

PAPER • OPEN ACCESS

U-Pb Geochronology of Subvolcanic and Pyroclastic Formations of the Zmeinogorsk Barite-Polymetallic Deposit (Rudny Altai)

To cite this article: O M Grinev *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **988** 032078

View the [article online](#) for updates and enhancements.

You may also like

- [Barite-polymetallic mineralization of Zmeinogorsk ore district and some genetic aspects of its formation](#)
K V Bestemianova and O M Grinev
- [Onset of Giant Planet Migration before 4480 Million Years Ago](#)
Stephen J. Mojzsis, Ramon Brasser, Nigel M. Kelly et al.
- [Provenance Area and U-Pb Age of Detrital Zircons from the Upper Proterozoic Deposits of the Polar Urals](#)
Natalia Ulyasheva, Oksana Grakova, Aleksandr Pystin et al.

U-Pb Geochronology of Subvolcanic and Pyroclastic Formations of the Zmeinogorsk Barite-Polymetallic Deposit (Rudny Altai)

O M Grinev¹, A S Semiryakov¹, K V Bestemianova¹, R O Grinev¹

¹Department of Geology and Geography, Tomsk State University, Lenin Avenue 36, Tomsk, 634050, Russia

E-mail: tomskgrom@yandex.ru, alexey.semiryakov@mail.ru, KsenijaVT@mail.ru, jadestone@yandex.ru

Abstract. Schemes of Zmeinogorsk ore field structure made in 1996, 1960 and 1949 have been analyzed. The schemes differ from each other in contents and prospecting trends. This study is based on the 1949 scheme, made on the basis of the results of extensive mining and drilling operations. Based on the analysis of stratigraphy, LA-Q-ICP-MS dating results by U-Pb method, rocks composition, plicative and disjunctive dislocations of sedimentary, volcanic and subvolcanic formations, as well as their relationship, an updated scheme of Zmeinogorsk ore field structure is suggested. It belongs to rhyolite dome-type, which is also characterized to the neighboring Leninogorsk ore district

1. Introduction

Zmeinogorskoye deposit mining and metallurgical production played an outstanding role in the development of the wealth of Altai and all of southern Siberia. This is noted in most of the historical references for the development of the region [1; 2; 3]. The field has been in operation for more than two centuries intermittently. Even today, small bodies are used to extract gold and silver from barite ores and waste from the Zmeinogorsk gold processing plant.

The deposit served as a general benchmark for the development of field criteria for the discovery of other ore-bearing objects. However, on a number of issues of the structure of its ore field and the age of its constituent rocks, there are serious disagreements. This is unacceptable in relation to a unique historical object.

For a number of years, the authors have been studying the morphotectonics, magmatism and ore genesis of the Zmeinogorsk and other ore districts of Rudny Altai, as well as their key ore objects. This made it possible to study in detail the structure of the ore field of the unique Zmeinogorsk deposit and significantly clarify its structure and history of formation. To establish the absolute age of volcanogenic formations, the method of laser ablation and mass spectrometry with inductively coupled plasma was used. Analytical studies were carried out in the laboratory of geochronology and geodynamics of the Tomsk state university.

The purpose of this work is to analyze the ore field, develop a model for the formation of the deposit based on mineralogical and geochemical studies and dating the enclosing rock and near-ore formations by the U-Pb method using zircon.



2. Method and technique of dating

At the Research Laboratory of Geochronology and Geodynamics, Tomsk State University, zircons were LA-Q-ICP-MS dated by the U-Pb method. Zircons from pyroclastic, subvolcanic and metasomatic formations were studied.

The control of the grains surface was carried out using a scanning electron microscope. (TESCAN VEGA 2 LMU). Images were obtained in the back-scattered electron mode – BSE, and in the cathodoluminescence mode – CL (Figure 1). Isotope studies were carried out by laser ablation and inductively coupled plasma mass spectrometry using the following equipment:

- Analyte Excite Excimer Laser Ablation System (Teledyne CETAC Technologies) (193 nm);
- Inductively Coupled Plasma Quadrupole Mass Spectrometer Agilent 7900 (Agilent Technologies).

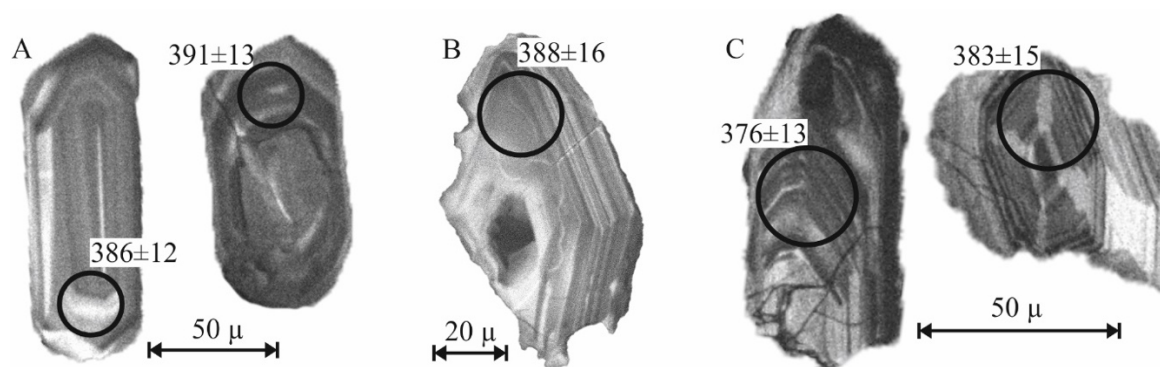


Figure 1. Cadodoluminescent images of zircon grains from subvolcanic, metasomatic and pyroclastic formations of the Zmeinogorsk field: A – rhyolite, B – secondary quartzite, C – acidic tuff. Laser beam diameter is 25 microns. Age in Ma in $^{206}\text{Pb}/^{238}\text{U}$

Data interpretation was carried out in the Iolite 3.7 package, which is an add-on to the Igor Pro 7 software [4]. Graphic models were built in IsoplotR [5].

3. Analysis of schemes of the structure of the ore field

The latest scheme of the structure of the ore field of the Zelenogorsk deposit was published in 1996 [6]. Later it was taken as a basis for a second generation state geological mapping at a scale of 1:200,000 (2001).

In this diagram, the barite-polymetallic mineralization has a purely stratigraphic character and is located in the form of a "stratigraphic lens" within the section of the silty-mudstone-calcareous-siliceous upper subformation of the Melnichnaya suite (D_2mn_3). The upper subformation is underlain by tuffs, lavas of rhyolites, rhyodacites of the middle subformation (D_2mn_2) and siltstones, sandstones, and felsic tuffs of the lower subformation (D_1mn_1) Melnichnaya suite. The dates of the sediments in the scheme are given on the basis of the identification of the Emsian marine fauna in the clayey limestones of the lower subformation. The contacts between the subformations in this scheme are stratigraphic, without complications by their tectonics and intrusion of igneous rocks.

An earlier scheme of the structure of the ore field was published in 1960 [7]. It has a markedly manifested tectono-stratigraphic character with the participation of metasomatic formations and the intrusion of magmatic melts. Ore in the diagram is confined to the contact zones of metasomatic secondary microquartzites, forming a lenticular body, widened in the west-northwestern part and pinch-out east-southeast. From the west, the microquartzites and ore is limited by a submeridional fault. In relation to the host coarse-bedded calcareous mudstones, microquartzites occupy a subconforming position. To a depth, the microquartzites is immersed at an angle of about 50-60° and pinch-out. The microquartzites is located in the crest line part of the brachyanticline, formed by a thick member of mudstones and clayey limestones of the lower subformation (D_1mn_1) Melnichnaya suite. In the western part of the microquartzite body, there is a small stock of dolerite, from which dikes of dolerite

porphyrites are distributed in a fan-like manner to the eastern, northern and northwestern, intersecting microquartzites and ores. The western flank of the ore field is composed of metamorphic shales. Age dates are not given in the diagram.

For a number of features, it contradicts the scheme published in 1996. Moreover, 1996 [6] and 1960 [7] schemes contradict or do not take into account many fundamental features characterizing the structure of the Zmeinogorskoye field.

An analysis of the stock literature showed that the 1960 scheme is a highly simplified fragment of the most detailed diagram of the structure of the Zmeinogorsk ore field, compiled on the basis of the materials of his mining and drilling operations in 1947-1949 (unpublished manufacturing report by F.N. Vyunov and F.D. Stakhovich "Report on the exploration of the Zmeinogorsk deposit in Altai for 1947-1949"). According to the authors, this scheme most objectively reflects the real structure.

4. Research results

The work is based on the geological scheme of 1949 of the Zmeinogorsk ore field, which most fully reflects the real geological picture. Based on this scheme, a morphotectonic analysis of the territory of the Zmeinogorskoye field was carried out. Also, a geochemical and isotope-geochemical study and dating by the U-Pb method were carried out using the zircons of the main structure-forming elements (metamorphic, subvolcanic, hydrothermal-metasomatic and pyroclastic rocks), supplemented by the observed relationship of rocks.

4.1. Subjacent foundation

The western flank of the Zmeinogorsk deposit is composed of complexly metasandstones and greenschales. They are crumpled into folding, and have only tectonic contacts with stratiform Devonian sediments.

Also, the basement high were investigated near other ore objects of the region – Strizhkovskoye and Petrovskoye deposits (Figure 2). According to U-Pb dating from detrital zircons from metasandstones and quartz-chlorite-sericite schists, the main epochs of zircon formation were the Middle-Late Cambrian (~496 Ma) and Late Riphean (~805 Ma).

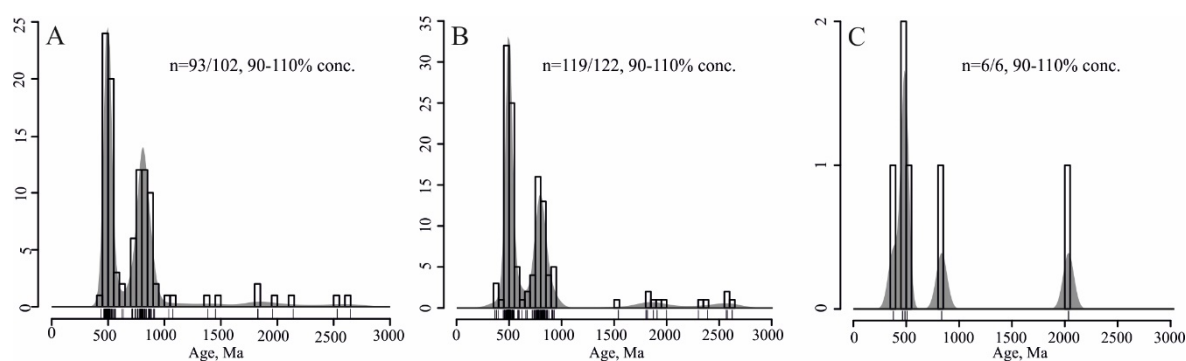


Figure 2. Distribution of U-Pb ages through time, based on probability density plots and histograms using the algorithm [5] for the metasandstones and greenschists from Zmeinogorsk ore district: A – Zmeinogorsk field, B – Strizhkovskoye field, C – Petrovskoe field. Bin width of histogram is 50 Ma.

The fact that zircons younger than 450 Ma do not participate in the formation of sedimentary rocks indirectly indicates the Lower Paleozoic age of sediments accumulation, which subsequently underwent greenschist metamorphism [8].

4.2. Country rock stratigraphic formations

Most of the area of the structure of the Zmeinogorsk ore field (about 60%) is formed by a depression, the lower part of which is traced almost along a complete circle by the river Zmeevka. On the satellite image of the area, the depression is manifested as a relict caldera of the zonal-ring type, it is described

in the previous paper [9]. The base of the depression has dimensions of 360×240 m, along the periphery it is framed by an annular zone raised in the relief with an outer diameter of 800×600 m. The depth of the depression is 80-100 m.

The base and most of the framing annular zone are composed of tectonic blocks of different sizes of the argillite-calcareous Lower Melnichnaya subformation (D_{1mn_1}). These blocks form the broken-plate structure. The orientation of the prevailing disjunctives is sublatitudinal, north-north-west, and diagonal (north-west and north-east).

The type of bedding and attitude of the Lower Melnichnaya subformation indicates that stratum formed an anticlinal structure here. The crest line is located in the northern third of the Zmeinogorsk ore field, where the Zmeinogorsk barite-polymetallic deposit was located. The Lower Melnichnaya subformation is contorted into an anticlinal fold of sublatitudinal (in the southern part) and west-northwestern (in the northern part) striking.

4.3. Subvolcanic formations

The Lower Melnichnaya subformation at the base of the caldera-like depression and, to a lesser extent, the framing ring zone is abundantly saturated with gentle subconcordant rhyolite sills and steeply sloping intersecting rhyolite dikes. Determination of the absolute age of zircons from rhyolites (Figure 1A) of the western framing zone of the caldera depression showed a concordant age of 389.8 ± 1.3 Ma (Figure 3A) [10]. This corresponds to the Eiffelian in the Middle Devonian.

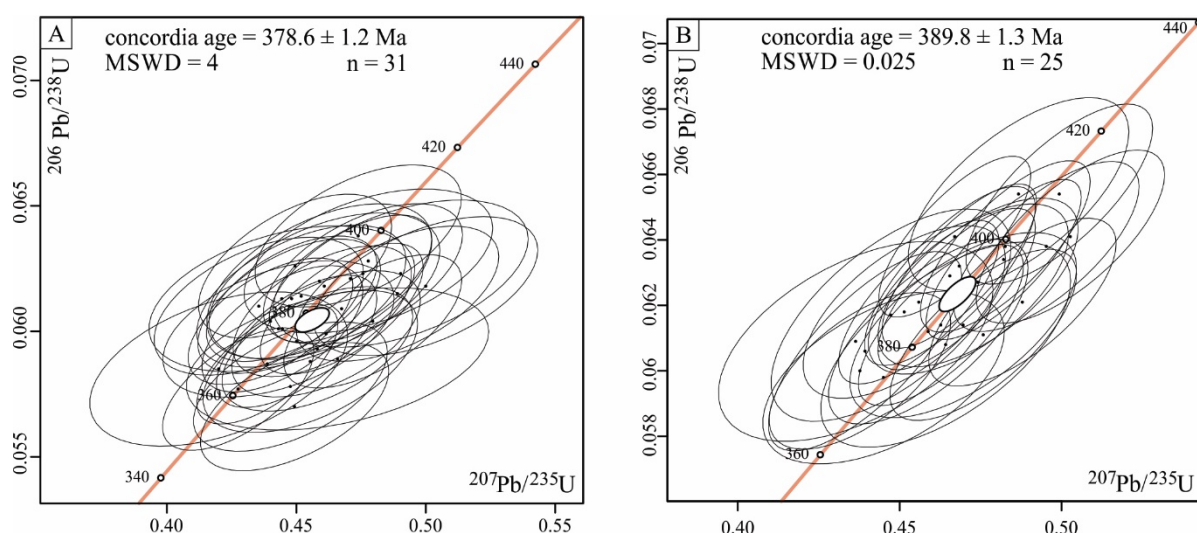


Figure 3. Wetherill concordia plots of U-Pb zircon data using the algorithm [5] for the subvolcanic and pyroclastic formations of Zmeinogorsk ore field: rhyolite sill (A), overlying rhyolite tuff (B).

4.4. Hydrothermal-metasomatic formations

Crushed and displaced blocks of the layered Lower Melnichnaya subformation contained a lenticular body of secondary microquartzites. At the beginning of the development of the deposit, the summit of Mount Zmeinaya was formed by a primary outcrop of weathered dark brown microquartzites. Today it has only peripheral relics of this body. The surviving quartzites are chalcedony-like bluish-gray quartzites of fine texture and massive structure. In the breccias zone fragments of quartzite are penetrated by micro-veins of barite [11].

Microquartzites was formed in the axis part of the brachyanticline under the influence of the intrusion of rhyolite melts penetrating the caldera structure. This is evidenced by the dating of a single zircon grain recovered from secondary quartzite (Figure 1B). It too corresponds to the Eiffelian in the Middle Devonian. Probably, this zircon grain is a relic captured by a metasomatic solution from the original felsic magma [10].

4.5. Barite-quartzite breccias

In the axis part of the brachyanticline, complicated by block tectonics and the formation of microquartzites, there is a stockwork zone of quartzite-barite breccias in the southern flank. Clast of breccias are composed of siliceous microquartzites and host rocks. Barite cement is composed of both fine-medium-grained barite aggregates and its coarse and pegmatoid lamellar crystals [11].

The stockwork is saturated with barite-sulfide schlieren-vein mineralization of copper specialization. Vein barite carries noble metal mineralization [11]. In the northern part, at the contact with the microquartzite body, the stockwork was opened by a Zmeinogorsk quarry. There is a stockwork-vein zone of barite-galena-sphalerite ores and their breccias not fully spent out by predecessors.

4.6. Overlapping tuff sequence

A sequence of slab joints of thin-bedded tuffs, tuff breccias and rhyolite lavas interlayers transgressively overlaps the northern periphery of the Zmeinogorsk brachyanticline. Apparently, initially this tuff stratum had areal development, including the inner and outer zones of the caldera-ring complex. Subsequently, the tuff sequence was largely eroded. Now it occupies only the northeastern and northwestern flanks of the Zmeinogorsk ore field.

The dating of zircons from the overlying tuffs (Figure 1C) of the northern wall of the caldera is characterized by a concordant age of 378.6 ± 1.2 Ma (Figure 3B), что соответствует франскому веку позднего девона [10]. This corresponds to the Frasnian in the Upper Devonian.

4.7. Final stage doleritic magmatism

Intrusion of dolerite dikes is final stage magmatism within the Zmeinogorsk ore field. They are located mainly within the fault zone of the caldera. The largest stock-like dolerite body is located in the marginal part to the west-north-west of the microquartzite body. Linear thin dolerite dikes are located radially from the stock and star-shaped stretched to the east, northeast, north, west-northwest. These dikes is transgressive with respect to tuffs, rhyolites, microquartzites and ores.

5. Conclusions

A step-by-step restoration of the history of the formation of the Zmeinogorsk ore field was carried out. Analysis of the schemes of the structure of the ore field and natural observations made it possible to establish the formation sequence of geological bodies. U-Pb dating of the main geological formations made it possible to establish the reference time of the formation of the main structure-forming elements.

It was found:

1. Country sedimentary and pyroclastic deposits are plicated into a brachyanticlinal fold.
2. The country rocks are penetrated by subvolcanic sills and rhyolite dikes. They are eiffelian.
3. Secondary microquartzites, which are derived from felsic magmas, intruded into the axis part of the brachyanticline. They are eiffelian too.
4. To the south in the axis part of the fold, there is a stockwork body of barite-quartzite breccias. They are carry noble metal mineralizations.
5. From the northeast and northwest the ore field is overlain by younger (Frasnian) rhyolite tuff deposits.
6. All geological bodies are cut through by radial dikes of basic composition.

Thus, the Zmeinogorsk deposit has to rhyolite dome-type and volcano-tectonic nature, similar to the polymetallic deposits of the neighboring Leninogorsk ore district. In this case, besides the stratigraphic ore control tectonic control is important.

6. References

- [1] Grinev O M 2002 Historical retrospective and potential of the Rudny Altai deposits as a source of gold and silver *Petrology of magmatic and metamorphic complexes* (Tomsk: Tomsk State University Press) vol 3 part I pp 44-58
- [2] Grinev O M 2002 The problem of technological development of gold-silver barite-polymetallic

- deposits of Rudny Altai *Petrology of magmatic and metamorphic complexes* (Tomsk: Tomsk State University Press) vol 3 part I pp 32-43
- [3] Chekalin V M 2008 Northwestern Altai as the birthplace of Siberian mining in the past, present and future *Int. Scientific and Practical Forum Raw Materials Base of Siberia* (Tomsk: Tomsk Polytechnic University Press) vol 2 pp 541-557
- [4] Paton C, Hellstrom J C, Paul B, Woodhead J and Hergt J 2011 Iolite: Freeware for the Visualisation and Processing of Mass Spectrometric Data *Journal of Analytical Atomic Spectrometry* **26** pp 2508-2518
- [5] Vermeesch P 2018 IsoplotR: a free and open toolbox for geochronology *Geoscience Frontiers* **9** pp 1479-1493 doi 10.1016/j.gsf.2018.04.001
- [6] Chekalin V M 1996 Geological and genetic model of the Zmeinogorsk gold-silver-barite-polymetallic deposit (Rudny Altai) *Ores and metals* **6** pp 55-65
- [7] Garmash A A 1960 Features of the structure of the Zmeinogorskoye field in Altai *Basic questions and methods of studying the structures of ore fields and deposits* pp 566-581
- [8] Semiryakov A S, Bestemianova K V and Grinev R O In Press New data of U-Pb dating of zircons from green shales of Zmeinogorsk ore region (Rudny Altai) *Problems of Geology and Subsurface Development* (Tomsk: Tomsk Polytechnic University Press)
- [9] Grinev O M, Bestemianova K V and Grinev R O 2017 Morphostructures and material composition of the Ems-Early Eifel volcanics of the Zmeinogorsk ore region (Rudny Altai) *Petrology of magmatic and metamorphic complexes* (Tomsk: Tomsk CSTI Publishing house) vol 9 pp 118-127
- [10] Semiryakov A S and Bestemianova K V 2021 Results of U-Pb dating of volcano-plutonic formations of the Zmeinogorsk deposit (Rudny Altai) *Actual problems of subsurface management* (Saint Petersburg: Saint Petersburg Mining University Press) vol 4 pp 90-92
- [11] Semiryakov A S, Grinev O M, Bestemianova K V and Grinev R O 2019 Mineralogy and prospect of noble metals of gold-bearing ore breccias from ore fields of polymetallic deposits of Ore Altai *IOP Conf. Series: Earth and Environmental Science* **319** 009

Acknowledgments

The reported study was funded by RFBR, project number 20-35-90036; was funded by Russian Ministry Science and Higher Education, project number 0721-2020-0041.