Granitoids of the North-West Altai

Guidebook for field excursion of the 2-nd International Geological Conference «Granites and Earth's evolution»

21-27
August
Novosibirsk-
Zmeinogorsk
2014

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Институт геологии и минералогии им. В.С. Соболева

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ПУТЕВОДИТЕЛЬ ПОЛЕВОЙ ЭКСКУРСИИ

(21-27 августа 2014 г., г. Змеиногорск, Россия)

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ГРАНИТЫ И КОНТИНЕНТАЛЬНАЯ КОРА»

(17-20 августа 2014 г., Новосибирск, Россия)

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ИЗДАТЕЛЬСТВО СИБИРСКОГО ОТДЕЛЕНИЯ
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Гранитоиды Северо-Западного Алтая: Путеводитель полевой экскурсии (21-27 августа 2014 г., Змеиногорск, Россия) II Международной геологической конференции «Граниты и эволюция Земли: граниты и континентальная кора» (17-20 августа 2014 г., Новосибирск, Россия) / Н.Н. Крук [и др], науч. ред. А.Г. Владимиров; Сибирское отделение Российской академии наук, Институт геологии и минералогии им. В.С. Соболева. – Новосибирск: Издательство СО РАН. 2014. – 84 с.

Геологическая полевая экскурсия (21-27 августа 2014 г.) посвящена изучению ключевых геологических объектов, расположенных на границе Горного и Рудного Алтая. Эта экскурсия подготовлена в рамках Второй международной геологической конференции «Граниты и эволюция Земли: граниты и континентальная кора» (17-20 августа 2014 г. Новосибирск). Главное внимание уделено изучению массивов гранитоидов, имеющих возраст от среднего девона до раннего траса и сформированных в различных геодинамических обстановках (активная окраина с субдукцией – трансформная окраина – коллизия – постколлизионный и внутриплитный этапы тектогенеза). Отдельный акцент сделан на анализ признаков мантийно-корового взаимодействия при формировании гранитоидов. Также рассмотрен ряд рудных объектов, связанных с базитовым и гранитоидным магматизмом. Путеводитель представляет интерес для широкого круга геологов, преподавателей ВУЗов, аспирантов и студентов.

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Siberian Branch of Russian Academy of Science
V.S. Sobolev Institute of Geology and Mineralogy

GRANITOIDS OF THE NORTH-WEST ALTAI

GUIDEBOOK FOR FIELD EXCURSION

(2014, 21-27 august, Zmeinogorsk, Russia)

of the 2nd International Geological Conference
«GRANITES AND EARTH'S EVOLUTION:
GRANITES AND CONTINENTAL CRUST»

(2014, 17-20 august, Novosibirsk, Russia)

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Granitoids of the North-West Altai. Guide of geological excursions (21-27 August 2014, Zmeinogorsk, Russia) of the 2-nd International Geological Conference «Granites and Earth's evolution: granites and continental crust» (17-20 August 2014, Novosibirsk, Russia) / N.N. Kruk [et al.], sci. ed. A.G. Vladimirov; Siberian Branch of Russian Academy of Science, V.S. Sobolev Institute of Geology and Mineralogy. – Novosibirsk: Publishing House of SB RAS. 2014 – 84 p.

Geological field trip (21-27 August 2014) devoted to the study of key geological objects, located on the border of the Gorny and Rudnyy Altai (Novosibirsk – Zmeinogorsk, 21-27 of August, 2014). This excursion is prepared within the Second International Geological Conference "Granites and evolution of the Earth: granites and continental crust" (17-20 August, 2014, Novosibirsk). The main attention is paid to the study of granitoid intrusions with the age from Middle Devonian to Early Triasic and correspond to different geodynamic settings (suprasubdution continental margin - transform margin - collision - post-collision and intraplate orogeny). Particular emphasis was placed on study of the evidences of the mantle-crust interaction during the granitoids formation. Consider a series of ore deposits associated with mafic and granitoid magmatism. This guide is interesting for a wide range of geologists, university teachers, postgraduates and students.

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EDITOR'S FOREWORD

The Altai accretion-collision system is a trapezoidal wedge, the wide side of which is covered by Biya-Barnaul depression on the north-west, and the south-east part is compressed by the Junggar Plate. The total length of the Altai system is 1,200 km, and its width varies from 150 to 600 km (Fig.1). The geodynamic evolution of Altai is now interpreted in the context of gradual approaching of the Kazakhstan and Siberian plates, with their clockwise rotation relative to each other and simultaneous reduction of the Ob'-Zaisan paleo-oceanic basin [Mossakovskii et al., 1993; Berzin et al 1994; Buslov et al., 2003; Vladimirov et al., 2003].

It is assumed that during the precollisional stage (D_{1-2}) the Altai margin of the Siberian continent was a transform boundary along which the Altai-Mongolian terrane with Neoproterozoic crust T_{Nd} (2-st) = 1.5-1.0 Ga was sliding. In this period, the Ob'-Zaisan paleo-oceanic basin interacted with the Kazakhstan and Siberian continents as two oblique subduction zones (Zharma-Saur and Rudny Altai). By the mid-Carboniferous, the ocean basin was completely closed, and the further evolution of the orogen proceeded against the background of general sinistral strike-slip deformations and mantle-crustal magmatism.

The territory of the North-West Altai is a part of the Altai accretion-collision system and of the Central Asian Mobile Belt as a whole, which is characterized by an abnormally wide development of Phanerozoic juvenile crust [Kovalenko et al., 1996, 2004; Jahn et al., 2000, 2004]. Geological ground of the excursion provides fairly complete information about the geological structure of the Altai margin of the Siberian continent and allows seeing a wide range of magmatic complexes being indicators of geodynamic settings, as well as features of mantle-crust interaction and their metallogeny.

The authors of the guidebook, compiling a general framework of the excursion and geological description of the outcrops, deserve sincere thanks. I only wish to emphasize Novosibirsk geologists: Nikolai Kruk, Maxim Kuibida, Sergei Khromykh, Nina Volkova and postgraduate student Pavel Kotler, without which the conference and geological excursion would have been impossible.

I wish participants of the geological excursion good weather, endurance during trips, successful routes, and sharp scientific debates.

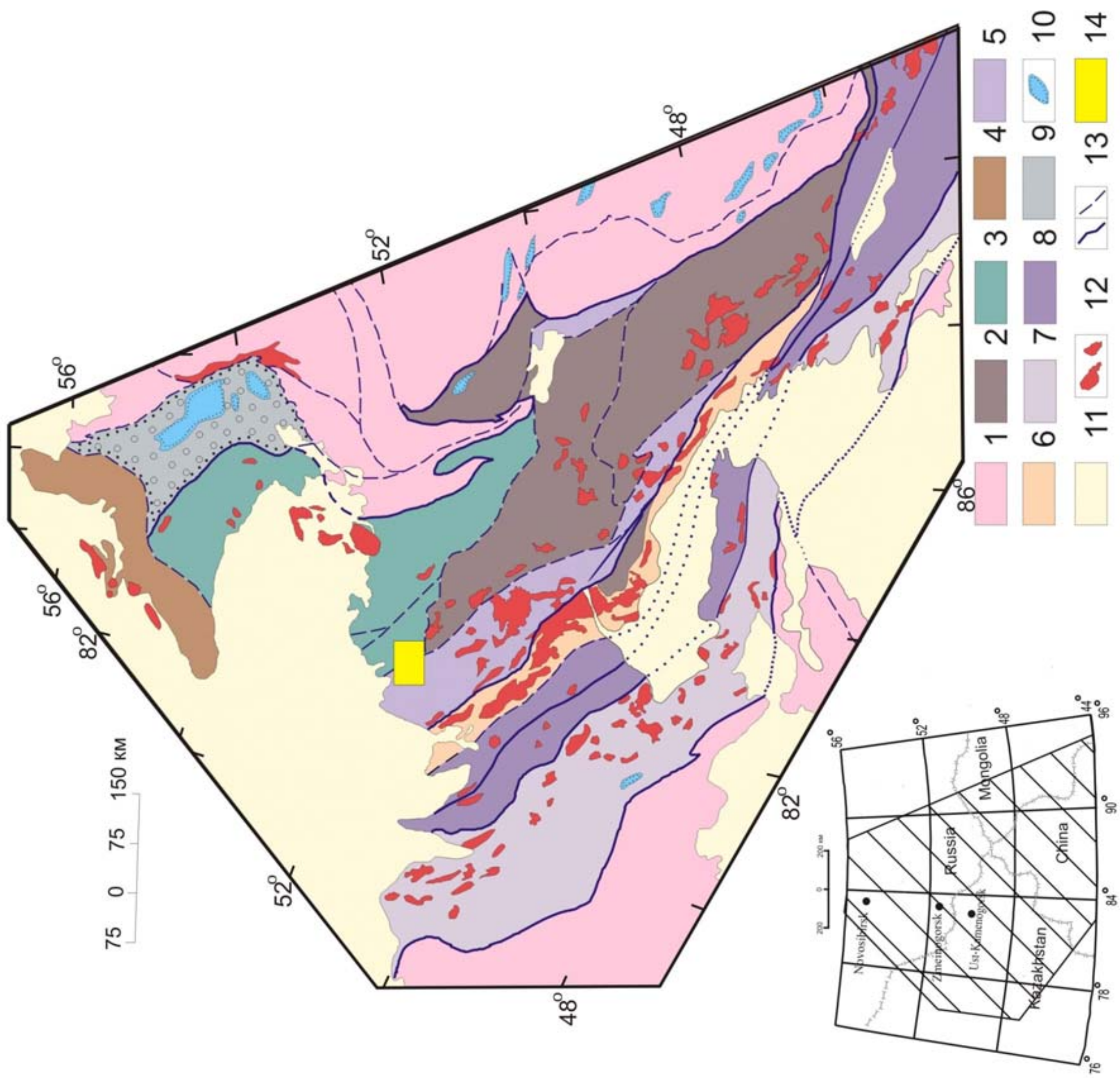
Sincerely yours, Prof. Alexander Vladimirov

Novosibirsk, August 5, 2014

Fig. 1. The location of the poligon of the geological excursion "Granites and Earth's evolution - 2014" in the structures of the Altai accretion-collision system [Vladimirov et al., 2003].

Left — Palinspastic reconstructions (used data [Buslov et al., 2003; Vladimirov t al., 2003] with author's modifications): 1 = continents, 2 = subduction zones, 3 = MOR or paleoMOR; GA = Gorny Altai, RA = Rudny Altai.

Right — Tectonic scheme (localized in the inset): 1 = Neoproterozoic-Early Paleozoic structure-composition complexes of the Siberian and Kazakhstan continents, undifferentiated; 2 = Altai-Mongolian microcontinent; 3–8 = continental-margin and oceanic terranes of Middle and Late Paleozoic age: 3 = Kolyvan'-Tomsk passive(?) margin, 4 = Rudny-Altai island-arc, 5 = Kalba-Narym turbidite, 6 = Zharma-Saur island-arc, 7 = Char oceanic terrane; 8 = Kuznetsk-Alatau and Junggarian oceanic rise and/or groups of seamounts; 9 = Kuznetsk sedimentary basin, including: 10 = traps of Triassic age; 11 = Cenozoic deposits; 12 = granitoids in the age range from Carboniferous through Early Jurassic; 13 = faults: a = proved, b = supposed, 14 = poligon of the geological excursion.



86°
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11 12 13 14
Novosibirsk
Zmeinogorsk
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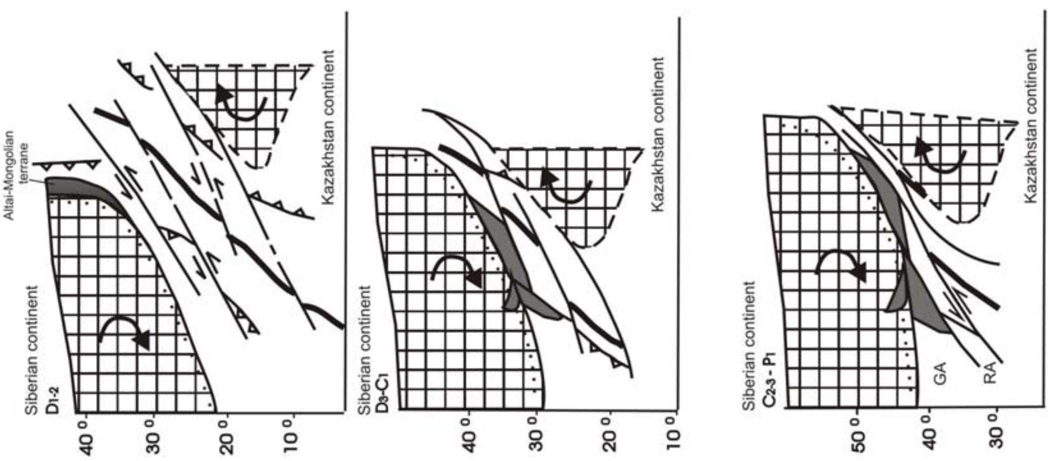
Russia
Mongolia
China
Kazakhstan



Siberian continent
D_{1-2}
Altai-Mongolian terrane
Kazakhstan continent
Siberian continent
D_3-C_1
Kazakhstan continent
Siberian continent
C_{2-3} - P_1
GA
RA
Kazakhstan continent

INTRODUCTION

The structure of the geological excursion area includes two blocks (terranes), which differ sharply in their nature and age. The eastern part (Charysh-Inya Block) is a part of the Caledonian structures of the Gorny Altai and represents a fragment of the Cambrian to Ordovician turbidite basin having an oceanic basement and filled with thick series of slightly metamorphosed flysch and molasse [Sennikov et al., 1959; Volkov, 1965, 1966; Berzin et al., 1994; Shokalsky, 1999; Kruk et al., 2010]. The western part (Rudny Altai terrane) is a fragment of the Hercynian Ob'-Zaisan folded system. Geophysical data [State ..., 2001a, b] suggest the significantly mafic composition of the Rudny Altai crust (the thickness of granite-metamorphic layer is reduced to 20 km or less; the Moho is fixed at a depth of 40-45 km; positive anomalies of gravitional and magnetic fields are observed throughout the region).

In the Early to Middle Devonian the territory of the North-West Altai was included in the structure of an active continental margin connecting with the subduction of the lithosphere of the Ob'-Zaisan oceanic basin under the Siberian continent margin. Development of subduction processes led to the formation of volcanic belts, consisting of bimodal and differentiated series of normal and high alkalinity [Rotarash et al., 1982; Berzin et al., 1994; Tikunov, 1995; Kruk et al., 2008]. In the Late Devonian (early Frasnian) in connection with the change in the regime of the active continental margin from subduction to a transform [Khanchuk et al., 2009; Kruk, 2014], the volcanic activity in the Gorny and Rudny Altai has been replaced by the formation of large granitoid batholiths.

The evolution of the Altai continental margin was culminated in closing of the Ob'-Zaisan basin at the boundary of the Early and Late Carboniferous, and in the collision of the Siberian and Kazakhstan continents [Berzin et al., 1994; Vladimirov et al., 2003, 2008; Kruk et al, 2009, 2011], accompanied by active granitoid magmatism in Rudny Altai [Kuibida et al., 2009, 2010, 2013, 2014]. The collisional processes were accompanied by the activation of shear displacements, which peaked in the Early Permian and led to the formation of "hot" shear system due to interference of plate- and plume-tectonic factors [Vladimirov et al., 2005, 2008]. In the Late Permian to Early Triassic, within-plate granitoid magmatism was manifested in the North-West Altai, as a consequence of the influence of the Siberian mantle plume on the lithosphere of Central Asia [Dobretsov, 1997; Dobretsov et al., 2005].

Complicated geological history and repeated change of tectonic regimes in the North-West Altai resulted in the manifestation of different-aged granitoid magmatism, represented by a wide range of petrogeochemical types, including subsynchronous ones. This is provides great scope for studying processes of granite formation. Comparison of mineralogical, geochemical and isotopic characteristics of subsynchronous granitoids, spatially associated with each other, makes it possible to establish the regularities of the evolution of magmatic systems. Comparison of coeval granitoids localized in two considered blocks within a single geological structure, but having sharply different composition, allows us to trace the influence of the nature and composition of crustal sources on geochemical and isotopic characteristics of the granitoids, to evaluate the role of mantle melts in the generation of granitic magmas. Analysis of the evolution of granitoid magmatism in time gives information about the processes of differentiation and evolution of the continental crust.

During the excursion, participants will have the opportunity to get acquainted with granitoid and gabbroid intrusive bodies, related to the main stages of the geological development of the region (from the Middle Devonian to Early Triassic). Objects of the excursion are key intrusive bodies as in Rudny, and the Gorny Altai (Fig. 2), which will allow participants to compare the features of granitoid magmatism in two blocks differing in nature and composition. In the outcrops you can see the features of the geological position of granitoid and gabbroic bodies, their relationships with host rocks, as well as petrographic and mineral characteristics of the granitoids. Detailed information on age, chemical composition, isotopic characteristics and petrological features of considered granitoids is given in this guidebook.

The organizers hope that the excursion will be fruitful, interesting and useful for all the participants.

PROGRAMM OF FIELD TRIP

GRANITOIDS OF NORTH-WESTERN ALTAY REGION
(21-27 august 2014, Novosibirsk-Zmeinogorsk, Russia)

1st day (21th august): Departure from Novosibirsk, arrival to v. Baranovka, 10 km from Zmeinogorsk, accommodation in sanatorium.

2nd day (22th august): Rudny Altay, the north-western part.

Stop 1-1. Pavlovsky massif granite, pavlovsky complex. Neighborhood of v. Pavlovka.

Stop 1-2. Ust'yansky massif granite, ust'yansky complex. Neighborhood of v. Ust'yanka.

Stop 1-3. Aleysky massif diorite and tonalite, gilevsky complex, the left coast of r. Dalnyaya Schelchikha.

Stop 1-4. Aleysky massif plagiogranites and postgranite dikes, gilevsky complex, the left coast of r. Makhovushka.

3rd day (23th august): Rudny Altay, the central part

Stop 1-5. Gabbroids, zmeinogorsky complex, neighborhood of v. Chekanovsky.

Stop 1-6. Pervomaysky massif plagiogranite, zmeinogorsky complex, v. Pervomaysky.

Stop 1-7. Ostraya hill massif granite, volchikhinsky complex.

Stop 1-8. Verkhneborovlyansky massif granite and postgranite dikes, volchikhinsky complex. Neighborhood of v. Borovlyanka.

Stop 1-9. Chyorny kamen massif granite (zmeinogorsky complex), Pervokamensky massif granodiorite and granite (volchikhinsky complex). v. Krasnoe razdolye.

4th day (24th august): Rudny Altay, the north part

Stop 1-10. Sawushinsky massif granitoid and pegmatite, sinyushensky complex. The north coast of Kolyvanskoe lake, neighborhood of Ortite hill.

Stop 1-11. Zmeinogorsk deposit quarry. Outskirts of Zmeinogorsk city.

Stop 1-12. Stepnoe deposit, fausteds. Neighborhood of v. Talovka.

5th day (25th august): Gorny Altay, Charysh-Inya block

Visiting the Kolyvan stone carving factory and the Altay museum of stone carving history in v. Kolyvan'.

Stop 2-1. Kolyvansky massif granodiorite (ust'-belovsky complex) with melane inclusions. Outskirts of v. Kolyvan.

Stop 2-2. Kolyvansky massif selvage diorite, ust'-belovsky complex. Near Beloe lake.

Stop 2-3. Mt. Ocharovatelnaya massif granite, borovlyansky complex.

Stop 2-4. Gwags and ore of Kolyvanskoe deposit, enclosing granitoid (ust'-belovsky and borovlyansky complexes). Neighborhood of deserted Kolyvanstroy village.

Stop 2-5. Sinyushensky massif granite (sinyushensky complex). Neighborhood of Mokhovoe lake, to the north of v. Kolyvanstroy.

6th day (26th august): Gorny Altay. Kharlovsky massif, kharlovsky complex

Stop 2-6. Ore-bearing gabbro with titan-magnetite. The north-east outskirt of v. Kharlovo.

Stop 2-7. Monzodiorite. The south-west outskirt of v. Kharlovo.

Stop 2-8. Granosyenite. The west outskirt of v. Kharlovo.

Visiting the mining development history museum of A. Demidov in Zmeinogorsk.

Discussion and friendly dinner.

7th day (27th august) : Departure from v. Baranovka to Novosibirsk.

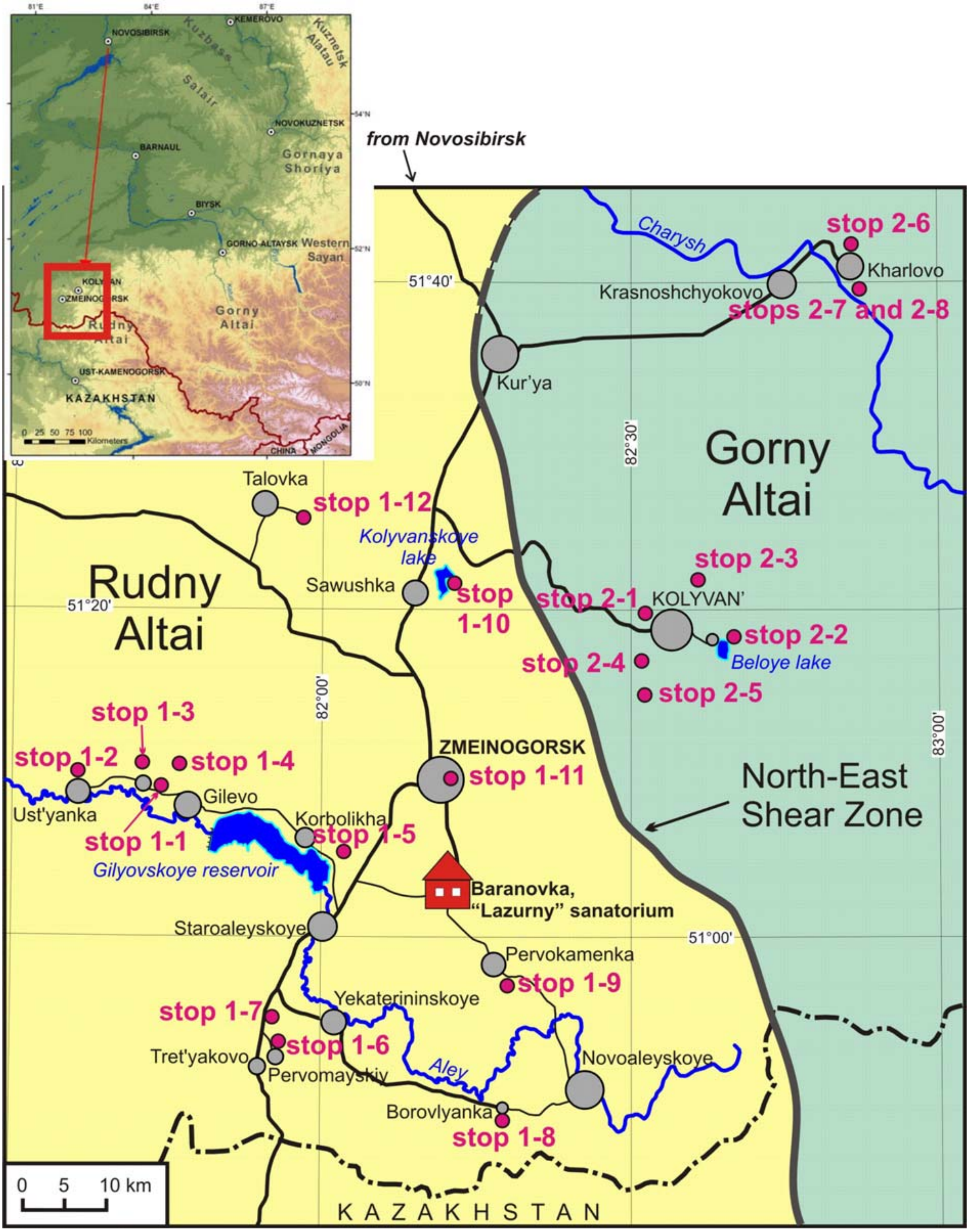


Fig. 2. Stop-points of the field excursion

CHAPTER 1. RUDNY ALTAI

GEOLOGICAL BACKGROUND

The Rudny Altai territory is the eastern termination of the Ob'-Zaysan Hercynian system. From the north-east it is separated by the North-Eastern zone of deformation from the Caledonian folded structures of Gorny Altai; in the south-west it is bordered by the structures of the Kalba-Narym Zone of East Kazakhstan along the major trans-regional Irtysh shear zone (Fig. 1.1). The northern border is covered by deposits of the Biya-Barnaul depression.

Geological history of Rudny Altai was essentially related to initiation and development of Devonian to Early Carboniferous active continental margin in the western part of the Siberian Craton [Rotarash et al., 1982; Berzin et al., 1994; Dobretsov, 2003; Vladimirov et al., 2003, 2005, 2008]. Evolution of the active continental margin was terminated by the Middle Carboniferous collision of the Siberian and Kazakhstan continents. It was then that the vast majority of volcanic and intrusive igneous complexes, as well as the main ore deposits were formed. At later stages of geological history (the end of the Late Paleozoic to Early Mesozoic) endogenous activity on the territory of the Rudny Altai was due to the influence of the Tarim (C_3-P_1) and Siberian (P_2-T_1) superplumes on the lithosphere of the region [Dobretsov et al., 2005; Borisenko et al., 2006; Vladimirov et al., 2008].

The oldest stratified deposits of Rudny Altai are sedimentary rocks of the ***Korbalikha series***. The series is composed of interbedded green-gray sericite-chlorite schists, green-gray medium- and fine-grained polymict metasandstones, phyllites and phyllitized shales. The sediments are characterized by high carbonate content. The total thickness is of >2500 m [State ..., 2001 a, b, 2011]. The section of the Korbalikha series is characterized by a multiordinal rhythmicity expressed in alternation of rhythmic flysch (turbidites) and unrhythmic (mostly shale and siltstone) packs. Rhythmic flysch packs have a thickness of 10-30 m to 40-70 m and are composed of interbedded phyllitized shales, phyllites, metasiltstones, and fine- to medium-grained metasandstones. The unrhythmic packs are of more thick and are composed of shales with rare thin (up to 0.1-1.0 m) interlayers and lenses of metasandstones and metasiltstones. Sometimes single packs (up to 20-30 m) of fine- to medium-grained metasandstones (with graded bedding) are observed in sections.

Usually the rocks are finely schistose with signs of plication and corrugation. They are penetrated by a dense network of intersecting quartz, quartz-carbonate and carbonate veins. The deposits are intensely deformed, crushed into complex folds, turned into spotted-banded, banded amphibole-epidote-quartz, epidote-quartz and epidote-quartz-chlorite hornfels in exocontact aureoles of granitoid intrusions.

Sediments of the Korbalikha series are unconformably overlain by Early-Middle Devonian thick volcano-sedimentary series, which includes Melnichnaya (D_{1e}-D_{2gv}), Zavodskaya (D_{2gv}), and Kamenevskaya (D_{2gv}-D_{3fr}) units. Local washouts and unconformities are fixed between the individual units, but in general all the deposits have a single structural plan. The total thickness of the section is > 200 m. A common feature of this section is shallow-marine character of sedimentary deposits, as well as an abundance of volcanic and pyroclastic rocks of predominantly acidic composition.

The volcano-sedimentary sequence is unconformably overlain by Late Devonian to Carboniferous series, represented by shallow-marine clastic sediments of the Snegirevskaya Unit ($D_{3fr-fm1}$), terrigenous-carbonate strata of the Tarhansky Unit (D_{3fm}) and carbonate-terrigenous sediments of the Bukhtarma Unit (C_{1t}). Overlying section consists of exclusively continental terrigenous (including coal-bearing) deposits.

With respect to the regional magmatic geology of Rudny Altai the key issue is the geological setting, volumes and nature of the Late Devonian volcanism. Along the western border of Rudny Altai a chain of volcano-tectonic structures (Loktev, Nicholaev, Kirov paleovolcanos; Fig. 1.1), composed of continuous rocks series from basalts to high-silica rhyolites, is developed. A distinctive feature of the basalts is enrichment in titanium (up to 2.5 wt. % of TiO_2), phosphorus (up to 1 wt. % of P_2O_5), and higher concentrations of HFSE and REE elements [Kruk et al., 2014]. The more acid rocks are dominated by andesites, practically unknown in the sections of the Early-Middle Devonian.

Opinions differ widely on the age and the nature of this volcanism. Based on the stratigraphic relationships between volcanic rocks and the underlying terrigenous strata, some researchers [Shokalsky, 1999; State ..., 2001 a; Kruk et al., 2014] suggested Late Devonian (Famennian to Frasnian) age of these volcanics (Pikhtovskaya Unit by [Shokalsky, 1999]), and related their formation to the stage of inversion of geodynamic regime and the formation of continental margin of the transform type. Other authors [State …, 2011], indicating the almost complete absence of volcanic material in Famennian fauna-bearing sediments of Rudny Altai, suggested the Middle to Late Carboniferos age of the volcanism, simultaneous to the collision of Siberia and Kazakhstan. The situation is complicated by the lack of reliable dating of volcanic rocks and a fauna-barren character of associated sediments. The study of these complexes is one of the important directions for further research.

MAGMATIC COMPLEXES of the RUDNY ALTAI

In the Rudny Altai territory a wide variety of granitoids composing large structurally complex multiphase intrusive bodies, is developed (Fig. 1.1). Nature, volumes and age of granitoids of Rudny Altai were the subject of debates for decades. Subdivision of granitoids and the creation of a compatible scheme of magmatism were hampered firstly by rare outcrops in the region, and, secondly, by visual similarity of rocks belonging to different (often different-aged) complexes (during the excursion their participants will be able to make sure themselves in this feature of the rocks). It should be noted that even now, with the development of precise dating and geochemical study of the rocks, this problem is not completely solved.

Systematization of data of long-term geological studies together with the results of petrological and geochronological study of granitoids suggest the subdivision of intrusive magmatic rocks of Rudny Altai into eight independent complexes: Aleisky (D_2), Pavlovsky (D_2), Zmeinogorsky (D_3), Ust'-Belovsky (D_3), Ust'yansky (D_3), Gilevsky ($C_{2\text{-}3}$), Volchikhinsky ($C_{2\text{-}3}$), and Sinyushensky (P_2-T_1).

Below is a brief description of these complexes and their composing rocks.

ALEISKY COMPLEX

The most acute problem in the magmatic geology of Rudny Altai has long been a question on the nature, scales and age of manifestations of the "oldest" plagiogranites, which are synchronous (or even older) to the formation of thick volcanic series of acid ore-bearing porphyries. In the second half of the XX century V.S. Kuzebny [1975], summarizing the systematic observations of the geological relationships of granitoids and fauna-characterized volcano-sedimentary rocks in different parts of Rudny Altai, concluded that in the northern part of Rudny Altai ancient plagiogranites are absent. Later, in the course of geological mapping [Shokalsky, 1999; Shokalsky et al., 2001; State ..., 2001 a, b], a number of intrusive bodies that have no apparent relationships with Middle Devonian volcanic series and consisting of strongly deformed rocks were combined into the Alei complex of conditionally Early Devonian age.

Recent geological, geochemical and isotopic-geochronological studies of almost all granitoid intrusive bodies related to the Alei complex, (Kuibida, Kruk, 2009; Kuibida et al., 2013, 2014; Kruk et al., 2014) have showed that in fact these granitoids belonged to three

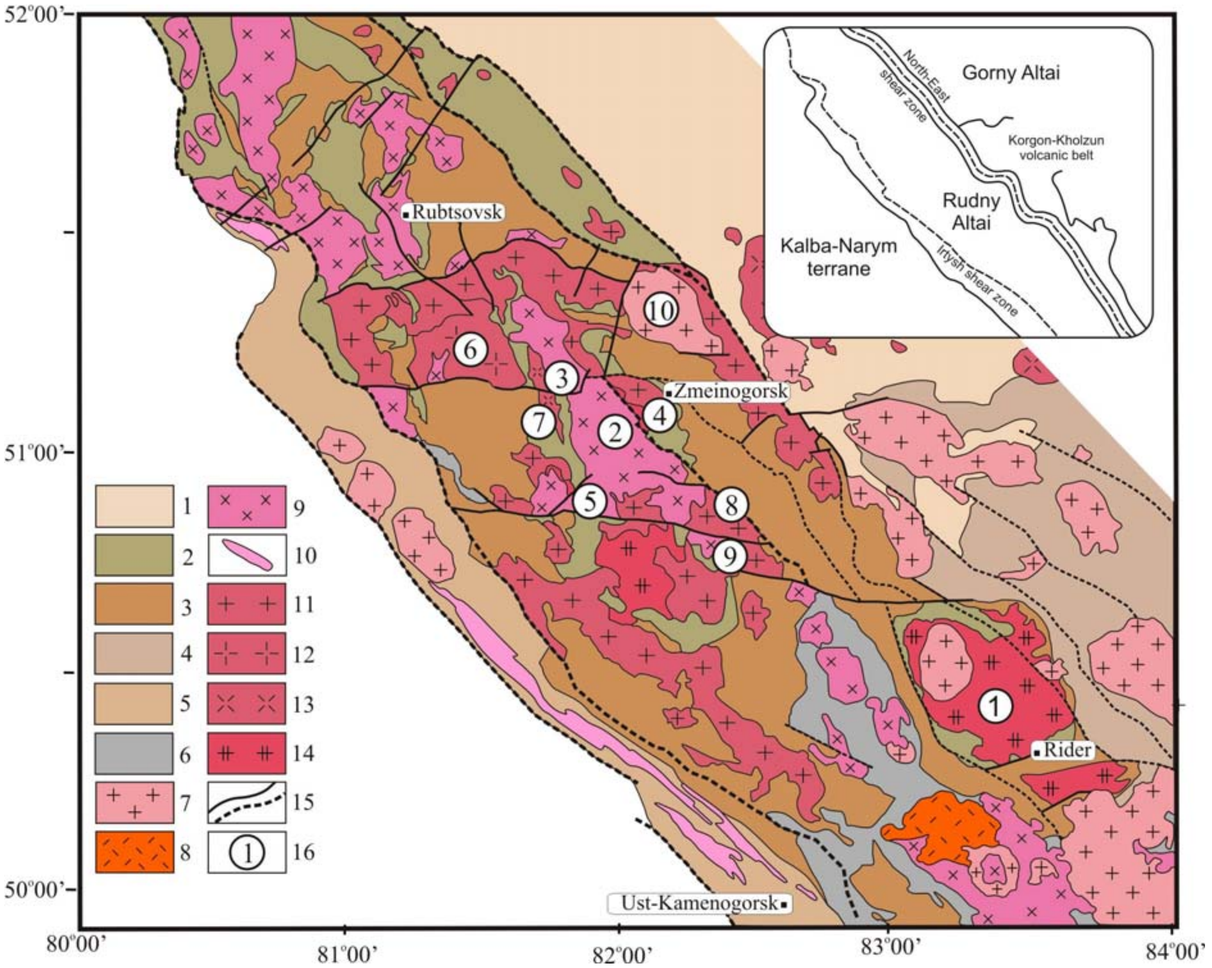


Fig. 1.1. Scheme of location of magmatic complexes of Rudny Altai (after [Kuybida, 2010]).
1 = south-western margin of the Altai-Sayan folded area (Gorny Altai, Pz); 2 = folded basement (turbidite basin) of Rudny Altai, S-D_1?; 3 = subduction-related volcanic belt of Rudny Altai, D_{1-3}; 4 = Korgon-Holzun volcanic belt in joint place of the Gorny and Rudny Altai, conditionally S-D_2; 5 = deep-sea trench sediments, D_{1-2}; 6 = continental deposits, C_1; 7 = granitoids of the Leninogorsy, Sinyushensky, and Kalbinsky complexes, P_1-T_2; 8 = granitoids and volcanics of the Serzhikhinsky Complex, C_3-P_1; 9 = granitoids of the Gilevsky and Volchikhinsky complexes, C_{2-3}; 10 = granitoids of the Irtysh shear zone, D_3-C_1; 11-13 = granitoids of the Gorny and Rudny Altai (11 = Zmeinogorsky Complex, 12 = Ust'yansky Complex, 13 = Ust'-Belovsky Complex, D_3-C_1; 14 = plagiogranites of the Aleisky Complex, D_2; 15 – faults; 16 - massifs, described or mentioned in the text (1 = Leninogorsky, 2 = Aleysky, 3 = Pavlovsky, 4 = Zmeinogorsky (Mokhnatye Sopki), 5 = Pervomaysky, 6 = Ust'yansky, 7 = Mezhdurechensky, 8 = Pervokamenksky, 9 = Verkhneborovlyansky, 10 = Sawushinsky).

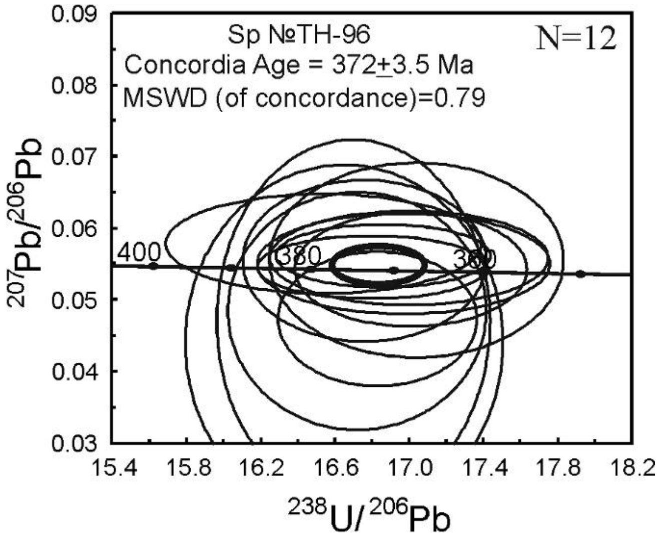


Fig. 1.2. Isotope diagram with concordia for zircons from plagiogranites of the Aleisky Complex.
Analyst is I.P. Paderin (VSEGEI, St. Petersburg). Zircons were selected by S.N. Rudnev (IGM SB RAS, Novosibirsk).

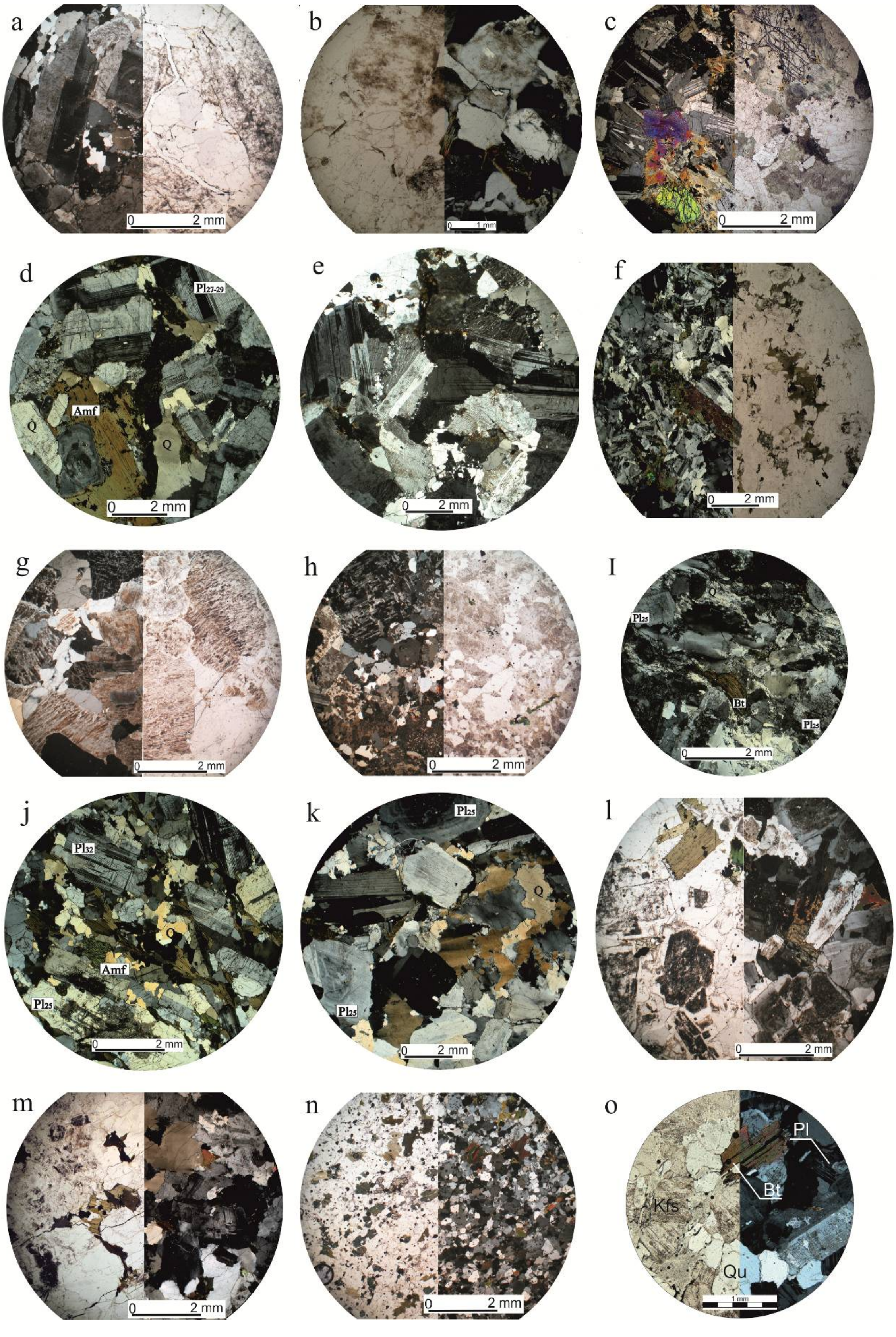


Fig. 1.4. Petrographic features of gabbros and granitoids of Rudny Altai (description in the text).
(a) = Aleisky Complex, Mokhnatye Sopki Massif, biotite granite; (b) = Pavlovsky Complex, Pavlovsky Massif, biotite granite, (c-e) = Zmeinogorsky Complex: (c) = Mokhnatye Sopki Massif, gabbro, (d) = Ekateriniansky Massif, melanocratic plagiogranite, (e) = Pervomaisky Massif, leucocratic plagiogranite; (f) = Ust'-Belovsky Complex, Mezhdurechensky Massif, diorite, (g-h) = Ust'yanka Complex, Ust'yanka Massif: (g) = coarse-grained biotite leucogranite, (h) = fine-grained biotite leucogranite; (I-k) = Gilevsky Complex, Aleisky Massif:

magmatic complexes of different age. Most of the intrusive bodies are estimated to be of the Late Devonian and Carboniferous. The older U-Pb dates were obtained only for plagiogranites of the Leninigorsk-Sinyukha intrusive body (area of Mt. Ridder, Kazakhstan), as well as for a body of plagio-leucogranites in the southwestern part of the Mokhnatye Sopki massif (Fig. 1.1)

Geological position and age of granitoids. In the northern (Russian) part of Rudny Altai the Aleisky Complex granitoids compose northwesterly-directed elongated intrusive body in size of ≈ 2×0.5 km. The plagiogranites intruded the Korbalikha Unit sediments (S-D_1), and were broken by melanocratic plagiogranites of the Zmeinogorsky Complex (D_3). Geologic relations with Devonian volcanic-sedimentary series aren't known yet.

The age of plagiogranites obtained on single zircon grains by U-Pb isotopic method using the ion microprobe SHRIMP-II (VSEGEI, St. Petersburg) is 395± 3 Ma (Fig. 1.2).

Petrographic features. The intrusive body is composed of homogeneous leucocratic weakly porphyritic medium- to coarse-grained plagiogranites. The main minerals are quartz (up to 40 %), oligoclase (45-50 %), and biotite (5-10 %). Occasionally anhedral grains of potassium feldspar occur. The rocks texture is hypidiomorphic (Fig. 1.3 a). Accessory minerals are apatite, zircon and iron oxides.

Rock chemistry. Plagiogranites of the Alei Complex correspond in their chemical composition to granite-leucogranite association of normal alkalinity with a predominance of sodium over potassium (Na_2O/K_2O = 1.29-2.41; Fig. 1.4 a, b). The rocks are oversaturated in alumina in relation to alkali and calcium (Fig. 1.4 c) and are characterized by higher contents of titanium for leucogranites (Table 1.1) and low Mg# (Fig. 1.4 d).

The trace-element composition of plagiogranites is characterized by moderate LILE and HFSE contents, typical of calc-alkaline granitoids. REE contents are 64 to 95 ppm, their spectra display weakly asymmetric distribution with $(La/Yb)_N$ = 2.5-3.5, with a distinct Eu anomaly (Fig. 1.5 a). In spidergrams (Fig. 1.5 b) the Sr, Ti, Ta and Nb minima, Zr and Hf maximums are observed.

Geochemical characteristics of the plagiogranites (Al_2O_3 <15 %, Yb = 2.9-3.4 ppm, Sr/Y = 4-6) indicate that they belong to the low-alumina type according to [Arth, 1979].

Geochemical and geochronological data suggest that plagiogranitoids of the Alei Complex have been comagmatic to Middle Devonian acid volcanics of Rudny Altai [Kuibida et al., 2014].

PAVLOVSKY COMPLEX

Geological position and age. Granitoids of the Pavlovka Complex have a restricted distribution in the territory of Rudny Altai. They compose only the Pavlovka Massif which occupies an area of ~15 km^2 and located to the west from Gilevo village (Fig. 1.1). The intrusive body embedded metamorphosed rocks of the Korbalikha series with the formation of hornfelses. The tectonic contacts with granitoids of the Gilevsky Complex (C_2) are marked by a zone of intensely schistose, cataclastic and mylonitized rocks. Relationships with rocks of the Ust'-Belovsky Complex (D_3) are unclear due to the lack of good exposures.

The age of the Pavlovsky Complex obtained by U-Pb zircon dating of granites of the main phase (SHRIMP-II, VSEGEI, St. Petersburg) is 386 ± 3 Ma (Fig. 1.6). We must recognize that the geological position of these granitoids was not studied enough yet; and a single U-Pb date along with the absence of similar granitoids in Rudny Altai served as the basis for their allocation into the separate complex.

Inner structure of the massif and petrographic features of rocks. Pavlovsky Massif is rather homogeneous and consists of coarse-grained biotite leucogranites.

(I) = tonalite, (j) = biotite-amphibole plagiogranite, (k) = biotite plagiogranite; (l-m) = Volchikhinsky Complex: (l) = Pervokamensky Massif, amphibole-biotite granodiorite, (m) = Verhneborovlyansky Massif, biotite granite; (n-o) = Sinyushensky Complex, Sawushinsky Massif: (n) = quartz monzodiorite (inclusion in granodiorite), (o) = biotite leucogranite.

In endocontact zone up to 2 km in thick, they give place to small- to medium-grained porphyritic leucocratic granites. The granitoids are broken by veins of aplitic granites and dolerite dykes (D_3).

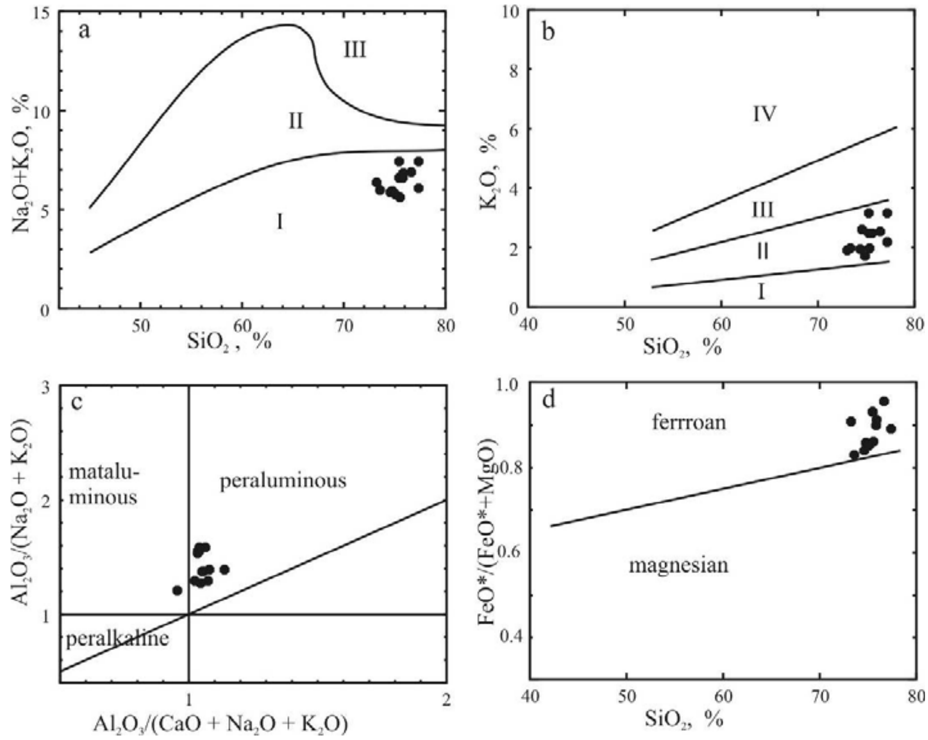


Fig. 1.4. Petrochemical diagrams for granitoids of the Aleisky Complex.

Hereinafter:

(a) TAS- diagram: fields of rock compositions I – normal alkalinity, II – moderately alkaline, III – alkaline (fields are from [Le Maitre, 1989]); (b) SiO_2-K_2O diagram; fields of rock compositions: I – low-potassium, II – moderately potassium, III – high-potassium, IV – ultra-potassium. The field boundaries are from [Le Maitre, 1989]; (c) $Al_2O_3/(CaO+Na_2O+K_2O)$ vs $Al_2O_3/(Na_2O+K_2O)$ diagram (mole quantitaties [Maniar, Piccoli, 1989]; (d) SiO_2 vs. $FeO^*/(FeO^*+MgO)$ diagram [Frost et al., 2001].

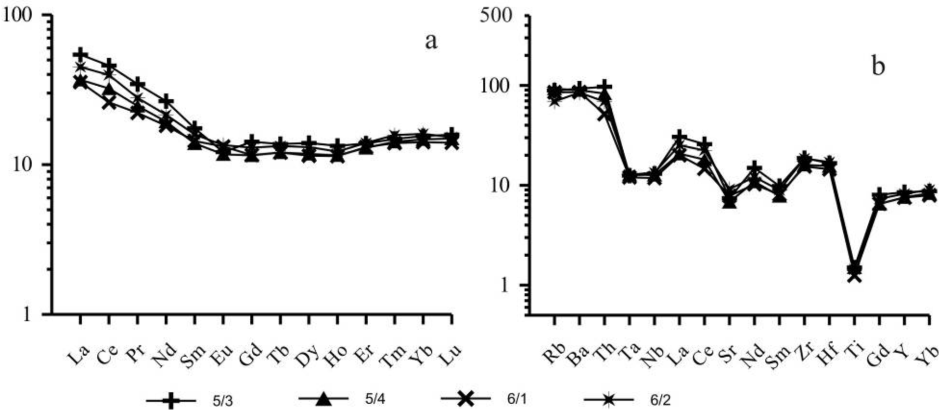


Fig. 1.5. REE spectra and spidergrams for granitoids of the Aleisky Complex.

Sample numbers correspond to Table 1.1.

Hereinafter:

REE contents are normalized to chondrite [Boyton, 1984], trace element contents are normalized to primitive mantle [Taylor, McLennan, 1985].

Table 1.1.

Major (wt. %) and trace (ppm) element contents in representative samples of granitoids of the Alei and Pavlovka Complexes

Sample	EX-5/3	EX-5/4	EX-6/1	EX-6/2	17	13-64/1	13-64/3
	1	*2*	*3*	*4*	*5*	*6*	*7*
SiO_2	74.58	75.53	73.56	75.07	75.08	75.24	75.2
TiO_2	0.24	0.24	0.2	0.23	0.21	0.14	0.15
AL_2O_3	13.07	12.85	13.44	13.5	12.8	12.76	12.71
$Fe_2O_3^*$	2.56	2.72	2.35	2.62	1.96	1.36	1.7
MnO	0.06	0.06	0.06	0.07	0.04	0.03	0.04
MgO	0.46	0.42	0.45	0.43	0.26	0.21	0.23
CaO	2.26	2.18	2.33	2.45	1.36	1.16	1.24
Na_2O	3.94	3.66	4.01	4.08	2.99	2.74	2.82
K_2O	1.93	1.96	1.96	1.69	4.57	4.83	4.79
P_2O_5	0.07	0.05	0.04	0.04	0.04	0.02	0.02
LOI	0.23	0.39	0.27	0.33	0.08	0.78	0.9
Total	99.47	100.14	98.77	100.6	99.51	99.37	99.77
Th	6.2	5.3	3.3	4.4	21.6	21.9	24
U	0.7	0.6	0.5	0.7	2.5	2.7	2.2
Rb	49	51	47	38	159	185	187
Ba	473	456	437	432	446	464	467
Sr	132	121	139	163	135	131	133
La	16.8	11.4	11	13.9	27.87	22.39	25.23
Ce	37	26	21	32	50.44	37.37	42.86
Pr	4.2	3	2.7	3.4	5.6	3.17	3.85
Nd	15.9	11.6	10.9	12.9	18.04	9.5	10.9
Sm	3.4	2.7	2.8	3.1	2.97	1.70	1.89
Eu	0.89	0.86	0.97	0.99	0.57	0.35	0.33
Gd	3.68	2.98	3	3.36	2.57	1.31	1.56
Tb	0.65	0.57	0.57	0.63	0.4	0.21	0.24
Dy	4.48	3.79	3.69	4.21	2.4	1.34	1.62
Ho	0.96	0.83	0.82	0.88	0.51	0.3	0.35
Er	2.90	2.71	2.75	2.93	1.7	0.91	1.01
Tm	0.48	0.46	0.45	0.51	0.27	0.18	0.2
Yb	3.24	3.08	2.95	3.35	1.97	1.39	1.48
Lu	0.51	0.48	0.45	0.49	0.32	0.21	0.24
Zr	155	133	128	154	108	105	104
Hf	4.5	4.2	3.9	4.6	3.5	3.1	3.1
Ta	0.5	0.51	0.48	0.51	1	0.8	1
Nb	7.3	7.1	6.6	7.5	9.1	7.4	8
Y	29	25.8	25.6	27.9	19	10	11

Note: samples are from collections by N.N. Kruk, M.L. Kuibida, P.D. Kotler..
1-4 = Aleisky complex, Mokhnatye Sopki Massif, coarse-grained granite; 5-7 = Pavlovsky complex, Pavlovsky Massif: 5 = coarse-grained granite of the central part of the massif, 6-7 = small-grained granites of the marginal part.

Biotite leucogranites are pinkish-gray, light gray weakly porphyritic coarse-grained massive rocks. Under the microscope, they display monzonite texture, sometimes in combination with micropegmatitic and myrmekitic textures. They consist of quartz (35 %), K-feldspar (microcline-perthite, 40-45 %), plagioclase (20 %), often chloritized biotite (3-5 %), single grains of muscovite, magnetite, hematite, apatite, zircon (Fig. 1.3 b). Pinkish-gray fine- to medium-grained porphyritic granites of the endocontact have a ineuigranular granitic texture in combination with micropegmatitic and myrmekitic textures. They are close in mineral composition to the above-mentioned granites.

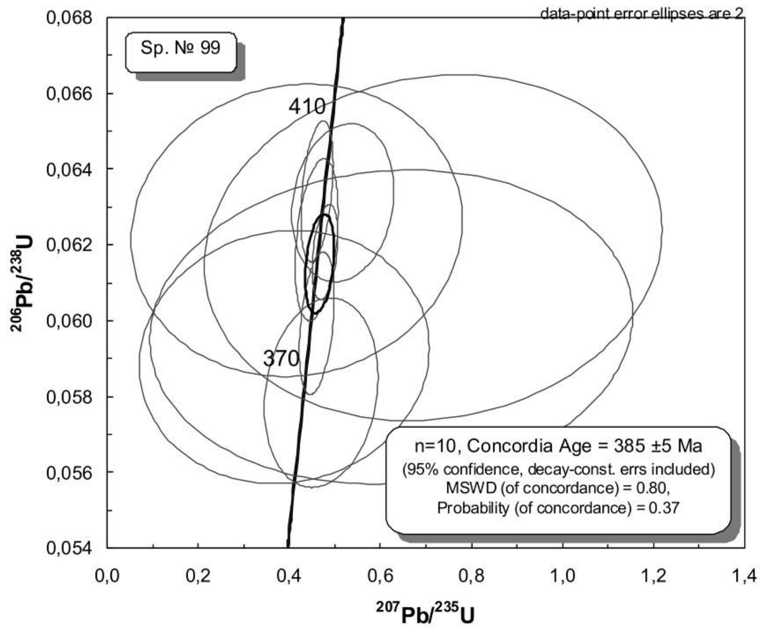


Fig. 1.6. The results of U-Pb isotope dating of zircons from granite of the Pavlovsky Massif.

Rock chemistry. The Pavlovka Massif granitoids in petrochemical composition correspond to unimodal granite-leucogranite association of normal alkalinity with a predominance of potassium over sodium (Fig. 1.7 a, b). The rocks are characterized by low contents of femic elements and calcium, high alumina content and low Mg# (Fig. 1.7 c, d).

The trace-element composition of granitoids is characterized by elevated contents of Rb, Cs, Th, U (Table 1.1), lower concentrations of Sr and Ba. The total REE contents constitute 80 to 115 ppm, their spectra have an asymmetrical shape with $(La/Yb)_N$ = 9 to 11.5. The left part of the spectra have a pronounced negative slope ($(La/Sm)_N$ = 6-8), and the right side is almost horizontal with a slight bend (Fig. 1.8 a). All REE spectra display an expressed Eu minimum; and spidergrams have negative anomalies for Ta, Nb, Ba, Sr and Ti. The rocks are selectively enriched in rocks Zr and Hf relative to REE (Fig. 1.8 b).

ZMEINOGORSKY COMPLEX

Geological position and age of massifs. The Zmeinogorsky Complex rocks constitute a significant part of the Late Devonian intrusive rocks of Rudny Altai (Fig. 1.1). Intrusive bodies are confined to the framing of the Alei uplift (fragment of brachyanticline on the Caledonian basement) and occupy an interformational position between the basement rocks (metaterrigenous shales of the Korbalikha series, S-D_1?) and plagiogranites of the Aleisky Complex (D_{2-3}), or break through all Devonian volcanic-sedimentary formations. The massifs were formed under hypabyssal conditions, as indicated by the fine-grained, porphyritic, micropegmatitic textures of the rocks and quenching zones in endocontacts of the massifs. Contacts of the plagiogranites with the frame rocks are sharp, intrusive ones.

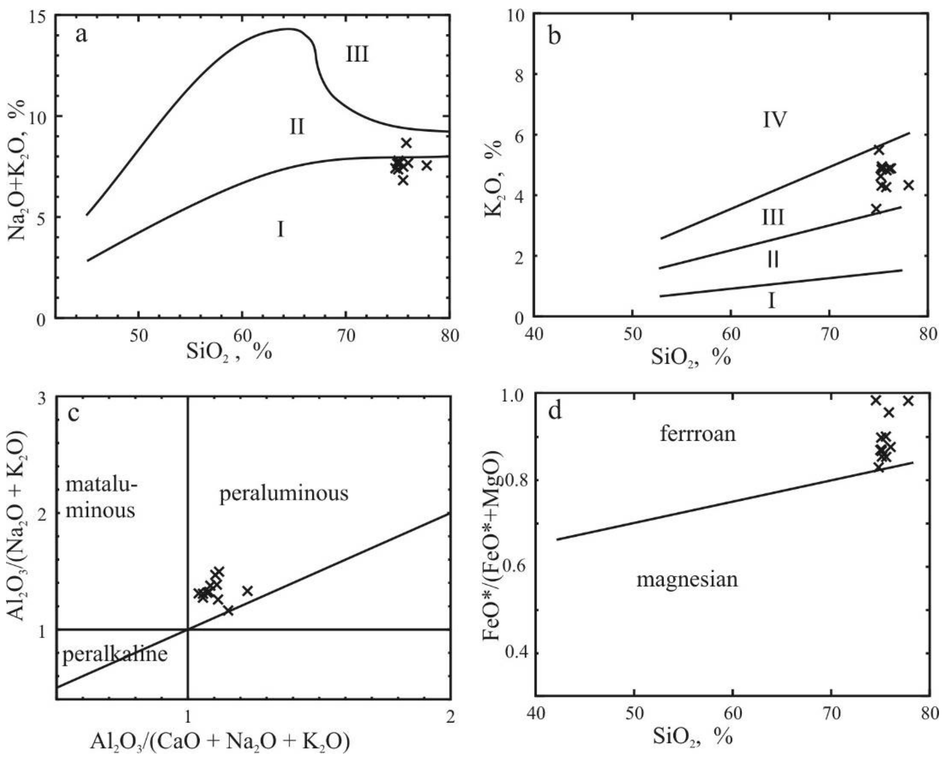


Fig. 1.7. Petrochemical diagrams for granitoids of the Pavlovsky Massif.

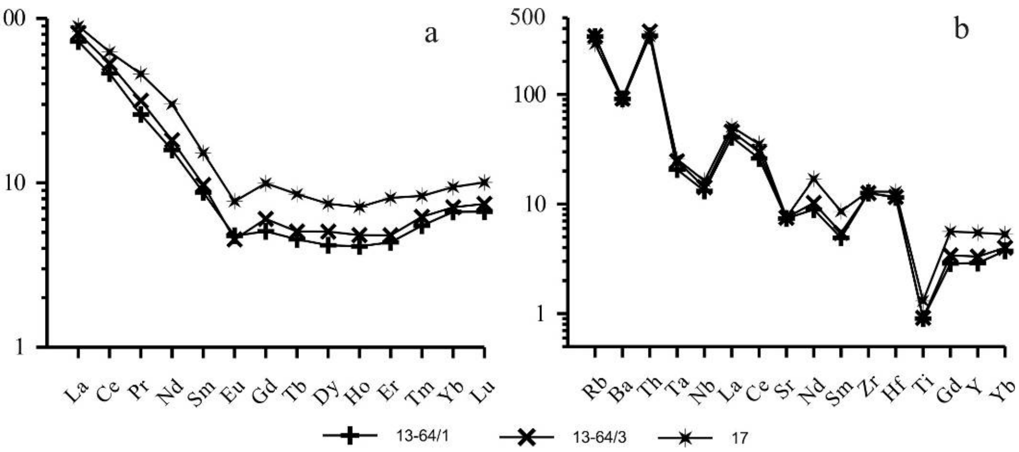
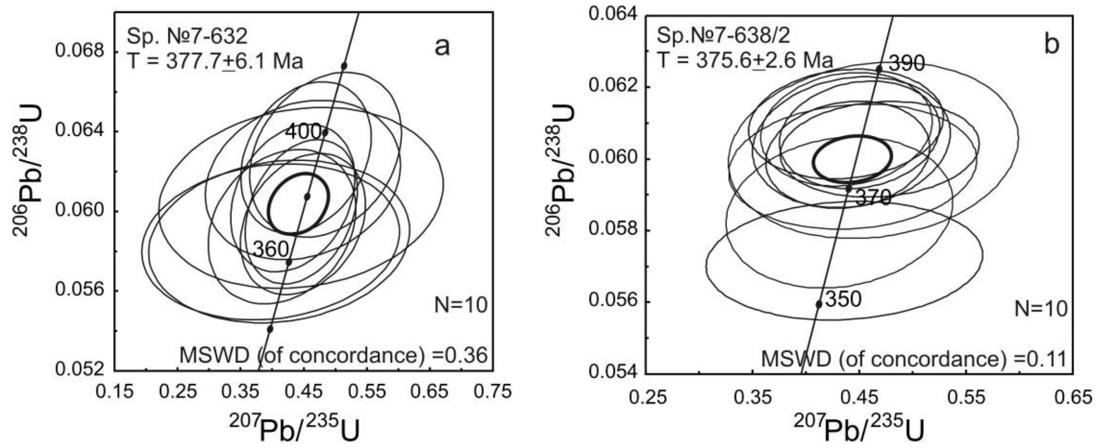


Fig. 1.8. REE spectra and spidergrams of granitoids from the Pavlovsky Massif.
Sample numbers correspond to Table 1.1.

The complex is subdivided into four phases (from early to late ones): (1) gabbro and diorites; (2) melanocratic amphibole-biotite plagiogranites; (3) biotite plagiogranites; 4) biotite plagioleucogranites. Rocks of the first phase compose small isometric and slightly elongated bodies within the granitoids of later phases. They are represented by gabbro, gabbronorite, melanocratic diorite, usually closely associated with each other. In addition, numerous fine-grained and porphyritic varieties of granitoids composing endocontact parts of the massifs, separate stock- and dyke-like bodies, are widely developed. The stock- and dyke-like bodies are located both as among the rocks of the earlier phases, and as separate intrusive bodies.

The age of granitoids of the Zmeinogorsky Complex obtained on zircons from plagiogranites of three massifs by U-Pb isotopic method (SHRIMP-II, VSEGEI, St. Petersburg) corresponds to the Late Devonian (378 ± 6, 376 ± 3, and 371 ± 2 Ma, Fig. 1.9).



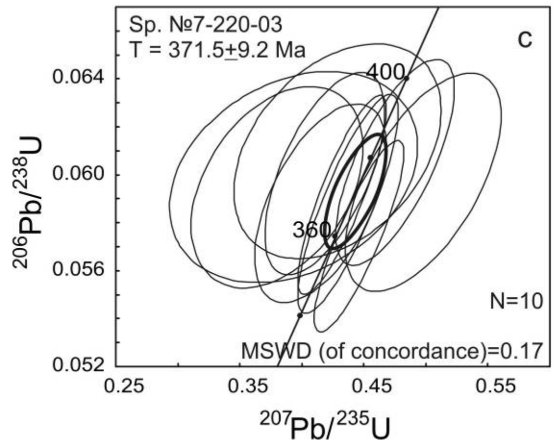


Fig. 1.9. The results of U-Pb isotope dating of zircons from granitoids of the Zmeinogorsky Compex.
(a) melanocratic plagiogranite of the Ekaterinian Massif, (b) plagiogranite of the Mokhnatye Sopki Massif, (c) leucoplagiogranite of the Pervomaika Massif.
The analyst is I.P. Paderin (VSEGEI, St. Petersburg). Zircons were separated by S.N. Rudnev (IGM SB RAS, Novosibirsk).

Petrographic features. Gabbros of the first phase are black, greenish-black or dark gray, fine- and medium-grained rocks with gabbroic and gabbro-poikilitic texture (Fig. 1.3 c). Quartz gabbros consist of zonal (from An_{55} in core to An_{33} in rim) plagioclase (45-55 %), pyroxene, entirely substituted by green hornblende (40 %), quartz (5-10 %). Late biotite is often present in the rock.

Melanocratic amphibole-biotite plagiogranites are macroscopically dark rocks with equigranular medium-grained granitic texture. They are composed of quartz (30-35 %), glomerocrystalline clusters of plagioclase (An_{12-27}, 55-60 %), ferrous hornblende (5-10 %), and biotite (5 %). Anhedral perthitic K-feldspar is present to a small extent (Fig. 1.4d). Biotite plagioleucogranites are light gray, yellowish rocks with porphyry small- to medium-grained texture; they are composed of quartz (45 %), laths of plagioclase (An_{14-22}, 40 %), biotite (up 8 %), amphibole (up to 5 %), and perthitic K-feldspar (5 %). The K-feldspar-rich rocks (up to 10 %) often have granophyric and micropegmatitic textures (Fig. 1.3 e).

Rock chemistry. According to their chemical composition the Zmeinogorsky Complex rocks belong to the series of normal alkalinity (Fig. 1.10 a). In gabbros, diorites and melanocratic plagiogranites sodium always prevails over potassium (Na_2O/K_2O = 1.2-8.4; up to 13.2 in some samples). Leucocratic granitoids show wide variations in alkali content and Na_2O/K_2O ratio (Fig. 1.10 b).

The gabbros are characterized by low alumina content, elevated concentrations of titanium and high Mg# (Table 1.2.). The granitoids are dominated by peraluminous varieties (especially leucoplagiogranites) with lower Mg# (Fig. 1.10 c, d).

The trace-element composition of the gabbros is characterized by extremely low

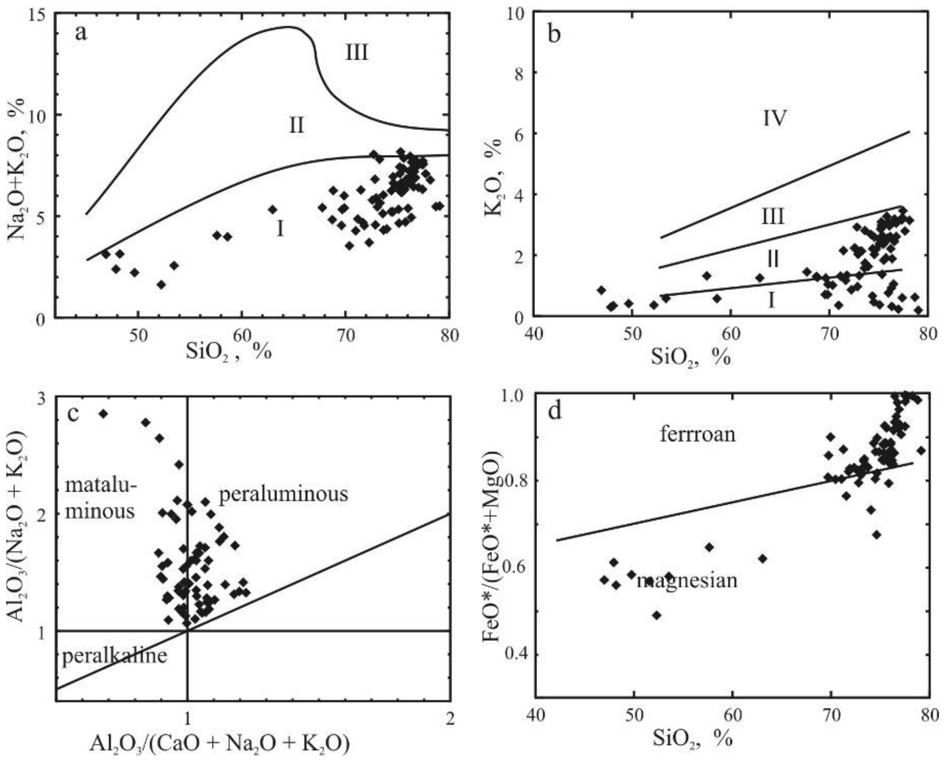


Fig. 1.10. Petrochemical diagrams for the Zmeinogorsky Complex rocks.

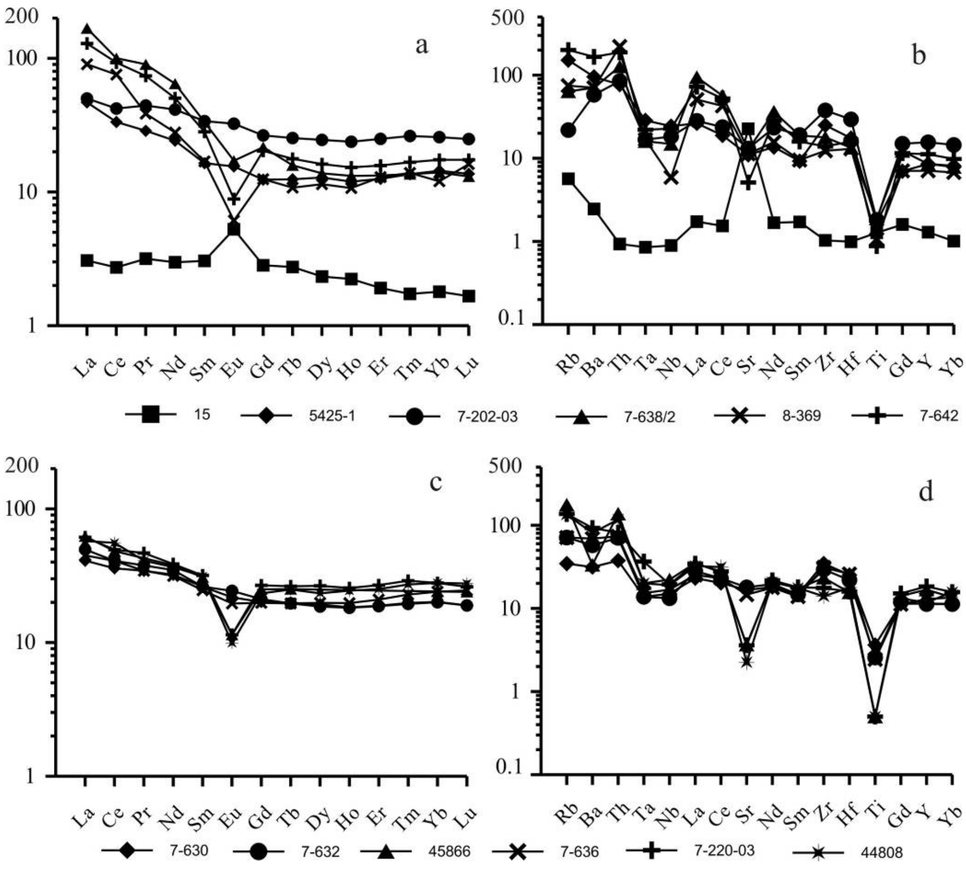


Fig. 1.11. REE spectra and spidetgrams for rocks of the Zmeinogorsky Complex.
(a-b) gabbro and melanocratic plagiogranites, (c-d) plagiogranites and plagioleucogranites.
Sample numbers correspond to Table 1.2.

Table 1.2.

Major (wt. %) and trace (ppm) element contents in representative samples of plagiogranites of the Zmeinogorsky Complex

Massif	Mokhnatye Sopki					Ekaterininsky			Pervomaisky		
Rock	1		2	3		1		3	1	3	
Sample	5425-1	7-202-03	7-638/2	8-369	7-642	7-630	7-632	45866	7-636	7-220-03	44808
SiO_2	72.64	75.2	73.08	75.73	76.54	69.66	72.94	75.36	71.75	75.62	76.03
TiO_2	0.27	0.29	0.3	0.17	0.14	0.58	0.41	0.08	0.39	0.08	0.08
AL_2O_3	14.13	13.26	13.6	14.06	13.1	13.98	13.9	11.96	14.4	12.76	11.82
$Fe_2O_3^*$	3.35	3.22	3.11	0.76	1.55	5.11	3.75	2.66	3.49	1.47	2.35
MnO	0.06	0.09	0.09	0.12	0.03	0.12	0.06	0.05	0.07	0.07	0.06
MgO	0.65	0.52	0.53	0.27	0.16	1.1	0.72	0.44	0.69	<0.1	0.27
CaO	2.89	2.35	2.89	3.16	1.29	4.62	3.7	0.62	4.06	0.89	0.65
Na_2O	3.52	4.23	3.95	4.07	3.81	3.78	3.56	5.93	3.46	5.64	5.68
K_2O	2.18	0.32	1.6	1.25	3.42	0.66	0.92	3.04	1.12	3.31	3.01
P_2O_5	<0.01	0.05	0.07	0.1	0.03	0.12	0.08	0.03	0.07	<0.03	0.01
LOI	0.79	0.46	0.72	0.29	0.32	0.31	0.56	0.12	0.85	0.34	0.3
Sum	100.33	100.04	100.01	99.69	100.43	100.1	100.45	100.17	100.25	100.24	99.96
Th	4.9	5.4	8.1	14.1	12	2.4	4.5	8.8	4.7	5.2	7.5
U	1.14	1.6	1.54	2.23	3.03	0.7	1.3	1.6	1.4	1.4	0.8
Rb	83	12	35	41	110	19	39	97	39	75	74
Ba	485	295	359	359	844	160	292	170	352	473	410
Sr	195	233	224	201	91	295	318	65	260	64	40
La	14.5	15.5	52	28	40	12.7	15.4	19.3	13.9	19	17.8
Ce	27	34	81	61	75	29	33	39	33	40	45
Pr	3.5	5.4	11	4.7	9	4.2	4.6	-	4.2	5.7	5
Nd	14.5	24.8	38.7	16.7	30.2	19.3	20.9	22.7	18.9	23.2	22
Sm	3.2	6.6	6.5	3.3	5.5	5.1	5.1	6	4.8	6.2	6.1
Eu	1.14	2.38	1.26	0.45	0.65	1.6	1.79	0.84	1.44	0.84	0.73
Gd	3.2	6.86	5.6	3.23	5.26	5.21	5.46	6.47	5.13	6.94	6.04
Tb	0.59	1.2	0.75	0.51	0.84	0.94	0.93	1.19	0.93	1.25	1.18
Dy	4.13	7.9	4.44	3.68	5.2	6.22	5.98	-	6.38	8.55	7.51
Ho	0.86	1.71	0.95	0.77	1.1	1.32	1.31	-	1.42	1.84	1.76
Er	2.63	5.24	2.79	2.71	3.31	3.96	3.93	-	4.4	5.64	5.27
Tm	0.44	0.85	0.44	0.45	0.54	0.64	0.63	-	0.74	0.94	0.88
Yb	3.01	5.37	2.92	2.51	3.64	4.21	4.18	5.03	5.02	5.83	5.84
Lu	0.44	0.8	0.42	0.52	0.56	0.61	0.61	0.77	0.79	0.84	0.89
Zr	207	312	148	102	115	287	243	193	257	146	116
Hf	4.7	7.9	3.6	3.5	4.3	6.8	5.9	4.2	7	4.3	4.8
Ta	1.14	0.67	0.64	0.67	0.88	0.55	0.55	0.8	0.61	1.46	0.8
Nb	13.6	10.2	8.3	3.3	12.7	8.4	7.4	12.4	9.4	10.9	10.6
Y	29	52.8	29	24.04	37.91	38.8	38.2	57	44	62.3	39.9

Note: 1 = melanocratic plagiogranite; 2 = plagiogranite; 3 = plagioleucogranite.
Dash denotes "not determined".
Samples are from collections by O.V. Murzin, N.N. Kruk, M.L. Kuibida.

concentrations of LILE (except Sr), HFSE and REE (Table 1.2.). REE patterns are weakly asymmetric with a positive slope and a pronounced Eu maximum (Fig. 1.11 a). The spidergrams (Fig. 1.11 b) display a positive Sr anomaly.

Melanocratic plagiogranites are characterized by higher HFSE and REE contents compared to gabbro (Table 1.2.). Their REE are gently sloping (La/Yb_N = 1.8-3.2) with a weak Eu minimum in some samples (Fig. 1.11 a). The spidergrams show negative anomalies for Ta, Nb, Ti, and sometimes Sr, and positive anomalies for Hf and Zr (Fig. 1.11 b). Plagiogranites have asymmetric REE spectra (ΣREE = 208 ppm, La/Yb_N = 1.9), weak Eu minima (Fig. 1.11 c), and negative anomalies for Sr, Ta, Nb, and Ti in the spidergrams. Plagioleucogranites have slightly asymmetrical spectra of REE and trace element distribution (ΣREE = 102-127 ppm, La/Yb_N = 1.6-2.6, Sr/Y = 0.9-1.0) with a bend close to a distinct Eu minimum (Eu/Eu* = 0.3-0.4) and negative anomalies for Sr, Ta and Nb.

The plagiogranitoids are characterized by positive values of εNd(T) (+1.8 in melanocratic plagiogranites and plagiogranites, +1.1 in plagioleucogranites).

Geochemical characteristics of the granitoids (Al_2O_3 <15 %, Yb> 1 ppm, Sr/Y <40, negative Eu anomaly in REE spectra) indicate the belonging of plagiogranites to the low-alumina type (according to [Arth, 1979]).

The results of petrological studies suggest that the formation of plagiogranitic magmas of the Zmeinogorsky Complex was due to remelting of magma chambers of island-arc low-K calc-alkaline and tholeiitic basalts at P = 8 kbar (T = 1000°C), with a gradual involvement of metaterrigenous basement rocks of Rudny Altai in the magma generation process at P = 5 kbar (T = 800°C) [Kuibida, 2010].

UST'-BELOVSKY COMPLEX

Geological position and age of granitoids. In Rudny Altai the Ust'-Belovsky Complex has a limited distribution and represented by a single Mezhdurechensky Massif, located southwest of the Zmeinogorsk city. The intrusive body is spindle-like shaped, extends in a northwesterly direction for a distance of 23 km, has a width of up to 4.5 km, and reaches a vertical thickness of up to 6 km. Granitoids of the complex formed in mesoabyssal conditions, as indicated by the absence of quenching zones in endocontacts.

The basic volume of the massif is composed of quartz diorite and granodiorite. From geophysical data and drilling, the early phase is represented by gabbro and gabbro-dolerite, composing several small (1.5 km^2) bodies among the granitoids. The rocks are cut by a series of dolerite, granodiorite, and granite porphyry dykes.

The Late Devonian age of Mezhdurechensky granitoids was estimated based on the fact that they intrude Frasnian volcanogenic-sedimentary rocks with formation of hornfelses. The geological position was confirmed by U-Pb isotopic dating (SHRIMP-II, VSEGEI, St. Petersburg) of single zircon grains (372 ± 3 Ma) from diorite of the main phase (Fig. 1.12.).

The obtained date coincides well with the age estimates of granitoids of the Ust'-Belovsky Complex from adjacent territories of Gorny Altai [Shokalsky et al., 2000; Vladimirov et al, 2001].

Petrographic features. Granodiorites of the main phase are light gray equigranular medium-grained rocks consisting of weakly zonal plagioclase (andesite, 45-55 %), quartz (10-15 %), K-feldspar (10-15 %), green hornblende (15 %), biotite (3-5 %) and single grains of augite. Quartz diorite have more fine-grained texture, lower quartz content and greater amounts of pyroxene among the dark-colored minerals: plagioclase (60 %), pyroxene - diallage (10 %), partially substituted by amphibole, biotite (25-30 %), quartz (5-10 %). The rock structures are massive, sometimes schlieren due to the large number of rounded inclusions of melanocratic fine-grained diorite. The textures are hypidiomorphic, rare prismatic-grained (Fig. 1.3 f). The accessory minerals are sphene, zircon, leucoxene, rutile, and magnetite.

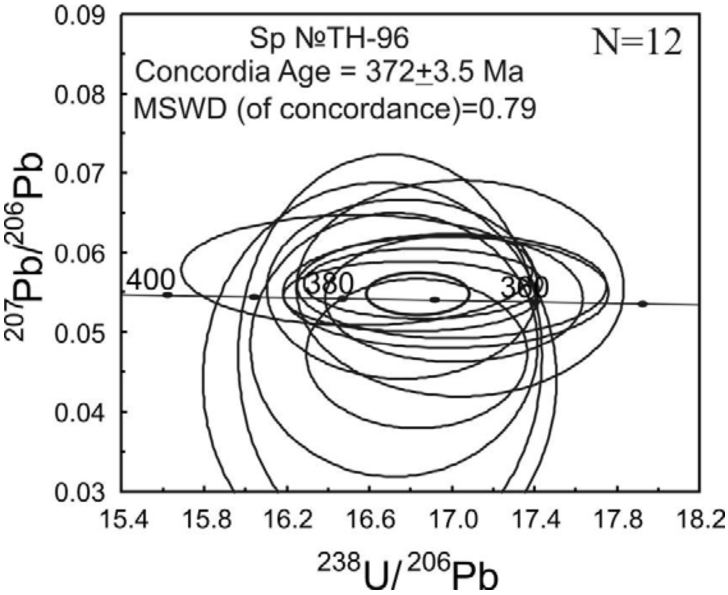


Fig. 1.12. The results of U-Pb isotope dating of zircons from quartz diorite of the Mezhdurechensky Massif.

Rock chemistry. The Ust'-Belovsky Complex rocks correspond in their chemical composition to the series of normal alkalinity with K-Na specialization of alkalis (Fig. 1.13 a, b). Gabbroids of the first phase) have elevated concentrations of titanium and calcium, moderate alumina content and Mg# [State ..., 2001 a]. Quartz diorites and granodiorites are characterized by slightly elevated concentrations of titanium and phosphorus, undersaturation in alumina, elevated concentrations of calcium and femic elements (Table 1.4.), moderate Mg# (Fig. 1.13 d).

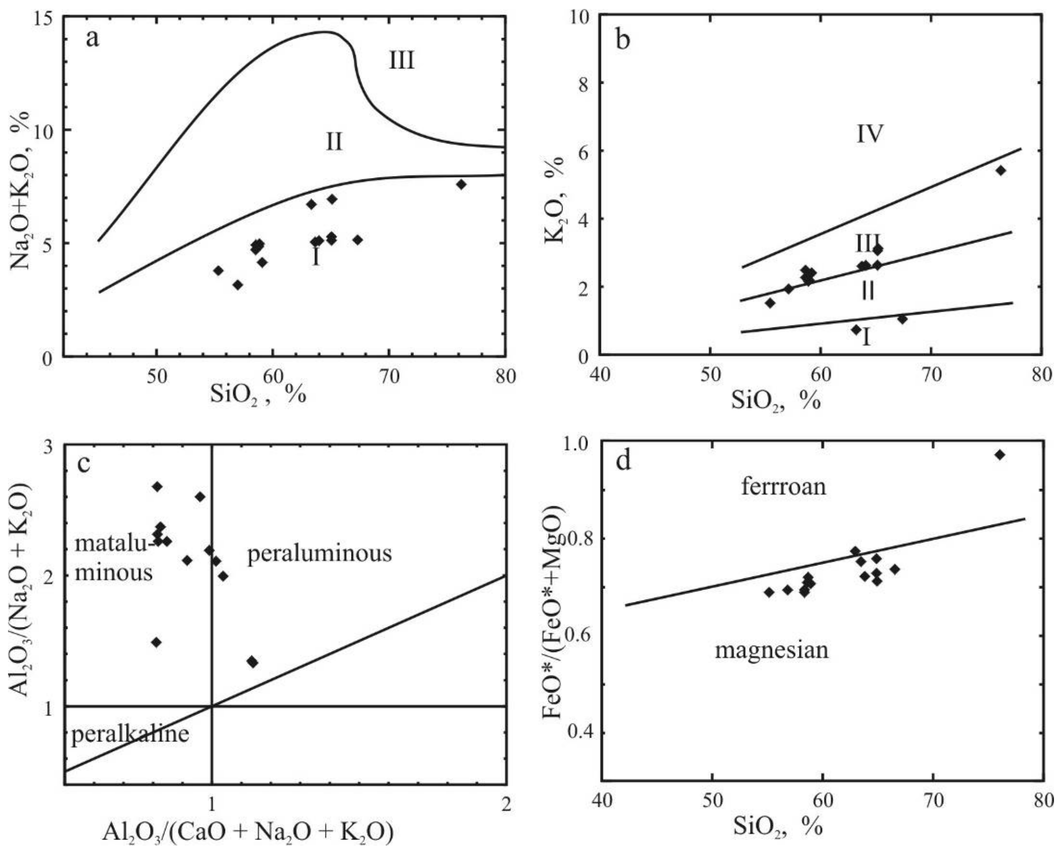


Fig. 1.14. Petrochemical diagrams for granitoids of the Mezhdurechensky Massif.

Table 1.3.

Major (wt. %) and trace (ppm) element contents in representative samples of the Ust'-Belovsky and Ust'yansky complexes

Sample	11/2	12/1	12/2	32836	31802	31801	9/1	9/2	9/3
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
SiO_2	58.56	58.9	55.36	75.83	75.49	76.39	77.57	77.17	77.97
TiO_2	0.82	0.91	0.94	0.21	0.15	0.2	0.07	0.07	0.06
AL_2O_3	15.45	15.79	16.25	12.2	12.32	12.73	12.06	12.26	11.56
$Fe_2O_3^*$	8.24	8.25	9.81	2.8	2.14	2.3	1.2	1.28	1.17
MnO	0.14	0.14	0.16	0.05	0.05	0.03	0.03	0.03	0.02
MgO	3.28	2.9	4	0.38	0.41	0.35	0.07	0.07	0.07
CaO	6.72	6.42	8.13	0.82	0.67	0.56	0.31	0.13	0.11
Na_2O	2.46	2.79	2.28	2.96	4.33	3.53	3.57	3.63	3.25
K_2O	2.27	2.19	1.52	4.33	4.27	3.39	4.49	4.72	4.60
P_2O_5	0.15	0.21	0.2	0.4	0.36	0.36	0.01	0.01	0.02
LOI	1.1	0.86	1.37	0.05	0.01	0.01	0.46	0.20	0.44
Sum	99.28	99.49	100.12	100.03	100.20	99.85	99.93	99.64	99.35
Th	6.7	5.7	4.5	8.23	12.4	7.31	15.7	18.5	18.8
U	1.6	1.6	1.6	1.63	2.28	1.28	2	2.5	1
Rb	72	69	40	101	127	76.8	137	136	124
Ba	306	395	234	421	274	496	163	194	343
Sr	274	345	347	54.8	41.2	71.4	18	19	19
La	18.8	23	15.9	24.5	14.2	26.8	31	26	23
Ce	41	54	35	57.8	40.4	49.9	63	67	51
Pr	5	6.7	4.1	6.7	4.55	7.5	8.7	7.6	7
Nd	19.4	26	17.2	27.3	19.6	31.2	35	28	26
Sm	4.8	6.7	4.2	6.31	5.47	7.56	10	7.9	6.8
Eu	1.05	1.45	1.12	0.71	0.68	1.48	0.35	0.33	0.33
Gd	4.4	5.9	3.7	6.44	5.94	7.65	8.8	7.5	6.3
Tb	0.78	0.97	0.65	1.17	1.16	1.29	1.61	1.35	1.21
Dy	4.8	5.9	4.1	7.02	7.28	7.27	9.4	8.7	7.9
Ho	1.02	1.27	0.81	1.54	1.63	1.55	1.82	1.81	1.75
Er	2.8	3.4	2.3	4.56	5.02	4.57	5.2	5.1	5.1
Tm	0.43	0.53	0.36	0.76	0.88	0.69	0.84	0.87	0.87
Yb	2.9	3.6	2.3	4.58	5.46	4.34	5.7	5.9	6
Lu	0.43	0.54	0.35	0.67	0.88	0.69	0.89	0.89	0.92
Zr	139	269	134	87.8	97.7	60.3	166	156	96
Hf	3.9	6.8	3.4	3.21	4.3	3	6.8	7.1	5
Ta	0.6	0.54	0.4	1.15	1.56	1.11	1.84	2.2	1.96
Nb	8.6	9.8	6.4	16.9	17.2	16.1	24	25	21
Y	29.2	36.2	23.5	41.7	43.3	38.2	51.4	48.6	49.9

Note: 1-3 = Ust'-Belovsky complex, Mezhdurechensky Massif, diorites. 4-9 = Ust'yansky complex, Ust'yansky Massif: 4 = coarse-grained biotite leucogranites of the first phase, 5 -6 = medium-grained biotite leucogranites of the second phase, 7-9 = small-grained biotite leucogranites of dikes and small bodies. The samples are from collections by O.V, Murzin, N.N. Kruk, M.L. Kuibida.

The trace-element composition of granitoids is characterized by moderate LILE and HFSE contents (Table 1.3.), typical of calc-alkaline granitoids. The total REE contents are 92 to 140 ppm; their spectra are weakly asymmetric (La/Yb_N = 4.4-4.6) with minor Eu minimum or without it (Fig. 1.14 a). The spidergrams of the massif rocks show negative anomalies for Ti, Ta and Nb, (minor – for Sr), and positive anomalies for Zr and Hf (Fig. 1.14 b).

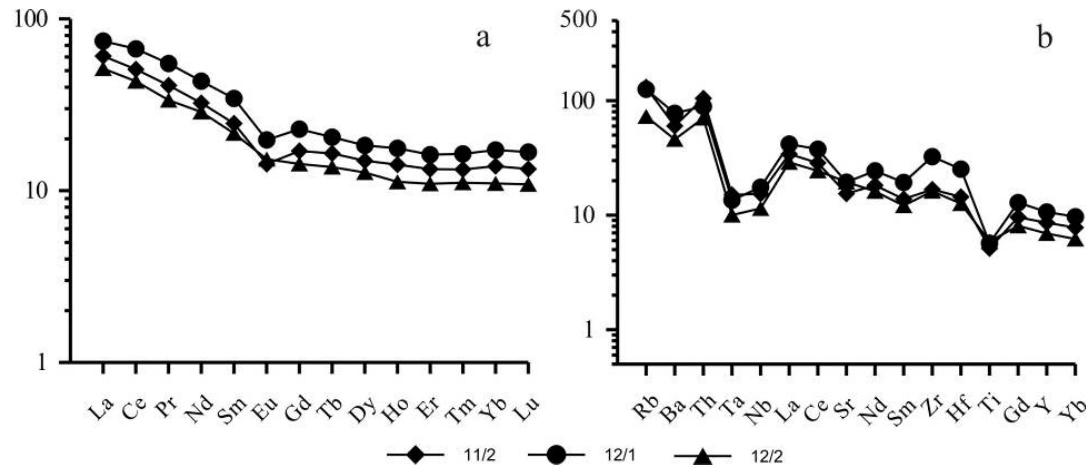


Fig. 1.14. REE spectra and spidergrams for rocks of the Mezhdurechensky Massif.
Sample numbers correspond to Table 1.3.

UST'YANSKY COMPLEX

Geological position and age. Granitoids of the Ust'yansky Complex compose a single massif of the same name, which locates in the valley of Alei River, to the west from Gilevo village. The massif is oval in shape, slightly elongated in sublatitudinal direction. It is reconstructed deep down as a thick two-root funnel-shaped intrusive body, sinking in a southerly direction [State..., 2001 a]. The intrusive body was formed in hypabyssal to mesoabyssal environment, as indicated by numerous miarolitic cavities, micropegmatitic texture and wide zones of fine-grained rocks in the endocontacts with enclosing hornfels of the Korbalikha series ($S\text{-}D_1$?).

In the complex two phases of intrusion are distinguished. The first main intrusive phase is represented by leucocratic equigranular, sometimes weakly porphyritic, medium- to coarse-grained granites. In endocontact zone of 600-800 m in width the main phase granites are changed for small- to medium-grained varieties. Among the rocks of the main phase, several arc-shaped bodies composed of fine-grained porphyritic granites of the second phase are located. Veined rocks form dikes of 0.5 to 3 m, rarely up to 5 m, in thickness, and of 500-600 m, rarely up to 1 km, in length. They occur in the system of transverse cracks or sometimes form small stock-shaped bodies, and are represented by aplitic granites and aplites. Sometimes occur pegmatite veins up to 2 m in thick and up to 50 m in length [State ..., 2001 a].

The Late Devonian age of granitoids of the Ust'yansky Complex obtained on zircons by "classical» U-Pb isotopic method is 372 ± 6 Ma (Fig. 1.15). The date value overlaps, within the limits of analytical error, with the age of granitoids of the Zmeinogorsky Complex. However, granitoids of the Ust'yansky Complex sometimes contain xenoliths of plagiogranites identical to rocks of the III phase of the Zmeinogorsky Complex.

Petrographic features. The first main phase is represented by leucocratic equigranular medium-grained granites of characteristic pink and red color. The rocks have granitic, micropegmatitic textures (Fig. 1.3 g) and consist of quartz (30-35 %), K-feldspar (35-40 %), oligoclase (25-32 %), biotite (1-5 %) ± fluorite, magnetite, apatite, and zircon. Granites of the second phase are porphyritic fine-grained rocks of pink, brownish-red color with granitic texture (Fig. 1.3 h). They are composed of plagioclase (30 %), K-feldspar

(40 %), quartz (30 %), biotite (1 %). Accessory minerals are fluorite, hematite, zircon, and apatite.

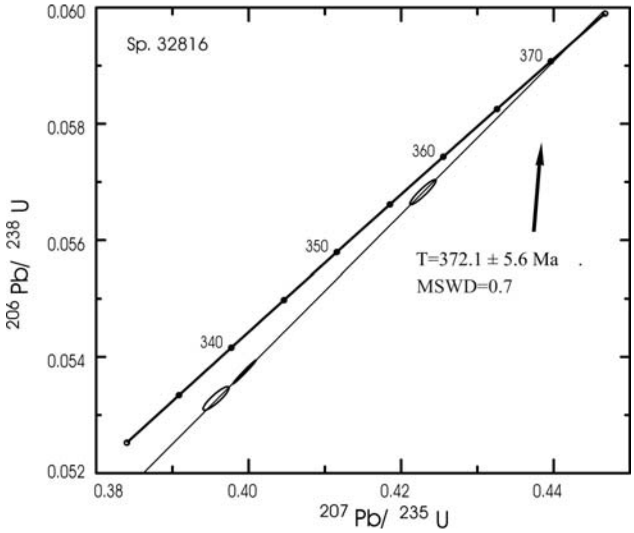


Fig. 1.15. The results of U-Pb isotope dating of zircons from granitoids of the Ust'yansky Massif.

Rock chemistry. According to their chemical composition the Ust'yansky Complex rocks belong to the potassium-sodium granite-leucogranite series of normal or slightly elevated alkalinity (SiO_2 = 72-77.8 wt.%, Na_2O/K_2O = 0.6-1.9) (Fig. 1.16 a, b).

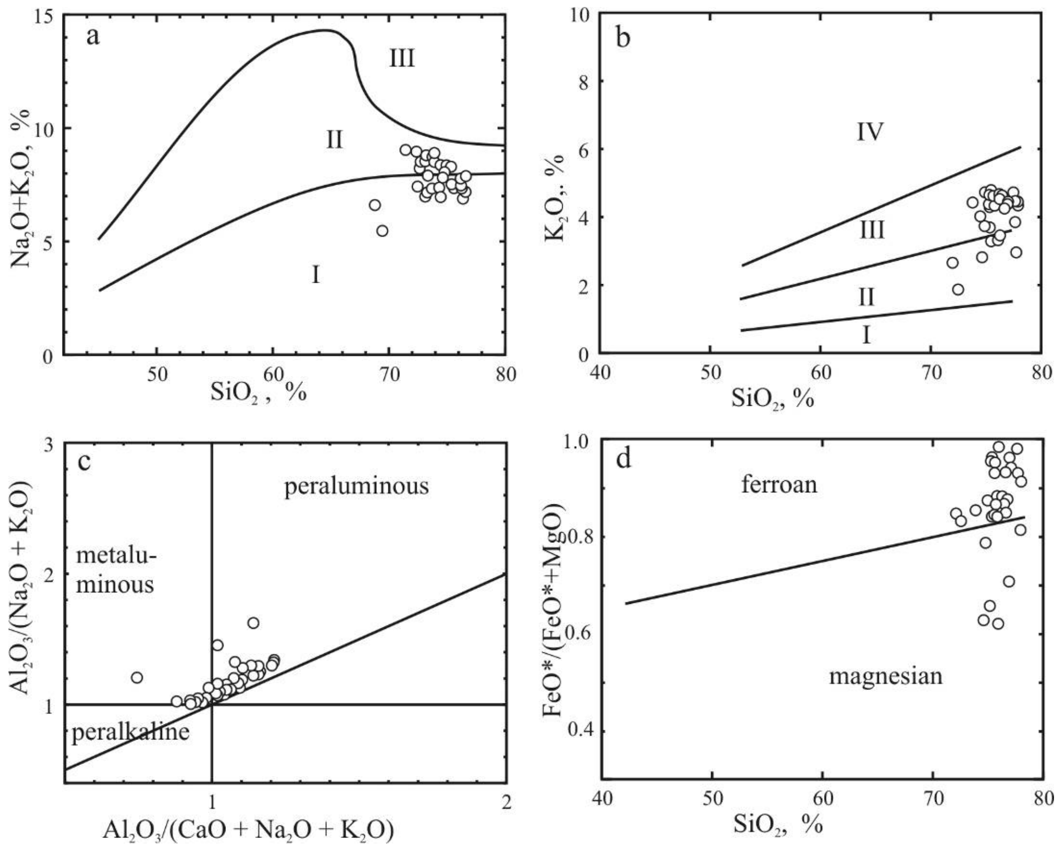


Fig. 1.16. Petrochemical diagrams for granitoids of the Ust'yansky Massif.

The granitoids are supersaturated in alumina and have low Mg# (Fig. 1.16 c, d). However, metaluminous magnesian rocks with elevated Na_2O/K_2O ratios occur sporadically among the least acid granitoid varieties.

The trace-element composition of granitoids is characterized by weakly elevated concentrations of U, Th, Nb and Ta, moderate contents of LILE (except Sr), Zr and Hf. Another characteristic of granitoids are elevated concentrations of HREE and Y (Table 1.3.). Granites show slightly asymmetrical REE spectra (ΣREE = 107.85-182.66 ppm, La/Yb_N = 3 to 5) with a bend close to a distinct Eu minimum (Fig. 1.17 a). In spidergrams (Fig. 1.17 b) deep Sr and Ti minima and positive Th anomaly are observed. Selective depletion in Nb and Ta, characteristic of most granitoids of Rudny Altai, becomes less apparent in the rocks of the Ust'yansky Complex (Fig. 1.17 b).

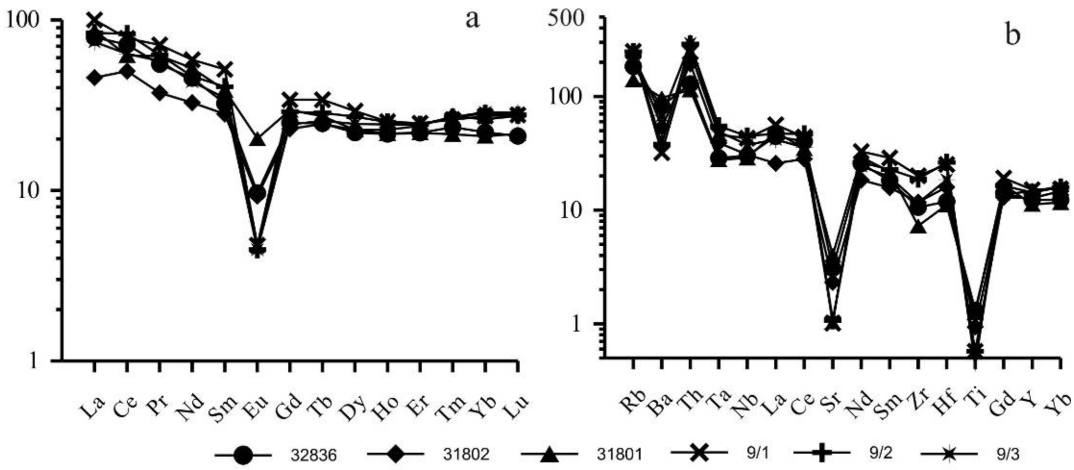


Fig. 1.17. REE spectra and spidergrams for the Ust'yansky Massif rocks.
The sample numbers correspond to Table 1.3.

GILEVSKY COMPLEX

Geological position and age of massifs. Plagiogranite intrusive bodies of the Gilevsky Complex located in the central part of Rudny Altai are confined to the central part of the Alei uplift (fragment of brachyanticline in the Caledonian basement) (Fig. 1.1). At the present erosion level they are manifested in the form of separate small outcrops on the northern shore of the Gilevo reservoir west of the city Zmeinogorsk, in the basins of Mohovushka, Beryozovka, Dal'naya and Blizhnyaya Schelchikha streams. From geophysical data and geological mapping they represent outcrops of a single large intrusive body that extends for more than 100 km from the south-east to north-west, with a width of 10-30 km.

Outcrops of intrusive rocks of the Gilevo Massif are extremely small; they can be observed in the sides of small streams. These intrusive bodies are confined to local zones of tectonic deformations, manifested within the Alei uplift: the Central deformation zone having northwestern orientation, and its feathering Submeridional deformation zone. Within the last zone all the intrusive rocks with an age range from the Devonian to Early Carboniferous, including melanocratic plagiogranites of the Zmeinogorsky Complex (D_3) and dolerite dykes (D_3-C_1) were subjected to tectonic deformations. The deformation zone is "sealed up" by granites of the Volchikhinsky Complex (C_2).

In the Central shear zone cataclazed diorites, tonalites and gneissous amphibole plagiogranites are localized. All the intrusive phases have general orientations of the emplacement, contacts and internal deformations, which coincide with those in the surrounding greenschists of the Korbalikha series (~310°). Gneissous biotite plagiogranites are localized in the Submeridional deformation zone. Gneissosity of the plagiogranites is oriented in submeridional direction at an angle of 345-350° and has the angle of dip of 50-60°. The plagiogranites are cut by a series of dikes having different strikes and different relations with tectonic deformations. The four main generations of dikes cutting each other, are distinguished.

The dike generation I is composed of synkinematic small- to medium-grained porphyritic biotite plagiogranites (thickness is 3 cm; strike azimuth is 160-165°). Orientation of the rock gneissosity coincides with that in the host plagiogranites (350°, dip angle is 65-70°). The dike generation II is composed of rocks macroscopically close to the previous ones (thickness is 10-50 cm, strike azimuth is 245°). Orientation of the rock gneissosity is identical to that described for the first dike generation. These dikes have undergone a sinistral shift with amplitude of 10 cm. The main reason for distinguishing of this generation was the chemical composition of the rocks. The dike generation III is represented by small-grained porphyritic plagiogranites (thickness is 25-40 cm; strike azimuth varies from 315 to 350° and generally coincides with the strike of the shear zone). The sinistral shift is detected from a character of the deformation (S-shaped structure). The dike generation IV is represented by small- to medium-grained porphyritic biotite plagiogranites (thickness is 5 cm, strike azimuth of 355° to 0°). In outcrops this phase rocks look the most massive and the least gneissous. Orientation of the gneissosity is 280°. For this dike generation it is supposed to be postkinematic injection.

In the western part of the massif quartz diorites of the Gilevsky Complex intruded in melanocratic plagiogranites of the Zmeinogorsky Complex (D_3). In endocontact zone of quartz diorites, a decrease of mineral grain sizes is observed; directly in the contact zone small apophyses and veins of quartz diorites are visible within the host plagiogranites (Kuibida et al., 2013). In the northern part of the massif quartz diorites, tonalites and amphibole plagiogranites intrude into metamorphic schists of the Korbalikha series (S-D_1). Contacts of the Gilevsky Complex rocks with granite-leucogranites of the Pavlovka Massif have a tectonic character: in the contact zone all the granitoid varieties are intensively gneissose and broken down.

The age of plagiogranitoids of the Gilevsky Complex was obtained on zircon by U-Pb "classic" isotope method (Vernadsky Institute of Geochemistry and Analytical Chemistry of RAS, Moscow) and SHRIMP-II (VSEGEI, St. Petersburg), as well as on amphibole and biotite by Ar-Ar method (IGM SB RAS, Novosibirsk). All the obtained dates fall in the narrow age interval of 322 to 318 Ma (Fig. 1.18).

Petrographic features. The confinement of intrusive bodies of the Gilevsky Complex to local zones of tectonic deformations and a synkinematic character of magma intrusions were responsible for an appearance and structural and textural features of the rocks. Everywhere the granitoids were turned into blastomylonites and gneisses (Fig. 1.3 i-k)

Diorites and tonalites are cataclazed rocks with medium-grained blastomortar texture; they are composed of plagioclase porphyroblasts (35 %) and quartz (10 %), curled in a fine-grained groundmass of similar composition. Dark-colored minerals are biotite (up to 5 %) and green amphibole (15 %). Gneissose biotite and amphibole plagiogranites are macroscopically similar rocks, with varying amounts of biotite (5-10 %) and amphibole (1-5 %). The mineral composition is dominated by short-prismatic zonal plagioclase (55-60 %) and anhedral quartz (25-30 %).

Rock chemistry. According to their petrochemical composition the Gilevsky Complex granitoids are rocks of a normal alkalinity with a predominance of sodium over potassium (Fig. 1.19 a, b). Granitoids, diorites, tonalites and melanocratic plagiogranites are characterized by supersaturated alumina in relation to alkali and calcium, moderate concentrations of femic elements and low iron index (Fig 1.19 c, d). Rocks of the postgranitic aplite dikes are heterogeneous in petrochemical composition: some of them are similar to the host granitoids, while others are characterized by high iron index and undersaturated in alumina (Table 1.6., Fig. 1.20 c, d).

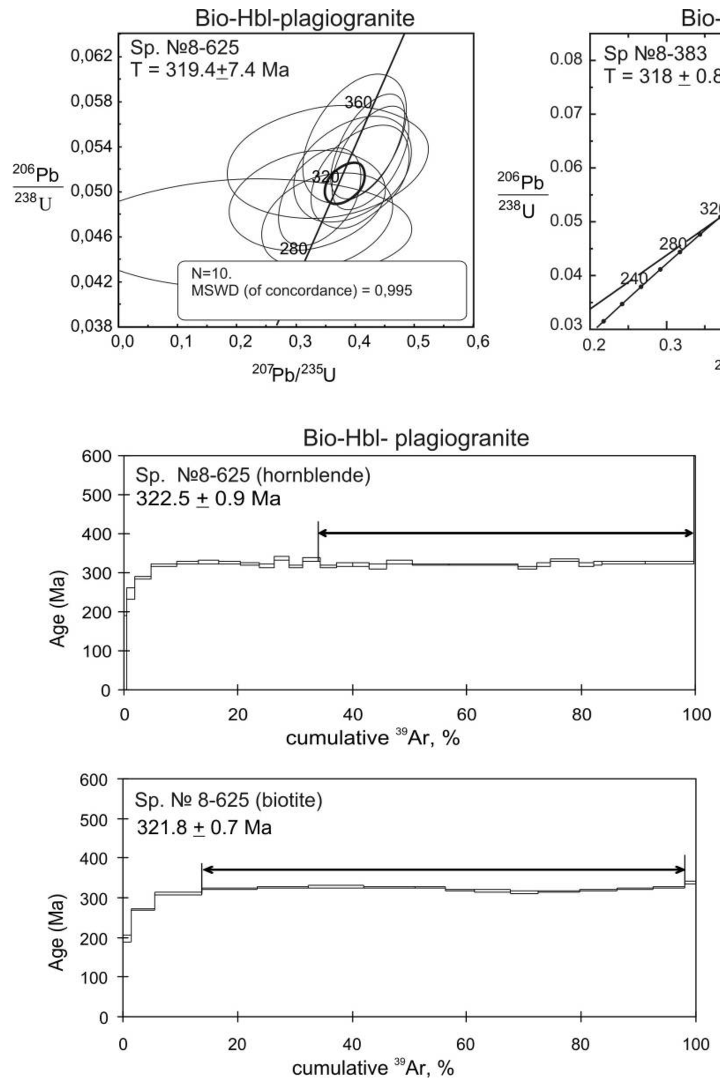


Fig. 1.18. The results of U-Pb and Ar-Ar isotope dating of plagiogranites of the Gilevsky Complex.

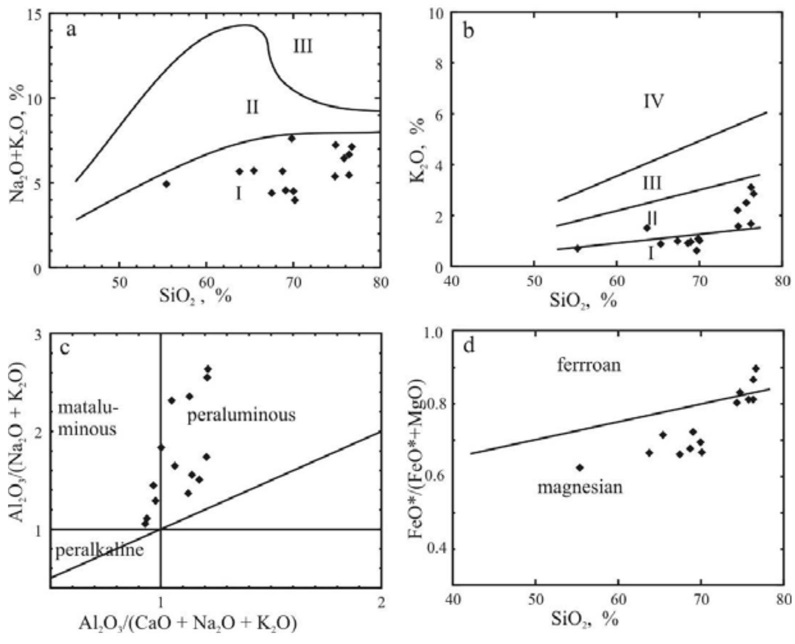


Fig. 1.19. Petrochemical diagrams for rocks of the Gilevsky Complex.

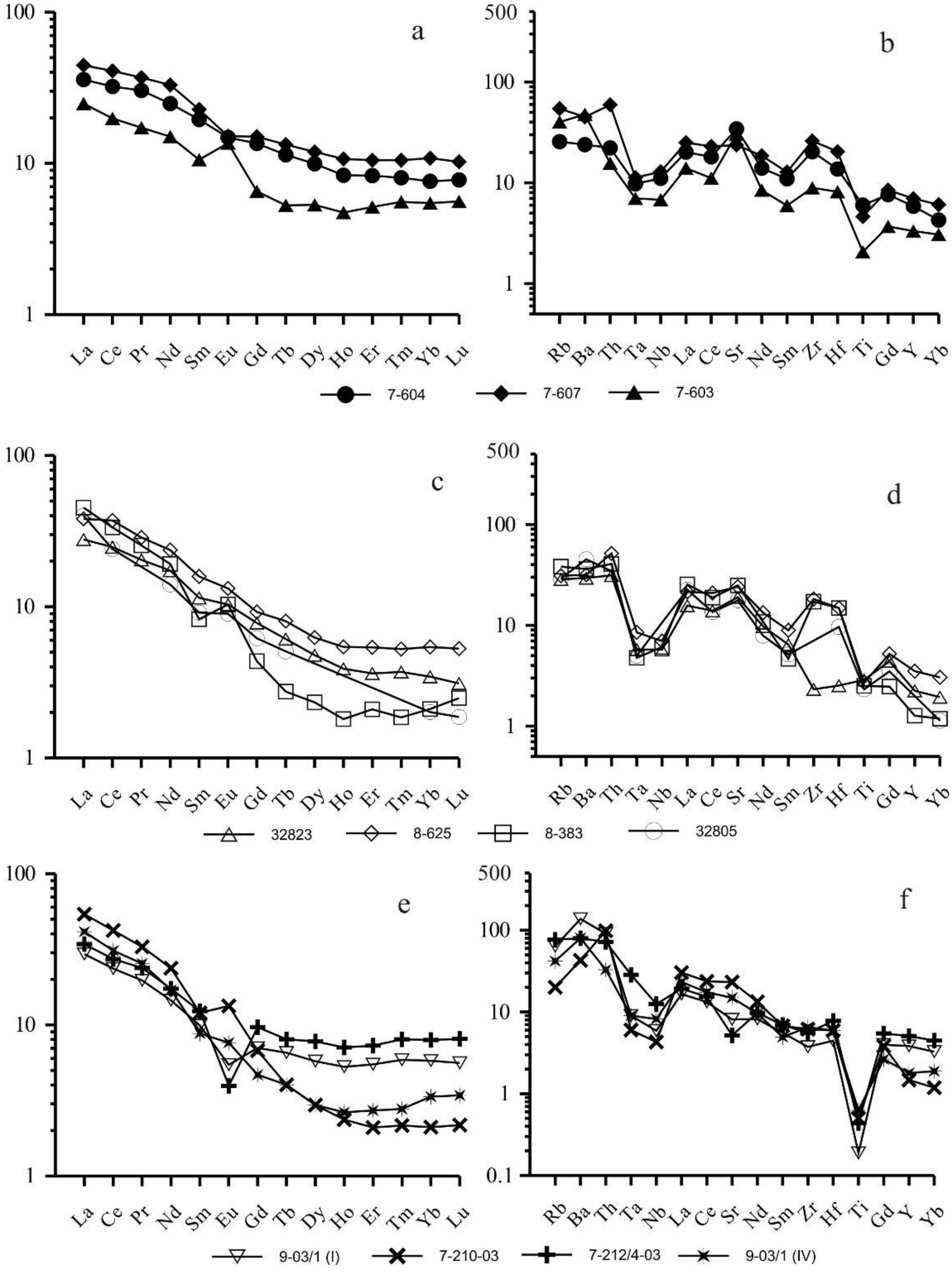


Fig. 1.20. REE spectra and spidergrams for the Gilevsky Complex rocks.
(a-b) diorites and tonalites, (c-d) plagiogranites and plagioleucogranites, (e-f) postgranitic dikes. Sample numbers correspond to Table 1.4.

Table 1.4.

Major (wt. %) and trace (ppm) element contents in representative rock samples of the Gilevsky Complex

Sample	7-607	7-603	32823	8-625	8-383	32805	9-03.1 (I)	7-210-03	7-212/ 4-03	9-03.1 (IV)
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
SiO_2	63.69	65.34	67.38	68.63	69.88	70.04	74.28	69.69	74.65	74.72
TiO_2	0.74	0.33	0.46	0.43	0.4	0.37	-	0.08	0.07	0.1
Al_2O_3	15.89	16.67	16.96	16.18	15.97	15.73	13.96	17.54	13.53	14.15
Fe_2O_3	5.47	3.92	4.2	3.2	3.17	4	0.91	0.99	1.2	1.18
MnO	0.09	0.1	0.06	0.06	0.11	0.05	<0.03	0.03	0.03	<0.03
MgO	2.56	1.46	2	1.42	1.3	1.86	0.21	< 0.05	0.23	0.44
CaO	5.21	5.14	4.02	3.99	4.01	3.82	1.21	3.25	0.89	1.89
Na_2O	4.17	4.84	3.4	4.78	3.42	2.97	5.29	6.99	5.65	5.66
K_2O	1.5	0.88	0.99	0.91	1.08	1.01	3.64	0.62	3.32	1.57
P_2O_5	0.15	0.11	0.15	0.12	0.17	0.11	<0.03	0.03	0.03	<0.03
LOI	0.5	1.17	0.28	0.01	0.05	0.16	0.3	0.27	0.34	0.32
Sum	100.04	100.05	99.92	99.75	99.56	100.14	99.94	99.98	99.98	100.09
Th	3.8	1	2	3.3	2.6	2.2	5.8	6.3	4.6	2.1
U	1.1	0.4	0.16	0.5	0.3	0.4	0.8	0.5	1	0.5
Rb	30	22	15.7	17	21	16	35	11	42	23
Ba	229	244	150	161	184	230	700	218	406	408
Sr	422	542	337	429	442	314	144	413	92	265
La	13.8	7.7	8.63	11.8	14	12.4	9.1	16.7	10.6	12.8
Ce	33	16	20	30	27	19.4	19	34	22	25
Pr	4.5	2.1	2.49	3.5	3.1	-	2.4	4	2.9	3.1
Nd	19.8	9	10.4	14.2	11.5	8.4	8.7	14.2	10.4	10.2
Sm	4.43	2.06	2.23	3.09	1.61	1.78	1.93	2.34	2.4	1.71
Eu	1.11	1	0.76	0.97	0.76	0.66	0.4	0.98	0.29	0.56
Gd	3.89	1.69	2.02	2.39	1.13	1.6	1.82	1.75	2.5	1.21
Tb	0.63	0.25	0.29	0.38	0.13	0.24	0.31	0.19	0.38	0.19
Dy	3.83	1.71	1.54	2.01	0.75	-	1.85	0.95	2.5	0.95
Ho	0.77	0.34	0.28	0.39	0.13	-	0.38	0.17	0.51	0.19
Er	2.2	1.08	0.76	1.13	0.44	-	1.15	0.44	1.53	0.57
Tm	0.34	0.18	0.12	0.17	0.06	-	0.19	0.07	0.26	0.09
Yb	2.26	1.14	0.72	1.13	0.44	0.42	1.21	0.44	1.66	0.7
Lu	0.33	0.18	0.1	0.17	0.08	0.06	0.18	0.07	0.26	0.11
Zr	216	74	19.2	151	142	-	31	51	46	54
Hf	5.5	2.2	0.68	4	4	2.6	1.2	1.6	2.1	1.6
Ta	0.45	0.28	0.23	0.34	0.19	0.2	0.36	0.24	1.14	0.36
Nb	7.2	3.8	3.2	3.9	3.4	-	3.3	2.4	7	4.6
Y	23.7	11.3	7.6	11.9	4.3	-	13	5	17.2	6.1

Note: Dash denotes “not determined”.
1 = diorite, 2 = tonalite, 3-4 = amphibole plagiogranite, 5-6 = biotite plagiogranite, 7 = dike of the I generation, 8 = dike of the II generation, 9 = dike of the III generation, 10 = dike of the IV generation.
Sample location: 1-5 = Shelchikha River ; 6-11 = Mokhovushka River. The samples are from collections by N.N. Kruk, M.L. Kuibida, O.V. Murzin.

In comparison to quartz diorite the plagiogranites are slightly depleted in Ba, Th and U, and have lower HREE and Y concentrations. The maximum depletion in HREE and Y is characteristic for biotite plagiogranites having strongly fractionated REE spectra with a Eu maximum (La/Yb_N = 21.5, Eu/Eu* = 1.05-1.63) and high (> 100) Sr/Y ratio (Fig. 1.20 c, d).

Abundances of SiO_2 (<70 wt. %) and Al_2O_3 (>15 wt. %) contents, high Sr/Y ratios (18-48 to 104), the deficiency in HREE (Yb = 0.42-1.59 ppm for tonalites and plagiogranites), increased Mg number (Mg# = 16-46) allow us to compare the Gilevsky Complex rocks with members of the high-alumina (continental according to [Arth, 1979]) TTG-series. At the same time, the geochemical characteristics of the dike series rocks show wide variations. Plagiogranites of the dike generations II and IV are close in chemical composition to the rocks of the main phases. Plagiogranites of the dike generations I and III correspond in their trace element characteristics to the rocks of low-alumina type (Fig. 1.20 e, f).

The data on petrological studies and the results of geochemical modeling [Kuibida et al., 2013] showed that the formation of tonalite-plagiogranite magmas of the Gilevsky Complex had been due to the partial melting of metabasalts under P-T conditions of 15 to 16 kbar, 1000°C. Geochemical characteristics of magma generation substrates were close to N-MORB. Extremely depleted nature of the sources of plagiogranite magmas is confirmed by isotopic composition of neodymium in plagiogranites: $^{147}Sm/^{144}Nd$ = 0.09186, $^{143}Nd/^{144}Nd$ = 0.512795, $\varepsilon_{Nd}(0)$ = +3.1, $\varepsilon_{Nd}(T)$ = +7.4.

VOLCHIKHINSKY COMPLEX

Geological position and age. In Rudny Altai the Volchikhinsky Complex rocks form a chain of linearly arranged bodies confined to the northeastern board of the Alei uplift (Fig. 1.1.). Location of the massifs is controlled by faults of northwest strike. The largest bodies are Pervokamensky and Verkhneborovlyansky massifs intruded into Middle Paleozoic deposits and granitoids of the Zmeinogorsky Complex (D_3) (Fig. 1.1). In adjacent territory of the Republic of Kazakhstan the intrusion of similar granitoids into faunistically characterized sediments of the Early Carboniferous, was proved [Nikonov, Shokalsky, 1993; Greate…, 1998; State ..., 2001].

At first, granodiorite massifs intruding Carboniferous sediments were excluded from the Zmeinogorsk Complex and were considered to be as the Volchikhinsky Complex. Later [State ..., 2001 a, b, 2011] investigations have shown that this complex also includes a number of massifs composed of granite-leucogranites.

The first attempts of U-Pb isotopic dating of granitoids of the Volchikhinsky Complex gave the Late Carboniferous age estimations (301± 7 Ma; [Vladimirov et al., 2001]). Obtained later U-Pb date on single zircon grains from granodiorite of the Pervokamensky Massif (SHRIMP-II, VSEGEI, St. Petersburg) was older: 324 ± 3 Ma (Fig. 1.21). Close ages were obtained for biotite and two-mica granites of the Verkhneborovlyanka Massif (data by N.I. Gusev).

Inner structure of massifs and petrographic features. Intrusive bodies of the Volchikhinsky Complex are composed of rocks related to three intrusive phases (from early to late): (1) medium- to coarse-grained granodiorites and melanogranites; (2) medium- to coarse-grained granites; (3) medium-grained leucocratic granites. In addition, gabbros and diorites composing xenoblocks among the granitoids in massifs of the southern part of Rudny Altai are regarded as the early phase of the complex. Quartz diorites, granodiorites and melanogranites compose the Pervokamensk Massif (58 km^2). The Verkhneborovlyanka Massif (44 km^2) is dominated by meso- and melanocratic granites which are cut by small bodies of leucogranites of the third phase and dykes of muscovite granite, granodiorite and granite porphyry.

Granodiorites and melanogranites of the first phase are gray or light gray, medium- to coarse-grained rocks of massive structure. The main minerals are plagioclase An_{30-33}

(40-50 %), quartz (5-20 %), biotite (10-12 %), hornblende (up to 20 %), microcline (<10 %). The rocks texture is hypidiomorphic (Fig. 1.3 l).

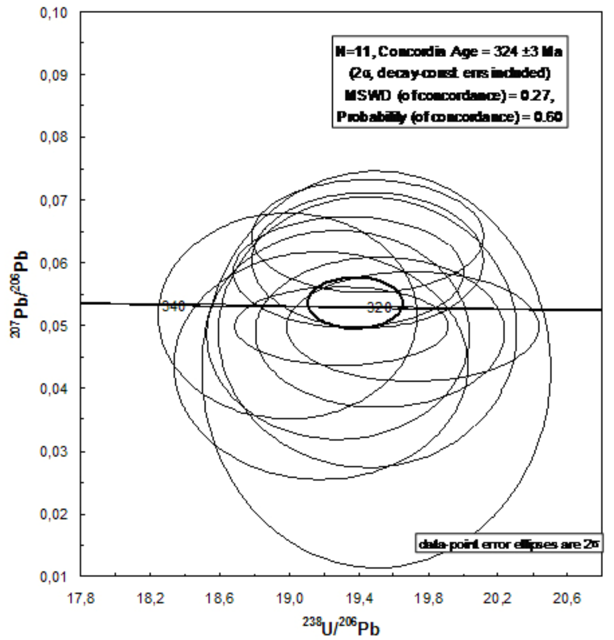


Fig. 1.21. The results of U-Pb dating of zircons from the Pervokamensky Massif rock.

Granites of the second phase are similar in their structural and textural features to the described above granodiorites (Fig. 1.3 m). They differ in higher contents of quartz (up to 25 %) and K-feldspar (up to 20 %), marked predominance of biotite over amphibole (up to the complete absence of the latter mineral).

Leucocratic granites of the third phase are light gray, brownish-gray, coarse- and medium-grained biotite and two-mica rocks with granitic texture. They consist of acid plagioclase An_{6-9} (30 %), quartz (25 %), microcline (35 %), biotite and muscovite (up to 10 %). Accessory minerals of the granitoids are apatite, zircon and magnetite.

Rock chemistry. According to their chemical composition, the Volchikhinsky Complex rocks are related to the magmatic series of normal alkalinity with a predominance of Na over K, except for the most acid rock varieties (Fig. 1.22 a, b). Granitoids are characterized by moderate amounts of phosphorus, titanium, femic elements and calcium (Table 1.7). Most of the rocks are supersaturated with alumina (Fig. 1.22 c) and characterized by slightly elevated iron index, which gradually increases with increasing silica content (Fig. 1.22 d).

The trace-element composition of granitoids is characterized by moderate contents of HFSE elements, typical of the calc-alkaline series rocks (Table 1.5), lower concentrations of Sr and Ba. The total REE contents in melanogranites vary from 130 to 200 ppm. REE patterns are asymmetric with $(La/Yb)_N$ varying from 4.6 to 9.5, with negligible Eu minimum (Fig. 1.28 a, c). Granites and leucogranites have lower REE concentrations (76 to 88 ppm) and flatter REE spectra with $(La/Yb)_N$ = 2.8-4.8, with a Eu minimum or without it (Fig. 1.23). The trace-element patterns in all the rock varieties are of the same type: they show minima for Sr, Ba, Nb, Ta and Ti; in some samples there are Zr and Hf maximums (Fig. 1.23 b, d).

Diorites composing single inclusions in granitoids are enriched in Zr, Hf, and Y (Table 1.5), have quasisymmetrical REE spectra with a distinct Eu minimum and do not exhibit any geochemical similarity with more acid rocks.

Granitoids of the Volchikhinsky Complex correspond in major- and trace-element composition to calc-alkaline rocks of crustal origin. Geological and geochronological data allow us to connect their formation with a collision of the Siberian and Kazakhstan paleocontinents in the early Late Paleozoic.

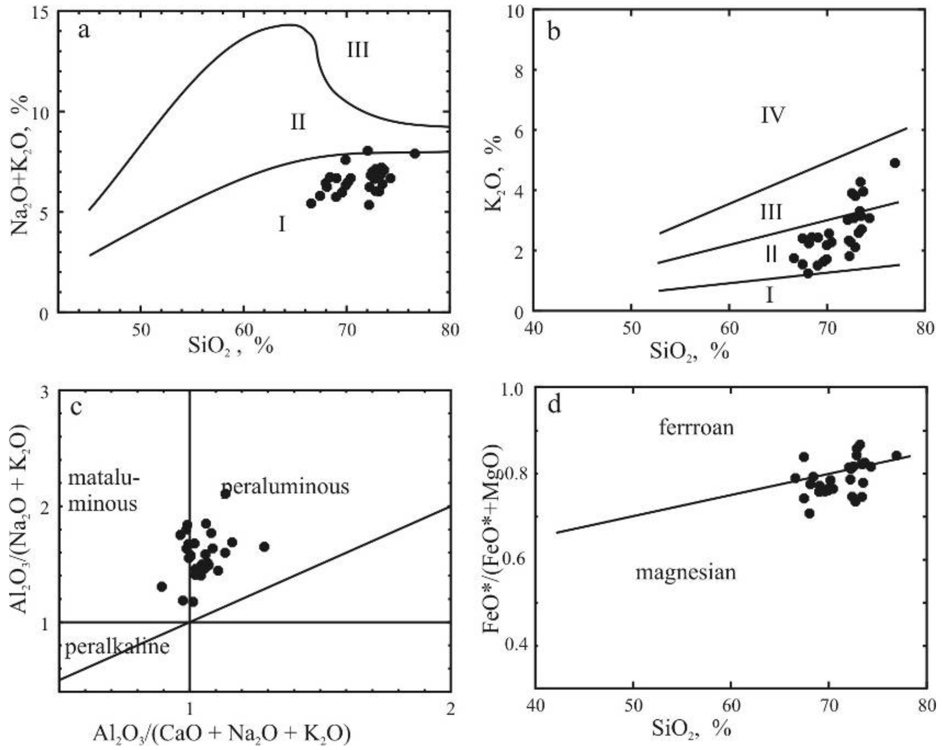


Fig. 1.22. Petrochemical diagrams for the Volchikhinsky Complex rocks.

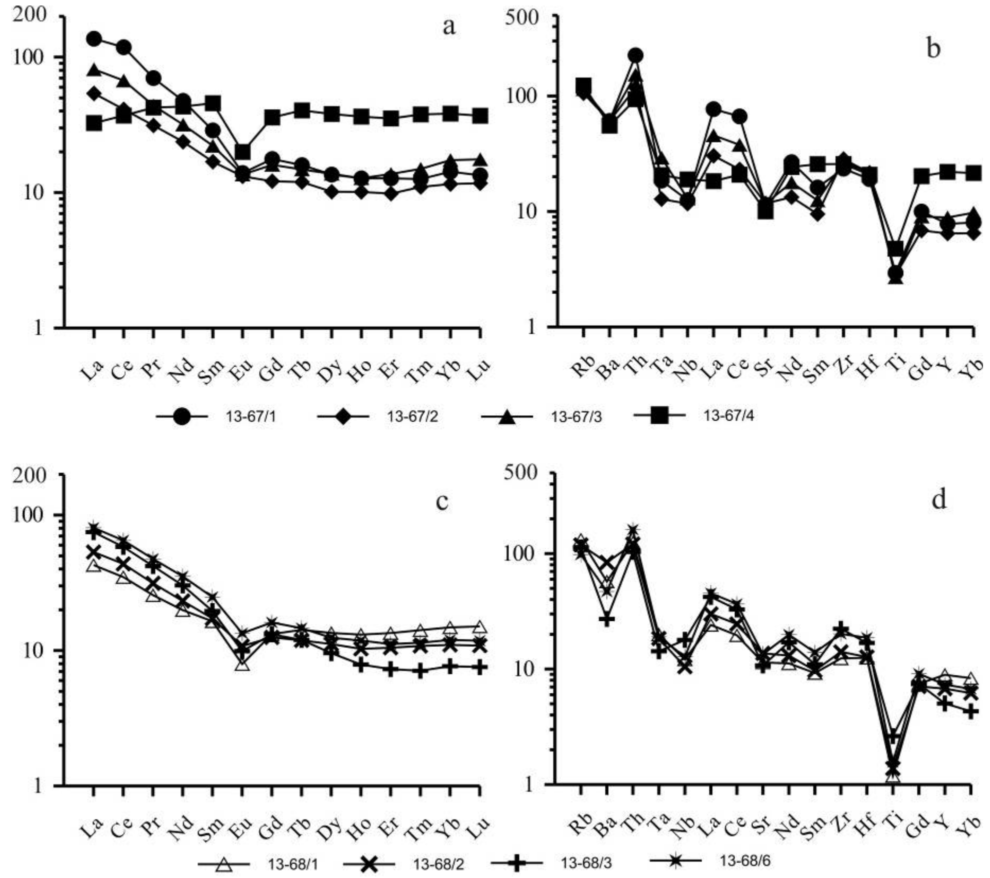


Fig. 1.23. REE spectra and spidergrams for the Volchikhinsky Complex rocks.
a-b = Pervokamensky Massif, c-d = Verkhneborovlyansky Massif. Sample numbers correspond to Table 1.5.

Table 1.5.

Major (wt. %) and trace (ppm) element contents in representative rock samples of the Volchikhinsky Complex

Sample	13-67/3	13-67/1	13-67/2	13-67/4	13-68/3	13-68/1	13-68/2	13-68/6
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
SiO_2	68.39	69.04	70.41	56.84	69.57	73.42	74.28	72.24
TiO_2	0.43	0.47	0.45	0.76	0.42	0.19	0.22	0.25
Al_2O_3	14.74	14.78	15.01	16.07	15.41	13.83	13.68	14.80
Fe_2O_3	4.1	3.87	3.5	8.61	4.08	2.22	2.43	2.78
MnO	0.07	0.07	0.07	0.28	0.1	0.06	0.05	0.07
MgO	0.97	1.04	0.98	3.39	1.18	0.44	0.50	0.59
CaO	2.81	2.82	2.90	5.23	2.96	1.77	1.98	2.42
Na_2O	4.26	4.22	4.38	4.62	4.31	4.03	3.57	4.40
K_2O	2.38	2.37	2.22	2.17	1.57	3.09	3.02	1.76
P_2O_5	0.1	0.11	0.11	0.13	0.15	0.05	0.07	0.09
LOI	0.3	0.58	0.4	1.26	0.58	0.68	0.48	0.65
Sum	98.65	99.46	100.51	99.47	100.4	99.85	100.36	100.1
Th	9.8	14.4	7.5	6	6.6	8	7.7	10.3
U	2.1	1.38	1.44	3.1	2.7	1.44	1.07	1.30
Rb	63	62	58	68	62	73	65	54
Ba	312	310	310	282	139	292	427	239
Sr	208	204	209	179	191	203	244	239
La	25	42	16.7	10.1	23	13.3	16.5	25
Ce	54	96	33	30	47	28	35	53
Pr	5.4	8.5	3.8	5.2	5.1	3.1	3.8	5.8
Nd	19.0	29	14.2	26	18.2	11.9	13.9	21
Sm	4.3	5.6	3.3	8.9	3.8	3.2	3.4	4.8
Eu	1.00	1.02	0.97	1.47	0.73	0.58	0.79	0.98
Gd	4.2	4.6	3.1	9.3	3.4	3.4	3.2	4.2
Tb	0.70	0.76	0.57	1.91	0.57	0.67	0.56	0.69
Dy	4.4	4.4	3.3	12.2	3.1	4.3	3.6	4
Ho	0.92	0.92	0.73	2.6	0.57	0.94	0.74	0.85
Er	2.9	2.7	2.1	7.4	1.53	2.8	2.2	2.3
Tm	0.48	0.41	0.36	1.22	0.23	0.46	0.35	0.37
Yb	3.6	3.0	2.4	8	1.6	3.1	2.3	2.5
Lu	0.57	0.43	0.38	1.19	0.24	0.48	0.35	0.38
Ta	1.17	0.74	0.51	0.83	0.57	0.8	0.74	0.76
Nb	7.2	7.0	6.5	10.6	10	6.8	5.9	7.1
Zr	223	195	236	214	185	103	117	167
Hf	5.9	5.1	5.8	5.6	4.5	3.4	3.4	5
Y	30	27	22	75	17.1	30	23	25

Note: 1-4 = Pervokamensky Massif, 5-8 = Verkhneborovlyansky Massif.
The samples are from collections by N.N. Kruk, M.L. Kuibida.

SINYUSHENSKY COMPLEX

Granitoid massifs of the Sinyushensky Complex are confined to the North-East shear zone separating the structures of Gorny Altai and Rudny Altai. They occupy an independent cutting position in relation to areals of previous magmatism. On the territory of Rudny Altai the Sinyushensky Complex includes Sawushinsky, Volchi Shkili, Ubin-Belorechensky massifs and a number of small bodies. The best-studied intrusive body is the Savushinsky Massif, which is located to the north of the Zmeinogorsk city near Kolyvan Lake

Geological position and age. The Sawushinsky Massif with a total area of about 200 km^2 is an elongated northwesterly-directed tear-shaped intrusive body intruding the Middle Paleozoic terrigenous and volcanic-terrigenous deposits and granitoids of the Revnevo-Amelikhinsky Massif of Zmeinogorsky Complex (D_3) (fig. 1.1). Contacts of the massif with host rocks are steep, with wide areoles of hornfelses in terrigenous rocks, skarnoids in carbonates, and recrystallization zones in granitoids.

The age of granitoids of the Sinyushensky Complex obtained by U-Pb zircon dating of granites from the Volchi Shkili Massif, is 253±5 Ma [Vladimirov et al., 2001]. The age estimates obtained by Rb-Sr isochron method for the Sawushka Massif rocks are slightly younger: 245.5±5 Ma [Vladimirov et al, 1997]. The Ar-Ar isotope date obtained on biotite from granodiorite of the II phase is 243.5±1 Ma (Fig. 1.24), that is very close to the Rb-Sr isochron.

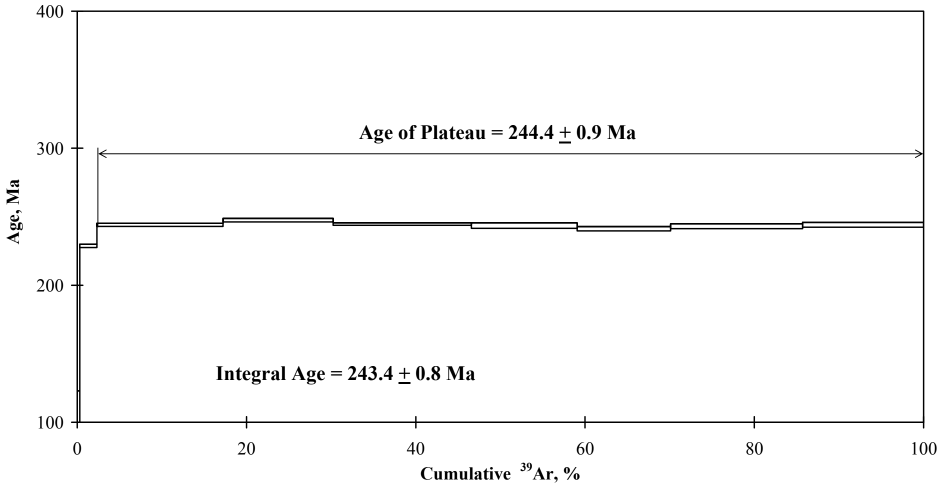


Fig. 1.24. The results of Ar-Ar isotope dating of biotite from granodiorite of the II phase of the Sawushinsky Massif (sample No. 13-57).

Inner structure and petrographic features. The Sawushinsky Massif is composed of rocks related to three intrusive phases (from early to late): 1 = small- and medium-grained equigranular or weakly porphyroid biotite-hornblende monzodiorites and quartz monzodiorites; 2 = porphyritic biotite and biotite-hornblende granodiorites and melanocratic granites; 3 = porphyritic leucocratic biotite granites. Intrusive contacts are noted between all the phases. Monzodiorites of the first phase form numerous xenoliths and small remnants among the later granitoids. Granodiorites of the second phase and leucogranites of the third phase compose the bulk volume of the massif; the first rocks are mainly developed in the central part, while the second ones occur in the peripheral part. Postgranitic dike series is represented by fine-grained granites, aplites and pegmatites. There are single dikes of diorite porphyry [State …, 2001b].

Quartz monzodiorites of the first phase are small- and medium-grained rocks with granitic, rarer monzonitic or prismatic-granular texture (Fig. 1.3 m). They consist of plagioclase (oligoclase to andesine, 40-45 %), K-feldspar (20-25 %), quartz (5-15 %), amphibole and biotite (15 % each). Clinopyroxene was found as a minor mineral.

Granodiorites of the second phase and leucocratic granites of the third phase have similar textures. Porphyritic appearance of the rocks is determined by the presence of K-feldspar phenocrysts, the amount of which varies from 5-10 to 40 % of the rock volume. The granitoids have granitic and hypidiomorphic texture and massive structure (Fig. 1.3 n). The main minerals are quartz (25-30 %), K-feldspar (30-35 %), weakly zoned plagioclase (An_{18-25}, sometimes An_{35-37} – 30-40 %), biotite (5-7 %). In granodiorites amount of quartz is reduced up to 20%; biotite and hornblende contents reach 10-15 % and 10 %, respectively. Accessory minerals are zircon, sphene, apatite, magnetite, and allanite.

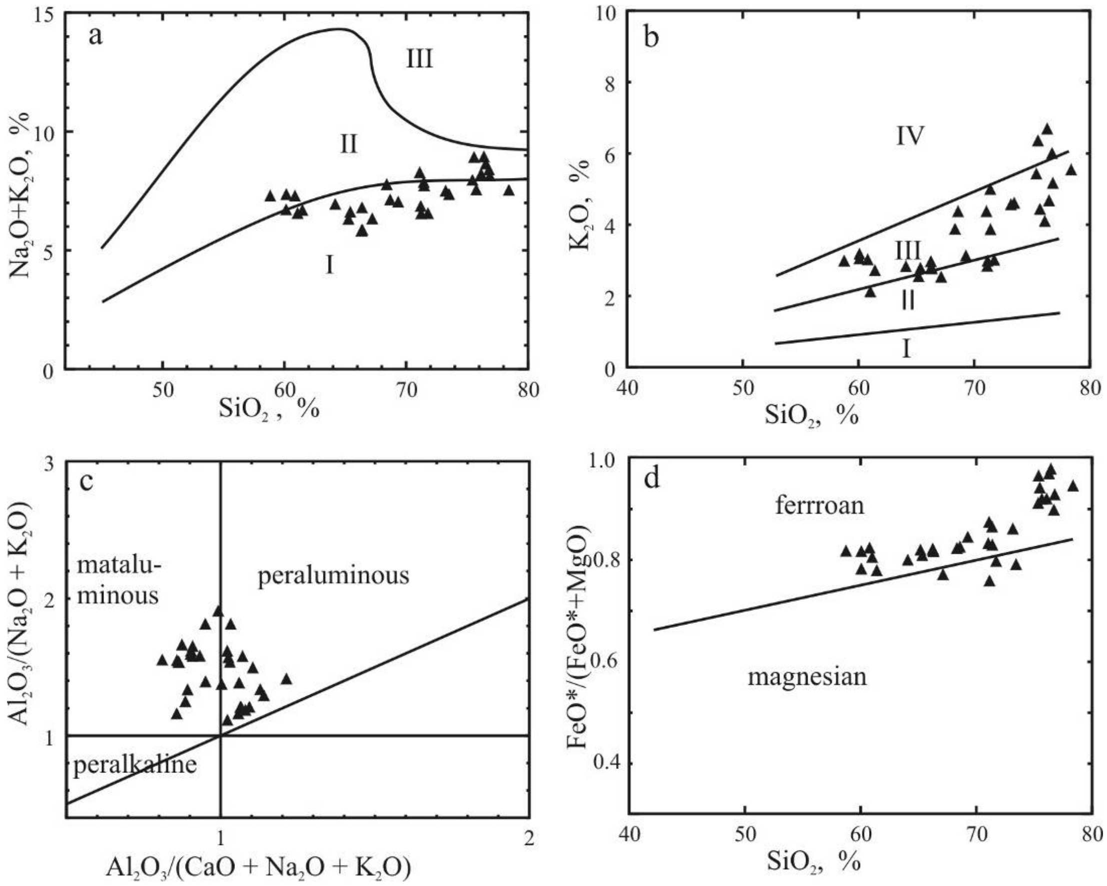


Fig. 1.25. Petrochemical diagrams for the Sawushinsky Massif rocks.

Rock chemistry. According to their petrochemical composition the Sawushinsky Massif rocks belong to a continuous series of moderate alkalinity. In quartz monzodiorites of the first phase sodium predominates over potassium; granodiorites of the second phase have K-Na specialization of alkalis; and leucogranites of the third phase potassium is dominant (Table 1.6, Fig. 1.25 a, b). Rocks of the phases I and II are characterized by higher contents of phosphorus and titanium, and mostly undersaturated in alumina; while leucogranites of the phase III contain normative corundum (Table 1.6, Fig. 1.25 c). All the granites are characterized by high iron index (Fig. 1.25 d).

The trace-element composition of monzodiorites and quartz monzodiorites of the first phase is characterized by high contents of alkaline earth metals (Sr - 600 ppm, Ba - up to 1700 ppm) and HFSE elements. The REE contents are also high (400 to 450 ppm); their spectra are asymmetric with $(La/Yb)_N$ = 6.3-6.6 and a small Eu minimum (Fig. 1.26 a). In spidergrams (Fig. 1.26 b) a selective depletion of the rocks in Ta, Nb, Sr and Ti, as well as an enrichment in Ba, Zr and Hf, are observed.

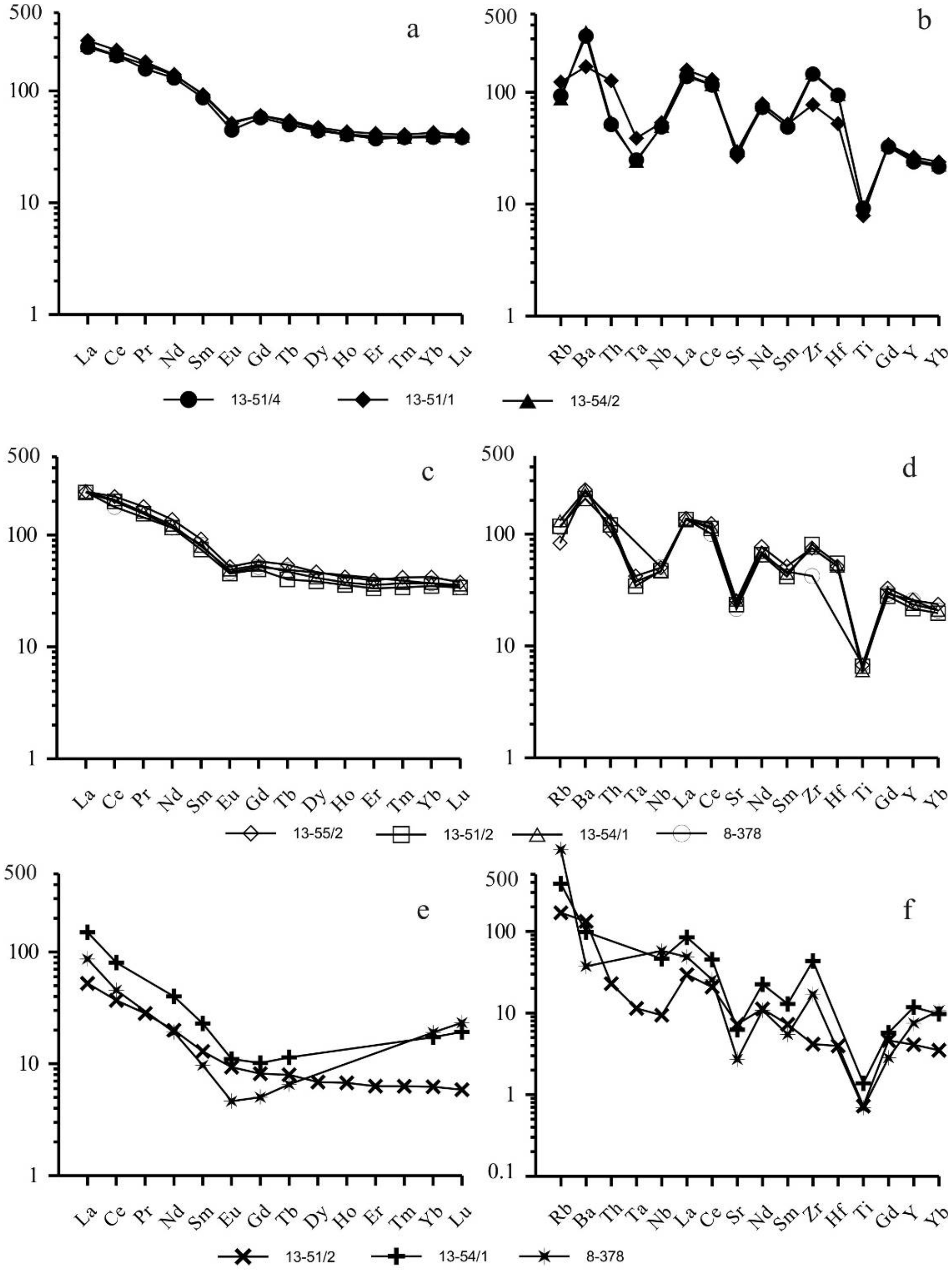


Fig. 1.26. REE spectra and spidergrams for the Sawushinsky Massif rocks.
(a-b) quartz monzodiorites, (c-d) granodiorites and melanogranites, (e-f) leucogranites.
Sample numbers correspond to Table 1.6.

Granodiorites of the second phase do not differ in trace element composition from previous monzodiorites (Table 1.6, Fig. 1.26 c, d). Leucogranites of the phase III have a lower content of alkaline earth elements, HFSE and REE elements (Table 1.6, Fig. 1.26 e, f).

In general, according to their features of the petrochemical and trace element composition (high alkalinity, high iron index, the level of accumulation of incompatible elements), granitoids of phases I and II of the Sawushka Massif correspond to A-type granites. It is consistent with their tectonic position and suggests an important role of mantle

Table 1.6

Major (wt. %) and trace (ppm) element contents in representative samples of granitoids of the Sawushinsky Massif

Sample	13-51/4	13-51/1	13-54/2	13-55/2	13-51/2	13-54/1	8-378	13-52/2	13-53/3	8-376	8-373/2
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
SiO_2	58.67	60.92	60	65.1	65.26	66.21	66.24	76.23	76.64	75.28	75.41
TiO_2	1.47	1.26	1.43	1.08	1.06	0.96	1.09	0.09	0.12	0.22	0.11
Al_2O_3	15.83	15.82	15.86	14.65	14.71	15.05	14.50	12.11	12.26	13.31	13.32
Fe_2O_3	8.57	7.49	8	6.64	6.10	5.74	6.95	1.25	0.71	1.78	1.09
MnO	0.17	0.2	0.16	0.13	0.14	0.12	0.16	0.01	0.01	0.12	0.15
MgO	1.77	1.68	1.66	1.36	1.34	1.18	1.32	0.04	0.08	0.15	0.06
CaO	4.49	4.69	4.41	3.96	3.86	3.61	3.97	0.53	0.54	1	0.63
Na_2O	4.22	4.35	4.23	3.69	3.75	3.91	3.01	2.17	2.31	2.45	2.48
K_2O	3.03	2.17	3.09	2.59	2.82	2.86	2.81	6.73	6.04	5.47	6.4
P_2O_5	0.43	0.41	0.41	0.36	0.35	0.31	0.34	0.01	0.01	0.07	0.05
LOI	0.48	0.36	0.34	0.26	0.33	0.31	0.25	0.18	0.26	0.31	0.41
Sum	99.46	99.53	99.88	100.03	99.92	100.48	100.6	99.40	99.09	100.2	100.1
Th	3.3	8.1	3.5	6.9	7.7	8.6	–	3.0	1.5	–	–
U	1.1	2.6	1.1	2.0	2.5	2.5	–	0.5	0.4	–	–
Rb	51	68	48	46	65	72	63	86	93	211	553
Ba	1621	863	1769	1269	1059	1249	1200	38	676	500	190
Sr	507	473	539	451	416	457	380	27	129	111	48
La	76.14	87.18	78.73	75.69	74.31	74.63	75	16.2	16.24	46.50	26.80
Ce	166.3	186.3	168.1	178.2	161.1	166.6	143.9	28.25	29.8	64.8	36.7
Pr	19.13	22.15	20.93	21.91	18.9	19.56	–	2.4	3.44		
Nd	78.08	84.06	82.41	82.42	69.72	73.37	69.6	6.46	11.96	24	11.50
Sm	16.91	18.01	18.28	17.91	14.47	15.44	16	0.84	2.52	4.47	1.89
Eu	3.28	3.77	3.87	3.83	3.32	3.58	3.42	0.84	0.68	0.81	0.34
Gd	14.91	15.62	15.59	15.07	12.75	13.92	13.4	0.58	2.11	2.63	1.3
Tb	2.36	2.57	2.5	2.57	1.9	2.23	2.31	0.08	0.38	0.54	0.31
Dy	14.15	15.16	14.57	15.04	12.37	13.33	–	0.46	2.21	–	–
Ho	2.92	3.10	2.94	3.03	2.57	2.71	–	0.09	0.49	–	–
Er	7.82	8.74	8.24	8.25	6.99	7.50	–	0.28	1.32	–	–
Tm	1.24	1.31	1.25	1.35	1.10	1.20	–	0.05	0.20	–	–
Yb	8.03	8.84	8.31	8.77	7.30	7.74	7.72	0.41	1.30	3.61	3.98
Lu	1.23	1.30	1.27	1.22	1.09	1.15	1.1	0.07	0.19	0.62	0.75
Zr	1206	641	1237	621	672	621	350	70	34	360	141
Hf	25.4	14.2	25.8	13.9	14.8	14.0	–	2.5	1.1	–	–
Ta	1.0	1.6	1.0	1.7	1.4	1.5	–	0.1	0.5	–	–
Nb	27.4	29.9	27.8	28.1	26.3	25.9	28.4	2.2	5.2	25.8	32.3
Y	81	90	85	87	73	80	87	3	14	40	26

Note: 1 = monzodiorite (I phase) 2-3 = quartz monzodiorites (I phase), 4-7 = granodiorites (II phase), 8-10 = leucogranites (III phase), 11 = aplite (postgranitic dike). Dash denotes "not determined".
The samples are from collections by N.N. Kruk, O.V. Murzin, P.D. Kotler, N.G. Murzintsev.

melts in the generation of granitoid magmas. Leucocratic granites of the phase III are close in their trace element composition to rocks of the I-type. Their formation is likely due to the crust melting by heat of more basic magmas.

DESCRIPTION OF THE FIELD EXCURSION STOP POINTS

Stop 1-1 is located on the north shore of the Gilevo reservoir, to the east from Pavlovka village, on the southern slope of the separate hill with triangulation point. Here small-grained weakly porphyritic biotite granites of marginal part of the Pavlovsky Massif (Fig. 1.27 a) are exposed in construction quarry. The freshest rocks, the least affected by postmagmatic changes are exposed in the eastern side of the quarry. In the northern side the granites are cut by a series of sub-vertical and gently falling dolerite dykes of the Early Carboniferous. In the apical part a xenoblock of intensely hornfelsed and metasomatized host rocks of the Korbalikha series, can be observed.

At 800 m to the west from the quarry, on the western slope of a hill the outcrops of medium- to coarse-grained biotite granites of the central part of the Pavlovsky Massif occur.

Stop 1-2 is located at 2 km to the north from the Ust'yanka village, on the southern edge of rocky ridge. Granitoids of the Ust'yansky Massif are uncovered in a small canyon. In outcrops and disintegrated blocks one can observed coarse-grained biotite leucocratic granites of the main phase, cutting by dikes and stock-like bodies of medium- and small-grained biotite granites (Fig. 1.27 b). In the right side of the canyon the granitoids are cut by Early Carboniferous dolerite dike of ~1 m in thick.

Stop 1-3 is located to the north-west from Pavlovka village, in the right bank of Dalnyaya Schelchikha River. Here the outcrops contain diorites, tonalites and plagiogranites of the Gilevsky Complex intruding metamorphosed deposits of the Korbalikha series. The dominant rocks are small-grained diorites, cutting by bodies of tonalites and plagiogranites (Fig. 1.27 c, d). All the rocks bear evidences of intense gneissosity, cataclasm, and partial recrystallization. Orientation of gneissosity generally coincides in all varieties of granitoids and country rocks. It is conformal to the strike of intrusive contacts (strike azimuth is ~ 310°).

On the left bank of the river, xenoblocks of metamorphosed rocks of the frame: sandstones of the Korbalikha series and, in rare instances, felsic volcanic rocks (probably, Middle Devonian) occur among the gneissous tonalites.

Stop 1-4 is located in the left bank of Mahovushka River. Here in the old riverbed gneissic biotite plagiogranites of the Gilevsky Complex are exposed. The orientation of gneissosity in plagiogranites is submeridional (~335-350°; angle of dip is ~50-60°), and coincides with the direction of the deformation zone. Biotite plagiogranites were cut by numerous plagiogranite dikes, varying in thickness, gneissosity degree, and relation to tectonic deformations. The plagiogranite dikes don't different in principle in their petrographic features and presented by porphyritic varieties with minor variations of quartz and biotite. The four generations dikes are distinguished (Fig. 1.27 e). The first generation has a thickness of 1-3 cm and strike of 70-75°. Dike rocks were subjected to intense gneissosity; the gneissosity orientation coincides with that in the host plagiogranites and with the direction of tectonic zone (~335°, the dip angle is ~65-70°), which allows us to consider these dikes as pre-deformational. The second generation of dikes of 10-50 cm in thickness is identical in structural and textural features, strike and orientation of gneissosity to the first one. The criterion to its distinguishing was the chemical composition of the rocks (see below). In the outcrops, dikes of this generation display brittle deformations (ruptures) with displacements of 10-25 cm along the sinistral shifts. The third dike generation is composed of fine-grained porphyritic plagiogranites; their thickness is 25 to 40 cm. These dikes cut dikes of the preceding generations. In the disrupt zones the dikes show evidences of plastic deformations with the formation of the characteristic S-shaped structures and drag folds (Fig. 1.27 f), which indicates that the magma has intruded immediately during a realization of shear stresses of sinistral kinematics. Strike azimuth of the dikes of this generation varies from 75 to 125°.

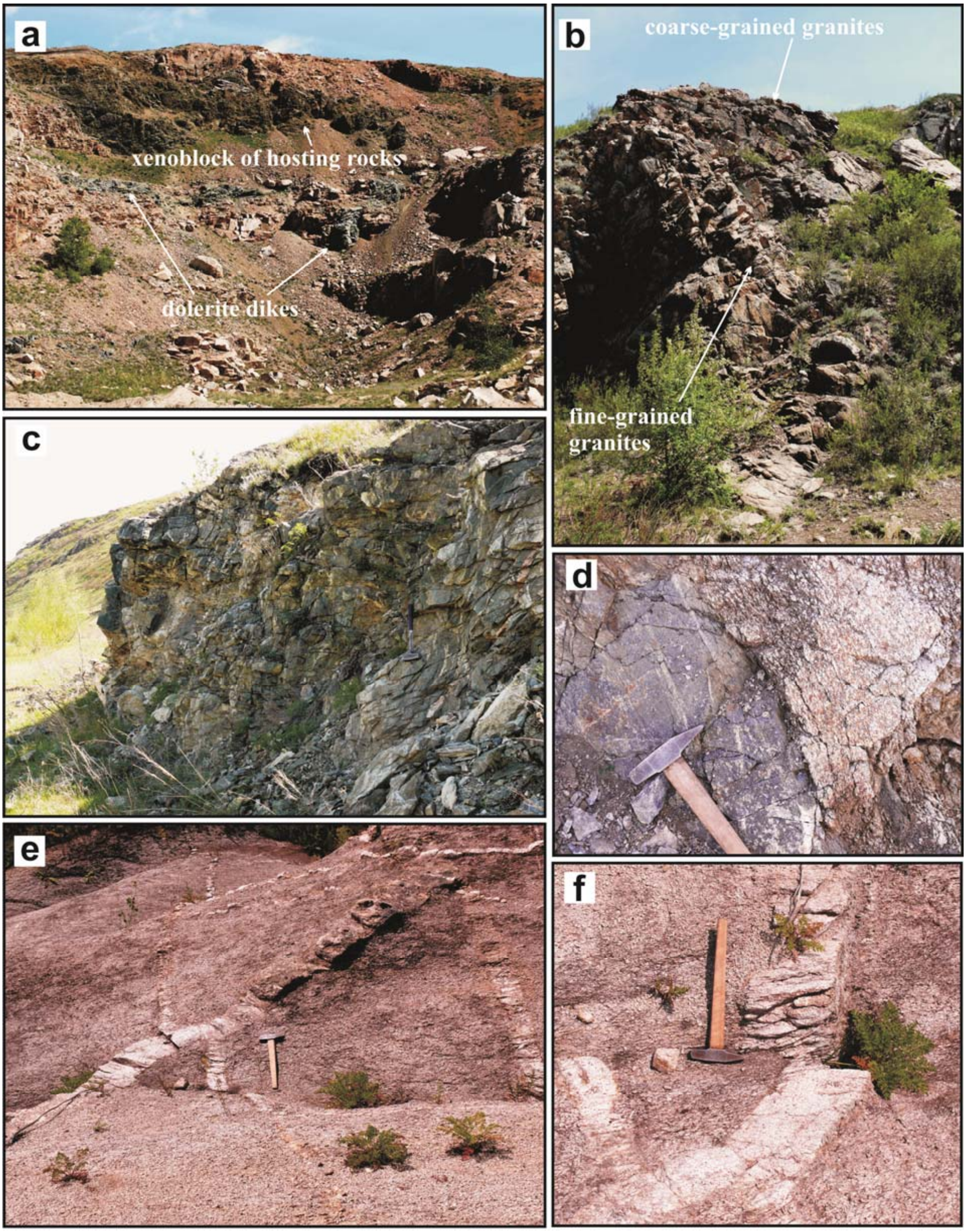
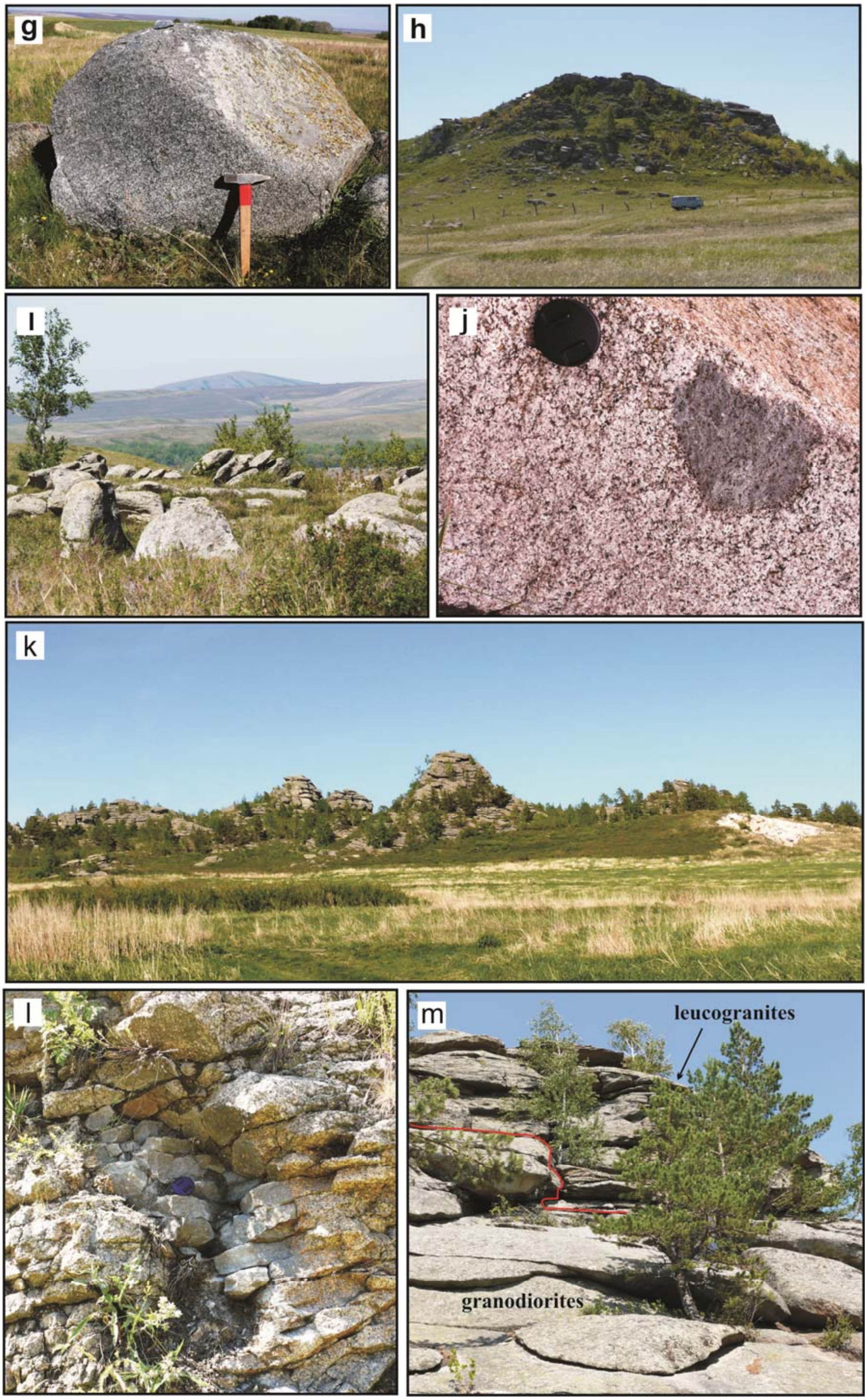


Fig. 1.29. The geological excursion objects.
a = granite outcrop of Pavlovsky massif (quarry is on the east of the v. Pavlovka, stop 1-1). Dikes and small bodies of dolerites intruding granitoids and enclosing rock xenoblock at the top of the far wall of the quarry are clearly visible; b = granitoid outcrops of Ust'yansky massif is on the north of the v. Ust'yanka (stop 1-2); c = outcrop of Gilevsky complex fine-grained gneissic diorites intruded by tonalite bodies (right coast of the riv. Dalnyaya Scheltikha, stop 1-3); d = contact of Gilevsky complex diorites with tonalities (right coast of the riv. Dalnyaya Scheltikha, stop 1-3); e = post granite dikes in Gilevsky complex plagiogranites (right


g
h
i
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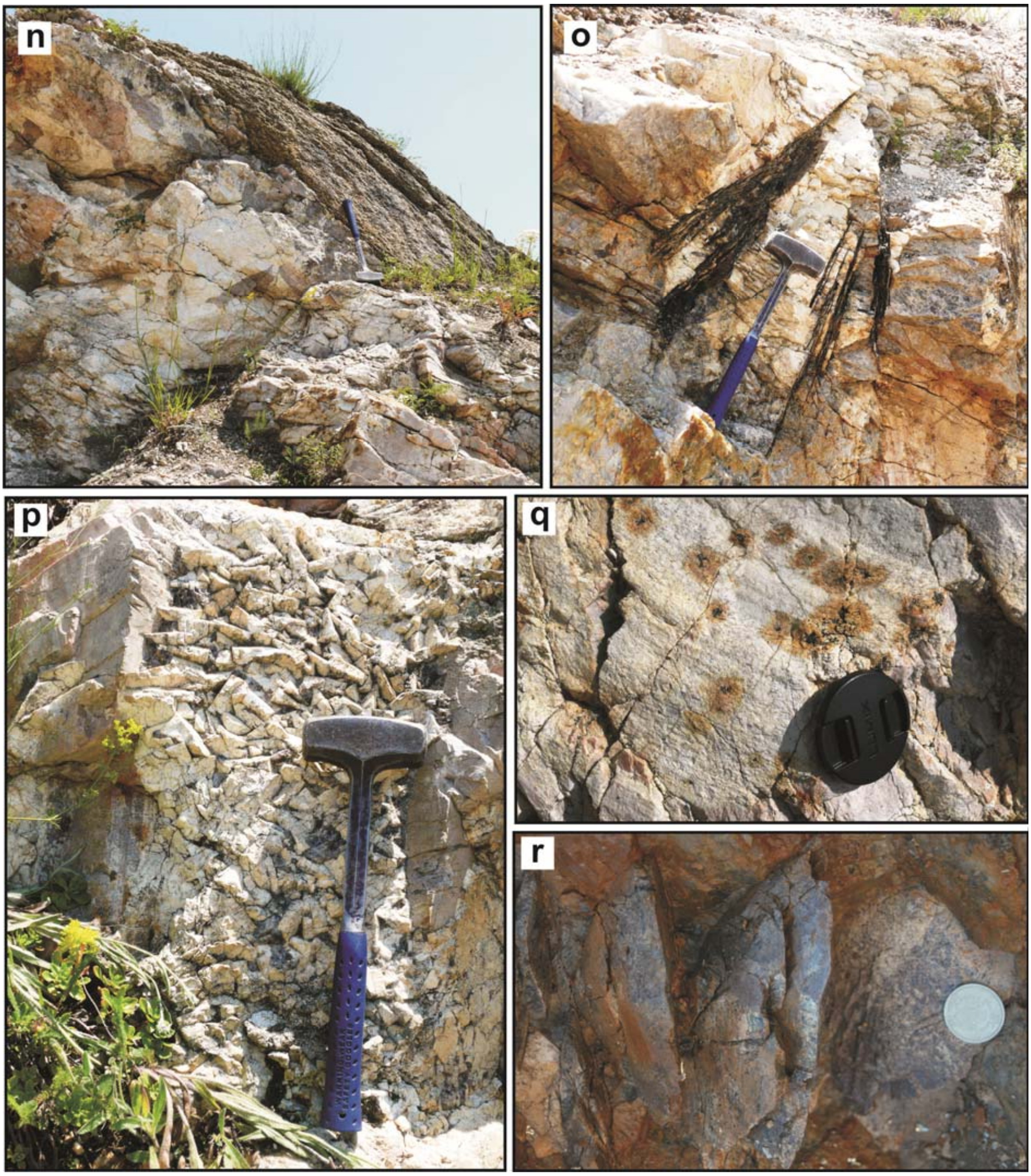
leucogranites
granodiorites



coast of the riv. Makhovushka, stop 1-4); f = left-handed displacement of fine-grained granite dike (right coast of the r. Makhovushka, stop 1-4); g = Zmeinogorsky complex gabbroid outcrop near the v. Chekanovsky (stop 1-5); h = Volchikhinsky complex granitoid outcrops (hill Ostraya, stop 1-7); I = outcrops of Volchikhinsky complex biotite granite near the v. Borovlyanka (stop 1-8); j = dolerite xenolithe in Volchikhinsky complex granite (Pervokamensky massif, stop 1-9); k= Sawushinsky massif granitoid outcrops (stop 1-10). In the right part of the photo – Ortite vein quarry; l = quartz monzodiorite xenolithe in Sawushinsky massif granodiorite (stop 1-10); m = contact of Sawushinsky massif granodiorite with leucogranite (stop 1-10). Contact position is marked by change of cleavage nature; n = contact of Ortite pegmatite vein with enclosing granitoid (stop 1-10); o = biotite large crystals in block zone of Ortite vein (stop 1-10); p = vein of coarse grained graphic pegmatite transverse block pegmatite (Ortite vein, stop 1-10); q= ortite crystals in feldspar blocks (Ortite vein, stop 1-10); r = large crystals of titanite between block potassium feldspar and quartz core (Ortite vein, stop 1-10).

Dikes of the fourth final generation are composed of small- to medium-grained porphyritic biotite plagiogranites. Their thickness is ~5 cm; strike azimuth varies from 355° to 0°, coinciding with the gneissosity orientation of enclosing biotite plagiogranites of the main phase. In the outcrops the rocks look the most massive, least deformed and, likely, are post-deformational ones.

Stop 1-5 is located in the southwestern part of the Mokhnatye Sopki Massif, to the north-west of Chekanovsky settlement. Here, medium-grained (to coarse-grained) gabbroids of the Zmeinogorsk Complex occur in disintegrated blocks among the fields (Fig. 1.27 g).

Stop 1-6 is located on the northern outskirts of Pervomaysky village. Here small-to medium-grained biotite leucocratic plagiogranites of the Pervomaisky Massif of the Zmeinogorsky Complex were uncovered by construction opening on a slope and exposed on the top of the separate hill. The plagiogranites are cut by small dikes of aplitic granites and aplites. To the east of the hill at the bottom of the ravine the coarse-grained gneissic melanocratic biotite-amphibole plagiogranites of the Zmeinogorsky Complex are exposed. They were intruded by subvolcanic body of Early Carboniferous gabbro-dolerites. Contact between the two varieties of granitoids is covered by Quaternary deposits and unavailable for direct observation.

Stop 1-7 is at 5 km to the north from Pervomaysky village, at western slope of the Ostraya hill (Fig. 1.27 h). Here granites of the Volchikha Complex are exposed. Two varieties of granitoids can be seen in the outcrops. The main volume is composed of medium- to coarse-grained leucocratic biotite granites, cut by a body of more fine-grained biotite (with single grains of amphibole) granites. In the northern part of the hill a direct contact between the two varieties of granitoids is available for direct observation.

Stop 1-8 is located to the south-west from Borovlyanka village, on the northern slope of the ridge of hills. Here, there are the outcrops of coarse- to medium-grained biotite and two-mica granites of the Verkhneborovlyansky Massif of the Volchikhinsky Complex (Fig. 1.27 i). The granitoids with large-block jointing intruded by dikes of fine-grained two-mica and muscovite granites and granite-aplites.

Stop 1-9 is located north-west of the Krasnoe Razdoliye village, on the western slope of Mt. Cherny Kamen'. The mountain is composed of equigranular medium-grained and weakly porphyritic biotite leucocratic granites of the Zmeinogorsky Complex. The granites were cut by dikes of fine-grained aplitic granites and Early Carboniferous dolerites. At the foot of the slope medium-grained biotite-amphibole melanogranites and granodiorites of the Pervokamensky Massif of the Volchikhinsky Complex occur as disintegrated blocks. Contact between the two granitoid varieties is overlapped by Quaternary sediments and is not available for direct observation. The Volchikhinsky Complex granodiorites contain xenoliths of the Zmeinogorsk granites and dolerite dykes (Fig. 1.27 j).

Stop 1-10 is located on the northern shore of Kolyvan Lake, near the Ortite hill. Here one can observed granodiorites and granites of the Sawushinsky Massif of the Sinyushensky Complex, which are cut by pegmatite vein (Fig. 1.27 k).

The granitoids are presented by two main varieties: (1) medium- to coarse-grained porphyritic biotite-amphibole granodiorite; (2) medium-grained porphyritic leucocratic biotite granite. In addition, fine- and medium-grained amphibole-biotite quartz monzodiorites occur as xenoliths in granodiorites and individual xenoblocks (Fig. 1.27. l). Intrusive contacts are observed between all the rock varieties. Change of rocks is clearly visible in the field, as the medium- to coarse-grained rocks show large-block hammock jointing, and the fine-grained rocks have a thin-platy jointing (Fig. 1.27 m).

The Ortite pegmatite vein is the largest and most interesting object (from mineralogical point of view) among pegmatites of the Sawushka Massif. The vein is uncovered by a small quarry and is a sublatitudinal tabular body with thick in a bulge of about 5 m, which plunges to the south. It is characterized by well-defined zonation (Fig. 1.27 n, 1.28). External parts of the vein are graphic quartz-feldspar pegmatite, transforming into coarse-grained pegmatite with a subordinate biotite. The thickness of this zone is small and in some parts reaches up to ~10 cm.

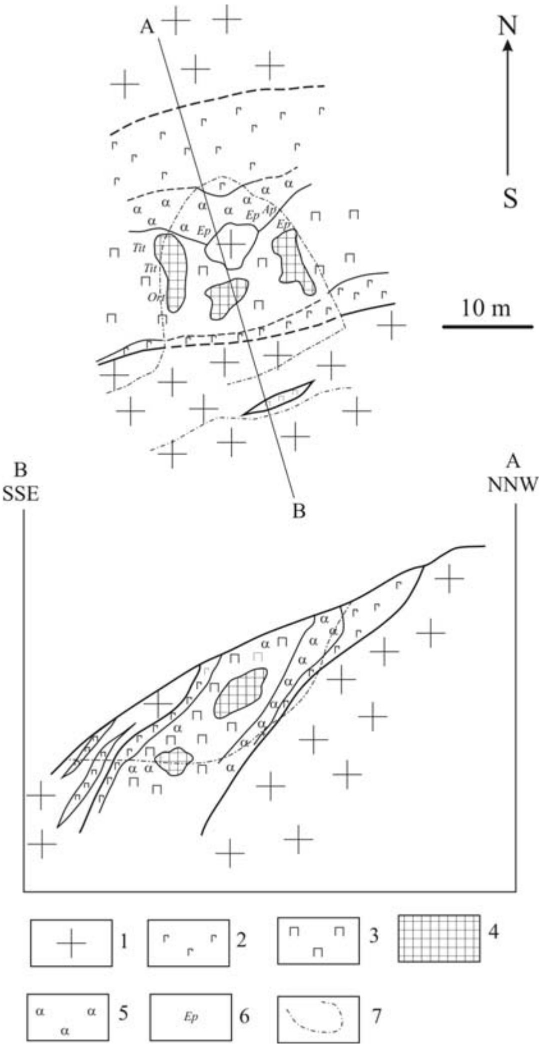


Fig. 1.28. Schematic sketch and cross-section of the Ortitovaya pegmatite vein.
1 –including granitoids, 2 – graphic pegmatite, 3 - coarse-grained pegmatite and blocky feldspar, 4 – quartz cores, 5-6 – muscovite-albite (+ epidote) assemblage, 7 - pit outlines.

The main volume of the vein is coarse- and giant-grained quartz-plagioclase-feldspar pegmatite with a block structure (Fig. 1.27 o, p). On the east wall of the quarry it is clearly seen that large crystals of orthite (allanite) and titanite are confined to just this zone, namely to the coarse-grained and giant-grained pegmatites (Fig. 1.27 q, r).

In 80-90 years of XX century in the upper part of the quarry a subvertical zone of vein fissures containing drusy regular overgrowths of well-formed crystals of smoky quartz on blocks of potassium feldspar with graphic quartz ingrowths, was opened. The zone had subvertical tubular shape and extends down from the zone of block pegmatite to a graphic pegmatite zone. Its formation is considered to be due to the processes of recrystallization of pegmatite parageneses by later pegmatitic fluid. A characteristic feature of this zone is a quartz-feldspar composition of drusy paragenesis.

In blocks of K-feldspar the substitution of potassium feldspar by albite is clearly evidenced. The replacement by albite occurs along fractures, with the formation of muscovite-albite veinlets. Some fractures contain regular overgrowths of blocks of pink-colored K-feldspar by white transparent albite. Albite of this stage is often associated with green muscovite and epidote.
Muscovite-albite veinlets often contain small cavities filled with epidote. Sometimes such cavities in diameter of up to 10-15 cm contain druses of muscovite and well-faceted smoky quartz crystals with ingrowths of translucent epidote. The very rare finds of crystals of turquoise-colored apatite with a very nice faceting of crystal heads, are known.

Despite the fact that the muscovite-albite (with epidote) and quartz-feldspar parageneses are suggested to be formed by late pegmatitic fluids, their mutual relations in the vein are not clear. Most likely they were formed in isolated systems of fissures from fluids circulating in different parts of the pegmatite body.

In block pegmatite zone, in the central part of the vein there are monomineral segregations of gray quartz - quartz nuclei. The size of the nuclei can reach 1 meter. At the boundaries of the quartz nuclei and blocked potassium feldspar, cavernous muscovite-albite associations replacing K-feldspar, are often developed.

Stop 1-11. The Zmeinogorsk deposit (Au-Ag-Cu-Pb-Zn). The Zmeinogorsk gold-silver-barite-polymetallic deposit is located in the Zmeinogorsk mining district in north-western part of Rudny Altai, on the outskirts of Zmeinogorsk city. It was discovered in the 20-30 years of XVIII century and has now fully worked out.

The deposit is localized among Emsian to Eifelian volcanic-sedimentary rocks (Melnichnaya Formation, $D_{1\text{-}2mn}$), which unconformably overlie the metamorphic schists of the Early-Middle Paleozoic (Fig.). The three units are distinguished in the Melnichnaya Formation: the Lower Unit of 65-160 m in thickness which is composed of argillaceous siltstones interbedded with felsic tuffs; the Middle essentially volcanogenic unit (lavas and tuffs of acid composition), and the Upper Unit consisting of argillaceous siltstones with rare interbedded felsic tuffs, and, on the deposit area, with siliceous rocks of several hundred meters in thickness. The structure of the deposit is a monocline of north-west strike with the dip to the north-east at an angle of 40-50°. It is complicated by the Main Fault of northeast strike with a dip to the north-west at an angle of 70-90°, which limits the ore zone to the west.

The ore zone is localized in the Upper Unit and is subdivided into three subzones (Fig. 1.29): the Bottom Subzone, composing of stockwork gold-polymetallic ores in siliceous rocks; the Middle Subzone presented by sheet deposits of gold-silver-barite-polymetallic ores (Bolshoi Raznos and Komisskoe ore bodies), and the Top essentially barite subzone.

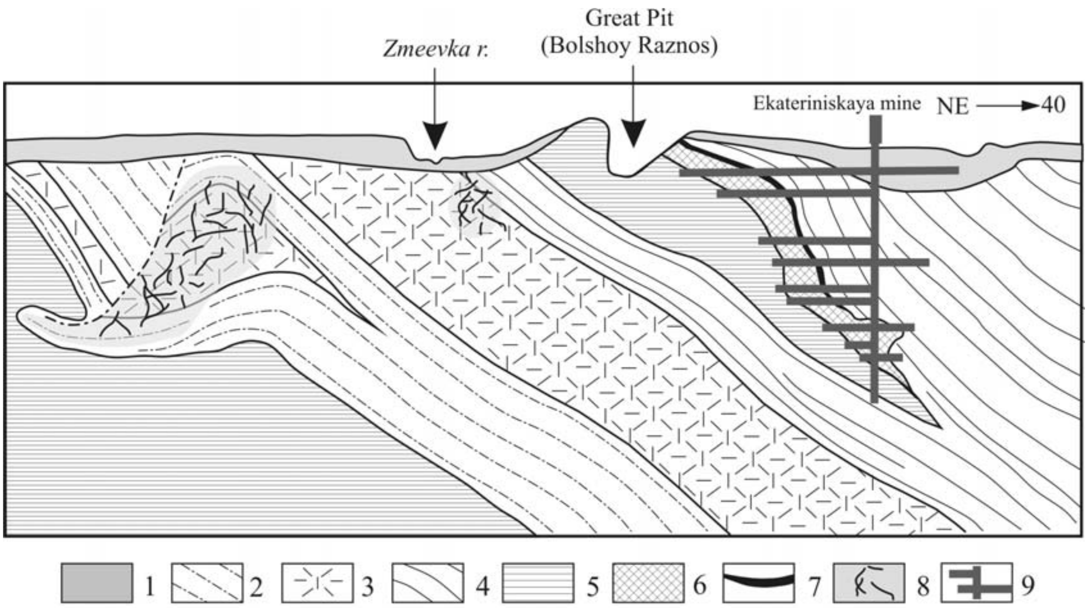


Fig. 1.29. Geological cross-section and the scheme of mining of the Zmeinogorsk deposit [State…, 2011b].
1 – lose sandy-clay Cenozoic sediments, 2 – 4 – deposits of the Melnichnaya formation ($D_{1\text{-}2}$), 2 – siliceous and calcareous siltstones, 3 – rhyolitic and rhyodacitic lavas and tuffs, 4 – siltstones, sandstones and felsic tuffs, 5 – Paleozoic metamorphic shales, 6 – 8 – upper subzone ores, 6 – gold-plymetallic, 7 – gold-silver-barite-polymetallic, 8 – barite, 9 – old mines.

According to the degree of exogenous transformation, the deposit is dominated by primary (sulfide) ores; and the secondary (oxide) ores are less developed. The main minerals of the primary ores are sphalerite (ZnS), galena (PbS), chalcopyrite ($CuFeS_2$), barite ($BaSO_4$), native gold (Au), and silver (Ag). The secondary ores are presented by chalcocite (Cu_2S), argentite (Ag_2S), covellite (CuS), cuprite (Cu_2O), chalcanthite ($CuSO_4 \bullet H_2O$), malachite ($Cu_2(CO_3)(OH)_2$), azurite ($Cu_3(CO_3)_2(OH)_2$), smithsonite ($ZnCO_3$), limonite ($Fe_2O_3 \bullet nH_2O$), native copper (Cu), gold (Au), silver (Ag), and many others. In addition, two gold placers were formed in the northern and southern foothills of the Batareinaya Hill as a result of oxidation and denudation of the top of the ore zone.

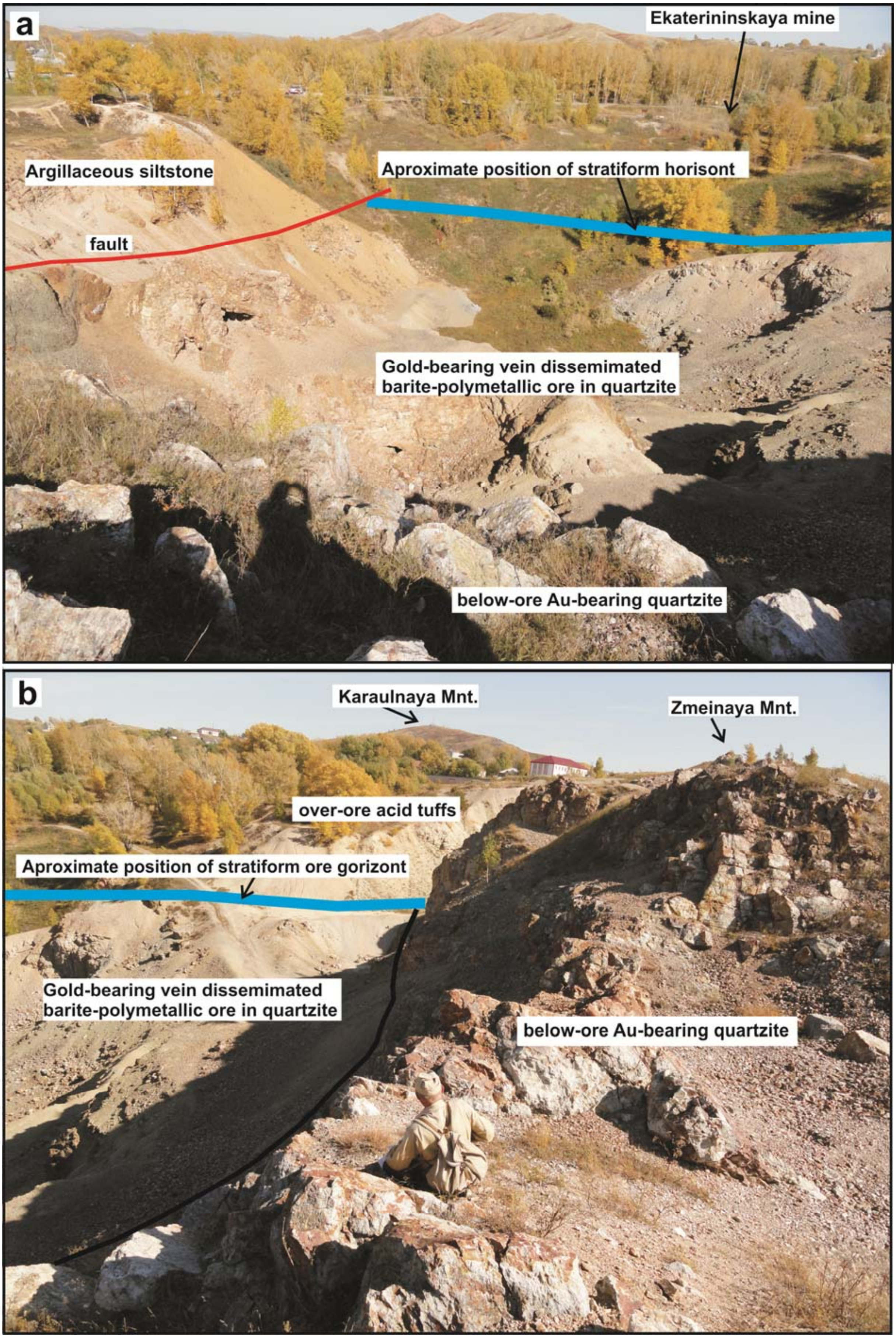


Fig. 1.30. Zmeinogorsk deposit quarry: view to the north-west (a) and south-west (b) walls.

The primary endogenous ores of the different subzones have various contents of ore components. Their lowest concentrations are found in stockwork ores of the Bottom Subzone: Cu = 0.2 to 0.6 wt. %, Pb = 1.2 to 1.52 wt. %, Zn = 1.87 to 2.37 wt. %, Au = 0.1 ppm, and Ag = 8 to 22 ppm. The gold-polymetallic and gold-silver-barite-polymetallic ores of the Middle Subzone contain 0.17 and 1.2 wt. % Cu, 0.85 and 5.5 wt. % Pb, 1.64 and 7.08 to 8.3 wt. % Zn, 2.0 and 5.3 ppm Au, 29.0 and 435 to 680 ppm Ag. Barite ores of the Top Subzone contain 92.45 to 99.22 wt. % $BaSO_4$, as well as 3 to 5 ppm of native gold.

Based on the geological structure of the Zmeinogorsk ore deposit one can assume that its formation was due to volcanic-hydrothermal processes in the near-surface zones and on the surface. The formation of the major gold-silver-barite-polymetallic ores of the Middle Subzone was probably connected with the sedimentation at the bottom of the sea basin. Vein and stockwork ores are considered to be the fragments of mineralization of feeding channels of the hydrothermal system.

Stop 1-12. Stepnoye deposit (Zn-Cu-Pb-Ag). The Stepnoe polymetallic deposit is located on the left bank of the Stepnaya river in its upstream, 4 km south-east of the Talovka village. The sulfide mineralization was found in 1951-1952. The deposit was discovered in 1960.

The deposit is confined to a small anticline complicating the SE closure of the Talovskaya syncline and is divided by the Central fault into the northern and southern blocks having the different thicknesses and composition of individual limbs. The mineralized zone is localized among the alternating clay, clayey siliceous siltstones and felsic tuffs belonging to the the upper part of the Kamenev suite. Carbonate-quartz-sericite and carbonate-sericite-quartz-chlorite metasomatites are developed in the mineralized zone. Quartz metasomatites are the most abundant; they occur in all ore bodies as the main ore-hosting rocks or are confined to the hanging wall of the ore bodies. Widely developed vein mineralization is represented by a stockwork of quartz and quartz-barite veinlets. Commercial polymetallic mineralization is localized in the ore bodies (more than 30) having a ribbon-like and chimney shape. The length of individual ore bodies along the strike is 50-900 m, 20-400 m down dip, with an average thickness from 1-2 to 7-8 m. The ore bodies occur in the inter- and intraformational weakened zones in accordance with stratification of the country rocks (the manteau type). In addition to concordant ore bodies there is a vertical body of barite-polymetallic and essentially barite ores crossing both the polymetallic ores and the folded structure of the deposit (Fig. 1.31). Ores are very extensively oxidized down to 30-50 m below the surface.

The ores were formed as a result of combination of hydrothermaly driven sedimentation and metasomatic processes related to increasing volcanic and tectonic activity in the area for a long time. The K-Ar radiogenic age of metasomatic ore-hosting rocks (sericitolites) of the Stepnoye and Talovskoe deposits varies from 362 to 384 Ma, which corresponds to the boundary between the Middle and Upper Devonian. Within the adjacent Talovskoe deposit, the radiological data indicate different ages for the sericitized rhyolitoids (340-360 Ma) and K-feldspathic rocks (242-263 Ma) [Chekalin, 2002].

Polymetallic ores include impregnated (54 %), streaky (32 %), and massive (14 %) varieties. Primary sulfide copper-lead-zinc ores prevail. The main primary ore minerals are sphalerite, pyrite, galena, chalcopyrite, while minor ore minerals are tennantite, pyrite (melnicovite). Primary ore minerals are disseminated in the veinlets cutting silicified metasomatized rocks. A several generations of ore minerals are distinguished in the veins.

The main minerals in oxidized ores are azurite, malachite, and cerussite; minor minerals are chalcocite, plumbojarosite ($PbFe_6[SO_4]_4(OH)_{12}$), covellite, cuprite, and anglesite. Oxidized ore minerals also form a network of cracks in the weathered metasomatized rocks. Apart from the fact that rocks from an oxidation zone are ores themselves, they may be used as ornamental stones for producing decorative plates and bowls.

The main gangue minerals are quartz, sericite, chlorite, barite, ankerite; the minor include dolomite, calcite, opal, gypsum, and fluorite.

Based on the structural features of the Stepnoe deposit, it has a complex genesis in which the major ore shoots formed in a similar manner as the other stratiform massive sulfide deposits associated with volcanic processes. However, these formations were later hydrothermally reworked in fault zones cutting pyrite deposits.

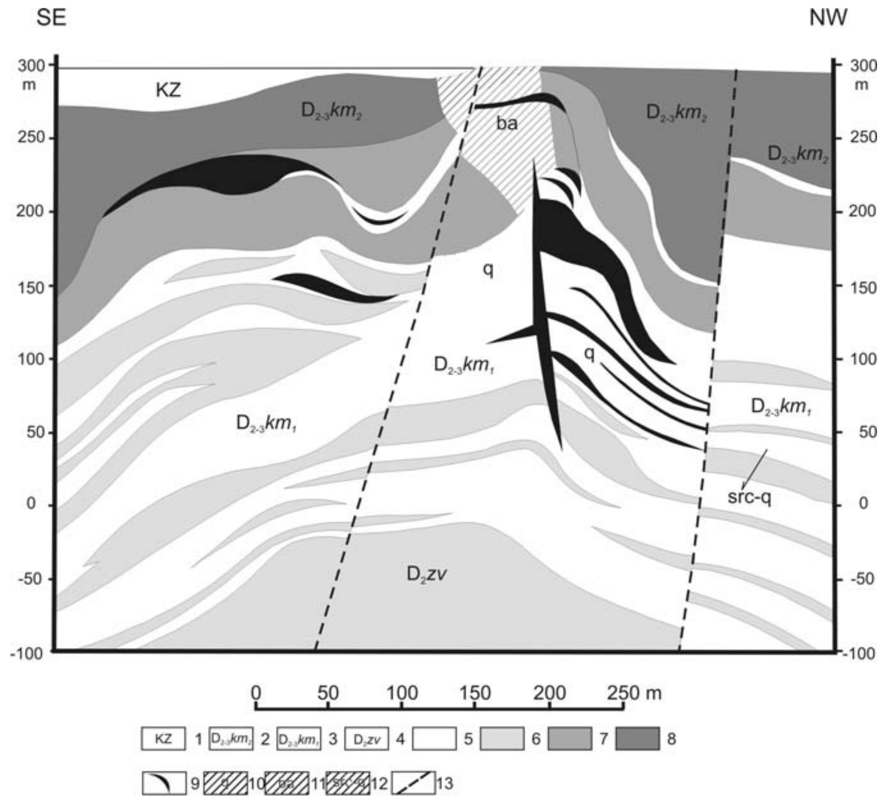


Fig. 1.31. Geological cross-section of Stepnoye deposit [State…, 2011].
1 – undivided Cenozoic sediments, 2 – Kamenevskay formation, upper subformation, 3 - Kamenevskaya formation, lower subformation, 4 – Zavodskaya formation, 5 – clay-siliceous and siliceous siltstones, 6 – rhyolites and siltstone tuff, 7 – alternation of siltstones, sandstones and felsic tuffs 8 – ignimbrites, 9 – ore bodies, 10 – hydrothermal metasomatic quartzites and hydrothermally silicified rocks, 11 – zones of hydrothermal baritization, 12 – metasomatic sericite-quartz rocks, 13 – faults.

Chapter 2. GORNY ALTAI (NORHT-WEST PARTH)

GEOLOGICAL BACKGROUND

Geological complexes of Gorny Altai, exposed in the area of the geological excursion, are the part of the Charysh-Inya Block, which is the extreme western edge of Caledonian structures of the Altai-Sayan Folded Area. Along the Northeast shear zone the Charysh-Inya Block is bordered on south-west by Hercynides of the Rudny Altai Block of the Ob'-Zaisan folded system; in the east it separates by the Charysh Fault from the Talitsa and Maralikha terranes. The northern border is covered by Quaternary sediments of the Biya-Barnaul depression; in the south stratified deposits of the the Charysh-Inya Block are transgressively overlapped by Early Devonian volcanic-sedimentary deposits of the Korgon trough (Fig. 2.1.).

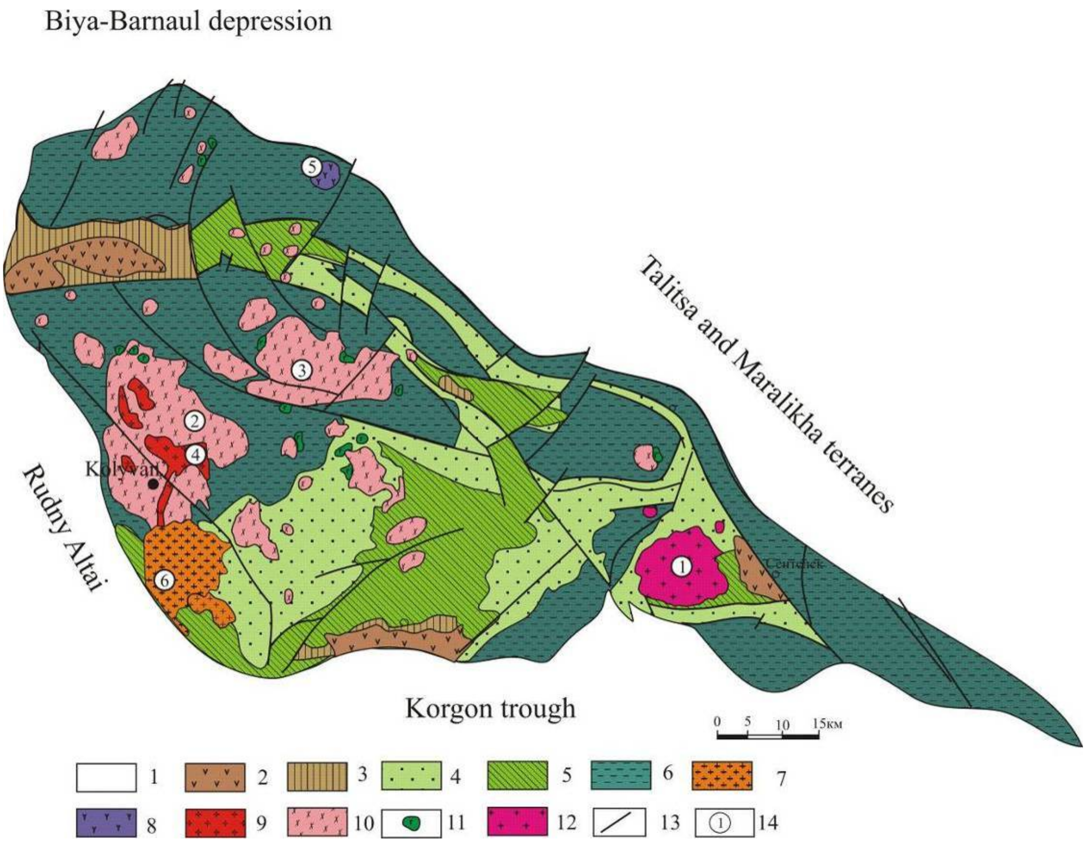


Fig. 2.1. Geological scheme of the Charysh-Inya Block, Gorny Altai (after [Shokalsky, 1990 a], with simplifications).

1 – flanking terranes, 2-6 – stratified formations: 2 – Early to Middle Devonian volcanogenic series, 3 – Lower Devonian terrigenous and terrigenous-carbonate deposits, 4 – Silurian terrigenous, terrigenous-carbonate, and carbonate strata, 5 – Mid-Upper Ordovician terrigenous deposits, 6 – Upper Cambrian to Lower Ordovician turbidites. 7-12 – intrusive formations: 7 – granitoids of the Sinyushensky Complex (P_2-T_1), 8 – high-Ti gabbros of the Kharlovsky Complex (C_2), 9 – Borovlyansky Complex granitoids (D_{3fm}); 10-11 – the Ust'-Belovsky Complex rocks (D_{3fm}): 10 – granitoids, 11 – gabbros and diorites, 12 – Mayorsky Complex granitoids (D_{3fr}), 13 – major faults. 14 – massifs, described or mentioned in the text: 1 - Mayorsky, 2 - Kolyvansky, 3 – Ust'-Belovsky, 4 – Ocharovatelny Mount, 5 – Kharlovsky, 6 - Sinyushensky.

The oldest stratified deposits of the Charysh-Inya Block are the Late Cambrian to Early Ordovician turbidites of the Gornoaltaisk series. They are called in this area as the

Suetka Unit, composing of lilac-gray, purple, greenish chloritized sandstones, siltstones, and shales interbedded with small bands of grits and conglomerates. In modern geological structure the Cambrian-Ordovician deposits are confined to the cores of anticlinal folds. They are intensively contorted, schistosed, subjected to boudinage in places, and transformed to hornfelses in exocontacts of granitoid intrusions. The total thickness of the Unit deposits is more than 2000 meters [State ..., 2001 b].

The Upper Cambrian to Lower Ordovician deposits are unconformably overlapped by Middle Ordovician to Silurian strata, having a total thickness more than 4000 m and subdividing into Bugryshikha and Hanhara (O_2), Tehtensk (O_3), Chineta, Polatinsk and Chagyr (S_1) units, lying on each other without visible unconformity. A common feature of the Ordovician-Silurian strata is an increase in the "maturity" degree of sedimentary rocks from bottom to top (gradual change of polymictic varieties by arkosic ones), as well as a change of terrigenous sedimentation by carbonate sedimentation (up to the formation of purely carbonate deposits of the Chagyrskaya Unit of the Early Silurian). In general, the evolution of the Ordovician-Silurian sedimentation demonstrated gradual shallowing of a marginal sea basin.

The Ordovician-Silurian deposits are transgressively (sometimes with an angular unconformity) overlapped by Devonian volcanic-sedimentary series. It is subdivided into Lower Devonian essentially terrigenous Baragash Unit (≈ 800 m), which is unconformably overlapped by Middle Devonian Kuyagan Unit composing of intermediate and acid lavas and pyroclastic rocks (about 600 m), and the Mid-Upper Devonian terrigenous (with subordinate carbonates) Malafeevka Unit (about 500 m), unconformably overlapped the Middle Devonian volcanic strata.

The abrupt change of compositions and facial conditions of accumulation of Devonian sediments, significant variations in their thicknesses and the presence of numerous unconformities indicate that the formation of the Devonian volcanic-sedimentary rocks has occurred in the active tectonic setting. This time interval corresponded to the existence of an active continental margin of the Andean type, that stipulated by subduction of the oceanic lithosphere of the Ob'-Zaisan basin under the edge of the Siberian continent.

The Late Devonian stage of geological history of the region accompanied by a large-scale manifestation of gabbroid and granitoid magmatism (see next section), isn't reflected in sedimentary chronicles. Lower Carboniferous sediments have very limited development, exposing only in the cores of synclinal structures. Starting from the Middle Carboniferous (peak collision of the Siberian and Kazakhstan continents) the region developed in the continental regime.

MAGMATIC COMPLEXES of the CHARYSH-INYA BLOCK

The Charysh-Inya Block is characterized by a wide development of granitoids that compose numerous intrusions, independently or in association with gabbroides (Fig. 2.1). The geological and geochronological studies [Shokalsky, 1990 a, b, 1999; Vladimirov et al., 1997, 2001; Shokalsky et al., 2000; Kruk et al., 2009, 2011] allowed distinguishing five separate magmatic complexes: Mayorsky gabbro (?)-granite-leucogranite complex (D_3fr), Ust'-Belovsky gabbro-diorite-granodiorite complex (D_3fm), Borovlyansky granite-leucogranite complex (D_3fm), Kharlovsky gabbro-monzodiorite-granosienite complex (C_1) and Sinyushensky granite-leucogranite complex (P_2-T_1).

Below is a brief description of intrusive complexes and their composing rocks.

MAYORSKY COMPLEX

Geological setting and Age of granitoids. In West Altai the Mayorsky Complex granitoids compose several intrusive bodies; the best known of them is Mayorsky Massif. In addition to it the complex includes several small intrusive bodies (Ust-Tulata, Chalsky, Chesnokov etc.) located in close proximity to the Mayor Massif and the Charysh-Terekta Fault (Fig. 2.1). The Mayorsky Complex granitoids were studied in detail by S.Shokalsky [1990 a]. According to his data the granitoids intrude Cambrian-Silurian terrigenous and terrigenous-carbonate deposits. In exocontact zones hornfelses and skarns were formed at the expense of sedimentary rocks and limestones, correspondingly. Zones of cataclasm and mylonitization are widely developed. The granitoids are accompanied by a large number of dikes of acid composition (aplite, microgranite, microgranite porphyry); dikes of basic composition are less common (diorite, diabase porphyry).

The U-Pb age of the Mayorsky Complex granitoids, obtained on zircons from granites of the main phase is 381 ± 4 Ma [Vladimirov et al., 2001].

The Mayorka massif is an isometric body with an area of 100 km^2, having a heterogeneous internal structure. The northern part of the massif is dominated by inequigranular (coarse- and medium-grained) two-feldspar biotite (± amphibole) granite, while the southern part is composed mainly of equigranular (medium- and fine-grained) biotite-amphibole granite-leucogranites with K-Na feldspar. The endocontact rim having width up to 700 m is composed riebeckite leucogranites. All described rock varieties are intruded by numerous bodies of fine-grained equigranular and porphyritic granite-leucogranites, aplite dykes of biotite granites and biotite-amphibole granite porphyry, sometimes containing alkali amphibole phenocrysts.

Petrographic features of the rocks. Biotite granites of the northern part of the massif are light-gray or pinkish-gray rocks composed of quartz (30-35 %), acid plagioclase (20-25 %) and latticed microcline (35-45 %). Mafic minerals are biotite (<5 %) and rare greenish-brown amphibole. Sometimes granitoids have porphyry appearance due to the presence of large (up to 1.5 cm) grains of quartz and acid plagioclase. These grains are often deformed and fragmented. The accessories are presented by magnetite, zircon and apatite

Single-feldspar amphibole granites are gray, pinkish-gray or pink inequigranular medium-grained rocks composed of quartz (30-35 %) and latticed microcline-perthite (60%). Sharply predominant mafic mineral is subalkalic amphibole. Biotite flakes occur extremely rarely. Accessory minerals are magnetite and zircon. The rocks textures are micropegmatitic and micropoikilitic, rarely granitic, extremely rare – prismatic. In general, the massif rocks are characterized by alternation of places with granitic (hypidiomorphic), allotriomorphic, micropoikilitic and micropegmatitic textures, even within a single thin section (Fig. 2.2 a-c).

Rock chemistry. The Mayorsky Complex rocks are characterized by higher alkalinity with predominance of potassium over sodium, moderate alumina content, low concentrations of calcium and phosphorus. The single-feldspar amphibole granite-leucogranites contain slightly more titanium, less alumina, more iron and less magnesium, compared with the two-feldspar biotite varieties. According to alkali contents the two-feldspar biotite granite-leucogranites correspond to the rocks of normal alkalinity, and single-feldspar amphibole granite-leucogranites correspond to moderately alkaline rocks (Fig. 2.3a). The granitoids are characterized by high iron content ($f > 80$ %, Fig. 2.3b), most of the rocks are slightly supersaturated with alumina.

Trace-element composition of the Mayorsky Complex granitoids is characterized by higher contents of rare alkalis, lower concentrations of alkaline earth metals, close contents of HFSE elements, compared with their crustal abundances (Table 2.1, Fig. 2.4a,b). REE contents in the two-feldspar biotite granite-leucogranites are close to their Clarke level. REE patterns of the left side of the spectra are asymmetric with a negative slope, and in the right side are subhorizontal. Eu minimum is clearly expressed and becomes deeper with increasing of silica content. The spidergrams (Fig. 2.4) demonstrate deep minima for Sr, Ba and Ti, minor negative anomalies for Nb and Ta, positive anomalies for Th, Zr and Hf.

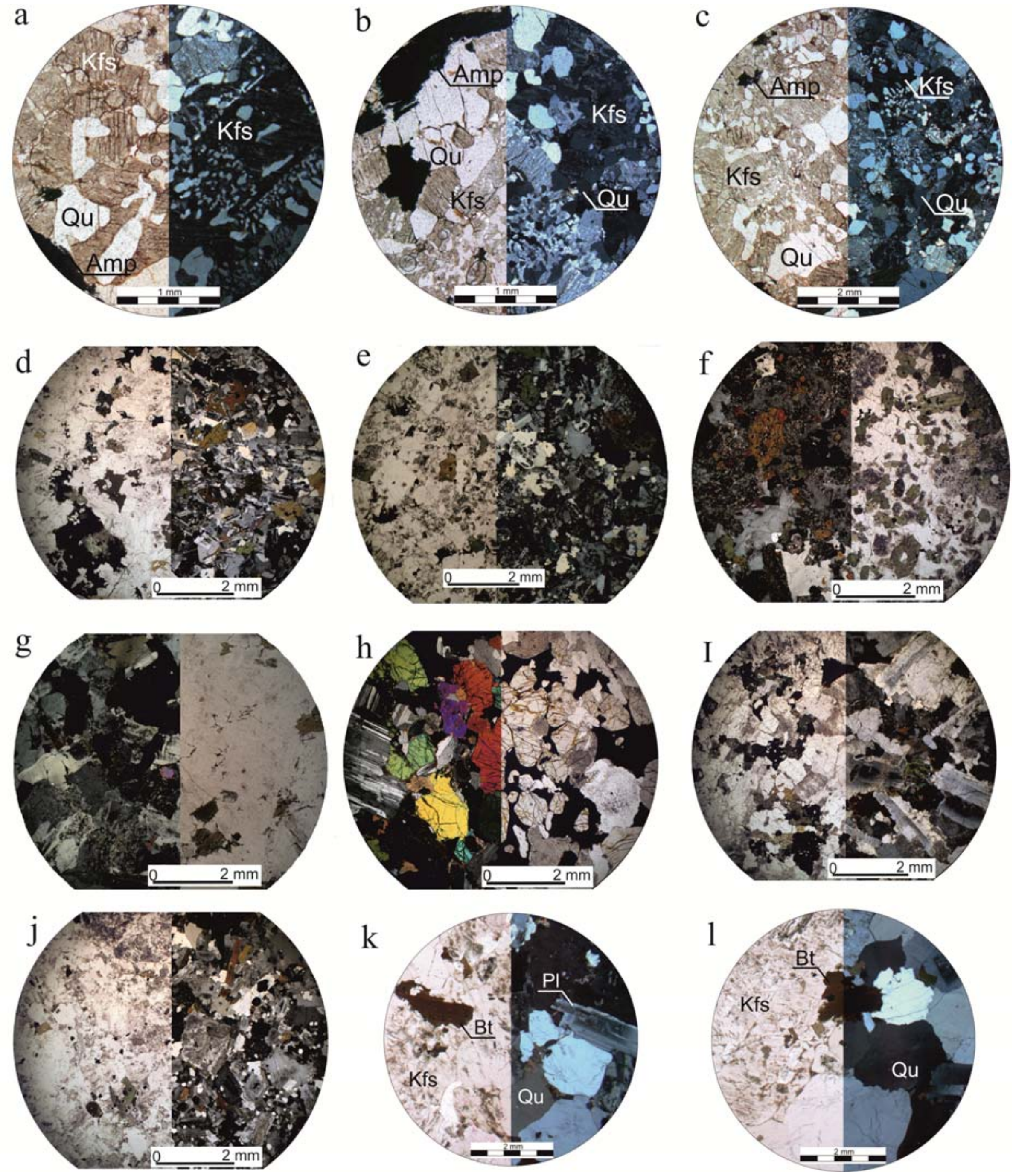


Fig. 2.2. Petrographic features of intrusive rocks of the Charysh-Inya block of the Gorny Altai (description in the text).
a-c = Mayorsky Complex (leucocratic granites from southern part of the Mayorsky Massif); d-f = Ust'-Belovsky Complex, Kolyvansky massif: (d) = diorite (marginal facies), (e) = granodiorite, (f) = diorite (melanocratic enclave in granodiorites); g = Borovlyansky Complex, Mt. Ocharovatelnaya Massif, biotite granite; h-j = Kharlovsky Complex, Kharlovsky Massif: (h) = melanocratic gabbro of the first phase, (i) = quartz monzodiorite of the third phase, (j) = granosyenite of the third phase; k-l = Sinyushensky Complex, Sinyushensky massif (leucocratic biotite granites).

The single-feldspar amphibole rocks are characterized by very high contents of Zr, Hf, Y, Th (Table 2.1). The total content of rare earth elements reaches 350-660 ppm. The shapes of REE spectra and spidergrams is similar to the two-feldspar varieties, but all the positive and negative anomalies are manifested more clearly.

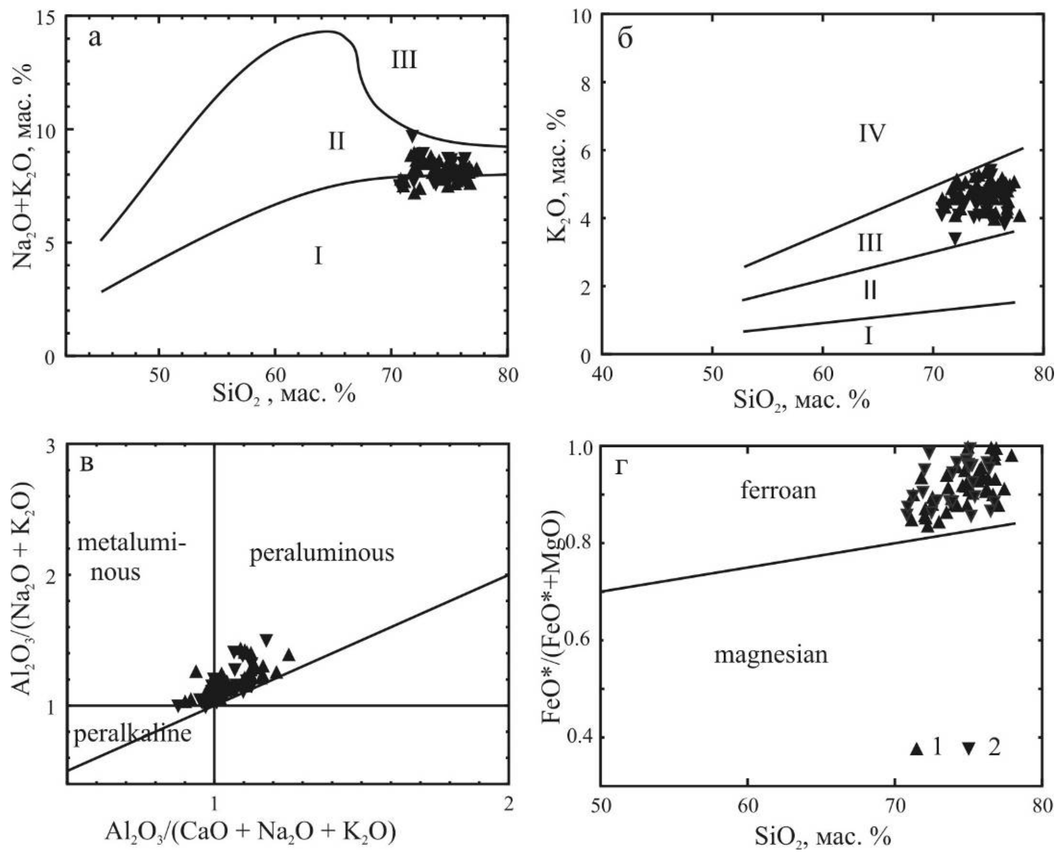


Fig. 2.3. Petrochemical diagrams for granitoids of the Mayorsky Massif.

Rocks of postgranitic dikes and small bodies are similar in trace element characteristics to the two-feldspar-biotite granite-leucogranite.

Granitoids of the Mayorsky Complex are characterized by an extremely radiogenic composition of neodymium (ε(Nd)T = +4.5 $T_{(Nd)}$DM-2 = 0.77 Ga), sharply different from all the rocks of continental crust in the region [Kruk et al., 2010, 2011].

As a whole, the Mayorsky Complex rocks correspond to the A-type granitoids (Fig. 2.5). It is assumed that an active role in the generation of granitoids was due to Early Frasnian mantle-derived magmas with geochemical characteristics of OIB and ε(Nd)T ≈ +8, similar to those described in the neighboring areas of the Gorny Altai [Kruk, Sennikov, 2012].

UST'-BELOVSKY COMPLEX

Geological position and internal structure of massifs. In the west Altai gabbros and granitoids of the Ust'-Belovsky Complex compose two major intrusive bodies (Kolyvan' and Ust'-Belovo), separated by a narrow strip of host rocks, as well as a number of smaller bodies (Fig. 2.1). The total area of the granitoid occurrences in the Charysh-Inya Block is about 640 km^2.

The host rocks for granitoids are Late Cambrian to Ordovician terrigenous and terrigenous-carbonate strata; sometimes intrusive contacts with younger formations (up to the Givetian inclusive) are observed [Shokalsky, 1990 a]. Granitoid intrusions are accompanied by wide (more than 1 km) areoles of hornfelses. The granitoids are intruded by bodies of granite-leucogranite of the Borovlyansky Complex (D_3), as well as by the Permian-Triassic granitoids of the Sinyushensky Complex. The U-Pb age of quartz diorite of the Ust'-Belovo Massif obtained on zirconc, is 364 ± 8 Ma [Vladimirov et al., 2001].

The internal structure of massifs of the Ust'-Belovsky Complex is characterized by a rough zoning: the outer parts of intrusive bodies are composed mainly of diorites and quartz

Table 2.1.1

Major (wt. %) and trace (ppm) element contents in representative samples of Mayorsky Complex granitoids

Sample	11-25	11-28	060-1	11-32/1	11-34/2	11-33/1	11-34/1	11-24/1
SiO_2	72.24	74.22	75.28	76.21	75.04	76.45	76.37	76.82
TiO_2	0.3	0.23	0.15	0.14	0.18	0.12	0.13	0.09
Al_2O_3	13.98	13.5	12.71	11.21	12.07	11.66	11.89	12.21
Fe_2O_3*	2.37	1.96	1.33	3.37	2.73	2.38	2.45	1.51
MnO	0.05	0.07	0.04	0.13	0.05	0.02	0.06	0.03
MgO	0.42	0.25	0.13	<0.1	<0.1	0.32	<0.1	<0.1
CaO	1.31	1.06	0.77	0.09	0.21	0.32	0.07	0.44
Na_2O	3.51	3.36	3.23	3.93	4.14	3.8	4.06	3.55
K_2O	5.06	5.19	5.07	4.6	4.49	3.83	4.65	4.72
LOI	0.48	0.07	1.48	0.35	0.57	0.63	0.35	0.44
P_2O_5	0.09	0.06	0.03	0.02	0.03	0.02	0.02	0.02
Total	99.85	99.98	100.27	100.08	99.62	99.58	100.1	99.87
Rb	177	194	228	218	146	156	231	217
Sr	128	67	42	3	22	16	4	30
Y	26	25	27	79	39	97	22	36
Zr	180	131	108	1691	380	443	471	96
Nb	15.4	17.1	31.0	65.8	31.2	37.0	39.2	26.3
Cs	4.8	7.9	7.7	1.8	3.7	1.4	4.1	2.9
Ba	354	167	108	91	170	64	52	87
La	34.94	41.96	15.66	125.46	74.85	86.49	37.92	10.77
Ce	68.48	82.58	44.89	274.12	167.02	133.48	90.82	36.45
Pr	8.05	9.52	3.8	33.46	17.22	23.8	9.27	3.26
Nd	29.2	31.69	13.69	122.12	57.69	87.06	30.86	12.77
Sm	5.11	5.13	3.04	23.42	8.84	17.19	4.74	3.56
Eu	0.95	0.64	0.31	0.75	0.48	0.53	0.21	0.2
Gd	4.33	4.12	3.20	19.71	7.57	15.99	3.74	4.09
Tb	0.73	0.79	0.59	3.26	1.14	2.68	0.63	0.79
Dy	4.12	4.61	3.47	18.06	6.37	15.48	4.25	5.54
Ho	0.87	0.97	0.8	3.85	1.33	3.22	1.08	1.23
Er	2.74	2.89	2.73	12.51	4.68	10.15	4.25	4.15
Tm	0.46	0.52	0.51	2.45	0.97	1.71	0.88	0.74
Yb	3.1	3.58	3.8	17.09	6.1	11.23	6.59	5.18
Lu	0.45	0.52	0.59	2.72	0.98	1.67	1.03	0.79
Hf	4.9	5.0	5.3	50.7	13.3	12.7	15	5.2
Ta	1.6	1.6	3.7	4.9	2.1	1.7	2.9	3.2
Th	17.4	27.8	32.6	34	26.5	13.8	26	49.1
U	3	3	6.5	17	4.6	6.4	5.7	7.1

Note: 1-3 – two-feldspar biotite granite-leucogranite, 4-6 – single-feldspar amphibole granite-leucogranite, 7-8 – post-granite dykes: 7 – fine-grained biotite-amphibole granite, 8 – aplite.
Fe_2O_3* - total iron.

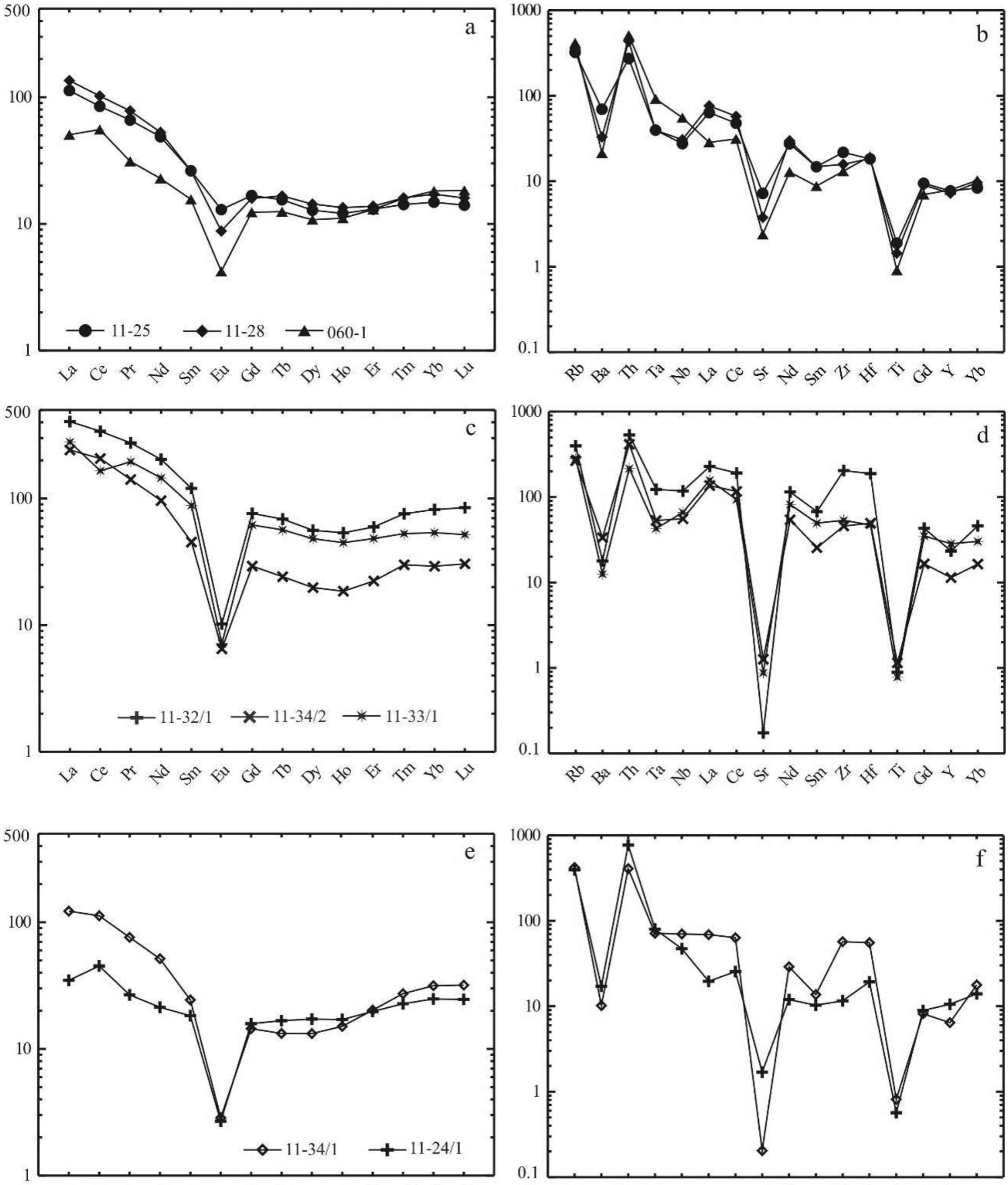


Fig. 2.4. Chondrite-normalized REE spectra and primitive mantle-normalized spidergrams of granitoids of the Mayorsky Massif.

a-b – two-feldspar granitoids of the northen part of the massif, c-d – single-feldspar granitoids of the southern part of the massif, e-f – late leucogranites of dykes and small bodies. Sample numbers correspond to Table 2.1.

diorites, while in the inner parts prevail tonalites, granodiorites and, rarely, melanocratic granites. Gabbroides of the early phase compose small bodies in the peripheral parts of the massifs, or occur as xenoblocks in granitoids. The gabbroid bodies show rhythmic layering with alternation of differences, enriched with plagioclase and mafic minerals. The clear intrusive contacts are observed between gabbroids, diorite and quartz diorites. The relationships between the tonalites, granodiorites and melanocratic granites have a facial character [Shokalsky, 1990 a]. The post-granitic dike series presents dolerites, diorite porphyrites, granodiorite - and granite-porphyries.

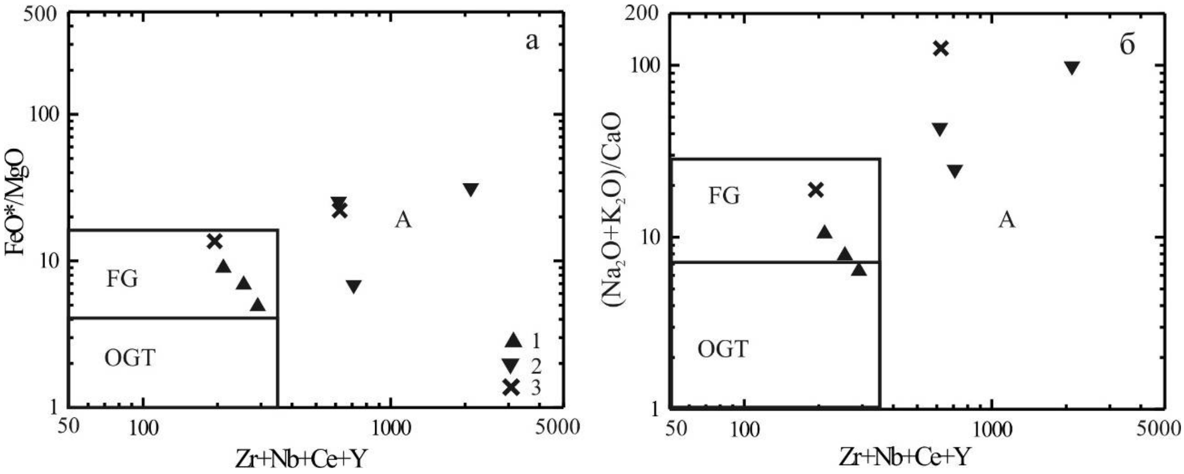


Fig. 2.5. Discrimination diagrams [Whalen, 1989] for granitoids of the Mayorsky Complex:
(a) Zr+Nb+Ce+Y vs. FeO*/MgO, (b) Zr+Nb+Ce+Y vs. (K_2O+Na_2O)/CaO. The fields: FG = fractionated granites, OGT – unfractionated granites of the M-, S- and I-types, A – granites of the A-type.
Legend: 1 = two-feldspar-biotite granites, 2 = K-feldspar-amphibole granites, 3 = post-granitic bodies and dykes.

A characteristic feature of the Ust'-Belovo massifs is the presence of a large number of schlieren-like melanocratic inclusions ranging in size from 1 to 30 cm (in rare cases, up to 1 m), composed of fine-grained rocks of magmatic appearance. The inclusions are found in rocks of different composition (from quartz diorite to melanocratic granites). Based on petrographic observations and a few petrochemical analyses, the composition of inclusions correlates with the host granitoid composition. In quartz diorites the inclusions are of gabbroid composition; in granodiorites they are presented by diorites and quartz diorites. The number of inclusions varies greatly in different exposures: from the almost complete absence to 20-25 % of the rock volume.

Mineralogical and petrographic features of the rocks. The gabbroids are dark gray (to black) medium-grained rocks of equigranular, rarely poorly porphyry appearance with gabbro, ophitic, rarely poikilitic texture. The rocks of the gabbroid phase vary in modal composition from gabbro-anorthosites to gabbro-norites and melanodiorites. Gabbro is composed of tabular crystals of zonal plagioclase (An_{65-55}) and elongated euhedral crystals of clinopyroxene (augite), when a subordinate role of brownish-green hornblende. Gabbro-norite contains, in addition, orthopyroxene, which grains are often surrounded by an augite rim. Gabbro-anorthosites are characterized by a high content of plagioclase, having isometric shape and high basicity (An_{84-89}). Diorites inherit petrographic characteristics of the gabbro, but differ from the latter by increased contents of amphibole (at the expense of pyroxenes) and the presence of small amounts of anhedral grains of quartz. Accessory minerals are presented by magnetite and apatite.

Quartz diorite, granodiorite and melanogranite are light gray medium-grained equigranular rocks with massive and schlieren structures. They consist mainly of tabular zonal plagioclase (from An_{39-41} in the cores of large crystals to An_{16-22} in rims and small individuals), laths of brown biotite (Mg# = 47-49), and euhedral elongated grains of brown-green amphibole which corresponds in composition to magnesio-hastingsite and common hornblende. Small xenomorphic grains of non-latticed K-feldspar (from 10 % in quartz diorites to 20 % in melanogranites) and quartz grains of irregular shapes occur in all the rocks. The rock textures are granitic and monzonitic, reflecting the crystallization sequence of two mineral parageneses: early (plagioclase + amphibole + biotite) and late (K-feldspar +

quartz + plagioclase + biotite) (Fig. 2.2. d, e). Accessory mineralization is represented by magnetite apatite, zircon, sphene.

Melanocratic inclusions in granodiorites of the Kolyvan Massif are composed of fine-grained equigranular (rarely poorly porphyry) quartz-bearing diorite, consisting of isometric tables of zoned plagioclase (45-55 %), elongated grains of brown hornblende (15-25 %), laths of dark-brown biotite (5-20 %) (Fig. 2.2. f), xenomorphic grains of potassium feldspar and quartz (<10 % each). The rocks sporadically contain clinopyroxene grains, often rimmed by hornblende.

Rock chemistry. The rocks of the Ust'-Belovo Complex correspond to continuous series from gabbro to granite. The common features of the gabbroids and granitoids are normal alkalinity and elevated calcium contents. Gabbroids are characterized by low concentrations of titanium and phosphorus (<0.55 wt. % of TiO_2, <0.15 wt. % of P_2O_5) and moderate (40-45 %) Mg# number (Table 2.2, Fig. 2.6). Only in the most "differentiated" gabbronorite (sample 04-9, Table 2.2) TiO_2 and P_2O_5 contents increase up to 1.0 and 0.25 wt.%, respectively, while Mg# decreases to 30 %.

The granitoids are characterized by normal alkalinity with a predominance of Na over K (Fig. 2.6 a,b), low concentrations of titanium and phosphorus, and increased calcium contents. Quartz diorite and tonalite are undersaturated in alumina, while the granodiorites and melanogranites are dominated by corundum-normative rocks (Fig. 2.6 c). In the diagram SiO_2-FeO* vs. MgO + FeO * (Fig. 2.6 d) figurative points of gabbro, tonalite and granodiorite compositions are localized in the field of magnesian rocks (except for the most differentiated gabbros, see above), while a few points of melanogranite fall in the field of ferriferrous rocks.

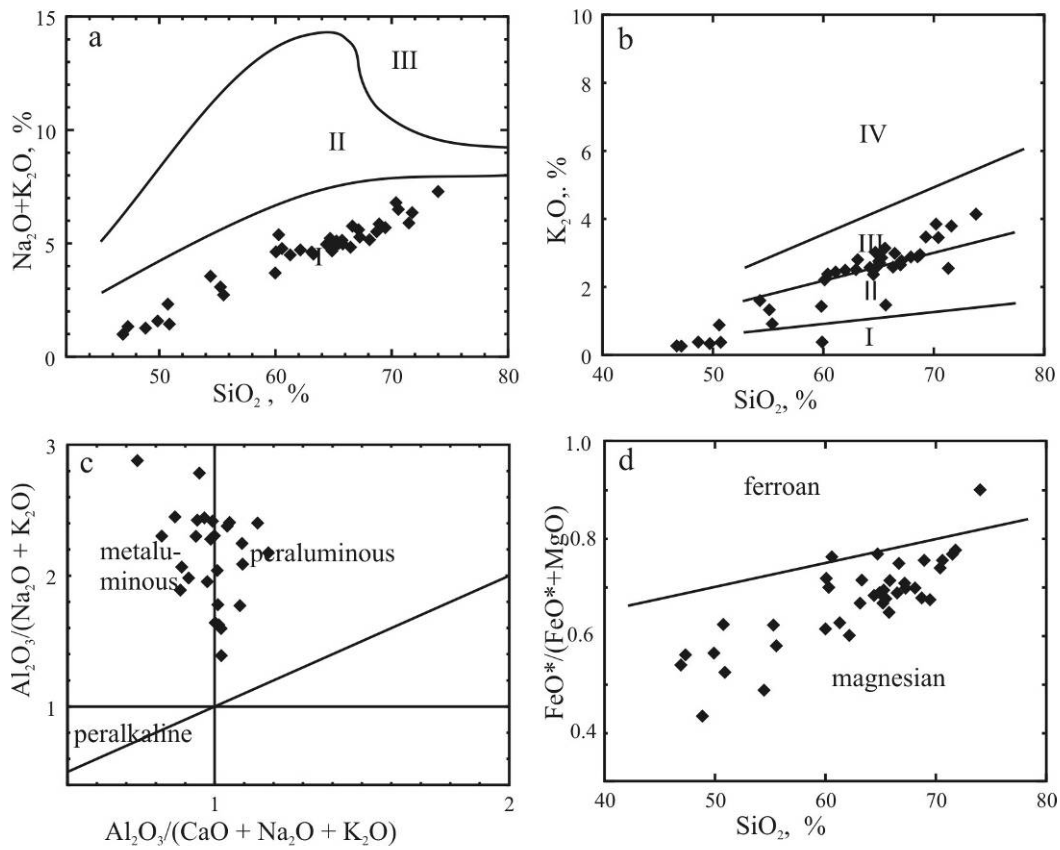


Fig. 2.6. Petrochemical diagrams for rocks of the Ust'-Belovo Complex.

Table 2.2

Major (wt. %) and trace (ppm) element contents in representative rock samples of the Kolyvan' and Ust'-Belovo massifs

Sample	04-10/1	04-10/4	04-10/5	04-9	04-6	04-3	04-8
	1	*2*	*3*	*4*	*5*	*6*	*7*
SiO_2	46.82	47.25	49.81	50.68	50.81	55.21	55.48
TiO_2	0.54	0.47	0.5	0.91	0.39	0.66	0.64
Al_2O_3	16.33	18.27	16.46	16.39	14.86	16.26	15.04
Fe_2O_3*	12.1	11.29	11.5	11.12	10.97	9.02	9.17
MnO	0.2	0.18	0.19	0.17	0.19	0.15	0.14
MgO	9.22	7.91	7.94	6.01	8.89	4.90	5.95
CaO	12.39	11.81	10.98	10.03	10.61	8.8	8.6
Na_2O	0.78	1.12	1.3	1.49	1.12	1.8	1.87
K_2O	0.22	0.21	0.28	0.83	0.33	1.28	0.87
P_2O_5	0.12	0.07	0.08	0.22	0.04	0.14	0.13
LOI	1.21	1.33	0.86	1.89	1.75	1.23	2.04
Total	99.94	99.93	99.93	99.77	99.97	99.48	99.96
Rb	8	8	8	23	8	40	23
Sr	255	273	294	272	228	274	247
Y	10	13	13	19	11	20	21
Zr	9	19	16	66	34	86	103
Nb	0.6	1	1.6	5.4	1.7	5.9	6
Cs	1.1	2.7	2.0	1.1	0.8	2.4	1.9
Ba	42	65	78	179	131	273	251
La	2.85	4.77	5.19	11.05	6.47	15.61	15.24
Ce	6.44	9.87	10.72	23.06	12.66	32.18	31.64
Pr	1.04	1.50	1.57	3.19	1.69	4.10	4.21
Nd	5.07	7.16	6.91	14.00	6.88	16.68	17.26
Sm	1.42	1.85	1.78	3.21	1.71	3.70	3.75
Eu	0.68	0.82	0.82	0.96	0.58	1.06	1.02
Gd	1.75	2.24	2	3.46	1.88	3.70	3.79
Tb	0.29	0.38	0.38	0.57	0.31	0.57	0.62
Dy	1.90	2.48	2.42	3.44	2.1	3.80	3.98
Ho	0.40	0.51	0.51	0.70	0.43	0.80	0.82
Er	1.14	1.46	1.47	2.16	1.27	2.29	2.34
Tm	0.19	0.25	0.24	0.33	0.22	0.37	0.37
Yb	1.20	1.65	1.66	2.04	1.4	2.29	2.53
Lu	0.19	0.25	0.24	0.32	0.2	0.33	0.37
Hf	0.4	0.7	0.6	2.3	1.3	3	3.4
Ta	0.1	0.1	0.1	0.4	0.1	0.4	0.5
Th	0.2	0.6	0.5	2.7	2.6	4.8	4.7
U	0.1	0.3	0.3	0.8	0.9	1.2	1.2

Table 2.2, cont.

Sample	8-603	8-603/1	8-602	04-12	8-602/1	8-602/2	8-602/5
	8	*9*	*10*	*11*	*12*	*13*	*14*
SiO_2	60.91	62.7	65.14	65.9	55.32	56.14	57.36
TiO_2	0.63	0.52	0.47	0.51	0.58	0.57	0.55
Al_2O_3	16.20	16.26	15.10	15.64	16.87	16.09	15.54
Fe_2O_3*	7.16	6.58	5.75	5.28	8.48	8.49	8.27
MnO	0.12	0.12	0.1	0.07	0.17	0.2	0.19
MgO	2.63	2.43	2.64	1.85	3.97	4.66	4.39
CaO	6.29	5.81	5.07	4.71	7.25	7.21	7.26
Na_2O	2.35	2.49	2.31	2.81	3.54	3.03	2.84
K_2O	2.06	1.94	2.8	2.42	2.28	2.70	2.18
P_2O_5	0.14	0.12	0.1	0.13	0.14	0.12	0.11
LOI	0.72	0.8	0.64	0.73	1.39	0.74	1.10
Total	99.26	99.8	100.11	100.05	100.02	99.98	99.83
Rb	64	61	102	75	74	82	70
Sr	254	218	204	270	235	189	204
Y	24	19	26	22	45	51	44
Zr	108	96	135	132	80	137	108
Nb	8.7	7.4	9.8	8.6	11.6	12.1	10.9
Cs	5	5.2			3.6	4.8	4.7
Ba	441	372	497	470	324	327	313
La	21.66	20.29	23.06	21.73	22.52	17.43	15.96
Ce	42.97	42.28	44.63	39.94	45.45	46.2	40.99
Pr	5.5	4.5	5.53	4.87	7.52	7.38	6.78
Nd	21.62	16.58	20.64	18.27	31.77	32.27	29.38
Sm	4.31	3.35	4.12	3.48	7.29	7.71	6.77
Eu	1.18	0.96	0.84	1.05	1.37	1.44	1.33
Gd	4.27	3.46	3.57	3.08	7.18	7.9	6.97
Tb	0.66	0.57	0.61	0.53	1.20	1.32	1.13
Dy	4.4	3.70	4.13	3.23	7.48	8.48	7.26
Ho	0.9	0.80	0.89	0.7	1.6	1.85	1.5
Er	2.65	2.10	2.67	2.09	4.92	5.74	4.71
Tm	0.44	0.35	0.41	0.31	0.82	0.97	0.78
Yb	2.78	2.3	2.92	2.28	5.43	6.32	5.22
Lu	0.42	0.34	0.47	0.36	0.79	0.95	0.77
Hf	3.8	3.5	3.7	3.2	3.9	5.9	4.4
Ta	0.8	0.7	1	0.6	1.1	1.7	1.4
Th	7.2	9.8	9.7	9.7	12.7	14.4	8.6
U	2	1.2	2.7	1.9	1.8	4.9	2.9

Note: 1 = melanogabbro, 2 = gabbro-troctolite, 3-4 = gabbro, 5 = gabbro-norite, 6-7 = two-pyroxene-amphibole diorite, 8 = biotite-pyroxene-amphibole quartz diorite, 9 = biotite-amphibole tonalite, 10-11 = amphibole-biotite granodiorite, 12-14 = melanocratic inclusions in granodiorites.
Fe_2O_3* = total iron.

Trace element characteristics of the Ust'-Belovo rocks are presented in Table 2.2 and Fig. 2.7. Gabbroids are characterized by low contents of LILE and HFSE elements (Table 2.2). The REE contents are also lower than the Clarke level (ΣREE = 25-40 ppm), their spectra are slightly asymmetrical with $(La/Yb)_N$ = 1.5-3 and with Eu maximum in most of the

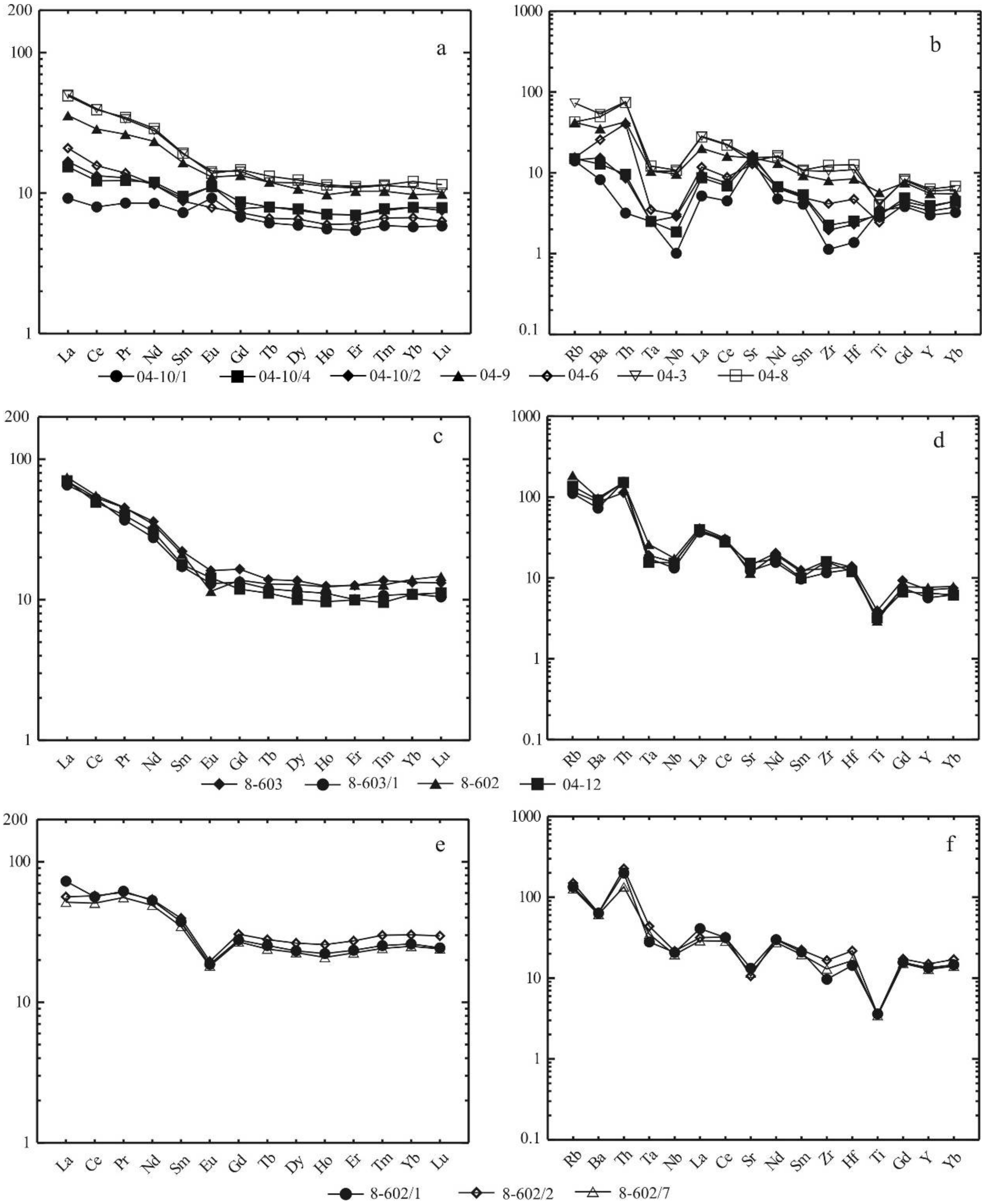


Fig. 2.7. REE spectra and spidergrams of the Ust'-Belovsky Complex gabbros and granitoids.
a-b = gabbros and diorites, c-d = quartz diorites and granodiorites, e-f = melanocratic enclaves in granodiorites. The sample numbers correspond to Table 2.2.

samples (Fig. 2.7 a). LILE, HFSE and REE contents slightly increase (Table 2.2, Fig. 2. 7 b) in the most differentiated gabbroids; the REE spectra display a weak europium minimum. The spidergrams show negative anomalies in Ti, Nb and Ta, and Sr maximum, gradually disappearing with the decreasing of Mg# number of the rocks.

Diorites are characterized by higher contents of LILE and HFSE elements (Table 2.2, Fig. 2.7 a, b), compared to gabbroids. The REE contents are close to the Clarke values for this rock group (ΣREE = 85-90 ppm). The REE spectra are asymmetric, with higher $(La/Yb)_N$ ratios (4.1-4.7) than in gabbros and small Eu-minimum. Quartz diorites are similar in composition to the diorites.

Tonalite, granodiorite and melanogranite are characterized by wide variations of trace element composition. They contain more Rb, Ba, Y, Zr, Hf, Th, and less Sr (Table 2.2). The REE concentrations are higher than the level typical of gabbros and diorites (ΣREE = 100-130 ppm). Their spectra are asymmetric, with $(La/Yb)_N$ = 5-11 (which increases with increasing silica content).The most acid rocks demonstrate a minor Eu-minimum (Fig. 2.7 c).

The fine-grained diorites of melanocratic inclusions in granodiorites of the Kolyvan Massif (Table 2.2) are characterized by moderate concentrations of LILE (Rb, Sr, Ba). The HFSE and REE contents are not only above the level characteristic of the host granodiorite, but reaches a maximum among all the rocks of the Ust'-Belovsky Complex. The REE patterns are asymmetric, gently sloping, that is due to the high HREE contents, with a distinct Eu minimum. Trace element patterns are close to that observed in the granodiorites (Fig. 2.7. e, f).

Data on the isotopic composition of neodymium in the rocks of the Ust'-Belovsky Complex are given in Table 2.3. Gabbroids are characterized by slightly positive (+0.4) values of $\varepsilon_{(Nd)}T$. On the one hand, granodiorites composing the bulk of the massif, slightly differ in isotopic composition of Nd ($\varepsilon_{(Nd)}T \approx 0$, $T_{(Nd)}DM\text{-}2$ = 1.15 Ga) from the gabbros, and on the other hand they are almost identical to the host rocks of the upper crust (Cambrian to Ordovician turbidites). At the same time, tonalites have a more radiogenic composition of neodymium ($\varepsilon_{(Nd)}T$ = +2.9, $T_{(Nd)}DM\text{-}2$ = 0.9 Ga). Fine-grained diorites from melanocratic inclusions are identical in Nd isotopic composition to the gabbroids.

Table 2.3

Results of Sm-Nd isotopic study of gabbros and granitoids from the Kolyvansky Massif

No.	Sample	Rock	Sm, ppm	Nd, ppm	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	ε_{Nd} (0)	ε_{Nd} (375)	t_{Nd}(DM), Ma	t_{Nd}(DM-2) Ma
1	04-10/5	gabbro	1.68	6.59	0.1543	0.512556 ±18	-1.6	0.4		
2	8-603/1	tonalite	2.78	13.9	0.1210	0.512600 ±18	-0.7	2.9	907	901
3	8-602	grano-diorite	2.98	14.3	0.1241	0.512453 ±7	-3.6	-0.1	1188	1154
4	8-602/2	diorite inclusion	7.71	32.3	0.1443	0.512531 ±8	-2.1	0.4		

Data of petrological studies [Kruk et al., 2008, 2011] indicate that the formation of granitoids of the Ust'-Belovsky Complex was due, primarily, to intensive interaction of gabbroids and rocks of the continental crust, scaled anatexis and mixing of mantle and crustal magmas. Joint melting of rocks of the upper and lower crust (Cambrian to Ordovician turbidites and their underlying oceanic basalts) and mixing of formed anatectic magmas in different proportions led to the formation of tonalite, granodiorite and melanogranite. The massive granite formation in the crust occurred against the background of differentiation of mantle basic magmas in intermediate chambers.

BOROVLYANSKY COMPLEX

Granitoids of the Borovlyansky Complex are widely developed in the western part of the Gorny Altai, where they compose large plutons of complex structure together with the rocks of the Ust'-Belovsky Complex and Permian-Triassic granitoids [Shokalsky, 1990 a;

Shokalsky et al., 2000; Kruk et al., 2011]. The bulk volume of the Borovlyanka granitoidsis is concentrated within the Talitsa and Maralikha terranes. In the Charysh-Inya Block they are represented by several intrusive bodies, the largest of which (about 50 km^2) is Mt. Ocharovatelnaya Massif (Fig. 2.1).

The massif is a body elongated in the sublatitudinal direction, which has intruded granitoids of the Ust'-Belovsky Complex. Endocontact zone of the massif is represented by fine-grained aplitic granites with width of 100 to 250 m. The bulk volume of the intrusive body is composed of coarse-grained porphyritic biotite and two-mica granite-leucogranites.

A dyke-shaped body of fine-grained aplite-like leucogranites (Kolyvanskaya apophysis) branches from the southern part of the massif and extends more than 10 km, and is cut off by the Permian-Triassic granitoids Sinyushensky Massif in its southern part.

The age of granitoids of Mt. Ocharovatelnaya Massif obtained by Ar-Ar method on biotite at the Analytical Center of IGM SB RAS (the analyst is A.V. Travin), is 375 ± 1 Ma (Fig. 2.8). The obtained date is somewhat older than the U-Pb age of the host granitoids of the Ust'-Belovsky Complex. Note that the latter age has been obtained with a large error and, probably, needs to be clarified.

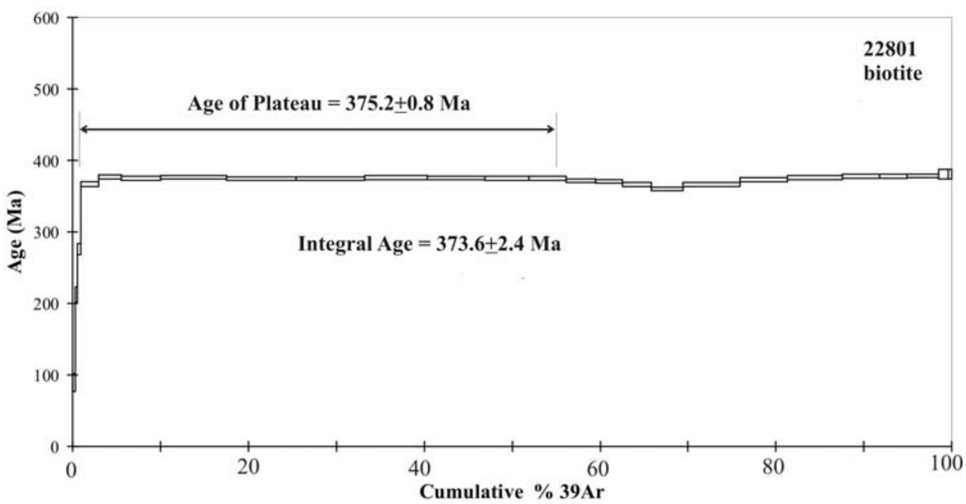


Fig. 2.8. The results of Ar-Ar isotope dating of biotite from granites (sample 22801) of the main phase of the Mt. Ocharovatelnaya Massif.

Petrographic features. Leucocratic biotite and two-mica granites composing the main part of the massif are large-to medium-grained gray or pinkish-gray rocks. They have irregularly manifested porphyry structure due to the presence of K-feldspar phenocrysts of size up to 3 cm (their quantity in individual samples reaches 15%). The groundmass of the rocks has hypidiomorphic texture (Fig. 2.2. g) and consists of smoky quartz (32-40 %), small isometric grains of perthitic latticed microcline (28-40 %), tabular plagioclase An_{20-27} (20-28 %), red-brown biotite (3-10 %), muscovite (0-5 %).

Aplitic granites composing the rim of the massif and the Kolyvan apophysis are light-gray, brownish-gray fine-grained porphyritic rocks. Phenocrysts present bipyramidal crystals of quartz and prismatic feldspar; the groundmass contains approximately equal amounts of quartz, K-feldspar and acid plagioclase. Dark-colored minerals are rare and are presented by solely biotite (< 2-3 %). Muscovite is also common. Accessory minerals are magnetite, ilmenite, apatite, zircon, monazite, rare orthite and tourmaline.

Chemical composition of granitoids. Rocks of the Mt. Ocharovatelnaya Massif correspond in their petrochemical composition to unimodal granite-leucogranite association of normal alkalinity, except for the most leucocratic varieties, whose compositions are systematically deflected toward moderately alkaline field (Fig. 2.9. a). The rocks are characterized by potassium specialization of alkalis (Fig. 2.9. b), low calcium contents and supersaturation in alumina, except for the most acid leucogranites (Fig. 2.9. c), low Mg# number (Fig. 2.9. d).

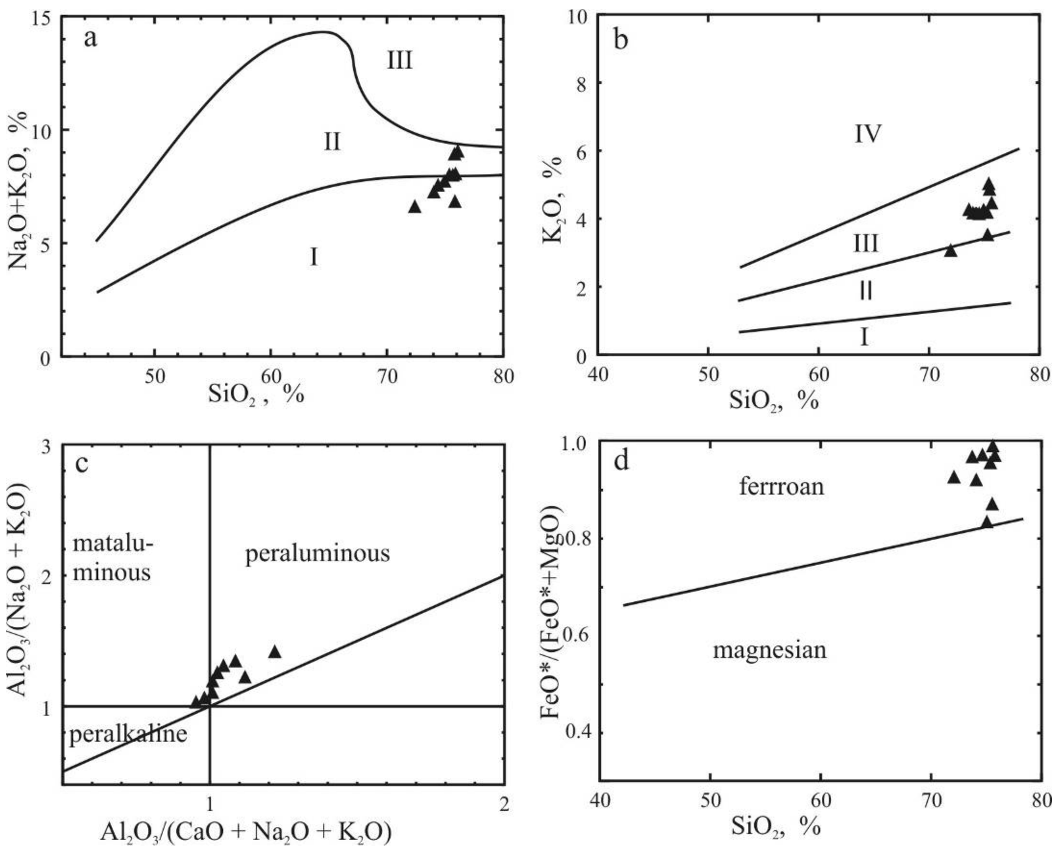


Fig. 2.9. Petrochemical diagrams for rocks of the Mt. Ocharovatelnaya Massif.

The trace-element characteristics of the massif are shown in Table 2.4. The granite-leucogranites exhibit Rb and Ba concentrations close to their crustal abundances, but lower contents of Sr and HFSE. The REE contents are lower than the Clarke level (ΣREE = 100-170 ppm). With increasing silica content in the rocks the HREE concentrations significantly increase, while the LREE and MREE contents remain almost unchanged (Table 2.4). As a consequence, the shape of the REE spectra in granitoids varies from strongly asymmetric (close to the V-shape in some samples) with $(La/Yb)_N \approx 9$ to asymmetric with $(La/Yb)_N = 5.2$ and deep Eu minimum (Fig. 2.10). The spidergrams demonstrate clear Sr, Ti, Ta and Nb minimums, and less distinct Ba minimum.

The described granitoides are confidently correlated in geological position, age, mineralogical, petrographic and geochemical features with high-alumina granitoids of the Borovlyansky Complex in the Talitsa block, Gorny Altai. However, the chemical typing of the massif rocks is difficult due to their high silica content.

KHARLOVSKY COMPLEX

Geologacal position and age. In the western Altai the Kharlovsky Complex is composed of intrusive bodies which form northwesterly-elongated areal, conformal to a structure of the Middle Paleozoic active continental margin of the Siberian continent. The areal includes five small massifs; the biggest of them is the Kharlovo Massif having an area of about 10 km^2. The massif is located in the eastern part of the Charysh-Inya Block near the Charysh Fault and intrudes Late Cambrian to Early Ordovician turbidite sequences. In exocontact of the massif a hornfels zone with thickness of 500-800 m is observed.

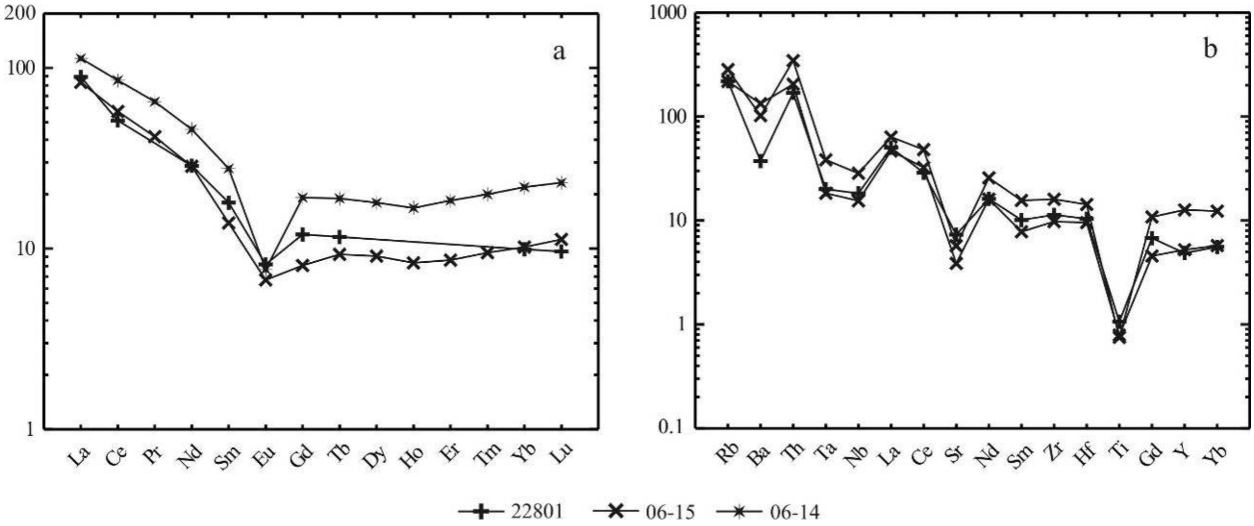


Fig. 2.10. REE spectra and spidergrams of granite-leucogranites from the Mt. Ocharovatelnaya Massif. The sample numbers correspond to Table 2.4.

The U-Pb age of the rocks of the Kharlovo Massif obtained on zircons (SHRIMP-II) in the Center of Isotope Studies of VSEGEI (St. Petersburg), is 328.8 ± 2.4 Ma (Fig. 2.11).

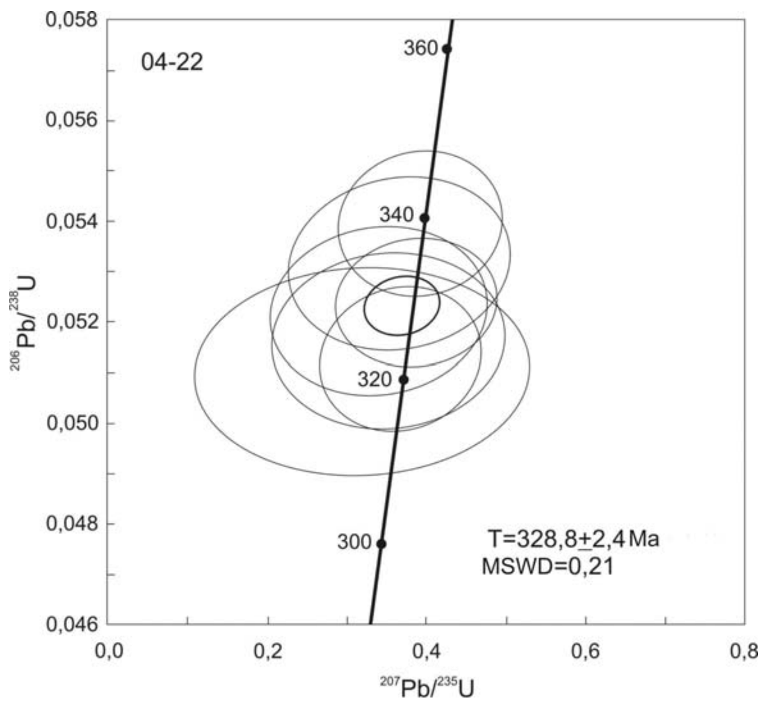


Fig. 2.11. The results of U-Pb isotope dating of zircons from quartz monzodiorite sample of the Kharlovsky Massif.

The Kharlovsky Massif was studied in detail by S.P. Shokalsky in the 80-ies of XX century when large-scale geological survey works conducting. There are distinguished four intrusive phases in the massif structure [Shokalsky, 1990 a, b; Shokalsky et al., 2000; Kruk et al., 2009]. The first phase composing the central part of the massif, presents leuco- and mesocratic gabbro, rarely olivine-bearing gabbro, Ti-magnetite olivine melanogabbro and clinopyroxenite, amphibole gabbro and troctolites. The rocks of the first phase are layered in varying degrees from thin-rhythmic up to a homogeneous massive or unclear banded. The second phase presents small bodies of fine-grained taxitic biotite-amphibole diorite in the peripheral parts of the massif. The diorite bodies are accompanied by small dikes (0.5 to 3 m) of diorite porphyrites and microdiorites. The third phase is represented by pinkish-grey biotite-hornblende quartz monzodiorites composing the bodies along contacts of the intrusion. Fine- to medium-grained pinkish-grey granosyenites of the fourth phase compose a small stock in the southern part of the massif. Postgranitic series presents a belt of diabase dikes, andesibasalt porphyrites and granodiorite-porphyries.

Petrographic features of the rocks. *Melanocratic gabbro* are dark gray medium- and fine-grained massive or thin-banded rocks with ophitic, granulitic-ophitic, sometimes poikilophitic and sideronitic textures. Cumulus minerals are presented by nonzonal labrador-bytownite (40-45 %), clinopyroxene (25-35 %) and olivine (10-15 %). Kaersutite, common hornblende, biotite and titanomagnetite apparently crystallized later (Fig. 2.2. h). The content of titanomagnetite in melanogabbro reaches 15 %. It occurs as a thick impregnation of irregular-shaped grains in size of 0.5 to 3 mm. Sometimes ore microschlierens (in size of up to 1.5 cm) elongated parallel to the rock banding, are observed. Along with titanomagnetite the rocks contain large quantities (up to 0.2 %) of ilmenite. The main accessory minerals are apatite, zircon, and sphene.

Gabbroids are gray, light gray, medium- to coarse-grained massive, rarely slightly trachytoid or banded rocks with ophitic and poikilophitic texture. They differ from melanogabbro by higher content of plagioclase with less (in sum <35-40 %) content of dark-colored minerals. Plagioclase varies sharply in its anorthite content (50-90 %); pyroxene is titanaugite; minor minerals are kaersutite, hornblende (after pyroxene), biotite, titanomagnetite. Olivine occurs as single grains.

Leucogabbro have higher apatite (up to 0.1%) and zircon contents. Pyrite is found in large quantities reaching 1-2 wt. %. The other accessory minerals are sphene, chalcopyrite, corundum, and garnet occurring as single grains.

Diorites of the second phase are gray fine-medium-grained rocks with prismatic-grained, locally hypidiomorphic texture. There are numerous small dark gray schlieres of melanocratic microdiorites. The main minerals are zoned plagioclase (55-60 %) (from labrador in cores to oligoclase in rims), greenish-brown hornblende (10-15 %), and biotite (7-10 %). The secondary minerals are clinopyroxene and kaersutite. K-feldspar and quartz are constantly present in small quantities. A common accessory mineral is sphene, which content reaches 0.1 % in some samples. Also magnetite, zircon, apatite are present.

Quartz monzodiorites of the third phase are gray or pinkish-gray coarse- to medium-grained rocks with hypidiomorphic-granular texture. K-feldspar is constantly present in the rocks; hornblende prevails in its amounts over biotite. Plagioclase displays zoning from andesine in core to oligoclase in rims. Brown-green hornblende often forms growths with dense-brown lepidomelane (Fig. 2.2. i). Ilmenite, zircon and titanomagnetite occur in large quantities. Apatite occurring as needle-like crystals is less common.

Granosyenites of the fourth phase are medium- to fine-grained pinkish-gray hornblende-biotite rocks with a massive, occasionally miarolitic structure and weakly manifested porphyry texture, stipulated by the presence of feldspar phenocrysts. The groundmass is inequigranular, characterized by hypidiomorphic or allotriomorphic textures (Fig. 2.2.j). The main minerals are quartz (15-20 %), zonal plagioclase (45-50 %), K-feldspar (15-20 %), biotite (8-15 %), hornblende (up to 3 %). Accessory mineralization is magnetite, zircon, apatite, monazite and rare sphene.

Rock chemistry. Gabbroids and granitoids of the Kharlovsky Complex correspond in petrochemical composition to rocks of the moderately alkaline series with a predominance of sodium over potassium (Table 2.5, Fig. 2.12 a, b). Chemical composition of the gabbros is characterized by high contents of TiO_2 (up to 6 wt. % in melanocratic varieties and up to 4 wt. % in leucocratic ones), Fe_2O_3 (up to 35 wt. %), potassium and phosphorus, and low alumina content (Fig. 2.12 c). These features of chemical composition are largely inherited by granitoids (Table 2.5).

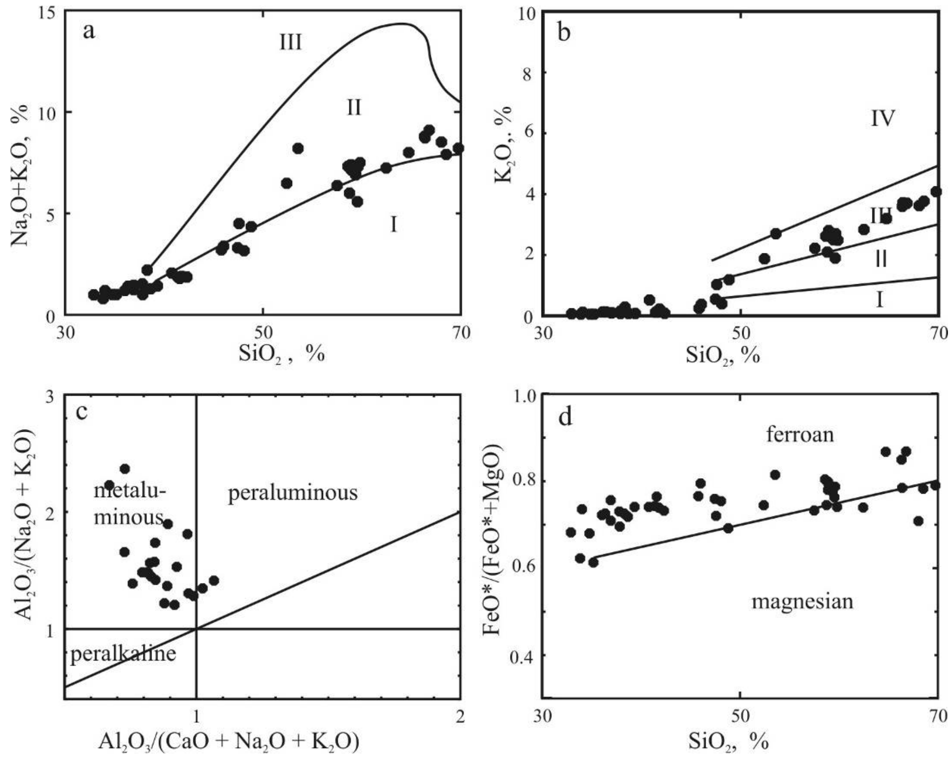


Fig. 2.12. Petrochemical diagrams for the Kharlovsky Massif rocks.

The trace-element composition of melanocratic gabbros is characterized by high contents of some "transitional" elements (up to 50 ppm of Sc, up to 700 ppm of V) and low concentrations of HFSE and REE (Table 2.5, Fig. 2.13). The spidergrams show intense maxima in Sr, Ba and Ti (Fig. 2.13). In general geochemical characteristics of the melanogabbro suggest their cumulus nature and indicate the key role of fractionation of plagioclase, olivine, clinopyroxene and titanomagnetite during formation of the layered series rocks [Shokalsky, 1990 b].

Leucocratic gabbro, by contrast, are enriched in REE (in total - up to 200 ppm), and LILE and HFSE elements, including Nb and Ta (up to 60 and 4 ppm, respectively, Table 2.5.). These rocks are close in chemical composition to subalkaline basalts of oceanic islands.
In a series from gabbro to subalkaline diorite and monzodiorite the contents of most of the trace elements increase, except Sr, Nb and Ta (their concentration slightly decrease). At the transition to granosyenites a marked decrease of REE (mainly HREE), Zr, Hf, and Ba concentrations is observed (Fig. 2.13). The inversion of behavior of a number of trace elements suggests a substantial autonomy of granosyenite magmas. However, in the postgranitic dikes we observed fine-grained gabbros, identical in composition to basites of the early phases; that proves the formation of all the massif rocks occurred within a single magma column. In general, the evolution of chemical composition of the Kharlovo intrusion rocks reflects the process of differentiation of gabbroic mantle magmas with the simultaneous development of crustal anatexis and the formation of hybrid crust-mantle melts.
Tectonic setting. The age of the Kharlovo Complex rocks corresponds to the boundary of the Visean and Serpukhovian stages of the Early Carboniferous and practically coincides with the time of the first geological evidences of collision of Siberia and Kazakhstan (overlap of melanged ophiolite complexes by rough flysch and shallow molasse

Table 2.5.

Major (wt. %) and trace (ppm) element contents in representative samples of the Kharlovsky Massif rocks

Sample	ex-27/1	04-14/6	04-14/4	04-17	04-22	04-15/2	04-13/1	04-13/2	04-18	04-13/3
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
SiO_2	32.58	47.6	48.83	57.51	58.49	62.46	68.53	69.76	59.81	66.39
TiO_2	4.82	4.07	3.36	1.75	1.75	1.07	0.55	0.47	1.63	0.69
Al_2O_3	9.82	15.24	15.39	16.07	15.58	15.84	15.44	15.15	15.57	16.07
Fe_2O_3	29.64	13.85	12.86	8.75	9.2	5.93	3.68	3.51	7.8	4.32
MnO	0.24	0.22	0.21	0.2	0.21	0.16	0.09	0.12	0.18	0.09
MgO	14.73	4.85	5.16	2.88	2.47	1.88	0.92	0.84	2.46	1.07
CaO	7.32	8.72	8.02	5.38	5.09	3.72	1.96	1.96	4.10	2.35
Na_2O	0.66	3.47	3.16	4.15	3.5	4.4	4.14	4.13	5.01	5.01
K_2O	0.08	1.03	1.19	2.22	2.28	2.84	3.77	4.08	2.49	3.72
P_2O_5	0.04	0.54	0.68	0.65	0.6	0.31	0.24	0.16	0.52	0.40
H_2O	0.10	0.59	0.72	0.4	0.6	1.03	0.58	0.16	0.32	0.18
Total	100.02	100.19	99.57	99.95	99.83	99.64	99.90	100.35	99.89	100.28
Rb	1	16	27	55	57	83	81	106	68	56
Sr	321	723	707	696	564	498	443	378	584	433
Y	5	44	48	50	50	58	26	33	49	31
Zr	28	358	243	422	393	525	429	399	384	425
Nb	2.5	42.6	40.9	35.4	46.1	49.3	56.6	63.3	39.3	61.5
Ba	313	210	223	393	374	595	444	491	531	431
La	1.70	30.21	32.29	39.97	38.06	53.77	41.19	51.21	43.71	46.99
Ce	4.42	70.8	75.73	87.7	87.94	113.	84.48	103.04	94.36	100.99
Pr	0.84	10.82	11.49	12.74	12.57	16.06	10.63	13.14	13.48	12.49
Nd	4.27	46.01	48.83	52.46	55.66	63.2	38	46.5	53.08	45.62
Sm	1.10	10.47	11.09	11.4	12.62	13.46	6.95	8.32	11.01	8.27
Eu	0.57	3.13	3.24	3.34	3.68	3.55	1.91	2.06	3.32	2.22
Gd	1.4	9.38	10.27	10.36	10.7	11.51	5.24	6.19	10.1	6.51
Tb	0.22	1.34	1.48	1.49	1.55	1.71	0.7	0.92	1.45	0.93
Dy	1.08	7.45	7.98	8.18	8.71	9.31	3.84	4.83	7.99	4.83
Ho	0.19	1.42	1.43	1.51	1.63	1.73	0.7	0.93	1.47	0.88
Er	0.46	3.69	3.68	4.09	4.45	4.63	1.98	2.48	3.96	2.38
Tm	0.07	0.51	0.51	0.6	0.68	0.69	0.3	0.39	0.63	0.37
Yb	0.40	2.83	2.87	3.28	4.14	4.19	1.79	2.42	3.45	2.19
Lu	0.06	0.38	0.37	0.48	0.57	0.6	0.25	0.33	0.47	0.30
Hf	0.9	8.1	6.1	9.7	9.8	12.2	10.1	9.7	9.1	10.1
Ta	0.3	2.7	2.4	2.3	3.2	3.2	3.9	5.6	2.6	4.4
Th	0.1	1.8	3.1	5	5.2	7.9	8	10.8	5.9	9.1
U	0.3	0.6	1.1	1.4	1.6	2.2	1.6	2.2	1.6	2.6

Note: 1 = melanocratic Ti-magnetite gabbro, 2-3 = leucocratic gabbro, 4-5 = subalkaline diorite, 6 = quartz monzodiorite, 7-8 = granosyenite, 9 = monzodiorite-porphyry (dyke), 10 = granosyenite-porphyry (dyke).

sediments in the Chara paleoceanic basin, East Kazakhstan [Polyansky et al., 1979]). When considering the nature of the magmatism, the following facts are principle: 1) the magmatic

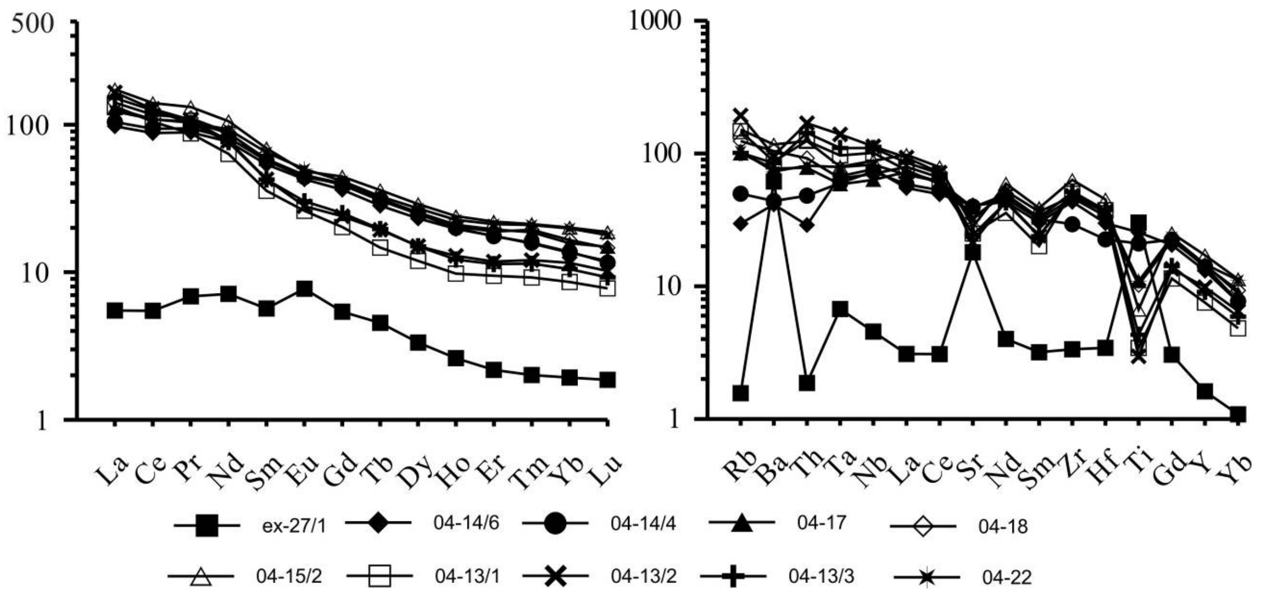


Fig. 2.13. REE spectra and spidergrams of the Kharlovsky Massif rocks.
The sample numbers correspond to Table 2.5.

events were confined to the early stages of collision; 2) the magmatic areal is conformed to the structure of active continental margin; 3) the magmatism has a local character, but a "point" character of its manifestations, is accompanied, however, by active crustal anatexis; 4) there was a significant (at least 25 Ma) time gap between magmatism and known manifestations of intraplate activity.

Based on these data, the formation of gabbros and granitoids of the Kharlovo Complex, was likely due to the slab detachment in the collision zone of the Siberian and Kazakhstan continents and the appearance of an upper mantle diapir.

SINYUSHENSKY COMPLEX

In the western part of the Gorny Altai granitoids of the Sinyushensky Complex compose a series of intrusive bodies, confined to the Northeast shear zone. The granitoid massifs are confined to long-lived faults of northwestern strike and occupy secant independent position in relation to areas of previous magmatism. The largest massifs are Tigirek (150 km^2), located in a remote mountainous area, and Sinyukha (102 km^2).

The Sinyukha Massif is located to the south from the Kolyvan village and represents near-isometric dome-shaped body with steep contacts. In the northern part it intruded the Late Devonian granitoids of the Ust’-Belovsky and Borovlyansky complexes, and in the western, southern and eastern parts it intruded Early-Mid Paleozoic terrigenous and terrigenous-carbonate strata. The age of granitoids of the Sinyukha Massif obtained by Rb-Sr isochron method, is 244.5+4.5 Ma [Vladimirov et al., 1997]. Similar age (Ma) was obtained by Ar-Ar method on biotite at the Analytical Center of IGM SB RAS (the analyst is A.V. Travin) (Fig. 2.14).

The internal structure of the massif is a rather homogeneous: it is almost completely composed of porphyroid biotite leucocratic granites: coarse-grained in the northern part of the massif, medium-grained in the central and western parts. Granites of the main phase rarely contain xenoliths of more melanocratic rocks: medium-grained biotite-hornblende equigranular or porphyritic quartz monzodiorites and granodiorites. Postgranitic dikes are presented by aplite granites and aplites.

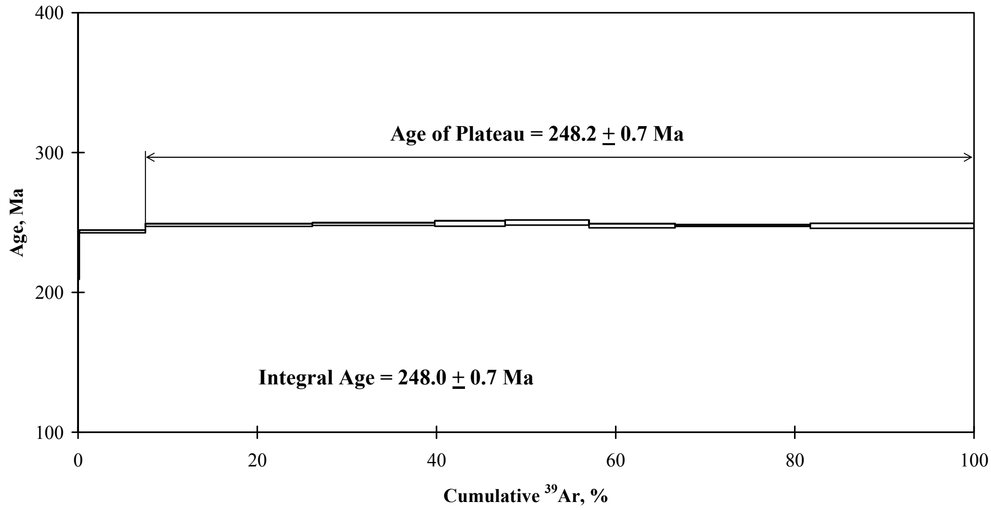


Fig. 2.14. The results of Ar-Ar isotope dating of biotite from granite of the Sinyushensky Massif (sample No. 11-02).

Petrographic features. Granite-leucogranites of the Sinyukha Massif are light gray or pinkish-gray porphyritic biotite rocks. Porphyry appearance is caused by the presence of K-feldspar megacrysts, whose quantuty ranges from 5-10 % to 40 % of the rock volume. The groundmass is medium- or coarse-grained and has granite or hypidiomorphic texture (Fig. 2.2 k-l), composed of quartz (25-30 %), K-feldspar (30-35 %), weakly zoned plagioclase (An_{18-25}, 30-35 %), brown or reddish-brown biotite (3-7 %).

Accessory minerals are magnetite, ilmenite, zircon, apatite, rare monazite, fluorite, very rare sphene and tantalum niobates [Shokalsky, 1990 a].

Rock chemistry. Rocks of the Sinyukha Massif correspond in their petrochemical composition breed to the unimodal granite-leucogranite association of normal alkalinity with a predominance of potassium over sodium (Fig. 2.15 a, b). Granitoids are characterized by low concentrations of mafic elements, calcium and phosphorus (Table 2.6), have low Mg# and are supersaturated with alumina (Fig. 2.15 c, d).

The trace-element characteristics of granite-leucogranites of the Sinyukha Massif are shown in Table 2.6. The rocks are characterized by higher concentrations of Rb and Cs as compared with their Clarke values, lower contents of iron-group elements, Sr, and to a lesser extent, Ba, the relative enrichment of HFSE. REE contents in the rocks are also higher than the Clarke level (ΣREE = 150-210 ppm). Their spectra are asymmetric with a negative slope ($(La/Yb)_N$ = 9.0-14.4) and a small Eu minimum. It is noteworthy that the coarse-grained granite of the northern part of the massif have lower contents of HFSE and REE elements as compared to medium-grained rocks of the central part (Fig. 2.16).

Geological position of granitoids of the Sinyukha Massif and data on their radiological age indicate their within-plate nature. However, the level of accumulation of typomorphic trace elements in the massif rocks are lower than in typical A-type granites (Fig. 2.17). On discrimination diagrams by J. Pearce for determining geodynamic position of granitoids (Fig. 2.18), the points of the Sinyukha Masif rocks are localized in the granitoids of volcanic arcs and collision zones near the border with the field of intraplate granites.

Thus, the geochemical characteristics of granitoids, as well as isotopic data indicate that the formation of the Sinyukha Massif rocks was due mainly by crust-anatectic processes and was not accompanied by active participation of mantle magmas in granite formation. It is likely that mafic melts only played the role of an energy source for melting rocks of the continental crust.

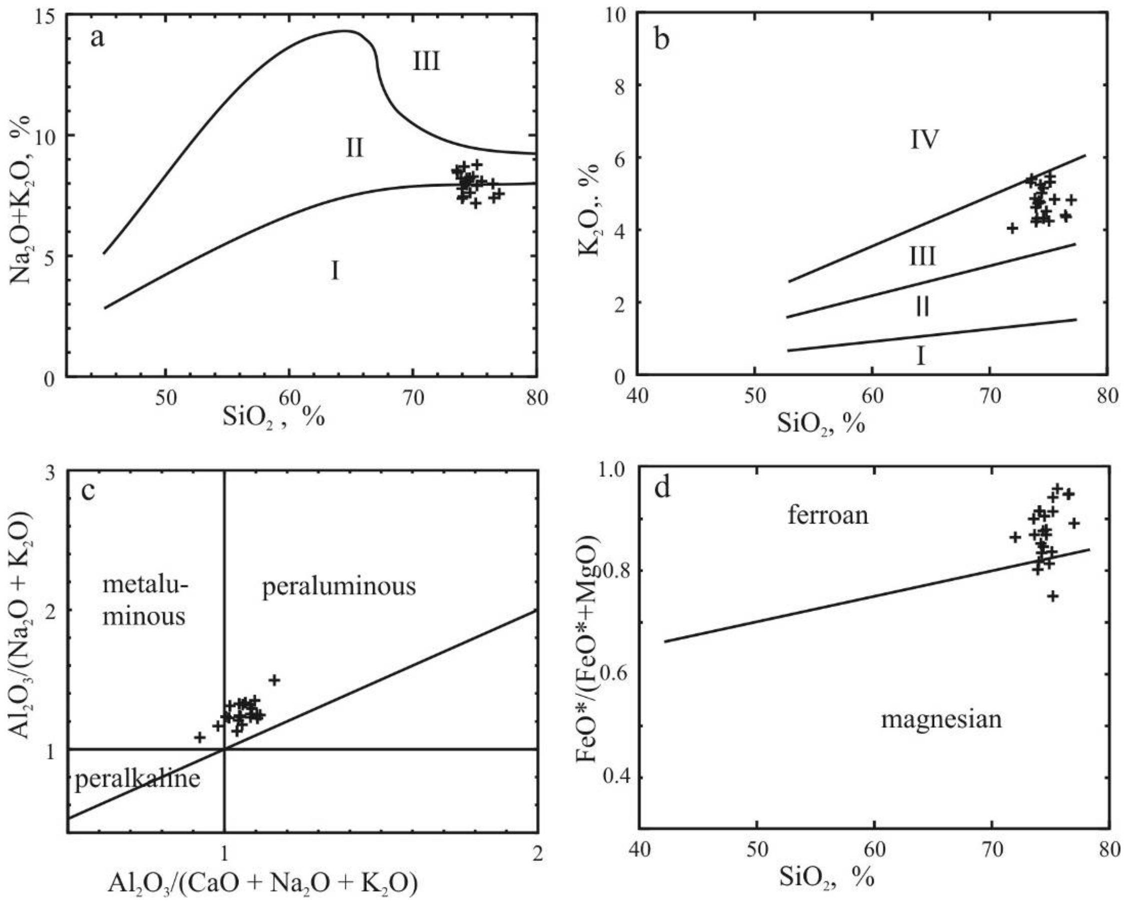


Fig. 2.15. Petrochemical diagrams for granite-leucogranites of the Sinyushensky Massif.

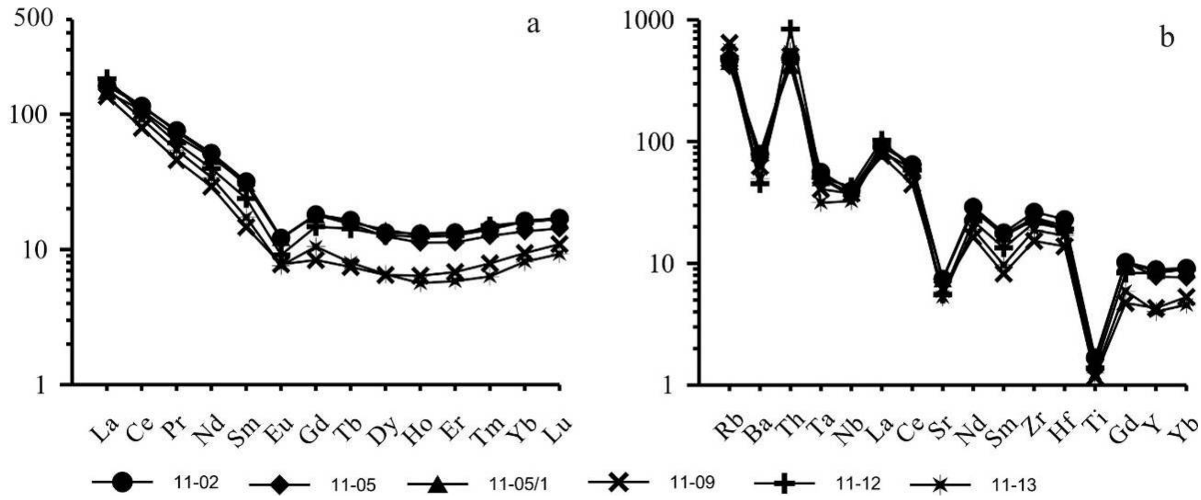


Fig. 2.16. REE spectra and spidergrams of the Sinyushensky Massif granites.
The sample numbers correspond to Table 2.6.

Table 2.6.

Major (wt. %) and trace (ppm) element contents in representative samples of leucocratic granites of the Sinyushensky Massif

Sample	11-02	11-05	11-05/1	11-09	11-12	11-13
	1	*2*	*3*	*4*	*5*	*6*
SiO_2	73.86	74.57	72.59	73.3	75.48	76.08
TiO_2	0.27	0.26	0.25	0.19	0.22	0.2
Al_2O_3	13.70	13.64	13.66	13.35	13.04	12.75
$Fe_2O_3^*$	2.49	2.32	2.52	1.62	1.78	1.85
MnO	0.07	0.06	0.06	0.06	0.06	0.05
MgO	0.44	0.44	0.43	0.25	0.27	0.25
CaO	1.64	1.61	1.57	0.96	0.97	0.92
Na_2O	3.21	3.11	3.10	3.04	2.90	2.91
K_2O	4.57	4.44	4.87	5.75	5.37	4.93
P_2O_5	0.08	0.07	0.07	0.05	0.06	0.05
LOI	0.38	0.3	0.07	0.37	0.14	0.34
Total	100.79	100.89	99.29	99.01	100.37	100.41
Sc	8.1	7.6	7.4	5.9	5.3	6.4
Co	3.2	3.2	3.3	1.9	2.1	2.2
Ga	17.5	17.9	17.2	17.8	16.4	17.4
Rb	259	231	248	356	270	311
Sr	133	131	131	110	99	94
Y	30	26	29	15	28	14
Zr	219	189	197	127	179	156
Nb	22.1	20.1	21.1	20.9	23.8	18.1
Cs	11.4	9.3	10.5	12.6	9.7	9.6
Ba	402	378	410	319	230	251
La	50.22	52.91	45.31	42.11	56.62	48.18
Ce	92.98	92.83	86.09	63.98	83.84	74.57
Pr	9.26	9.04	8.4	5.59	7.49	6.64
Nd	30.92	30.09	28.96	17.5	23.79	20.43
Sm	6.2	5.81	5.95	2.86	4.65	3.37
Eu	0.9	0.88	0.89	0.57	0.67	0.56
Gd	4.69	4.7	4.62	2.16	3.81	2.72
Tb	0.78	0.73	0.75	0.35	0.67	0.38
Dy	4.28	4.02	4.5	2.08	4.1	2.11
Ho	0.94	0.81	0.91	0.46	0.89	0.41
Er	2.80	2.37	2.66	1.43	2.65	1.22
Tm	0.46	0.41	0.46	0.26	0.48	0.2
Yb	3.40	2.84	3.36	1.97	3.33	1.7
Lu	0.55	0.46	0.54	0.35	0.54	0.3
Hf	6.2	5.2	5.5	3.7	5.2	4.6
Ta	2.2	2.0	2.0	1.6	2	1.3
Th	31.1	29.8	26.7	32.2	53.8	35.1
U	12.1	8.7	11	13.2	10.6	9.6

Note: 1-3 = medium-grained granites of the central part of the massif, 4-6 = coarse-grained granites of the northern part of the massif.
Fe_2O_3* - total iron.

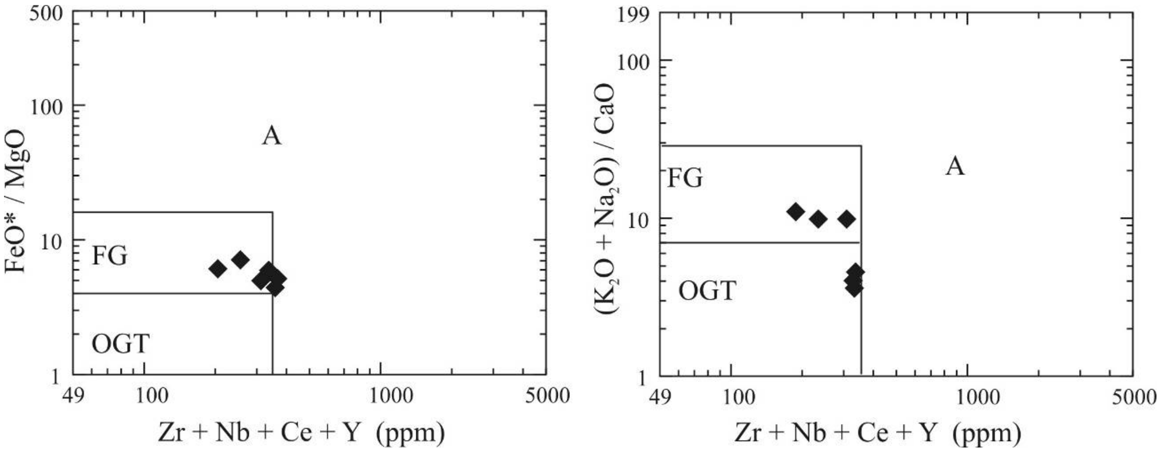


Fig. 2.17. Discrimination diagrams [Whalen, 1989]: (a) Zr+Nb+Ce+Y vs. FeO*/MgO, (b) Zr+Nb+Ce+Y vs. $(K_2O+Na_2O)/CaO$ for granitoids of the Sinyushensky Massif.
The fields: FG = fractionated granites, OGT = unfractionated granites of the M-, S- and I-types, A = granites of the A-type.

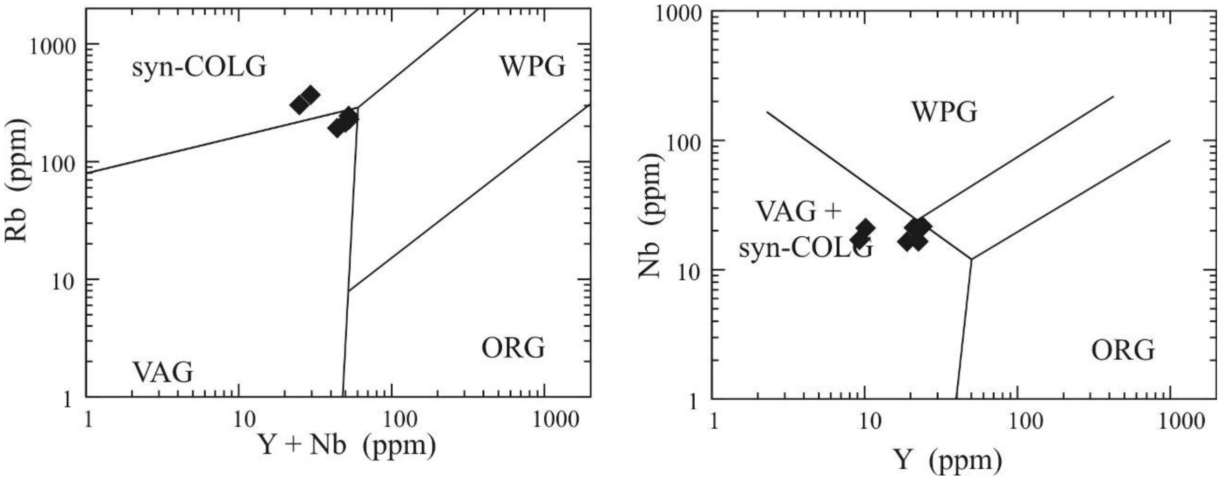


Fig. 2.18. Discrimination diagrams [Pearce et al., 1984] for granite-leucogranites of the Sinyushensky Massif.
ORG = granites of oceanic ridges, VAG = volcanic-arc granites, Syn-COLG = syncollisional granites, WPG = within-plate granites.

DESCRIPTION OF THE FIELD EXCURSION

Stop 2-1 is located on the northwestern margin of Kolyvan village (Fig. 2.19, 2.20 a). The medium-grained biotite-amphibole granodiorites of the Kolyvan Massif belonging to the Ust'-Belovsky Complex (D_3) are exposed in a small quarry. Granodiorites are saturated in rounded inclusions of fine-grained melanocratic rocks, corresponding in composition to quartz diorite (Fig. 2.20 b). In addition, granodiorites contain various (in size and shape) xenoliths of host rocks (Cambrian-Ordovician metamorphosed turbidites).

Stop-2-2 is located near the north-eastern outskirts of the Vosmoe Marta village, at the northern shore of Lake Beloe, in eastern endocontact of the Kolyvan Massif, Ust'-Belovsky Complex. The outcrops of equigranular fine-grained amphibole (sometimes with biotite) diorites of marginal facies, are observed (Fig. 2.20 c).

Stop 2-3 is located at the top of Mt. Ocharovatelnaya, to north-east from Kolyvan' village. In the outcrops occur coarse- to medium-grained biotite, sometimes two-mica, porphyritic leucocratic granites of the main phase of the Mt. Ocharovatelnaya Massif, belonging to the Borovlyansky Complex (D_3). Granites have a pronounced hammock jointing (Fig. 2.20 d). Crosscutting dikes of fine-grained two-mica granites and aplites are observed among the coarse-grained granites.

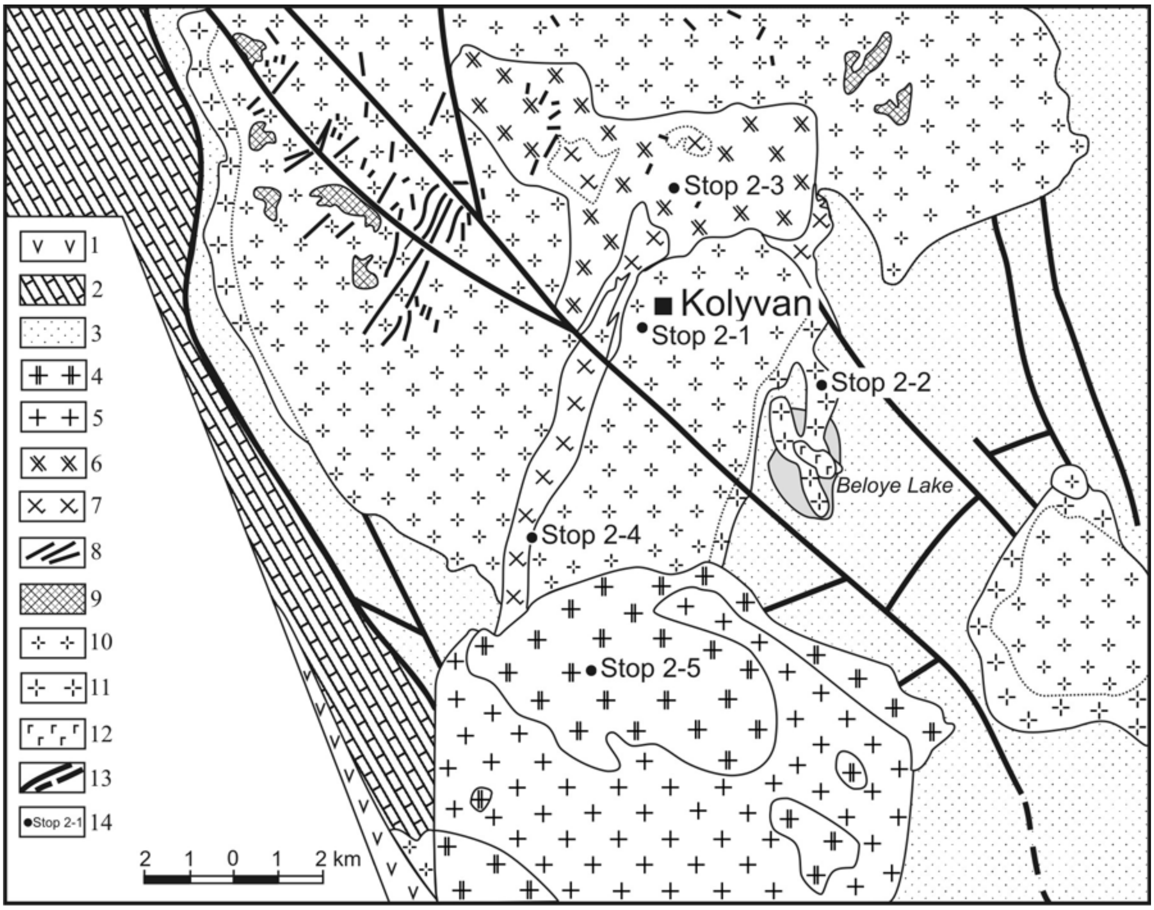


Fig. 2.19. Geological scheme of the central part of the Kolyvan magmatic areal (after [Shokalsky, 1990 a], with simplifications).

1 = Devonian volcanic and volcano-sedimentary series, 2 = Ordovician-Silurian terrigenous-carbonate and carbonate deposits, 3 = Cambrian-Ordovician turbidites. 4-11 = magmatic formations: 4-5 = porphyritic biotite granites of the Sinyushensky Complex, P_2-T_1 (4 = coarse-grained, 5 = medium-grained), 6-7 = granitoids of the Borovlyansky Complex, D_3 (6 = fine-grained and aplitic granite, 7 = porphyritic biotite granites), 8 = dikes of tonalite and granodiorite-porphyry, 9-12 = rocks of the Ust'-Belovsky Complex, D_3 (9 = fine-grained and aplitic granites, 10 = hornblende-biotite granodiorites and adamellites, 11 = biotite-hornblende tonalites and quartz diorites, 12 = gabbroids), 13 = faults, 14 = stop points.

Stop 2-4 is located in an abandoned village Kolyvanstroy, to northwest from the Kolyvan village, on the flank of the Kolyvan tungsten deposit. This deposit is known from 1721–1723 years as a copper deposit, but in the middle of the XX century (1936–1960.) it was developed already as tungsten deposit with copper and bismuth.

The ore bodies occur in the Kolyvan' apophysis which is the thick (15-300 m) dyke-like submeridional vertically-falling body of aplite granites. They intrude granodiorites of the Ust'-Belovskyo Complex (Fig. 2.21) and in their southern part are cut by porphyritic granites of the Sinyukha Complex. The ore field is divided by tectonic faults of a strike-shift character into three blocks: Southern, Central, and Northern. Each block is represented by a series of quartz ore-bearing veins of submeridional strike with a very steep, mostly western dip. The veins are in length of 50-350 m along the strike and up to 150-200 m along the dip. Thickness of the industrial veins is mostly 0.2 to 0.7 m and reaches 1 to 2 m in bulges, sometimes more.

The ore-bearing veins are exposed in all the blocks. Each of the blocks differs in erosion level (the Southern block is the most lowered relative to the Central block and, especially, the North block), a shape of manifestation of quartz veins, their size and number, relationships with their host granites, reserves, etc. In the Southern block the veins are of smaller size, more lenticular, fall in different directions, occur in greisenized granites. The Central block is characterized by the greatest number of industrial veins, their larger size along the dip than the strike, frequent bulges and branches. The Northern block is characterized by the relative simplicity of the vein structure. To date, on the surface one can see deep slit-like trenches, fully imitating the form of the veins (Fig. 2.20 e).

The veins are composed of gray quartz. Coarse-grained muscovite of gray and greenish color is developed in near-selvage parts. Sometimes quartz contains large fluorite crystals of pale pink and green color. Quartz-tourmaline clusters often occur in greisenized granites. The main ore mineral is wolframite, occurring as fine impregnations in quartz and greisenized granites; sometimes it forms large clusters of crystals. Wolframite crystals are tabular and thin-plated; they often form growths. In addition to wolframite, vein quartz also contains arsenopyrite, pyrite, scheelite, chalcopyrite, bismuthinite, molybdenite and sulfosalts of Bi.

In the oxidation zone, descending to a depth of 25-30 m, tungsten ocher, hematite, limonite, covellite, chalcocite, cuprite, malachite, azurite are found.

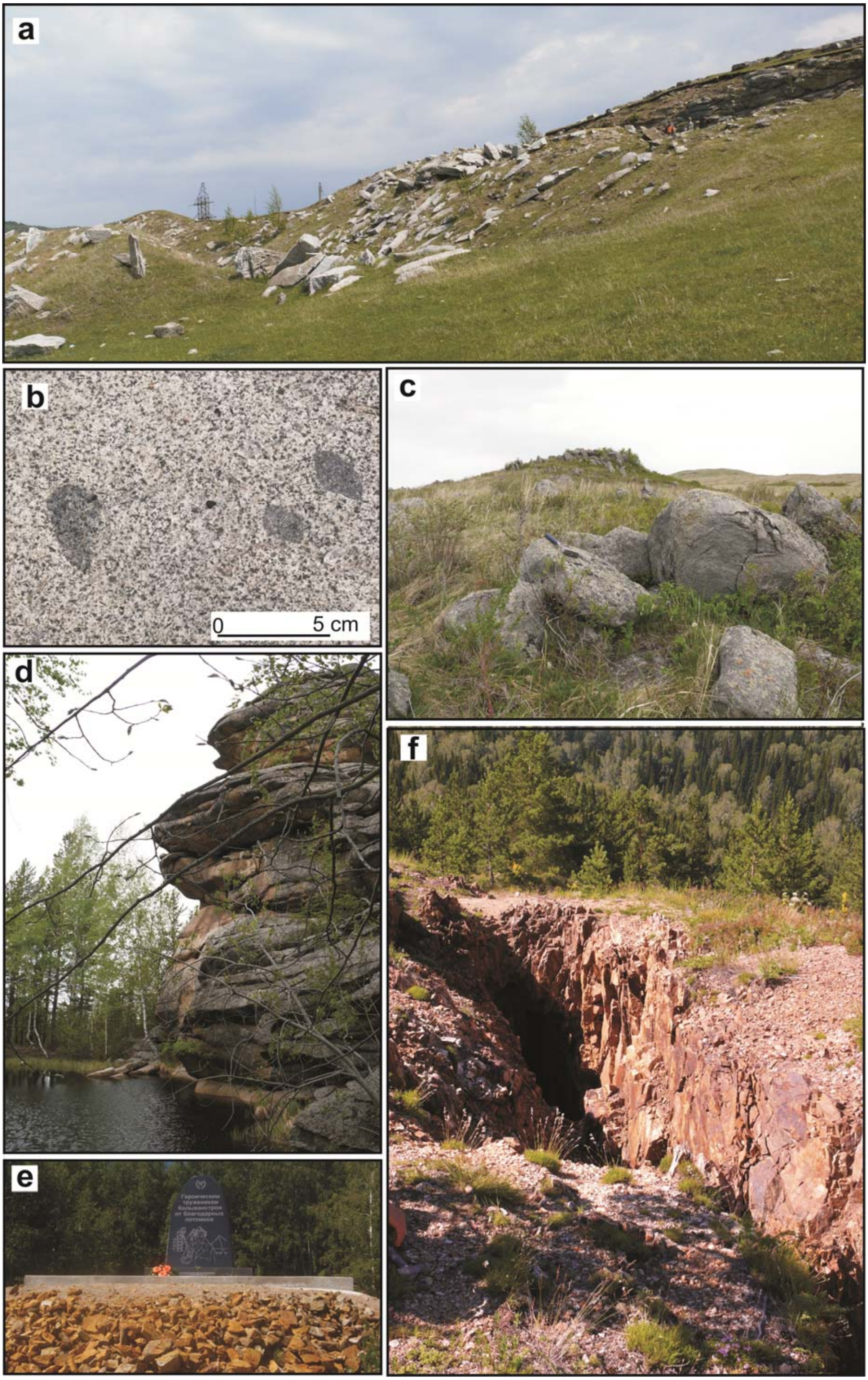
Stop 2-5 is located close to Lake Mokhovoe, north of the abandoned village Kolyvanstroy. Coarse-grained porphyritic biotite granites of northern part of the Sinyushensky Massif belonging to the Sinyushensky Complex (P_2-T_1), are exposed in outcrops around the lake. Porphyritic appearance of the rocks is determined by the presence of K-feldspar phenocrysts in size up to 5 cm. The granites have blocky and hammock jointing, leading to formation of quaint forms of relief (Fig. 2.20 f).

Very rarely the granites contain reprocessed xenoliths of host rocks: Cambrian to Ordovician sandstones and siltstones (Fig. 2.20 g).

Stop 2-6. is located on the eastern outskirts of Kharlovo village, in the right bank of Kamyshinka River (Fig. 2.1, 2.22). Melanocratic gabbros enriched in titanomagnetite and ilmenite can be observed in a small outcrop. In some places the gabbros have a thin layering caused by alternating of rocks rich in plagioclase or mafic minerals (olivine, Ti-augite) (Fig. 2.20 i).

Stop 2-7 is located near the southern end of the Kharlovo village, on the left bank of the Charysh River. The outcrops present medium-grained equigranular amphibole-biotite (with clinopyroxene) quartz monzodiorites of the third phase of the Kharlovsky Complex (C_1) (Fig. 2.20 j). The truncated dike of titaniferous moderately-alkaline dolerites is observed among monzodiorites (Fig. 2.20 k).

Stop 2-8 is located at the southern outskirts of Kharlovo village, near Mt. Vostrushka. In the outcrops granitoids of the Kharlovsky Complex (Fig. 2.20 l) can be observed. Mt. Vostrushka is a stock-shaped body of massive equigranular medium-grained amphibole-biotite granosyenites, which are changed by fine-grained varieties in the marginal parts of the massif, and by granosyenite porphyry in a zone of direct endocontact. Granosyenites contain xenoliths of quartz monzodiorites, as well as fine-grained gabbros and monzodiorites, visually identical to dikes intruding the rocks of the earlier phases. The granosyenites were intruded by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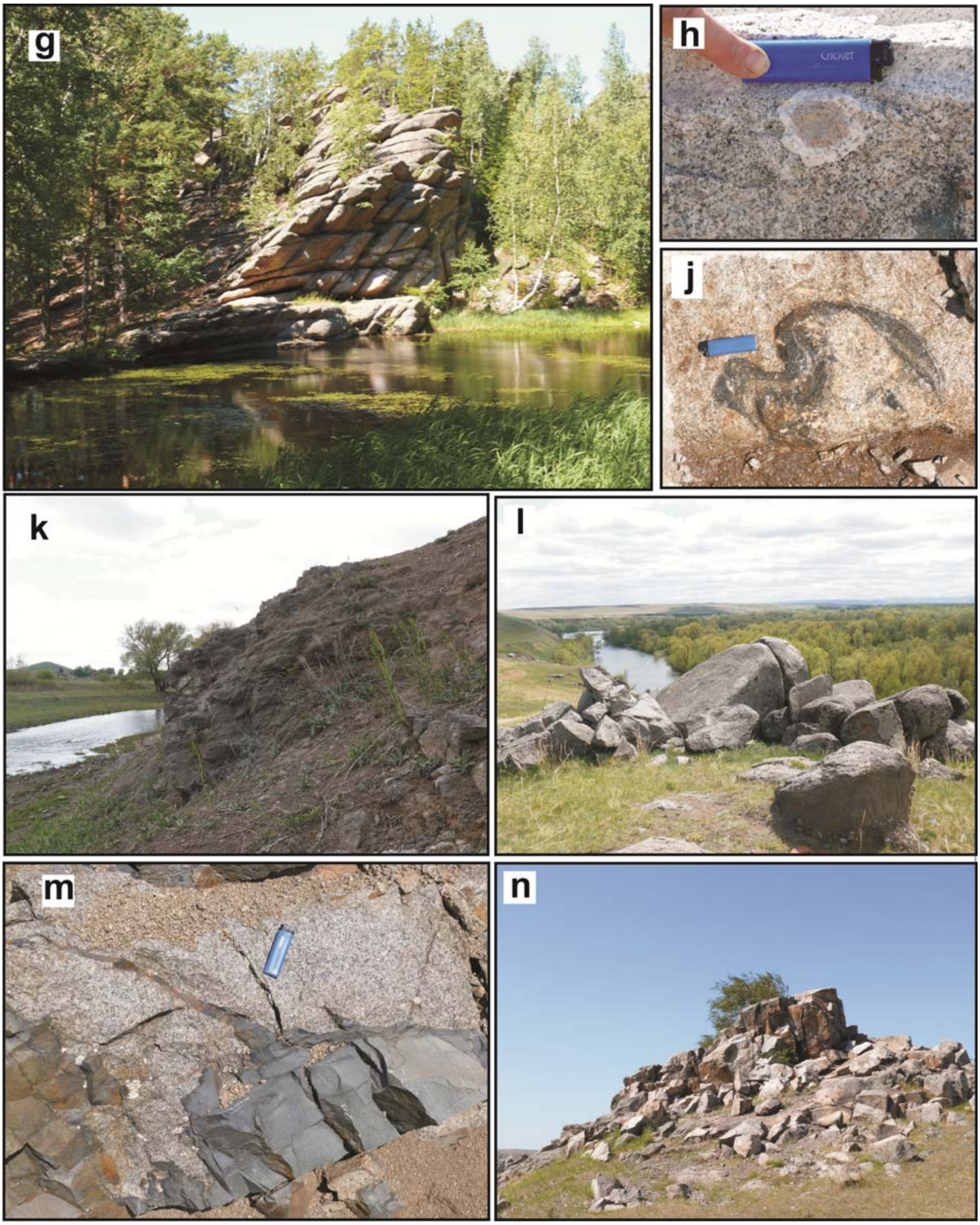

Fig. 2.20. The geological excursion objects.
a = Ust-Belovsky complex granodiorite outcrops on the outskirts of the v. Kolyvan’ (stop 2-1); b = melanocratic inclusion in Kolyvansky massif granodiorite (stop 2-1); c = Ust-Belovsky complex quartz diorite outcrop is on the north coast of Beloe lake (stop 2-2); d = Borovlyansky complex granite outcrop on the top of the mt. Ocharovatelnaya (stop 2-3); e = memorial of Kolyvan’ deposit miners (stop 2-4); f = old mines of Kolyvan’ deposit (stop 2-4); g = outcrops of Sinyushensky massif coarse-grained granite (Mokhovoe lake, stop 2-5); h = overgrowing of the potassium feldspar phenocrysts by albite hems (Sinyushensky massif); I = resorbed xenolithe of sedimentary rocks in Sinyushensky massif granite; j = Kharlovsky complex titanomagnetite gabbroid outcrop on the coast of the r. Kamyshinka (stop 2-6); k = third phase of Kharlovsky complex monzodiorite outcrop (left coast of the r. Charysh, stop 2-7); l = basite dike in Kharlovsky massif monzodiorite (stop 2-7); m = fourth phase of Kharlovsky complex granosyenite outcrop (mt. Vostrushka, stop 2-8).

a series of dikes of basaltic andesite porphyry to granodiorite porphyry. Near the foot of the southern slope of the mountain one can see a fragmentary exposed contact with monzodiorites and gabbro.

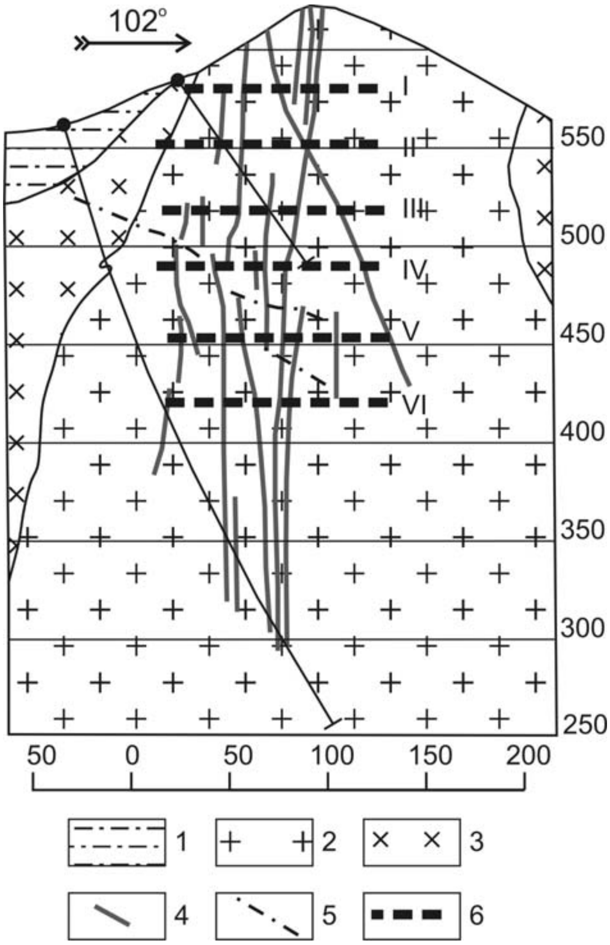

Fig. 2.21. Geological cross-section of the Kolyvan' W-Cu-Bi deposit [State…, 2011b].

1 – loose sediments, 2 – aplites and aplite-like granites, 3 – granodiorites, 4 – ore veins, 5 – faults, mining horizons.

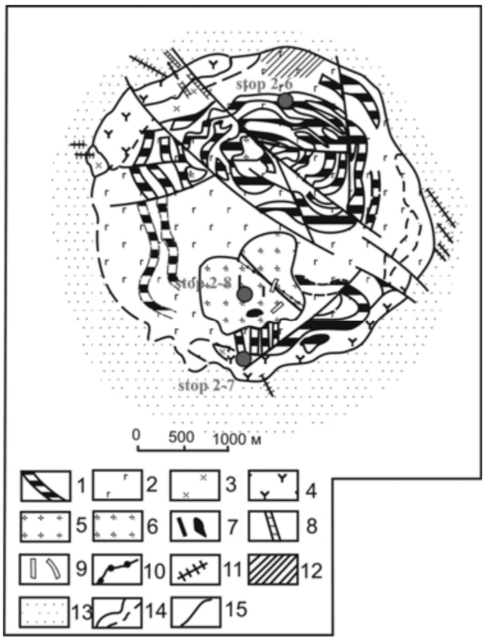

Fig. 2.22. Geological scheme of the Kharlovsky Massif [Schokalsky, 1990 b].

1 = melanocratic olivine and non-olivine gabbro, kaersutite gabbro, titanomagnetite troctolite; 2 = leuco- and mesocratic gabbro, anorthosite; 3 = subalkaline biotite-hornblende diorite; 4 = biotite-hornblende quartz monzodiorite; 5 = hornblende-biotite granosyenite; 6 = medium- to fine-grained konga diabase and basaltic andesite porphyry; 7 = dikes and small bodies of dolerites and basaltic andesite porphyry; 8 = dikes of microdiorites and diorite porphyry; 9 = dikes of microsyenites and aplites; 10 = granosyenite porphyry; 11 = plagiogranite porphyry; 12 = metasomatized gabbro; 13 = Late Cambrian to Early Ordovician hornfelsed siltstones and sandstones; 14 = geological boundaries; 15 = faults.

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