third stage of volcanism; 9 - extrusive domes of biotite-amphibole dacite; 10 - extrusive domes and pumice of biotite rhyodacite; 11 - lava flows of biotite-plagioclase obsidian; 12 - extrusive domes and pumice of pyroxene-biotite dacite; 13 - pumice of pyroxene-biotite dacite.
14 - Rocks of the fourth stage of volcanism; lava flows of olivine basalt.
16 - Direction of pumice flow; 17 - main faults that bound caldera; 18 - faults of Vodopadny uplift; 19 - radial faults; 20 - explosion crater; 21 - lines of geologic cross sections.

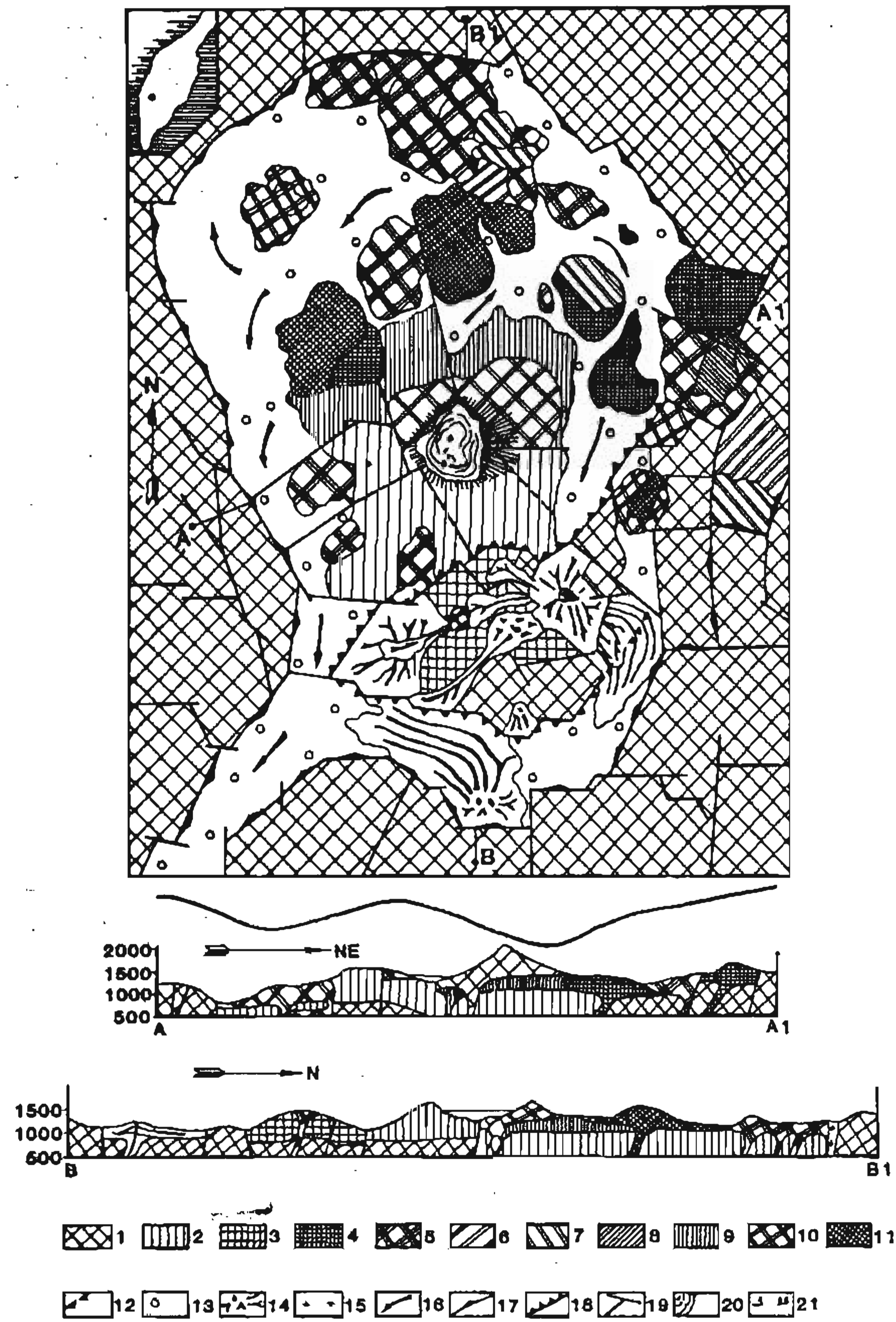

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Fig. 90. Oblique aerial photograph of Khangar volcano (from Sviatlovsky, 1959). The scarp that bounds the volcano-tectonic depression is clearly visible left of the center of the photograph.

Khangar volcano is composed of two parts that are apparently coeval--a stratovolcano in the western part of edifice and a large extrusive dome in the eastern part. In the following discussion this is called the main dome. The last event in the development of the volcano was a great explosive eruption that destroyed the summit of the edifice. Numerous dacitic pumice-flow deposits, which cover the slopes of the volcano and the bottom of the depression, were emplaced late in this eruption. The last stage of volcanic activity within the central edifice was probably the extrusion of two small domes that form islands within the lake (Fig. 90).

Volcanic History.

First we need to mention the absense of any traces of volcanism that predate the formation of the volcano-tectonic depression. So the first stage of development of the structure was subsidence of the depression block. Volcanism then started within the depression.

From the data of Kutiyev, Lebedev and Maximonsky (1976), four stages of volcanic activity can be recognized in the development of the depression. During the first stage of volcanism, the central andesite stratovolcano was formed as were extrusive domes of plagioclase andesites to the north of the stratovolcano. During the second stage, biotite dacites and rhyolites of the main extrusive dome erupted. Simultaneously extrusive domes were formed in the northeast part of the caldera; they form northwest-striking and arcuate zones of domes. During the third stage of volcanism, a silicic volcanic complex of biotite-plagioclase obsidian and amphibole-biotite dacite were formed on the north flank of the main cone and within the Vodopadniy block to the south of the volcano. Pumice eruptions during the formation of the summit caldera of the Khangar volcano also belong to this stage. The radiocarbon age of this eruption is about 6000 yr B.P. As a result of this explosive eruption, a summit caldera about 2 km in width was formed which is now occupied by a lake. The pumice can be divided into two types: (1) biotite rhyolite to dacites and (2) pyroxene-biotite dacites. The extrusive domes of the islands in the lake that occupies the summit caldera were probably formed at the end of the third stage.

The fourth stage of volcanic activity is represented by olivine basalts in the southern part of the depression. The location of the basaltic vents is controlled by a northeast-trending tectonic zone.

Some Important Genetic Features.

Khangar volcano is especially interesting because the metamorphic terrane on which it is located belongs to the granitic layer of the crust based on deep seismic data (see Erlich and Gorshkov, 1979). It is a rare case in Kamchatka to have a Quaternary silicic volcanic center located immediately on the granitic layer.

Another important feature is that the formation of the large Quaternary volcano-tectonic depression was not preceded by any earlier Neogene or Quaternary volcanic activity. Thus, there is no evidence of a long-lived magma chamber in the area. Another very important feature of the Khangar caldera is the absence of any evidence of ignimbrite eruptions connected with the formation of the volcano-tectonic depression. Melekestsev (personal commun.) thinks that ignimbrites connected with the formation of the Khangar volcano-tectonic depression probably form some river terraces in the adjacent area of the western slope the the Sredinny Ridge. However, there is no confirmation of this hypothesis. The volume of terraces appears too small to be connected with the formation of the outer caldera.

Estimated temperatures of the silicic volcanic rocks and minor-element and isotopic data suggest that the silicic rocks of Khangar volcano-tectonic depression were derived from a mantle source (see Bakumenko and others, 1970; Erlich and Gorshkov, eds., 1979; Erlich and others, 1970; and Kutiyev, Lebedev and Maximovsky, 1967) when speaking about the genesis of the Khangar volcano-tectonic depression emphasized that domal uplift which controls its structural position is the morphological expression of a metamorphic dome and there exists zonality of metamorphic facies distribution around this dome.

The location of the volcano-tectonic depression on the domal uplift, the absence of any traces of volcanic activity that pre-dates the formation of the volcano-tectonic depression, and the absence of silicic pyroclastic material connected with the time of formation of volcano-tectonic depression probably indicate that subsidence of the volcano-tectonic depression area is the result of a doming process. This doming can be either tectonic or thermal in nature. In the case of the Khangar, there is strong evidence present of both types of doming.

7.2. Ichinsky Volcano-tectonic depression.

History of study.

Due to its remote location, the Ichinsky volcano-tectonic structure has only been studied during geologic mapping (Erlich, 1958, 1960) or during special expeditions (Marenina, 1962, 1963; Sviatlovsky, 1960; Ogorodov, 1962, 1962a, 1972). Erlich (1966) first suggested the existence of a great volcano-tectonic depression, in which Ichinsky volcano is located.

Structural position.

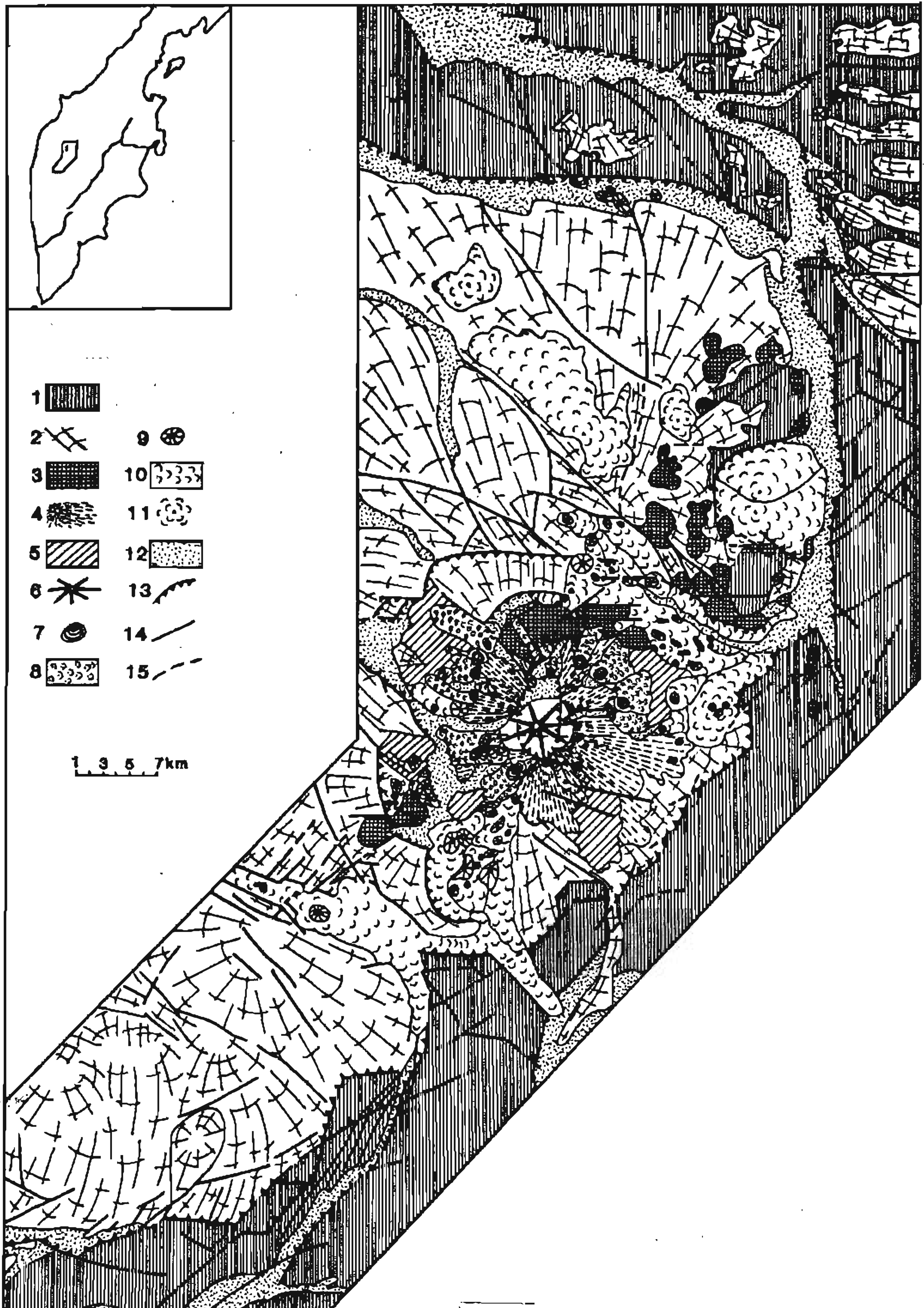
The structural position of Ichinsky volcano-tectonic depression is defined by two structural features. One of these is the sudden diving of the roof of the Kamchatka Median Massif metamorphic terrains, whose northern boundary is just south of the Ichinsky volcano. The second is a sharp decrease in the elevation of the Tertiary roof rocks on the western wing of the Kozyrevsky linear uplift, on the boundary between the Neogene central Kamchatka volcanic zone and the western Kamchatka linear rear depression, which is filled by a thick sequence of Tertiary sediments.

General description of the structure and history of volcanism.

The depression has an oval shape (50X60 km across), elongated N 25-30° E (Fig. 91). Most of its boundary follows faults with displacements of several hundreds of meters. The faults cut a complex of shield volcanoes and a plateau of Upper Pliocene-Lower Quaternary age, composed mainly of basalts and basalt-andesites. The Ichinsky volcano is located inside the depression. Several Lower to Middle Pleistocene basaltic shield volcanoes are located in arcuate zones parallel to the northern boundary of the depression. The Ichinsky volcano is an andesitic stratovolcano about 3000 m in height, with a summit caldera 3-3.5 km across filled by a large glacier. It is notable that, on the plain and plateau around the volcano-tectonic depression, there are no traces of ignimbrites or other kinds of silicic pyroclastic rocks associated with the formation of the depression. Their absence is not the result of erosion--moraines and other kinds of loose Quaternary deposits in the same places are preserved. The absence of silicic pyroclastic associated with caldera formation and/or volcano-tectonic depression formation is a characteristic feature of the Quaternary Sredinny Ridge volcanic zone.

Fig. 91. Geological map of Ichinsky Volcano (after Erlich and Gorshkov, eds., 1979).

1. Pre-Quaternary dislocated complexes of the basement. First cycle of Quaternary volcanism - Pliocene - Lower Middle Plesitocene: 2. basaltic shield-like volcanoes; 3. extrusive domes (from andesite to obsidian in composition);
Main stage of silicic volcanism - upper part of Middle - lower part of Upper Pleistocene: 4. andesite-dacitic stratovolcanoes; 5. extrusive domes composed of amphibole-bearing andesites;
Latest stage of post-caldera volcanism - Upper Pleistocene--Holocene: 6. dacitic stratovolcanoes; 7. dacitic extrusive domes; 8. flows of viscous acid lava;
Stage of youngest basaltic volcanism - Uppermost Pleistocene--Holocene: 9. small volcanoes and cinder cones; 10. lava flows; 11. shield-like volcanoes; 12. unconsolidated Quaternary sediemnts (alluvial, glacial and fluvioglacial); 13. faults on the rim of volcano-tectonic depressions; 14. normal faults (observed); 15. faults (inferred).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The formation of Ichinsky volcano summit caldera was associated with the eruption of dacitic ignimbrites, which are located on the northern slope of the volcano, within the volcano-tectonic depression. Ichinsky is also surrounded by a ring complex of extrusive domes and short lava flows composed of two-pyroxene, amphibole-pyroxene and hypersthene-amphibole andesites and andesite-dacites. This ring structure was deformed by movements along strike-slip faults with east-west, north-south, and northeast strikes. The emplacement of the summit cone of Ichinsky volcano was almost synchronous with the emplacement of the domes of the ring complex.

Recent activity of Ichinsky volcano are limited to fumaroles which cut the glacier within the summit caldera.

7.3. Ukslchan Caldera.

Structural Position.

Uksichan volcano, and the caldera of the same name, lie on the drainage divide of Sredinny Ridge (Fig. 92). They are located on a structural block in the eastern part of the Kozyrevsko-Bystrinsky horst-anticline. Uksichan caldera lies at the intersection of two faults. One fault is inferred along the Uksichan River valley and has a northwest strike, the other fault runs along the northern border of the pre-caldera complex and has an east-west strike.

General Structure and History of Volcanism.

The Uksichan caldera is located in the summit of a great shield-like volcano, called Uksichan volcano (Fig. 93), which covers an area of 300-km^2. The summit of the volcano is 1685 m above sea level and stands about 600 m above the surrounding region. The edifice is built of numerous lava flows 5-20 m thick. Initial lava flows had great mobility and range from 15-20 km long. Later lava flows are shorter and thicker due to their greater viscosity. The western and southwestern slopes of the volcano are composed exclusively of lava flows. Boundaries of the lava flows are clearly expressed and are represented by small quantities of scoria and agglutinate in quenched zones. The eastern and southeastern slopes contain a significant quantity of pyroclastic material including agglutinates, tuffs, and tuff-breccias. The slopes form gently sloping plateaus. Inclination of these plateaus reflect the primary dips of the volcanic rocks, which are radial to the center of the volcano.

The volcano has a summit caldera about 12 km in diameter and about 900 meters deep. Some relicts of the pre-caldera edifice are located inside the caldera. Silicic pyroclastic deposits are absent from around the caldera. This is not the result of erosion, because loose morainal deposits of late Pleistocene age on the slopes of the volcano are preserved.

Rocks of the pre-caldera edifice show some increase in alkali content with time and range from basalts and basaltic andesites to trach-andesites and trachytes. Paleomagnetic studies and the degree of glacial erosion of the lavas suggest they are early to middle Pleistocene in age.

Fig. 92. Schematic tectonic map of the region around Uksichan Volcano (from Ogorodov et al., 1967). 1 - zone of domal uplift along the Kozyrevsky-Bystrinskya horst-anticline; 2 - zone of relative subsidence west of Uksichan Volcano; 3 - zone of uplift in the Yanga-Yagay region; 4 - zone of subsidence around Ichinsky volcano; 5 - regional faults; 6 - local faults (of the second order); 7 - faults of the third order (fractures of extension); 8 - faults of the third order marked by linear zones of cinder cones; 9 - axis of the Kozyrevsko-Bystrinsky horst-anticline; 10 - slopes of Uksichan Volcano; 11 - caldera of the Uksichan volcano; 12 - Quaternary volcanic rocks (shown in sections); 13 - hot springs.

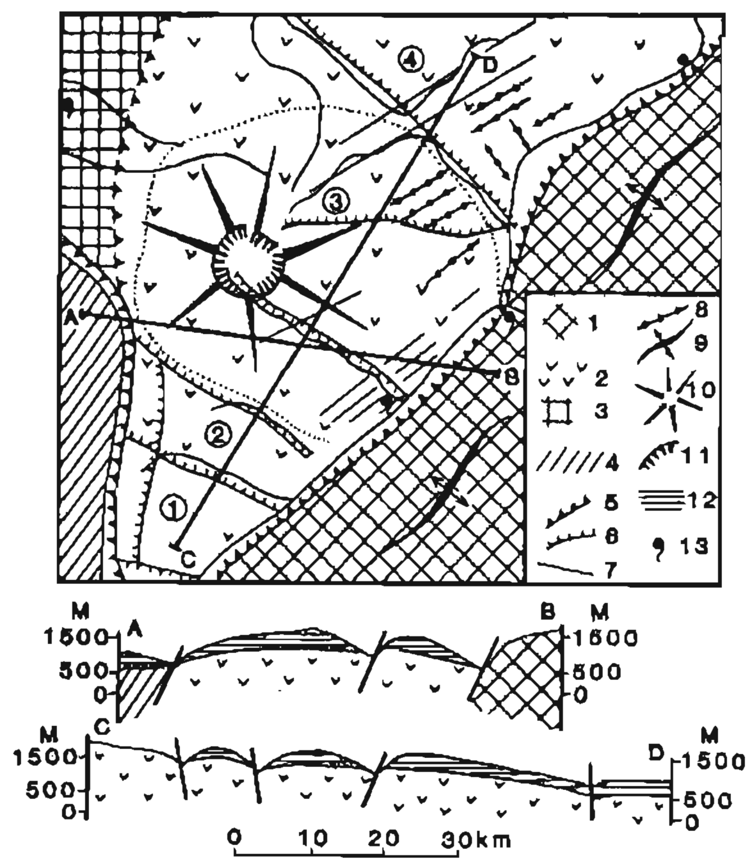
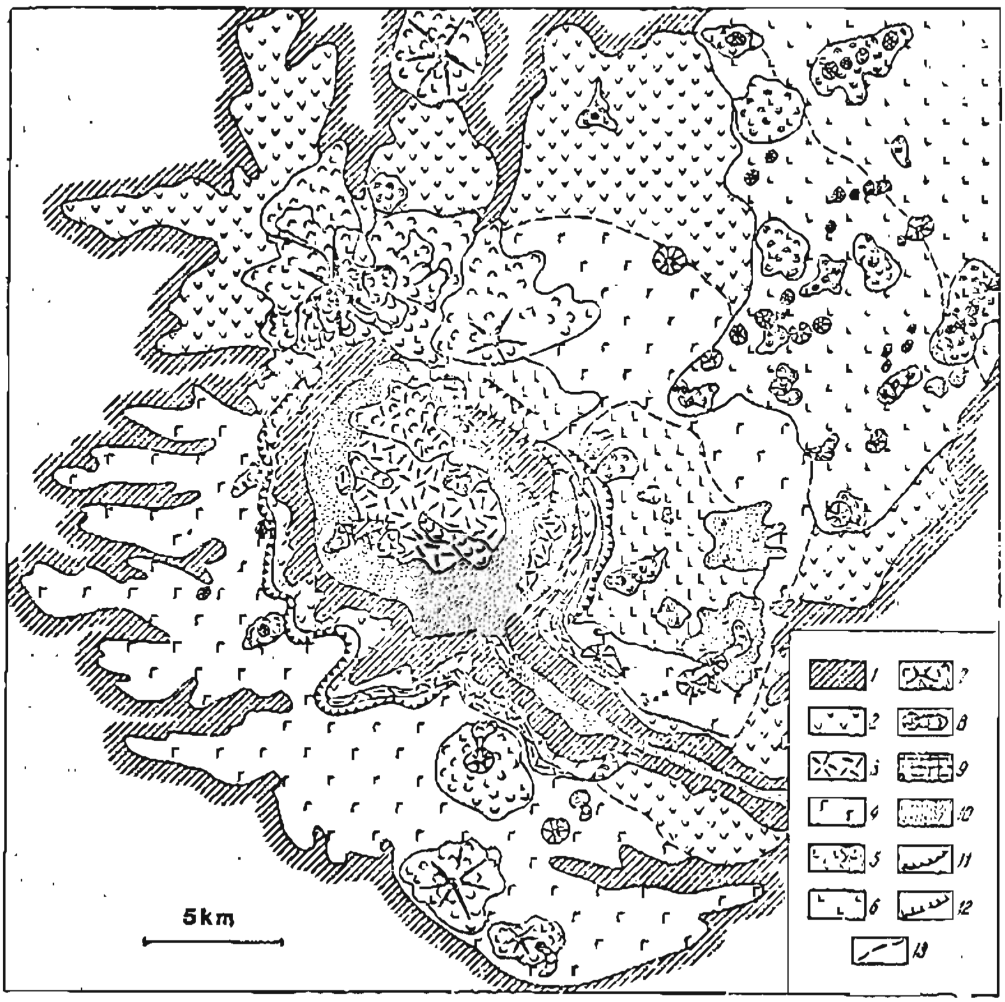


Fig. 93. Schematic geologic map of Uksichan Volcano (Ogorodov and others, 1967). 1 - Basement rocks of volcanic plateau; 2 - andesites and trachyandesites; 3 - biotite andesite-dacite and trachytes; 4 - basalts and basaltic andesites with intercalated tuffs; 5 - basalts of shield volcanoes and cinder cones (upper Pleistocene to Holocene); 6 - shield volcanoes and their lava flows; 7 - hydrothermally altered zones; 8 - undivided Quaternary sedimentary deposits; 9 - caldera of the volcano; 10 - faults; 11 - boundaries between different complexes (approximately drawn).
NOTE: Caldera boundary is indicated by the authors along the upper part of the caldera rim.



The caldera is nearly filled with several dacitic domes. The largest among them--Mt. Uksichan--occupies a great part of caldera and is about 8 km in diameter and stands about 900 m above the caldera floor. Three other domes are of much a smaller size.

The slopes of the volcano are parlty covered by several very small upper Pleistocene to Holocene basaltic scoria cones and icelandic-type, monogenetic basaltic shield volcanoes that belong to the second cycle of basaltic volcanism in Quaternary time. The largest of these volcanoes, Chingeingein, overlaps the northern rim of Uksichan caldera.

Ogorodov and others (1967, 1972) explained the origin of Uksichan caldera as a normal Krakatau-type caldera. But neither their data nor the data from geologic mapping indicate any traces of silicic pyroclastic material on the volcanic plateau around Uksichan caldera. Also, all the data available on volcanic structure and composition of the volcanic rocks indicate the similarity between this caldera and calderas of the Hawaiian type. The presence of silicic domes within the caldera doesn't contradict this idea, because small amounts of silicic material are associated with some basaltic volcanoes.

7.4 - 7.9. Group of caldera-volcanoes of the Western part of Sredinny Ridge volcanic zone.

Caldera-volcanoes Bolshoy, Kekuknaysky (Leningradets), Bolshoy Chekchebonay, Maly Chekchebonay, Perevalovy, and Tigilsky are located in the westernmost part of the Quaternary Sredinny Ridge volcanic zone (Fig. 94). They form a northeast-trending cluster of volcanoes located approximately along the contact between the western Kamchatka linear basin, which is filled by a thick sequence of Tertiary sedimentary rocks, and the Neogene volcanic zone of central Kamchatka. The position of certain centers is determined by short east-west-trending, strike-slip faults that show small horizontal displacements of the basement rocks (sometimes there are only slight indications of such horizontal displacement along these faults).

Calderas of all these volcanoes occupy the summits of large shield-like volcanic edifices (Figs. 95-98). Diameters of these calderas are 3-4 km on the average. The basement of these volcanoes is typically sedimentary rocks of Pliocene age. All of these edifices are composed mainly of basalts and basaltic andesites. Ages of all are thought to be early to middle Pleistocene. Only Maly Chekchebonay has been dated as middle Pleistocene based on paleomagnetic data. Slopes of these volcanoes are very low--5-10°. They are composed mainly of lavas. The quantity of pyroclastics in sections does not exceed 10-15%. Thickness of lava flows ranges from 10-15 m, thickness of the pyroclastic layers does not exceed 1-2 m. In the summit areas of these volcanoe lava flows and extrusive domes of dacite are present.

Formation of all of these volcanoes were completed before the first stage of late Pleistocene glaciation. Their slopes are extensively dissected by U-shaped valleys, so some volcanoes are formed by a series of plateau-like interfluves that slope outward from the center of the volcano. The characteristic features of these calderas is the absence in their surroundings of any significant quantity of silicic pyroclastic deposits. Blast or

Fig. 94. Schematic map showing the distribution of volcanoes in the western region of the Sredinny Ridge volcanic zone (after Ogorodov and others, 1972). 1. Shield-like differentiated (basalts to andesites) volcanoes of lower and middle Pleistocene age; 2. calderas; 3. late Pleistocene and Holocene basalts; 4. volcanogenic rocks of the central Kamchatka, Neogene volcanic zone; 5. Upper Neogene sedimentary rocks of the West Kamchatka linear rear basin. Volcanoes: 1. Bolshoy; 2. Kekuknayasky; 3. Malaya Ketepana; 4. Bolshaya Ketepana; 5. Tigylsk; 6. Bolshoy Chekchebonay; 7. Perevaloviy; 8. Maly Chekchebonay; 9. Ovalny; 10. Shlen.

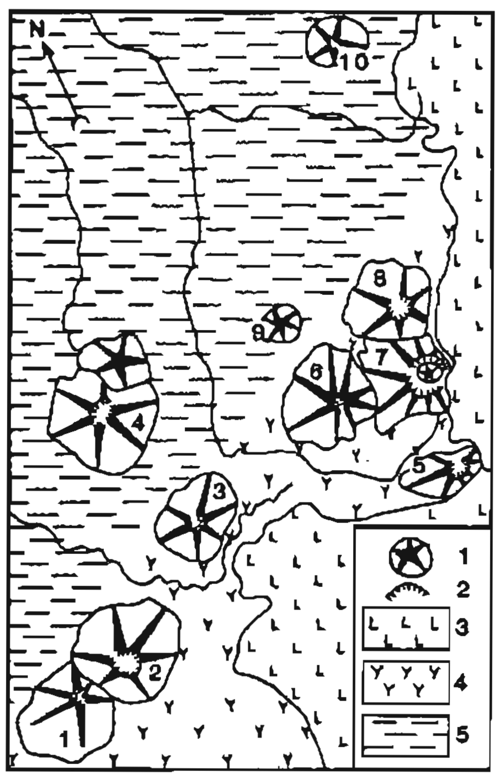


Fig. 95. Schematic geologic map of Bolshoy and Kekuknaysky volcanoes of the western region of the Sredinny Ridge volcanic zone (Ogorodov and others, 1972).
1 - Holocene basaltic scoria cones and lava flows; 2 - lava covers, undivided; 3 - slopes of volcanoes; 4 - calderas; 5 - U-shaped glacial valleys; 6 - moraines of the second stage of late Pleistocene glaciation (Q_3); 7 - faults, inferred; 8 - basaltic lava flows; 9 - andesite; 10 - andesite and dacite lavas and tuffs.

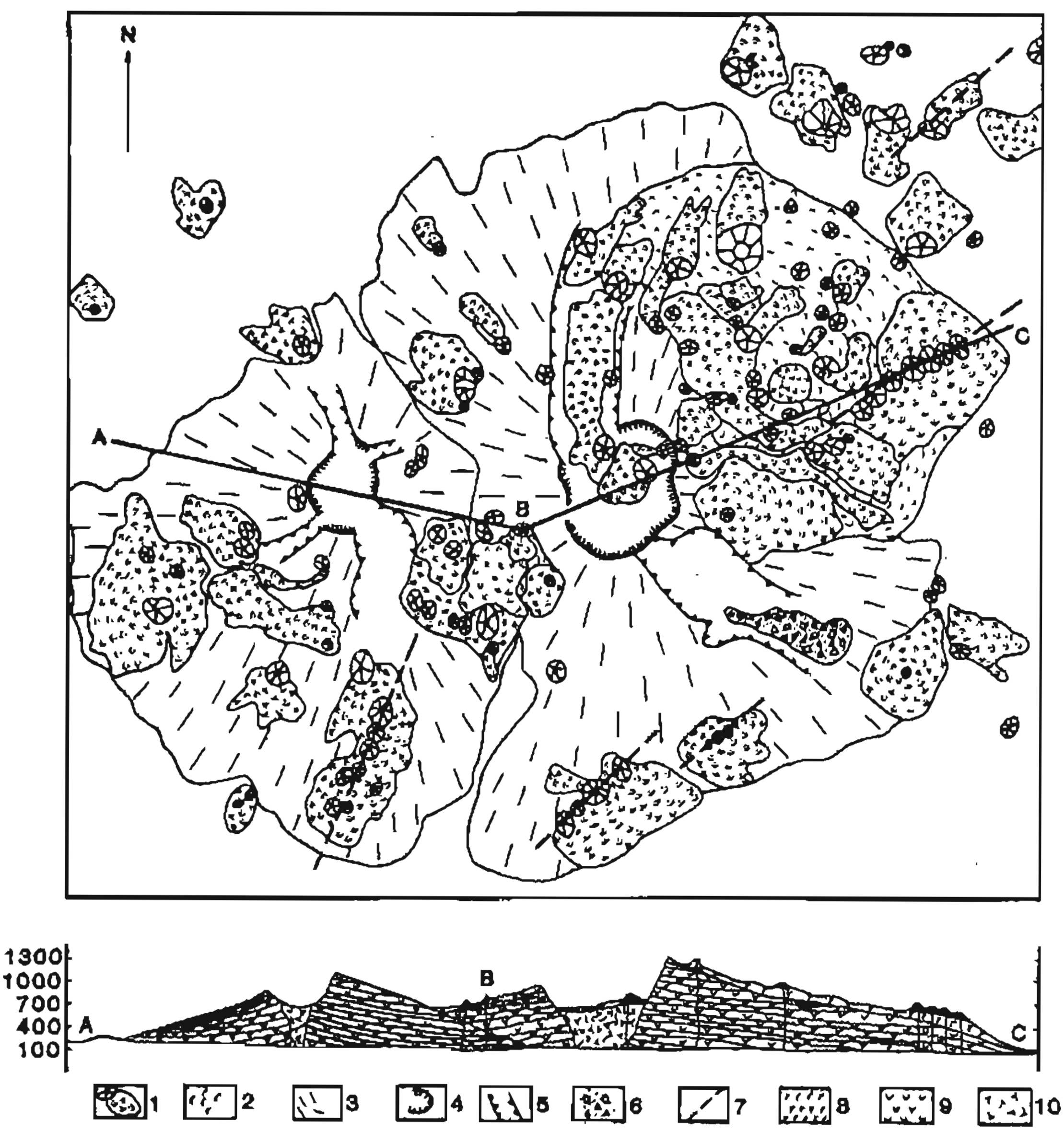


Fig. 96. Morphology of Perevalovy volcano (Ogorodov and others, 1972).

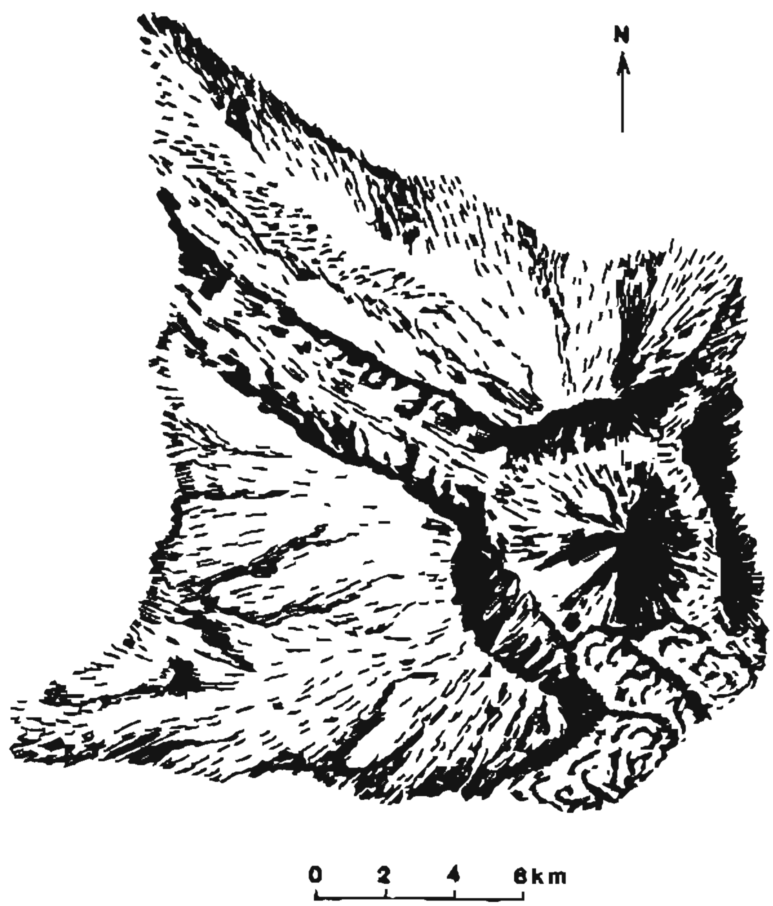


Fig. 97. Morphology of Bolshoy Chekchebonay volcano (Ogorodov and others, 1972).

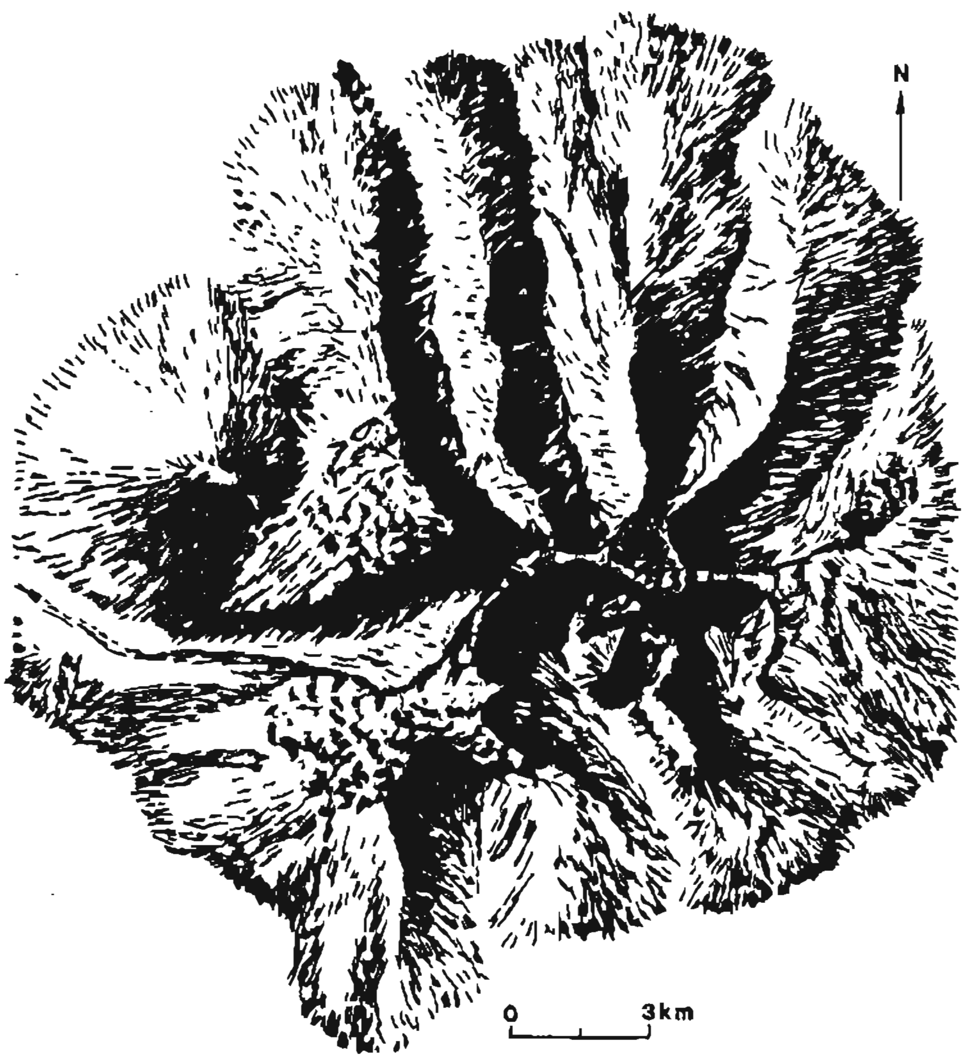


Fig. 98. Morphology of Maly Chekchebonay volcano (Ogorodov and others, 1972).

pyroclastic deposits are also absent in these calderas. An insignificant quantity of silicic ashes, which form the middle Pleistocene Krutoyarovsky horizon in the Tigyl region and in upper Pleistocene terraces in the central Kamchatka depression are thought by some authors to be related to caldera-forming eruptions of these volcanoes (Daragan, Il'ina, 1976; Braitseva, Melekestsev, 1975). However, the volume of these pyroclastic deposits is much less than the volume of these calderas. The lack of silicic pyroclastics cannot be explained by erosion--sometimes loose middle or upper Quaternary deposits are present around these volcanoes, but there is absolutely no indication of ignimbrites and/or tuffs. Previously we have seen in southern and eastern Kamchatka the same structural conditions present near calderas that are surrounded by large fields of silicic pyroclastic rocks. But in the Quaternary Sredinny Ridge volcanic zone they are absent around Khangar, Uksichan, Alney and this group of calderas in the western region. It is possible to conclude that the absence of caldera-forming pyroclastics is a characteristic feature for calderas of this zone as a whole.

The origin of these calderas is the same as that of Uksichan caldera--they are considered by authors who described them as normal calderas of the Krakatau type. But the absense of any traces of silicic pyroclastic material and all the data about the structure of these volcanoes and the composition of their rocks indicate that they are of the Hawaiian type.

The post-caldera stage of volcanism on some of these volcanoes is present in the form of silicic extrusive domes. Also, on the slopes of the pre-caldera edifices and sometimes inside the calderas are located numerous basaltic shield volcanos and scoria cones of the upper Pleistocene to Holocene cycle of basaltic volcanism that are widely represented in the region.

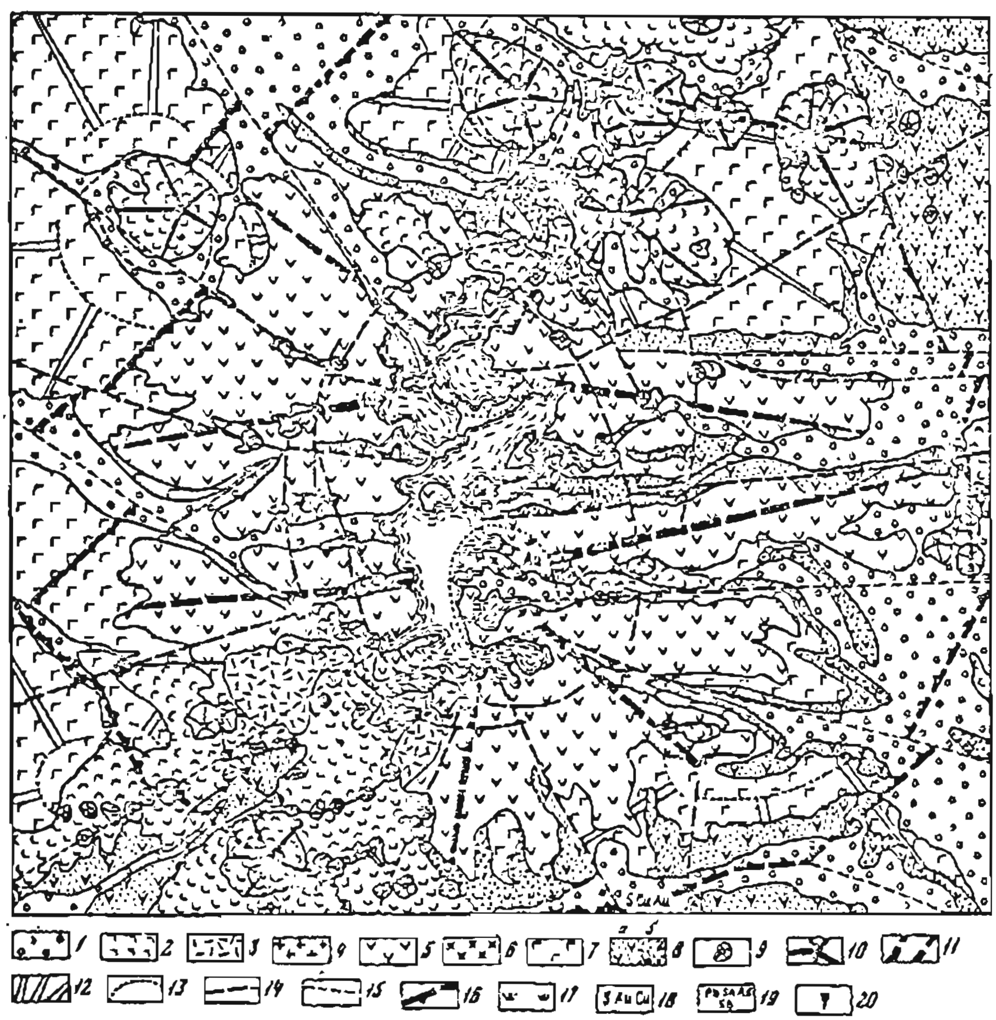
7.10. Alney-Chashokondzha Volcano-tectonic depression.

The large and long-lived Alney-Chashokindzha volcano-tectonic structure lies at the intersection of the Neogene central Kamchatka volcanic zone and an east-west transverse fault that can be traced from Sredinny Ridge to the east coast of the Kamchatka Peninsula.

The basement of the volcano-tectonic structure is composed of rocks of early Pliocene age (Fig. 99), based on plant fossils. Small outcrops of these rocks are located along the structure's southeast boundary, as well as along the north-south axis of the structure in its center and on its northern and southern boundaries. These early Pliocene rocks consist of andesitic and basaltic tuffs and lavas and volcanogenic sedimentary deposits that together have a thicknesses of up to 400 m. They are extensively deformed and locally have dips up to 40-45^{o}.

The Lower and Upper Pliocene rocks in the central part of the structure have radially outward dips. This and the absence of an unconformity between them indicates that the pattern of upper Pliocene and lower Quaternary structures are the same as that of lower Pliocene structures.

Fig. 99. Schematic geologic map of the Alney-Chashokondzha volcano-tectonic structure (after Stefanov and Shiroky, 1979).
1 - Unconsolidated Quaternary deposits; 2 - Holocene and late Pleistocene lava flows, scoria and breccia of basalt, basaltic andesite, and andesite; 3 - late Pleistocene rhyolite lava domes and flows; 4 -late Pleistocene rhyodacite extrusive domes; 5 - middle Pleistocene lava flows of andesite, andesite-dacite, basaltic andesite, and dacite; 6 - middle Pleistocene andesitic extrusive domes; 7 - early Pleistocene lava flows and tuffs of basalt and basaltic andesite; 8 - Pliocene rocks, a) late Pliocene basalt and basaltic andesite lava flows and tuffs, b) early Pliocene lava flows of andesite and basalt and tuffaceous sedimentary rocks; 9 - monogenetic basaltic volcanoes of Holocene and partly late Pleistocene age; 10 - stratovolcanoes of Holocene age and Late Pleistocene to Holocene age; 11 - middle Pleistocene Alney and Chashokondzha lava stratovolcanoes; 12 - early Pleistocene shield-like basalt volcanoes; 13 - boundaries of eroded calderas and craters; 14 - faults; 15 - inferred, concealed faults; 16 - faults that bound the Alney-Chashokondzha volcano-tectonic structure; 17 - hydrothermally altered rocks; 18 - areas of copper sulfide and gold mineralization; 19 - geochemical haloes containing Pb, Sn, As, and Sb; 20 - hot springs.



Development of the structure in late Pliocene time was characterized by the formation of a large shield volcano and subsidence along ring faults that bound the volcano-tectonic structure. The volcano is composed mainly of basaltic andesite and andesite flows 15-20 m thick interbedded with rare tuff layers up to 30 m thick. The greatest measured thickness of all these rocks in the central part of the structure is 250 m. Dips of lavas are less than 3-5°. The vents for these lavas determined by the radial dip of flows is near the summit of Alney Mountain. These lava flows can be traced up to 20 km from their source.

Quaternary volcanic events in the area of the structure can be divided into four stages. The first stage is characterized by basaltic volcanism synchronous to the Lower Pleistocene plateau basalts elsewhere in the zone. These basalts were erupted from a series of comparatively small shield volcanoes located around the boundary of volcano-tectonic structure. Volcanic rocks of this stage are absent from the central part of the structure.

During the second stage, the large middle Pleistocene volcanic edifice of Alney-Chashokondzha was formed. It consists of two lava stratovolcanoes that are approximately equal in volume, but are greatly eroded especially by glacial processes. They are composed mainly of amphibole and biotite andesites, but their lower parts, about 150 m thick, are mainly basaltic andesites. The sequence of Alney volcano is formed mainly of amphibole-biotite and biotite andesite-dacites and dacites with numerous lenses of different varieties of these rocks mixed together. The summit parts of both volcanoes are extrusive andesitic domes.

The third stage which corresponds to the time of the main stage of silicic volcanism and caldera formation for all of Kamchatka is only partly expressed in the Alney-Chashokondzha structure. After formation of a series of radial faults that displace lavas of the second stage, three rhyodacitic and rhyolitic extrusive domes with short flows erupted along a system of ring faults enclosing a 20 X 15-km area that is elongated in a north-south direction. The two extrusive domes of rhyodacites on the southwest slope of the Chashokondzha volcano form an irregular plateau with a total area of 1.5-2.0 km^2. They are accompanied by rhyolite flows up to 4 km long. On the northern slope of Alney volcano is located another saddle-like rhyolite lava flow of about 1-1.5 km^2. There is about 100-200 m of displacement on these ring faults and the volume of three extrusive domes and short lava flows is comparatively small, but it is possible to consider this event as an analogue of the caldera-forming process in other parts of Kamchatka.

The genesis of this volcano-tectonic structure is not clear. It is probable that the fault-bounded, outer volcano-tectonic depression was formed as a result of a collapse connected with some kind of doming process. A small quantity of silicic volcanic rocks is associated with this event. The presence of a dome composed of Pliocene rocks in the center of this depression probably indicates that the first stages of subsidence took place at the beginning of Pleistocene. The absence of any kind of pyroclastic covers connected with the caldera (volcano-tectonic depression) forming stage is characteristic.

CHAPTER IV
THE TEMPORAL DISTRIBUTION OF SILICIC VOLCANISM IN THE WESTERN CIRCUM-PACIFIC DURING THE QUATERNARY

Evaluation of data available.

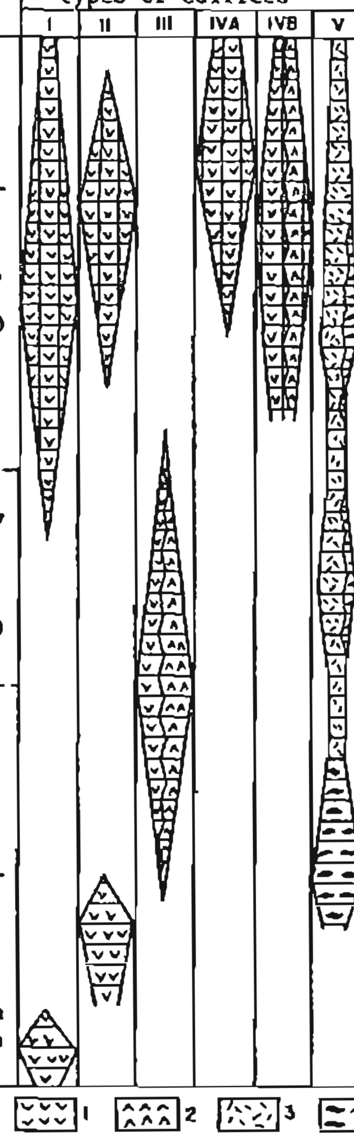
Age determinations of Quaternary volcanic rocks which are now available practically for all parts of the Western Circum-Pacific and are based mainly on the correlation with glaciations of marine transgressions. Quantity of available radiometric dates of any kind (K-Ar, fission treck, radiocarbon) is insufficient to produce any reliable precise correlation. Also the degree of study is very different for different regions. But in any case, the most favorable for correlation of Quaternary tectonic and volcanic development in Western Circum-Pacific are comparatively uplifted geotectonic systems of Kamchatka type, where it is possible to compare volcanic activity with development of structures filled by sedimentary sequences. Among the most studied systems of this type are Kamchatka, Japan, North Island of New Zealand, and to a lesser degree - Indonesia (Sumatra) and the Kuriles. For this reason these regions are chosen as the bases for preliminary correlation.

Stages of Quaternary silicic volcanism and tetonic movements in the Kamchatka.

For the first time specific phases of silicic volcanism in Kamchatka has been divided in the Sredinny Ridge zone (Erlich, 1960). Time was determined on the bases of the connection with glacial deposits as the end of the Middle Pleistocene. This conclusion was confirmed by Ogorodov (1966). Detailed study of ignimbrite and pumice covers of the Southern and Eastern Kamchatka (area 11,000 km^2, volume 2000 - 2500 km^3) show, that they were formed during two impulses of explosive silicic volcanism (Melekestsev, 1967). The first coincided with Middle Pleistocene glaciation. Ignimbrites and pumices formed during this period were overlapped by moraines of two stages of the Upper Pleistocene glaciation. One among the greatest calderas of this stage, Uzon, is filled by inter-glacial deposits (Averiev and others, 1969). At the same time the calderas of the Great Semiachik, Karymsky Lake (ancient) and others, were formed (Table 2).

The second impulse of silicic volcanism coincideed with Upper Pleistocene glaciation. During this period the calderas Krasheninnikov, Maly Semiachik, Gorely, Opala and the pyroclastic covers connected with them were formed. These deposits are dated on the basis of their connection with moraines of two stages of the Upper Pleistocene glaciation, by pollen and diatomic analysis of intra-ignimbrite sedimentary horizons and correlation with ash horizons such as dated by fauna sediments in the Central Kamchatka Depression and within seas, which surrounded Kamchatka (Romankevich and others, 1966). Radiocarbon age of one of the youngest ignimbrites sheets in Eastern Kamchatka is equal to 17,100±800 years B.P. Formation of the most ancient extrusive domes in the Central Kamchatka Depression (Kliuchevskaya group, Sheveluch volcano) is connected with the second impulse of silicic volcanism. It is probable, that Middle-Upper Pleistocene age have extrusive domes in the Eastern Ridge of Kamchatka.

Both phases of silicic volcanism occurred throughout Kamchatka, but, the form of expression of the volcanism depend upon local tectonic conditions. In the graben-synclines of southern and eastern Kamchatka, there prevails

Part	Stage	Index	Age in 10^4 Years	Paleogeographic Stges in Ctrl Kamchatka Dep.	Character of neotectonic movements	Main stage of effusive volcanism & their specific findings	Main morphological types of edifices* (I, II, III, IVA, IVB, V)	Main Stages of explosive volcanism
HOLOCENE		Q_4	1	Post-glacial epoch	Strongly differentiated with general tendency to uplift.	The second (young) stage: fissure-type basaltic volcanism in the Sredinny Ridge zone, Kliuchevskaya volcanic group and in South Kamchatka; formation of Icelandic type shield volcanoes in Sredinny Ridge (Shishel Leutongey, Kebeney, Cherny, Kireunsky, Anaun, Buduli, Bunanaya and others) and small islandic-type shield volcanoes in South Kamchatka.		The third (recent) stage formation of calderas, craters & associated pyroclastic flows (region of Sheveluch, Bezimianny volcanoes in Central Kamchatka Dep., Ichinsky, Khangar in the Sredinny Ridge volcanic zone, Ksudach, Zheltovsaky, young caldera of the Kurile Lake in Southern Kamchatka & others). Growth of basaltic and andesites mainly pyroclastic strato-volcanoes (Kliuchevsky, Krasheninnikov, Maly Semiachik, Gorely, Nutnovsky, Zheltovsky.
PLEISTOCENE	UPPER	Q_4^3	2	II Phase of glaciation				
		Q_3^3	3, 4	Interstadial				
		Q_3^2	5, 6	I Phase of glaciaton		Formation of the essentially lava basaltic andesite strato-volcanoes (volcanoes of Khodutka mountains, Unana, Tolmachev and others)		The second (Upper Pleistocene Stage) -formation of calderas & associated with pyroclastic covers in Eastern (Krasheninnikov, Uzon, Maly Semiachik, Young Karymsky Lake Caldera), and Southern (Gorely, Opala, Ksudach), Kamchatka.
		Q_3^1	15	Interstedial		The first (ancient) stage: basaltic volcanism of scattered and fissure type; formation of large shield-like volcanoes (Uksichan, Malaya and Bolshaya Ketepana, Maly and Bolshoy Chekchebonay, Kekuknaysky, Nikolka, Shmidta, Zhupanovskiye Vostriaky, Ipelka and others in Sredinny Ridge, Central Kamchatka Depression Eastern & Southern Kamchtaka		Formation of dacite-andesite strato-volcanoes, Aag, Arik, Dzedzur and others.
	MIDDLE	Q_2^2	21	Maximum glaciation	TECTONIC RECONSTRUCTION			The first (Middle Pleistocen) Stage: The ignimbrite forming main period in Kamchatka: formation of calderas, ring volcano-tectonic complexes & associated with them pyroclastic covers in Sredinny Ridge (Khangar, Ichinsky) on Eastern (Greak Semiachik, Geyzernay caldera, Karymsky Lake-(ancient) & Southern (Kurile Lake-ancient, Puzhetka volcano-tectonic depression) Kamchatka.
		Q_2^1	38	Interstadial	Weakly differenciated with general tendency to uplift.			
	LOWER	Q_1	100					

1-basalts, basaltic andesites; 2-andesites; 3-pumices; 4-ignimbrites; 5-volcanic formations of the first cycle; 6-volcanic formations of the second cycle.

Table 2 Distribution in time of characteristic Quaternary volcanic formations in Kamchatka from Erlich (1973). By the data of Aprelkov (1966), Braitseva and others (1966, 1968), Braitseva and Melekestsev (1966), Vinogradov and others (1962), Vlodavets, Piip (1957), Geologiya SSSR, t. XXXI, p. 1 (1964), Ermakov and others (1968), Zavaritsky (1955), Ivanov (1970), Kozemiaka (1966), Kochegura and others (1969), Melekestsev and others (1967), Ogorodov (1966), Sirin (1968), Timerbaeva (1967), Favorskaya and others (1965), Cherdyntsev and others (1966), Erlich (1960, 1966).
1-basalts, basaltic andesites; 2-andesites; 3-pumices; 4-ignimbrites; 5-volcanic formations of the first cycle; 6-volcanic formations of the second cycle. *I. forms connected with fissure basaltic volcanism; II. shield and shield-like volcanoes; III. mainly lava strato-volcanoes; IVa. mainly pyroclastic basaltic and basaltic andesite strato-volcanoes; IVb. mainly pyroclastic andesitic strato-volcanoes; V. pyroclastic covers.

ignimbrites and pumice covers in the Central Kamchatka Depression - extrusive domes and on the junction between the eastern Kamchatka graben-syncline, and a rigid block of transverse structure appears to be mainly lava silicic andesite-dacite stratovolcanoes (Aag, Arik, Dzendzur).

Extrusive and explosive activity of silicic volcanic centers continues in Holocene time. In this connection two moments have to be noted: First: - the centers of Holocene volcanism continues to develop centers of the Pleistocene silicic volcanism, founded at the time of previous impulses (region of the Kurile Lake and Karymsky volcano in the Eastern and Southern Kamchatka, Bezimianny volcano and Sheveluch in the Central Kamchatka Depresion, Khangar and Ichinsky volcano in Sredinny Ridge volcanic zone). Second: - the scale of the Holocene silicic volcanism is strongly reduced in comparison with Pleistocene time. The total area of the Holocene pumice covers do not exceed 300 km^2, their volume is 40-50 km^3. Ignimbrites are absent. This indicates that these manifestations are connected with later stages of development of the magma chambers, founded in Middle and Upper Pleistocene.

Simultaneously with impulses of silicic volcanism in sedimentary rocks of the Central Kamchatka Depression, size and quantity of fragments grew progressively: instead of clays, diatomites and sands, characteristic for the Lower and the first part of the Middle Pleistocene, there appeared pebble-beds and pebble- and boulder-bearing sediments with non-volcanic clasts in the upper part of the Middle and Upper Pleistocene and Holocene. So in the Middle-Upper Pleistocene a progressive uplift of mountain belts (non-volcanic horst-anticlinals) occurred and the moment of the maximum rate of uplift coincided with the impulses of silicic volcanism (Braitseva, Melekestsev, 1966; Braitseva and others, 1968). During this period such horsts as the eastern Kamchatka Ridge and Kozyrevsky-Bystrinsky horst-anticlines in Sredinny Ridge zone were formed. In parallel was formed a system of grabens which cut these ridges (grabens of river valleys Paratunka, Schapina, Kovycha and Bystraya-Kozyrevskaya and others). Total amplitude of uplift reached 600-700 m and total range of movements, putting into attention subsidence of grabens, reached about 1200 m. Within the volcanic belts, during this epoch, calderas and volcano-tectonic depressions with a diameter of 8-12 km up to 40 km were formed with amplitudes of subsidence along the boundary faults of up to 1000 m.

Stages of Quaternary silicic volcanism and tectonic movements in the Kuriles.

In the Kurile Island Arc during the Middle and Upper Pleistocene great stage of explosive volcanism occurred in connection with the formation of calderas and pumice and ignimbrite covers. Rewashed pyroclastic material of this stage is in sediments of 100-120 meters marine terrace of the Kunashir and Iturup Islands, formed during the Upper Pleistocene interstadial. The age of plants relicts, buried by pyroclastic deposits, connected with Mendeleev and Golovnin calderas is about 40,000 years B.P. Calderas of this stage are expressed in relief. Ignimbrite and pumice covers, connected with them are preserved as inconsiderable relicts. To this period belong formation of calderas and associated with them pyroclastic covers on the islands Iturup (Urbich, Tsirk, Medvezhiya calderas), Simushir (Zavaritsky caldera-ancient, Broutona caldera), Onekotan (Nemo caldera). Strong outburst of silicic volcanism took place on the Kurile Islands during the first half of the Holocene. To this time belong formation of calderas L'vinaya Past (9460±50 years B.P., 9400±60 years B.P.), and Tao-Rusyr (7500±80 years B.P.). In parallel numerous silicic extrusive domes andesitic and andesite-dacitic in composition within series of large calderas were formed (Table 3).

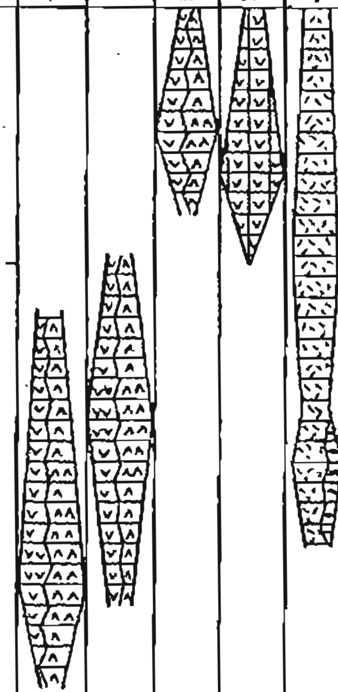
Part	Stage	Index	Age in 10^4 Years	Paleogeographic Stges in Ctrl Kamchatka Dep.	Character of neotectonic movements	Main stage of effusive volcanism & their specific findings	Main morphological types of edifices* (I, II, III, IV, V)	Main Stages of explosive volcanism
HOLOCENE		Q_4	1	Post-glacial epoch	Intensive differentiated movements with clear tendency to uplift.	Recent Stage: Outpouring of of andesite lava flows within linear cluster zones on islands Paramushir, Urup, Iturup & lava flows (basalts to andesites) on the central volcanoes within islands Paramushir, Alaid, Iturup, Kunashir and others.		Recent stage: forming of pyroclastic covers & associated calderas (Tao-Rusyr, L'vinaya Past). Forming of Bezymyenny-type volcanoes (Kharomkotan and others) and mainly pyroclastic strato-volcanoes (Alaid, Chikurachki, Tyatus, Peak Fussa, Peak Prevauss and others).
PLEISTOCENE	UPPER	Q_3^4	2	II Phase of glaciation				
		Q_3^3	3 – 4	Interstadial		Middle-Upper Pleistocene (the main) stage: scattered outpouring of andesitic and basaltic lavas on islands Paramushir, Urup, Iturup, formation on mainly lava strato-volcanoes (Tao-Rusyr, Medny, Kamuy, Ruruy, Beraturabe and others).		Upper Pleistocene (the main) stage: forming of vast pumice-pyroclastic covers and calderas on islands Kunashir (Golovnin, Mendeleev), Iturup (Urbich, Tsirk, Vetrovoy Isthmus), Simushir (Brouton, Zavaritsky - ancient, Onekotan (Nemo).
		Q_3^2	5 – 6	I phase of the glaciation				
		Q_3^1	15	Interstadial				
	MIDDLE	Q_2^2	21	Maximal glaciation	TECTONIC RECONSTRUCTION			
		Q_2^1	38	Interstadial				
	LOWER	Q_1	100					

Table 3 Distribution in time of characteristic Quaternary volcanic formations in Kurile Islands (Erlich, 1973). By the data of Geologiya SSSR, t. XXXI., p. 1 (1964); Gorshkov (1967); Markhinin (1967); Markhinin and Pospelova (1959); Neverov, Sergeev (1960); Ostapenko (1967); Rodionova and others (1964, 1966).

* I. lava covers; II. mainly lava strato-volcanoes; III. volcanic formations of the linear cluster zones (Gorshkov, 1967); IV. mainly pyroclastic strato-volcanoes; V. pyroclastic covers. Other signs are the same as on Table 2 .

Stages of Quaternary silicic volcanism and tectonic movements in Japan.

In north-eastern Japan manifestations of silicic volcanism was concentrated in the frontal, eastern Nasu volcanic zone, where in Pleistocene time an outburst of silicic pyroclastics took place; the welded tuffs and pumices which occurred at this stage, are the largest of all Cenozoic time (Kawano, Yagi, Aoki, 1961). These rocks are dated as belonging to Wurm glaciation - beginning of the post-glacial epoch. Close to this time is the formation of the greatest center of silicic volcanism in the region of Fossa Magna - Hakone volcano (Table 4). Here, after formation of the Pliocene-Lower Pleistocene basalt - basaltic andesite strato-volcano of the first stage of activity, in the Middle Pleistocene, dike swarm was formed andesite to dacite in composition. Simultaneously with this event was formed the caldera of Glen-Co type. Afterward following the growth of a shield volcano inside the caldera which directly continued the line of the old somma development. At the end of the Upper Pleistocene (end of Wurm) an outburst of silicic pyroclastics occurred and the second, young caldera was formed, within which a series of extrusive domes and a central strato-volcano composed by pyroxene andesites are nested.

The end of the Middle, beginning of the Upper Pleistocene, marks the beginning of silicic volcanism in the region of the Unzen Volcano (Kyushu Island) and a complicated system of grabens was formed (Sendo and others, 1967).

The age of large ignimbrites, welded tuffs and pumice covers, connected with large calderas on Kyushu and Hokkaido (Aso, Aira, Ata, Kutcharo and others) have been lowered in series of old works, up to the Lower Pleistocene. Radiocarbon data (see Table 5) shows that all, or at least the main part of them, are very young. Silicic volcanism in these centers continued in Holocene time and some centers are still active. But the activity of these volcanoes, as in the Kamchatka case, is of relict character and the development of the centers formed at the end of the Middle and during the Upper Pleistocene is continued. For Aso there appears several K-Ar dates, which indicate that during the time interval 0.3-0.05 ma, four large scale pyroclastic flows erupted (Aramaki and others, 1981).

No numerous manifestations of silicic volcanism of Izu-Bonin arc are dated by K-Ar and fission treck method (Kaneoka, Ozumi, 1979). Received figures are 270,000 B.P. for altered rhyolites on Kozu-Shima, 80,000 B.P. for obsidians on the same island and 300,000 B.P. for trachytes of Iwo-Jima, corresponding with Japanese Archipelago period of silicic volcanism intensification.

During the period of the main impulse of silicic volcanism in Japan great structural reconstruction occurred during the general uplift and the islands received their now existing configuration. Fast growth of the mountain systems took place and at the same time Kwanto Basin in central Japan, stopped its development. For the last time there disappeared a tie between Japan and Korea - the continental bridge between these regions in Tsusima strait ceased to exist and Daisen volcanic zone became extinct. The last eruption, dated by radiocarbon took place 30,200±350 years B.P. (Minato and others, eds., 1965). Calderas and volcano-tectonic depressions were formed during this stage with diameters of 8-20 km and more.

Part	Stage	Index	Age in 10^4 Years	Formations of Kwanto Basin	Character of neotectonic movements	Main stage of effusive volcanism & their specific findings	Main morphological types of edifices* I	II	IIIA	IIIB	IV	Main Stages of explosive volcanism
HOLOCENE		Q_4		Yurekucho	Intensive differentiated with general tendency to uplift, partly reconstruction of the structure.	Upper Pleistocene-Holocene Stage: formation of small basaltic lava covers, small shield. Recent stage: outpouring of andesitic lava flows on volcanoes (Kokuzo, Fukueshima, Ojika-shima, Abu, volcanic group Omuro-yama and others) effusive activity on the large central strato-volcanoes.						Holocene stage (recent): Formation of small calderas, craters, extrusive domes & associated with the pyroclastic covers on Islands Hokkaido (Mushu, Tarumai, Me-Akan, Usu and others), Honshu (volcanoes Asama, Haruna, central craters in Towada caldera and others), Kyushu (in calderas Aso, Ata), Ryukyu (in Kikai caldera, volcano Okinawa-Tori-Shima and others), andesitic and basaltic mainly pyroclastic strato-volcanoes (Shiretoko-Iwo-Zan, Daisetsu, Komagatake, Iwaki, Fudji, Kirishima and others).
PLEISTOCENE	UPPER	Q_3^4	1, 2	Tashikawa								
		Q_3^3	3, 4	Mussasino								
		Q_3^2	5, 6	Shimo-Suyoshi								
		Q_3^1										The Upper Pleistocene Stage: formation of large calderas and associated pyroclastic covers on Hokkaido (Kuttaro, Akan, Shikotsu, Toya), Honshu (Hakkoda, Onikobe, Tazawa, Towada and others), Kyushu (Aso-young, Aira, Ata), Ryukyu (Kikai).
	MIDDLE	Q_2^2	21		TECTONIC RECONSTRUCTION							
		Q_2^1		Bebugara, Naganuma	Weakly differentiated with general tendency to uplift.	Low Pleistocene(?)-Upper Pleistocene Stage: formation of large andesitic and basaltic-andesitic mainly lava strato-volcanoes: Sekamubetsu, Yokotsu, Piashiri, Numa-Dake, Hano-Dake, Daisen, Tara and others.						
	LOWER	Q_1	38, 100	Kasamori, Shonan								The Middle Pleistocene Stage: Formation of large calderas, volcano-tectonic depressions and associated with them large pyroclastic covers on Hokkaido (Tokachi), Honshu (pyroclastic covers Hida, Kuro-Fudji), Kyushu (Aso-the ancient, pyroclastic flows Kudju, Yabakey(?) Seenay(?), and others).

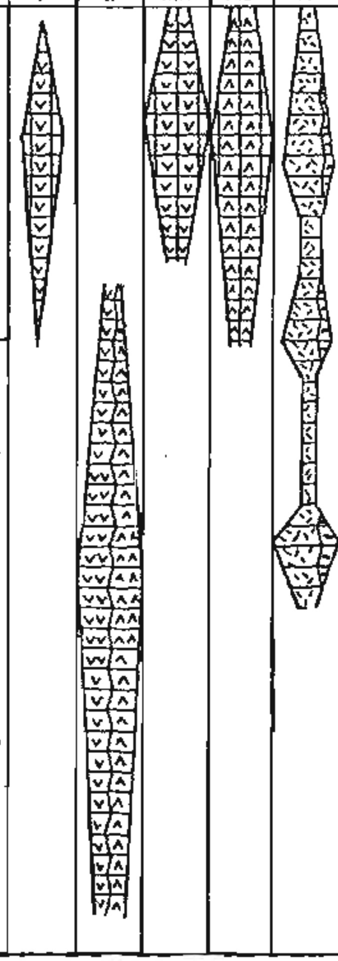


Table 4 Distribution of time of characteristic Quaternary volcanic formations in Japan (Erlich, 1973). By the data of Minato and others (1965); shikawa and others (1962); Gohara (1963); Katsui, Oba, Satoh (1969); Kaneoka, Ozumi (1970); Kawachi, Kitazawa (1967); Kobayashi (1965); Okada (1969). I. forms, connected with scattered and fissure-type volcanism; II. large shield-like volcanoes and mainly lava strato-volcanoes; IIIa. mainly yroclastic andesitic strato-volcanoes; IIIb. mainly pyroclastic basaltic and basaltic andesites strato-volcanoes; IV. pyroclastic flows. ther signs are the same as on Table 2.

Table 5

Radiocarbon Age of Some Pyroclastic Covers in Japan

1.	Kutcharo	23300±3000(Gak-866) 2000
2.	Atosanupuri	11720±220 32300±3000(Gak-870) -2000(Gak-866)
3.	Mashu	6460±130(Gak-147) 7190±230(Gak-248)
4.	Shikotsu	31900±1700(Gak-713) 32200±2000(Gak-714) 32200±4700 -3100(Gak-519)
5.	Toya	13900±250 16400±300(Gak-868)
6.	Nigirokawa	12900±270(Gak-1605)
7.	Towada	10400±220(Gak-460) 12000±250(Gak-385) 12700±260(Gak-205)
8.	Aso	20100±600(Gak-479) 23000±760(Gak-480) 26400±1100(Gak-478) 33100±3100(Gak-554) 1900 35600±5600(Gak-553) 1900
9.	Aira	16350±350(Gak-473)
10	Ata	24500±900(Gak-472)
11.	Asama	1-650±250(Gak-311)
12.	Yatsugatake	24600±100(Gak-616)
13.	Nasu	29800(Gak-1649)

Radiocarbon dates for calderas 1-9 cited from Ishikawa, Katsuii, Oba, Satoh, 1969; dates for calderas 10-12 from Kobayashi, Kawachi, Kitazawa, 1967; for caldera 13 from Okada, 1969.

Stages of Quaternary silicic volcanism and tectonic movements in Indonesia.

The main region of silicic volcanism in Indonesia is Sumatra. Eruption of silicic volcanic products here are closely connected with ring strctures, located along the Semangko Rift zone. Such as, the depressions of Toka Lake, Ranau and others. Gigantic eruptions of silicic pyroclastic material of these structures are dated to the end of the Middle - beginning of the Upper Plesitocene. Pumice connected with the eruption in the Toba region overlaps relicts of paleolithic Tampan culture on the Malakka peninsula. Smith-Sibinga (1948) dated the Upper Palembang strata of silicic tuffs in the oil-bearing region of eastern Sumatra to Upper Pleistocene and correlated it with the riss-Wurm interglacial epoch in Europe. It is characteristic, that after formation of the Upper Palembang strata, sedimentation in this region stopped and all regions underwent folding. After the Toba tuffs eruption on Sumatra an abrupt uplift of the Batak domal structure took place. At the end of Pleistocene-Holocene time on Sumatra small centers of silicic volcanism continued to exist. In particular are known pumice outbursts on the Lake Ranau Caldera, Pilomasin volcano-tectonic (Westerveld, 1952) depression, and are closely located with Sumatra Bali Island-on Batur Caldera (Marinelli, Tazieff, 1968).

Stages of Quaternary silicic volcanism and tectonic movements in New Zealand.

The main stage of Quaternary silicic volcanism in the North Island, New Zealand is characterized by outbursts of silicic pyroclastics in the Taupo-Rotoroa region (Healy, Vuchetich, and Pullar, 1964; Thompson, 1964; Thompson and Kermode, 1965; Vuchetich and Pullar, 1969). The beginning of this stage was marked by the appearance of the first fragments of ignimbrites in Lower Castlecliff layers within the eastern Depression. Starting from this moment the quantity fragments of silicic volcanic rocks in sedimentary rocks of the Eastern Depression grew constantly. In some horizons of the Late Castlecliff time their volume reached several cubic miles. With an epoch of ignimbrite and pumice covers, there is a connecting formation of linear grabens stretching from Ruapehu volcano to the Bay of Plenty (Grindley, Harrington, and Wood, 1959). At the end of the Castlecliff time, ignimbrite eruptions in the Taupo zone were reduced considerably; simultaneously the formation of Taupo graben was completed (Kingma, 1959). There is an indication, that on the periphery of the structure, thin ignimbrite cover overlies the stable blocks - Kaingaroa Plateau and the western Taupo Plateau. Parallel uplift and folding took place within the Eastern Depression, after which part of the Depression, located on the North Island ceased to exist. The fast uplift of the linear mountain system Ruahine-Rimutake between Taupo graben and Eastern Depression, finished the development of the Wanganui depression. The beginning of the uplift coincided with generation of the Taupo volcanic zone, and for a long time a direct connection between the Taupo Zone and Eastern Depression existed. It was broken only at the moment which corresponded to the main phase of ignimbritic volcanism (Table 6). This indicated, that the main impulse of uplift corresponded to the main impulse of ignimbritic eruptions. Sedimentation in the Eastern Depression stopped at the beginning of the Upper Plesitocene. On the South Island the Upper Wanganui Suite is represented by thick sequence of gravel beds, formed at the time of the fast uplift of the Southern Alps. Layers of rocks are strongly inclined and sometimes have a vertical dip. The end of the Castlecliff time is characterized by intensification of movements, starting at the end of the Pliocene which lead to the formation of the now existing structural plan.

Part	Stage	Index	Age in 10^4 Years	Stratigraphic Scheme of Eastern Dep.		Character of neotectonic movements	Main stage of effusive volcanism & their specific findings	Main morphological types of edifices* (I, II, III)	Main Stages of explosive volcanism
HOLOCENE		Q_4		Hawera		Intensive, differentiated with strong tendency to uplift.	Second (young) stage: outpouring of basalts in regions of Aukland-Pukakohe, Kaikohe, Hwangarei-Keriker, formation of basaltic volcanoes Pirongia, Karfon and others.		Recent Stage: Formation of the youngest pumice covers within Taupo-Rotorua graben; outbursts of pyroclastics on andesitic volcanoes within Tongariro National Park, Mt. Egmont and others.
PLEISTOCENE	UPPER	Q_3^4	1, 2	Suite and recent sediments					
		Q_3^3	3, 4	UPPER WONGANUI SUITE	Castlecliff Stage		First (ancient) stage: formation of basaltic covers, formation of plateau waipona-Tutuce and Banks peninsula andesitic basements of Tongariro volcanoes		The Upper Pleistocene Stage: The formation of pumice and the youngest ignimbrite covers within Taupo-Rotorua graben; outbursts of pyroclastics on the beginning stage of formation of andesitic volcanoes within Tongariro National Park, Mt. Egmont and Others
		Q_3^2	5, 6						
		Q_3^1	15						
	MIDDLE	Q_2^2	21			TECTONIC RECONSTRUCTION			
		Q_2^1	38			Weakly differentiated with general tendency to uplift.			The Middle Pleistocene Stage: The main ignimbrite-forming phase on the North Island. Forming of ignimbrite covers in the Taupo-Rotorua graben and on the Koromandel peninsula.
	LOWER	Q_1	100		Nukumaru Stage				

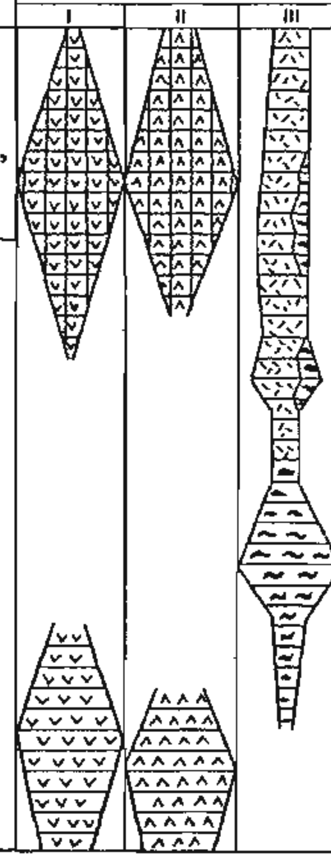


Table 6 .Distribution in time of characteristic volcanic formations in New Zealand (Erlich, 1973). By data of Wood, Grindley, Harrington (1959); Blank (1965); Cowie (1964); Healy, Vucetich, Pullar (1964); Grant-Taylor (1964); Grant-Taylor, Rafter (1962); Searle (1961a, b); Thompson (1964); Thompson, Kermode (1965a, b); Thompson, Kermode (1965); Vucetich, Pullar (1969). I – volcanic forms connected with basaltic volcanism; II – andesitic strato-volcanoes; III – pyroclastic covers. Other figures are the same as Table 2 .

The last stage of silicic volcanism in New Zealand embraced the Middle and the end of the Upper Pleistocene and Holocene time. Two stages of volcanic activity are distinguished here. The first is characterized by the formation of a vast pumice pyroclastic cover (Rotoehu and Okareka ashes, Mangaoni lapilli, Ozami formation and others). Rarely are formed pumice-ignimbrite covers. In Holocene time, in the central volcanic region, there appeared a ring complex of rhyolite extrusive domes. At the last stages of their growth, there occurred pumice outbursts. The test pumice was dated by radiocarbon as 1800 years B.P. Caldera formation and pumice outbursts took place on the Mayor Island (8390±135 years B.P.). But volume of silicic pyroclastics formed in Holocene is comparatively small in comparison with the volume of pyroclastic material formed during the main phase of silicic volcanism.

General inter-region correlation

The total volume of silicic volcanism produced in the Western Circum-Pacific is shown on fig. 100. In calculations of total volume, figures for Indonesia (Westerveld, 1951), are used. It is well seen pulsation character of silicic volcanism and really great amount of erupted material (about 16,000 km^3).

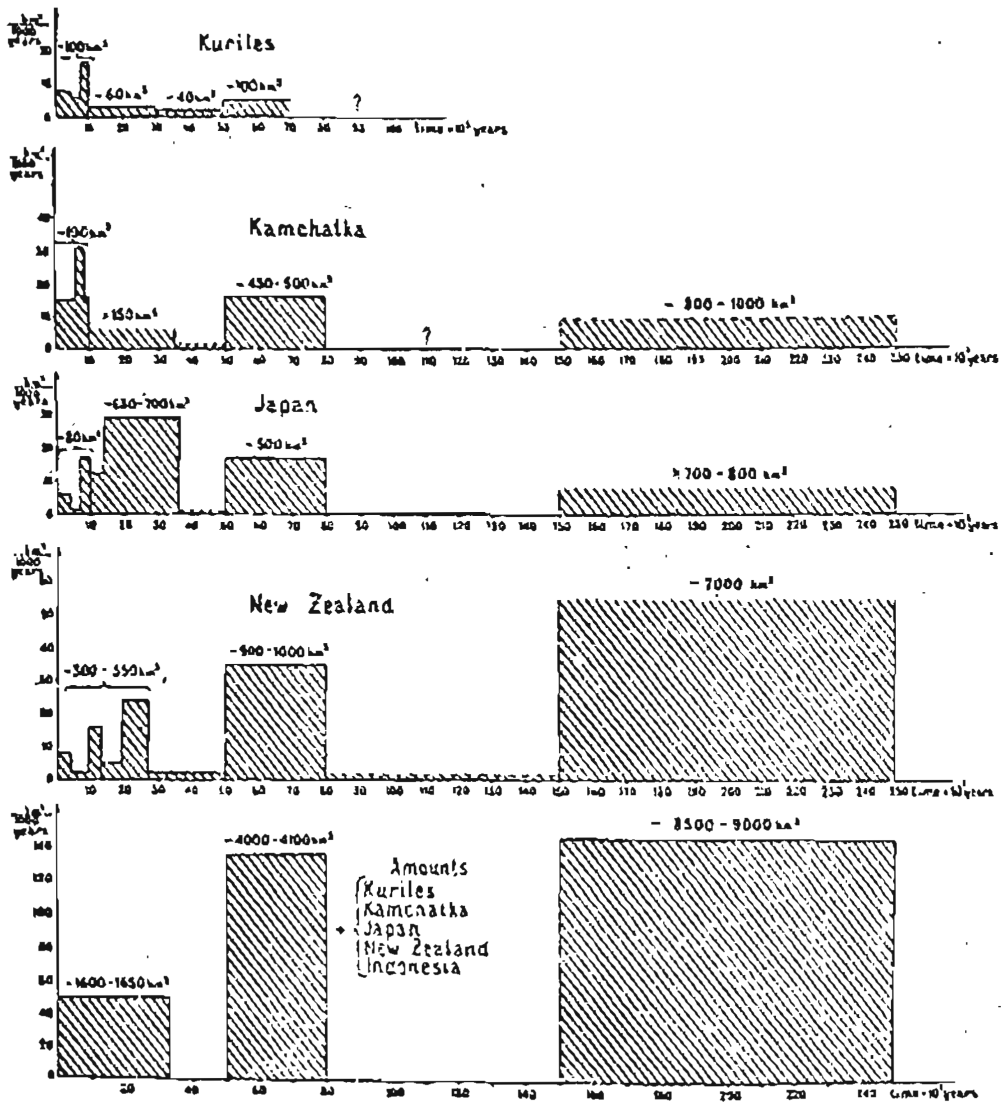
It is very possible, that due to accumulation of new radiometric data, there will be marked another (or maybe even several) epoch of great intensification of silicic volcanism within now poorly dated radiometrically interval between 0.2 and 1 mln. years B.P. It is the author's opinion that such epoch probably had place also around 700,000 years B.P., when the last epoch of polarity reversal took place. It was marked by one of the greatest known Quaternary eruptions of silicic pyroclastics - formation of the Bishop tuffs, associated with formation of the Long Valley caldera.

Concentration of the considerable amount of radiocarbon dates now available within narrow time intervals is not occasional, but rather is proportional to the quantity of the amount of erupted silicic pyroclastics. It has been mentioned above, that part of silicic calderas in northeastern Japan were formed during late Wurmian epoch, i.e., about 30,000 years B.P. The same radiocarbon dates were obtained for covers of silicic pyroclastics in Alaska (T. Miller, personal communication) and for greatest in Pliocene-Quaternary eruption in Italy - formation of Campanian ignimbrites (Barberi, 1978). The thickest tephra horizon from deep-sea drill-holes in the eastern Mediterranean, was formed at the time of an ignimbrite formation on the Santorini caldera with a radiocarbon age of 36000 ± 1025, 950 years B.P. (Pichler, Friedrich, 1976).

Duration of the longest impulses of silicic volcanism is about 80-10,000 years. They are common for all Circum-Pacific and probably are of global character. Radiocarbon data within a long impulses can be divided into two impulses with a duration of 20-30 thousand years each, which was well traced throughout the Western Circum-Pacific.

As a rule, the first ancient stage of volcanism is stronger, volume of pyroclastics of the first stage is 2-2.5 times more than second stage. The most probable is that the smaller in scale impulses are also of planetary character.

Fig. 100. Distribution of the volume of silicic volcanic rocks in Quaternary time within Western Circum-Pacific (after Erlich and Melekestsev, 1973).



There are impulses smaller in scale and with a duration of 4-5 thousand years. These impulses are connected with relatively strong explosive volcanism during the first half of the Holocene in Kamchatka, Kuriles and Japan. But in New Zealand these impulses shifted in time, maximum activity during Early Holocene took place about 13-8 thousand years ago and a relative minimum has place 8-3.5 thousand years and continues up to the present time. Within 4-5 millenium rhythm can be divided on 1.8-2 milleniums maximums and minimums characteristic for certain volcanic regions or groups or even greater volcanic centers.

CHAPTER V

SOME PETROLOGICAL PROBLEMS CONNECTED WITH CALDERAS IN ISLAND ARCS AND KAMCHATKA-TYPE GEOTECTONIC SYSTEMS.

SOME PROBLEMS OF BASALTS PETROLOGY

Two types of basalts in Kamchatka.

General pecularities of petrochemistry of the Kurile - Kamchatka Cenozoic volcanic province and the problems of basalt chemistry in particular have been described in several works (Naboko, 1963; Erlich, 1966, 1973, and others). Here it is important to mention two moments:

(1) Average chemistry of basalts, connected with Holocene centers of scattered and fissure volcanism is practically the same for the whole Kamchatka territory and shows no dependence from earthquakes foci depth (which is more or less proportional to the distance from the Pacific shore). Such similarity explains very well similarity between Holocene basalts from Central Kamchatka Depression and the Sredinny Ridge Volcanic Zone, marked by Erlich (1966a). Distance between these zones is equal to about 50 km. The same was noted for basalts from fissure zones of southern Kamchatka by Sheimovich and Zubin (1984).

(2) On opposite, in process of studying of basalts from Uzon caldera have been for the first time mentioned, that basalts, connected with contrast volcanic series are poor in alkalies, especially in potassium and practically belong in chemistry to normal oceanic tholeitic basalts (Nakoko, ed., 1974). To the same type belong basalts from other volcanoes located within silicic calderas of eastern and southern Kamchatka (Masurenkov, ed., 1980, 1980a) volcanoes Ksudach, Il'insky, Zheltovsky and others.

Comparison of these two stable types of basalts with average composition of basalts from different island arc systems shows that one of these types correspond with normal high-allumina basalts which are close to the composition of parental magma for the sequence high-alumina basalts - basaltic andesites - andesites. High-alumina basaslts are especially characteristic for inner volcanic belts in pair system of volcanic belts developed in island arcs and Kamchatka-type geotectonic systems. Another type of basalt, as has been mentioned above, is close to normal oceanic tholeites. With the last type of basalts contrast series, basalt-dacite, is connected. Basalts of this type are typical for outer (frontal) volcanic belts, where main centers of silicic volcanism are located.

Specific features of high-alumina basalts.

The composition of high-alumina basalts is characterized by strong disequilibrium between phenocrysts and groundmass. With the presence of 12-15% of olivine phenocrysts (i.e., not less than in oceanic tholeites and alkaline olivine basalts) their total composition is characterized by comparatively high (50-52%) silica content, general saturation of silica, comparatively decreased quantity of mafic components, MgO in particular. These facts indicate on much more silicic groundmass of these basalts, than it is possible to expect from the quantity of olivine and pyroxene phenocrysts in it. In the groundmass of such basalts crystobalite is often present. In basalts from Anaun volcanic region and Avacha volcano (Sredinny Ridge volcanic zone and eastern Kamchatka accordingly) and some other places are present big (up to 2 mm in diameter) grains of quartz. These quartz grains are characterized by the absence of any kind of inclusions, characteristic fissure system, which indicate on sudden increasing of grains volume, presence of halo of clinopyroxene grains on the rim. Electrone microprobe analysis of basalt groundmass from Anaun volcanic region indicate that in some points of it silica content reaches 65-71%.

Kuno's sequence of differentiation.

Comparison between average composition of basalts from different tectonically homogenous volcanic zones (Table 7) with sequence of differentiation of basaltic stratovolcanoes of Kliuchevsky - Fuji type (Kliuchevsky, Kronotsky, Viliuchik, Fuji, Chokai etc.) is shown on the Figure 101. Coincidence of these two sequences is pretty well seen. Such type of differentiation trend can be called Kuno's sequence, by the name of the famous Japanese petrologist and volcanologist Hisashi Kuno. It is seen that the main process of differentiation in this sequence is characterized by anorthitic component accumulation. Such accumulation has a place either in liquid form or in crystals. Maximal concentration of anorthitic component in basalts do not exceed meaning, which corresponds with cotectic point in the system albite-anorthite-diopside. The same row of rocks is formed on this type of volcanoes even during single erutpions (Fig. 101).

So it is possible to conclude that there does exist a kind of convergence between process of basaltic magma differentiation on Kliuchevsky - Fuji type of volcanoes and basaltic magma generation in process of basalt's fusion from the Upper Mantle. Composition of some typical basalts from different regions of the world are shown in Table 8.

The most mafic basalts on Kliuchevsky - Fuji type of basaltic stratovolcano contain considerable quantity of olivine phenocrysts (Fo_{80}). Such basalts are characterized by the increase in comparison with tholeities quantity of alkalies (Na_2O-up to 3.0%, K_2O-up to 1.2%). In the same time quantity of alumina is decreased up to 15-16%. Such basalts appear on the final stages of eruptions and reflect the composition of the lower part of magmatic columnes.

Low-potassium tholeites and problems of their origin.

As it has been mentioned above, another stable type of basalts in island arcs and similar with them geotectonic systems is connected with centers of silicic volcanism. For chemistry of these basalts low alkalies content (especially K_2O-0.3-0.4%) is characteristic. By this and other chemical features, they are similar with normal oceanic-type tholeites. This chemical type of basalt is very constant. It is characteristic not only for whole intra-oceanic plates, but also for intra-oceanic island arcs such as Izu, Bonin, Tonga, Marianas and others, where on both side of island arc system there present stable blocks with normal oceanic Crust and amplitude of modern uplift is extremely low, so hypsometric level of pre-Quaternary tectonic relief is approximately at sea level or even below it (see Table 9). Such type basalts are also widespread within frontal volcanic belts in Kamchatka-type geotectonic systems similar with island arcs, where there are present a

Table 7

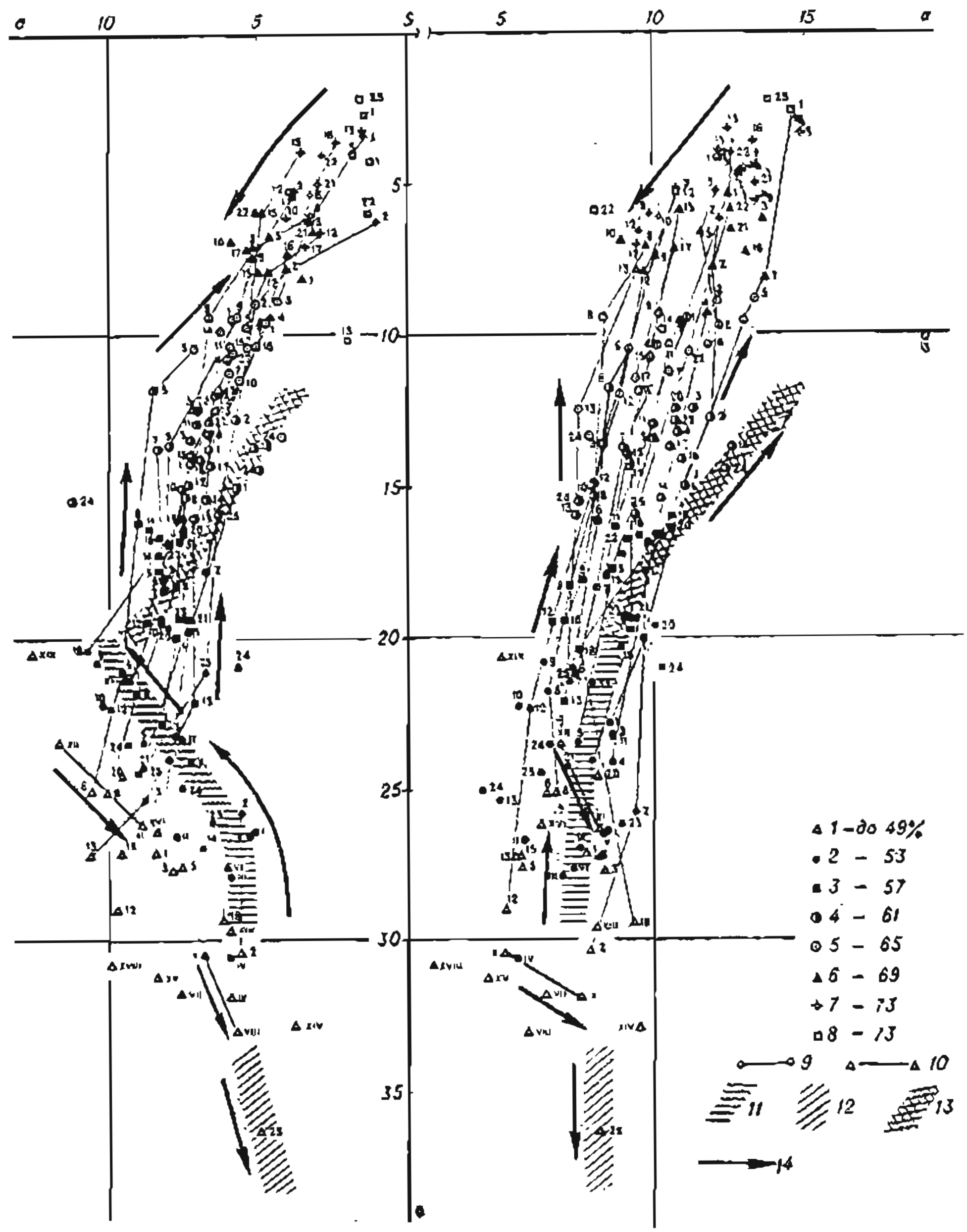
Silica average interval	Less than 45%	49.6 – 53.10%	Less than 49%	49.0 – 53.1%	49.0 – 53.1%	Less than 49%	49.1 – 53.0%	Less than 49%	49.7 – 53.0%	49.5 – 53.0%	Less than 49%	49. – 53%	49.1 – 53.0%	49.1 – 53.0%	49.1 – 53.0%
Oxides	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	47.89	50.41	47.65	51.21	51.48	48.18	51.18	47.90	50.81	50.86	47.63	51.50	51.63	51.26	51.19
TiO_2	1.63	1.49	0.88	1.03	1.02	0.87	0.91	0.91	0.71	1.11	0.91	0.96	0.95	0.89	1.08
Al_2O_3	14.25	15.53	17.54	17.81	17.02	19.06	18.38	18.92	19.58	18.37	18.82	17.67	18.91	18.31	17.27
Fe_2O_3	3.94	3.63	4.30	3.57	4.02	6.72	3.64	4.57	4.40	3.71	4.76	3.76	3.07	3.20	3.91
FeO	5.02	5.73	6.18	6.05	5.53	3.40	5.83	5.66	5.07	6.63	5.58	7.22	6.87	6.95	5.97
MnO	0.18	0.16	0.12	0.14	0.17	0.16	0.15	0.11	0.13	0.21	0.11	0.72	0.24	0.16	0.15
MgO	8.59	7.85	8.64	5.98	6.55	5.56	6.19	6.36	4.41	5.10	6.19	4.46	3.95	5.07	5.68
CaO	10.69	8.45	10.26	9.34	9.35	11.57	9.41	11.20	10.28	10.01	10.97	10.27	10.69	10.40	9.50
Na_2O	2.71	3.39	3.00	2.87	2.99	1.96	2.70	2.20	2.41	2.46	2.26	2.30	2.33	2.17	3.17
K_2O	1.30	1.39	0.88	1.21	1.26	0.67	0.96	0.80	1.01	0.66	0.90	0.79	0.35	0.39	1.04
K_2O/Na_2O	0.98	0.41	0.29	0.42	0.42	0.34	0.36	0.36	0.42	0.25	0.40	0.34	0.24	0.18	0.33
Fe_2O_3/Fe_2O_3+FeO	0.44	0.35	0.41	0.37	0.42	0.66	0.38	0.45	0.46	0.30	0.46	0.35	0.31	0.32	0.40
alkel	18.26	20.07	21.37	21.90	21.27	22.09	22.04	21.52	22.15	21.49	21.98	20.70	21.78	20.87	21.48
Average from analyses	12	7	6	37	67	7	44	14	22	9	13	7	6	32	12

Footnotes to the table:

Analyses 1, 2 – Northern Kamchatka – Olyutorsky block; analyses 3, 4, – Sredinny Ridge volcanic zone; 5 – Central Kamchatka Depression; 6, 7, – Souther and Eastern Kamchatka; 8, 9, – Northern Kuriles; 10 – Central Kuriles;; 11, 12, – Southern Kuriles; 13 – North-East Hokkaido; 14 – Nasu volcanic zone, NE Japan; 15 – Chokai volcanic zone, inner zone NE Japan; 16, 17, – Fossa Magna volcanic region; 18, 19, – Izu, Marian Island arcs; 20 – Shikoku South-Western Honshu (Daisetsu volcanic zone); 21 – Kirishima volcanic zone, outer zone of Kyushu island; 22 – Unzen – Kudju volcanic zone (inner zone on Kyushu island); 23, 24, – Eastern Sunda Island arc; 25, 26, – inner Java volcanic zone (include volcanoes Tangkuban, Prahu Tjarmet, Slamet, Dieng, Ungaran); 27 – Krakatau volcano (outer zone of Sumatra); 28 – Inner Sumatra zone; 29 – Ryukyu Island arc; 30 – Rat Islands, Aleutians; 31 – Andreanoff Islands, Aleutians; 32 – Fox Islands, Aleutians.

Analyses 1-28 by Erlich (1973); analyses 29-32 by Gorshkov (1965).

Fig. 101. Diagram of average chemical composition of Quaternary volcanic rocks from the western Circum-Pacific and way of their differentiation by Zavaritsky's method (Erlich, 1973). 1-8 average intervals by SiO_2. Roman numerals denote average composition of basalts of oceanic islands and continental fields of flood basalts (correspond with numerals of analyses in Table 7). Arabic numerals denote average composition of Quaternary volcanic rocks in different regions of Circum-Pacific (correspond with numerals of analyses in Table 8). 9 - variation lines of the average chemical compositions of volcanic rocks from different regions from the western Circum-Pacific; 10 - variation lines of average composition of volcanic rocks from Hawaii and Galapagos islands; 11 - field of figurative points for chemical composition oon volcanic rocks from Kliuchevsky volcano; 12 - field of figurative points of basalts from Auckland and Koromandel (rear volcanic zone of North Island, New Zealand); 13 - figurative points of the chemical compositions of volcanic rocks from some Kamchatka shield volcanoes; 14 - direction of differentiation for Figures 101 and 103 widespread in USSR method of Zavaritsky (1950) is used. By this method each analysis is shown by a vector in two projections. Chemical composition is recalculated to molecular quantities. Parameters a, c, b,s are calculated in percents from the total molecular quantities. Parameter (a) shows the alkali content in rocks, (b) the content of mafic components including CaO contained in pyroxenes, (c) the content of anorthitic lime ad s - acidity. Vector inclination in the left part (plane csb) reflects the ration of K_2O (horizontal axis) to Na_2O (vertical axis). Vectors in the right part (plane asb) reflect the ratio of Mg, Fe, and Ca (in pyroxenes) for normal rocks. For Al_2O_3 oversaturated rocks the vector on the plane asb shows the ratio of Mg, Fe and Al excess. In this case the vector is inclined to the left.
Simplification of this methods used on Fig. 101, uses only points without vectors. The same simplification was used by Gorshkov (1970).



1 - до 49%
2 - 53
3 - 57
4 - 61
5 - 65
6 - 69
7 - 73
8 - 73
9
10
11
12
13
14

Table 8

Average Chemical Composition of Basalts from Different Regions of the World

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX
SiO_2	50,0	52,5	51,3	49,8	49,98	50,66	45,0	48,35	46,46	49,36	45,6	46,5	50,0	48,3	49,3	49,8	50,3	48,73	49,62
TiO_2	—	1,0	1,9	1,7	2087	1,30	—	2,77	3,01	2,50	1,8	1,7	—	2,0	0,6	1,4	1,6	0,63	0,87
Al_2O_3	13	15,4	14,0	15,0	13,74	14,28	15,0	13,18	14,61	13,94	18,2	20,9	15,0	13,3	15,8	17,3	19,1	16,53	20,37
Fe_2O_3	13	1,2	3,3	2,7	2,37	3,41	13,0	2,35	3,27	3,03	7,3	1,6	11,5	5,1	3,7	4,5	4,7	3,37	2,61
FeO		9,3	10,1	10,2	11,60	8,58		9,08	9,11	8,53	5,0	6,2		6,6	7,3	5,6	5,0	8,44	6,71
MnO		0,2	0,3	0,2	0,24	0,12	----	0,14	0,14	0,16	0,3	0,2	----	0,2	0,2	0,1	0,1	0,29	0,17
MgO	5,0	7,1	5,5	6,5	4,73	6,92	8,0	9,72	8,19	8,44	6,0	5,9	8,5	9,4	9,4	6,3	4,3	8,24	4,05
CaO	10,0	10,3	9,8	10,9	8,21	8,60	9,0	10,34	10,33	10,30	10,2	12,8	8,5	9,9	11,5	11,8	11,0	12,25	11,97
Na_2O	2,8	2,1	2,8	2,2	2,92	2,92	2,5	2,42	2,92	3,13	3,2	2,6	3,0	3,4	1,8	2,5	2,6	1,21	1,89
K_2O	1,2	0,8	0,7	0,6	1,29	0,72	0,5	0,58	0,84	0,38	0,8	0,4	102	1,8	0,4	0,7	1,3	0,23	0,31
P_2O_5	----	0,1	0,3	0,2	0,78	----	----	0,34	0,37	0,26	----	----	----	----	----	----	----	----	0,07
H_2O+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	0,39

Footnotes to Table:

I – tholeitic magmatic types by Kennedy; II – average dolerite Karroo; III – average basalt, Deccan; IV – average basalt, Siberian trapps; V – basalt or Oregon, average from 6 analyses; VI – basalts of New Jersey, average from 8 analyses; VII – olivine-basalt magmatic type, by W. Kennedy; VIII – Hawaii, average olivine basalt, Hawaii; IX – alkaline olivine basalt, Hawaii, average from 28 analyses; X – tholeitic basalt, Hawaii, average from 181 analyses; XI – olivine basalt, Galapagoss Islands; XII – tholeitic basalt, Galapagoss Islands; XIII – parental magma for province of olivine basalts, trachytes and phonolites, Victoria, Australia, average from 23 analyses; XIV – basalt, San Martin volcano, Mexico, 1 analysis; XV – basalt, Cerro Negro volcano, flow of 1947,1 analyses; XVI – basalt, Nicaragua, average from 4 analyses; XVII – basaltic andesite, Nicaragua, average from 6 analyses; XVIII – parental magma of pigeonitic series, Izu-Hakone province, average from 2 analyses (some oversaturated aphiric olivine basalts); XIX – olivine basalt, pigeonitic series, close to parental magma, Hakone.

Analyses I, V, VII, XIII, XVIII, XIX, from the work of Terner and Verhoogen (1960), II, IV, VIII, from the work of Barth (1955), IX, XII, XIV, IXII from Gorshkov (1970).

Table 9. Low alkaline tholetic basalts from some Kamchatka caldera volcanoes.

SiO_2	49.58	52.05	49.42	53.94	49.02	52.57	57.88	49.34	51.78
TiO_2	0.76	0.86	0.92	1.00	0.95	0.85	0.72	1.18	0.95
Ae_2O_3	18.98	18.36	19.10	17.75	20.22	17.77	16.10	20.65	18.45
Fe_2O_3	4.15	3.95	5.29	3.94	4.11	3.34	4.57	6.60	3.00
FeO	6.09	6.63	3.50	5.45	7.18	7.30	4.43	2.93	7.03
MnO	0.17	0.11	0.19	0.11	0.18	0.19	0.18	0.26	0.29
MgO	6.01	5.39	4.84	4.56	3.84	4.73	3.50	2.64	4.21
CaO	10.59	9.62	8.41	9.15	11.19	9.15	7.42	10.73	8.51
Na_2O	2.29	2.37	2.70	3.15	2.55	3.05	4.00	2.58	3.74
K_2O	0.36	0.30	0.28	0.5	0.19	0.39	0.60	0.60	0.60
H_2O-	1.00	0.10	--	0.00	Less than	Less than	Less than	1.78	0.26
H_2O+	0.32	0.00	--	0.09	0.5	0.5	0.5	0.30	0.54
P_2O_5	0.19	0.13	0.06	0.05	0.07	0.15	0.11	0.30	0.09
CO_2	0.00	0.66	4.78	0.28	0.31	0.21	--	--	--
Total	100.49	100.50	99.99	100.15	99.50	99.50	99.50	99.87	99.45

1-2 Zheltovsky volcano (after Masurenkov, ed., 1980); 3-4 Zheltovsky volcano (after Masurenkov, ed., 1980); 5-7 Ksudach volcano (courtesy of Solovieva); 5 pre-caldera basalt; 6 basaltic dike of caldera-forming stage; 7 post-caldera Stübel cone, formed in 1907; 8-9 Uzon Geyzernaya caldera (after Naboko, ed., 1974).

Two analyses were taken from each volcano in order to show changes in alkalies with increasing silica content.

pair of parallel volcanic belts (Nasu zone, northeast Japan, southern and eastern Kamchatka). In Kamchatka to this type belong basalts from several caldera-volcanoes: Il'insky, Zheltovsky, Ksudach, Uzon, Stena. Examples of analyses of such basalts from Kamchatka caldera volcanoes are shown in Table 9. In both cases, for volcanic belts is characteristic presence of basaltic volcanoes on which outbursts of dacitic pumice are developed.

On some calderas of Kamchatka and Japan can be seen, that just after caldera-forming eruption of dacitic pumice in ever kind of places, from which such pumice can be erupted (i.e., radial and arcuate dikes and central vent) come typical low-potassium tholeiites. So it is possible to suggest, that dacites represent the uppermost part of a magmatic column, lower part of which is composed by tholeiitic basalts. So specific features of low-potassium tholeiites chemistry appears to be due to a specific type of eruption. Sometimes the changing of dacitic pumice by low-potassium tholeiites was observed during a single eruption - Ksudach volcano in south Kamchatka, eruption in 1907, Oshima volcano, northernmost Izu islands, eruption in 1956. The primary magma which is divided in all these cases on dacitic and tholeiitic parts is high-alumina basalt. It is interesting to note, that in cases where such volcanoes are cut by linear zones of monogenetic volcanoes and cinder cones, all these forms are composed by high-alumina basalts.

In all the above mentioned volcanoes and many others, when a contrast series of rocks were formed in both types of rocks-dacitic pumice and low-potassium tholeiites a characteristic type of inclusions were present. These inclusions ranging in size from 1-3 cm up to 1-2 m in diameter are on 80% composed of anorthite No 90-95, and other 20% of their volume are composed by olivine, pyroxene and basaltic glass. With all the features of chemical and mineralogical composition it is only a single type of terrestrial anorthosites which is the same as a Lunar anorthosites (see Table 10). The presence of anorthositic inclusions in both types of rocks either in dacitic pumice or tholeiitic basalts, zonal texures in some of these inclusions (sometimes with druses of anorthite crystals in the center of inclusion) indicates, that the origin of such inclusions is connected with the separation of two independent parts - dacitic and basaltic, from parental magma, and this separation takes place in the upper part of the magmatic column.

The generation of low-potassium tholeiites as a result of the separation of a great amount of silicic pumices from a parental magma can be very widespread. On this probably indicates floating fields of pumice observed practically in each case of a submarine eruption on oceanic volcanoes. Wolff (1929) indicates that on Atlantic beaches of Argentina there are present a lot of pumice. But the nearest source of their eruption can be connected only with volcanoes located along the Mid-Atlantic Ridge.

It is possible to suggest, that the difference in composition between low-potassium oceanic type tholeiites and high-alumina basalts is connected, not with a different composition of the primary magmas, but rather with a different behavior of SiO_2, alkalies in the single parental melt, but under different conditions. In one case--high-alumina basalts, silica is preserved in parental melt and sequence basalt—andesite-dacite-rhyolite was formed. In another case--low potassium tholeiites, silica is evacuated by volatiles from primary melt and is concentrated in dacitic pumice.

Table 10

Composition of anorthosite inclusions in volcanic rocks of Kamchatka (from Erlich and Gorshkov, eds., 1979).

	1	2	3	4	5	6	7
SiO_2	40.10	41.22	42.82	39.46	42.74	46.0	45.4
TiO_2	0.42	0.13	0.10	0.42	0.16	0.3	traces
Al_2O_3	27.15	24.06	25.03	26.39	26.46	27.3	33.8
Fe_2O_3	4.13	1.65	0.90	1.56	0.76	---	---
FeO 5.40	5.55	4.66	6.04	4.16	6.2		2.8
MnO 0.12	0.12	0.10	0.10	---	0.1		0.1
MgO 7.97	12.69	9.42	9.71	11.09	7.9		1.7
CaO 13.35	13.38	15.94	15.64	14.15	14.1		17.5
Na_2 0.95	0.34	0.50	0.69	0.73	0.3		0.4
K_2O 0.15	---	---	0.32	0.04	traces	traces	
H_2O+	0.06	0.50	0.12	0.06	0.03	---	---
H_2O-	0.78	0.12	0.10	---	---	---	---
P_2O_5	---	---	---	0.03	0.03	---	---
CO_2 0.09	---	---	---	---	---	---	
Total	100.67	99.76	99.60	100.80	100.35	102.5	101.7

Analyses 1-5--Anorthosite inclusions in calc-alkaline rocks of Kamchatka and Kurile islands (accoding to Bogoyavlenskaya and Erlich, 1969); analyses 6, 7--lunar anorthosites (according to Wood et al., 1979).

Proposed model of origin of low-potassium tholeiites does not exclude the possibility of their origin in process of partial fusion of the Upper Mantle matter. It is important to note that in this last case, low-potassium tholeiites are characterized by some increase MgO content.

Way of low-potassium tholeiites evolution - Engel's sequence and its connection with Kuno's sequence.

The differentiation of mafic low-potassium tholeiites is well studied on Hawaii and other oceanic volcanoes. In a general way their evolution lead, in it's final stage, to the formation of alkalic olivine basalts. It is important to note, that this line of differentiation has opposite tendency in comparison with Kuno's sequence. This process of differentiation was characterized by a steady increase of mafic components content and alkalies concentration and simultaneous decrease of anorthitic component content. The final member of this sequence was represented by alkaline olivine basalts. In its classical form this way of evolution was described in Hawaii by Macdonald and Katsura (1964). It is possible to call this sequence Engel's sequence in name of the distinguished American petrologists who studied oceanic basalts, A. E. G. Engel and C. G. Engel.

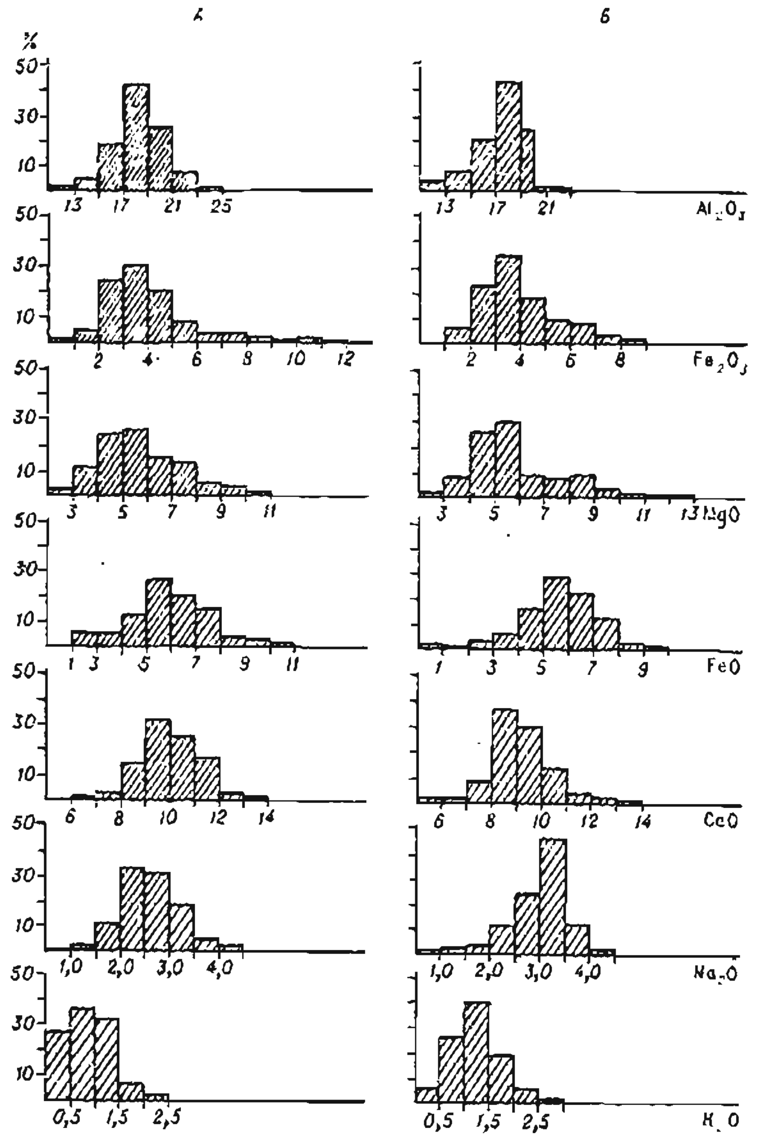
On island arcs and in similar geotectonic systems, Engel's sequence is developed as complementary in the process of Kuno's sequence development. Tendency to such process of development was described during the last eruption of Tolbachik volcano (Fedotov, ed., 1984), where eruptive products of an earlier, northern breakthrough were represented mainly by high-alumina basalts and the eruptive products of a later, southern breakthrough were represented by basalts enriched in MgO. The appearance of tholeiitic basalts in the process of Kuno's sequence development reflects the changing of the magma-generation zone composition as a result of an accumulation in the root part of the feeding channel of the Kliuchevsky-Fuji type of volcanoes magmatic residues, which correspond to Engel's sequence. This leads to the changing of the Upper Mantle composition in the roots of volcanoes and by this means creates premises for the next stage of tectonic development, and in particular the transition to trachybasaltic volcanism. It is very characteristic, that the average basalt composition in mature orogenic regions (for example in the North Kamchatka-Olyutorsky block) belong to this type, which can be defined as alkaline tholeiites. These tholeiites have the same trend of evolution as oceanic tholeiites - to alkaline olivine basalts. Basalts of Auckland and the Koromandel region of North Island, New Zealand, belong to the normal type of alkaline olivine basalt.

General problems of genesis.

The presence on island arcs and Kamchatka-type geotectonic systems of two stable types of basalts and connected with them different associations of volcanic rock (continuous row basalt - andesite - dacite - rhyolite versus contrast basalt-dacite, or even basalt-rhyolite series) permits to propose a new approach to the explanation of some general petrochemical regularities.

Due to the difference in tectonic conditions in frontal and rear volcanic belts (in case if a pair of volcanic belts is present) or in frontal and rear parts of a single volcanic belt there will be different proportions of two of the above mentioned types of basalts (Fig. 102).

Fig. 102. General character of petrogenetic oxides distribution in Quaternary basalts from outer A and inner B volcani zones. For column A 179 analyses were used and 249 from column B (after Erlich 1973).



Such different proportions of two stable types of basalts reflecting the difference in tectonic conditons and explains the increasing alkalies content in basalts much better than an existing model which is connected to it by the increase of earthquakes foci in the same direction.

So the difference in alkalies content between frontal and rear volcanic zones is an important characteristic of the tectonic regime in certain geotectonic systems (Table 11).

The mechanism of the separation of silica and alkalies from parental magma is still unclear. Nevertheless, it is possible to suggest different levels (and probably different mechanisms) of such separation. One, as we saw, is separation in the upper part of magmatic column. Another way, can be separation in process of transformation of lowermost horizons of the Crust, a kind of ultrametamorphic process. But in any case and on any level, silicic part of primary matter is evacuated by volatiles.

Interesting examples of such process, going even under surface conditions-in lava flows, are described in different volcanic regions in western North America: Northern California, Eastern Cascades, Modoc Plateau, Togiak Peninsula and Nunivak Island, Alaska, and some part of Columbia Plateau. In all these regions within basaltic covers and flows, i.e., practically on the surface, there present vesicle cylinders, filled by silicic volcanic material. Descriptions of such vesicles have been recently summarized by Goff (1977). Composition of host basalts in these cases can be different, from tholeites to high-alumna basalts and alkali olivine basalts. Near vertical vesicle cylinders range in diameter from 2 to 20 cm. Vertically they are traced for several meters. These cylinders began growth within 0.5 m of the flow base, or on any higher level in the lower half of the flow. The lavas containing vesicle cylinders show the dihotaxitic texture, ascribed to water vapor exsolving from the melt during the last stages of crystallization. The last residues of solidify within the cylinders consist of dacitic-rhyolitic glass, Fe-Ti oxides, anorthoclase, fayalite, aegirine; vesicles may or may not contain crystobalite spherules.

Some approach to physico-chemical mechanism of such process of silicic matter separation from primary matter under any physical conditions, melted or not melted, is provided by experimental studies (Tuttle and others, 1978). These authors studied the behavior of the basalt sample under pressure 10 kbars in presence of water, under influence of the temperature gradient without melting. As a result of the experiment, after a week in the relatively cold end of the capsule, there was a concentration of about 25% of granitic matter (as it is known, in process of fractional separation of silicic melts from basaltic magmas their quantity does not exceed 5% from the primary volume). The most movable components in this process have naturally been silica and alkalies. Separation of fractions, enriched in silica can have place as in form of melt so in form of fluid.

Another way of evacuation of silica and alkalies from parental melt is provided by geotherms. Connection of geothermal fields with fluids strongly enriched by silica and alkalies with calderas volcano-tectonic depressions and other types of structures which control silic volcanism is well known. So it is enough to mention here such greatest geothermal systems as Pauzhetka, Uzon, Geyzer Valley, Great Semiachik, Bolshe-Banny and Paratunka in Kamchatka, Goriachy Pliazh and Goriachy Lake on Kunashir Island, Southern Kuriles, Wairakey and Waiatapu in Northern Island, New Zealand, geothermal fields of

Table 11

Difference in alkalies content in basalts from frontal and inner volcanic zones of some island arcs and similar with them geotectonic systems (Erlich, 1973)

Pairs of volcanic belts	ΔNa_2O	ΔK_2O	$\Delta(Na_2O + K_2O)$
Nasu-Chokai,	1.1	0.8	1.9
Kirishima-Unzen-Kudju	0.8	0.6	1.4
Krakatau volcano-inner zone of Sumatra	0.56	0.52	1.08
Northern group of Great Kurile chain-Western volcanic zone of Kuriles	0.2	0.4	0.6
Eastern Kamchatka volcanic zone-Sredinny Ridge volcanic zone	0.3	0.3	0.6
Central Kamchatka Depression-Sredinny Ridge volcanic zone	0	0	0

Kudju and Unzen regions on Kyushu, Usu on Southern Hokkaido, Geyzers of Yellowstone National Park, localized in connection with great centers of silicic volcanism. It is possible to suggest that well-known association of spilite-keratophiric belts with enriched in silica sediments (radiolarites, jasperoids and so on) also in part is the result of evacuation of silica from parental basaltic melt by geotherms.

General Pecularities of Silicic Volcanism

Geological pecularities

General geological features, characteristic for silicic volcanism on island arcs and similar with them geotectonic systems are:

1. The great scale of process, which lead to formation of volcanic products different in scale and composition in different types of geotectonic systems (normal island arcs vs Kamchatka-type geotectonic systems), but certain in certain types of geotectonic systems and in certain epochs.

2. Short time intervals of epochs of silicic volcanism and synchroniety of these epochs in great territories (probably in global scale).

3. Independence of the degree of any kind of deep-seated process (different types of heat flow reflected in volcanism, metamorphism, hydrothermal process and so on) from the degree of subsidence of certain structures, which is emphasized by overlapping character of the main volcanic centers and their close connection with deep-seated faults.

General features of silicic volcanic rocks mineralogy.

As has been noted by Erlich and Melekestsev (1974) usual associaton of phenocrysts in silicic volcanic rocks either for caldera-forming or post-caldera stages of silicic volcanism is quartz, acid plagiocalase,. hypersthene. Absence of K-feldspar as in form of phenocrysts so in groundmass of these rocks indicate that temperature of rock formation exceed minimum in the system, plagioclase--K-feldspar--quartz.

This conclusion is confirmed by the absence of quartz in form of regular well-formed phenocrysts. It is met rather in form of xenolith-like, partly melted grains. Temperature of crystallization of these grains is 1190-1260°C on the first stage and 800-830°C on the last stage of crystallization. In parallel with decreasing of temperature, composition of gases in fluid inclusions changes regularily (Bakumenko and others, 1970).

Although accessory minerals are not still well studied, often finding of almandine in silicic rocks is marked. Garnets of almandine - pyrope serie from silicic effusives occupy intermediate position between garnets from metamorphic complexes and shallow granitoid intrusions (Marakushev, Tararin, 1964). Olivine is constantly present as accessory mineral. Very characteristic is also presence among accessory minerals native metals and minerals - indicators of high pressure. So in unaltered obsidians from Khangar volcano is found native mercury, in silicic andesites from extrusive domes on Avacha volcano is found native lead, for the region of Kurile Lake is characteristic, native tin. Also very characteristic is finding of moissonite (SiC) in silicic volcanic rocks. All these facts indicate on the possibility of high pressure and from another side - reduction conditions in the moment of crystallization of silicic volcanic rocks.

At the same time in rare case, when silicic volcanic rocks lie on metamorphic terranes (Khangar volcano) - relict minerals of gneisses and crystalline shists are absent. It indicates on high temperatures and pressure in the early stages of silicic magma crystallization, which lead to the dissolving of such minerals.

Specific features of volcanic rocks chemistry of caldera-forming stage.

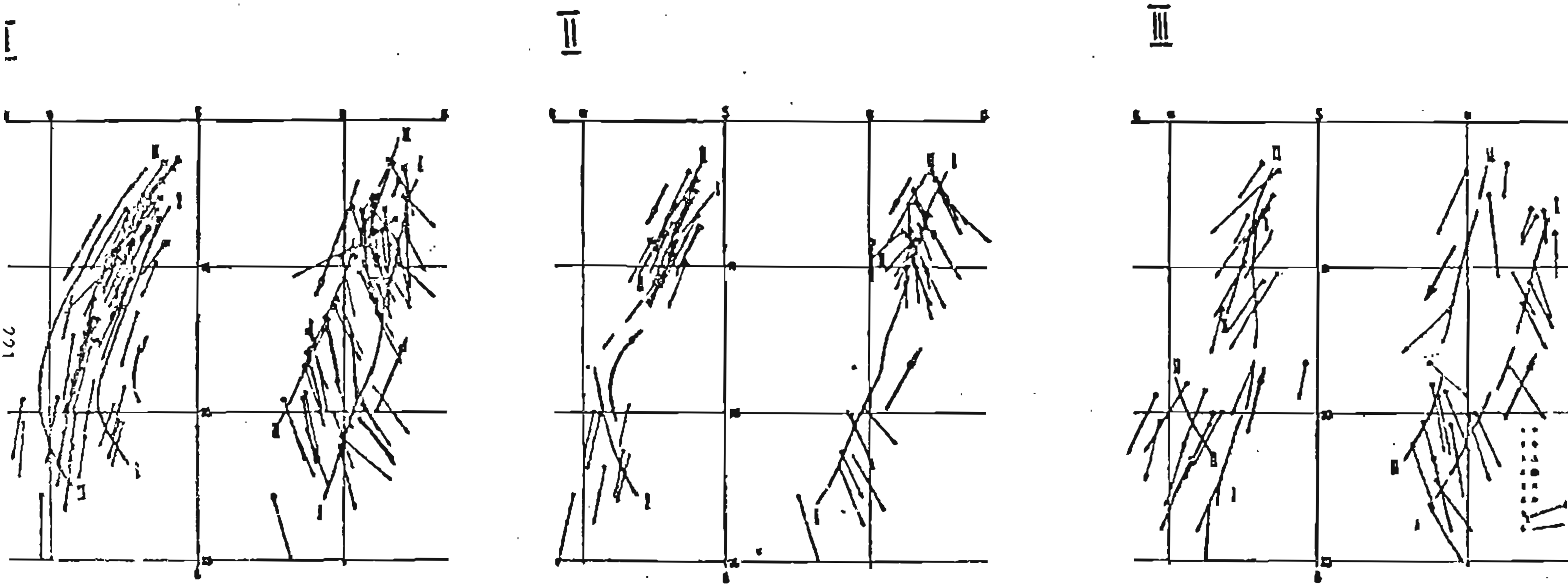
Speaking about characteristic features of rocks chemisty on caldera-forming stage, it is possible to note for the first, the uniformity of rock chemistry and the absence of any connection between it and composition of the basement of volcanoes. Second, it is possible to note close connection of petrochemistry of these rocks and rocks of basalt - basaltic andesites series of pre-caldera stage of volcanism. The last feature is observed in both cases: when calderas inherited their positon from pre-caldera volcano, or on opposit - when a caldera is superimposed on non-volcanic basement. In the last case comparison can be produced with pre-caldera stage of volcanism in the region as a whole. For the rocks of caldera-forming stage of volcanism is characteristic comparatively small (2-3% in rare case - 5%) quantity of phenocrysts. For general chemistry of the rocks of this certain stage is characteristic increased role of K_2O: $Na_2O + K_2O$ ratio of this rocks changes from 0.5-0.7 for the most silicic rocks within basalt - basaltic andesite serie to 0.8-0.95 in silicic pyroclastics of caldera-forming stage. Important specific features of volcanic eruption on the caldera-forming stage - abrupt change of voltaile phase quantity and its role in the volcanic process, which lead to the explosions of Katmaian and Pelean type.

Specific features of volcanic rocks chemistry on post-caldera stage.

On post-caldera stage of volcanism in all cases is observed decreasing of alkalies and anorthite content in comparison with the most silicic members of basalt - basaltic andesite row. In the result on the petrochemical diagrams, characteristic bends are observed. Such picture remind paantelleritic tendency (Zavaritsky, 1950). This picture is observed as in process of single volcano development (Gorely, Zimina, Sheveluch) so within entirely geologically connected groups where some volcanoes represent line of development from basalts to basaltic andesites (i.e., before the bend on petrochemical diagrams), and another -silicic andesites or dacites - after the bend (Kliuchevskoy and Bezimianny volcanoes respectively) (Fig. 103).

Changing of ratio of alkalies and feldspar lime is accompanied by other petrochemical changes: abrupt decrease of Ca and Fe content and appearing of rocks oversaturated by alumina, general sequence and character of volcanism process also were changed. It becomes characteristic short reversal (antidromic) cycles of volcanic activity with the evolution from mafic to silicic rocks within a single eruption. In this connection eruptions of Bezimianny (1955-1956) and Sheveluch (1945) are characteristic (Meniaylov, 1955, Gorshkov, Bogoyavlenskaya, 1965). The same was observed in process of other volcanoes development. So, after outburst of rhyolite pumices on the Kurile Lake caldera, andesite-dacitic Diky Greben extrusive dome had been formed. Y. Katsui (1963) noted, that this is characteristic for development of volcanic process on post-caldera stage for all post-caldera volcanoes in Hokkaido.

Fig. 103. Petrochemical diagram for some centers of silicic volcanism in Kamchatka by Zavaritsky's method (after Erlich 1973).
I - Great Semiachik volcano-tectonic depression; II - Uzon-Geyzernaya caldera; III - Gorely caldera. 1 - pre-caldera basatls; 2 - ignimbrites of the main caldera-forming stage; 3 - post-caldera extrusive domes; 4-5 - ignimbrites of post-caldera stage; 6 - post caldera basalts; 7 - variation lines; 8 - direction of differentiation.



The most siliceous volcanic rocks, formed during the first stages of antidromic cycle has as a rule alkalies content, which correspond to the normal development of basalt - basaltic andesites row. In those rocks oversaturating of alumina is not characteristic. In process of formation of more mafic rocks, during antidromic cycle, quantity of alkalies decreased and the curve which reflects this decreasing does not coincide with normal curve of the Mantle-derived basalts and basaltic andesites of pre-caldera stage of volcanism. In this process all above mentioned characteristic features of chemistry are formed.

For the composition of rocks of post-caldera stage of volcanism increased role of crystalline phase is characteristic. In the result quantity of phenocrysts on this stage in average is equal 5-10% and in maximum reach 15-25%. Simultaneously on the last stages of post-caldera complex formation have place extrusion of almost pure glasses, which correspond to the most siliceous rocks--rhyolites. Process of the crystalline phase accumulation and fractionation of pure glass (as a result of squeezing under the pressure) is the leading process of differentiation on this stage.

All these characteristic features become stronger during post-caldera stage of volcanism.

For the rocks of post-caldera stage it is characteristic presence of partly melted cognate granitoid inclusions, which are completely absent in the rocks of caldera-forming stage. This has been shown for the Karymsky volcano (Ivanov, 1970; Masurenkov, 1969). Special checking shows that such xenoliths present on Khangar volcano only in rocks of the main dome and products of the last catastrophic pumice eruption, so only on the post-caldera stage. The same has been observed on Uzon caldera, where granitic xenoliths present only in pumices of the latest eruption and some post-caldera extrusive domes. The same has been observed on the Ichinsky volcano. By the data of Ivanov (1970) granitoid xenoliths on Karymsky volcano are characterized by the same petrological features as lavas of the post-caldera Karymsky volcano. Leonova, Udaltsova and Ivanov (1969) mark similar content of the rare and radioactive components in basalt-andesite complex of pre-caldera pra-Karymsky volcano volcanic rocks, post-caldera lavas and granitoid xenoliths.

All these petrological data and connection of this complex with calderas show, that it's specific features reflect crystallization within intrusive chambers, located in the Crust and feeding post-caldera volcanoes. Systematic character of deviations from the normal way of crystallization, which are observed for different centers in different regions show, that the main role in its formation play not the process of the host-rocks assimilation but rather crystalline phase accumulation, gas transfer and filter-pressing.

General problems of genesis of silicic volcanic rocks.

Speculating on the nature of silicic volcanism it is possible to remind mentioned above close connections between silicic and basaltic volcanism as in geology, so in mineralogy and geochemistry. In the same time overlapping character of main centers of silicic volcanism, absence of any dependence of volcanic rocks and composition from the composition of the basement of volcanoes indicate on absence (or at least insignificant degree) of assimilation of the Crust material. Sr and He isotope data also support ideas about mantle origin of silicic magmas in island arcs and similar with them geotectonic systems (see Tables 12, 13).

Table 12

Strontium isotopes in Quaternary volcanic rocks from Southern Kamchatka
(After Masurenkov, ed., 1980)

Types of rocks Name of volcano	SiO_2,%	K_2O,%	Rb g/t	Sr, g/t	($^{87}Sr/^{86}Sr$)
Basaltic andesite, Cherniye Skaly volcano, Pauzhetka region	57,71	1,61	29	460	0,7054±0.0002
Basaltic andesite, volcano with height 1102 m, Pauzhetka Region	—	0,74	10	450	0,7035±0,0003
Dacite, Il'insky volcano	64,88	1,31	14	358	0,7054±0,0002
Ignimbrite (andesite-dacite), Gorely volcano	62,70	2,64	46	393	0,7034
Ignimbrite (dacite), Ksudach volcano	62,40	0.99	14,5	322	0,7033
Ignimbrite (dacite), Pauzetka River	68,41	1,29	9	350	0,7036±0,0003
Ignimbrite (dacite), Golygin Mountains	70,39	1,77	26	300	0,7023±0,0005
Ignimbrite (rhyolite), Golygin Mountains	71,89	1,64	25	400	0,7036±0,0002

Table 13

Content of lithium, radioactive elements, helium, argon and strontium in dacites and rhyolites from Kamchatka volcanic rocks (after Tolstikhin and others, 1976).

Number of Samples	K	Li	Rb	Sr	U	Th	Ar^{40}_{Rad}	He^4	He^3	Isotopic Ratio				Age accepted years
	Weight percent	g/t					$(cm^3/year) .10^{-8}$			measured		calculated		
										Sr^{87}/Sr^{86}	$\frac{He^4}{Ar^{40}_{Rad}}$		$He^3/He^4 .10^{-6}$	
1	3,25	45	72	195	2	6,8	146	5,0	3,1*	0,702 ±0,002	0,03	0,63	0,022	$(7-11)-10^6$
2	2,12	22	--	--	1,6	5,4	10,6	1,7	6,3*	—	0,16	3,17	0,013	10^4
3	2,85	22	--	—	3,0	6,2	32,7	2,1	8,6*	—	0,06	4,1	0,013	10^5
4	1,31	14	18	328	1,1	5,4	26,3	7,1	37*	0,704 ±0,002	0,06	22	0,008	10

$*10^{-6}$

It is characteristic, that "mantle-type" isotope ratio of Sr and He are typical for volcanic rocks from different volcanic zones and different stages of volcanism-either ignimbrite and pumice of the main caldera-forming stage or lava flows and extrusive domes of post-caldera stage of volcanism (Hedge and Gorshkov, 1977, Masurenkov, ed., 1980a, Tolstikhin and others, 1976). Ideas of mantle-origin of silicic volcanic rocks do not contradict modern experimental and physico-chemical data (Matsumoto, 1964).

Way of origin may be different. By quantitive correspondence of silicic volcanic rocks with basalts two cases can be distinguished. From one side we saw, that some basaltic volcanoes are characterized by outbursts of dacitic pumices, which probably form the uppermost part of magmatic column. But in the same time a lot of cases indicate that silicic magmas which come to the surface are result of the same kind of deep-seated process. In this case to the surface even on caldera-forming stage of volcanism come great amount of silicic volcanic material with absence or absolutely insignificant amount of basalts and basaltic andesites. Such great volumes even in case when some basalts also are present it is difficult to produce directly from basalts by any kind of differentiation.

Here it is possible to indicate a close connection between silicic volcanism, rejuvenation of metamorphic belts and granitic intrusions. In all cases, when erosion is deep enough, it is marked coincidence between radiometric age of these three types of formations (rejuvenated metamorphism, granitoid intrusions and volcanic rocks series, formed in process of silicic volcanism). In Kamchatka, Japan, New Zealand, it is seems that metamorphic terranes were formed long time before the main phase of silicic volcanism, but during periods which coincide with impulses of silicic volcanism there have place general uplift and repeated phase of potassium metasomatism. So, in Median Massif of Kamchatka the most ancient radiometric data for metamorphic rocks is about 178 mln. years, a lot of samples have radiometric age 40-45 mln. years, which coincide with age of granitic intrusions which cut these metamorphic series and at least there present some rocks with age 5-6 mln. years which corresponds with youngest granitoid intrusions in the region. In southwestern Japan, metamorphism of the Ryoke belt by geological data have place in time interval between Middle Permian and Late Triassic periods (Minato and others, eds., 1965). But radiometric age of metamorphic rocks correspond with the age of granitoids comagmatic with ignimbrites and tuffs of Nohi sequence (Shibata, 1968). By the geological and K-Ar data the main phase of metamorphism on the South Island, New Zealand, belongs to pre-Upper Jurassic time. In the same time K-Ar ages of biotites from gneisses in areas close to the Alpine fault are equal 4-6 mln. year. These figures correspond with time of impulse of silicic volcanism in the Hauraki province, North Island and intensive uplift of the South Alps. In this connection two additional facts have to be mentioned: (1) Gneisses of high-grade metamorphism for the first time appeared in New Zealand in pebbles from Pleistocene sedimentary sequence; (2) along the Alpine Fault recent hot springs are widely developed.

These facts lead Hattori (1968) to the conclusion that the last phase of metamorphism along Alpine Fault have been connected with uplift during time interval 4-8 mln years and tectonic and thermal events connected with final movements of this phase are continued up to now.

It is possible to remind mentioned in Chapter I connection between centers of silicic volcanism and recently developed zones of high-temperature metamorphism in immediate closeness to deep-seated fault zones. Mentioned above common association of phenocrysts in silicic volcanic rocks: quartz, acid plagioclase, hypersthene, accessory olivine and almandine is very close to such association in charnokites. Same also is usual in both cases rocks association: plagiogranites (or their volcanic analogues), gabbro (or basalts) and anorthosites (or anorthositic inclusions). Similar also are temperatures and pressure conditions typical for both rocks associatons. Marakushev and Tararin (1964) indicate on analogy in composition of charnokites and granitoid intrusions in Kurile-Kamchatka zone. This analogy have been extended by Erlich and Melekestsev (1974) who thought that silicic volcanism in island arc system reflect process of charnokitization of the deep horizons of the Crust.

CHAPTER VI
TYPES OF CALDERAS AND MODE OF THEIR ORIGIN. REGIONAL COMPARISONS

In the development of different forms of calderas there exist a tendency to two different kinds of movements which appear around volcanoes in connection with volcanic activity.

The first is the tendency to subsidence in connection with discharge of magmatic material and consequent decreasing pressure.

The second is the tendency to uplift connected with doming in process of emplacement of magma intrusions in the upper horizons of the Crust and increasing pressure on the roof of the magma chamber.

These two tendencies reflect two opposite ways of caldera formation, but structures created in the result of both processes are similar and so processes are convergent.

STRUCTURES CREATED IN THE RESULT OF DECREASING MAGMA PRESSURE.

In dependence with level on which decreasing of magma pressure has place it is possible to divide calderas of this group in two types. Decreasing pressure in the both cases is connected with discharging of magmatic material. Calderas connected with this type of process are associated mainly with basaltic volcanoes. Different type of discharging reflect different levels of decreasing magmatic pressure.

The first group of caldera (or volcano-tectonic depresions) is connected with discharging of magmatic material through volcanic centers located inside caldera (or volcano-tectonic depression).

The second group of calderas is connected with discharging of magmatic material through the upper part of magmatic column which for a long time exist beneath great central (mainly shield) volcanoes. Depending from the position of the vents through which discharging of magmatic material has place inside the last group are divided;

- Hawaiian-type calderas, where discharging has place through linear system of vents (so-called rift zones); and
- Galapagos-type calderas, where discharging has place through concentric system of fissures surrounding central summit crater.

A. CALDERAS (VOLCANO-TECTONIC DEPRESSIONS) CONNECTED WITH GREAT BASALTIC VOLCANOES (TOLBACHIK - ETNA TYPE STRUCTURES).

The first group of calderas connected with decreasing magma pressure is associated mainly with great basaltic volcanoes or group of volcanoes. These volcanoes (or volcanic groups) are located within great circular in plan depressions and their lavas flow to the scarps of relief, which express arcuate fault zones. Amplitude of displacement along these faults ranges from 100 up to 500 meters or more. Sometimes there exist concentric system of faults, outer of which divide uplifted blocks of pre-volcanic basement and inner displace lower part of the central volcanic edifice (or group of edifices). As it has been mentioned above, the central volcano (or volcanic group) is composed mainly by basalts, but sometimes also are present compound volcanic groups composed by a bi-modal series of rocks - basalt - dacite or basalt - rhyolite. The area occupied by volcano-tectonic depression experienced general slow subsidence. Good example of a great volcano-tectonic depression of this type is represented by the Tolbachik volcano-tectonic depression (see Chapter III, 6.0).

From the Chapter III it is possible to see that all large volcano-tectonic depressions of this type in Kamchatka were developed on the background of great basaltic shields (Zhupanovsky, Great Semiachik, Ichinsky, Inkaniush depressions, depression in which the Ksudach volcano is located).

Displacement along faults of the outer system on the Zhupanovsky (Karymsky) volcano-tectonic depression is comparatively small—it does not exceed 100 m. Inside the structure are located two large silicic calderas—Stena-Soboliny and Polovinka calderas, which are associated with a great amount of silicic pyroclastic material. So one can refer to these later eruptions of silicic pyroclastics as to a reason for subsidence along the outer fault system (see Chapter III, 5.2).

But displacement along outer ring faults on Ichinsky volcano-tectonic depression is quite large--several hundred meters, and it is obvious that no silicic pyroclastics are connected with it. The same is true about Inkaniush volcano-tectonic depression and its outer ring of faults, which surround Ksudach volcano. In all these cases development of subsidence along ring faults is connected with the activity of basaltic volcanoes--Il'insky, Zheltovsky and Ksudach volcanoes (see Chapter III, 4.2-4.3).

Surprisingly these types of structures have been neglected in most regions. In the Kuriles it is possible to recognize such structures on the basis of the previous descriptions of the volcanoes—Tiatia volcano on Kunashir Island and Atsonupuri volcano on Iturup Island (see Chapter II, 1.3-1.5). In Alaska lavas of the basaltic Veniaminoff volcano flow under scarp of pre-volcanic relief (Fig. 104). Circular faults of the same type were developed to the south of Ugashik caldera (Fig. 105).

To this type of structures belong probably great volcano-tectonic depression around the Medicine Lake volcano, California (Heiken, 1972). The same kind of structures appear around Fuji in central Honshu Island, Japan, and Etna in Sicily, Italy. These two volcano-tectonic structures are described below.

Fuji Volcano-Tectonic Depression.

A joint analysis of geology and topography of the region of Fuji volcano show that the volcanoes Fuji and Ashitake-yama are surrounded by uplifted blocks with a height up to 1,000 m or more and composed of pre-Quaternary rock complexes. To the north of the Fuji volcano these blocks consist of Early to Middle Miocene andesites and basalts cut by intrusions of Pliocene quartz diorites and granites (Geological map of Japan, 1:1,000,000; 1978). Some lava flows from Fuji flow into areas of these deposits through erosional valleys. To the south and southwest lavas from these blocks consist of Pliocene and Upper Miocene to Pliocene mudstones, sandstones, conglomerates and volcanoclastic rocks. Fuji lavas flow over scarps of relief which bound these blocks to not more than several hundred meters. As a result, a series of impounded lakes were formed along this scarp to the north of Fuji.

By all these data it is possible to conclude, that Fuji volcano is located in volcano-tectonic depression, circular in shape, with diameter of about 50 km. From the southeast side volcanic rocks of Fuji and Ashitake-yama close foothills of the Hakone volcano. On geological map of Japan in scale 1:500,000 (sheet 8, 1982), faults are shown only to the north of Hakone volcano and to southwest from Fuji.

Summary of structural interpretation is seen on Fig. 106 and volcano-tectonic depression is seen on the shuttle-photo of the Fuji volcano (Fig. 106).

Fig. 104. Airborne radar image of the Veniaminoff volcano, Alaska (courtesy of J. Friedman). To the east and southwest, lavas of the volcano flow under tectonic scarps of pre-volcanic formations.

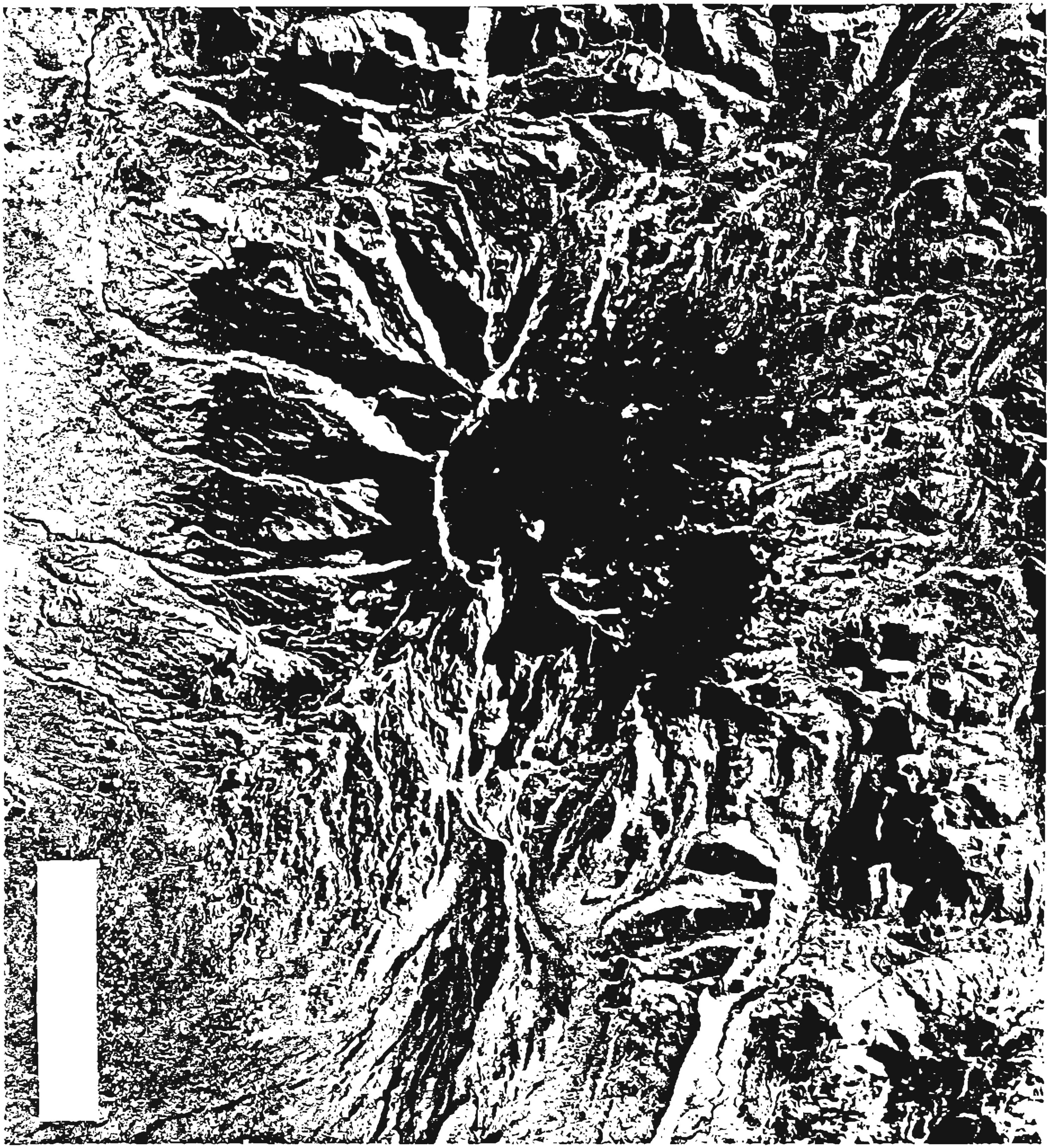


Fig. 105. Airborne radar image of the Ugashik caldera (courtesy of J. Friedman). Arcuate tectonic scarp is seen southwest of the volcano along with a series of east-west fault zones which control the position of the volcano.

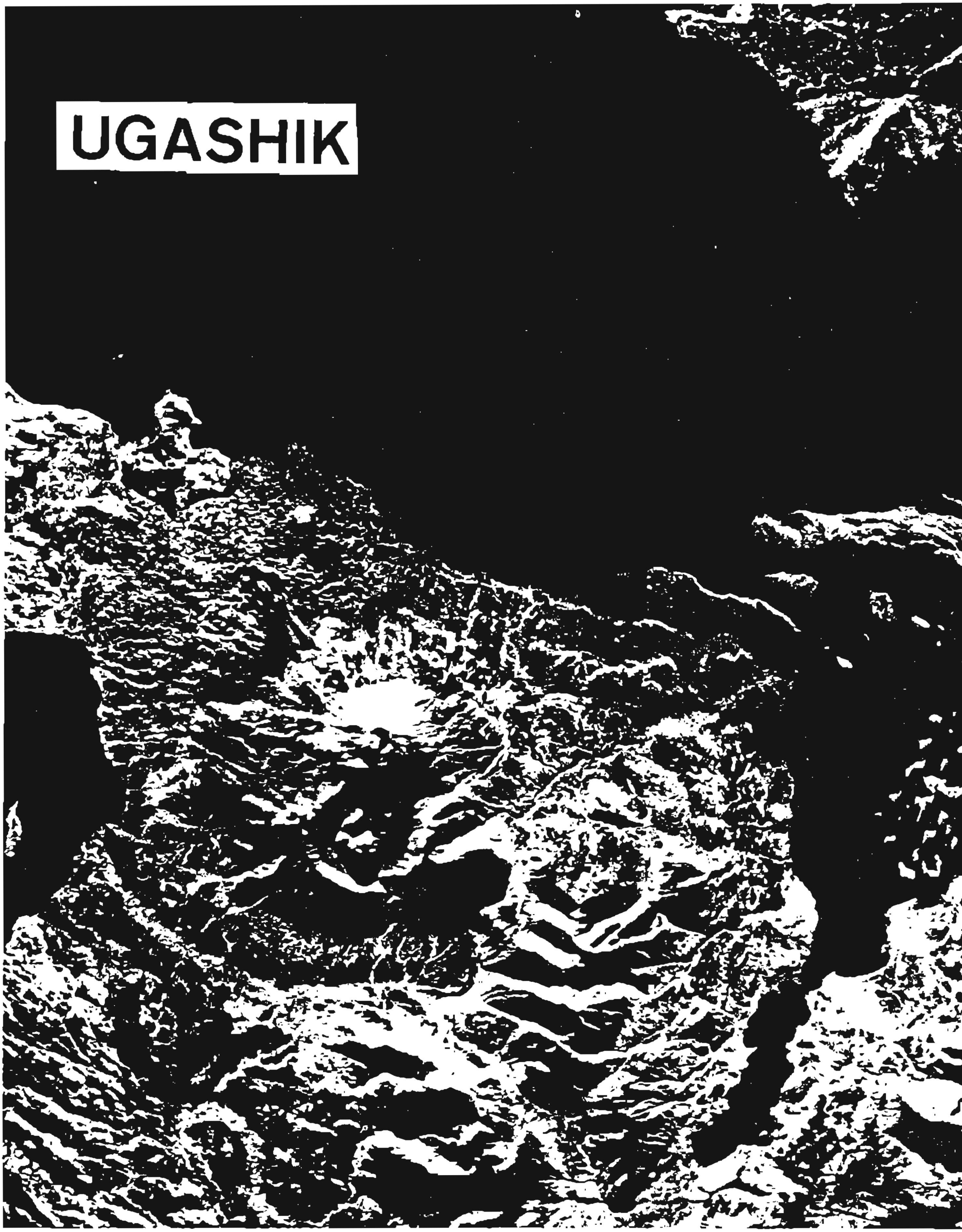
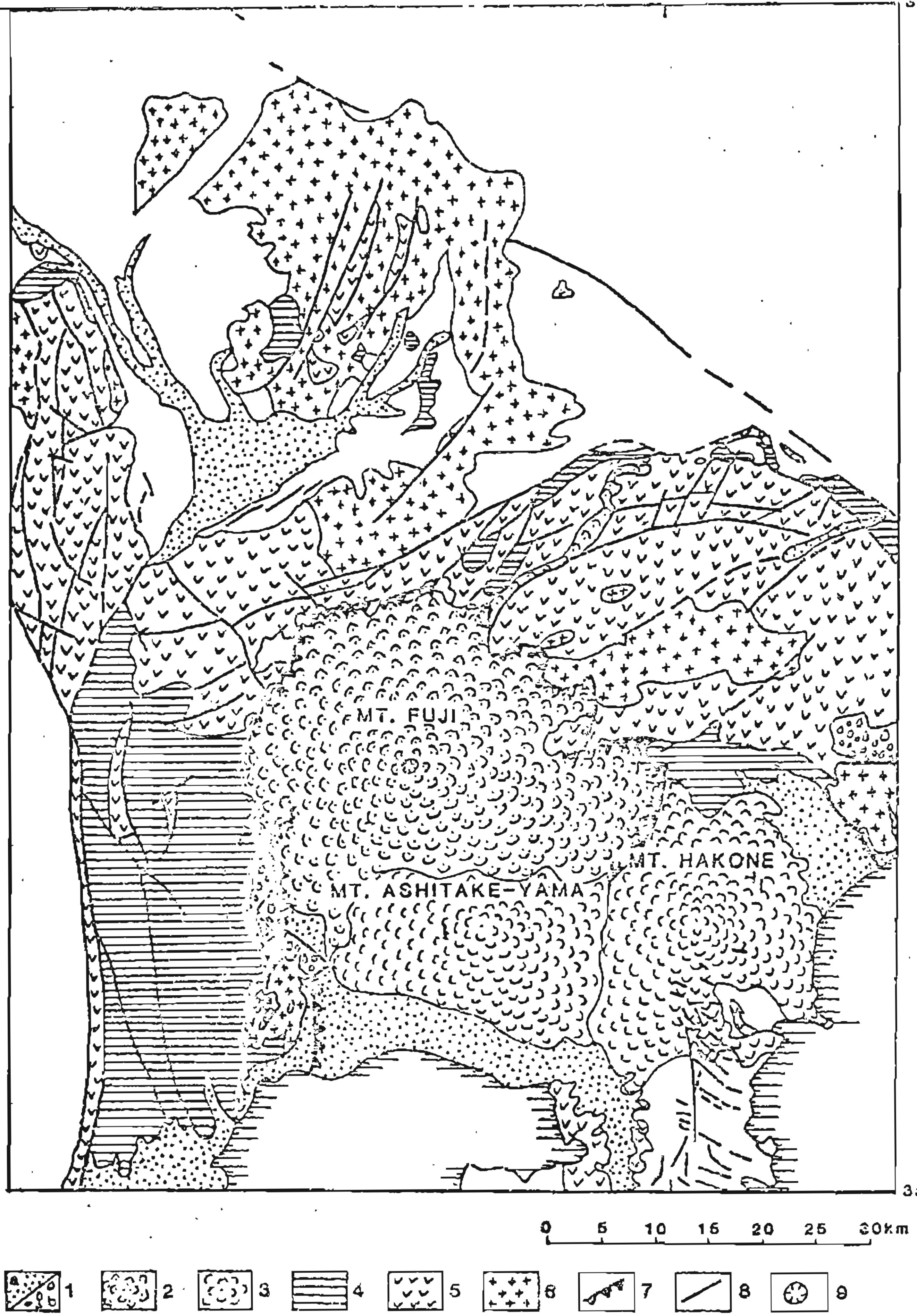


Fig. 106. Schematic tectonic map of Fuji volcano. 1 - unconsolidated Quaternary deposits; 2 - Fuji; 3 - Ashitake-yama; 4 - Hakone; 5 - Miocene to Pliocene sedimentary rocks; 6 - Neogene granitic intrusions; 7 - Lower to Middle Miocene volcanic rocks; 8 - Scarps along faults that bound the volcano-tectonic depression; 9 - tectonic zones and strike-slip faults.


MT. FUJI
MT. ASHITAKE-YAMA
MT. HAKONE
35°
0 5 10 15 20 25 30km
1
2
3
4
5
6
7
8
9

Etna Volcano-Tectonic Depression.

A joint analysis of geological and topographical maps of the region show, that to the north and west from Etna are ridges 700-1000 m high, arcuate in shape, and composed of pre-Upper Pliocene folded complexes. These ridges are separated from Etna lavas by arcuate tectonic scarps. Etna's lava flows to these scarps at a height of 200-400 meters. These scarps are horizontally displaced by a series of strike-slip faults mainly of eastwest and northeast strike . Amplitude of this horizontal displacement reaches 2-3 km.

Catania Plain is located to the south of Etna where folded pre-Quaternary basement is subsided at about 1,000-1,500 m. The subsided area is filled by loose Pliocene(?) and Quaternary sedimentary sequence up to 1,500 m thick. In the lower part of this sequence, several lava flows are present in drill holes. The northern part of the plain is overlapped by lava and the southwest depression continues to the south coast of Sicily. Total length of this structure is about 140 km, with a width of about 40 km. Iblean Fields is located in the middle of the plain which corresponds to the depression; and is interrupted by low hills composed of Pliocene volcanic rocks, alkali basalts, and pyroclastics.

Immediately to the south of Etna, this depression joins a belt of Pliocene sedimentary deposits on an eastwest strike about 30 km wide. It is probably a recently formed linear depression which evolved during an uplift in Quaternary time, which is characteristic for most of Sicily. Located around Iblean Fields are areas of Plio-Pleistocene terrigenic-skeletal limestones. Small areas of these deposits are located inside Iblean Fields. All these data indicate that the region of Iblean Fields on the first state of its geological development was a part of a linear depression, and only afterward was it involved in the process of domal uplift.

Compiling all these data it is possible to conclude, that Etna volcano is located within 40 x 50 km across the northeastern edge of a linear volcano-tectonic depression similar to graben-synclines, which control the position of volcanic belts in Kamchatka. Iblean Fields is located in the central part of this linear depression. It is important to emphasize, that there are no indications in literature on any outbursts of silicic pyroclastic material connected with the moment of generation of this depression. In size, structure, and connection with volcanism, this depression is very similar to Tolbachik and Fudji volcano-tectonic depression.

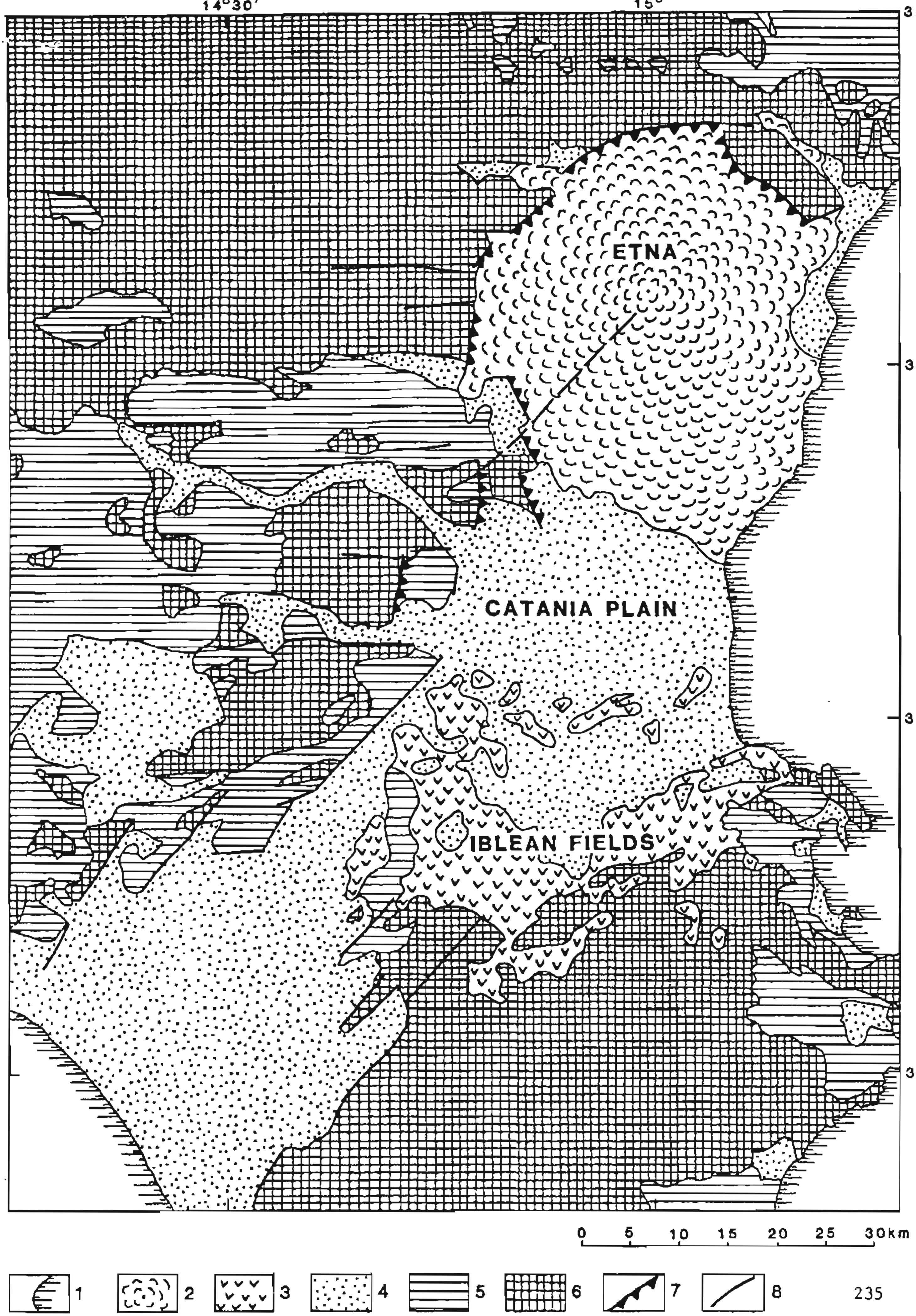
The resulting structural scheme is presented on Fig. 107.

Proposed model of origin of great basaltic volcano-tectonic depressions.

Due to connection of these structures with Mantle-located magma-generation zone, it is not surprising that with the data now available no indications on gravity anomalies connected with such calderas exist. In rare cases, such anomalies are present within depressions, usually they are connected with secondary features. For example, silicic calderas (Polovinka and Stena-Soboliny on Zhupanovsky volcano-tectonic depression, Ichinsky center of silicic volcanism inside Ichinsky volcano-tectonic depression).

General explanation of the gnesis of volcano-tectonic depressions, connected with basaltic volcanism leads us to wonder about the influence of decreased pressure in areas around the volcanoes within the magma-generation zone in the Mantle (in contrast with shallow magma chambers, connected with silicic volcanism - Fig. 108). After long periods of discharge of magma through the central large basaltic volcano in the magma-generation zone, there will appear the conic zone of the decreased pressure. Analogy of this process

Fig. 107. Schematic structural map of the region around Etna volcano, eastern Sicily. 1 - Shoreline; 2 - volcanic complex Etna volcano; 3 - Pliocene volcanic rocks of the Iblean fields; 4 - Depression filled with unconsolidated Pliocene and Quaternary deposits; 5 - Pliocene sedimentary complexe that was uplifted in Quaternary time; 6 - folded pre-Pliocene rocks; 7 - faults that bound the volcnao-tectonic depression; 8 - regional faults and strike-slip faults.


14°30'
15°
38°
37°40'
37°20'
37°
ETNA
CATANIA PLAIN
IBLEAN FIELDS
0 5 10 15 20 25 30km
1
2
3
4
5
6
7
8

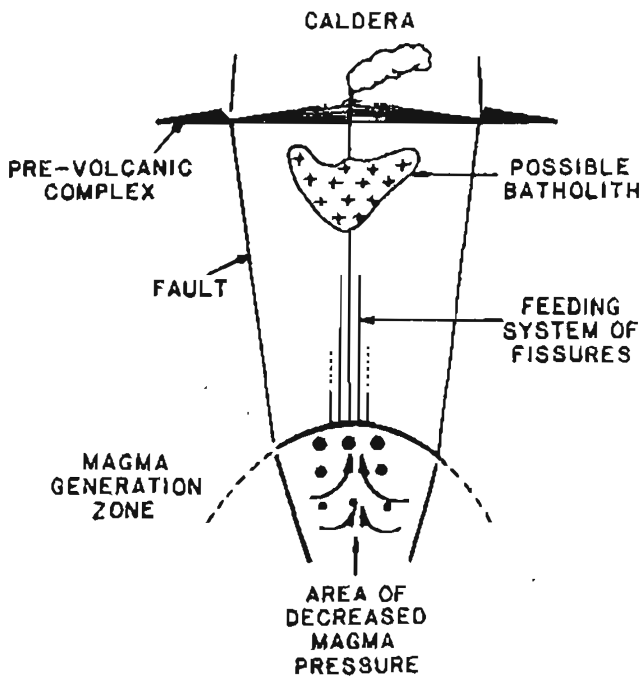


Fig. 108. SCHEME OF FORMATION OF CALDERAS (VOLCANO-TECTONIC DEPRESSIONS) CONNECTED WITH GREAT BASALTIC VOLCANOES (TOLBACHIK-ETNA TYPE OF STRUCTURES)

can be seen around oil wells where funnels of decreased pressure appear within oil-bearing horizons and there is even subsidence on the surface. Similar mechanism of subsidence is proposed by J. Moore (1971) for the origin of depression, which surrounds the big island of Hawaii.

B. HAWAIIAN - TYPE CALDERAS

A similar type of process--subsidence as a result of decreasing pressure inside magmatic columns--due to the pouring off of magmatic material through rift zones and is connected with basaltic volcanoes: Hawaiian-type calderas.

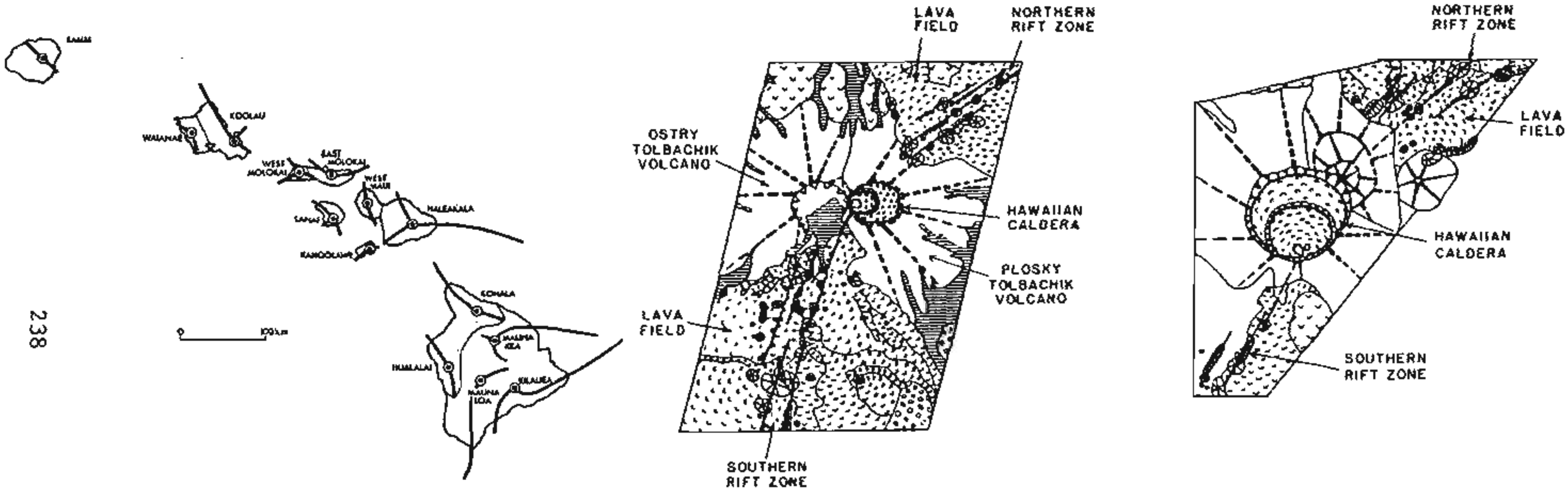
These calderas are connected with intrusion of basaltic magma, which are placed mainly on the summit of basaltic shield volcanoes. Intrusions have a form of stocks, central (ring or conic) dike swarms, combined with linear systems of fissures, reflected on the surface in the form of a rift zone. For these rift zones, constant changing of the strike after intersection with summit calderas is characteristic.

In the beginning in Kamchatka, only two such calderas were described: Plosky Tolbachik and Polsky. Afterward it was recognized that a series of calderas on basaltic volcanoes in eastern Kamchatka (Krasheninnikov, Maly Semiachik) were of the same type. On the basis of careful analysis of existing materials in Chapter III, indications are that some calderas of Sredinny Ridge also belong to the Hawaiian-type category.

In the Kuriles any description of Hawaiian-type calderas are missing. In Japan, Hawaiian-type calderas are indicated on Oshima volcano near the western shore of Hokkaido (Katsui and Satoh, 1970). S. Aramaki (1977) referred to the same type of caldera on the Oshima volcano located in the northernmost Izu Island arc. But this conclusion is based mainly on basaltic composition of the pre-caldera edifice. The type to which this caldera belongs will be discussed below.

Comparing the most impressive Kamchatka calderas of this type, calderas of Plosky Tolbachik and Plosky volcanoes, it is noted that they are very similar in structure and volcanism with normal Hawaiian calderas. They have the same characteristics of the central volcano, position and size of calderas, the same presence of linear zones of fissure volcanism to the south and north of both volcanoes connected with their calderas, the same angle on which strike of these zones changes after intersection with summit calderas (Fig. 109), and the presence of central intrusive bodies beneath calderas of this type is noted by geophysical data on Maly Semiachik caldera volcano (see Chapter III - 5.2.2.). There is also a connection between caldera subsidence and volcanic activity within linear rift zones.

At the same time it is important to note the several specific features of Hawaiian-type calderas in Kamchatka. For the first linear zone of volcanism to the south of Plosky Tolbachik and Plosky volcanoes do not form a single fissure zone but rather are represented by distributed in en-echelon small cinder cones and lava volcanoes. Further, these zones mainly lay out the limit of the edifice of the central volcano. There are no volcanoes adjacent to these linear zones of fissure volcanism which can influence their strike. This difference makes it possible to connect gnesis of the linear zones of fissure volcanism with landslides and the influence of adjacent volcanic edifices, as proposed by Fiske and Jackson (1972). Rather we have to return to an earlier point of view (Malahoff and Woolard, 1968) who spoke about the regional character of these fissure zones. It does not exclude the presence of landslides and influences of adjacent volcanoes on the strike of the linear rift zones in cases where such adjacent volcanoes really exist. But, I think,



HAWAIIAN VOLCANOES
After Fiske and Jackson, 1972

TOLBACHIK VOLCANO, KAMCHATKA
After Erlich and others, 1973

DAL'NY PLOSKY VOLCANO, KAMCHATKA
After Erlich and others, 1972

Fig. 109. CHANGING OF THE RIFT ZONE STRIKE AFTER INTERSECTION WITH SUMMIT HAWAIIAN CALDERAS

that constant changing of the strike rift zones after intersection at the summit part of the central volcanoes, is analogues to changing the direction of the beam of light in a result of refraction after passing through a different media.

Another specific feature of Hawaiian-type calderas in Kamchatka is connected with composition of volcanic rocks of the post-caldera stage of volcanism. On Kamchatka, calderas are represented either by basalts (Plosky Tolbachik caldera), or by andesites (Plosky caldera volcano), or by dacites (Uksichan and Maly Chekchebonay calderas). This is probably connected with direct differentiation of the ascending basaltic magma within the feeding conduit.

STRUCTURES CONNECTED WITH DOMING PROCESS.

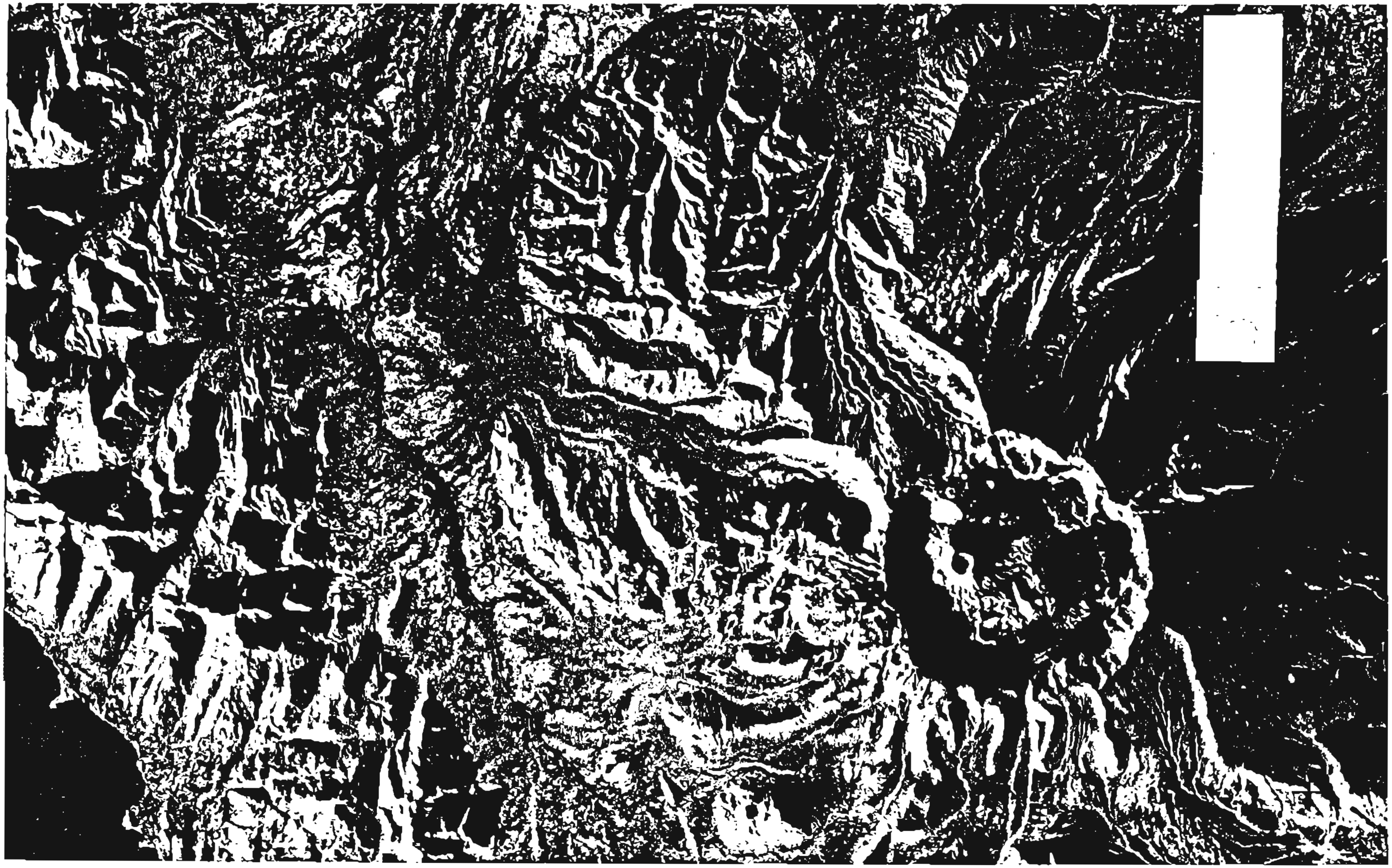
Absolutely another kind of strain appear around calderas, formation of which is connected with emplacement of magmatic bodies in the upper horizons of the crust. With such calderas, part of which is connected with silicic magmas, moment of the magma chamber emplacement is characterized by strong tendency to doming. Direct location of calderas on tectonic domes is observed in comparatively rare cases, because within volcanic belts tendency to doming is hidden by intensive accumulation of volcanic products. In Kurile-Kamchatka region classical example of such tendency is represented by Khangar volcano-tectonic depression located on the dome formed by metamorphic terranes (see Chapter III, 7.1.). Within the Eastern Kamchatka volcanic belt detailed structural analyses lead Yu. P. Masurenkov (Masurenkov, ed., 1980a) to the conclusion that doming precedes the formation of some volcano-tectonic depressions, in particular, Zhupanovsky (Karymsky) volcano-tectonic depression (see Chapter III, 5.2). Sometimes doming is not expressed in surficial structures, but geophysical data clearly indicates that domes are present beneath the calderas (Golovnin caldera, see Chapter II, 1.1.).

In Alaska a classic example of a caldera located on a tectonic (or volcano-tectonic) dome is represented by Aniakchak caldera, located on the top of a dome composed of Tertiary and Jurassic rocks and elevated at about 3000 feet (Determann and others, 1982). Figure 110 shows a landslide on the slope of the dome, generated probably in the process of emplacement of a magmatic body.

Doming process obviously preceded the formation of the Valles caldera in New Mexico (Smith and Bailey, 1968). A clear indication on the doming process is present around several Japanese calderas of the same type. Calderas Aira and Ata cut uplifted Jurassic and Cretaceous terranes (Matsumoto, 1943). Calderas in Hokkaido-Tokachi and Akan also overlap pre-volcanic complexes without any traces of pre-caldera volcanic activity in Quaternary time (Minato and others, eds., 1965). The presence of tectonic domes beneath some calderas in Japan are indicated as a result of drilling. These results under the bottom of the northern part of Aso caldera have been observed granites (Taneda, 1963, Matsumoto and Fudjita, 1960). Drilling within Hakone caldera shows that under the bottom there is a Tertiary basement (Kuno and others, 1970). Beneath Kakuto caldera in Kyushu, drill holes reach ancient volcanic terranes (Katsui, 1969).

Process of the magma chamber emplacement in the upper Crust's horizons reflect uplift of the temperature front—a kind of the metamorphic doming. So it is possible to speak not about simply tectonic, but rather tectonic/metamorphic domes beneath silicic calderas.

Fig. 11D. Airborne radar image of the Aniakchak caldera (courtesy of J. Friedman). Located on the top of the circular tectonic dome is the volcano nested inside the caldera (Determans and others, 1967). A landslide, dissected by faults, is shown on the southwest slope of the dome; and in the southeast, linear tectonic depression bounded by linear faults are shown.



A general tendency to doming is reflected in a system of fissures generated around a significant part of silicic calderas. Low quantity of xenolithic material of any kind of silicic pyroclastic products erupted during caldera-forming stage (as a rule not more than 5-10%) indicates the presence of open fissures in the host rocks, through which caldera-forming eruptions took place. Configurations of these fissures obviously indicate that they were generated due to pressure of the ascending magmatic columns. The ring of extrusive bodies located along the caldera rim of the Uzon-Geyzernaya caldera has been emplaced in the moment of a caldera-forming eruption.

The same tendency to doming process exists in the post-caldera stage of volcanism leading to resurgent doming. Resurgent doming is observed on Zavaritsky caldera and the Golovnin caldera in the Kuriles (see Chapter II, 1.1 and 2.3) a resurgent dome—Kambalny Ridge horst--is present inside the Pauzhetka volcano-tectonic depression (see Chapter III, 4.1). The tendency to resurgent doming is expessed in Uzon-Geyzernaya caldera on some post-caldera extrusive domes where xenolithic blocks of Tertiary rocks are present, calculated uplift of which reaches 1,000 m.

Absence of resurgent tectonic doming in some calderas of this type do not indicate the absence of the doming process. Simple tectonic doming on some calderas takes the form of emplacement of great masses of volcanic material going to the surface during eruptions.

In general the close connection of calderas with the doming process retains in modified form, the old ideas about calderas as a reflection of uplifted craters, developed by L. Buch (1809).

Existing ideas about the gnesis of the different types of silicic calderas are based mainly on their connection with strong eruption of the considerable amount of pyroclastic material during the caldera-forming eruption. It is suggested that calderas were formed as the result of collapse of the roof inside cavity in the upper part of the magma chamber. So, by this idea the moment of caldera formation reflect the final stage of the magma chamber existence.

A series of facts connected with such calderas indicate that intrusion of silicate melt, emplaced during a caldera-forming eruption beneath the caldera, continues to exist during all subsequent stages of the calderas existence. So calderas reflect the existence of magma chambers beneath the volcanoes and consequently, the origin of such types of calderas reflect not the moment of magma-chamber drainage, but rather the first moment of its generation. Such facts are:

1. As it has been noted previously, these calderas overlap basement different in age and nature and have no connection with pre-caldera volcanic activity.
2. Calderas of this type are, as a rule, bounded by normal faults and all data indicates not on sudden collapse, but rather on continuous subsidence.
3. Inside calderas of this "broken plate type of structure", an irregular pattern of fissures are absent, but on the other hand, a very regular system of arcuate or ring lines of post-caldera domes exists.
4. Volcanic activity within calderas of this type are not finished at the moment of the caldera formation, but rather continues to exist and is characterized by a long life span.
5. Geophysical data directly indicates that shallow magma chambers exist beneath these calderas.
6. Petrological changings timed to the moment of the caldera formation-sudden increase of phenocrysts content, changing of the role of volatiles,

presence of a large amount of blasts, pyroclastic flows and other forms of sudden volatiles release, and the development of volcanism in the form of short reverse (antidrome) cycles.

The type of caldera connected with the emplacement process by magmatic bodies in the Crust and their existence depends on three factors:

(1) the depth of intrusive body emplacement;

(2) composition and specific properties of the silicate part of the melt;

(3) specific features of volatiles behavior during a caldera-forming eruption. It is possible to come close to the reconstruction of all three genetical features through composition of volcanic rocks of caldera-forming and post-caldera stage, particular features of caldera-forming eruptions, caldera size and morphology, and the distribution of fissures around the calderas.

Calderas of the group under consideration are connected mainly with silicic magmas. By specific features of their structure and the mode of the caldera-forming eruption they can be divided in several types:

I. Ring complexes of domes without (or with very small) displacement on the boundaries (Bolshe-Banny - Haroharo type of strucutres).

II. Calderas surrounded by great fields of silicic pyroclastics. Among them by the mode of caldera-forming eruption and composition of vesiculated magma can be divided:
   1. Calderas related to ignimbrite eruptions (Uzon--Long Valley type);
   2. Calderas related to pumice airfalls:
      a. Calderas asociated with vesiculation of silicic melts (Mashu Karymsky or Crater--Lake type);
      b. Calderas asociated with vesiculation of basaltic magma (Ksudach - Oshima type);

III. Calderas related to poorly vesiculated magma (Khangar--Hakone type);

IV. Calderas related to lateral blasts (Avacha--type);

I. RING COMPLEXES OF EXTRUSIVE DOMES WITHOUT (OR WITH SMALL) DISPLACEMENT ON THE BOUNDARIES (HAROHARO-BOLSHE-BANNY TYPE OF STRUCTURES).

The absence of subsidence along boundaries of structures of this type can be connected with the depth of the emplaced silicic intrusion, high viscosity and poorness of volatiles in its magmatic matter. A combination of these factors also is possible.

Among calderas connected with silicic magmas it is possible to divide the first ring volcano-tectonic structures without any subsidence (or with very small amounts) along the faults of their boundaries. The Bolshe-Banny volcano-tectonic structure (see Chapter III, 4.7.), the ring complexes of silicic extrusive domes in the upper part of Paratunka River Valley, and Baby Kamen and Barkhatnaya sopka ring complexes are examples of this type of structure (see Luchitsky, ed., 1974, p. 156-162 and Fig. 40). In North Island, New Zealand examples are: Haroharo and Mokai (Healy, 1964) and in Japan the Kudju ring complex on Kyushu. In all cases, along boundaries of these structures are complexes of rhyolitic and dacitic extrusive domes, combined with a lesser amount of basaltic cinder cones, which are distributed as rings around the centers where the largest extrusive domes are concentrated (Maroa center in Mokai ring structure, Okaitana center in Haroharo structure, New Zealand, Bolshe-Banny center inside Karymshinsky volcano-tectonic structure, Kamchatka). In the early stages, ignimbrites are connected with the center formation of pumice covers.

On the basis of Chapter V, it is suggested that the bimodal character of volcanic rock distribution characteristic for these structures reflect the process of the Crust transformation during the growth of a tectonic /metamorphic domes. The scheme of formation of this type of structures is shown on the Fig. 111 (Fig. 111).

II. CALDERAS SURROUNDED BY FIELDS OF SILICIC PYROCLASTICS.

This is probably the most widespread type of calderas. Existing classifications join within this group all kinds of calderas associated with ignimbrites and pumices covers. Japanese authors (Katsui, 1969; Aramaki, 1977) divided inside this group calderas of the Haruna type. But they described this type of structure mainly as small calderas of the Crater Lake type associated with only 3-10 km^3 of erupted pyroclastic material. Such purely quantitive distinction is probably insufficient to consider them as a specific class of structures. As it was mentioned above as the basis for classification of this group of calderas author use combination of two groups of genetic features: the mode of the caldera-forming eruption and the type (composition) of the vesiculated magma. Using these features it is possible to divide:

1. ignimbrite-related and
2. airfall-related calderas.

Of course,speaking about the type of eruption (airfall or ash-flows) we consider only prvailing type of deposits. With all ignimbrite-related calderas are connected inconsiderable amount of airfall deposits and with some airfall-related calderas are inconsiderable amount of ignimbrite or ash flows. Nevertheless this statistical difference create basis for dividing of this large group of structures in two subgroups. Silicic pyroclastics which surround all these calderas in the most cases is connected with silicic magma, but as we saw in some cases silicic (dacitic mainly) pyroclastics form only the upper part of the ascending column of basaltic magma. For all calderas of this group is characteristic complete absence of any type of blast deposits without any difference are these calderas located on the summit of a single volcanic edifice or cut groups of volcanoes or even non-volcanic terranes.

1. Calderas related to ignimbrite eruptions (Uzon-Long Valley type).

The most impressive and largest in size calderas of this group are associated with great fields of ignimbrites.

Examples of this type are the calderas of Japan, Kamchatka and Alaska: Aso, Aira, Ata in Kyushu; Tokachi, Akan in Hokkaido; Katmai in Alaska; Pauzhetka, Opala, Gorely in southern Kamchatka; Uzon-Geyzernaya, Polovinka, Stena-Soboliny in eastern Kamchatka.

These calderas are characterized by size (8-12 km in average and up to 25 km in diameter), most of these calderas overlap not a single but rather a series of volcanic edifices and sometimes cut pre-Quaternary geological formations which are different in age and nature. Practically all calderas of this type are characterized by intensive negative gravity anomalies. All are surrounded by clearly expressed faults with considerable amplitude of subsidence.

It is characteristic, that despite the degree of study of certain structures around these calderas, there are no types of blast deposits and quantity of xenolithic material in products of the main caldera-forming eruption does not exceed a 5-15 voluminous percent. So in combination with character of the fissures formed at this stage of their formation, there

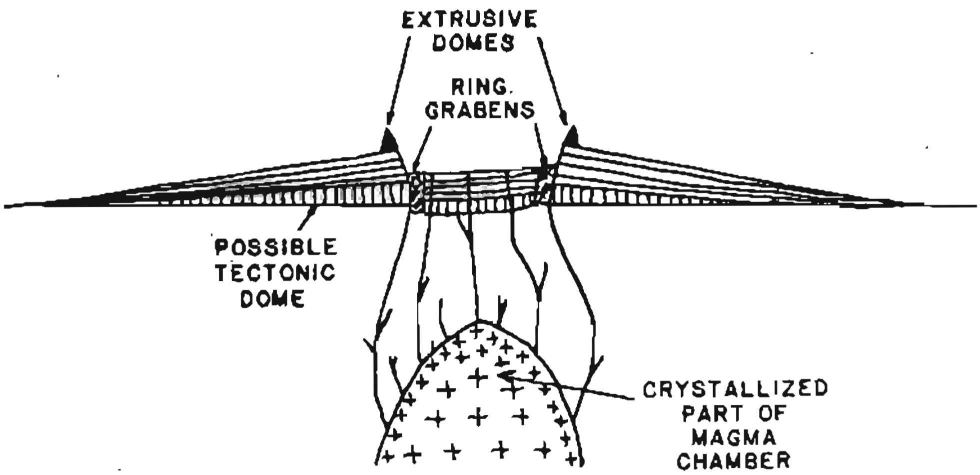


Fig.111. SCHEME OF FORMATION OF RING COMPLEXES OF EXTRUSIVE DOMES WITHOUT (OR WITH SMALL) DISPLACEMENT ON THE BOUNDARIES (BOLSHE-BANNY-HARCHARO TYPE OF STRUCTURES)

exists a direct indication that on the first stage of a caldera-forming eruption, magmatic material comes to the surface through open fissures, which have been cleaned by jets of juvenile volatiles.

The main process of caldera-forming eruptions on these calderas are flows of ignimbrite-forming magmatic matter, which lead to the formation of great ignimbrite covers. Mode of movements forming this matter is very similar to lavas, moreover with very liquid flood-basaltic lavas. It is not unusual that different authors in different regions apply these rocks term "lava" in different form: "aso lavas" in Kyushu (Matsumoto, 1943), "tuff lavas" in Kamchatka (Vlodavets, 1953, 1957), "foam-lavas" in Italy (Locardi and Mittempergher, 1967), froth-flows in Yellowstone region and Kenya (Boyd, 1961, McCall, 1964). A similar mechanism of eruption has been proposed for such rocks on Katmai, Alaska (Bordet and others, 1963).

Quantity of normal unwelded pumice material, connected with ignimbrites is subordinate. So vesiculation is characteristic but does not embrace the whole volume of ignimbritic magma. For ignimbrites it is the characteristic presence of silicate material in two forms - compact viscous fiammes and highly vesiculated groundmass. It is possible that the origin of fiamme is connected not (or at least not only) with welding, but rather with immiscibility of two types of silicic melts very similar in composition of silicate part but different in volatiles content and ability to vesiculation. If this mode of origin really has place, at least the volume connected with future compact fiammes has not been vesiculated.

Along the rim of such calderas are often located rings of extrusive domes, composed by silicic rocks. Supposedly these domes were emplaced at the end of caldera-forming eruption along fissures through which on the first stage of eruption ignimbritic material erupted.

As described above, within this type of structure on the first stage of caldera-forming process, a tectonic/metamorphic dome was formed. The last stage of dome-forming process is characterized by an eruption of great amount of ignimbrites followed by subsidence. So uplift of silicate melt in this case is the part of the doming process. And it is possible to say, that the pressure of silicate melt of an ascending magmatic column is the leading caldera-forming force.

The most widely studied (but not the largest) calderas of this type are Uzon-Geyzernaya caldera in Kamchatka and Long Valley caldera in the Western USA. Geodynamic model of formation of such calderas worked out for certain Uzon-Geyzernaya volcano-tectonic depression is described below.

Dynamic model of formation of the Uzon-Geyzernaya volcano-tectonic depression.

A model for formation of the Uzon-Geyzernaya volcano-tectonic depression must be done in two stages of development (see Chapter III, 5.4.). During the first stage, volcanic centers of different composition existed along northwest-trending fissures on either side of the east-west fault zone. This indicates different conditions on different sides of the fault. Basaltic magma on the north erupted to form a shield volcano while a silicic magma chamber formed on the south. In the second stage, the caldera-formation stage, was marked by sudden and large-magnitude changes in the dynamic conditions on both sides of the fault. The main caldera-forming stage was accompanied by outbursts of silicic pyroclastics (Figs. 112 A and B). The two separate fields of ignimbrites suggested a lateral character to the eruptions, as there was only limited topographic control on ignimbrite distributrion. During this stage, most of the eruptive activity was focused in the Uzon

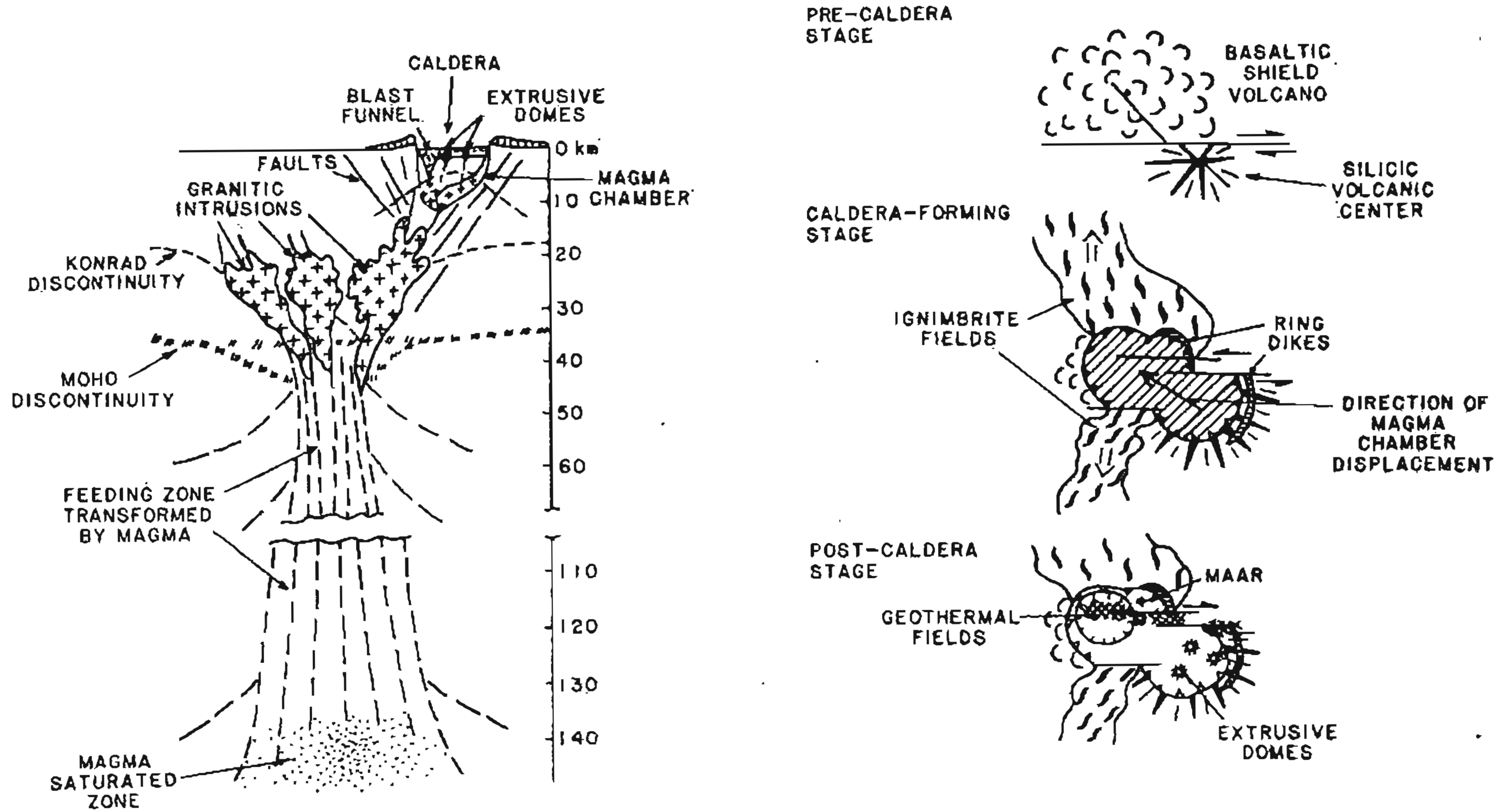


Fig. 112. GEODYNAMIC SCHEME OF FORMATION OF UZON-GEYZERNAYA CALDERA, KAMCHATKA

After Naboko, 1974

caldera, which lay in the area of basaltic eruptions during the first stage. This marked the formation of the volcano-tectonic depression and the development of the centers of post-caldera silicic eruptions on both sides of the east-west fault. The orientation of the axes of elongation of both calderas (N50°W) coincides with the direction of shear-fracture zones that branched off the main fault. This leads to a hypothesis of lateral migration of the silicic magma chamber along the east-west fault during the caldera-forming eruptions. In this case the silicic pyroclastic eruptions were probably caused by displacements of the magma chamber under the influence of tectonic movement along the east-west zone.

These events during both the pre-caldera and caldera-forming stages also explain the difference in the character of the post-caldera activity in both calderas. In the Geyzernaya caldera, which laid over the main magma chamber, the post-caldera activity was dominated by the extrusion of many silicic domes. These domes filled the caldera to the height of the pre-caldera complex. In the Uzon caldera, the post-caldera activity consisted of large explosions. Some were caused by a silicic magma that formed the explosion-funnel. Others were caused by basaltic magma and formed the maar of Dal'nyeye Lake. Thus, following the caldera formation there may have been two different magmas in the Uzon caldera and another one in the Geyzernaya caldera.

In this model, the formation of the magmas that led to the formation of the volcano-tectonic depression is viewed as follows (Fig. 112 B). Uneven raising of isotherms led to the formation of thermal domes in the root-zone of the volcano-tectonic depression. The process of dome formation was accompanied by the opening of fracture systems above the dome and intrusion of the fractures by magma. The rise of the magma led to the foundering of the roof and to large pyroclastic eruptions. The unerupted portions of the melt then formed shallow crustal magma chambers. Progressive crystallization of these magma chambers provided some space in the upper part of the magma chamber for steady subsidence of the roof.

The formation of the hydrothermal system is related to the post-caldera stage of volcanism. Hot springs are localized along the main east-west fault zone. Most hot springs are connected with fissures that branch off this fault zone. Large ring faults, in particular the ring fault in the Geyzernaya Valley, drain hot water from the main east-west fault zone and cause lateral migration of the hot water to the Geyzernaya Valley.

2. Pumice airfall related calderas (Karymsky-Mashu or Crater Lake type of structures).

The classification of silicic calderas surrounded with covers of silicic pyroclastic material is uncertain. Japanese authors (Katsui, 1969, Aramaki, 1977) divided inside this group calderas of Haruna type. But they described this type of structure mainly as small calderas of the Crater Lake type, associated with 3-10 km^3 of erupted pyroclastic material. Such purely quantitive distinction is probably insufficient to consider them as a specific class of structure. But if one carefully put into consideration all specific features of different silicic calderas it will would become possible to divide among them a specific type formed mainly as a result of vesiculation in the upper part of the ascending magmatic column. In contrast with ignimbrite related calderas, calderas of this type are located on the volcanic edifice of the pre-caldera stage of volcanism. Calderas of this type are comparatively small in size (2-6 km in average) and are often nested inside ignimbrite related calderas of the previous stage of caldera-forming process. Such are caldera of the Karymsky volcano inside Zhupanovsky volcano-tectonic depression, caldera Akademii Nauk (Karymsky Lake) inside Polovinka caldera within the same Zhupanovsky volcano-tectonic depression (see Chapter III, 5.2.), Mashu caldera within Kutcharo caldera in Hokkaido.

These calderas are often characterized by the presence of shallow funnel-like structures, filled by pyroclastic material. On some calderas of this type as in Japan, the ring fault around the caldera boundary is absent (Aramaki, 1977). Caldera-forming eruptions on these calderas is represented by pumice air fall, rarely associated with subordinate amount of pumice flows (Katsui, 1963; Ivanov, 1970). Although a series of such calderas are well studied there is no indication of blast deposits associated with them. Real ignimbrites with fiamme are absent around these calderas, even in the Crater Lake caldera only a thin sheet is present (Bacon, 1976). The quantity of xenolithic material of a pre-caldera edifice or material of volcano basement is very low or nonexistent. Around calderas of this type any regular ring or arcuate fissures filled by magmatic material is absent. So caldera-forming eruptions probably took place from the central vent.

As seen on the Karmysky volcano, beneath the caldera are shallow magma chambers, but in the caldera-forming stage vesiculation started before the ascending magmatic column reached the surface. Haruna-type calderas divided by Japanese volcanologists form a part of Karymsky-Mashu type of calderas. As mentioned above, the size of the caldera cannot be the main reason to define these structures as a special type.

The main features of the airfall - related calderas indicate that the leading role in their formation belongs to jets of volatiles connected with the process of vesiculation. These volatiles cleaned the upper part of the feeding conduits, throwing out a lot of pumice after which subsidence of the caldera takes place. Mode of origin of these calderas is probably close to the model previously proposed by Escher (1929) and some types of calderas described by Reinolds (1956).

Really important are the differences in the compositon of the ascending magmatic column. On the basis of composition of vesiculated magma within this type of caldera, two subtypes can be divided:

2a. Calderas connected with vesiculation of originally silicic magmas (silicic andesites, dacites, rarely rhyolites).

Calderas of such subtype are represented by Mashu and Shikotsu calderas in Hokkaido (Katsui, 1963), Nemo and Tao-Rusyr calderas in Kuriles (see Chapter II, 3.3. and 3.5), summit Khangar caldera in the Sredinny Ridge volcanic zone of Kamchatka (Chapter III, 7.1), Kurile Lake caldera in south Kamchatka (Chapter III, 4.1), caldera of Karymsky volcano and Akademii Nauk (Karymsky Lake) caldera in eastern Kamchatka (Chapter III, 5.2). Also belong to the type is the Crater Lake caldera, Oregon, described by Williams (1942) and later by Bacon (1983). These calderas can be called calderas of Karymsky-Mashu type (or Crater Lake type).Model of formation of this type of calderas is shown on the Fig. 113 (Fig. 113).

2b. Calderas connected with vesiculation in the upper part of the ascending column of the basaltic magma.

As a result in the early stage of eruptions, dacitic pumice was formed (in the form of air-fall and partly-pyroclastic flows). On the next stage of the eruptions, from any place which can be considered as feeding channels, central vent, radial and concentric arcuate fissures, comes basaltic material,

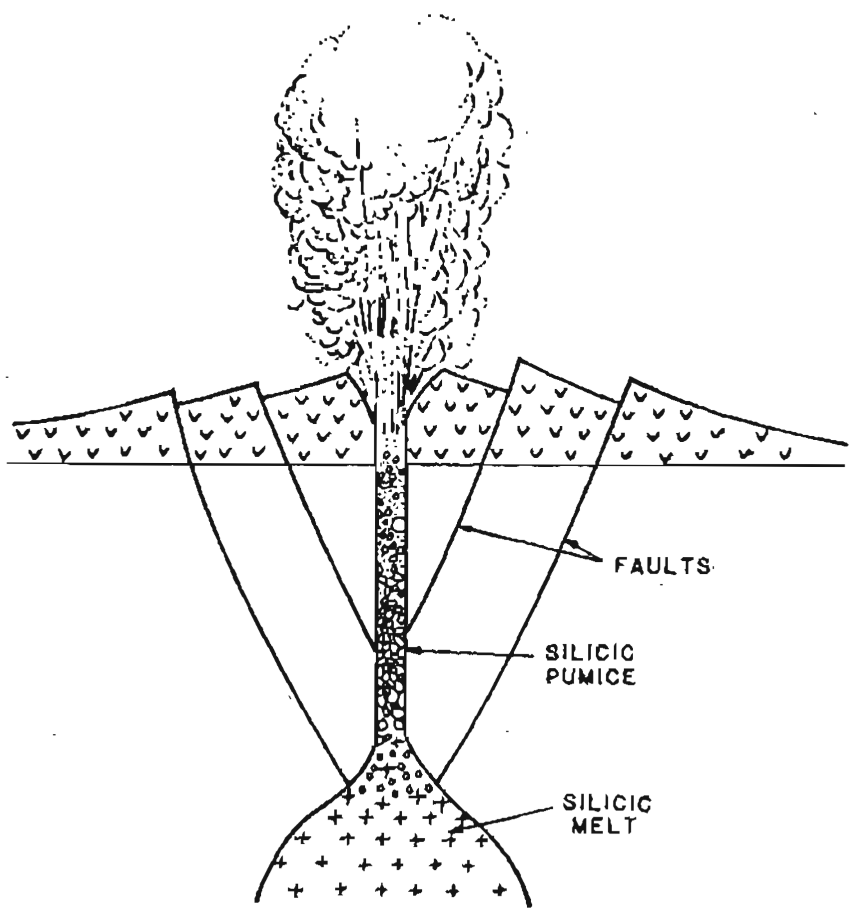


Fig. 113. SCHEME OF FORMATION OF AIRFALL-RELATED CALDERAS (KARYMSKY-MASHU TYPE)

forming a system of dikes and the central post-caldera edifice. These types of eruptions were described in Chapter V.2. In Kamchatka the calderas of this type are repressented by Ksudach caldera in southern Kamchatka and Krasheninnikov caldera in eastern Kamchatka (Chapter III, 4.3 and 5.5 accordingly). Shimodzuru (1978) described the eruption of this type on Oshima volcano, northernmost Izu Islands. So the calderas of this type can be called Ksudach-Oshima structures. On the bases of detail stratigraphic study Nakamura (1964) mark on the Oshima volcano subsidence with amplitude at least 160 m

General scheme of formation of this type of calderas is shown on the Fig. 114 (see Fig. 114).

3. Calderas related with poorly vesiculated silicic magma (Khangar-Hakone type).

If the intrusion, emplaced during the process of doming, consists of very viscous, comparatively poor volatiles and not easily vesiculated silicic magma, discharge of silicic pyroclastics during the main caldera-forming stage may be absent. In this case subsidence is gradual in character and is provided for by crystallization of the intrusion, which was emplaced at the moment of caldera origin. Examples of this type of caldera formation can be seen on Khangar volcano-tectonic depression, outer caldera within which Khangar volcano is located (see Chapter III, 7.1) and Alney-Chashakondzha volcano tectonic depression (see Chapter III, 7.10). It is possible, that to the same type belong also ancient Hakone caldera (Kuno, 1962). Suggested caldera-forming mechanism for calderas of this group are close to the ideas of Williams (1941) regarding the role of a decreasing magmatic support. General model of formation of this type of calderas is shown on the Fig. 115 (Fig. 115).

4. Lateral blasts related calderas (Avacha-type).

In cases where the magma was largely crystallized (or has little volatiles), where there is little vesiculation of juvenile material, and magma chambers are very shallow, laterally directed explosions accompanied by series of pyroclastic flows took place. The main type of displacements on the surface is represented by landslides. Subsidence sometimes does not occur as in the case of Bezimianny and Mount St. Helens, but sometimes a small caldera can be formed (see Chapter III, 5.1, Avacha volcano). Model of formation of this type of calderas is shown on the Fig. 116 (Fig. 116).

REGIONAL COMPARISONS

A regional comparison immediately shows the difference in size and type of calderas along the strike of an island arc system—between normal type island arcs and Kamchatka type geotectonic systems (see Chapter I) or across the strike, between frontal and rear volcanic belts or in cases when pairs of volcanic belts occur within a certain region.

Looking on the distribution of calderas in the Kuriles, it is important to note the absence of influence on the thickness of the Crust in the diameter and type. As mentioned in Chapter I, thickness of the Crust changes from the central Kuriles north and southward. Nevertheless, neither diameter nor type

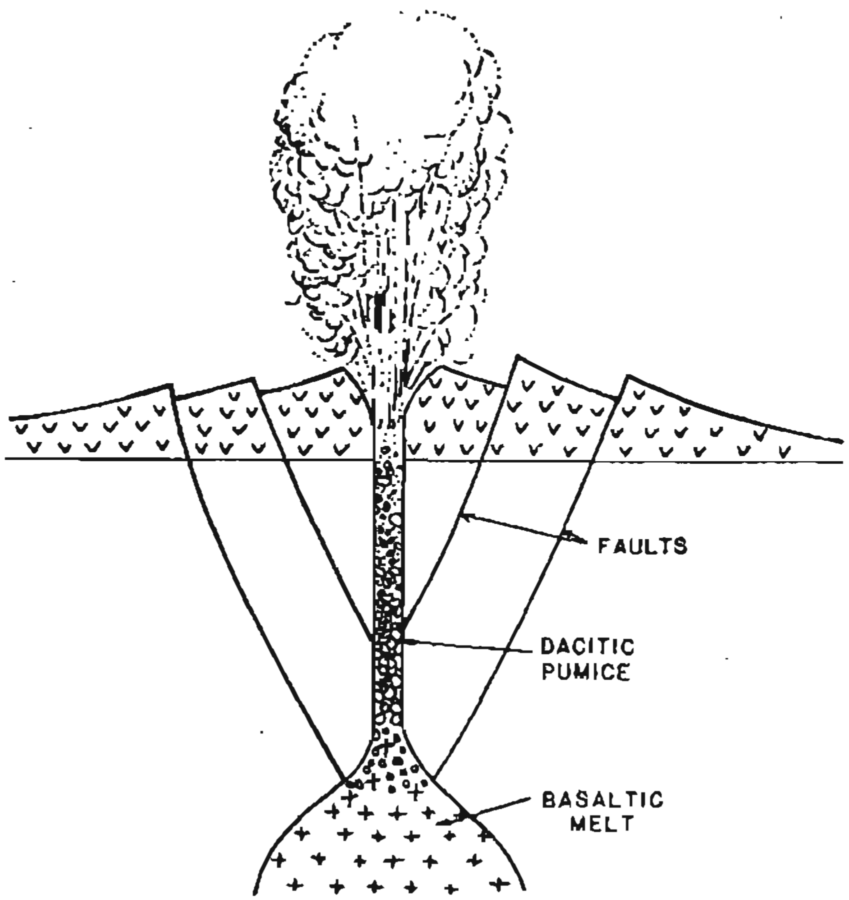


Fig. 114. SCHEME OF FORMATION OF AIRFALL-RELATED CALDERAS (KSUDACH-OSHIMA TYPE)

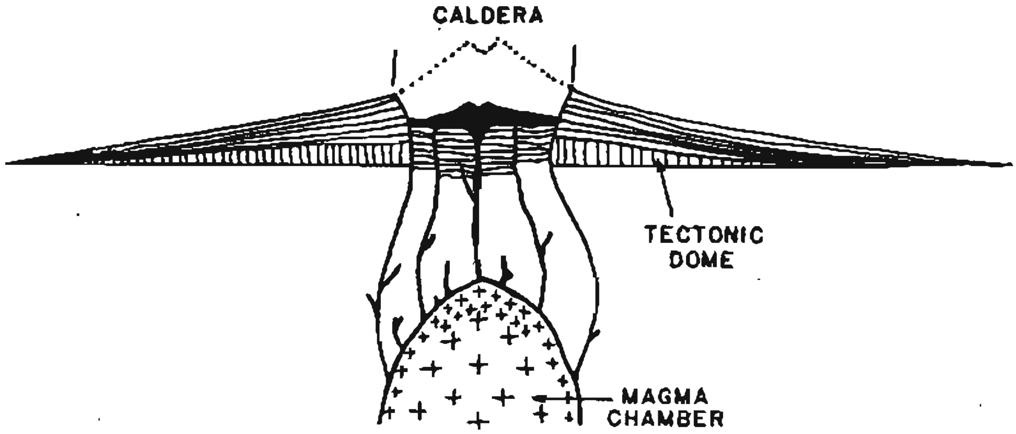


Fig. 115. SCHEME OF FORMATION OF CALDERAS RELATED WITH POORLY VESICULATED MAGMA (KHANGAR-HAKONE TYPE)

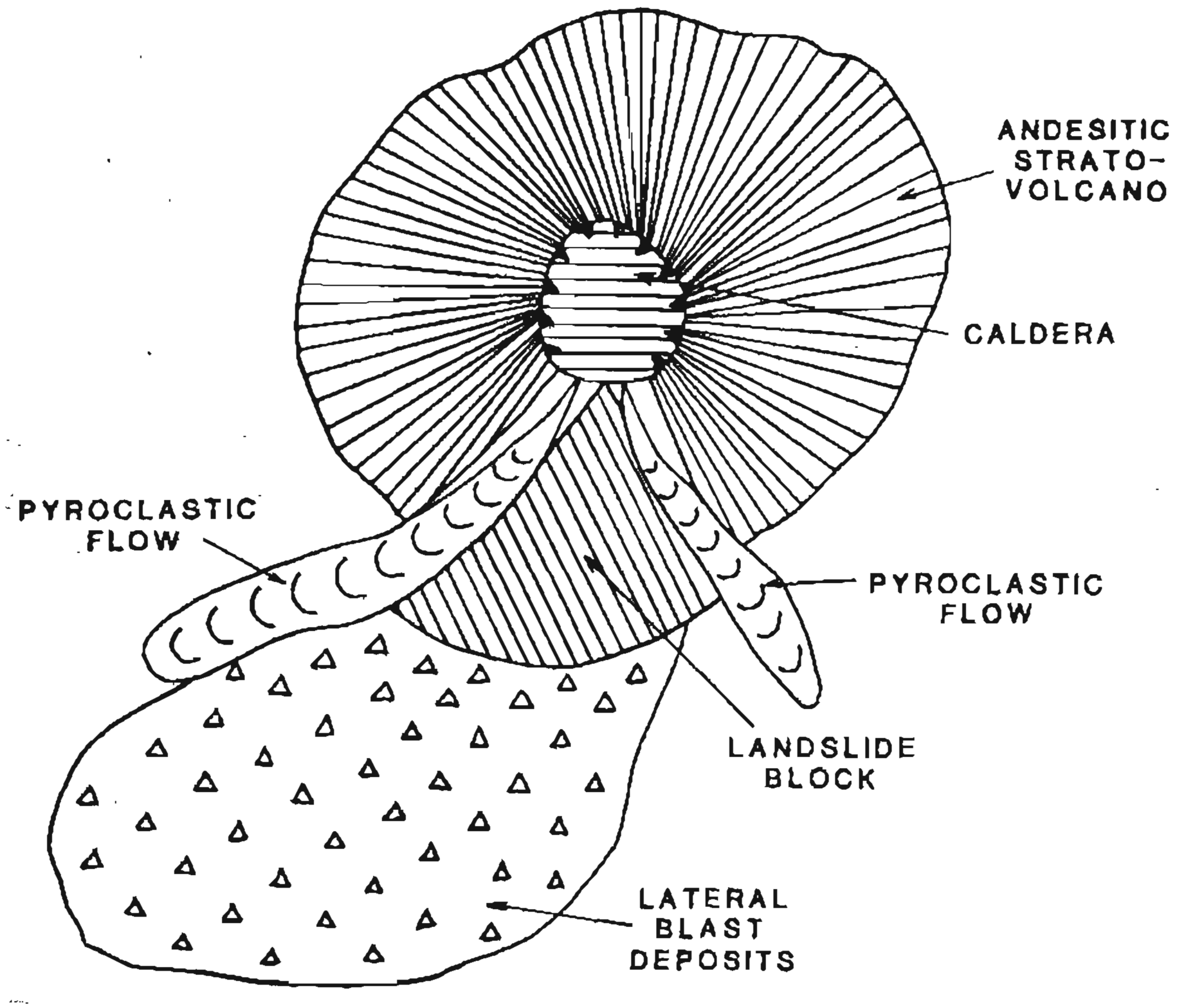


Fig. 116. SCHEME OF FORMATION OF BLASTS-RELATED CALDERAS (AVACHA TYPE)

of calderas within the central group of islands are the same as those within the southern or northern groups. The average diameter of a calderas in the Kuriles, or on normal island arcs in general, is equal to 2-4 km. In rare cases diameters reach 6-8 km. The most widespread type of calderas in the Kuriles belong to the Kayrmsky-Mashu type. Uzon-Long Valley type calderas are very rare.

Differences occur when any normal island arc enter Kamchatka-type geotectonic system. Silicic calderas appear to be much larger in the beginning. Such structures as Pauzhetka, Zhupanovsky (Karymsky), Great Semiachik, and Ichinsky volcano-tectonic depressions appear in Kamchatka. The average diameter of silicic calderas is equal to 12 km and at a maximum they reach several tens km. On the southern end of the Kuriles, where they enter Hokkaido, large silicic calderas such as, Tokachi, Kutcharo and Akan are located. When Ryukyu island arc enter Kyushu island such great calderas as Aira, Ata, Aso and Kakuto volcano-tectonic depression are located. On the intersection of Izu Island arc with central Honshu Island are located Hakone caldera and Fuji volcano-tectonic depression. Simultaneously with the changing of size, the connection between calderas and volcanoes of the pre-caldera stage of volcanism also changes. On normal island arc (see Chapter I) calderas, are in 80 percent of the cases, located on the summit of a pre-caldera edifice. On Kamchatka-type geotectonic systems they overlap basement different in age and nature and the location of a silicic caldera on the top of pre-caldera volcanic edifices is coincidental.

The appearance of a large amount of Quaternary basalts on Kamchatka-type geotectonic systems results in the appearance of two types of volcano-tectonic structures connected with basaltic volcanism.

The first is volcano-tectonic depressions such as, Tolbachik, Fuji, Ichinsky, Veniaminoff which are absent on normal island arcs. As previously mentioned, in the Kuriles uncertain indications on the presence of such type of structures exists only on Tiatia and Atsonupuri volcanoes. The second is the presence on a Kamchatka-type geotectonic systems of Hawaiian-type calderas. Holocene calderas of this type are absent in the Kuriles and, as author knows, on any other normal island arcs. At best, it is possible to find only uncertain indications that some volcanoes in their early stages of development pass through Hawaiian-type shields, for example, Medvezhiya caldera (Ostapenko, 1969)

As it has been mentioned above all these differences in size and type of calderas within Kamchatka-type geotectonic systems in comparison with normal island arcs are not conected with changing of the Earth Crust thickness, but rather with changing of geodynamic conditions.

In the Kamchatka-type geotectonic systems the difference between frontal and rear volcanic belts was mentioned in Chapter I.

The most part of silicic calderas are located in the frontal volcanic belts (Southern Kamchatka graben-syncline) or, if there exist a pair of volcanic belts, within the frontal volcanic belt (Eastern Kamchatka graben-syncline, Central Kamchatka Depression in Kamchatka, Nasu zone in northeastern Japan). Within the same structures are located the most part of volcanoes with which are associated lateral blasts (Avacha, Bezimianny, Sheveluch in Kamchatka, Bandai and Asama in Northeastern Japan).

Quaternary silicic calderas in the rear parts of single volcanic belts (Southern Kamchatka), or, if there exist a pair of volcanic belts,within the rear volcanic belts (Sredinny Ridge volcanic zone) are connected mainly with poorly vesiculated magma (Khangar-Hakone type). It is not occasional that here are absent great fields of silicic pyroclastics around such calderas as

Khangar (outer caldera), Uksichan, Bol'shoy and Maly Chekchebonay, Perevalovy, Tigilsky, Alney-Chashokondzha. At the same time inside all these calderas are located large centers of silicic volcanism--composed by silicic volcanic rocks stratovolcanoes, large extrusive domes or groups of domes. So the nature of these calderas is very uncertain. In literature they are described as normal Krakatoan type calderas (Ogorodov et. al., 1963) despite absence of any traces of silicic pyroclastic material around them. However all structural features of these structures resemble those of Hawaiian-type calderas. Probably it reflects the specific characteristic of silicic magmas in these volcanic zones such as their impoverishment in volatiles and the low ability for vesiculation. In the result among located here silicic calderas there prevail calderas related to poorly vesiculated magma (Khangar-Hakone type).

As a result of the changing of geodynamic conditions during volcanic evolution, different types of calderas replace each other in time.

It is important to note, that the specific features of the rear volcanic belt appear in the Sredinny Ridge volcanic zone only on the Quaternary stages of the development. In Neogene time normal silicic calderas associated with great amount of ignimbrites and pumice were formed within the same zone (Vlasov, 1964). The same it is posible to note about changing of different types of calderas within the frontal volcanic belt of the Eastern Kamchatka. In general great volcano-tectonic depressions of Tolbachik-Etna type--Tolbachik, outer system of faults on the Zhupanovsky (Karymsky), Ichinsky, Great Semiachik volcano-tectonic depressions, great Hawaiian-type calderas on volcanoes Uksichan, Bol'shoy and Maly Chekchebonay, Kekuknaisky in the Sredinny Ridge volcanic zone, outer caldera of the Plosky volcano in the Central Kamchatka Depression are associated with the final stages of the first cycle of basaltic volcanism, started in the Lower Pleistocene and continued up to the end of the Middle Pleistocene (see Chapter IV). This reflects general tendency to extension and subsidence in the begining of the volcanic cycle.

Inside these volcano-tectonic depressions in the end of the Middle Pleistocene are developed silicic calderas and centers of silicic volcanism (calderas Polovinka, Stena-Soboliny inside Zhupanovsky volcano-tectonic depression, Ichinsky center of silicic volcanism within volcano-tectonic depression of the same name and so on). On this stage of silicic volcanism on the background of general subsidence in the central parts of volcano-tectonic depressions formed in the end of the stage of basaltic volcanism there appear general tendency to doming process--a kind of inversion of the structure which can be compared with formation of a resurgent dome on the post-caldera stage of development within some silicic calderas.

If formation of volcano-tectonic depressions connected with basaltic volcanoes reflects decreasing pressure in magma-generation zone around roots of volcano (an analogy with bore-hole, in an oil-bearing horizon), on the next stage of development reserves of liquid silicic melt which are able to come to the surface are exhausted and feeding zone become saturated with volatiles from the remote parts of magma basin. Oversaturation of magma with volatiles and increasing volatile pressure in it lead to emplacement of intrusions in the Upper Crust horizons and formation of calderas related with silicic pyroclastics (ignimbrite- and airfall-related calderas).

If one consider proposed model of silicic calderas formation as a reflection of emplacement of granitic intrusions, its coincidence with intensification of the mountain-building process it will become quite understandable, because the caldera-forming process reflects the changes (in this case uplift) of the average level of the magma chambers. So it reflects a stage of emplacement of granitic intrusions--an event which usually coincides with the mountain-building impulses.

As it has been shown in the Chapter IV, development of Quaternary volcanism goes in the form of two consequent cycles of basaltic volcanism. Development of the second, young cycle of basaltic volcanism in the end of the Upper Pleistocene-Holocene time lead to formation of series of large basaltic volcanoes with summit Hawaiian-type calderas. Sometimes these volcanoes are nested inside large silicic calderas formed during the main stage of silicic volcanism in the end of the Middle Pleistocene time: Hawaiian calderas on the Krasheninnikov and Maly Semiachik volcanoes, nested inside silicic calderas with the same names (see Chapter III). In the Holocene time there follow a new, comparatively short phase of silicic volcanism with which are connected series of young silicic calderas (mainly of the Karymsky-Mashu or Ksudach-Oshima types): calderas of Kartymsaky volcano, Avacha, summit caldera on the Khangar volcano, Kurile Lake and Ksudach calderas and so on.

Characteristic features of the Upper Pleistocene-Holocene silicic calderas is that practically all of them belong to Karymsky-Mashu type accompanied with pumice (not ignimbrite) covers.

Repeated cycles of basaltic and silicic volcanism, regular changing in time of different types of calderas, continuing existence in the Crust's upper horizons of silicic magma chambers formed on the previous stages of silicic volcanism in time when it starts new cycle of basaltic volcanic activity, create observed very complicated combination of different types of simultaneously active volcanoes.

REFERENCES

Aprelkov, S. E., 1966, Geology of the Late Neogene and Quaternary volcanoes of Ivulk ridge in Kamchatka: Vulkanicheskiye i volkano-plutonicheskiye formatsii. Trudy II Vesesoyuzn. Vulkanol. Sovsch., Moscow, Nauka, p. 56-71. (R)

Aramaki, S., 1977, Pyroclastic flows and calderas in Japan: In Vulkanism Ostrovnikh Dug, Moscow, Nauka, p. 164-172. (R)

Aramaki, S., and others, 1982, Field excursion guide to Sakuradjima, Kirishima and Aso volcanoes: Volcanol. Soc. Japan, 45 p.

Averianova, V. N., 1968, Detal'naya characteristica seismicheskikh ochagov Dal'nego Vostoka: Moscow, Nauk, 192 p. (R)

Bacon, Ch., R., 1983, Eruptive history of Mt. Mazama and Crater Lake caldera, Cascade Range, USA: Journ. Volcanol. and Geotherm. Res., v. 18, p. 57-115.

Bakumenko, I. T., Shugurova, N. A., Erlich, E. N., and Popova, N. M., 1970, Genesis of quartz from pumices of Khangar volcano: Doklady, Ac. Sci. USSR, 191-3, p. 660-663. (R)

Barberi, F., 1978, The Campanian ignimbrite: a major prehistoric eruption in the Neapolitan area (Italy): Bull. Volcanol., v 41, no. 1, p. 10-31.

Barth, T. F. W., 1952, Theoretical Petrology, New York, Wiley, 387 p.

Bemmelen, R. W. van, 1949, The geology of Indonesia: The Hague, v. 1, 506 p.

Blank, H. R., 1965, Ash-flow deposits of the Central King County, New Zealand: N. Z. Journ. Geol. & Geoph., v. 8, no. 4, p. 588-607.

Bordet, P., Marinelli, G., Mittempegher, M., and Tazieff, H., 1963, Contribution a la étude volcanologique du Katmai et de la Valee des dix mille fumees (Alaska): Mem. Soc. Belge de geologie, ser. v. 8, no. 7

Boyd, F. R., 1961, Welded tuffs in the rhyolite plateau of Yellowstone Park, Wyoming: Geol. Soc. Amer. Bull., 72,387-426 p.

Braitseva, O. A., Melekestsev, I. V., Evteeva, I. S., Lupikina, E. G., 1968, Stratigraphy of Quaternary deposits and glaciations in Kamchatka: Moscow, Nauka, 227 p.

Carta Geologica D'Italia, Scale 1:500,000 foglio 5, Servizio Geologico D'Italia, 1976.

Cherdintsev, V. V., Alexeev, V. A., Kind, N. V., Popova, V. S., Sulerzhitsky, L. S., 1964, Radiocarbon dates of the laboratory of Geological Institute Ac. of Sci., USSR, Geochimiya, no. 4, p. 315-324. (R)

Cowie, J. D., 1964, Aokautera ash in the Manawatu district, New Zealand: N. Z. Journ. Geol. & Geoph., v.7, no. 2, p. 67-77.

Detterman, R. L., Miller, T. P., Yount, M. E. and Wilson, F. H., 1981, Geologic map of Chignik and Sutwik Island quadrangles, Alaska: Published by USGS.

Detterman, R. L., Yount, M. E., Miller, R. P., and others, 1982, Generalized geological map, Ugasshik, Bristol Bay and part of Karluk Quads, Alaska: Published by USGS.

Erlich, E. N., 1960, On the evaluation of Quaternary volcanism in the Sredinny Ridge volcanic zone of Kamchatka, Izvestiya Ac. Sci. USSR, ser. geol., no. 2, p. 65-76. (R)

Erlich, E. N., 1966, New data about volcano-tectonic structures of Kamchatka and problems of the development of Quaternary volcanism: Geotectonica, no. 6, p. 48-63.

Erlich, E. N., ed., 1966a, Petrokhimiya Kainozoiskoy Kurilo-Kamchatskoy vulkanicheskoy provintsii: Moscow, Nauka, 279 p. (R)

Erlich, E. N., 1973, Sovremennaya strukiura i chetvertichnyi vulkanism zapadnoy chasty Tikhookeanskogo Koltsa: Novosibirsk, Nauka, 243 p. (R)
Erlich, E. N., and Gorshkov, G. S., eds., 1979, Quaternary volcanism and tectonics in Kamchatka: Bull. Vulcanol., v. 42, no. 1-4, 298 p.
Erlich, E. N., and Melekestsev, I. V., 1972, Quaternary acid volcanism of Kanchatka: Modern Geology, v. 3, p. 183-193. (R)
Erlich, E. N., Melekestsev, I. V., Tarakanovsky, A. A., and Zubin, M. I., 1973, Quaternary calderas in Kamchatka: Bull. Volcanol., v. XXXVI, p. 222-237.
Ermakov, V. A., Egorova, I. A., Alypova, O. M., 1968, New data about composition and age of the Alney suite in south-east Kamchatka: Doklady Ac. Sci., USSR, t. 183, no. 2, p. 408-411. (R)
Escher, B. G., 1929, On the formation of calderas: "Leids. Geol. meded,": B. II, p. 571-589.
Ewart, A., 1964, The Taupo-Quaternary pumice sequence and its bearing on the prediction of future ash eruptions: N. Z. Journ. Geol. & Geoph., v. 7, no. 1, p. 101-105.
Fedotov, S. A., 1966, Deep structure, properties of the Upper Mantle and volcanic activity in Kurile-Kamchatka arc by seismological data for 1964: In Vulkanism i glubinnoye stroyeniye Zemli, Moscow, Nauka, p. 8-29. (R)
Fedotov, S. A., ed., 1984, Large Tolbachik Fissure Eruption. Kamchatka 1975-76: Mocow, Nauka, 637 p. (R)
Firsov, L. V., 1964, Absolute age of intrusive rocks of Kunashir and Urup Islands (Kurile Islands): Doklady Ac. Sci. USSR, t. 156, no. 4, p. 891-892. (R)
Fiske, R. S., and Jackson, E. D., 1972, Orientation and growth of Hawaiian volcanic rifts: the effect of regional structure and gravitational stresses: Royal Soc. London Proc., v. 329, p. 299-326.
Geological map of Japan, scale 1:500,000, sheet 8, Tokyo Quadr., Geol. Survey of Japan, 1966.
Geological map of Japan, scale 1:1,000,000, Geol. Survey of Japan, 1978.
Goff, F. E., 1977, Vesicle cylinders in vapor-differentiated basalt flow. Dissertation submitted for the degree of Doctor of Philosophy: University of California, Santa Cruz.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle: Plenum Press, New York, London, 385 p.
Gorshkov, G. S. and Bogoyavlenskya, G. E., 1965, Bezimianny volcano and specific features of its last eruption, 1955-63: Moscow, Nauka, 166 p. (R)
Grant-Taylor, T. L., 1964, Volcanic history of Western Taranaki: N. Z. Journ. Geol. & Geoph., v. 7, no. 1, p. 78-86.
Grant-Taylor, T. L., Rafter, R. A., 1962, New Zealand radiocarbon age measurements: N. Z. Journ. Geol. & Geoph., v. 5, no. 2, p. 331-359.
Grindley, G. W., Harrington, H. J., and Wood, B. L., 1959, The Geological map of New Zealand, 1:2,000,000: New Zealand Geol. Surv. Bull., 6-6, 111 p.
Hattori, H., 1968, Late Mezoic to recent tectonogenesis and its bearing on metamorphism in New Zealand and in Japan: Geol. Survey of Japan, Rept. 229, 45 p.
Healy, J., Vuchetich, C. G., Pullar, W. A., 1964, Stratigraphy and chronology of late Quaternary volcanic ash in Taupo, Rotorua and Gisborne districts: Bull. New Zealand Geol. Surv., no. 73, p. 85.
Heiken, G., 1976, Depressions surrounding volcanic fields: A reflection of underlying batholiths: Geology, v. 4,. no. 3, p. 568-572.

Ishikawa, T., Katsui, Y., Oba, Y., Satoh, H., 1969, Some problems of the calderas in Hokkaido: Bull. Volc. Soc., Japan, v. 14, sec. ser., no. 2, p. 92-108.
Ivanov, B. V., 1970, Eruption of the Karymsky volcano in 1962-1965 and volcanoes of the Karymsky group: Moscow, Nauka, 132 p. (R)
Kaneoka, I., Ozimia, M., 1970, On the radiometric ages of volcanic rocks from Japan: Bull. Volc. Soc., Japan, v. 15, no. 1, page unknown.
Katsui, Y., 1963, Evolution and magmatic history of some Krakatoan caldera in Hokkaido, Japan: Journ. Fac. Sci. Hokkaido University, ser. IV, v. XI, p. 631-650.
Katsui, Y., 1969, Some problems of the theory of caldera formations: Bull. Volcanol. Soc. Japan, ser. 2, p. 55-76.
Katsui, Y., Satoh, H., 1970, Explanatory text for the 1:50,000 scale geologic map "Oshima-Oshima": Geol. Survey Japan.
Kawachi, S. H., Kitazawa, K., 1967, The absolute age of the Oshio pyroclastic flow, Yatsugatake, ^{14}C-Age of Quaternary deposits in Japan, XXXII: Earth Science (Chikyi Kagaku), v. 21, no. 3, p. 21-22.
Kawano, Y., Yagi, and Aoki, K., 1962. Petrography and petrochemisty of the volcanic rocks of Ouaternary volcanoes of Northeastern Japan: Sci. Rpts. Tohoku University, 3 series, v. 7, p. 2-46.
Kobayashi, K., 1965, Late Quaternary chronology of Japan: Earth Science (Chikyi Kagaku), no. 79, p. 1-17.
Kochegura, V. V., Ogorodov, N. V., Kozhemiaka, N. N., 1969, Paleomagnetic correlation of the Pliocene-Pleistocene effusives of Sredinny Ridge of Kamchatka: Geol. & Geoph., no. 8, p. 81-90. (R)
Koronovsky, N. N., 1971. The structure of the feeding channels of the ingimbrite and tuff lava complexes of the Northern Caucasus: Bull. Volcanol., t. XXXIV, p. 639-637.
Kosminskaya, M. P., Zverev, S. M., Veitsman, Yu. V., Tulina, Yu. V., and Kraskshina, R. M., 1963, Main features of Earth's Crust structure of Okhotsk sea and Kurile-Kamchatka zone of Pacific by data of deep-seismic sounding: Izvestiya Ac. Sci. USSR, ser. geoph. no. 2, p. 19-42. (R)
Kuno, H., 1953, Formation of calderas and magmatic evolution: Trans. Am. Geoph. Union, 34, p. 141-176.
Kuno, H., Oki, Y., Ogino, K. and Hirota, S., 1971, Structure of Hakone caldera as revealed by drilling: Bull. Volcanol., t. XXXIV, p. 713-725.
Lipman, P. W., 1984, The roots of ash flow caldera in Western North America: windows into the tops of granitic batholiths: Journ. of Geoph. Res., v. 89, B10, p. 8801-8841.
Locardi, E., and Mittempergher, M., 1967, On the genesis of ignimbrites; how ignimbrites and other pyroclastic products originate from a flowing melt: Bull. Volcanol. v. 32, p. 131-152.
Leonova, L. L., Udaltsova, N. L., Ivanov, B. V., 1969, Rare alkalies and radioactive elements in rocks from Karymsky volcano: In Volcanism, gidrotermi i glubini Zemly, Petropavlovsk-Kamchatsky, p. 51. (R)
Luchitsky, I. V., 1971, Osnovy Paleovulcanologii, t. 2, Moscow, Nauka, 480 p. (R)
Macdonald, G. A., and Katsura, T., 1964, Chemical composition of Hawaiian lavas: Jour. Petrology, v. 5, p. 82-133.
Malahoff, A., and Woolard, G. P., 1968, Magnetic and tectonic trends over the Hawaiian Ridge: Am. Geoph. Union Geophys. Mono, 12, 241-276.

Marakushev, A. A., and Tararin, I. A., 1964, On the depth of granitoids formation: Doklady Sov. Geologists on the XXII session of IGC: Petrographicheskiye formatsii i problemi petrogenesisa, problema 16, p. 113-136. (R)
Markhinin, E. K., Pospelova, G. A., 1953, Some results of paleomagnetic studies in Kurile Islands: Izvestiya Ac. Sci., USSR, ser. geoph, no. 10, p. 1517-1519. (R)
Markhinin, E. K., 1964, Calderas and peripheric magma chambers: Trudy Lab. Paleovulcanol. Kaz IMS, vyp. 3, p. 138-146. (R)
Markhinin, E. K., 1967, Rol' vulkanisma v formirovanii zemnoy kori: Moscow, Nauka, 259 p. (R)
Masurenkov, Yu. P., ed., 1980, Dologozhivuschiy tsentr endogennoy aktivnosty Yuzhnoy Kamchatki: Moscow, Nauka, 360 p. (R).
Masurenkov, Yu. P., ed., 1980a, Vulkanichesky Tsentr:stroyeniye, dinamika, veschestvo . Karymskaya struktura. Moscow, Nauka, 299 p. (R)
Matsumoto, T., 1955, Some aspects of the formation of primary granitic magmas in the Upper Mantle: Upper Mantle Symposium (New Dehli, 1964), J.S.G.S., p. 112-126.
Matsumoto, H., and Fujita, Y., 1960, Noticable result of a drilling on the northwestern floor in Aso caldera: Bull. Volcanol. Soc. Japan, ser. 2, 14, p. 1-7. (J)
McCall, G. J. H., 1964, Froth lavas in Kenya: Geol. Rundsch. 54, p. 1148-1198.
Meniaylov, A. A., 1955, Sheveluch volcano, its geology and eruptions: Trudy Lab. Volc. Ac. Sci. USSR, vyp. 11, 264 p. (R)
Minato, M., Gorai, M., and Hunahashi, M., eds., 1965, The geologic development of the Japanese Islands: Tsukiji Shokan, Tokyo, 442 p.
Moore, J. G., 1971, Relationship between subsidence and volcanic load, Hawaii: Bull. Volcanologique, t. XXXIV, p. 562- 576.
Naboko, S. I., 1963, Petrochemical features of young and recent lavas in Kamchatka: In Petrockhimicheskiye osobennosti molodogo vulksnisma: Moscow, Nauka, p. 24-34. (R)
Naboko, S. I., ed., 1974, Vulkanism, gydrotermalny process i rudoobrazovaniye: Moscow, Nauka, 262 p. (R)
Nakamura, K., 1964, Volcano-stratigraphic study of Oshima volcano, Izu. Bull. Earthqu. Res. Inst., Tokyo, 41, p 649-728.
Neverov, Yu. L., Sergeev, K. F., 1966, The main stages of development of Cenozoic volcanism of the Great Kurile Chain: Vulkanicheskiye i vulkano-plutonichesiye formatsii. Trudy II Vsesoyuzn. Vulkanol. Sovesch., Moscow, Nauka, t. II, p. 72-75. (R).
Ogorodov, N. V., 1966, Quaternary volcanism of Sredinny Ridge of Kamchatka: Vulkanicheskiye i vulkano-plutonicheskiye formatsii. Trudy II Vsesoyuzn. Vulkanol. Sovesch., Moscow, Nauka, p. 50-55. (R).
Okada, A., 1969, Quaternary deposits and ^{14}C ages of the northern foot of Nasu volcano in South Aizu, Fukumoto Perfecture: ^{14}C Age of Quaternary deposits in Japan: (48) Earth Science (Chikyu Kagaku), v. 23, no. 6 (105), p. 261-262.
Ostapenko, V. F., 1967, Welded tuff of Medvezhya caldera (Iturup Island, Kurile Islands),: Doklady Ac. Sci. USSR, t. 174, no. 4, p. 941-944. (R)
Pichler, H., and Fredrich, W. F., 1976, Radiocarbon dates of Santorini volcanics: Nature, no. 5567, p. 373-374.
Reynolds, D. L., 1956, Calderas and ring complexes. Koninkl. Nederl. Geol. Mijnbowk. Genoot. Verhandel., 16, p. 355-379.

Rodionova, R. I., Fedorchenko, V. I., Shilov, V. V., 1964, Volcanic plateau of the Vernadsky Ridge (Paramushir Island, Northern Kuriles), Basalti Plateau: Moscow, Nauka, p. 129-135. (R)
Rodionova, R. I., Fedorchenko, V. I., Shilov, V. N., 1966, Geological structure of Quaternary volcanoes of th Kurile Ilsands, Trudy Sakhalin complex: Sci.Res.Int., vyp. 16, Yuzhno-Sakhalinsk, page unknown. (R)
Ross, C. A., and Smith, R. L., 1961, Ash-flow tuffs: their origin, geologic relations and identification: U.S.G.S., Professional Paper no. 366, p. 1-77.
Searle, E. J., 1961a, The age of Auckland volcanoes: New Zealand geographer, v. 17, no. 1, p. 52-63.
Searle, E. J., 1961b, Volcanoes of the Otahuhu-Manurewa district, Auckland: N. Z. Journ. Geol. & Geoph., v. 4, no. 3, p. 239-255.
Shantser, A. E., Chelebayeva, A. I., Geptner, A. R., 1966, Stratigraphy and correlation of Neogene deposits of Tumrok Ridge and some other regions of Kamchatka: Moscow, Nauka, Trudy Inst. Volcanology, vyp. 23, p. 86-96. (R)
Sheimovich, V. S. and Zubin, M. I., 1976, Structure of the Earth's Crust and petrochemistry of the Late Cenozoic volcanoes of the Southern Kamchatka: Doklady Ac. Sci. USSR, 230, no. 41, p. 934-937. (R)
Shibata, K., 1968, K-Ar age determinations on granitic and metamorphic rocks in Japan: Geol. Survey of Japan, rep. no. 227, 73 p.
Shimodzuru, D., 1978, Volcano-tectonics of the northern part of Idzu Islands: In Geodynamica i vulkanism osrovnikh dug severo-zapadnogo sectors Tikhookeanskogo kol'tsa. Sovietsksya Radio, Moscow, p. 5-16. (R)
Sirin, A. N., 1967, Osootnoshenii tsentralnogo i arealnogo vulkanisma: Moscow, Nauka, 196 p. (R)
Smith, R. L., 1960, Ash Flows: Geol. Soc. of America Bulletin, v. 71, p. 795-842.
Smith, R. L. and Bailey, R. A., 1968, Resurgent cauldrons: Mem. Geol. Soc. America, 116, p. 613-622.
Smith-Sibinga, G. L., 1948, Pleistocene eustacy and glacial chronology in Java and Sumatra: Verh. Ned. Geol. Mijnb. Gen. Geol. Ser., 15 p.
Taneda, S., 1963, Boring granite in Aso caldera: Bull. Volcanol. Soc. Japan, 8, 45.
Thompson, B. N., Kermode, L. O., Ewart, A., 1965, New Zealand volcanology. Central volcanic region New Zealand: Dept. Sci. Industr. Res., Inf. Ser., no. 50, Wellington, New Zealand, 211 p.
Thompson, B. N., Kermode, L. O., 1965b, New Zealand volcanology, Northland, Coromandel, Auckland, New Zealand: Dept. Sci. industr. Res. , Inf. ser., no. 49, Wellington, New Zealand, 102 p.
Thompson, B. N., 1964, Quaternary volcanism of the Central Region: N. Z. Journ. Geol. & Geoph. v. 8. no. 1. p. 45-60.
Timberbaeva, K. M., 1967, Petrologiya Kliuchevskikh vulkanovna Kamchatke: Moscow, Nauka, 207 p. (R)
Tolstikhin, I. N., Drubetskoy, E. R., Erlich, E. N., and Mamyrin, B. A., 1976, On the origin of silicic volcanic rocks in Kamchatka: Geokhimiya, no. 7, p. 997-1002. (R)
Vinogradov, A. P., Devirts, A. L., and others, 1962, Determinations of absolute age by ^{14}C: Report 3, geochemiya, no. 5, p. 387-401. (R)
Vlasov, G. M., ed., 1964, Geologiya SSSR, tom XXXI. Kamchatka, Kurile and Komandor Islanda, Nedra, Moscow, 733 p. (R)
Vlodavets, V. I., 1944, Classification of negative forms of volcanic relief: Izvestiya Ac. Sci. USSR, ser. geol., no. 5, p. 137-147. (R)

Vlodavets, V. I., 1953, Some Semiachik tuff lava and their origin: Trudy Inst. Volcanol., vyp. 15, p. 96-106. (R)
Vlodavets, V. I., Piip, B. I., 1959, Catalogue of the active volcanoes of the World (Kamchatka and Continental Asia), p. VIII, Naples, 110 pp.
Vuchetich, C. G., Pullar, W. A., 1969, Stratigraphy and chronology of Late Pleiostocene volcanic ash beds in Central North Island, New Zealand: N. Z. Journ. Geol. & Geoph., v. 12, no. 4, p. 784-821.
Westerveld, J., 1952, Quaternary volcanism on Sumatra: Bull. Geol. Soc. of America, v. 63, n. 6, p. 561-594.
Williams, H., 1941, Calderas and their origin: Bull. Calif. Univ. Dept. Geol. Sci., v. 25, no. 6, p. 239-346.
Wolff, F. von, 1929, Der Vulkanimus. Band II, Stuttgart, 810 p.
Wood, C. A., Dickey, J. S., Jr., Marvin, U. B. and Powell, B. N., 1970, Lunar anorthosites: Science, v. 67, no. 3918, p. 602-604.
Zavaritsky, A. N., 1950, Vvedeniye v petrochimiyu izverzhennikh porod: Moscow, Nauka, 399 p. (R)
Zavaritsky, A. N., 1955, Volcanoes of Kamchatka: Trudy Lab. Volc. Ac. Sci. USSR, vyp 10, 151 p. (R)

APPENDIX

THE BIBLIOGRAPHY OF LITERATURE ABOUT CALDERAS IN KAMCHATKA AND THE KURILES.

General remarks

In the list are included all the materials available on the subject up to the end of 1984. All the material is divided into geographical/structural regions and within it is distributed according to individual single calderas. Here are included all the calderas and volcano-tectonic structures in existance, all of which are well proven and recognized. Structures which from the beginning have been described as calderas, but afterwards not confirmed as such are excluded from the list. An example of this can be "calderas" of volcanoes Anaun and Bakening, mentioned by A. E. Sviatlovsky (1959) but not confirmed by following authors. Names of volcanoes are given in form accepted by Catalogues of Active Volcanoes of the World, published by IAVCEI. Within each cluster, devoted to a single caldera, literature is arranged in alphabetical order. In cases, when a series of normal calderas, are located within the boundaries of great volcano-tectonic depression, they are integrated into a single cluster. But if quantity of articles for each caldera is great enough, I considered them separately.

Within Zhupanovsky volcano-tectonic structure where a series of volcano-tectonic depressions and calderas are divided, but the part of literature about this region is devoted to two calderas - Karymsky volcano caldera and Maly Semiachik calders. Names of some calderas now recognized in this region have only recently appeared in literature and even quantity of these structures is still uncertain. Some structures are not described at all and have only been mentioned in recent works. In description and organizing bibliography for this region, author based on dividing and names of the structures provided by the most recent work (Masurenkov, 1980a).

Due to these reasons, the bibiliography for the region is generalized and clustered into two groups. One group includes calderas located in the southern part of the Zhupanovsky volcano-tectonic structure. Polovinka caldera and calderas of the volcanoes Akademii Nauk (Karymsky Lake), Odnoboky, Karymsky, and Dvor. Another part is devoted to volcano-tectonic depression Stena-Soboliny, located in the northern part of the same structure. Inside this depression are located calderas of volcanoes Pra-Semiachik, Maly Semiachik, and Soboliny. Joint list of the bibliography is made for Pauzhetka volcano-tectonic depression, and calderas of Kurile Lake and Il'insky volcano. In the list for the Plosky Tolblachik volcano are included only works connected with summit calderas and excluded all works about eruptions, geology, deep structure and geochemistry connected with adjacent rift zones.

In each cluster are included all types of works which carry any original information about certain caldera (even new types of geological maps or schemes) - in geology, geochemistry, deep structure, ore minerals, volcanic and geothermal activity, if any. Separate parts of the bibliography contain Russian literature in general problems, devoted to calderas of Kamchatka and Kuriles and also original works of Japanese volcanologists about calderas of Japan, published in Russian.

Titles of papers are given in translation into English. Titles of journals, books, and collections of papers - in transliteration. Abbreviations of titles for international journals are given in accepted form. Abbreviations for titles of Russian journals are given in the following form: Bulletin of Volcanological Stations of Institute of Volcanology, Far

East Division Academy of Science USSR is abbreviated as Bull.Volc.Stn. without any difference of several changes of the name and subordination in time. Izvstiya Academy of Science USSR, ser. geol. is abbreviated as Izv.Ac.Sci., ser.geol. Transactions of Laboratory Volcanology Academy of Science USSR are abbreviated as Trudy Lab.Volc., Memoirs of the Russian Geographical Society (or Geographical Scoiety of USSR) are abbreviated as Zapisky Georg.Soc.Russia (or USSR). Journal Volcanologia i Seismologia is abbreviated as Volcanol.i Seismol. At the end of each reference is indicated if it was published in Russia - (R), in German - (G), or in French (F), in Swedish (SW).

In order to shorten bibliography and simplify the system of references, collections of papers and collective monographs are given under the name of the editor, and in the form in which they appear in libraries catalogues.

CALDERAS OF KURILE ISLANDS AND KAMCHATKA
BIBLIOGRAPHY

I. SOUTHERN KURILE ISLANDS (Kunashir, Iturup, Urup, Cherniye, Bratya)

1.1. Golovnin caldera:

Dunichev, V. M., 1969, On the localization of hydrothermal system of Goriachy Pliazh to the region of the Pilocene acid volcanism. in: Volkanizm, gidrotermi i glubini Zemli, Petropavlovsk in Kamchatka, p. 103. (R)

Fedorchenko, V. I., 1962, Main stages in the postcaldera period of development of Golovnin volcano (Kunashir): Trudy SakhKNII, no. 12, p. 127-142. (R)

Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)

Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas: pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.

Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)

Korsunskaya, G. V., 1948, Volcanoes of the southern group of Kurile Islands: Zapisky Geogr. Soc. USSR, v. 80, fasc. 4, p. 433-442. (R)

Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

Markhinin, E. K., 1957, "Turtle" structure over recent baccolith in the Golovnin caldera: Soviet Geology, iss. 61, p. 147-149. (R).

Markhinin, E. K., 1959, Volcanoes of the Kunashir Island, in: Vulkanizm Kamchatki i kurilskikh ostrovov, Trudy Lab. Volc., iss. 17, p. 64-115. (R).

Markhinin, E. K., 1980, Outpouring of liquid sulphur in Golovnin caldera in summer, 1979, in: 5 Vsesouznoe Vulk. sovesch., Symp. 2, Abstr., Tbilisi, p. 153-154. (R)

Miyadi, D., 1938, Bottom fauna of the lakes in Kunasiri-sima of the South Kurile Islands: Int. Rev. der gesamt. Hydrobiol. u. Hydrograph., Bd. 37, H. 1-3, p. 125-163.

Naboko, S. I., 1958, On the formation of lake's sulphur on Golovnin volcano: Bull. Volc. Stn., no. 27, p. 38-43. (R)

Ostapenko, V. F., Fedorchenko, V. I., Shilov, V. N., 1967, Pumices, ignimbrites, and rhyolite from the Great Kurile Arc: Bull. Volcanol., v. 30, p. 81-92.

Sidorov, S. S., 1966, Hydrothermal activity of Golovnin caldera: Bull. Volc. Stn., no. 42, p. 17-22. (R)

Voronova, L. G., Sidorov, S. S., 1966, Comparative characteristics of the fumarole gases from some volcanoes of Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., T. I., Nauka Press, p. 146-153. (R)

Zlobin, T. K., Fedorchenko, V. I., 1982, Deep structure of Golovnin volcano by the data of study of waves of earthquakes voluminous, in: Vulkanol. i seismol., no. 4, p. 99-103. (R)

1.2. Mendeleev volcano:

Brezgunov, V. S., Dunichev, V. M., Zotov, A. V., Riznich, I. I., Soifer, V. N., Tkachenko, R. I., 1968, To the proiblem of genesis of thermal waters on Mendeleev volcano, Kunashir island: Doklady Acad. Nauk USSR, iss. 178, no. 1, p. 179-182. (R)

Dunichev, V. M., 1966, On the interconnections of copper-polymetallic and sulphur mineralization and their connections with volcanism on the Kunashir island (Kurile Islands), in: Sovremenny vulkamizm, Trudy 2 Vsesouzn. Vulkan. sovesch., Moscow, Nauka Press, p. 253-257. (R)

Dunichev, V. M., 1971, Acid welded tuffs within hydrothermal system Goriachy Pliazh, in: Vulkanizm i glubiny Zemli, Moscow, Nauka Press, p. 276-280. (R)

Dunichev, V. M., Riznich, I. I., 1968, Steam-hydrotherms of the Goriachy Pliazh (new data by the results of drilling in 1966): Bull. Volc. Stn., no. 44, p. 52-60. (R)

Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)

Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples IAVCEI, 99 pp.

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.

Korsunskaya, G. V., 1948, Volcanoes of the southern group of the Kurile Islands: Zapisky Geogr. Soc. USSR, v. 80, fasc. 4, p. 433-442. (R)

Kovalev, G. N., Slezin, Yu. B., 1970, Heat capacity of Mendeleev volcano (Kunashir Island): Bull. Volc. Stn., no. 46, p. 42-46. (R)

Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

Markhinin, E. K., 1956, Mendeleev volcano and its state in the summer of 1954: Bull. Volc. Stn., no. 24, p. 28-33. (R)

Markhinin, E. K., 1956, On the time of steamhydrothermal manifestations to faults on Kunashir Island: Bull. Volc. Stn., no. 24, p. 33-39. (R)

Markhinin, E. K., 1957, Quarts-olivine dacite from Kunashir Island: Bull. Volc. Stn., no. 26, p. 86-101. (R)

Markhinin, E. K., 1959, Steam exposures on the Kunashir Island (Goriachy Pliazh): Bull. Volc. Stn., no. 28, p. 23-33. (R)

Milne, J., 1886, The volcanoes of Japan: Trans. Seism. Soc. of Japan, v. 9, pt. 2, Yokohama, 184 pp.

Naboko, S. I., Sil'nichenko, V. G., 1959, Formation of sulphides and sulphates on the Mendeleev volcano: Bull. Volc. Stn., no. 28, p. 33-43. (R)

Naboko, S. I., Dunichev, V. M., Glavatskykh, S. F., Riznich, I. I., 1969, Geological structure and metasomatic effect of region of unloading of thermal water on Goryachy Pliazh deposit, in: Molodye gidrotermalno-izmenenniye porody i mineraly Kamchatki i Kurilskikh ostrovov, Moscow, Nauka Press, p. 48-80. (R)

Ozerova, N. A., Dobrovolskaya, M. G., Dudikina, A. S., 1971, On the question of conditions of forming of mercury-sulphide mineralization of Mendeleev volcano, in: Vulkanizm i glubiny Zemly, Materialy 3 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 317-325. (R)

Polunin, G. V., 1969, About absolute age of high terrace and Mendeleev volcano on Kunashir Island: Bull. Volc. Stn., no. 45, p. 53-55. (R)
Voronova, L. G., Sidorov, S. S., 1966, Comparative characteristics of the fumarole gases from some volcanoes of Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., t. I., Nauka Press, p. 146-153. (R)

1.3. Tiatia Volcano

Abdurakhamanov, A. I., 1974, Specific features of eruptive mechanism of Tiatia volcano in July, 1973; in: VIII konference molodikh uchenikh posviaschen, 250 Ak. , Nauk USSR, Abstracts, Yuzhno-Sakhalinsk, p. 1-2. (R)
Golovnin, V. M., 1949, Abbreviated notes of fleet lieutenant captain Golovnin on his voyage on "Diana" to describe the Kurile Islands in 1811; in: Sochineniyua, T. 1-2, Izd. Glavsevmorput, 506 pp. (R).
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R).
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Guschenko, I. I., 1979, Eruptions of Volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R).
Gusev, G. M., Zhukova, E. M., Nepeina, L. A., Pavlov, A. P., Slobodsky, P. M., 1976, Specific features of chemistry of products of Tiatia volcano eruption in 1973: Doklady Ac. Sci. USSR, 222, no. 6, p. 1438-1441. (R).
Korsunskaya, G. V., 1948, Volcanoes of the southern group Kurile Islands, Zapisky Georg. Soc. USSR, v. 80, fasc. 4., p. 433-442. (R).
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Maleev, E. F., 1975, Ashes of the Tiatia volcano: Bull. Volc. Stn., no. 51, p. 3-19. (R).
Markhinin, E. K., 1967, Rol' vulkanizma v formirovanii zemnoy kory: Nauka, Moscow, 254 pp. (R).
Markhinin, E. K., Anikiev Yu. A., Granik, V. M., Grabkov, V. K., Abdurakhmanov, A. I., Vasil'ev, B. I., Dolganova, P. S., Zemtsov, A. A., Trogn, A. A., Trukhin, Yu. P., Shuvalov, R. A., 1974, Eruptions of Tiatia volcano, Kurile Islands in 1973: Geol. and Geoph., no. 10, p. 20-31. (R).
Milne, J., 1879, A cruise among the volcanoes of the Kurile Islands, Geol. Mag., v. 6, p. 337-348.
Milne, J., 1886, The volcanoes of Japan, Trans. Seism. Soc. of Japan, v. 9, pt. 2, Yokohama, 184 pp.
Radkevich, R. A., Radkevich, R. O., Markhinin, E. K., Dolganova, P. S., Shutova, G. S., 1977, Ore-bearing ashes from Tiatia volcano in connection with dynamics of ash clouds movement during eruption in 1973 on Kunashir Island: Geol. and Geoph., no. 2, p. 62-71. (R).
Snow, H. J., 1897, Notes on the Kurile Islands, London, 91 pp.
Vergasova, L. P., 1976, Minerals of exhalations of Tiatia volcano (breakthrough July 14, 1973): Bull. Volc. Stn., no. 52, p. 75-83. (R).

Zemtsov, A. N., Trogn, A. A., Markhinin, E. K., 1976, On the electrical manifestations in ash-gas clouds, appeared during volcanic eruptions, Bull. Volc. Stn., no. 52, p. 18-23. (R)
Zobin, V. M., 1976, Seismotectonic conditions of eruption of Tiatia volcano (Kunashir Island) in July, 1973: Bull. Volc. Stn., no. 52, p. 24-29. (R).

1.4. L'vinaya Past' caldera:

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

1.5. Urbich caldera:

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

1.6. Atsonupuri volcano:

Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc, fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Gubler, A., 1932, Die Kurilen: Mitt. Geogr. Ethnogr. Ges., Bd. 32, Zurich, p. 1-104. (G)
Korsunskaya, G. V., 1948, Volcanoes of the southern group of Kurile Islands: Zapisky Geogr. Soc. USSR, v. 80, fasc. 4, p. 433-442. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Milne, J., 1886, The volcanoes of Japan: Trans. Seism. Soc. of Japan, v. 9, pt. 2, Yokohama, 184 pp.
Wolff, F. von, 1929, Der Vulkanismus, Bd. 2, Teil 1, Stuttgart, 810 pp. (G)

1.7. Grozny group of volcanoes (Tebenkov cone, Machekha crater):

Efremov, Yu. K., 1951, Kuriles necklace, Moscow: 223 pp. (R)
Korsunskaya, G. V., 1948, Volcanoes of the southern group of the Kurile Islands: Zapisky Geogr. Soc. USSR., v. 80, fasc. 4, p 433-442. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 285 pp.

Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

1.8. Chirip volcano-tectonic depression:

Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gubler, A., 1932, Die Kurilen: Mitt. Geogr. Ethnogr. Ges., Bd. 32, Zurich, p. 1-104. (G)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Milne, J. 1886, The volcanoes of Japan: Trans. Seism. Soc. of Japan, v. 9, pt. 2, Yokohama, 184 pp.
Wolff, F. von, 1929, Der Vulkanismus, Bd. 2, Teil 1, Stuttgart, 810 pp. (G)

1.9. Vetrovoi Isthmus caldera:

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

1.10. Tsirk caldera:

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

1.11. Kamuy caldera:

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

1.12. Medvezhya caldera (Kudriavy volcano):

Antipin, 1775, Report on the academy expedition of the nobleman Antipin in the Kurile Islands: Sobr. novostei, St. Petersburg, September, 49-50. (R)
Efremov, Yu. K., 1951, Kuriles necklace: Moscow, 233 pp. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.

Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)
Guillemard, F. H., 1889, The cruise of the Marchesa to Kamchatka and New Guinea, New York, 455 pp.
Kichina, E. N., Ostapenko, V. F., 1976, Geological and petrographic characteristic of Quaternary lavas of caldera volcanoes, Kurile Islands, in: Vulkanicheskiye i vulkanopluto nicheskiye komplexi Vostochnoi Azii, Vladivostok, p. 45-53. (R)
Korsunskaya, G. V., 1948, Volcanoes of the southern group of the Kurile Islands: Zapisky Geogr. Soc. USSR, v. 80, fasc. 4, p. 433-442. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Ostapenko, V. F., 1967, Petrography of Quaternary extrusive domes of Medvezhiya caldera, Iturup Island, Kurile, in: Magmatich. i metamorphich. complexy Dal'nego Vostoka USSR, Khabarovsk, p. 169-172. (R)
Ostapenko, V. F., 1967, Welded tuff of Medvezhya caldera, Iturup Island, Kuriles: Doklady Acad. Nauk USSR, v. 174, no. 4, p. 941-944. (R)
Ostapenko, V. F., 1969, About character of previous eruptions of Medvezhiy zone (Iturup Island), in: Vulkany i izverzhenia, Moscow, Nauka Press, p. 122-126. (R)
Ostapenko, V. F., 1969, Products of volcanic activity of Kurile Islands calderas as favorable object for study of magmatic processes, in: Vulkanizm, gidrotermy i glubiny Zemli, Petropavlovsk. Kamch., p. 56-57. (R)
Ostapenko, V. F., 1970, Morphology and structure of caldera-volcano Medvezhiy (Iturup Island, Kurile): Izv. Sakhalin div. of Geogr. Soc. USSR, iss. I, p. 99-108. (R)
Ostapenko, V. F., Fedorchenko, V. I., Schilov, V. N., 1967, Pumices, ignimbrites and rhyolites from the Great Kurile Arc: Bull. Volcanol., v. 30, p. 81-92. (R)
Snow, H. J., 1897, Notes on the Kurile Islands: London, 91 pp.
Snow, H. J., 1910, In Forbidden Seas: London, 303 pp.
Tatarinov, M., 1783, Neue Beschreibung der Kurilischen Inseln: Neue Nord. Beit., Bd. 4, SPB, pp. unknown. (G)
Tatarinov, M., 1784, Description of the Kurile Islands, Hist. and Geogr. Calendar 1785, St. Petersburg, pp. unknown. (R)

1.13. Volcano-tectonic depression of Krishtofovich Ridge:

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

1.14. Trezubets and Berg volcanoes and calderas:

Chirkov, A. M., Baranov, L. N., Basharina, L. A., Zelenov, K. K., 1972, State of some volcanoes of the Kurile Islands in summer 1970, Bull. Volcanol., v. 48, p. 29-33. (R)

Doroshin, P. O., 1870, On some volcanoes, their eruptions and earthquakes in former American domains of Russia, Zapisky St. Petersburg Min. Soc., ser. 2, 25 pp. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kruile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)
Korsunskaya, G. V., 1948, Volcanoes of the southern group of the Kurile Islands: Zapisky Geogr. Soc. USSR, v. 80, fasc. 4, p. 433-442. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Neverov, Yu. L, Khvedchenya, O. A., 1962, New data on the geology and ore mineralization of Urup: Trudy SakhKNII, no. 12, p. 220-228. (R)
Piskunov, B. N., 1975, Volcanism of the Great Kurile chain and petrology of high-alumine rock serie on example of Urup and Simushir Islands: Novosibirsk, Nauka Press, 187 pp. (R)

1.15. Chirpoy caldera:

Atlas of Geographic Discoveries in Siberia and Northwestern America in the Seventeenth and Eighteenth Centuries, 1964, Moscow, Nauka Press. (R)
Chirkov, A. M., Baranov, L. N., Basharina, L. A., Zelenov, K. K., 1972, State of some volcanoes of the Kurile Islands in summer 1970: Bull. Volc. Stn., no. 48, p. 29-33. (R)
Escher, O., 1858, Expedition nach dem Amur: Peterm. Mitt., H. 4. pp. unknown. (G)
Golovnin, V. M., 1949, Abbreviated notes of fleet lieutenant captain Golovnin on his voyage on "Diana" to describe the Kurile Islands in 1811, in: Sochineniya, T. 1-2, Izd. Glevsevmorput, 506 pp. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Gubler, A., 1932, Die Kurilen: Mitt. Geogr. Ethnogr. Ges., Bd. 32, Zurich. (G)
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)
Kamio, H., 1931, Earthquake in Moroton Strait on Simushir in June 1920 and the eruption on Matua in January 1923: Geol. J. (of Japan), v. 38, no. 458, p. .
Korsunskaya, G. V., 1948, Volcanoes of the southern group of the Kurile Islands: Zapisky Geogr. Soc. USSR, v. 80, fasc. 4, p. 433-442. (R)
Krasheninnikov, S. P., 1755, Description of the land of Kamchatka, St. Petersburg. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

Milne, J. 1886, The volcanoes of Japan: Trans. Seism. Soc. of Japan, v. 9, pt. 2, Yokohama, 184 pp.
Nemoto, T., 1937, Geological and petrological study of the Central Kurile Islands, VI-Zigoku volcano, Uruppu: Bull. Volcanol. Soc. Japan, v. 3, no. 2, 15 pp.
Piskunov, B. N., 1975, Volcanism of the Great Kurile chain and petrology of high-alumine rock serie, on example of Urup and Simushir Islands: Novosibirsk, Nauka Press, 187 pp. (R)
Polonsky, A., 1871, Kuriles: Zapisky Russ. Geogr. Soc., Sect. Ethnogr., v. 4, p. 367-576. (R)
Snow, H. J., 1897, Notes on the Kurile Islands: London, 91 pp.
Snow, H. J., 1910, In Forbidden Seas: London, 303 pp.
Tatarinov, M., 1784, Description of the Kurile Islands, Hist. and Georg. Calendar 1785, St. Petersburg, pp. unknown. (R).

II. CENTRAL KURILE ISLANDS (Simushir, Ketoi, Ushishir, Rasshua, Matua)

2.1. Goriaschaia Sopka volcano and caldera:

Escher, O., 1858, Expedition nach dem Amur: Peterm. Mitt, H. 4., pp. unknown. (G)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)
Korsunskaya, G. V. 1956, The volcanoes of Simushir Island: Bull. Volc. Stn., no. 24, p. 52-61. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Piskunov, B. N., 1975, Volcanism of the Great Kurile chain and petrology of high-slumine rock serie, on example of Urup and Simushir Islands: Novosibirsk, Nauka Press, 187 pp. (R)
Snow, H. J., 1897, Notes on the Kurile Islands: London, 91 pp.
Snow, H. J., 1910, In Forbidden Seas: London, 303 pp.
Soloviev, A. I., 1945, Kurile Islands, Moscow, Glavsevmorput, 195 pp. (R)
Tanakadate, H., 1925, The volcanic activity in Japan during 1914-1924: Bull. Volcanol., nos. 3 and 4, Napoli, p. 4-19.

2.2. Milne volcano and caldera:

Doroshin, P. 1870, On some volcanoes, their eruptions and earthquakes in former American domains of Russia: Zapisky St. Petersburg Min. Soc., Ser. 2, 5 p. (R)
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Korsunskaya, G. V., 1956, The volcanoes of Simushir Island: Bull. Volc. Stn., no. 24, p. 52-61. (R)

Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Piskunov, B. N., 1975, Volcanism of the Great Kurile chain and petrology of high-alumine rock serie, on example of Urup and Simushir Islands: Novosibirsk, Nauka Press, 187pp. (R)

2.3. Zavaritsky caldera:

Bernshtein, V. A., 1960, On the magnetic field on Zavaritsky volcano: Bull. Volc. Stn., no. 30, p. 50-55. (R)
Bernshtein, V. A., 1960, About possible changing of magnetic field in the region of Zavaritsky volcano in the first half of 1958: Bull. Volc. Stn., no. 30, p. 55-69. (R)
Chirkov, A. M., Baranov, L. N., Basharina, L. A., Zelenov, K. K., 1972, State of some volcanoes of the Kurile Islands in summer 1970: Bull. Volc. Stn., no. 48, p. 29-33. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1960, Zavaritsky caldera: Bull. Volc. Stn., no. 30, p. 24-30. (R)
Gorshkov, G. S., 1961, Welded tuff in Zavaritsky caldera (Simushir Island, Kurile Islands): Trudy Lab. Volc., no. 20, p. 102-107. (R)
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Korsunskaya, G. V., 1956, The volcanoes of Simushir Island: Bull. Volc. Stn., no. 24, p. 52-61. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Markhinin, E. K., 1960, The eruption of Zavaritsky on Simushir Island in the autumn of 1957: Bull. Volc. Stn., no. 29, p. 3-7. (R)
Ostapenko, V. F., Fedorchenko, V. I., and Shilov, V. N., 1967, Pumices, ignimbrites, and rhyolites from the Great Kurile Arc: Bull. Volcanol., v. 30, p. 81-92. (R)
Piskunov, B. N., 1975, Volcanism of the Great Kurile chain and petrology of high-alumine rock serie, on example of Urup and Simushir Islands: Novosibirsk, Nauka Press, 187 pp. (R)
Soloviev, A. I., 1945, Kurile Islands: Moscow, Glavsevmorput, 195 pp. (R)
Suzuki, J., 1937, Active volcanoes on Hokkaido and Chishima (Kuriles) Islands in Japan: Intern. Geol. Congr., p. 140.
Tovarova, I. I., 1960, Fumarolic activity in the Zavaritsky caldera: Bull. Volc. Stn., no. 30, p. 30-50. (R)
Zelenov, K. K., Kanakina, M. A., 1962, Biriuzovoye lake (Zavaritsky caldera) and changing of its water chemistry in the result of eruption in 1957: Bull. Volc. Stn., no. 32, p. 24-33. (R)

2.4. Uratman volcano and caldera:

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.

Korsunskaya, G. V., 1956, The volcanoes of Simushir Island: Bull. Volc. Stn., no. 24, p. 52-61. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Piskunov, B. N., 1975, Volcanism of the Great Kurile chain and petrology of high-alumine rock serie, on example of Urup and Simushir Islands: Novosibirsk, Nauka Press, 187 pp. (R)

2.5. Ketoi caldera (Pallas volcano):

Bogoyavlenskaya, G. E., Gorshkov, G. S., 1966, Active volcanoes of Central Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Mocow, Nauka Press, p. 86-93. (R)
Chirkov, A. M., Baranov, L. N., Basharina, L. A., Zelenov, K. K., 1972, State of some volcanoes of the Kurile Islands in summer 1970: Bull. Volc. Stn., no. 48, p. 29-33. (R)
Doroshin, P., 1879, On some volcanoes, their eruptions and earthquakes in former American domains of Russia: Zapisky St. Petersburg Min. Soc., ser. 2, 25 pp. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Gubler, A., 1932, Die Kurilen: Mitt. Geogr. Ethnogr. Ges., Bd. 32, Zurich, p. 1-104. (G)
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Perrey, A., 1864, Documents on the earthquakes and volcanic phenomena in the Kurile archipelago and on Kamchatka: Ann. Sci. Phys. et Nat. d'Agric. et d'Indust. de Lyon, ser. 3, v. 8, p. 209-374. (F)

2.6. Ushishir caldera volcano:

Bergman, S., 1933, Sport and Exploration in the Far East: London, 296 pp.
Bogoyavlenskaya, G. E., Gorshkov, G. S., 1966, Active volcanoes of Central Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 86-93. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Markhinin, E. K., Stratula, D. S., 1966, New data about volcanoes of Central Kurile Islands, in: Sovremenny vulkanism, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 94-97. (R)

Milne, J., 1886, The volcanoes of Japan: Trans. Seism. Soc. of Japan, v. 9, pt. 2, Yokohama, 184 pp.
Polonsky, A., 1871, Kuriles: Zapisky Russ. Geogr. Soc., Sect. Ethnogr., v. 4, p. 367-576. (R)
Snow, H. J., 1897, Notes on the Kurile Islands: London, 91 pp.
Tatarinov, M., 1784, Description of the Kurile Islands: Hist. and Geogr. Calendar 1785, St. Petersburg, pp unknown. (R)

2.7. Rasshua caldera volcano:

Doroshin, P., 1870, On some volcanoes, their eruptions and earthquakes in former American domains of Russia: Zapisky St. Petersburg Min. Soc., Ser., 2, 25 pp. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Markhinin, E. K., Stratula, D. S., 1966, New data about volcanoes of Central Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 94-97. (R)

2.8. Matua caldera (Sarychev Peak volcano):

Andreev, V. N., Shantser, A. E., Chrenov, A. P., Nechaev, V. N., 1978, Eruption of the Peak Sarychev in 1976: Bull. Volc. Stn., no. 55, p. 35-40, (R)
Bogoyavlenskaya, G. E., Gorshkov, G. S., 1966, Active volcanoes of Central Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 86-93. (R)
Glavatsky, S. N., Efremov, Yu. K., 1948, The eruption of the Peak Sarychev volcano in November, 1946: Bull. Volc. Stn., no. 15, p. 8-12. (R)
Gorshkov, G. S., 1948, Peak Sarycheva volcano: Bull. Volc. Stn., no. 14, p. 3. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R).
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)
Kamio, H., 1931, Earthquake in Moroton Strait on Simushir in June 1920 and the eruption on Matua in January 1923: Geol. J. (of Japan), v. 38, no. 458, p. 589-596.
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Milne, J. 1886, The volcanoes of Japan: Trans. Seism. Soc. of Japan, v. 9, pt. 2, Yokohama, 184 pp.

Polonsky, A. 1871, Kuriles: Zapisky Russ. Geogr. Soc., sect. Ethnogr., v. 4, p. . (R)
Shilov, V. N., 1962, Eruption of Sarychev Peak volcano in 1960: Trudy SakhKNII, no. 12, p. 143-149. (R)
Tanakadate, H., 1931, Volcanic activity in Japan and vicinity during the period between 1924 and 1931: Jap. J. Astr. Geoph., v. 9, no. 1, Tokyo, p. 4-19.
Tatarinov, M. 1783, Neue Beschreibung der Kurilischen Inseln: Neue Nord. Beit., Bd. 4, SPB. (G)
Tatarinov, M. 1784, Description of the Kurile Islands: Hist. and Geogr. Calendar 1785, St. Petersburg. (R)

III. **NORTHERN KURILE ISLANDS** (Shiashkotan, Onekotan, Paramushiz)

3.1. Kuntomintar caldera volcano:

Bogoyavlenskaya, G. E., Gorshkov, G. S., 1966, Active volcanoes of Central Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 86-93. (R)
Chirkov, A. M., Baranov, L. N., Basharina, L. A., Zelenov, K. K., 1972, State of some volcanoes of the Kurile Islands in summer 1970: Bull. Volc. Stn., no. 48, p. 29-33. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Gubler, A., 1932, Die Kurilen: Mitt. Geogr. Ethnogr. Ges., Bd. 32, Zurich, p. 1-104. (G)
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Markhinin, E. K., Stratula, D. S., 1966, New data about volcanoes of Central Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 94-97. (R)
Stratula, D. S., 1969, About regularities of changing of some specific features of Quaternary volcanism within rows of volcanoes in Kurile Island Arc, in: Vulkany i izverzhenia, Moscow, Nauka Press, p. 127-139. (R)

3.2. Sinarka caldera volcano:

Bogoyavlenskaya, G. E., Gorshkov, G. S., 1966, Active volcanoes of Central Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 86-93. (R)
Doroshin, P., 1870, On some volcanoes, their eruptions and earthquakes in former American domains of Russia: Zapisky St. Petersburg Min. Soc., ser. 2, pp. 25. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Markhinin, E. K., Stratula, D. S., 1966, New data about volcanoes of Central Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 94-97. (R)
Selsky, 1858, Fire spitting mountain on Shiashkotan Island: Zapisky Russ. Geogr. Soc., West Siberian Dept., Book 5, Sec. II, p. 3-5. (R)
Selsky, 1858, Le volcan de l'ile Shiachkotan: Bull. Soc. des Naturalists de Moscow, t. 2, pp. unknown. (F).
Snow, H. J., 1897, Notes on the Kurile Islands: London, 91 pp.

3.3. Tao-Rusyr caldera (Krenitsyn Peak volcano):

Bogoyavlenskaya, G. E., Gorshkov, G. S., 1966, Active volcanoes of Central Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 86-93. (R)
Gorshkov, G. S., 1954, Krenitzyn Peak: Bull. Volc. Stn., no. 20, p. 52-60. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)
Kimura, M. 1978, Significant eruptive activities related to large interplate earthquakes in the northwestern Pacific margin: Jour. Phys. Earth, v. 26, Suppl., p. S557-S570.
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Piip, B. I., and Sviatlovsky, A. E., 1954, The eruption of Krenitzyn Peak in 1952: Bull. Volc. Stn., no. 20, p. 60-64. (R)
Snow, H. J., 1897, Notes on the Kurile Islands: London, 91 pp.
Sviatlovsky, A. E., 1955, Eruption of Krenitzyn volcano: Nature, no. 1, p. 85-88. (R)
Tatarinov, M. 1783, Neue Beschreibung der Kurilischen Inseln: Neue Nord. Beit, Bd. 4, SPB, pp. unknown. (G)
Tatarinov, M. 1784, Description of the Kurile Islands: Hist. and Geogr. Calendar 1785, St. Petersburg, pp. unknown. (R)

3.4. Kryzhanovsky caldera:

Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.

3.5. Nemo caldera (Nemo Peak volcano):

Bogoyavlenskaya, G. E., Gorshkov, G. S., 1966, Active volcanoes of Central Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 86-93. (R)
Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc, fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Gubler, A., 1932, Die Kurilen: Mitt. Geogr. Ethnogr. Ges., Bd. 32, Zurich, p. 1-104. (G)
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Tatarinov, M., 1783, Neue Beschreibung der Kurilischen Inseln: Neue Nord. Beit, Bd. 4, SPB, pp. unknown. (G)
Tatarinov, M., 1784, Description of the Kurile Islands: Hist. and Geogr. Calendar 1785, St. Petersburg, pp. unknown. (R)

3.6. Karpinsky caldera:

Gorshkov, G. S., 1954, Chronology of the eruptions of the Kurile range of volcanoes: Trudy Lab. Volc., fasc. 8, p. 58-99. (R)
Gorshkov, G. S., 1954, Volcanoes of Paramushir island and their state during the summer of 1953: Bull. Volc. Stn., no. 22, p. 8-9. (R)
Gorshkov, G. S., 1958, Catalogue of active volcanoes of the World including solfatara areas, pt. VII, Kurile Islands: Naples, IAVCEI, 99 pp.
Gorshkov, G. S., 1970, Volcanism and the Upper Mantle. Investigations in the Kurile Volcanic Arc: New York, Plenum Press, 385 pp.
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Moscow, Nauka Press, 474 pp. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Piip, B. I., Sviatlovsky, A. E., 1954, Eruptions of Krenitzyn Peak in 1952: Bull. Volc. Stn., no. 20, p. 60-64. (R)
Voronova, L. G., Sidorov, S. S., 1966, Hydrothermal activity in the region of the Karpinsky ridge (Paramushir Island): Bull. Volc. Stn., no. 41, p. 35-41. (R)
Voronova, L. G., Sidorov, S. S., 1966, Comparative characteristics of fumarole gases from some volcanoes of Kurile Islands, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. sovesch., t. I, Nauka Press, p. 146-153. (R)

IV. SOUTHERN KAMCHATKA

4.1. Pauzhetka volcano-tectonic depression (Kurile Lake caldera, Il'inskaya Sopka:

Aprelkov, S. E., 1961, Ignimbrites of Golygin mountains (Southern Kamchatka): Trudy Lab. Volc, iss. 20, p. 92-96. (R)

Aprelkov, S. E., Ezhov, B. V., Otochkin, Y. V., Sokolikov, V. A., 1979, Volcano-tectonic of the Southern Kamchatka: Bull. Volc. Stn., no. 57, p. 72-78. (R)

Aver'ev, V. V., 1961, Conditions of unloading of Pauzhetka hydrothermal system on the south of Kamchatka: Trudy Lab. Volc. iss. 19, p 80-98. (R)

Aver'ev, V. V., Belousov, V. I., and others, 1965, Pauzhetka hot waters in Kamchatka: Moscow, Nauka Press, 208 pp. (R)

Aver'ev, V. V., Svíatlovsky, A. E., 1961, Volcano-tectonic structures of Southern Kamchatka: Izv. Ac. Sci. USSR, ser.geol., No. 6, p. 98-100. (R)

Belousov, V. I., 1965, Geological structure of Pauzhetka deposit of high-thermal waters, in: Pauzhetsky goryachie vody na Kamchatka, Moscow, Nauka Press, p. 23-30. (R)

Belousov, V. I., 1967, Geological structure of the hydrothermal systems of Kamchatka: Bull. Volcanol., v. 30, p. 63-73.

Belousov, V. I., Sugrobov, V. M., 1971, Geological aspects of the connection between Pauzhetka hydrothermal fields and thermal fields of Kambalny ridge in the south of Kamchatka, in: Vulkanizm i glubiny Zemly, Materialy 3 Vsesouzn. Vulkan. sovesch., Moscow, Nauka Press, p. 225-229. (R)

Belousov, V. I., Sugrobov, V. M., Sugrobova, N. G., 1976, Geological structure and hydrogeological specific features of Pauzhetka hydrothermal system, in: Gidrotermalniye sistemy i termalniye polia Kamchatki, Vladivostok, p. 23-57. (R)

Braitseva, O. A., Krayevaya, T. S., Sheimovich, V. S., 1965, On the genesis of Kurilsky lake and pumices of this region, in: Voprosy geographii Kamchatki, iss. II, Petropavlovsk--Kamchat., p. 49-57. (R)

Ditmar, K. von, 1860, Die Vulkane und heissen Quellen Kamtschatkas: Petermann Mitt, p. 66-76. (G)

Ditmar, K. von, 1900, Reisen und Aufenthalt in Kamtschatka in den Jahren 1851-1855: T.2, Abt. 1, Beitr. zur Kenntniss d. Russ. Reiches, 35, Bd. 805, 273 pp. (G)

Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)

Konradi, S. A. and Kell', N. G., 1925, The geological section of the Kamchatka expedition, 1908-1911: Izv. Vsesouz. Geograf. obsch., t. 57, nip. 1, p. 3-32. (R)

Kozhemyaka, N. N., 1979, Quaternary pumice, tuff-ignimbrites fields and center of eruptions in Southern Kamchatka: Bull. Volc. Stn., no. 57, p. 26-38. (R)

Kozhemyaka, N. N., Ogorodov, N. V., 1977, Some specific features of volcanism and genesis of Pauzhetka volcano-tectonic structure, Southern Kamchatka: Bull. Volc. Stn., no. 53, p. 93-101. (R)

Kozhemyaka, N. N., Ogorodov, N. V., Litasov, N. E., 1973, Geological effect and some specific features of Quaternary volcanism in Southern Kamchatka: Bull. Volc. Stn., no. 49, p. 65-69. (R)

Krayevaya, T. S., 1967, New data about young pumice deposits in the region of Kurilsky lake, in: Voprosy geographii Kamchatki, iss. V, Petropavlovsk-Kamch., p. 128-131. (R)

Krayevaya, T. S., Braitseva, O. A., Sheimovich, V. S., Egorova, I. A., Lupikina, E. G., 1979, Deposits of Quaternary calderas of Kamchatka: Vulkanol. i Seismol., no. 4, p. 3-11. (R)

Leonov, V. L., 1981, Faults of Pauzhetka volcano-tectonic structure: Vulkanol. i Seismol., no. 1, p. 24-36. (R)
Levina, V. I., Firstov, P. P. and Zobin, V. M., 1900, Seismicity of the Pauzhetka geothermal region in Kamchatka: Volkanol. i Seismol., no. 2, p. 81-97. (R)
Litasov, N. E., Ogorodov, N. V., Kozhemyaka, N. N., Khatkevich, Yu. M., Sugrobova, N. G., Barabanov, L. N., 1974, Pauzhetka volcano-tectonic structure, in: Vulkani i geotermalniye sistemy Kamchatki, Petropavlovsk-Kamch., p. 49-72. (R)
Lonshakov, E. A., 1979, Rows of volcano-tectonic structures and structural matter paragenesis of the South Kamchatka region: Bull. Volc. Stn., no. 57, p. 79-91. (R)
Masurenkov, Yu. P., ed., 1980, Dolgozhivuschy tsentr endogennoy aktivnosty Yuzhnoy Kamchatki: Moscow, Nauka Press, 300 pp. (R)
Naboko, S. I., 1954, Geizers of Pauzhetka: Bull. Volc. Stn., no. 22, p. 9-30. (R)
Naboko, S. I., 1954, Hydrosolfataras of Dikiy Greben: Bull. Volc. Stn., no. 22, p. 44-59. (R)
Naboko, S. I., Fil'kova, E. M., 1966, Vertical zonality in hydrothermal clays of Pauzhetka: Bull. Volc. Stn., no. 41, p. 29-32. (R)
Nekhoroshev, A. S., 1959, Hydrothermal activity in the region of Kambalny ridge on the Southern Kamchatka: Bull. Volc. Stn., no. 28, p. 21-23. (R)
Novograblenov, P. T., 1932, Catalogue of Kamchatka volcanoes: Zapisky Russ. Geogr. Soc., Vol. 64, fasc. 1, p. 88-99. (R)
Ogorodov, N. V., Volynets, O. N., Koloskov, A. V., Popolitov, E. I., 1978, Dikiy Greben: Bull. Volc. Stn., no. 54, p. 75-88. (R)
Piip, B. I., 1937, Thermal springs of Kamchatka: SOPS, Ac. Sci. USSR, Kamchatka ser., fasc. 2, 268 pp. (R)
Piip, B. I., 1947, Traverse geological obsevations in the South of Kamchatka: Trudy Lab. Volc., iss. 3, p. 89-134. (R)
Sheimovich, V. S., 1974, Specific features of pre-Quaternary volcano-tectonic depressions in Kamchatka: Geotectonika, no. 6, p. 118-125. (R)
Sugrobov, V. M., 1965, Influence of experimental exploration of Pauzhetka deposit on surficial heat exposures and regime of boiling springs: Bull. Volc. Stn., no. 39, p. 35-47. (R)
Sugrobova, N. G., 1971, On the regime of Pauzhetka boiling springs and geyzers: Bull. Volc. Stn., No. 47, p. 69-72. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Vlodavets, V. I., and Piip, B. I., 1957, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.
Zubin, M. I., Nikolaev, A. S., Sheimovich, V. S., 1982, New data about origin of Kurile lake in Kamchatka: Vulkanol. i seismol., no. 1, p. 85-88. (R)

4.2. Zheltovsky volcano and caldera:

Ditmar, K. von, 1860, Die Vulkane und Heissen Quellen Kamtschatka's: Petermann, Mitt, p. 66-76. (G).
Ditmar, K. von, 1900, Reisen und Aufenthalt in Kamtschatka in den Jahren 1851-1855: Beitr. Russ. Reiches, no. 8, 273 pp. (G)
Erlilch, E. N., Gorshkov, G. S., eds., 1979, Quaternary volcanism and tectonics in Kamchatka: Bull. Volcanol., v. 41:1 (special issue), 298

pp. (R)
Khrenov, A. P., Ogorodov, N. V., 1973, Zheltovsky volcano: Bull. Volc. Stn., no. 49, p. 60-64. (R)
Konradi, S. A. and Kell', N. G., 1925, The geological section of the Kamchatka expedition, 1908-1911: Izv. Vsesouz. Geograf. obsch., t. 57, vyp. 1, p. 3-32. (R)
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Masurenkov, :Yu. P., ed., 1980, Vulkanichesky center: structura, dinamika i veschestvo. Karymskaya struktura: Moscow, Nauka Press, 300 pp. (R)
Novograblenov, P. T., 1932, Catalogue of Kamchatka volcanoes, Zapisky Russ. Geogr. Soc., v. 64, fasc. 1, p. 88-99. (R)
Piip, B. I., 1947, Traverse geological observations in South Kamchatka: Trudy Lab. Volc., iss. 3, p. 89-134. (R)
Vlodavetz, V. I. and Piip, B. I., 1959, Catalogue of active volcanoes of the World including softatara areas, Pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.

4.3. Prizrak-caldera (Kell volcano):

Erlich, E. N. and Gorshkov, G. S., eds., 1979, Quaternary volcanism and tectonics in Kamchatka: Bull.Volcanol., v. 42: 1-4, (special issue), 298 pp.
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)

4.4. Ksudach volcano:

Ditmar, K, von., 1900, Reisen and Aufenthalt in Kamtschatka in den Jahren 1851-55: Beitr. Russ. Reich., no. 8, 273 pp. (G)
Dubik, Yu. M., 1969, Xenoliths and ultrabasic inclusions in lavas of Ksudach volcano (South Kamchatka): in: Vulkanizm, gidrotermy i glubiny Zemli, Petropavlovsk-Kamch. p. 44. (R)
Dubik, Yu. M., Meniaylov, I. A., 1971, Gas-hydrothermal activity of Ksudach caldera: Bull. Volc. Stn., no. 47, p. 40-43. (R)
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)
Hulten, E., 1924, Eruption of a Kamchatka volcano in 1907 and its atmospheric consequences: Geol. Foren. Forhandl, Bd. 46, H. 5, p. 407-417. (G)
Hulten, E., 1923, Some geographical notes on the map of the South Kamchatka: Geografiska Annaler, 8.5, p. 329-250.
Karpinsky, A. P., 1908, Notes on volcanic ashes fallen on March 15-16, 1907 in Petropavlovsk on Kamchatka: Bull. Ac. Sci., 6 ser., vol. 2, no. 5, p. 423-432. (R)
Kozhemyaka, N. N., 1979, Quaternary pumice, tuff-ignimbrites fields and centers of eruptions in Southern Kamchatka: Bull. Volc. Stn., no. 57, p. 26-38. (R)
Kozhemyaka, N. N., Ogorodov, N. V., Litasov, N. E., 1973, Geological effect and zone specific features of Quaternary volcanism in Southern Kamchatka: Bull. Volc. Stn., no. 49, p. 65-69. (R)
Lonshakov, E. A., 1979, Rows of volcano-tectonic structures and structural matter paragenesis of the South Kamchatka region: Bull. Volc. Stn., no. 57, p. 79-91. (R)

Piip, B. I., 1941, On the name of Ksudach volcano and Stubel volcano: Bull. Volc. Stn., no. 9, p. 22-27. (R)
Piip, B. I., 1941, On the intensity of the eruption of Ksudach volcano in March, 1907: Bull. Volc. Stn., no. 10, p. 12-23. (R)
Piip, B. I., 1947, Traverse geological observations in the South Kamchatka: Trudy Lab. Volc., fasc. 3, p. 89-134. (R)
Sheimovich, V. S., 1966, Ksudach volcano in August 1963: Bull. Volc. Stn., no. 41, p. 20-25. (R)
Sheimovich, V. S., 1976, Kainozoic basaltic volcanism as indicator of extension of the Earth's Crust: Izv. Ac. Sci. USSR, ser. Geol., no. 11, p. 14-18. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Vlodavets, V. I. and Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.

4.5. Gorely volcano:

Ditmar, K. von, 1900, Reisen und Aufenthalt in Kamtschatka in den Jahren 1851-55: Beitr. Russ. Reich., no. 8, 273 pp. (G)
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)
Kirsanov, I. T., 1964, State of Mutnovsky and Gorely volcanoes for period from October 1959 up to October 1960: Bull. Volc. Stn., no. 35, p. 22-34. (R)
Kirsanov, I. T., 1964, Volcanoes of Southern and Central Kamchatka in 1963: Bull. Volc. Stn., no. 37, 3 pp. (R)
Kirsanov, I. T., 1965, Acid volcanicity and thermal activity in the vicinity of Mutnovsky and Gorely volcanoes (Southern Kamchatka): Intern. Assoc. Volcanol. Intern. Sympos. Volcanol., New Zealand, 1965, Abstracts, Wellington, p. 93-94.
Kirsanov, I. T., 1967, Acid volcanism and thermal manifestations in the area of Mutnovsky and Gorely volcanoes, southern Kamchatka: Bull. Volc.Stn., no. 30, p. 139-151. (R)
Kirsanov, I. T., 1981, Eruption of Gorely volcano in 1980: Vulkanol. i Seismol., no. 1, p. 70-74. (R)
Kirsanov, I. T., Ogorodov, N. V., Chirkov, A. M., 1964, State of the Mutnovsky and Gorely volcanoes for period from November 1960 up to June 1961: Bull. Volc. Stn., no. 36, p. 37-39. (R)
Kirsanov, I. T., and Ozerov, A. Yu., 1983, Composition of products and energy effects of the eruption of Gorely volcano, 1980-81: Volcanol. i Sesimol., no. 1, p. 25-42. (R)
Kozhemyaka, N. N., 1979, Quaternary pumice, tuff-ignimbrites fields and centers of eruptions in southern Kamchatka: Bull. Volc. Stn., no. 57, p. 26-38. (R)
Kozhemyaka, N. N., Ogorodov, N. V., Litasov, N. E., 1973, Geological effect and some specific features of Quaternary volcanism in southern Kamchatka: Bull. Volc. Stn., no. 49, p. 65-69. (R)
Kulakov, V. S., 1935, Volcanological observations on Kamchatka: source unknown. (R)
Novograblenov, P. T., 1930, Eruption of Gorely volcano in 1929-30: Zapisky Russ. Geogr. Soc., vol. 62, fasc. 4, p. 459-461. (R)

Popkov, V. F., and Sosunov, N. F., 1941, Activity of Avachinsky and Mutnovsky volcanoes for the first quarter of 1939: Bull. Volc. Stn., no. 9, p. 3-4. (R)
Smithsonian Institution, Scientific Event Alert Network (SEAN), 1980, Gorely Khrebet: SEAN Bulletin, v. 5:7.
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Vlodavets, V. I., and Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.
Volcanological Society of Japan, 1982, Gorely Khrebet: Bulletin of Volcanic Eruptions, No. 20, p. 62.
Voyage around the world, carried out by the order of His Majesty Emperior Nicolas I on a military boat "Seniavin" in 1826, 1827, 1828, and 1829 by fleet captain Fedor Litke, Pt. 3 compiled by Alexander Postels, SPB, 1836. (R)

4.6. Opala volcano:

Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)
Kozhemyaka, N. N., 1979, Quaternary pumice, tuff-ignimbrites fields and centers of eruptions in southern Kamchatka: Bull. Volc. Stn., no. 57, p. 26-38. (R)
Kozhemyaka, N. N., Ogorodov, N. V., Litasov, N. E., 1973, Geological effect and some specific features of Quaternary volcanism in southern Kamchatka: Bull. Volc. Stn., no. 49, p. 65-69. (R)
Krayevaya, T. S., Braitseva, O. A., Sheimovich, V. S., Egorova, I. A., Lupikina, E. G., 1979, Deposits of Quaternary calderas of Kamchatka: Vulkanol. i Seismol., no. 4, p. 3-11. (R)
Novograblenov, P. T., 1932, Catalogue of Kamchatka volcanoes: Zapisky Russ. Geogr. Soc., vol. 64, fasc. 1, p. 88-99. (R)
Sheimovich, V. S., Patoka, M. G., 1979, Opala volcano and other Holocene centers of acid explosive eruptions in south Kamchatka: Vulkanol. i Seismol., no. 5, p. 92-95. (R)
Sgibnev, A., 1869, Historical sketch of the main events on Kamchatka: Marine Digest, nos. 6, p. 37-70, and 7, p. 1-130, SPB. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Vlodavets, V. I., and Piip, B. I, 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.
Voyage around the world carried out by the order of His Majesty Emperior Nicolas I on a military boat "Seniavin" in 1826, 1827, 1828, and 1829 by fleet captain Fedor Litke, Pt. 3 compiled by Alexander Postels, SPB, 1836. (R)

4.7. Bolshe-Banny ring structure:

Belousov, V. I., 1967, Geological structure of the hydrothermal systems of Kamchatka: Bull. Volcanol., v. 30, p. 63-73.
Erlich, E. N. and Gorshkov, G. S., eds., 1979, Quaternary volcanism and tectonics in Kamchatka: Bull. Volcanol., v. 41:1 (special issue), 298 pp.

Erlich, E. N., Trukhin, Yu. P., 1969, Example of mapping of Neogene-Quaternary thicknesses of one of the regions in southeastern Kamchatka, in: Metodika kartirovania vulkan. formatsii, Moscow, Nauka Press, p. 97-100. (R)
Kovalenko, V. Ya., Evtukhov, A. D., Krayevoy, Yu. A., 1969, Bolshe-Bannaya hydrothermal system in Kamchatka, in: Vulkanizm, gidrotermy i glubiny Zemli, Petropavlovsk-Kamch., p. 105-106. (R)
Krayevoy, Yu. A., Kovalenko, V. Ya., Evtukhov, A. D., 1971, Bolshe-Banny hydrothermal system in Kamchatka, in: Vulkanizm i glubiny Zemly, Materialy 3 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 246-253. (R)
Lonshakov, E. A., 1979, Rows of volcano-tectonic structures and structural matter paragenesis of the South Kamchatka region: Bull. Volc. Stn., no. 57, p. 79-91. (R)
Novograblenov, P. T., 1929, The hot springs in the basin of Bannaya River: Izv. Vses. Geograph. obsch., v. 61, iss 1, p. 41-58. (R)
Serezhnikov, A. I., 1969, Associations of volcanic manifestations in the region of Bolshe-Banny deposit of the overheated waters and Karymshina geothermal springs (South Kamchatka), in: Vulkanizm, gidrotermi i grubing Zemli, Petropavlovsk-Kamchat., p. 102-103. (R)

V. EASTERN KAMCHATKA

5.1. Avachinsky volcano:

Balesta, S. T., 1970, Diffraction of seismic waves in magma chamber and structure and state of the metter within Avachinsky volcano magma chamber: Bull. Volc. Stn., no. 46, 3 p. (R)
Bogdanowitsch, K., 1904, Geologische Skizze von Kamtschatka: Petrm. Geogr. Mitt., H. 3, 34 pp.
Ditmar, K. von., 1900, Reisen und Aufenthalt in Kamtschatka in dar Jahren 1851-1855: Beitr. Russ Reich., Bd. 8., 273 pp. (G)
Dmitriev, L. B., 1967, Repeated geodetic works of Avacha volcano: Bull. Volc. Stn., no. 43, p. 9-23. (R)
Dmitriev, L. B., 1970, Changing of the height of repers of Avacha proving ground in 1967-1968: Bull. Volc. Stn., no. 46, p. 9-15. (R)
Dmitriev, L. B., 1971, Recent volcano-tectonic movements on Avachinsky volcano, in: Vulkanizm i glubiny Zemly, Materialy 3 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 120-122. (R)
Fedotov, S. A., Balesta, S. T., Droznin, V. A., Masurenkov, Yu. P., Sugrobov, V. M., 1977, About possibility of usage of heat of magma chamber of the Avachinsky volcano: Bull. Volc. Stn., no. 53, p. 27-37. (R)
Fedotov, S. A., Farberov, A. I., 1966, On the shiuelding of the transversal seismic waves in magmatic chamber and the Upper Mantle in the region of Avachinsky group of volcanoes, in: Vulkanizm i glubinnoe stroenie Zemli, Trudy 2 Vsesoyuz. Vulkan. sovesch., vol. III, Moscow, Nauka Press, p. 43-48. (R)
Gavrilov, V. A., Malkin, A. P., Chebrov, V. N., Sorokin, V. V., 1978, Radiotelemetric system of collection of seismic information on Avachinsky-Koriaksky proving ground: Bull. Volc. Stn., no. 54, p. 22-26. (R)
Glavatsky, S. N., 1948, Observations on Avachinsky, Koriaksky and Mutnovsky volcanoes in 1945: Bull. Volc. Stn., no. 14, p. 8-13. (R)

Gorel'chik, V. I., 1970, Distribution of earthquakes foci in region of Avacha-Koriaka and Zhupahovsky groups of volcanoes in 1964-1967: Bull. Volc. Stn., no. 46, p. 3-9. (R)
Gorel'chik, V. I., 1978, On the registration of weak earthquakes in the region of Avachinsky volcano: Bull. Volc. Stn., no. 54, p. 9-21. (R)
Gorel'chik, V. I., Basharina, L. A., Dmitriev, L. B., 1972, Regime observations of Avacha volcano in 1970: Bull. Volc. Stn., no. 48, p. 3-21. (R)
Gorel'chik, V. I., Dmitriev, L. B., Meniaylov, I. A., 1971, State of Avachinsky volcano in 1969: Bull. Volc. Stn., no. 47, p. 23-29. (R)
Kirsanov, I. T., 1964, State of active volcanoes of southern and central Kamchatka for period from June 1961 up to July 1962: Bull. Volc. Stn., no. 36, p. 39-48. (R)
Kirsanov, I. T., 1964, Volcanoes of southern and central Kamchatka in 1963: Bull. Volc. Stn., no. 37, 3 p. (R)
Kirsanov, I. T., 1964, Activity of Avachinsky and Koriaksky volcanoes for period from October 1959 up to June 1961: Bull. Volc. Stn., no. 35, p. 9-22. (R)
Kirsanov, I. T., Medvedeva, G. G., Serafimova, E. K., 1964, Fumarolic activity of Avacha and Koriaka volcanoes: Bull. Volc. Stn., no. 38, p. 3. (R)
Krasheninnikov, S. P., 1755, Description of Kamchatka. (R)
Melekestsev, I. V. and Kiryanov, V. Yu., 1984, When Avacha volcano in Kamchatka will erupt: Vulkanol. i seismol., no. 2, p. 107-110. (R)
Meniaylov, A. A., 1939, Eruption of Avacha volcano in 1939: Bull. Volc. Stn., no. 6, p. 3-20. (R)
Meniaylov, A. A., Sosunov, N. F., 1939, The activity of Avachinsky and Mutnovsky volcanoes (April-September 1938): Bull. Volc. Stn., no. 7, p. 9-18. (R)
Meniaylov, A. A., and Sosunov, N. F., 1940, Activity of Avacha and Mutnovsky volcanoes from October 1 up to December 31, 1938: Bull. Volc. Stn., no. 8, p. 41-43. (R)
Nowograblenow, P. and Tschirwinsky, P., 1928, Der Vulkan Avatschinsky in Kamtschatka und die Produkte seines Ausbruches vom 28 Morz 1926: Z.d. deutsch. geol. Ges., p. 483-496. (G)
Novograblenov, P. T., 1932, Catalogue of Kamchatka volcanoes: Zapisky Russ. Geogr. Soc., v. 64, fasc. 1. (R)
Piip, B. I., 1941, Eruption of Avacha volcano in 1938: Bull. Volc. Stn., no. 10, p. 9-12. (R)
Piip, B. I., 1946, On the burning aglomerate flows of Avacha and type of eruptions of this volcano: Bull. Volc. Stn., no. 12, p. 14-18. (R)
Piip, B. I., 1953, The eruption of Avachinsky volcano in 1945: Bull. Volc. Stn., no. 17, p. 3-6. (R)
Popkov, V. F. and Sosunov, N. F., 1941, Activity of Avachinsky and Mutnovsky volcanoes for the first quarter of 1939: Bull. Volc. Stn., no. 9, p. 3-5. (R)
Ryndin, E. A., Chirkov, A. M., Steinberg, G. S., 1964, Magnetic survey on the Avacha volcano: Bull. Volc. Stn., no. 38, p. 3-33. (R)
Sirin, A. N. and Timerbaeva, K. M., 1956, Ascent on the Avacha volcano in September 1954: Bull. Volc. Stn., no. 24, p. 21-28. (R)
Sosunov, N. F., 1941, Observations for activity of Avachinsky and Mutnovsky volcanoes from April 1 to June 1, 1939: Bull. Volc. Stn., no. 10, p. 5-9. (R)
Sosunov, N. F., 1946, The activity of Avachinsky and Mutnovsky volcanoes (from June 1940 up to March 1941): Bull. Volc. Stn., no. 12, p. 79-80. (R)

Sosunov, N. F., 1947, Observations for activity of Avachinsky and Mutnovsky volcanoes from June 2 up to October 1, 1939: Bull. Volc. Stn., no. 11, p. 3-11. (R)

Steinberg, G. S., 1966, Geological structure of Avacha volcano by geophysical data, in: Vulkanizm i glubiny Zemli, v. 3, Moscow, Nauka Press, p. 49-56. (R)

Steinberg, G. S., Balesta, S. T., Zubin, M. I., Tarakanovsky, A. A., 1966, Geological structure of the Avachinsky volcano by geophysical data, in: Vulkanizm i glubinnoye stroyenie Zemli, Trudy 2 Vsesoyuz. Vulk. sovesch., v. III, Moscow, Nauka Press, p. 49-55. (R)

Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)

Telegramms about eruption of Avachinsky volcano, 1939: Bull. Volc. Stn., no. 5, 3 pp. (R)

Tokarev, P. I., 1971, On the long term prediction of eruptions of Avachinsky volcano: Bull. Volc. Stn., no. 48, p. 29-33. (R)

Tokarev, P. I., Shirokov, V. A., 1977, State and seismic regime of Avachinsky volcano in 1971-1973: Bull. Volc. Stn., no. 53, p. 46-52. (R)

Vlodavets, V. I., and Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.

Voyage around the world, carried out by the order of His Majesty Emperor Nicolas I on a military boat "Seniavin" in 1826, 1827, 1828, and 1829 by fleet captain Feodor Litke, Pt. 3, compiled by Alexander Postels, SPB, 1836. (R)

Zavaritsky, A. N., 1935, Avacha volcano on Kamchatka and its state in summer of 1931: Trudy Centr. Sci. Res. Geol. Prosp. Inst., fasc. 35, p. . (R)

Zavaritsky, A. N., 1977, Avacha volcano in Kamchatka: Moscow, Nauka Press, 308 pp. (R)

Zubin, M. I., Fedorov, M. V., Chirkov, A. M., Steinberg, G. S., 1964, Crater of the Avachinsky volcano and its state in summer 1961: Bull. Volc. Stn., no. 36, p. 17-24. (R)

5.2. Zhupanovsky (Karymsky) volcano-tectonic depression:

5.2.1. Polovinka volcano-tectonic depression: - Calderas of volcanoes Akademii Nauk (Karymsky Lake), Karymsky and Dvor

Borovik, S. A., Vlodavets, V. I., 1946, Distribution of elements in some lavas of Karymsky region: Bull. Volc. Stn., no. 13, p. 22-23. (R)

Braitseva, D. A., Egorova, I. A., Sulerzhitsky, L. D., 1979, Tephrochronological study of Karymsky volcano: Vulkanol. i seismol., no. 1, p. 48-58. (R)

Chirkov, A. M., 1970, Karymsky volcano in 1967-1968: Bull. Volc. Stn., no. 46, p. 33-42. (R)

Chirkov, A. M., 1971, On the content of radon-222 in hydrotherms of Kamchatka: Doklady Ac. Nauk USSR, v. 199, no. 1, p. 202-203. (R)

Chirkov, A. M. 1971, Radon in gases some volcanoes and hydrothermal systems of Kamchatka, in: Vulkanizm i glubiny Zemli, p. 359-363. (R)

Chirkov, A. M. 1975, Radon as a possible criterion for predicting eruptions as observed at Karymsky volcano: Bull. Volcanol. v. 39, p. 126-131.

Ditmar, K. von, 1900, Reisen und Aufenthalt in Kamtschatka in den Jahren 1851-55: Beitr. Russ. Reich., no. 8, 273 pp. (G)

Dubik, Yu. M., Ogorodov, N. V., Abdurakhmanov, A. I., Khrenov, A. P., Tokarev, P. I., Firstov, P. P., Shirokov, V. A., Lemzikov, V. K., 1972, The beginning of the new eruptive cycle of activity of Karymsky volcano in May 1970: Bull. Volc. Stn., no. 48, p. 3-20. (R)

Erlich, E. N., 1966, New data about volcano-tectonic structure of Kamchatka and problems of Ouarternary volcanism evolution: Geotectonika, no. 6, p. 48-63. (R)

Erlich, E. N., Melekestsev, I. V., Tarakanovsky, A. A., Zubin, M. I., 1972 (1973), Quaternary calderas of Kamchatka: Bull. Volcanol. v. 36, no. 1, p. 222-237.

Firstov, P. P., Chirkov, A. M., 1978, Radon in spontaneous gas of thermal spring of Karymsky volcano (1966-1975): Bull. Volc. Stn., no. 54, p. 35-40. (R)

Firstov, P. P., Lemzikov, V. K., and Feofilaktov, V. D., 1978, The seismic regime of Karymsky volcano in 1975 and some problems of forecasting of time of the terminal eruptions: Bull. Volc. Stn., no. 54, p. 27-34. (R)

Firstov, P. P., Lemzikov, V. K., and Rulenko, O. P., 1977, The seismic regime of Karymsky volcano, 1970-73, in: Avdeiko, G. P., ed., Vulkanizm i Geodynamika, Nauka Press, Moscow, p. 161-178. (R)

Firstov, P. P., Tokarev, P. I., Gusev, N. A., Rulenko, O. P., Simbirev, I. B., 1978, Dynamics of eruption and seismic regime of Karymsky volcano in 1976: Bull. Volc. Stn., no. 55, p. 27-34. (R)

Firstov, P. P., Tokarev, P. I., Lemzikov, V. K., 1978, Filming of outbursts and scheme of explosive process of the Karymsky volcano: Bull. Volc. Stn., no. 55, p. 151-157. (R)

Gorel'chik, V. I., 1964, Seismological study of activity of the Karymsky volcano: Bull. Volc. Stn., no. 36, p. 3-17. (R)

Gorshkov, G. S., 1962, Notes on the eruption of Karymsky volcano in 1960: Bull. Volc. Stn., no. 32, p. 20-24. (R)

Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)

Ivanov, B. V., 1967, Present-day formation of illow lavas under subaerial conditions of Karymsky volcano: Intern. Geol. Rev., iss. 9, no. 8, p. 1036-1041

Ivanov, B. V., 1969, Specific features of zones of the acid volcanism on the example of Karymsky ring structure in Kamchatka, in: Vulkanizm, gidrotermy i glubiny Zemli, Petropavlovsk-Kamch., p. 61. (R)

Ivanov, B. V., 1969, Geological and energetical effect of eruption of Karymsky volcano in 1962-65, in: Vulkany i izverzheniya, Moscow, Nauka Press, p. 94-97. (R)

Ivanov, B. V., 1969, Ignimbrites of region of Karymsky volcanic group, in: Vulkanicheskii fatsii Kamchatki, Moscow, Nauka Press, p. 105-109. (R)

Ivanov, B. V., 1970, The eruption of Karymsky volcano in 1962-65, and the volcanoes of Karymsky group: Moscow, Nauka Press, 135 pp. (R)

Ivanov, B. V., 1974, Recent hydrothermal activity in the region of Karymsky volcano group, in: Gidrotermalnii mineraloobraz. rastvory oblastey aktivnogo vulkanizma, Novosibirsk, Nauka Press, p. 32-38. (R)

Ivanov, B. V., Fedorov, M. V., 1964, The eruption of Karymsky volcano in 1962: Bull. Volc. Stn., no. 36, p. 1-3. (R)

Ivanov, B. V., Fedorov, M. V., Kirsanov, I. T., 1966, The Karymsky volcano and specific features of its eruption in 1962-1963, in: Sovremenny vulkanizm, Trudy 2 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 36-45. (R)

Ivanov, B. V., Kirsanov, I. T., Serafimova, E. K., Skripko, K. A., Fedorov, M. V., 1965, Karmysky volcano in 1963: Bull. Volc. Stn., no. 39, 3 pp. (R)
Ivanov, B. V., Shuvalov, R. H., 1971, Recent hydrothermal activity in the region of Karymsky volcano: Bull. Volc. Stn., no. 47, p. 58-65. (R)
Khrenov, A. P., Dubik, Yu. M., Ivanov, B. V., Ovsyannikova, A. A., Pilipenko, V. P., Taran, Yu. A., Firstov, P. P., Chirkov, A. M., 1982, Eruptive activity of Karymsky volcano for 10 years (1970-80): Vulkanol. i seismol., no. 4, p. 29-48. (R)
Kirsanov, I. T., Ogorodov, N. V., Fedorov, M. V., Chirkov, A. M., 1964, State of Karymsky volcano in 1960-1961 and products of its eruptions: Bull. Volc. Stn., no. 35, p. 3-9. (R)
Kulakov, V. S., 1936, On the activity of Kamchatka volcanoes: Nature, no. 8, p. 21-28. (R)
Leonova, L. L., Udaltsova, N. I., Ivanov, B. V., 1971, Radioactive (U,Th) and rare alkaline (Li, Rb, Cs) elements in rock of Karymsky volcano (Kamchatka), in: Vulkanizm i glubiny Zemli, Materialy 3 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 181-185. (R)
Maguskin, M. A., 1978, Displacements of the earth's surface in region of Karymsky volcano by measurement in 1972-74, in: Sovremenie dvizheniya zemnoy kory, Issledovaniya na geodinam. polygonakh, Novosibirsk, p. 49-50. (R)
Maleev, E. F., 1968, Charter of pyroclastic of volcano-strombolian blasts of Karymsky volcano: Bull. Volc. Stn., no. 44, p. 45-48. (R)
Masurenkov, Yu. P., ed., 1980a, Vulkanichesky center: structura, dynamika i veschestvo. Karymskaya struktura: Moscow, Nauka Press, 300 pp. (R)
Masurenkov, Yu. P., Goritsky, Yu. A., Stolyarenko, D. A., 1981, Checking of the hypothesis about connection between geologic-structural and chemical data for volcanic center (on the example of the Karymsky center): Vulkanol. i seismol., no. 3, p. 41-46. (R)
Menlaylov, A. A., Solov'ev, N. A., 1939, The activity of Karymsky and Zhupanovsky volcanoes (from 18 to 30 June, 1938): Bull. Volc. Stn., no. 7, p. 18-20. (R)
Rulenko, O. P., Lipkova, A. V., Kodnyanskaya, L. I., 1981, Changing of SO_2 gas concentration in the air of cities Petropavlovsk in Kamchatka and Elizovo connected with activity of Karymsky volcano in 1979: Vulkanol. i seismol., no. 4, p. 105-108. (R)
Seliangin, O. B., 1974, Karymsky group of volcanoes, in: Vulkany i gidrotermy Kamchatki, Moscow, Nauka Press, p. 105-137. (R)
Shilin, B. V., Zelenov, E. N., Rastorguev, N. G., Gruzdev, V. N., 1975, Study of active Karymsky volcano by infrared air-mapping: Izv. Ac. Sci. USSR, ser. geol., no. 3, p. 128-132. (R)
Sotnikov, I. I., Ivanov, B. V., Arnautov, N. V., 1971, Distribution of molybdenum in products of eruption of some volcanoes of Karymsky group, in: Vulkanizm i glubiny Zemly, Materialy 3 Vsesouz. Vulkan. sovesch., Moscow, Nauka Press, p. 313-317. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Tokarev, P. I., Firstov, P. P., 1967, Seismic studies of the Karymsky volcano: Bull. Volc. Stn., no. 43, p. 3-9. (R)
Tokarev, P. I., Firstov, P. P., 1977, The eruption of Karymsky volcano in 1970-1973. Geophysical studies, in: Vulkanizm ostrovnikh dug, Moscow, Nauka Press, p. 65-76. (R)
Tokarev, P. I., Firstov, P. P., Lemzikov, V. K., 1969, Seismic studies on the Karymsky volcano in 1966: Bull. Volc. Stn., no. 45, p. 12-21. (R)

Troitzky, V. D., 1947, Short geomorphological sketch of the Karymsky volcano region: Trudy Volc. Stn., fasc. 3, p 49-88. (R)
Vergasova, L. P., 1975, Minerals of exgalations of Karymsky volcano: Bull. Volc. Stn., no. 51, p. 36-43. (R)
Vlodavets, V. I., 1939, The Karymsky group of volcanoes: Bull. Volc. Stn., no. 7, 3 pp. (R)
Vlodavets, V. I., 1947, Volcanoes of the Karymsky group: Trudy Lab. Volc., fasc. 3, p. 47-48. (R)
Vlodavets, V. I., 1948, On the activity of Karymsky volcano in 1943-1947: Bull. Volc. Stn., no. 14, p. 13-17. (R)
Vlodavets, V. I. and Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.
Volcanological Society of Japan, 1973, 1978, Karymsky: Bulletin of Volcanic Eruptions, no. 11, p. 31-32, no. 16, 45 pp.
Zlobin, B. I., Ivanov, B. V., 1971, Distribution of copper in lavas of some volcanoes of the Karymsky group: Bull. Volc. Stn., no. 47, p. 72-76. (R)

5.2.2. Stena-Soboliny volcano-tectonic depression: Calderas of volcanoes Pra-Semiachik, Maly-Semiachik, Odnoboky, Soboliny.

Braitseva, O. A., Egorova, I. A., Nesmachny, I. A., Seliangin, O. B., Sulerzhitsky, L. D., 1978, Tephrochronological dating of lava complexes and reconstruction of history of forming of the recent volcano: Bull. Volc. Stn., no. 55, p. 41-53. (R)
Braitseva, O. A., Egorova, I. A., Nesmachny, I. A., Seliangin, O. B., Sulerzhitsky, L. D., 1978, Teophrochronological study as a method of investigation of regularity of volcano's cyclical development: Bull. Volc. Stn., no. 54, p. 41-52. (R)
Braitseva, O. A., Litasova, S. N., 1981, On the age of Karymsky and Maly Semiachik volcanoes: Vulkanol. i seismol., no. 3, p. 92-96. (R)
Ditmar, K. von, 1900, Reisen und Aufenthalt in Kamtschatka in den Jahren 1851-55: Beitr. Russ. Reich., no. 8, 273 pp. (G)
Gorshkov, A. P., 1976, Structure of volcanic edifice and some problems of dividing of volcanic regions (on the example of Maly Semiachik volcano): Bull. Volc. Stn., no. 52, p. 30-36. (R)
Gorshkov, A. P., Grebzdi, E. I., Samoilov, B. I., Slezin, Yu. B., 1975, To calculation of the heat and mass balance in the crater lake of Maly Seimachik volcano: Bull. Volc. Stn., no. 51, p. 43-50. (R)
Masurenkov, Yu. P., ed., 1980a, Vulkanicheskii tsentr: stroenie, dinamika, veschectvo: Karimskaia Struktura: Moscow, Nauka, 299 p. (R)
Novograblenov, P. T., 1932, Catalogue of Kamchatka volcanoes: Zapisky Russ. Geogr. Soc., v. 64, fasc. 1, p. 88-99. (R)
Polyak, B. G., Seliangin, O. B., Braitseva, O. A., 1979, Dynamics of Maly Semiachik volcano activity: Doklady Ac. Sci. USSR, 244, no. 1, p. 175-179. (R)
Seliangin, O. B., 1977, The evolution of the caldera complex, rithmicity and direction of the development of volcanic process within the Karymsky volcano group, Kamchatka, in: Audeiko, G. P., ed., Vulkanizm i geodynamika, Moscow, Nauka Press, p. 187-201. (R)
Seliangin, O. B., Braitseva, O. A., 1980, Regularities of development of volcano by geological and tephrochronological studies: 5 Vsesouzn. Vulkan. sovesch., Symp. 2, Abstr., Tbilisi, p. 190-191. (R)

Seliangin, O. B., Braitseva, O. A., Egorova, I. A., Sulerzhitsky, L. D., Nesmachny, I. A., 1979, Geological and tephrochronological study of recent volcano, in: Problemy glubinnogo magmatizma, Moscow, p. 31-49. (R)
Shavrova, N. N., 1958, Radon and Thorium content in lavas of the Semiachik volcanic group: Bull.Volcn.Stn., no. 17, p. 43-51. (R)
Sheimovich, V. S., Braitseva, O. A., Krayevaya, T. S., 1969, Quaternary ignimbrites of Semiachik region in Kamchatka, in: Vulkanizm, gidrotermy i glubiny Zemli, Petropavlovs-Kamch. p. 61-62. (R)
Sheimovich, V. S., Braitseva, O. A., Kraevaya, T. S., 1972, Regularities of structure and forming of the Quaternary ignimbrite thickness on the example of Semiachik region, in: Kisliy vulkanizm, Moscow, Nauka Press, p. 110-119. (R)
Skorokhodov, N. V., 1979, Dynamics of development of ring structures on the examples of Kamchatka volcanoes Uksichan, Krasheninnikov and Maly Semiachik, in: Problemi glubinnogo magmatizma, Moscow, Nauka Press, p. 117-124. (R)
Slezin, Yu. B., Kovalev, G. N., Grebzdi, E. I., Cheglezova, E. A., 1971, About activity Maly Semiachik volcano: Bull. Volc. Stn., no. 47, p. 33-37. (R)
Steinberg, G. S., 1966, About caldera of Maly Semiachik: Bull. Volc. Stn., no. 41, p. 29-30. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Vlodavets, V. I., 1962, Sur les causes provoquant de diverses evolutions de la composition des lavas des volcans Mali Semiatchik et Karymsky: Bull. Volcanol., t. XXIV, p. 167-170. (F)
Vlodavets, V. I., Morozov, A. I. and Troitzky, V. D., 1948, Maly Semiachik volcano: Bull. Volc. Stn., no. 14, p. 17-19. (R)
Vlodavets, V. I., and Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.

5.3. Centralny Semiachik (Great Semiachik, Burlyaschy):

Aver'ev, V. V., Vakin, E. A., 1966, Thermal fields of the volcanic massif Great Semiachik: Bull. Volc. Stn., no. 42, p. 3-16. (R)
Erlich, E. N., 1966, New data about volcano-tectonic structures of Kamchatka and problems of Quaternary volcanism evolution: Geotectonika, no. 6, p. 48-63. (R)
Erlich, E. N., and Gorshkov, G. S., eds., 1979, Quaternary volcanism and tectonic in Kamchatka: Bull.Volcanol., v. 42:1, (special issue), 298 pp.
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)
Kurenkov, I. I., 1960, Warm springs on the shore of Semiachik estuary: Bull. Volc. Stn., no. 29, p. 47-51. (R)
Piip, B. I., 1937, Thermal springs of Kamchatka: SOPS, USSR Ac. of Sci., Kamchatka ser., fasc. 2, 268 pp. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Vlodavets, V. I., 1949, Volcanoes of the Soviet Union: Moscow, Geogr. Publ. House, 163 pp. (R)
Vlodavets, V. I., 1953, On some Semiachinsky tuff lavas and their origin: Trudy Lab. Volc., no. 3, Moscow, Ac. Sci. Press, p. 96-106. (R)

Vlodavets, V. I., 1958, Volcanoes and volcanic formations of Semiachinsky region: Trudy Lab. Volc., no. 15, Moscow, Ac. Sci. Press, 193 pp. (R)
Vlodavets, V. I., and Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.

5.4. Uzon-Geyzernaya caldera:

Aver'ev, V. V., Bogoyavlenskaya, G. E., Braitseva, O. A., Vakin, E. A., Pilipenko, G. F., 1971, Volcanism and hydrotherms of Uzon-Semiachik geothermal region in Kamchatka, in: Vulkanizm i glubiny Zemli, Moscow, Nauka Press, p. 207-211. (R)
Belousov, V. I., Ivanov, B. V., 1967, Pumice formations in the area Uzon depression-Geyzernaia valley in Kamchatka: Bull.Volcanol. v. 30, p. 75-79.
Belousov, V. I., Vinogradov, V. N., 1964, Geizer valley, in: Guide book of excursions of the 2nd Volcanological Congress, Petropavlovsk in Kamchatka. (R)
Beskrovny, N. S., Naboko, S. I., Glavatskikh, S. F., Ermakov, V. I., Lebedev, B. A., Taliev, S. D., 1971, On the oil-bearings of hydrothermal systems, connected with volcanism: Geologia i Geophisika, no. 2, p. 3-14. (R)
Braitseva, O. A., Bogoyavlenskaya, G. E., Erlich, E. N., Pilipenko, G. F., Karpov, G. A., 1974, Uzon-Semiachik volcanic region, in: Vulkany i gidrotermy Kamchatki: Moscow, Nauka Press, p. 139-191. (R)
Chirkov, A. M., 1971, On the content of radon-222 in hydrotherms of Kamchatka: Doklady Ac. Sci. USSR, v. 199, no. 1, p. 359-363. (R)
Chirkov, A. M., 1971, Radon in gases of zone volcanoes and hydrothermal system of Kamchatka, in: Vulkanizm i glubiny Zemli, p. 202-203. (R)
Ditmar, K. von, 1900, Reisen und Aufenthalt in Kamtschatka in den Jahren 1851-55: Beitr. Russ. Reich., no. 8, 273 pp. (G)
Erlich, E. N., 1966, New data about volcano-tectonic structures of Kamchatka and problems of Quaternary volcanism evolution: Geotectonika, no. 6, p. 48-63. (R)
Erlich, E. N., Melekestsev, I. V., Tarakanovsky, A. A., Zubin, M. I., 1972 (1973), Quaternary calderas of Kamchatka: Bull. Volcanol., v. 36, no. 1, p. 222-237.
Florensky, I. V., 1984, On the question of the age of Uzon and Krasheninnikov calderas: Vulkanol. i seismol., no. 1, p. 102-106. (R)
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)
Karpov, G. A., 1980, On the dynamics of recent hydrothermal process (on the example of Uzon caldera, Kamchatka): 5 Vsesouzn. Vulkan. sovesch. Symp. 2, Abstr., Tbilisi, p. 161-162. (R)
Komarov, V. L., 1912, Voyage to Kamchatka in 1908-1909, Kamchatka expedition of F. P. Riabushinsky, Botanical dept., fasc. 1, 458 pp. (R)
Meniaylov, I. A., 1974, Heavy hydrocarbons and metals in gases of Uzon steam-hydrotherms, in: Gidroterm. mineraloobraz. rastvori oblastey activnogo vulkanizma, Nauka, Novosibrisk, p. 133-135. (R)
Naboko, S. I., 1954, On the evaporation of gases condensate in the region of geizers: Bull. Volc. Stn., no. 22, p. 59-65. (R)
Naboko, S. I., 1954, Geizers of Kamchatka: Trudy Lab. Volc., iss. 8, p. 126-209. (R)

Naboko, S. I., Glavatskikh, S. F., 1971, Recent mercury-stibuite-arsenikum sulphide mineralization on Uzon (Kamchatka), in: Vulkanizm i glubiny Zemli, Moscow, Nauka Press, p. 299-305. (R)
Naboko, S. I., Glavatskikh, S. F., 1978, High-silice zeolithes in Geizers Valley in Kamchatka: Bull. Volc. Stn., no. 55, p. 101-106. (R)
Novograblenov, P. T., 1932, Catalogue of Kamchatka volcanoes: Zapisky Russ. Geogr. Soc., v. 64, fasc. 1, p. 88-99. (R)
Piip, B. I., 1937, Thermal springs of Kamchatka: SOPS, USSR Ac. of Sci., Kamchatka ser., fasc. 2, 268 pp. (R)
Piip, B. I., 1961, Ignimbrites of Kronotsky region, Kamchatka: Trudy, Lab. Volc., iss. 20, p. 90-91. (R)
Piip, B. I., 1963, Kronotsky ignimbrites in Kamchatka: Bull.Volcanol., iss. 25, p. 31-32.
Pilipenko, G. F., 1969, Hydrochemical differentiation of overheated waters of Uzon caldera in unloading area, in: Vulkanizm, gidrotermy i glubiny Zemli, Petropavlovsk-Kamch. p. 99-100. (R)
Pilipenko, G. F., 1971, Hydrothermical anomalie of Uzon thermal field, Kamchatka, in: Vulkanizm i glubiny Zemli, Moscow, Nauka Press, p. 228-238. (R)
Pilipenko, G. F., 1974, Hydrotherms of Uzon caldera, in: Gidrotermalniye mineraloobraz. rastvory oblastey aktivnogo vulkanizma, Novosibirsk, Nauka Press, p. 24-32. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Ustinova, T. L., 1946, Geizer in the valley of Shumnaya river: Bull. Volc. Stn., no. 12, p. 80-81. (R)
Ustinova, T. I., 1955, Geizers of Kamchatka: Moscow, Ac. Sci. Press, 199 pp. (R)
Vlodavets, V. I. and Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.

5.5. Krasheninnikov volcano:

Erlich, E. N., Melekestsev, I. V., Tarakanovsky, A. A., Zubin, M. I., 1972 (1973), Quaternary calderas of Kamchatka: Bull. Volcanol., v. 36, no. 1, p. 222-237.
Erlich E. N., and Gorshkov, G. S., eds., 1979, Ouaternary volcanism and tectonic in Kamchatka: Bull. Volcanol., v. 42:1 (special issue), 298 pp.
Florensky, I. V., 1984, On the question of the age of Uzon and Krasheninnikov calderas: Vulkanol. i seismol., no. 1, p. 102-106. (R)
Frolova, M. L., 1974, Region of Kronotskaya sopka and Krasheninnikov volcano, in: Vulkany i gidrotermy Kamchatki: Moscow, Nauka Press, p. 193-223. (R)
Komarov, V. L., 1912, Voyage to Kamchatka in 1908-1909, Kamchatka expedition of F. P. Riabushinsky: Botanical Dept., fasc. 1., 458 pp. (R)
Novograblenov, P. T., 1932, Catalogue of Kamchatka volcanoes: Zapisky Russ. Geogr. Soc., v. 64, fasc. 1, p. 88-99. (R)
Scherbakov, A. V., 1941, Geological investigations along the route from village Kirganik to village Khalaktyrka: SOPS, Ac. Sci. USSR, Trans. Kamch. complex. exped. 1936-1937, fasc. 3., p. 55-81. (R)

Schmidt, P. Yu., 1916, Work of the zoological department on Kamchatka in 1908-1909, Kamchatka expedition of F. P. Riabushinsky, Zool. Dept., Moscow, fasc. 1., 468 pp. (R)
Skorokhodov, V. N., 1978, Main features of evolution of the Krasheninnikov volcano (Eastern Kamchatka), in: Voprosy izucheniya osadochnoyi obolochky Zemli, Novosibirsk, p. 26-36. (R)
Skorokhodov, V. N., 1979, Dynamics of development of ring structures on the example of Kamchatka volcanoes Uksichan, Krasheninnikov and Maly Semiachik, in: Problemi glubinnogo magmatizma, Moscow, Nauka Press, p. 117-124. (R)
Steinberg, G. S., 1964, On the activity and structure of the Krasheninnikov volcano: Bull. Volc. Stn., no. 37, p. 3-16. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Ustinova, T. L., 1948, Krasheninnikov volcano: Izvestia Georg. obsch. USSR, v. 80, no. 4, p. 421-432. (R)
Vlodavets, V. I. and Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.

VI. CENTRAL KAMCHATKA DEPRESSION

6.1. Plosky Tolbachik volcano:

Abramov, V. A., Volinets, O. N., Petrov, L. L., Flerov, G. B., 1978, On the geochemical model of the Great Fissure Tolbachik eruption by data of kinetics of basaltic melts mixing: Bull. Volc. Stn., no. 55, p. 3-12. (R)
Alypova, O. M., 1964, On the magnetic field in crater of Plosky Tolbachik: Bull. Volc. Stn., no. 38, p. 45-62. (R)
Erlich, E. N., 1966, New data about volcano-tectonic structures of Kamchatka and problems of Quaternary volcanism evolution: Geotectonika, no. 6, p. 48-63. (R)
Erlich, N. E., Melekestsev, I. V., Tarakanovsky, A. A., Zubin, M. I., 1972 (1973), Quaternary calderas of Kamchatka: Bull. Volcanol., v. 36, no. 1, p. 222-237.
Ermakov, V. A., Vazheevskaya, A. A., 1973, Volcanoes Ostry and Plosky Tolbachiks: Bull. Volc. Stn., no. 49, p. 36-43. (R)
Fedotov, S. A., ed., 1984, Large Tolbachik Fissure Eruption: Kamchatka 1975-76: Moscow, Nauka, 637 p. (R)
Fedotov, S. A., Markhinin, E. K., eds., 1983, The Great Tolbachik Fissure eruption, geological and geophysical data 1975-1976: Cambridge Univ. Press, 341 pp.
Fedotov, S. A., Gorel'chik, V. I., Stepanov, V. V., 1979, Seismological data on mechanism and development of the Great Fissure Tolbachik eruption in 1975-1976: Bull. Volc. Stn., no. 56, p. 3-14. (R)
Guschenko, I. I., 1979, Eruptions of volcanoes of the World, a Catalog: Nauka Press, Moscow, 474 pp. (R)
Gusev, N. A., Dvigalo, V. I., Razina, A. A., 1979, Remote sensing methods in process of studying of Tolbachik eruption, in: Vulkanol. i seismol., no. 2, p. 27-42. (R)
Kirsanov, I. T., Ponomarev, G. P., 1974, Eruptions of Plosky Tolbachik volcano and some specific features of its products: Bull. Volc. Stn., no. 50, p. 45-53. (R)

Krasheninnikov, S. P., 1755, Description of Kamchatka, SPB. (R)
Kulakov, V. S., 1936, On the activity of Kamchatka volcanoes: Nature, no. 8, p. 21-28. (R)
Markhinin, E. K., 1964, Crater of Plosky Tolbachik volcano on September 6-8, 1962: Bull. Volc. Stn., no. 37, p. 34-35. (R)
Markhinin, E. K., Stratula, D. S., Abdurakhmanov, A. I., 1973, Wavy lava flows of Plosky Tolbachik: Bull. Volc. Stn., no. 49, p. 77-83. (R)
Meniaylov, A. A., 1953, State of Tolbachik volcano in 1946-48: Bull. Volc. Stn., no. 17, p. 32-41. (R)
Novograblenov, P. T., 1932, Catalogue of Kamchatka volcanoes: Zapisky Russ. Geogr. Soc., v. 64, fasc. 1, p. 88-99. (R)
Perrey, A. 1864, Docuements sur les tremblements de terre et les phenomenes volcaniques dans l'archipel des Kouriles et au Kamtschatka: Ann. Sci. phys. et natur, d'agricul. et d'indust., publiees par la Soc. imper. d'agricul. etc. de Lyon. 3 serie, t.8, Lyon, p. 209-374. (F)
Piip, B. I. 1946, Activity of Tolbachik volcano: Bull. Volc. Stn., no. 12, p. 69-70. (R)
Piip, B. I., 1954, Tolbachik volcano: Bull. Volc. Stn., no. 20, p. 64-69. (R)
Piip, B. I., 1956, Klyuchevskoy volcano and its eruptions in 1944-1945 and in the past: Trudy Lab. Volc., no. 11, 310 pp. (R)
Popkov, V. F., 1946, Volcanic activity of Plosky Tolbachik in 1940: Bull. Volc. Stn., no. 12, p. 29-54. (R)
Popkov, V. F., 1947, Observations for the activity of volcanoes Kliuchevskoy and Plosky Tolbachik from July 1, 1939 up to January 1, 1940: Bull. Volc. Stn., no. 11, 3 pp. (R)
Popkov, V. F., 1947, Macroseismic observations in the region of Kliuchevskoy and Plosky Tolbachik volcanoes from June 3, 1939 up to June 22, 1940: Bull. Volc. Stn., no. 11, p. 14-22. (R)
Pronin, A. A., Serafimova, E. K., Fedorov, M. V., 1970, Active crater of the Plosky Tolbachik volcano in 1965-1966: Bull. Volc. Stn., no. 46, p. 24-26. (R)
Rudich, K. N., Sirin, A. N., Timerbaeva, K. M., 1962, State of the Plosky Tolbachik volcano in August 1961: Bull. Volc. Stn., no. 32, p. 14-20. (R)
Sirin, A. N., Farberov, A. I., 1963, Eruption of the Plosky Tolbachik volcano in 1961-1962: Bull. Volc. Stn., no. 34, p. 3-8. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Telegramms about eruptions of Plosky Tolbachik and Zhupanovsky volcanoes, 1941: Bull. Volc. Stn., no. 10, p. 3-4. (R)
Telegramms about eruptions of Kamchatka volcanoes, 1946: Bull. Volc. Stn., no. 12, p. 81-84. (R)
Vlodavets, V. I., 1937, Visit to crater of the Plosky Tolbachik volcano on August 13, 1936: Bull. Volc. Stn., no. 2, p. 25-27. (R)
Vlodavets, V. I., 1940, Klyuchevskaya group of volcanoes: Trudy Kamch. Volc. Stn., fasc. 1, pp. unknown. (R)
Vlodavets, V. I. and Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.
Zavaritsky, A. N., 1935, Northern group of Kamchatka volcanoes: SOPS, USSR, Acad. Nauk, Kamchatka ser., fasc. 1, 54 pp. (R)

<u>6.2. Dalnaya Ploskaya volcano:</u>

Erlich, E. N., Melekestsev, I. V., Tarakanovsky, A. A., Zubin, M. I., 1972 (1973), Quaternary calderas of Kamchatka: Bull. Volcanol., v. 36, no. 1, p. 222-237.
Piip, B. I., 1956, Klyuchevskoy volcano and its eruptions in 1944-45 and in the past: Trudy Lab. Volc., no. 11, 310 pp. (R)
Sirin, A. N., 1968, On the connection between central and areal volcanism (on the example of Plosky volcano and scoric cones of Kliuchevsky dol on Kamchatka): Nauka Press, Moscow, 196 pp. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Vlodavets, V.I. and Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.
Zavaritsky, A. N., 1935, Northern group of Kamchatka volcanoes: SOPS, USSR, Acad. Nauk, Kamchatka ser., fasc. 1., 54 pp. (R)

6.3. Zarechny caldera volcano:

Erlich, E. N. and Gorshkov, G. S., eds., 1979, Ouaternary volcanism and tectonic in Kamchatka: Bull. Volcanol., v. 41:1 (special issue), 298 pp.
Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'nego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).
Meniaylov, A. A., 1949, Volcanoes of the Kharchinsky Mountains: Trudy Lab. Volc., v. 6, p. 53-61. (R)
Ogorodov, N. V. and Belovusov, V. I., 1961, Some new data on Kharchinsky and Zarechny volcanoes: Bull. Volcn. Stn., no. 31, p. 46-51. (R)
Piip, B. I., 1956, Klyuchevskoy volcano and its eruptions in 1944-1945 and in the past: Trudy Lab. Volc., no. 11, 310 pp. (R)

VII. SREDINNY RIDGE

7.1. Khangar volcano:

Bakumenko, I. T., Shugurova, N. A., Erlich, E. N., and Popova, N. M., 1970, Genesis of guarts from pumices of Khangar volcano: Doklady Acad. Nauk USSR, 191-3, p. 660-662. (R)
Erlich, E. N., 1960, On the evolution of Ouaternary volcanism in the Sredinny Ridge zone of Kamchatka: Izv. Acad. Sci. USSR, ser. geol., no. 2, p. 77-90. (R)
Erlich, E. N., Groshkov, G. S., eds., 1979, Quaternary volcanism and tectonic in Kamchatka: Bull. Volcanol., v. 41:1 (special issue), 298 pp.
Erlich, E. N., Kutyev, F. Sh., Zubin, M. I., Tarakanovsky, A. A., 1971, Acid volcanism of Khangar caldera: Symp. "Acid Volcan." XV IUGG General Assembly, Abstr. of reports, Moscow, Acad. Sci. Press, 242 pp.
Kutyev, F. Sh., Erlich, E. N., 1970, Native mercury in volcanic glasses of Khangar caldera, Kamchatka: Doklady Acad. Nauk USSR, v. 193, p. 916-917. (R)
Kutyev, F. Sh., Lebedev, M. M., Maximovsky, V. A., 1976, On the nature of volcano-tectonic structure Khangar: Izv. vysshykh uchebnykh zavedeniy, Geologia i Razvedka, n. 7, p. 35-46. (R)
Marenina, T. Yu., 1959, Khangar volcano in the Sredinny Ridge of Kamchatka: Trudy Lab. Volc., iss. 17, p. 3-65. (R)

Ogorodov, N. V., Kozhemyaka, N. N., Vasheevskaya, A. A., Ogorodova, A. S., 1972, Volcanoes and Quaternary volcanism of the Sredinny Ridge of Kamchatka: Moscow, Nauka Press, 190 pp. (R)
Puzankov, Yu. M., Volynets, O. N., Patoka, M. G., 1979, Geochemistry of products of eruptions of volcanoes Ichinsky and Khangar in connection with problem of acid magma: Vulkanol. i seismol., no. 6, p. 11-22. (R)
Svlatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)

7.2. Ichinsky volcano-tectonic depression:

Aprelkov, S. E., Ezhov, B. V., Patoka, M. G., Uspensky, V. U., 1978, Payalpan volcano-tectonic structure in Sredinny Ridge of Kamchatka, in: Regionalnaya morphotectonika, geomorphologia i chetvertichnaya geologia Dal'nego Vostoka, Vladivostok, p. 68-73. (R)
Bogdanowitsch, K., 1904, Geologische Skizze von Kamtschatka: Peterm. Geogr. Mitt., H. 3, 34 pp. (G)
Erlich, E. N., 1958, Ascent on the Ichinsky volcano: Bull. Volc. Stn., no. 27, p. 51-55. (R)
Erlich, E. N., 1960, On the evolution of Quaternary volcanism in the Sredinny Ridge zone of Kamchatka: Izv. Acad. Sci. USSR, ser. geol., no. 2, p. 77-90. (R)
Erlich, E. N., Gorshkov, G. S., eds., 1979, Quaternary volcanism and tectonic in Kamchatka: Bull. Volcanol., v. 42:1 (special issue), 298 pp.
Kulakov, V. S., 1936, On the activity of Kamchatka volcanoes: Nature, no. 8, p. 21-28. (R)
Marenina, T. Yu., 1961, Welded tuffs of Ichinsky volcano in the Sredinny Ridge of Kamchatka, in: Trudy Lab. Volc., iss 20, p. 108-116. (R)
Marenina, T. Yu., 1962, Ichinsky volcano in the Sredinny Ridge of Kamchatka: Trudy Lab. Volc., iss. 2, p. 3-65. (R)
Marenina, T. Yu., 1963, Specific features of petrochemistry of Ichinsky volcano lavas, Kamchatka, in: Osobennosty petrokhimii molodogo vulkanizma, Moscow, Acad. Nauk USSR Press, p. 71-74. (R)
Novograblenov, P. T., 1932, Catalogue of Kamchatka volcanoes: Zapisky Russ. Geogr. Soc., v. 64, fasc. 1, p. 88-99. (R)
Ogorodov, N. V., 1960, Some notes about Ichinsky volcano: Bull. Volc. Stn., no. 30, p. 17-24. (R)
Ogorodov, N. V., Kozhemyaka, N. N., Vazheevskaya, A. A., Ogorodova, A. S., 1972, Volcanoes and Quaternary volcanism of the Sredinny Ridge of Kamchatka: Moscow, Nauka Press, 190 pp. (R)
Patoka, M. G., 1978, Structural position of Ichinsky volcanic region: Bull. Volc. Stn., no. 55, p. 139-146. (R)
Puzankov, Yu. M., Volynets, O. N., Patoka, M. G., 1979, Geochemistry of products of eruptions of volcanoes Ichinsky and Khangar (Kamchatka) in connection with problem of acid magma: Vulkanol. i seismol., no. 6, p. 11-22. (R)
Sviatlovsky, A. E., 1959, Atlas of the volcanoes of the Soviet Union: Moscow, Ac. Sci. Press, 172 pp. (R)
Sviatlovsky, A. E., 1960, Ichinsky volcano in Kamchatka: Trudy Lab. Volc., no. 18, p. 35-42. (R)
Vlodavets, V. I., 1955, Alcuni risultati delle ricerche vulcanologiche nell' USSR: Bull. Volcanol., ser. 2, Tome 16, p. 147-160. (It.)

Vlodavets, V. I., Piip, B. I., 1959, Catalogue of active volcanoes of the World including solfatara areas, pt. VIII, Kamchatka and continental areas of Asia: Naples, IAVCEI, p. 1-98.

7.3. Uksichan volcano:

Erlich, E. N., 1960, On the evolution of Quaternary volcanism in the Sredinny Ridge zone of Kamchatka: Izv. Acad. Sci. USSR, ser. geol., no. 2, p. 77-90. (R)

Ogorodov, N. V., Kozhemyaka, N. N., Vazheevskaya, A. A., Ogorodova, A. S., 1967, Volcano Uksichan in the Sredinny Ridge of Kamchatka: Trudy of Inst. of Volcanol., iss. 24, p. 93-111. (R)

Ogorodov, N. V., Kozhemyaka, N. N., Vazheevskaya, A. A., Ogorodova, A. S., 1972, Volcanoes and Quaternary volcanism of the Sredinny Ridge of Kamchatka: Moscow, Nauka Press, 190 pp. (R)

Skorokhodov, V. N., 1979, Dynamics of development of ring structures on the example of Kamchatka volcanoes Uksichan, Krasheninnikov and Maly Semiachik, in: Problemi glubinnogo magmatizma, Moscow, Nauka Press, p. 117-124. (R)

7.4. Leningradets (Kekuknaysky) volcano:

Erlich, E. N., 1960, On the evolution of Quaternary volcanism in the Sredinny Ridge zone of Kamchatka: Izv. Acad. Sci. USSR, ser. geol., no. 2, p. 77-90. (R)

Ogorodov, N. V., Kozhemyaka, N. N., Vazheevskaya, A. A., Ogorodova, A. S., 1972, Volcanoes and Quaternary volcanism of the Sredinny Ridge of Kamchatka: Moscow, Nauka Press, 190 pp. (R)

7.5. Alney volcano-tectonic depression:

Kirsanova, T. P., 1971, Hydrotherms of the Kireun valley in the Sredinny Ridge of Kamchatka, in: Vulkanizm i glubiny Zemli, Moscow, Nauka Press, p. 239-245. (R)

Ogorodov, N. V., Kozhemyaka, N. N., Vazheevskaya, A. A., Ogorodova, A. S., 1972, Volcanoes and Quaternary volcanism of the Sredinny Ridge of Kamchatka: Moscow, Nauka Press, 190 pp. (R)

Okrugin, V. M., Shirokiy, B. I., 1976, Ore minerals of inclusions of solidificated magmatic melts in phenocrysts of rocks of the acid extrusive domes of Chashakondsha Volcano (Central Kamchatka): Bull. Volc. Stn., no. 52, p. 135-144. (R)

Ozerova, N. A., Aidin'yan, N. Kh., Dobrovolskaya, N. G., 1971, On the recent forming of mercury mineralization within Kurile-Kamchatka volcanic region, in: Vulkanizm i glubiny Zemli, Moscow, Nauka Press, p. 293-298. (R)

7.6. Chekchebonay volcano:

Daragan, E. V., Ilyina, G. A., 1976, Caldera-volcano Maly Chekchebonay, in: Magmatizm severo-vostochnoy Asii, Magadan, p. 136-142. (R)

Erlich, E. N., 1960, On the evolution of Quaternary volcanism in the Sredinny Ridge zone of Kamchatka: Izv. Ac. Sci. USSR, ser. geol., no. 2, p. 77-90. (R)

Ogorodov, N. V., Kozhemyaka, N.N., Vazheevskaya, A. A., Ogorodova, A. S., 1972, Volcanoes and Quaternary volcanism of the Sredinny Ridge of Kamchatka: Moscow, Nauka Press, 190 pp. (R)

VIII. GENERAL PROBLEMS CONNECTED WITH CALDERAS AND VOLCANO-TECTONIC DEPRESSIONS OF KAMCHATKA AND KURILES

Aver'ev, V. V., 1966, Hydrothermal process in volcanic regions and its connection with magmatic activity, in: Sovremenni vulkanizm, t. 1, Moscow, Nauka Press, p. 118-128. (R)

Belousov, V. I., 1967, Geological structure of the hydrothermal systems of Kamchatka: Bull. Volcanol., v. 30, p. 63-73.

Belousov, V. I., Sugrobov, V. M., 1977, On the connection between volcanism and hydrothermal activity in geothermal regions of Kamchatka, in: Vulkanism ostrovnikh dug, Moscow, Nauka Press, p. 110-115. (R)

Budanov, V. I., 1970, To the problem of mechanism of ring complex formation: Doklady Ac. Sci. USSR, v. 191, no. 3, p. 639-642. (R)

Enman, V. B., 1974, State of studying of recent movements of the Earth's crust in Kamchatka: Bull. Volc. Stn., no. 50, p. 81-92. (R)

Erlich, E. N., 1966, New data about volcan-tectonic structure of Kamchatka and problems of Quaternary volcanism evolution: Geotectonics, no. 6, p. 48-63. (R)

Erlich, E. N., ed., 1966, Petrochemistry of the Kurile-Kamchatka Cenozoic volcanic province: Moscow, Nauka Press, 279 pp. (R)

Erlich, E. N., 1971, Problem of calderas on International Symposium "Roots of Volcanoes," Oxford, September 7-13, 1969: Bull. Volc. Stn., no. 48, p. 79-83. (R)

Erlich, E. N., Gorshkov, G. S., eds., 1979, Quaternary volcanism and tectonic in Kamchatka: Bull.Volcanol., v. 42:1 (special issue), 298 pp.

Erlich, E. N., Melekestsev, I. V., 1972, Quaternary acid volcanism of Kamchatka: Jour. Modern Geology, 3, no. 4, p. 183-193.

Erlich, E. N., Melekestsev, I. V., 1972, Evolution of Quaternary volcanism and tectonics in the west part of the Pacific rim: Pacific Geology, v. 4, p. 1-22.

Erlich, E. N., Melekestsev, I. V., Tarakanovsky, A. A., Zubin, M. I., 1972 (1973), Quaternary calderas of Kamchatka: Bull. Volcanol., v. 36, no. 1, p. 222-237.

Erlich, E. N., Melekestev, I. V., 1973, Main stages of volcanism and tectonic reconstructions of Quaternary time in the Western Circum-Pacific: Bull. MOIP (Moscow Society of Naturalists), v. 48, no. 3, p. 5-26. (R)

Gorshkov, G. S., Markhinin, E. K., Fedorchenko, V. I., and Shilov, V. N., 1964, Description of the volcanoes of the Kurile Islands: Geology of the USSR, v. 31, part 1, p. 581-603. (R)

Leonova, L. L., Udaltsova, N. I., 1971, Rare elements in volcanic rocks of Kuril Islands, in: Vulkanizm i glubiny Zemli, Materialy 3 Vsesouz. Vulk. sovesch., Moscow, Nauka Press, p. 178-181. (R)

Leonova, L. L., Udaltsova, N. I., 1974, Geochemisty of Uranium and Thorium in volcanic process on the example of Kurile-Kamchatka zone: Novosibirsk, Moscow, Nauka Press, 103 pp. (R)

Luchitsky, I. V., 1971, Bases of the paleovolcanology: v. 2: Moscow, Nauka Press, 480 pp. (R)

Luchitsky, I.V., ed., 1974, Istoriya razvitiya reliefa Sibiri i Dal'hego Vostoka. Kamchatka, Kurile and Komandor Islands: Moscow, Nauka Press, 430 pp. (R).

Markhinin, E. K., 1964, Calderas and periphery magma chambers: Trudy Lab. paleovolcanol., Kaz.IMS, Alma-Ata, iss 3, p. 138-146. (R)

Masurenkov, Yu. P., 1979, Vulkany nad intrusiyami: Moscow, Nauka Press, 219 pp. (R)

Masurenkov, Yu. P., 1980, System volcano-magma chamber-structure (geological and petrological aspects of the problema): Vulkanol. i seismol., no. 4, p. 34-49. (R)

Naboko, S. I., Vlasov, G. M., Vasilevsky, M. M., 1964, Kamchatka, Kuril'skiye i Komandorskiye ostrova, in: Geoloogiya SSSR, v. 31, chast 1., p. 303-367. (R)

Piskunov, B. N., 1978, Petrochemical series of volcanic rocks and their lateral distribution in the structure of island arcs, in: Geodinamika i vulkanizm ostrovnikh dug severo-zapadnogo sectora Tikhookean. koltsa: Moscow, Soviet Radio Press, p. 60-67. (R)

Polyak, B. G., 1966, Geothermal specific features of the region of recent volcanism (on the example of Kamchatka): Moscow, Nauka Press, 170 pp. (R)

Rustamov, M. I., Tkhostov, T. M., 1982, On the origin and classification of calderas: Vulkanol. i seismol., no. 5, p. 90-100. (R)

Sheimovich, V. S., 1979, Ignimbrites of Kamchatka: Moscow, Nedra Press, 180 pp. (R)

Sheimovich, V. S., 1979, Problems of ignimbrites petrology: Bull. Volcanol., no. 1-4, p. 218-283.

Shirokov, V. A., 1978, Connection between eruptions of Kamchatka volcanoes and earthquakes in the upper mantle: Bull. Volc. Stn., no. 54, p. 3-8. (R)

Sidorov, S. S., 1966, Thermal waters of Kurile islands, in: Sovremenny vulkanizm: Moscow, Nauka Press, p. 211-217. (R)

Simbirev, I. B., 1978, Ring magmatic complexes of Kamchatka: Bull. Volc. Stn., no. 54, p. 53-60. (R)

Simbirev, I. B., Simbireva, I. G., 1978, Mechanism of formation and dynamic of development of ring magmatic complexes of Kamchatka: Bull. Volc. Stn., no. 55, p. 107-111. (R)

Simbireva, I. G., Fedotov, S. A., Feofilaktov, V. D., 1977, Geodynamics of Kurile-Kamchatka arc by seismological data, in: Avdeiko, G. P., ed., Vulkanizm i geodinamika, Nauka Press, Moscow, p. 91-103. (R)

Steinberg, G. A., 1969, About blast origin of calderas, in: Vulkanizm gidrotermy i glubiny Zemli, Petropavlovsk-Kamch., p. 56. (R)

Steinberg, G. S., 1973, On the blast genesis of calderas: Doklady Acad. Nauk USSR, 208, no. 6, p. 1342-1345. (R)

Vasilevsky, M. M., 1978, Energetic classes of orthotectonic structures of the Pacific region and probmes of metallogeny of the Pacific mergins: Bull. Volc. Stn., no. 55, p. 112-130. (R)

Vlasov, G. M., 1960, Volcanic sulfur deposits and some problems of near-surface ore formation (in the case of Kamchatka and Kurile Islands), in: Information on the Natural Resources of Kamchatka and the Kurile Islands, Magadan, p. 39-62. (R)

Vlodavets, V. I., 1944, Classification of the negative forms of volcanic relief: Izv. Ac. Sci. USSR, ser. geol., no. 5, p. 137-147. (R)

Vlodavets, V. I., 1954, On the volcano-tectonics: Bull. Volc. Stn., no. 23, p. 33-38. (R)

Vlodavets, V. I., 1955, Alcuni risultati delle ricerche vulcanologiche nell'USSR: Bull.Volcanol., ser. 2, tome 16, p. 147-160.

Vlodavets, V. I., 1957, On the origin of rocks named tuffs lavas and ignimbrites: Trudy Lab. Volc., Moscow, Ac. Sci. Press, no. 14, p. 9-16. (R)

Yarmoliuk, V. V., 1970, Volcanogenic structures of Okhotsk-Chukotka volcanogenic belt: Geol. i Geoph., no. 6, p. 143-147. (R)

Zubin, M. I., Tarakanovsky, A. A., 1980, Spatial position of volcanic centers in Kamchatka as a reflection of regional tectonics: 5 Vsesouzn. Vulkan. sovesch., Symp. 2, Abstr., Tbilisi, 91 pp. (R)

IX. ORIGINAL PAPERS ABOUT CALDERAS OF JAPAN PUBLISHED IN RUSSIAN

Aramaki, S. V., 1977, Pyroclastic flows and calderas of Japan, in: Vulkanizm ostrovnikh dug, Moscow, Nauka Press, p. 164-172. (R)

Ehara, S., 1977, Heat regime of the Earth's Crust and Upper Mantle of the region of Hokkaido by the data of terrestrial heat flow, in: Vulkanizm ostrovnikh dug, Moscow, Nauka Press, p. 116-126. (R)

Katsui, E., Oba, E., Soya, T., 1978, Types of historic eruptions and nature of magma in the Northern Japan, in: Geodinamika i vulkanizm ostrovnikh dug severo-zapadnogo sektora Tikhookean. koltsa, Moscow, Soviet Radio Press, p. 77-89. (R)

Kubotera, A., Mitsunami, T., 1978, A row of earthquakes in the northern part of Aso caldera and migration of their foci, in: Geodinamika i vulkanizm ostrovnikh dug severo-zapadnogo sektora Tikhookean. koltsa, Moscow, Soviet Radio Press, p. 17-23. (R)

Oki, K., Hirano, T., Hiraga, S., 1977, Geothermal activity of volcano, in: Vulkanizm ostrovnikh dug, Moscow, Nauka Press, p. 137-147. (R)

Ono, K., Ito, K., Iizuka, S., Hasegawa, I., Hiroshima, T., Kakuta, T., Ichikawa, K., Suzuki, H., 1977, Explosion seismic studies near and around Sakurajima volcano, in: Vulkanizm ostrovnikh dug, Moscow, Nauka Press, p. 43-55. (R)

Shimodzuru, D., 1977, The 1973 explosive activity of Asama volcano, in: Vulkanizm ostrovnikh dug, Moscow, Nauka Press, p. 77-85. (R)

Shimodzuru, D., 1978, Volcano-seismotectonics of the northern part of Idzu islands, in: Geodinamika i vulkanizm ostrovnikh dug severo-zapadnogo sectora Tikhookean. koltsa, Moscow, Soviet Radio Press, p. 5-16. (R)

Ui, T., 1977, Pyroclastic eruption on the south of Kyushu island which had been 6000 years ago, in: Vulkanizm ostrovnikh dug, Moscow, Nauka Press, p. 182-189. (R)

Yokoyama, I., 1977, Crustal deformations and remarkable earthquakes associated with volcanic activities, in: Vulkanizm ostrovnikh dug, Moscow, Nauka Press, p. 14-23. (R)

Yokoyama, I., 1978, Volcanic processes defined by data about deformation of the Earth's Crust, in: Geodinamika i vulkanizm ostrovnikh dug severo-sapadnogo sectora Tikhookean. koltsa, Moscow, Soviet Radio Press, p. 33-41. (R)