



HOKKAIDO UNIVERSITY

Title	Genesis of precious metal mineralization in the Central Kamchatka, Far East of Russia
Author(s)	Andreeva, Elena
Degree Grantor	北海道大学
Degree Name	博士(理学)
Dissertation Number	甲第11094号
Issue Date	2013-09-25
DOI	https://doi.org/10.14943/doctoral.k11094
Doc URL	https://hdl.handle.net/2115/53927
Type	doctoral thesis
File Information	Elena_Andreeva.pdf



Genesis of precious metal mineralization
in the Central Kamchatka, Far East of Russia

(極東ロシア, 中央カムチャツカにおける貴金属鉱化作用の成因)

by

Elena D. Andreeva

Thesis Submitted for the degree of Doctor of Philosophy

Department of Natural History and Earth Science,
Graduate School of Science, Hokkaido University

August, 2013

Genesis of precious metal mineralization in the Central Kamchatka, Far East of Russia

Elena D. Andreeva

Abstract

Epithermal deposits of High Sulfidation and Low Sulfidation type are hosted broad range of precious metals (dbtelluride or selenides), and are dominantly located in the volcanic-arc setting of the Pacific Ocean region. Epithermal style Au-Ag mineralizations are occurred from the dilute, meteoric-water enriched, low and typically variable in temperatures hydrothermal fluids (150-300 °C) at the shallowest depths under distinctly variable physicochemical conditions.

Central Kamchatka mining district contains open-space filling epithermal veins of Au-Ag-Te, Au-Ag and Au-Au-Base metal mineralization types, occurring within the volcanic calderas of coincident age. Au-Ag-Te Aginskoe and Au-Ag Baranevskoe, Zolotoe and Kungurcevskoe deposits were chosen as subjects of the PhD research on the reason of currently active mining and exploration works at this area. The research is mainly aimed on: (1) estimation the physicochemical conditions of mineral deposition; (2) definition of the style of mineralization and (3) construction of the genetic models of Au-Ag-Te and Au-Ag mineralizations in the Central Kamchatka mining district. Additionally, the factors controlling the chemical composition of the Au-Ag alloy and the relationship of volcanism to the ore formation process were discussed. The information provided in this dissertation includes absolutely new data obtained from fieldworks, laboratory studies and a compilation of the existing Russian literature pertaining to regional fault systems that control metallic mineralization in Central Kamchatka.

The Aginskoe deposit is a only active mine in the Central Kamchatka mining district, producing annually approximately 2 t of gold. It is composed of 14 steeply dipping to SE and NW quartz- adularia vein groups intruded into a sequence of andesitic basalt volcanic rocks of Middle Miocene. Unexposed epithermal veins of 300 m in length contain native gold, gold-silver-tellurides. sulfides and various secondary minerals most of which are still not identified. Gold-silver-tellurium-bearing ores have been formed from 7.1 to 6.9 Ma based on K/Ar dating of vein adularia obtained from this research. Aginskoe veins are confirmed to be formed in six paragenetic stages. Productive Au-Ag-Te mineralization is occurred in the stage II in crustiformed banding ores, characterized by presence of adularia, calcite and silica gel precursors. Dominated vein minerals are native gold, calaverite, hessite, altaite, petzite, chalcopyrite, and sphalerite accompanying with minor electrum, pyrite and galena. Special characteristic of the Aginskoe vein system is an intensive ore oxidized completely modifying the primary vein mineral assemblages. Exotic secondary minerals with great number of unknown phases and native mustard gold are developed in fairly each ore body of the mine. Despite heavy oxidation of the ores calaverite and rare petzite are still preserved as primary phases in ores. Au-Ag tellurides of stage II were deposited from fluids under the temperatures of 250-260 °C and salinity less

than 2 wt% NaCl at $\log f\text{Te}_2 < -9$, and $\log f\text{S}_2$ is assumed to be -13. Ratio of $f\text{Te}_2/f\text{S}_2$ is decreased as the ore deposition proceeds further. Native gold (Au 88-92 at%) was simultaneously deposited with Au-bearing tellurides such as calaverite prior to deposition of altaite-hessite-sphalerite assemblages. In oxidation zone Te was leached out from primary Au-Ag tellurides with accumulation of native mustard gold on the porous surface of decomposed mineral. Boiling phenomena is confirmed by presence of adularia, wide range of homogenization temperature, types of inclusions and quartz textures. Stable isotope study made on quartz of metallic stage II and amethyst of post-ore stage IV indicate that quartz-adularia-carbonate veins were deposited from the meteoric water-enriched hydrothermal fluids circulated at the shallow depth.

The Baranevskoe deposit is located within the Balkhach super-volcanic caldera in the south-east of the Central Kamchatka mining district in approximately 40 km away from the Aginskoe Au-Ag-Te deposit. Two principally different ore types were defined at the Baranevskoe deposit: cupriferous and gold-silver-quartz-carbonate-adularia ores formed under different physicochemical conditions and the fluids source. Also single gold was found in cavities of alkaline metasomatites, hosting the cupriferous ores. Cupriferous ores have been formed prior to gold-silver from probably different the fluids in source. This ore type consists of early pyrite-electrum-chalcopyrite-bornite-sphalerite and later tetrahedrite-tennantite assemblages. Bornite and chalcopyrite are showing micrographic texture caused by the relatively rapid cooling of the hydrothermal fluid. Electrum (Au 59-64 at%) is very rare mineral in cupreous ores, and tends to associate with pyrite and chalcopyrite. The tetrahedrite-tennantite series mineral is predominant by tetrahedrite component showing heterogeneous distribution of Sb and As within tetrahedrite_{ss}. Tetrahedrite was likely occurred in replacing of chalcopyrite and chalcopyrite-bornite. Tetrahedrite in cupriferous ores is characterized by a high Cu content and a high Zn/Fe ratio. Fluid inclusions show lower homogenization temperatures from 154 to 232 °C with salinity of 0.7-1.1 wt% NaCl equiv.. Although liquid-rich inclusions were observed in co-existing with gaseous inclusions, a boiling is not confirmed yet. Presence and dominance of the tetrahedrite and types of the alteration rocks suggests deposition of Cu-bearing ores from the low-temperature slightly alkaline fluids of high $f\text{S}_2$ relegates to the intermediate sulfidation state. The gold-silver ores occur as open-fractures filling veins, tiny stockworks and carbonate-rich ores. Both veins and stockwork are characterized by abundant occurrence of gold in association with sphalerite, galena, pyrite, chalcopyrite and trace amounts of tetrahedrite-tennantite. Carbonate-rich veins host moderate amounts of gold crystallized in interstices. The Au content in electrum varies broadly from 52 to 72 at%. Based on the fluid-inclusion studies, quartz-carbonate-adularia veins, stockwork and carbonate-rich ores are confirmed to be deposited from the hydrothermal fluids in shallow-depth with relatively lower temperatures of 190-280 °C and a salinity approximately 2wt% NaCl equiv.. Alteration rock styles support fluid of slightly acid-neutral to alkaline-neutral pH state. Stable isotope studies suggest a magmatic contribution in the hydrothermal fluids. Kungurcevskoe and Zolotoe deposits are located in the same area with Baranevskoe deposit in a distance of about 12 km.

Hydrothermal fluids of Zolotoe and Kungurcevskoe deposits are meteoric-water in origin based on the stable isotope studies. Both deposits are classified as LS type epithermal veins.

Acknowledgments

This research could not be completed without a MEXT scholarship provided by the Ministry of Education of Japan. I wish to express my deepest gratitude to my principle adviser professor of the Hokkaido University Hiroharu Matsueda for his financial supports, guidance, reading and correcting my papers. I wish to thank professor of the Kamchatka State University Victor Okrugin, who inspired me to do this study. I am very grateful for his endless assistance, advice and financial support.

I would like to thank Dr. Ono Sh., who devoted a much of his precise time to help me in EPMA analysis and interpretation of data.

I would like to thank committee of geological and exploration departments of KamGold and Zoloto Kamchatki Company for field guidance, reading and graphic materials. Special thank is for the Society of Resource Geology of Japan on the funds for the analysis of chemical composition of ores and stable isotope measurement. I thank Ryohei Takahashi for his valuable advises. I would like also to thank Chris Osterman and Tom Tindell (Kyushu University) for reviewing of my thesis and correcting English. I thank for all my colleagues of the Resource Geology Group of Hokkaido University. I will always remember your help and kindness.

I thank all of my friends, who believed in me and get me inspired. I thank my mom, my sister and my little niece for their patient to me, and love, and believe.

Content

Abstract

Acknowledgment

List of figures

List of tables

Chapter I. General introduction of the research.....1

 1.1.Introduction.....2

 1.2. Location of Kamchatka, physicography and geological features.....5

 1.3. The mining history and present mining activities in Russia.....7

 1.3.1. History of mining in Russia.....8

 1.3.2. Type of developed deposits and gold productions.....12

 1.3.3 Gold resources and potential areas.....14

 1.3.4. Recent operative mines in Kamchatka.....15

 1.4. Aim and significance of the research.....17

 1.4.1. Research aims.....17

 1.4.2. Significance.....17

 1.5. Description of research methods.....18

Chapter II. Epithermal mineralization occurring along Pacific Ocean cost: types, styles and relationship to magmatism.....23

 2.1. Active continental margins: origin of magmatism and an influence to the deposits..24

 2.1.1. General introduction to the magmitism originated in the subduction zone.....25

 2.1.2. The Kuril-Kamchatka volcanic arc system.....27

 2.1.3. Descriptions of the Kamchatka Volcanic Belts and present location of the subduction zone.....29

 2.2. Volcanic hosted epithermal deposits.....34

 2.2.1. Classification of epithermal deposits.....34

 2.2.2. Distribution of deposits in South-Western part of Pacific Fire Rim.....37

 2.2.3. Descriptions of epithermal deposits occurring in Kamchatka.....45

Chapter III. Geology and metal mineralization of the Central Kamchatka Volcanic Belt.....46

 3.1. Regional geology and tectonic settings of the Central Kamchatka Volcanic Belt.....47

 3.2. Characteristics of precious metal deposits distributed within the Central Kamchatka Volcanic Belt.....48

 3.3. The Central Kamchatka Mining District.....48

3.3.1. Geological background.....	49
3.3.2 .Tectonics.....	49
3.3.3. Precious metal deposits.....	51
Chapter IV. Gold-silver-telluride mineralization at the Aginskoe deposit.....	53
4.1. Exploration and investigation history.....	54
4.2. Geology of the Aginskoe deposit.....	55
4.2.1. Magmatic units and faults.....	58
4.3. Structure of the Aginskoe deposit.....	58
4.3.1. Mineralization stages.....	59
4.3.2. Age of precious mineralization.....	72
Chapter V. Mineralogy of mineralized veins and hydrothermal altered rocks at the Aginskoe deposit.....	74
5.1. Geochemistry of ore and REE.....	75
5.2. Alteration mineralogy.....	94
5.3. Vein mineralogy.....	97
5.4.Quartz texture.....	108
Chapter VI. Characteristics of hydrothermal fluids.....	115
6.1. Fluid inclusions.....	116
6.1.1. Nature of fluid inclusions.....	117
6.1.2. Melting and homogenization temperature.....	121
6.2. Gas composition of fluid inclusions.....	128
6.3. Stable isotopes of quartz and carbonate.....	128
Chapter VII. Oxides telluride mineralogy and secondary supergene mineralization in epithermal deposits.....	130
7.1. Tellurium behavior in the hydrothermal solution: Te-bearing species and its transport in the hydrothermal solution (importance to gold deposition mechanism)....	131
7.2. Te behavior under the oxidation conditions: tellurium oxides formed under the supergene conditions.....	134
7.3. Au-Ag-Te epithermal deposits at Kamchatka.....	135
Chapter VIII. The cycling of historical gracious periods in Kamchatka and affects on the deposits.....	137
8.1. The glacier periods in Kamchatka.....	138
8.2. Affect of glacier cover on the certain deposits.....	139

Chapter IX. Discussions on source and physicochemical environment of Au-Ag-Te Aginskoe deposit.....141

9.1. Source of hydrothermal fluids.....142

9.2. Boiling and mixing of hydrothermal fluids.....143

9.3. The physicochemical environment.....145

9.4. Origin of Te-enriched veins.....147

Chapter X. Gold-silver epithermal mineralization at the Balkhach volcanic-tectonic structure.....149

10.1. Exploration and investigation history.....150

10.2. Geology of the Balkhach volcanic-tectonic structure.....151

10.3. Magmatic units and major faults.....153

10.4. Vein systems of precious metals deposits in the Balkhach ore cluster.....155

10.4.1. Ore occurrence.....156

10.4.2. Age of ore mineralization.....160

Chapter XI. Geochemistry and mineralogy of veins and hydrothermally altered rocks at the Balkhach ore cluster.....162

11.1. Geochemistry of host rocks and ores.....163

11.2. Alteration mineralogy.....175

11.3. Vein mineralogy.....177

Chapter XII. Characteristics of hydrothermal fluids.....199

12.1. Fluid inclusions.....200

12.1.1. Nature of fluid inclusions.....200

12.1.2. Melting and homogenization temperature.....203

12.2. Gas composition of fluid inclusions.....215

12.3. Stable isotopes of quartz and carbonate.....215

Chapter XIII. Discussions on source and the physicochemical environment of Au-Ag mineralization at the Balkhach ore cluster.....217

13.1. Nature and characteristics of hydrothermal fluids218

13.2. The physicochemical environment.....222

Chapter XIV. Discussion on genesis of gold mineralization in the Central Kamchatka Mining District.....227

14.1. Genesis of precious metals mineralization in Central Kamchatka.....228

14.2. Factors controlling chemical composition of gold in epithermal deposits of Central Kamchatka.....230

Chapter XV. Summary and Conclusions.....232

References.....234

List of figures

Fig.1.1. A map of Kamchatka showing distribution of the volcanic belts with location of active volcanoes and precious metal deposits.

Fig.1.2. The schematic map of the Central Kamchatka mining district, showing distribution of Au-Ag (yellow circle), Au-Cu (red-green circle) and Cu-Ni-Pt (quarter of green, red and blue) deposits. Location of two active volcanoes Ichinsky on the north and Khangar on the south is shown (a map was composed by mining geologists).

Fig.1.2.1. A map of Russia showing a division on administrative subjects (source: Wikipedia). Kamchatka is localized in the easternmost area, highlighted by a yellow color.

Fig.1.2.2. Relief of the Central Kamchatka volcanic belt. The photo is taken by Daria Bukhanova during geological survey in 2010.

Fig.1.3.1. Localization of gold-silver deposits of different types within Russian Federation. Most of gold-silver deposits are localized in the mountains of Central and Far East districts.

Fig.1.3.1.1. A tendency of gold resource (a) and gold mining (b) in % from the total Russian Au resources (a) and mining (b).

Fig.1.3.2.1. Gold mining in Russia for period from 1971 to 2005.

Fig. 1.3.2.2. Gold production in Far East, Siberia, Ural and other regions of the Russian Federation.

Fig.1.3.3.1. A sketch map of Russian Far East region with localities of largest Au deposits. Colored blocks show number of known Au primary and placer deposits and their tonnage within brackets. A map was created using data from the official site of the Far East Department of Raw Resource.

Fig.1.5.1. The microscope Nikon eclipse E400 POL with Nikon digital camera was used for the observation of quartz textures, ore and host rocks minerals.

Fig.1.5.2. Rigaku Mini FLEX used for XRD analysis of altered host rocks and veins samples at the Hokkaido University.

Fig.1.5.3. Renishaw inVia Raman microscope in the Open Facilities of the Hokkaido University. \

Fig.2.1.1. A map of different style of plates' boundaries.

Fig.2.1.1.1. The cartoon illustrating Ringwood's subduction zone model for a primitive island arc composed of basalt. A model includes major elements: subducted oceanic crust, release of H₂O from amphibolites, formation of tholeiitic magma and a volcanic front.

Fig.2.1.2.1. A satellite image of the North-West area of the Pacific Ocean. The Kuril-Kamchatka island arc is connected to the Aleutian non-active arc in the north-east and to the Japanese active arc in the south-east. A map was created by author using Google map satellite image.

Fig.2.1.3.1. A sketch map showing occurrence of Late Pleistocene volcanoes and their eruption products in the Central and Eastern volcanic belts and the Central Kamchatka depression zone. A map is taken from Ponomareva *et al.*, 2007.

Fig.2.1.3.2. The 3-D model of Kamchatkan subduction zone illustrating a increasing of the depth of seismofocal zone towards to the Central Kamchatka volcanic belt (Central Range here). EVB – Eastern volcanic belt, CKD – Central Kamchatka Depression and SR – Sredinnyi Range. A 3-D model is borrowed from Gorbatov *et al.*, 1997.

Fig.2.1.3.3. View on the Central Kamchatka volcanic belt looking to the North-West. Quarternary volcanic rocks are covering destroyed volcanic calderas of Oligocene-Miocene. On the background of the photo is the Ichinsky composite volcano. The photo was taken by undergraduate student Perelygin Alexei during the geological prospecting works in the Central Kamchatka mining district in 2011.

Fig.2.1.3.4. Various K_2O (wt%) vs. SiO_2 (wt%) diagrams showing division of Kamchatkan volcanic rocks into high-K, medium-K and low-K varieties. Diagrams are borrowed from: a – Ponomareva *et al.*, 2007: EVE – Eastern Volcanic Front, SCKD – volcanics from the south of the Central Kamchatka Depression Zone and NCKD – from north of the Central Kamchatka depression zone, SR (IAB) – island-arc type basalts from the Sredinny Range, SR (WP) – within-plate type rocks from the Sredinny Range. Lower diagrams FeO/MgO vs. SiO_2 . b – Churikova *et al.*, 2001 and c – Bindeman *et al.*, 2010. Abbreviation is same as in Fig. 2.1.3.4a.

Fig.2.2.1.1. Corbett's cartoon model explaining origin of the epithermal LS and HS deposits (Corbett & Leach, 1997).

Fig.2.2.1.2. Colloform-banded (a) and brecciated (b) textures of ores from the Aginskoe deposit, Central Kamchatka.

Fig.2.2.2.1. A map showing distribution of copper porphyry, copper of various types and epithermal gold-silver deposits in the south-west of Pacific region. Modified after USGS report, 2005.

Fig.2.2.2.2. A map of distribution of gold-silver and base metal vein and disseminated type epithermal deposits in Japan. Most of mines were closed due to exhaustions of mineral from late 50s to 80s. A map is taken from Shikazano, 1986.

Fig.2.2.2.3. A map of gold-silver deposits in Philippines. Location of Baguio and Mindanao districts are shown.

Fig.2.2.2.4. Mineral prospects and mining in the Indonesia.

Fig.2.2.2.5. Distribution of gold-silver and gold-copper deposits within South-West, Central collisional and North-East geological provinces of Papua New Guinea.

Fig.2.2.2.6. A map of Northland, Coromandel and Taupo volcanic zones hosting major gold-silver deposits of New Zealand.

Fig.3.3.2.1. A simplified geological map, showing localization of volcanoes composed by basaltic, andesitic, dacitic and rhyolitic volcanic, hosting metallic mineralization in Central Kamchatka mining district. Shaded lines displace approximate orientation of the Major Kamchatka Blind fault controlled Au-Ag mineralization in the district.

Fig.4.2.1. A geological map of Aginsky volcano with location of Aginskoe and South Aginskoe deposits and Naichan ore manifestation.

Fig.4.3.1. System of mineralized fractures of the Aginsky batch, Aginskoe deposit. Based on crosscutting relationship of fractures they have been subdivided into three groups. The first group is the shear zones hosting high-grade ore bodies such as Aginskoe, Bluzdayushee, Surprise and Malysh. The second group is the shear zones linking Aginskoe vein with Surprise vein. The third type is the ruptures, for example, Hakhodka vein.

Fig.4.3.1.1. General sequence of mineralization stages distinguished in Aginskoe ore body mainly.

Fig.4.3.1.2. Ore specimens from Aginskoe ore body showing sequence of the mineralization stages. a) rhythmically colloform-banding or combing Au-Ag-Te occurring within milky quartz bands and Ag-Au-Te-sulfide occurring in semitransparent quartz; b) dendritic mode occurrence of native gold, Au-bearing tellurides and chalcopyrite within quartz-adularia aggregates; c) a hydrothermal breccia showing time relationship between stages II, III and IV.

Fig.4.3.1.3. Ore specimens from Bluzdayushee ore body showing sequence of the mineralization stages. a) colloform-banding ore hosting Au-Ag-Te within milky quartz growing from a wall of host rocks. Remnants of adularia crystals are recognizable macroscopically; b) fragment of quartz hosting Au-Ag-Te mineralization of the stage II in hydrothermal breccia of the stage III; c) bands of quartz referring for sub-stages trough 9 to 11 of the stage II with rich Ag-Te-sulfide mineralization are coating brecciated fragments of sub-stages 1-6 of the stage II; d) specimen from Aginskoe ore body used as standard for the comparison of the mineralization stages.

Fig.4.3.1.4. Occurrence of amethyst quartz in ore bodies Bluzdayushee, Aginskoe, Malysh and Surprise. Amethyst is filled free spaces in breccias.

Fig.4.3.1.5. Ore specimens collected along Surprise ore body. Most of samples are hydrothermal breccias, hosting Au-Ag-Te mineralization. Specimen in the square is from Aginskoe ore body used as standard for the comparison of the mineralization stages.

Fig.4.3.1.6. Ore specimens collected along Olimpiskoe apophyse and Malysh ore body. a,b) ore samples of the Olimpiskoe apophyse showing preserved fragments of the stage III with Au-Ag-Te mineralization in breccias of the stage II; c) hydrothermal breccias from Malysh ore body hosting quartz fragments resemble for a stage II; d) specimen from Aginskoe ore body used as standard for the comparison of the mineralization stages.

Fig.4.3.1.7. Occurrence of euhedral quartz aggregates from Malysh ore body (upper left); Surprise ore body (upper right). Similar appearance is showing single quartz crystals in hydrothermal breccias of Surprise ore body (lower left) and Aginskoe ore body (lower right).

Fig.4.3.1.8. Ore specimens collected from Yasnoe ore body (a), Valeri ore body (b), Noyabr'skoe ore body (c).

Fig.5.1.1. Scattered diagrams of Au vs. Ag, Te, Cu and As; Pb vs. Zn; Te vs. Se made for Aginskoe and Bluzdayushee ore bodies.

Fig.5.1.1. Continued. Scattered diagrams of Au vs. Ag, Te, Cu and As; Pb vs. Zn; Te vs. Se made for Surprise and Malysh ore bodies.

Fig.5.1.2. Chondrite normalized incompatible element diagram (a) and rare earth element abundance for host rocks of Aginskoe deposit.

Fig.5.1.3. Chondrite normalized incompatible element diagram for Aginskoe ore body (a) and Bluzdayushee ore body (b).

Fig.5.1.4. Chondrite normalized incompatible element diagram for Surprise ore body: a) first group of samples; b) second group of samples (b); c) rare earth element abundance diagram in samples of the first group.

Fig.5.1.5. Chondrite normalized incompatible element diagram (a) and rare earth element abundance diagram (b) for Malysh ore body.

Fig.5.1.6. Chondrite normalized incompatible element diagram (a) and rare earth element abundance diagram (b) for Noyabr'skaya ore body.

Fig.5.2.1. $\text{Na}_2\text{O}+\text{K}_2\text{O}$ vs. Si_2O in host rocks of Aginskoe, Baranevskoe and Zolotoe deposits

Fig.5.2.2. Typical patterns of propylitic and potassic alteration of $(\text{CaO} + \text{Na}_2\text{O})$ vs. K_2O in host rocks of Aginskoe, Baranevskoe and Zolotoe deposits.

Fig.5.2.3. X-ray diffraction patterns of chlorite, chlorite-kaolinite mixed layer, K-feldspar (adularia and albite) and quartz from Valery ore body, Aginskoe deposit.

Fig.5.2.4. Microphotographs illustrating type of alteration in host rocks of Aginskoe deposit. a,b) partially replacement of pyroxene phenocrysts by chlorite-kaolinite mixed layer mineral (greenish) and pyrite (black); b,c) development of chlorite-kaolinite mixed-layer mineral in groundmass.

Fig.5.3.1. Microphotographs of tellurides from Aginskoe deposit. a) association of hss, alt and sph in the sub-stage 9 of the stage II from Aginskoe ore body; b) intergrowth of alt, hss and cp in the sub-stage 9 of the stage II from Aginskoe ore body; c) intergrowth of au and alt in the Surprise ore body; d) au in contact with hss in Bluzdayushee ore body; e) association of hss and alt in the sub-stage 9 of the stage II from Aginskoe ore body; f) early association of cp, hss and au is replaced by late sph in the sub-stage 2 of stage II from Bluzdayushee ore body; g) decomposed clv in intergrown with alt and au in the sub-stage 2 of stage II from Bluzdayushee ore body; h) primary tellurides clv and ptz are slightly decomposed in the sub-stage 2 of stage II from Bluzdayushee ore body; i) mutual contact of alt, cp, ptz and au in the sub-stage 2 of stage II from Bluzdayushee ore body; j) small patches of ptz is adjusted to anhedral alt in the sub-stage 9 of the stage II from Aginskoe ore body; k) sph, ptz and alt association in the sub-stage 9 of the stage II from Aginskoe ore body; l) primary tellurides alt and ptz in intergrown with au in Surprise ore body. *Abbreviations*: alt: altaite, hss: hessite, clv: calaverite, ptz: petzite, cp: chalcopyrite, sph: sphalerite, py: pyrite, au: gold, etm: electrum.

Fig.5.3.2. Microphotographs of sulfides from Aginskoe deposit. Abbreviations listed in Fig. 5.3.1. a) au in intergrown with hss enclosed in cp from sub-stages 1-3 of the stage II un Aginskoe ore body; b) cp hosting inclusions of alt and hss from the sub-stage 9 of the stage II in Aginskoe ore body; c) au in contact with cp hosting inclusions of hss in Surprise ore body; d) inclusions of py in cp from sub-stages 1-2 of the stage II in Malysh ore body; e) anhedral sph from the sub-stage 9 of the stage II in Aginskoe ore body; f) mutual contact of sph, cp and dissolved (?) in Surprise ore body; g) association of au, cp, ptz, alt and late sph in sub-stages 1-3 of the stage II in Malysh ore body; h) sph replaces alt in sub-stages 1-3 of the stage II in Olimpiskoe apophyse; i) cataclased py in intergrowth with au and supergene minerals in sub-stages 1-3 of the stage II in Aginskoe ore body; j) fractured py with au inclusions in Surprise ore body; k) au inclusions in py in Surprise ore body; l) pyrite enclosed in cp in intergrown with au and hss in sub-stage 1-2 of the stage II in Malysh ore body.

Fig.5.3.3. FeS content in sphalerite from Aginskoe and Surprise ore bodies.

Fig.5.3.4. CdS in sphalerite from Aginskoe deposit.

Fig.5.3.5. Microphotographs of native gold and electrum from Aginskoe deposit. Abbreviations listed in Fig. 5.3.1 a) & b) individual au crystals hosting inclusions of hss in sub-stages 1-3 of the stage II in Aginskoe ore body; c) intergrowth of au with secondary minerals in sub-stages 1-3 of the stage II in Aginskoe ore body; d) & e) au from sub-stages 1-3 in Bluzdayushee ore body; f) elongated au crystals associate with cp in sub-stages 1-3 of the stage II in Bluzdayushee ore body; g) free au from Surprise ore body; h) etm enclosed in pyrite in Surprise ore body; i) association of au with secondary minerals in Surprise ore body; j) free au in sub-stage 1-3 of the stage II in Malysh ore body; k) au in intergrown with secondary minerals in Malysh ore body; l) decomposed tellurides in contact with au. Secondary phase are still contain primary telluride.

Fig.5.3.4. Au content in native gold from Aginskoe deposit.

Fig.5.3.5. Microphotographs of secondary and altered minerals from Aginskoe deposit. Abbreviations listed in Fig. 5.3.1. a), b) & c) development of secondary minerals on the surface of primary tellurides from Bluzdayishee ore body; d) & e) relicts of hypogene tellurides in the secondary minerals in Bluzdayushee ore body; f) completely altered tellurides in Aginskoe ore body. Along fractures gold has been accumulated; g) altaite intergrown with secondary minerals from Bluzdayushee ore body; h) & i) release of or reprecipitation of au on the surface of the secondary minerals in Bluzdayushee and Aginskoe ore bodies, respectively; j) au presumably intergrown with altaite in Surprise ore body; k) altered altaite from Aginskoe ore body; l) altered hss with au from Surprise ore body.

Fig.5.4.1. Textures of quartz observed in Aginskoe deposit. a) flamboyant texture of quartz;

b) flamboyant texture developed on margin of quartz crystals: c.d) ghost sphere texture in mosaic quartz. Left photo is taken with open nicols, right – closed nicols: e.f) pseudo-acicular quartz texture. In groundmass of microcrystalline quartz outlines of needle-shaped adularia crystals are preserved. Left photo is taken with open nicols, right – closed nicols.

Fig.6.1.1.1. Mode of occurrence of primary fluid in inclusions in Aginskaya vein. a) primary two-phase fluid inclusions in Aginskoe ore body. Liquid-rich inclusions display variety of morphology; b) primary individual liquid-rich inclusions of negative crystal shape in quartz from Bluzdayushee ore body. Specimens on right side of a figure show quartz crystal used for fluid inclusions study.

Fig.6.1.1.2. Mode of occurrence of primary fluid in inclusions in Surprise vein. a) primary two-phase liquid-rich fluid inclusions of typical tube and negative crystal shape co-existing with two-phase vapor-dominated inclusions. Necking-down fluid inclusions were also observed; b) occurrence of minute size primary fluid inclusions in quartz aggregates of Malysh ore body. Specimens on right side of figure show quartz crystal used for fluid inclusions study.

Fig.6.1.1.3. Mode of occurrence of primary fluid in inclusions in quartz vein of South-Aginskoe deposit. Fluid inclusions are mainly consisted of two-phase with dominant aqueous. Specimen of tuff with quartz veins show quartz crystal used for fluid inclusions study.

Fig.6.1.2.1. Histograms of homogenization temperatures for fluid inclusion in Aginskoe deposit.

Fig.6.1.2.2. A scattered diagram of salinity vs. homogenization temperature for primary inclusions in Aginskoe deposit.

Fig.6.1.2.3. A histogram of homogenization temperatures for fluid inclusion in amethysts quartz of stage IV from Malysh ore body, Aginskoe deposit.

Fig.6.1.2.4. Scattered diagram of salinity vs. homogenization temperatures for primary inclusions in quartz from South-Aginskoe deposit.

Fig. 7.1.1. Ternary Au-Ag-Te diagram showing the phase relationships between Au-Ag tellurides.

Fig.8.1.1. A map showing distribution of ice in Late Pleistocene time. Deep blue color indicates an area with intensive glaciation. A thick line surrounded Kamchaka showing the ice cover.

A map is adopted from Bigg *et al.*, 2008.

Fig.9.2.1. Isotopic composition of hydrothermal water of Aginskoe epithermal deposit in relationship to the meteoric water line. Isotopic value of H was measured directly from the fluid inclusions. Value of O was calculated using the homogenization temperature of fluid inclusions ($T=250\text{ }^{\circ}\text{C}$).

Isotopic composition of present meteoric water in South Kamchatka is taken from Okrugin and Zelensky, 1997.

Data on the isotopic composition of water of Koryu and Chitose deposits in Japan, Philippines deposits, Judith deposit in USA, Emperor in Fiji and Broadlands in New Zealand is taken from Shimizu and *et al.*, 1998; Ahmad *et al.*, 1987; White, 1974.

Fig.9.3.1. Estimated $\log f_{\text{Te}_2}$ vs. $\log f_{\text{S}_2}$ conditions for the Aginskoe deposit based on the mineral assemblages and FeS content in sphalerite. A black arrow indicates shifting f_{Te_2} from the sub-stage 1-6 to sub-stages 7-9. Equilibria were calculated at $250\text{ }^{\circ}\text{C}$ using data listed in Afifi *et al.* (1988a, b). Abbreviations; clv: calaverite, Au: gold, hss: hessite, acan: acantite, po: pyrrhotine, py: pyrite, alt: altaite, gn: galena.

Fig.9.3.2. Ternary diagrams of Au-Ag-Te system. a) ideal phase relations among Au-Ag tellurides based on the synthetic experiments; b) natural assemblages observed in various epithermal deposits in the world; c) tellurides associations confirmed in Aginskoe deposit by this study. Au-rich tellurides were precipitated simultaneously with native gold in sub-stages 1.2.3 of the stage II followed by deposition of Ag-bearing and Au-free tellurides mostly in sub-stage 9 of the stage II. Diagrams are

plotted in wt%. *Abbreviations*: clv: calaverite, knr: krennerite, slv: sylvanite, emp: empressite, stz: stuzite, hss: hessite, ptz: petzite, etm: electrum.

Fig.10.2.1. A schematic sketch of the Balkhach volcanic-tectonic structure with location of main gold-silver deposits (Bol'shakov *et al.*, 2010).

Fig.10.4.1.1. Macrophotographs of gold-silver and cupriferous ores from Baranevskoe deposit. a) a hydrothermal breccia consists of fragments of massive quartz and andesite host rocks cemented by translucent from Central vein; b) crosscutting relationship between quartz-carbonate-adularia veins hosting gold and some sulfides in Stockwork ore body; c) carbonate-quartz ore hosting invisible gold mineralization from Yuznaya vein; d) brecciated cupriferous ores from Rhzavaya vein.

Fig.10.4.1.2. Mineralization stages and mineral sequence in Baranevskoe deposit.

Fig.10.4.1.3. Macrophotographs of gold-silver ores from Zolotoe deposit. a) sulfide-rich ore with pyrite comprising 90 %; b) sulfide-poor ore consists of fragment of host rocks and massive quartz hosting metallic mineralization.

Fig.10.4.1.4. Macro- and microphotographs of gold-silver ores with typical mode of gold occurrences from Kungurcevscoe deposit. a) breccias from Main ore body (left) with occurrence of gold (right); b) quartz-carbonate-clays ores from vein 17 (left) and gold occurring in quartz interstices (right); c) hydrothermal breccias from vein 17 (left) and typical gold occurring in quartz-clay gangue (right).

Fig.11.1.1. Scattered diagrams of Au vs. Ag, Te, Cu and As; Pb vs. Zn; Te vs. Se plotted for ores of the Baranevskoe deposit.

Fig.11.1.2. Chondrite normalized incompatible element diagram (left side) and rare earth element abundance (right side) for host rocks (two upper plots) and ores (two lower plots) of Baranevskoe deposit. Chondrite REE compositions from McDonough and Sun (1995).

Fig.11.1.3. Scattered diagrams plotted for main commodity in gold-silver ores from Zolotoe deposit.

Fig.11.1.4. Chondrite normalized incompatible element diagram (left side) and rare earth element abundance (right side) for host rocks (two upper plots) and ores (two lower plots) of Zolotoe deposit. Chondrite REE compositions from McDonough and Sun (1995).

Fig.11.1.5. Chondrite normalized incompatible element diagram and rare earth element abundance for gold-silver ores of Kungurcevscoe deposit. Chondrite REE compositions from McDonough and Sun (1995).

Fig.11.2.1. Types of alteration in host rocks of Baranevskoe deposit: a) chlorite in groundmass; b) plagioclase crystals are replaced by sericite.

Fig. 11.2.2. XRD spectrum of chlorite (chl), chlorite-smectite (chl-sm) chlorite-kaolinite (chl-kl), quartz (q) adularia and albite (ad-alb).

Fig.11.3.1. Microphotographs of ore mineral assemblages occurring in quartz-carbonate-adularia and cupriferous ores from Baranevskoe deposit. a) euhedral pyrite (py) in contact with gold (au) from Stockwork ore body; b) py intergrown with galena (ga) from the gold-silver ores; c) sphalerite (sp) intergrown with chalcopyrite (cp), py and ga from carbonate-base ores; d) intergrowth between sp and ga; e) tennantite-tetrahedrite (ten-tet) replacing cp; f) assemblage of cp, bornite (bor) and ten-tet; g) micrographic texture of exsolution cp from bor; h) au inclusion in euhedral py; i) au enclosed in cp; k) au crystals from the carbonate-quartz ore facies.

Fig.11.3.2. Impurities of Cd and Fe in sphalerite from brecciated quartz-carbonate-adularia-gold-silver ores. Left plot: scattered diagram of Cd vs. Mn content of sphalerite. Right plot: diagram of FeS content in sphalerite.

Fig.11.3.4. Microphotographs and back-scattering electron images showing relationship of tetrahedrite-tennantite series minerals: a) assemblages of chalcopyrite (cp)+bornite (bor)+tetrahedrite-tennantite (tet-ten) in cupriferous ores; b) microphotographs under back-scattered electron image. Red colored frame is enlarged in c; c) chalcopyrite (cp)-bornite (bor) intergrowth is replaced by tetrahedrite-tennantite (tet-ten) minerals.

Fig.11.3.5. Chemical variation of tetrahedrite-tennantite fahlore from Baranovskoe deposit as a function of $Fe/(Fe+Zn)$ and $Sb/(Sb+As)$.

Fig.11.3.6. Typical euhedral single gold crystal is grown on aggregates of euhedral quartz in vug of metasomatite. Single gold crystals are rare. Clear growth steps are seen on the surface of crystal.

Fig.11.3.7. Au content in gold from different ore types of Baranovskoe deposit.

Fig.11.3.8. Mode of occurrence of sulfide in sulfide-poor ores from Zolotoe deposit. a) euhedral pyrite (py) in association with galena (ga) and sphalerite (sph); b) chalcopyrite (cp) hosting galena (ga) and intergrown with sphalerite (sph); c) galena (ga) with chalcopyrite (cp) inclusions; d) intergrowth between chalcopyrite (cp), sphalerite (sph) and galena (ga).

Fig.11.3.9. Impurities of Cd and Fe in sphalerite from brecciated quartz-carbonate-adularia-gold-silver ores from Zolotoe deposit. Left plot: scattered diagram of Cd vs. Mn content of sphalerite. Right plot: diagram of FeS content in sphalerite.

Fig.11.3.10. Au content in gold from Zolotoe deposit.

Fig.11.3.11. Au content in gold from Kungurcevscoe deposit.

Fig.12.1.1.1. Mode of occurrence of primary fluid inclusions in Baranovskoe (a,b), Zolotoe (c,d) and Kungurcevscoe (e,f) deposits: a) two-phase liquid-rich primary fluid inclusion with negative crystal outlines in gold-silver ores of Baranovskoe deposit; b) rare vapor-dominated primary fluid inclusion in gold-silver ores of Baranovskoe deposit; c) vapor primary fluid inclusion in sulfide-poor ore of Zolotoe deposit; d) co-existing of primary liquid-rich fluid inclusion with primary vapor fluid inclusion in sulfide-rich ore of Zolotoe deposit; e) primary two-phase fluid inclusion in quartz from vein 14 of Kungurcevscoe deposit; f) group of liquid-rich primary fluid inclusions with typical negative crystal shape in quartz from Main ore body of Kungurcevscoe deposit.

Fig.12.1.2.1. Homogenization temperatures obtained from fluid inclusions for quartz from brecciated quartz-carbonate-adularia ores (a), cupriferous ores (b) and quartz from metasomatites (c) of Baranovskoe deposit.

Fig.12.1.2.2. Homogenization temperatures obtained from fluid inclusions for quartz from Au-Ag quartz-carbonate-adularia ores from Zolotoe deposit (upper diagram) and Au-Ag ores from Kungurcevscoe deposit (lower diagram).

Fig.12.1.2.3. Salinity vs. homogenization temperatures: a) Baranovskoe deposit, b) Zolotoe deposit; c) Kungurcevscoe deposit.

Fig.13.1.1. Cupriferous ores (left) were likely formed prior to gold-silver ores (right). Gold-silver ores consist of brecciated varieties, stockwork and carbonate-enriched ore types.

Fig.13.1.2. Paragenetic sequence of vein minerals observed in the cupriferous ores. In left column rare minerals reported by previous researchers are listed.

Fig.13.1.3. Microphotographs illustrating paragenetic sequence of vein minerals observed in the cupriferous ores.

Fig.13.1.4. Isotopic composition of hydrothermal water of Baranovskoe, Zolotoe and Kungurcevscoe epithermal deposits in relationship to the meteoric water line. Isotopic value of H was measured

directly from the fluid inclusions. Value of O was calculated using the homogenization temperature of fluid inclusions (T=250 °C, 280 °C).

Isotopic composition of present meteoric water in South Kamchatka is taken from Okrugin and Zelensky, 1997.

Data on the isotopic composition of water of Koryu and Chitose deposits in Japan, Philippines deposits, Judith deposit in USA, Emperor in Fiji and Broadlands in New Zealand is taken from Shimizu and *et al.*, 1998; Ahmad *et al.*, 1987; White, 1974.

Fig.13.2.1. Plot of $\log fS_2$ vs. temperature showing variation in value of the sulfur fugacity during formation of the cupriferous and the gold-silver ores.

Fig.13.2.2. Plot $\log fS_2$ vs. temperature showing value of sulfur fugacity of gold-silver ores of Zolotoe deposit. A plot is borrowed from Barton, 1964.

Fig.13.2.3. Hydrothermal breccias of vein 14 showing deposition sequence of clays hosting gold and comb quartz. Clays is composed of chlorite dominantly.

List of tables

Table 4.3.2.1. K/Ar dating for ore and host rocks samples of Aginskoe deposit (after Petrenko, 1999).

Table 4.3.2.2. K-Ar age of Bluzdayushee orebody.

Table 5.1.1. Bulk composition of host rocks of Aginskoe deposit.

Table 5.1.2. Bulk composition of quartz-adularia ores: Aginskoe ore body.

Table 5.1.2. Continued: Bluzdayushee ore body (B1,2,3) and Noyabr'skaya ore body (N1,2,3).

Table 5.1.2. Continued: Surprise ore body.

Table 5.1.2. Continued: Malysh ore body.

Table 5.1.3. ICP data for trace and REE for host rocks.

Table 5.1.4. ICP data for trace and REE: Aginskoe ore body.

Table 5.1.4. Continued: Bluzdayushee ore body.

Table 5.1.4. Continued: Surprise ore body.

Table 5.1.4. Continued: Malysh ore body.

Table 5.3.1. Representative micro-probe analysis of altaite from Aginskoe, Bluzdayushie, Surprise and Malysh ore bodies.

Table 5.3.2. Representative micro-probe analysis of hessite from the Aginskoe ore body.

Table 5.3.3. Representative micro-probe analysis of calaverite from Bluzdayushee and Malysh ore bodies.

Table 5.3.4. Representative micro-probe analysis of petzite from Aginskoe, Bluzdayushie, Surprise and Malysh ore bodies.

Table 5.3.5. Representative micro-probe analysis of sphalerite from Aginskoe, Bluzdayushie, Surprise and Malysh ore bodies.

Table 5.3.6. Representative micro-probe analysis of native gold from Aginskoe ore body.

Table 5.3.6. Continued: representative micro-probe analysis of native gold from Bluzdayushie ore body.

Table 5.3.6. Continued: representative micro-probe analysis of native gold from Surprise ore body.

Table 5.3.6. Continued: representative micro-probe analysis of native gold from Malysh ore body.

Table 6.1.2.1. Fluid inclusions data on vein quartz from Aginskoe ore body.

Table 6.1.2.2. Fluid inclusions data on vein quartz from Bluzdayushee ore body.

Table 6.1.2.3. Fluid inclusions data on euhedral quartz from Surprise ore body.

Table 6.1.2.4. Fluid inclusions data on gold-associated quartz from Malysh ore body.

Table 6.1.2.5. Fluid inclusions data on vein quartz from South-Aginskoe deposit.

Table 6.3.1. Stable isotope data on quartz and calcite (‰).

Table 7.2.1. Tellurite and tellurate identified (after Yakhontova and Zverev, 2000).

Table 11.1.1. Bulk chemical composition of host rocks for Zolotoe (Z1-Z5) and Baranevskoe (B1-B3) deposits.

Table 11.1.2. Bulk chemical composition of quartz-carbonate-adularia veins of Kungurcevskoe (K1-K4), Zolotoe (Z6-Z9) and Baranevskoe (B4-B7) deposits.

Table 11.1.3. ICP data for trace and REE elements for host rocks of Zolotoe (Z1-Z4) and Baranevskoe (B1-B3) deposits.

Table 11.1.4. ICP data for trace and REE elements for ores of Kungurcevskoe (K1-K4), Zolotoe (Z6-Z9) and Baranevskoe (B4-B7) deposits.

Table 11.3.1. Representative micro-probe analysis of pyrite from gold-silver quartz-carbonate-adularia ores of Baranevskoe deposit.

Table 11.3.2. Representative micro-probe analysis of sphalerite from gold-silver quartz-carbonate-adularia ores of Baranevskoe deposit.

Table 11.3.3. Representative micro-probe analysis of galena from gold-silver quartz-carbonate-adularia ores of Baranevskoe deposit.

Table 11.3.4. Representative micro-probe analysis of tetrahedrite-tennantite series minerals from cupriferous ores of Baranevskoe deposit.

Table 11.3.5. Representative micro-probe analysis of native gold from gold-silver quartz-carbonate-adularia ores of Baranevskoe deposit.

Table 11.3.6. Representative micro-probe analysis of native gold from stockwork of Baranevskoe deposit.

Table 11.3.7. Representative micro-probe analysis of native gold from carbonate ores of Baranevskoe deposit.

Table 11.3.8. Representative micro-probe analysis of sphalerite from gold-silver quartz-carbonate-adularia ores of Zolotoe deposit.

Table 11.3.9. Representative micro-probe analysis of galena from gold-silver quartz-carbonate-adularia ores of Zolotoe deposit.

Table 11.3.10. Representative micro-probe analysis of native gold from gold-silver quartz-carbonate-adularia ores of Zolotoe deposit.

Table 10.3.11. Representative micro-probe analysis of native gold from Main ore body of Kungurcevskoe deposit.

Table 11.3.12. Representative micro-probe analysis of native gold from vein 17 of Kungurcevskoe deposit.

Table 12.1.2.1. Fluid inclusions data on gold-silver quartz-carbonate-adularia ores from Baranevskoe deposit.

Table 12.1.2.1. Continue: Fluid inclusions data on copper ores from Baranevskoe deposit.

Table 12.1.2.1. Continue: Fluid inclusions data on quartz druses from Baranevskoe deposit.

Table 12.1.2.2. Fluid inclusions data from Zolotoe deposit.

Table 12.1.2.3. Fluid inclusions data on quartz from Main ore body of Kungurcevscoe deposit.

Table 12.1.2.3. Continue: Fluid inclusions data on quartz from vein 17 of Kungurcevscoe deposit.

Table 12.1.2.3. Continue: Fluid inclusions data on quartz from vein 14 of Kungurcevscoe deposit.

Table 12.3.1. Stable isotope data on quartz and calcite (‰).

Chapter I. General introduction of the research

1.1. Introduction

1.2. Location of Kamchatka, physicography and geological features

1.3. The mining history and present mining activities in Russia

1.3.1. History of mining in Russia

1.3.2. Type of developed deposits and gold productions

1.3.3. Gold resources and potential areas

1.3.4. Recent operative mines in Kamchatka

1.4. Aim and significance of the research

1.4.1. Research aims

1.4.2. Significance

1.5. Description of research methods

Chapter I. General introduction of the research

1.1. Introduction

Epithermal gold-silver and polymetallic deposits of LS and HS type are well known along the Pacific Ocean coast in such islands-countries as Japan, Philippines, Indonesia, Papua New Guinea and etc. and along the margins of continents as Far East of Russia, North and South Americas. Many scientists have studied these lodes during the long history of world gold exploration. For first time these deposits were recognized by a Swedish-American economic geologist Waldemar Lindgren in 1922. He described these deposits as “...metalliferous lodess formed in shallower part of the core by the ascending thermal waters and in genetic connection with igneous rocks...” in the Mineral Deposits monograph (Lindgren, 1933). Lindgren provided an invaluable contribution to the investigation of epithermal gold deposits. Based on the depth of veins deposition, stratigraphic characteristics of sedimentary and volcanic rocks, veins mineralogy and alteration styles W. Lindgren created a first classification of the epithermal deposits, which we still use in present. Epithermal deposits are generally formed from low and typically variable in temperatures hydrothermal fluids (150-300 °C) at depth within 2 km from a present surface.

Kamchatka is a typical volcanic-arc terrane, located in the north-west of the Pacific Ocean rim. It is an element of presently active the Kuril-Kamchatka volcanic-island arc system. In Kamchatka and Kuril archipelago are all known Russian volcanoes situated, including highest and currently active volcano in Eurasia – Kluchevskaya sopka (4850 m sl.), which located in the North Volcanoes Group in Kamchatka. Volcanoes are arranged along linear structure forming volcanic belts stretching from north-east to south-west (Fig. 1.1.). In vicinity of volcanoes the hot springs and the precious metals deposits are recognized. Among metallic deposits following types are known: placer deposits of PGM and Au, epithermal vein type complex Au-Ag-Polymetallic, Precious Metals, Cu-Ni, and Sb-Hg.

The epithermal Au-Te and Au-bearing deposits studied in PhD project are located in the Central Kamchatka mining district in the southern area of the Central Kamchatka volcanic belt (Fig. 1.2.). Two active volcanoes, Ichinsky on the north-

west and Khangar on the south, and more than 30 epithermal gold-silver and gold-copper

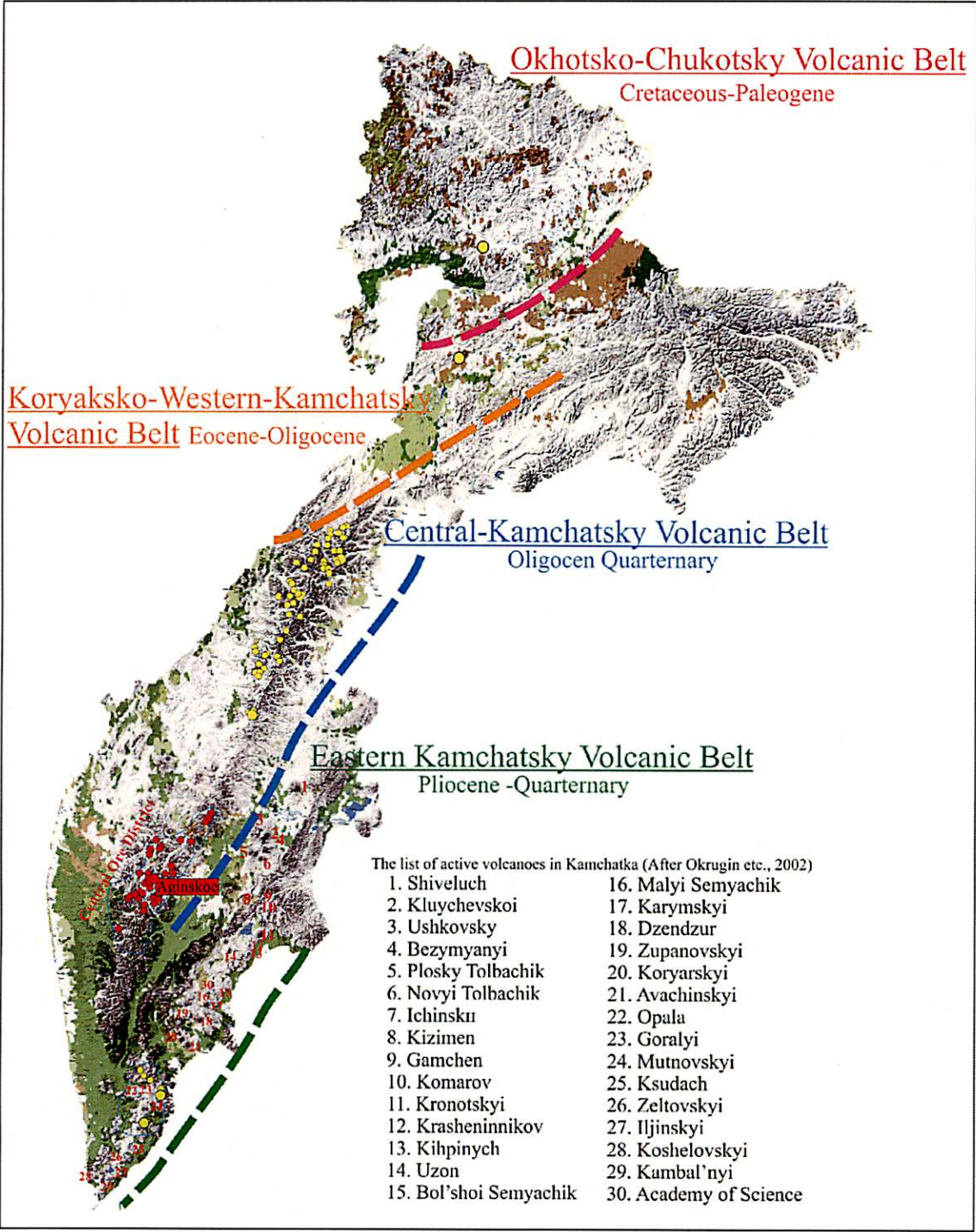


Fig.1.1. A map of Kamchatka showing distribution of the volcanic belts with location of active volcanoes and precious metal deposits (<http://maps.google.ru/>). Thick dashed lines of different color show the location of subduction zones in the relation to the volcanic belts.

deposits and ore manifestations associated with volcanic calderas and granitoid intrusions are recognized in the District. Recently restarted geological survey and prospective works in the district promote to obtain ore and wall rock samples for the detailed investigation in the laboratory. Studying area, including Au-Ag-Te Aginskoe and Au-Ag Baranevskoe, Zolotoe and Kungurcevskoe deposits, is situated in mountain range relief and located around 127 and 45 km northwest from the nearest Mil'kovo city.

Aginskoe deposit is a part of the Abdrahimovskoe ore field (Aginskoe deposit, South Aginskoe deposit, V'yun and Naichan ore manifestations) occurring on the north-east slope of the Aginsky volcano, having elevation ranging from 900 to 1360 m above sl. (Fig. 1.2.). The Aginsky volcano is an oval shaped caldera has appeared in the Middle Miocene. Epithermal veins are mainly of quartz- adularia and rare carbonate filling numerous shear fractures. The total mined and unmined resources are approximately

39 t of gold with average grade of 38.6g/t and 20 t of silver with average grade of 17.3 g/t. The Au/Ag ratio is 2-7:1 respectively. Exploitation using the underground method has started by local KamGold Company in December, 2006. Since 2006 more than 10 t of gold-silver dore has been yielded from bonanza-type veins of the mine. The Aginskoe mine connected to Mil'kovo city by a 127 km causeway.

The Balkhach ore cluster, including gold-silver Baranevskoe, Zolotoe and Kungurcevskoe deposits, occurs in 40 km away to the southeast from the Aginskoe mine in the Central Kamchatka mining district (Fig. 1.2.). Three major Au-Ag

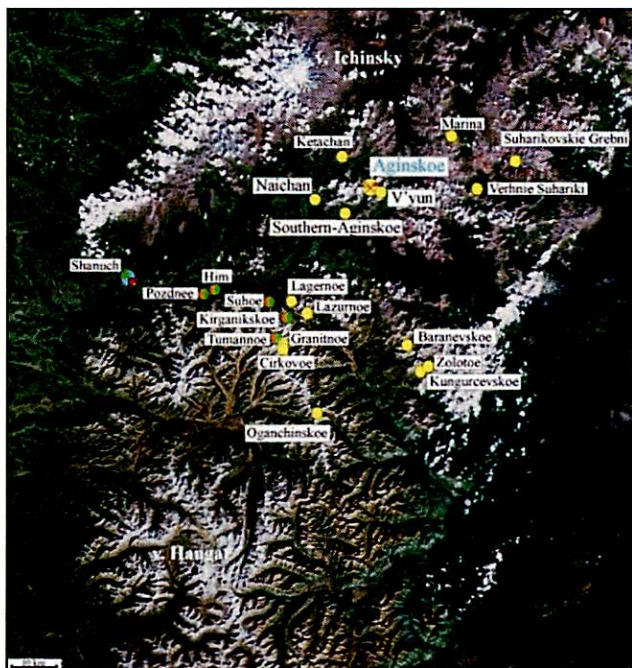


Fig.1.2. The schematic map of the Central Kamchatka mining district, showing distribution of Au-Ag (yellow circle), Au-Cu (red-green circle) and Cu-Ni-Pt (quarter of green, red and blue) deposits. Location of two active volcanoes Ichinsky on the north and Khanga on the south is shown (a map was composed by mining geologists).

deposits (Baranevskoe, Zolotoe and Kungurcevskoe), one perspective mineral prospect (Uglovoe) and range of small scale insignificant in terms of gold resources ore manifestations are recognized within the ore cluster. An estimated proven reserve for three deposits is about 45 t (<http://www.zolotokamchatki.ru>). Exploration has been done by ZolotoKamchatki Company in 200-2011. The deposits are currently being explored with future mining planned in the incoming years.

1.2. Location of Kamchatka, physicography and geological features

Kamchatka is located in the north-east of Russia, officially known as the Kamchatsky Krai. The Kamchatsky Krai is the 41st federal subject of Russian Federation (Fig. 1.2.1.). It joins a peninsular part (named as Kamchatka peninsula), mainland area and Komandor islands with total area of 472,300 km². Kamchatka peninsula having area of 270,000 km² and length of 1,250 km is adjusted to the mainland by narrow isthmus (Fig. 1.1.). On the mainland area the Kamchatka region is bordered with the Chukotka region in the north and the Magadan region in the west. From west passive coast, a peninsula is washed by the Okhotskoe Sea and from the east intensively indented coast is washed by the Bering Sea from the north and the Pacific Ocean from the south (Fig. 1.1.).



Fig.1.2.1. A map of Russia showing a division on administrative subjects (source: Wikipedia). Kamchatka is localized in the easternmost area, highlighted by a yellow color.

Kamchatka is consisted of different age volcanic belts, among which Central and Eastern volcanic belts are two youngest, composing the present structure of peninsular part. In these belts 31 presently active volcanoes are located. Meanwhile, 29 of them are occurred in a youngest Eastern Kamchatka volcanic belt, which is connected to the northwesterly subduction zone. Only two volcanoes with moderate fumarolic activities are situated in the Central Kamchatka volcanic belt (Fig. 1.1.).

Volcanic belts, distributed in Kamchatka, reflected upon its appearance. Mostly Kamchatka presents an area of high mountains separated by the lowlands. Almost 800 km long the Central Kamchatka volcanic belt or the Sredinnyi Massive or the Central Mountain Range (as it is frequently called in literature) is running from north to south hosting over 100 ancient and modern shield and composite volcanoes (Fig. 1.2.2.). The Eastern Kamchatka volcanic belt involves the volcanic belts itself and Central Kamchatka depressions zone, which lies in northern part between the Central and Eastern volcanic belts.

Rivers network is very well developed in Kamchatka because of snowy winters, high precipitations during a year, poor evaporation and mountains relief. The main longest river in the Kamchatka peninsula is the Kamchatka River with length of about 758 km. It starts in mountain range of the Central Kamchatka volcanic belt and inflows into the Pacific Ocean.

As it was mention above Kamchatka is an area of active volcanism, also, consists of more than 200 hot and cold spring spots. Some of them are located within volcanic calderas or at the bottom of volcanoes in the Eastern Kamchatka volcanic belt predominantly.

Climate is distinctly changing from the coast to the central area of the peninsula. Mostly the weather is cold and windy with prevalence of foggy and rainy days. First snow falls in late August in the mountains and in October in lowlands. Snow covering starts melting in April, however, in the mountain range persist until end of June. These specific climate features are strongly influenced on the geological survey seasons. Usually the field geological works targeting on mineral prospecting start in July and end in October. Drilling programs however continue for a whole year.

Flora and Fauna of Kamchatka are also strongly depends of weathers' conditions and reliefs. It consists of number of species of northern areas mainly; however, it is

very diversity. Unique wild nature with rarest animals and plants species led to organization of several the State Nature Conservation Zone, the National Parks and a hundred natural monuments.

Human settlements are randomly located in Kamchatka. Biggest cities are situated in southern territory with total population of around 300,000 people. The capital city, Petropavlovsk-Kamchatsky, is situated along coast of the Avacha Bay in the south-east (Fig. 1.1.). Central, West and North Kamchatka are poorly settled with people. Small towns and villages are dominantly built up along rivers and seacoast because of main occupations - fishing, hunting and gathering berries. Aborigines of Kamchatka are koryaks, itelmeny, evens, aleuts and chukchi.



Fig.1.2.2. Relief of the Central Kamchatka volcanic belt. The photo is taken by Daria Bukhanova during geological survey in 2010.

1.3. The mining history and present mining activities in Russia

Based on analytical data of 2012 Russia ranks as a 5th place on the world gold production country after China, Australia, USA and South Africa. On the known gold resources the Russian Federation occupies second position after South Africa.

Major Russian mining districts with currently active gold mines are as following: Krasnoyarsk, Irkutsk, Chita, Amur, Khabarovsk, Yakutiya and Magadan (Fig. 1.3.1.).

Russia Federation covers an area of 17,098,246 km² and consists of 83 federal subjects distinctly differs in geological and climate characteristics. The territories of Central and South Russia are old platforms with various deposits of coals and iron ores. The eastern area of Russian Federation is dominated by mountains ranges, in which deposits of gold, silver and tungsten are found. Russia includes world's largest mineral resources, in particular report of the US geological Survey concluded that Russia hosts the third most extensive gold resources (Mining Journal, 2010). Until discovery of the huge alluvial gold deposits in Siberia and Far East of Russia, the Ural region was an ancient mine leader in Russia.

1.3.1. History of mining in Russia

Russian gold mining industry began in middle of VIII century after discovery of the primary gold-bearing quartz veins on slopes of the Ural Mountains. Although, Russia is known for the huge and richest alluvial gold deposits, first gold was mined out from the hard rock deposit. Gold-bearing quartz veins were immediately put into exploitation after they were discovered in Ural Mountain Range. However, unprofessionalism and lack of experience in the explorations of mining workers affects on the slow development of the gold mining in Russia. The advance of Russian Empire eastward led to the finding of huge alluvial gold deposits, which became a main source of gold for more than 300 years Russian mining history (Fig. 1.3.1.1.). There are some reasons, which will be maintained in this chapter. Dominance of alluvial gold production distinct Russia from main world class gold producing country as South Africa, America, Australia and etc. Meanwhile, exploitation of alluvial placers rushes efforts on finding primary veins, from which placers were formed. For years primary gold deposits were in a shadow of placers gold source.

There are three large periods in Russian gold mining history. The first is time of Peter of Great ruling, who proclaimed the beginning of gold mining in Russia. The second period is related to the Soviet Union Time, generally characterized by

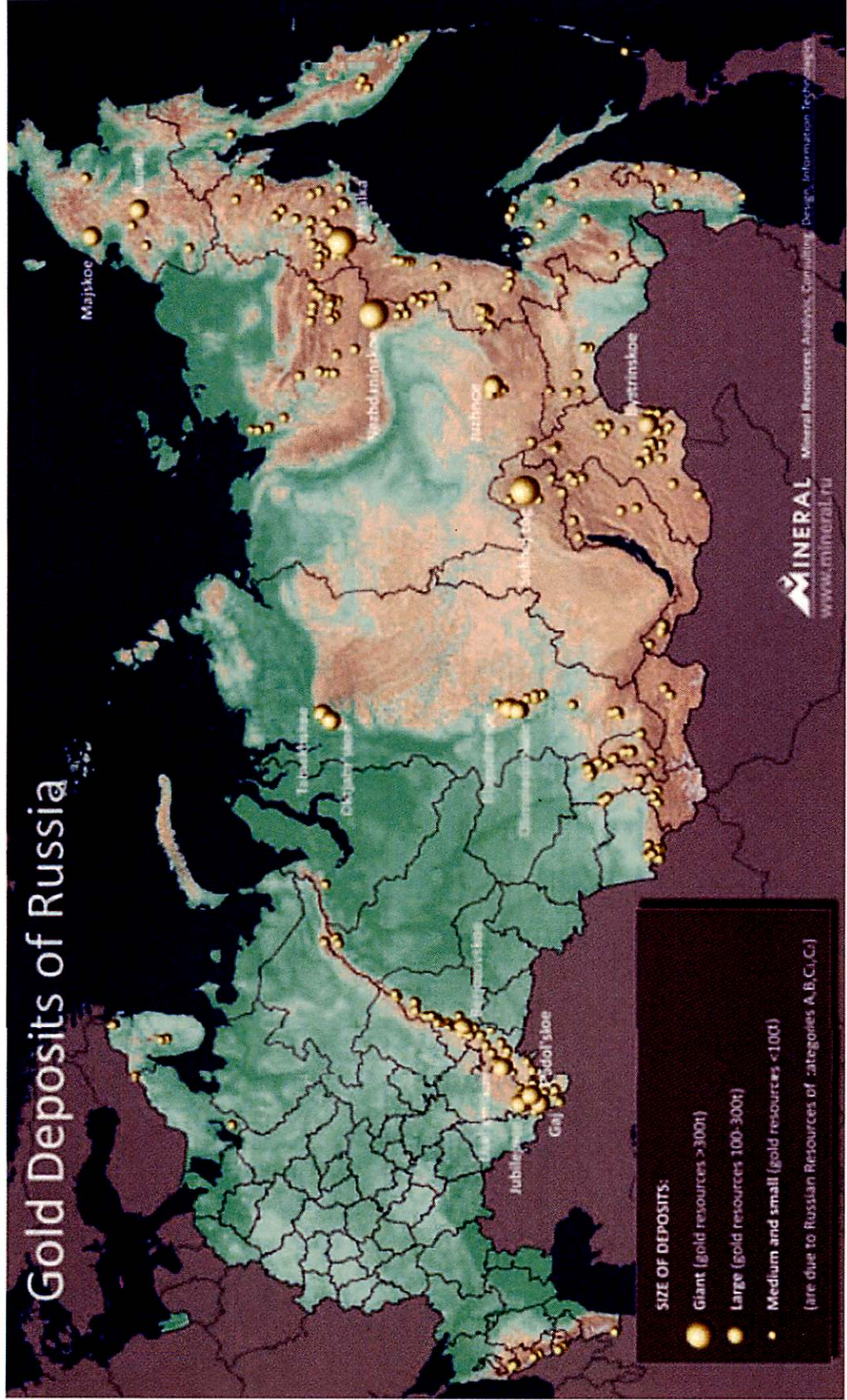


Fig.1.3.1. Localization of gold-silver deposits of different types within Russian Federation. Most of gold-silver deposits are localized in the mountains of Central and Far East districts.

intensive prospecting works activities in all regions of the country and discoveries of economic potential large primary gold deposits in Siberia and Far East of Russia. The third period is a dissolving of the USSR leading to the declining of all the kinds of geological works in the Russia and creating a new rules and law on raw resources.

Peter of Great was a high educated and innovated person. He created a law of the mining privileges stimulating the gold explorations in the entire Russia Empire. Around 18 years later posting of this Law the gold deposits were discovered in different areas and districts promising huge national resources in raw materials.

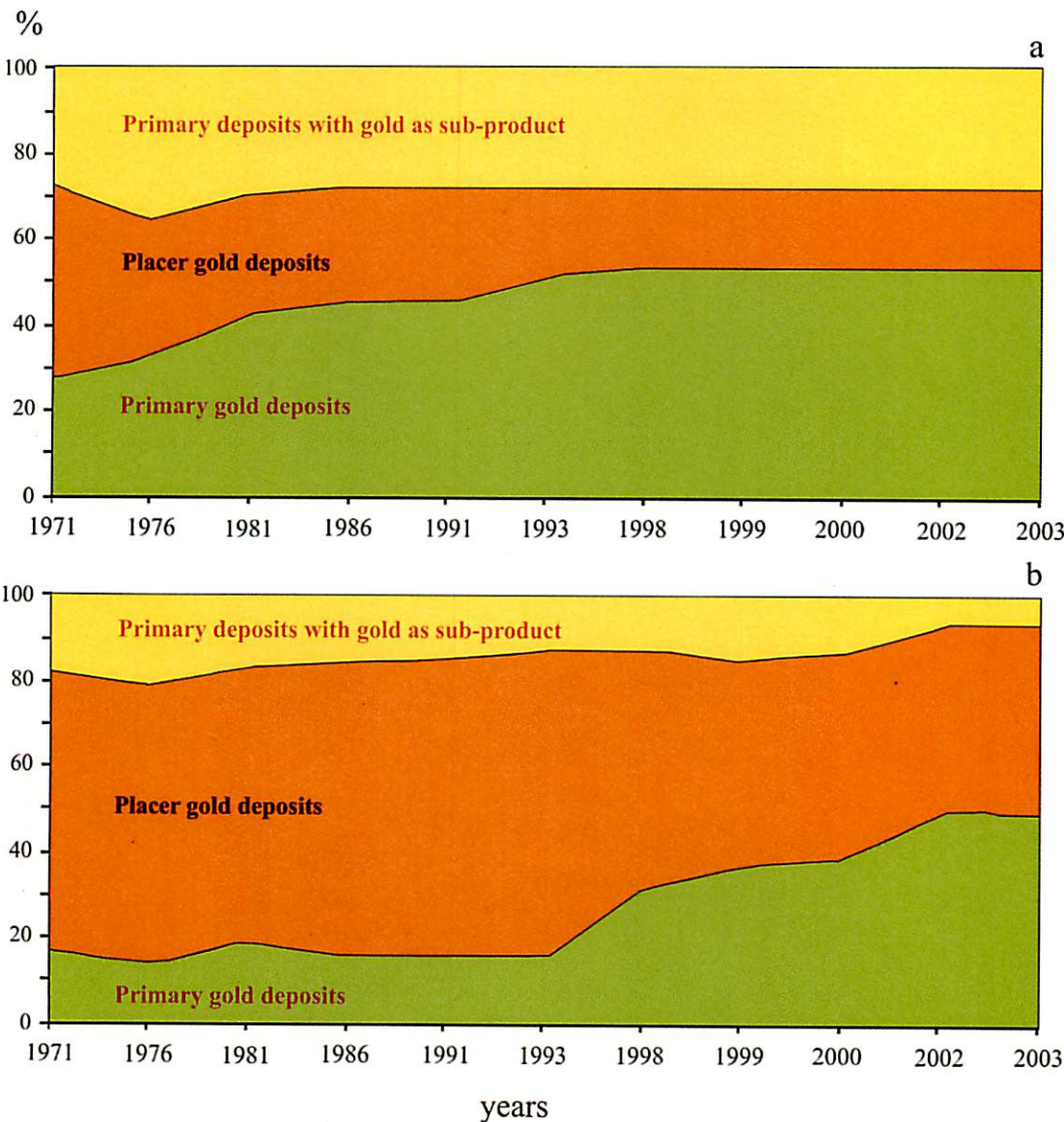


Fig.1.3.1.1. A tendency of gold resource (a) and gold mining (b) in % from the total Russian Au resources (a) and mining (b).

However, unprofessionalism of Russian geologists in the explorations led to slow growth of the mining gold industry in the Russia Empire. Furthermore, majority of Russia are wild areas, which are isolated and characterized by the severe climate conditions naturally postponed geological investigation for years. However, in that time hundreds of alluvial deposits were discovered in the mountains of Altay, Sayany and Eniseisky Krayzh. Later the Amur River placer gold deposits in Amur administrative district and Kolyma River placer gold deposits in Magadan administrative district were also found. Large reserves of gold, easy way of mining, low cost and lack of experience in the underground mining are the main factors of that the alluvial gold deposits keep monopolies positions in the Russian gold mining industry for years.

Active geological prospecting works have eventually started in the Soviet Union Time and opened a new page in Russian mining history. Although, the Soviet Mine Police was mainly targeted on continues the explorations of large scale alluvial gold deposits, the importance of the primary gold deposits was also raised for first time in this period.

During Russian Empire and the Soviet Union Time the Russian gold mining industry was owned monopoly by the government. When the Soviet Union was dissolved Russia have lost several huge gold deposits located in CIS countries, that lead to decline of total gold production in Russia. After collapsing of USSR Russia has struggled for several years under crisis and unstable economic situations, which are also negatively affected on the mining industry. Until 1998 Russian gold production has been constantly dropped, but then after a positive trend is observed. In begging of 2000 mining companies began to look for primary ores, because of depletion of gold resource in placers (Fig. 1.3.1.1.). For latest years Russian mining sector is showing stability of increasing of the gold production (Fig. 1.3.2.1.) with annual gold output of about 190 t. Experts concluded that Russia's resource potential can enable annual production approximately 300 t of Au (German Pikhiya, Gold Mining in Russia).

1.3.2. Type of developed deposits and gold productions

Statistic of gold productions from 1971 to 2005 from placer, primary and complex deposits is illustrated in Fig. 1.3.2.1. It is showing a gradually changing in a tendency of gold production from placer to primary deposits. Main mining regions regarding to the gold production and annual products are shown in Fig. 1.3.2.2. Most of the gold mines are located in eastern areas of the Russia Federation in Siberia and Far East regions (Fig. 1.3.2.2.). The third region is the Ural Mountain Range, which gold potential is concealed due to lack of prospecting works.

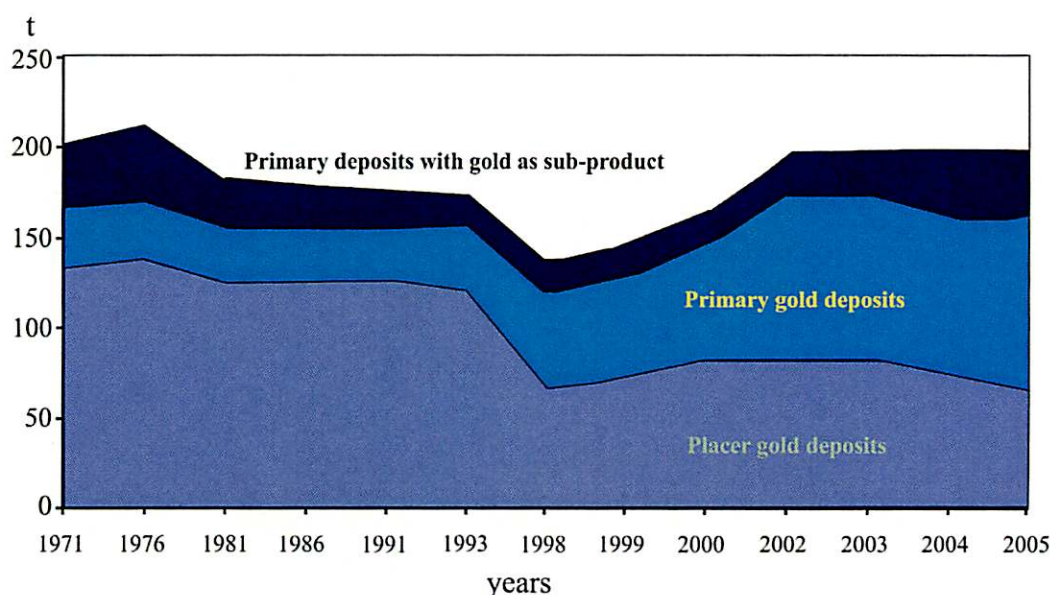


Fig.1.3.2.1. Gold mining in Russia for period from 1971 to 2005.

In Central Russia gold deposits were mainly found in Ural Mountain Range (Fig. 1.3.1.). And as it was said the Ural region was the first place, where primary gold-bearing quartz veins were found and mined in Russia. The exploitation of the Berezovskoe mine in 1744 opened a mining history in Russia. As many other mining districts now days Ural is suffering from lack of explorations works holding back mining sector in the region. In Ural three alluvial gold districts are recognized: the Southern, the Northern and the Subpolar areas, distinguished by distinct mineralization types of deposits. Although, production of gold is decreasing with years the experts keep expectation that this area is a highly potential for future finding of both alluvial and underground resources. Gold is mainly found in quartz and sulfide deposits and bedrocks (Mining Journal, 2010).

In Siberia region several mining districts are known, which are preferentially located in the south area (Fig. 1.3.1.). This region is famous for the alluvial operation started in 1830. Now days a leader of gold producing is Krasnoyarsk territories, supplying about 20% of internal gold production. Gold deposits are basically found in the Enyseisky Kryaz, however, there are some potential areas for gold finding in the eastern and the western Sayan territories and also in Tymir district. In Siberia the exploration future is also associated with Zabaikalsky Krai and Irkuts, known for the large gold productions from alluvial deposits. Although, the alluvial gold industry presently undergoes depletion in resources it is still dominant on the underground outputs in this area. Largest underground gold resource with tonnage over 300 t of Au established in Sukhoi Log, Baleeskoes, Bamskoe and Olimpiada deposits.

Far East of Russia is enriched in mineral raw resources, not only gold (Fig. 1.3.2.2.). Magadan, Khabarovsk Krai, Sakha and others administrative districts of Far East include deposits with gold resources of about 100 t each. Khabarovsk krai is one of the districts in the Far East region poses as a first place, where hard-rock gold production overcomes alluvial (Mining Journal, 2010).

Generally primary deposits are still remained unmined. Tendency of changing exploration from alluvial to the primary deposits is observed, however, placer gold deposits are leaders of gold industry in many regions.

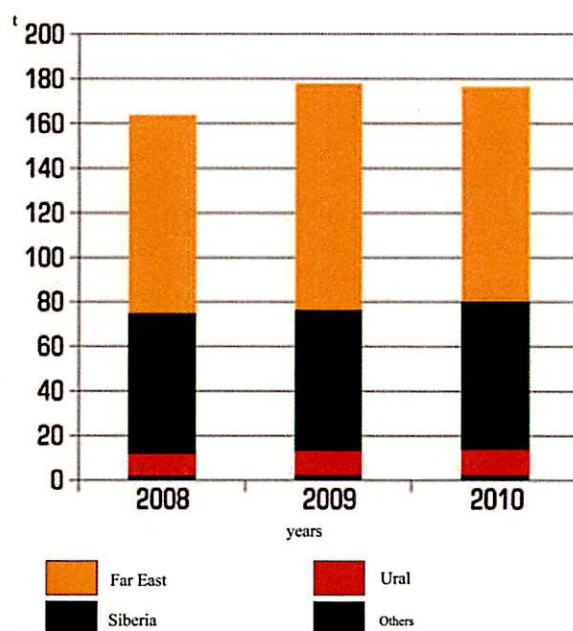


Fig.1.3.2.2. Gold production in Far East, Siberia, Ural and other regions of the Russian Federation.

1.3.3. Gold resources and potential areas

As it was described previously majority of gold underground resources are not mined yet in Russia. Almost half of Russian's gold has been produced in Magadan, Krasnoyarsk and Sakha Republic. Siberia and Far East federal subjects contribute around 163 t of Au annually, which is almost 93 % of total mined gold in Russia. However, Far East is a doubtless leader in mining industry (Fig. 1.3.2.2.), producing gold in two times greater than Siberia. Alluvial gold, being a main metal source for years, was however used in explorations. It is provided great geological information on gold mineralization at the certain areas. For examples, large alluvial placers known along the Lena River indicates a high erosion of the primary ores. Recent discovery of such huge deposit as Shikhoi Log in Irkutsk oblast is an evidence of high potential of this area on the underground mining.

Most active regions in terms of gold producing with 100 years history of mining are following: Krasnoyarsk, Magadan, Chukotka, Amur, Sakha (Yakutia) and Irkutsk, which are hosted majority of Russian gold (Fig. 1.3.3.1.). Most of gold were produced from the Kolyma River in Magadan region during Soviet Union Time. During exploration of the alluvium gold a number of the hard-rock deposits were discovered in Magadan in 1940s, however, intensive exploration has began in 1980s. In 1980-90s numerous large deposits were found there. Among them Kubaka, Shkol'noe, Arilakh, Lunnoe and Julieta Au-Ag deposits. Some companies continues exploration on the placer gold, however, currently established gold resources of primary deposits are in two times higher than alluvium ones in the region. The primary gold is concentrated in epithermal deposits of three types: gold-silver, gold-quartz and gold-sulfide-quartz. Magadan was also first region in Russia, who made a contract on exploration works with foreign companies.

Republic Sakha, Krasnoyarsk, Irkutsk, Chita, Amur and Khabarovsk Krai are also consisted of giant deposits with gold reserves over 100t (for examples: Natalka, Nezdansinskoe Sukhoi Log and Bamskoe), but mining of these deposits have been started yet.

Kamchatka is located in far easternmost area in the Far East region. Within the volcanic belts enormous numbers of epithermal deposits are scattered. They are typically of LS types, but some of HS are also known. Besides Kamchatka is a

promising area for finding porphyry deposits. Mining with full gold refractory is operated at the Aginskoe Au-Ag-Te deposit in the Central Kamchatka mining district and recently started at the Asachinskoe Au-Ag deposit in the South Kamchatka mining district.

In 2007 the State Reserves Register reported of 5862 gold deposits in Russia. Among them 5443 are placers, 419 are primary and 133 are in which gold is as a sub-product. Russian gold deposits are remarkably differing from foreign analogous. Average gold grade in Russian deposits is about 2.38 g/t and cutoff for explicated deposits is 4.06 g/t, while worlds' standard is from 1.9 to 3 g/t. Exact number of primary and placer Au deposits with total tonnage located in Far East is shown in Fig. 1.3.3.1.

1.3.4. Recent operative mines in Kamchatka

In Kamchatka gold was found during expedition headed by Karl Ivanovich Bogdanovich in 1897. It is noteworthy, that first gold discovery was made in the Central Kamchatka mining district a leader of mining in present. The expedition, organized by the Administration Committee of the Russian for Mineral Resources and State Property, was targeted on discovery gold provinces along the western coast of Kamchatka peninsula. During the geological survey in the Central Kamchatka Mounting Range, Bogdanovich washed out alluvial sand in the Oblukovina River and found specks. Prior to Bogdanovich's coming to Kamchatka, local people and migrant workers talked the myth about huge placer gold deposits and large gold nuggets. However, the highland relief and bad infrastructure made this region as the inaccessible area for years. Also, Kamchatka is fairest region of Russia, thus the financial expenses for the development of such "wild" territory as Kamchatka was forbid the mining activity (<http://www.npacific.ru/np/library/publikacii/smyshliaev/geolkam.htm>).

By the middle of the XX century geological prospecting works were reactivated in Kamchatka. Financially supported by the government the intense mineral prospecting works for over 10 years have resulted in the discovery of 14 gold-silver deposits, 100 mineral prospects and 400 small placer deposits. First mining operation with full gold recovery has begun at the Aginskoe mine in

December, 2006. The deposit is located in the Central Kamchatka mining district. For last 6 years it was the one mine in Kamchatka. In September, 2010 the Asachinskoe deposit, which located in the South Kamchatka mining district, was finally set on the exploitation. The Asacha deposit is owned by the Trevoznoe Zarevo Company.

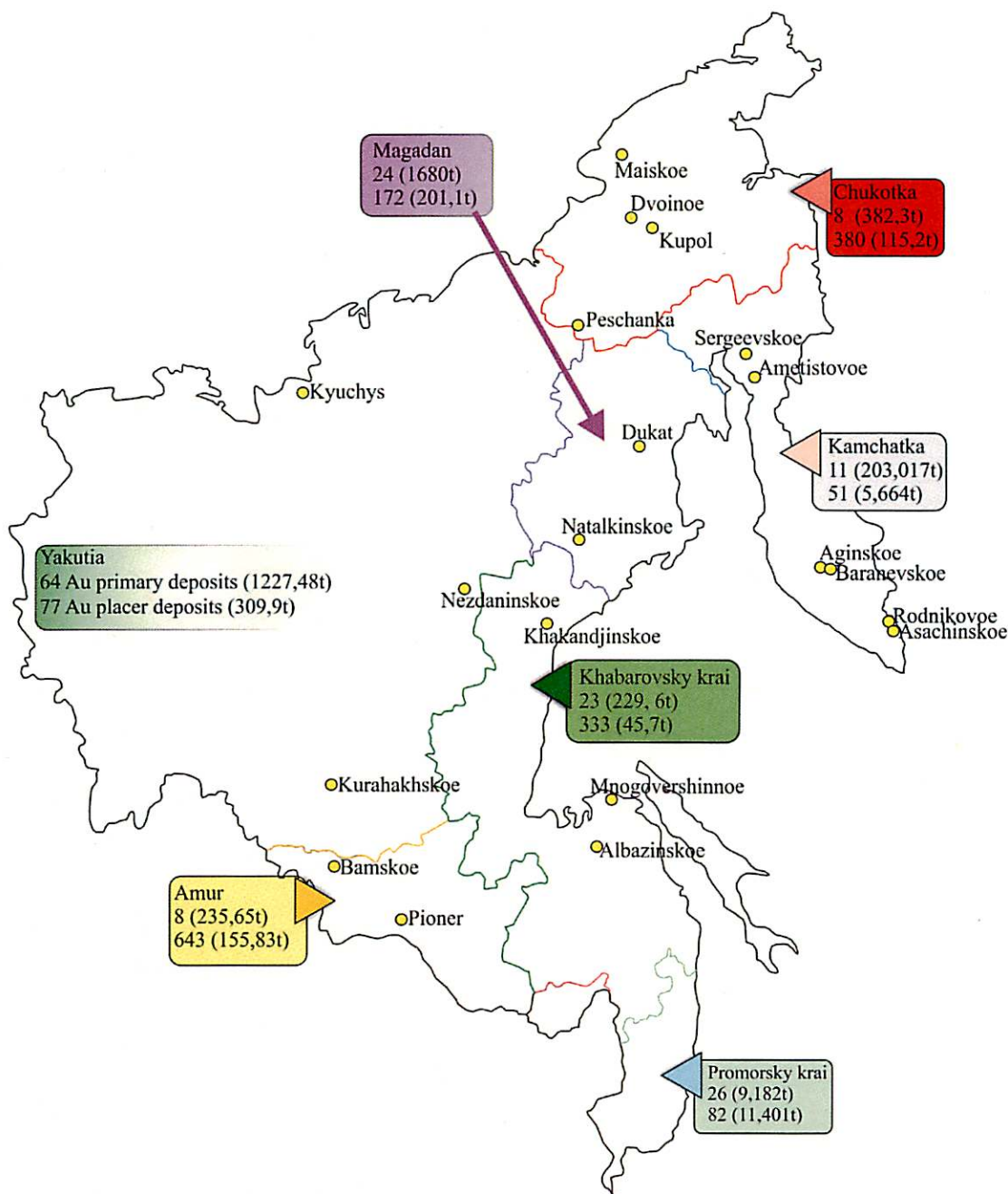


Fig. 1.3.3.1. A sketch map of Russian Far East region with localities of largest Au deposits. Colored blocks show number of known Au primary and placer deposits and their tonnage within brackets. A map was created by author using data from the official site of the Far East Department of Raw Resource.

1.4. Aim and significance of the research

1.4.1. Research aims

Epithermal style precious metal deposits associated with volcanic calderas of coincident age have been studied in this PhD project. The main aim of this research is to estimate physicochemical conditions of mineral deposition and to constrain the genetic model of Au-Ag-(Te) epithermal mineralization in the Central Kamchatka mining district. Additionally, the author attempted to define factors controlling the chemical composition of the Au-Ag alloy and the relationship of volcanism to the ore formation process.

1.4.2. Significance

The information provided in this dissertation includes absolutely new data obtained from fieldwork, laboratory study and a compilation of existing Russian literature pertaining to regional fault systems that control metallic mineralization in Central Kamchatka. The studying area is currently intensively investigated on the purpose to explore known Au-Ag deposits with re-studying of geology and re-estimating mineral resources, and to find new economic potential epithermal veins. First mineral prospecting work have started in late 60s, since then very limited data on styles of metallic mineralization, specify of ore occurrence, vein and alteration rocks mineralogy, and relationship with intrusive bodies have been published. The result of this study may be applied in the exploration works.

1.5. Description of research methods

A collection of ore and host rocks samples used in the PhD research was collected from Au-Ag-Te Aginskoe deposit and some Au-Ag deposits, located at the Balkhach ore cluster in the Central Kamchatka mining district. Specimens were collected in the underground tunnels in the Aginskoe mine and the trenches and outcrops of veins in the Balkhach ore cluster. Additional extra samples for a research were provided by professor of the Kamchatka State University Victor Okrugin.

To attained a main aim of the research – estimation of the physicochemical conditions and construction of the genetic models for Au-Ag-Te and Au-Ag mineralization occurring in the Central Kamchatka mining district samples were investigated by following methods: ore microscope observation, elemental mapping, electron microprobe analysis, X-ray fluorescence spectrometry, inductively coupled plasma atomic emission spectrometry, fluid inclusion, Ar-Ar analysis for vein samples, X-ray powder diffraction, petrography of host rocks, stable isotope analysis and Raman spectroscopy.

Microscope observation

The polished thick sections prepared for electron-micro probe analysis and double-polish thin sections for the fluid inclusion studies were primary investigated by the microscope Nikon eclipse E400 POL in the Hokkaido University (Fig. 1.5.1.). Minerals, their association and fluid inclusions were pictured by the digital camera Nikon. Polish sections, prepared for the host rock samples and ores for the investigation quartz textures were also observed under Nikon reflect and transparent light microscope.

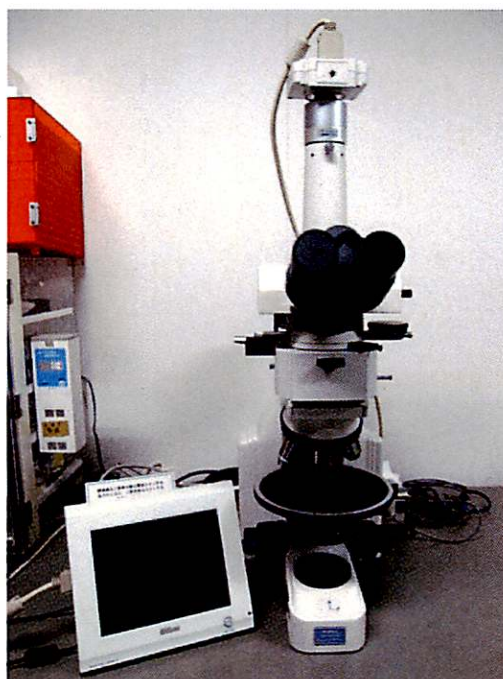


Fig.1.5.1. The microscope Nikon eclipse E400 POL with Nikon digital camera was used for the observation of quartz textures, ore and host rocks minerals.

Elemental mapping of vein samples was conducted in the Hokkaido University using machine SEM-EDS JSM-5310 & Oxford Energy200 with sensitive x-ray detector. Elemental mapping provided information of distribution of elements within the minerals, textural context and compositional zonation.

Electron Microprobe Analysis

The main purpose of the electron probe micro-analyzer EPMA is the quantitative elemental analyses of solid-state materials at the micron scale. In other words, a solid material such as a mineral, metal or glass can be analyzed at a scale of a few microns or less. This allows the detection of small compositional variations within an individual crystal, for example, which could not be observed by some sort of bulk chemical analysis. Unknown secondary Te-bearing minerals, which are represented a mixture between three or even four minerals were not measured by means of EPMA in this study.

Chemical compositions for individual ore minerals grains were identified in 60 µm thick sections by "EPMA, JXA-733" and Camebax with EDS of Oxford Instrumental X-mas 80 at the Laboratory of Volcanogenic Ore Formation, Institute of Volcanology and Seismology Far East Russia, Kamchatka. Detector conditions were 20 kV acceleration voltage, 20 nA beam current, and probe diameter of 1-2 µm. Natural galena and chalcopyrite along with synthetic pure metals of Au, Ag, Se and Te were used as standards materials for correlation.

X-ray fluorescence spectrometry was used for bulk analyses of larger fractions of geological materials. In this study X-ray fluorescence method was applied for bulk samples of host rocks to determine major and rare earth elements concentration. Approximately 30 samples of host rocks were analyzed by using the S4-PIONEER in the Institute of Volcanology and Seismology, Kamchatka, Far East of Russia.

Inductively Coupled Plasma Atomic Emission Spectrometry and X-ray fluorescence spectrometry

The chemical composition of ore samples for high grade ores and altered host rock samples were obtained by Inductively Coupled Plasma Atomic Emission Spectrometry at the Nuclear physics and Mass-spectral Laboratory, Moscow, Russia and ACME labs, Vancouver, Canada.

Inductively Coupled Plasma was used to determined concentration of main elements in the ore. By the ICP data histograms of distribution elements have been created.

Age dating

Main reason of age dating was to establish a time gap or continuous deposition of banded quartz-adularia ores from the Aginskoe deposit. K/Ar age dating on two concentrate samples of vein adularia was obtained at the Isotopic Geochemistry and Geochronology laboratories, Moscow, Russia.

Fluid inclusion study

Around 60 doubly polish think section were prepared of transparent quartz to measure the homogenization and the melting temperatures of the fluid inclusions. The ore minerals such sphalerite, which commonly used for the fluid inclusions study were not used this time because of very small size of grains. The preparation was followed by the classic methodology. Firstly, transparent parts of the vein were cut off by Hitachi cutting machine. The following three stages consisted of polishing. Square-cut blocks were smoothed by coarse grained sand from 200 to 800, using Hitachi polish machine. The next stage consisted of polishing by hand using fine-grained sand from 1000 to 4000 mesh on the glass. Blocks were polished smoothly using Hitachi polish machine on three diamond disks. When quartz became clear it was attached, using glue, to transparent glass. The secondary cutting was done by «Buehler Isomet low speed saw» and new sides of the samples were polished from the beginning.

Microthermometric measurements were performed on vein quartz using a Linkam TH-600 heating-cooling stage at the Hokkaido University. The heating rates for ice melting and homogenization were $0.1\text{ }^{\circ}\text{C min}^{-1}$ and $1\text{ }^{\circ}\text{C min}^{-1}$, respectively.

X-ray Powder Diffraction

Alteration of wall rocks and gangues minerals were determined for 20 samples using X-ray diffraction. Data for host rock alteration were complemented by petrographic examination. XRD was done for powdered bulk rocks and clay-separate using Rigaku Mini FLEX at Hokkaido University (Fig. 1.5.2.).

In purpose to get the clear spectrum of the clay minerals and separate smectite and chlorite diffraction peaks the quantity weighed for XRD analysis were prepared by following technique. The bulk probes of host rocks were crushed and melt down in the distillation water for 8 hours. The clay minerals due to more light weight concentrate on the upper lever, however, more heavier plagioclases settled down. The clay-mineral rich layer was concentrated on the bottom by machine.

Stable isotope analysis

Isotopic compositions of gangue (quartz, adularia, carbonate, clays) and ore (pyrite, sphalerite, galena) minerals are essential for the discussion on the origin of hydrothermal fluids and ore mineralization. In this study gangue quartz and calcite associating with ore minerals were used for the isotope studies. Oxygen and calcite stable isotope analyses were carried out at the Stable isotope laboratory, Vladivostok city, Russia. Isotopic values of quartz are reported relative to the reference international standard VSMOW in ‰, and carbon values are reported PDB in ‰. Hydrogen isotopic analyses were completed at Actlabs, Canada. Results of analyses are given in the familiar notation in per mil relative to the V-SMOW standard.

Raman spectroscopy is a non-destructive technique used for the identification of solid, liquid and gaseous phases trapped in inclusions. The most significant the Raman spectroscopy allows to analysis phases with diameter 1-10 μm . Around 60 polish-thin sections were analyzed by the Raman spectroscopy method using

Renishaw inVia Raman microscope in the Open Facilities of the Hokkaido University (Fig. 1.5.3.).



Fig.1.5.2. Rigaku Mini FLEX used for XRD analysis of altered host rocks and veins samples at the Hokkaido University.



Fig.1.5.3. Renishaw inVia Raman microscope in the Open Facilities of the Hokkaido University.

Chapter II. Epithermal mineralization occurring along Pacific Ocean coast: types, styles and relationship to magmatism

2.1. Active continental margins: origin of magmatism and an influence to the ore deposits

2.1.1. General introduction to the magmatism originated in the subduction zone

2.1.2. The Kuril-Kamchatka volcanic arc system

2.1.3. Descriptions of the Kamchatkan volcanic belts and present location of the subduction zone

2.2. Volcanic hosted epithermal deposits

2.2.1. Classification of epithermal deposits

2.2.2. Distribution of Au-Ag epithermal deposits in South-Western part of Pacific Fire Rim

2.2.3. Descriptions of epithermal deposits occurring in Kamchatka

Chapter II. Epithermal mineralization occurring along Pacific Ocean coast: types, styles and relationship to magmatism

2.1. Active continental margins: origin of magmatism and an influence to the deposits

The plate tectonics theory is a dominant model, explaining the origin of the magmatism within plates and on the margins of the continents. Depends on the tectonic activities generally two types of continent margins are commonly recognized: active and passive. The former type of the continental margins includes subduction zone and collision zone subdivision. The subduction zone is generally occurred at coastline of the Pacific Ocean, where an oceanic plate is being sinking under the continental one (for example, Far East of Russia, Japanese islands, Philippines, Indonesia, Papua New Guinea, Fiji, Solomon Islands and New Zealand). In these areas the majority of present magmatic activity along with high-volumetrically volcanic eruptions and earthquakes is occurred (Fig. 2.1.1.). The zone of subduction differs from the passive margins in structure, morphology and tectonics. Meanwhile, the passive margins are typically occurred at the back-arc sea. The subducted oceanic plate and overriding continental plate form a wedge-shaped mode known as an ocean trench. All magmatic acts expressed as earthquakes and volcanic eruptions on the surface or plutonic igneous rocks in the upper horizons of the continental crust are originated in the zone extending from the ocean trench to the deepest parts of the subducted oceanic plate. Typical feature of the subduction zone made them recognizable from other types of active convergent margins is a chain of volcanoes built up right after a subduction zone. To this reason, they are often called as the volcanic-arc systems or in case of islands the island arc system. Some of island arc systems are consisted of one chain of volcano, while others consist of two or three volcanic belts (for example, Kamchatka island arc). Chains of volcanic belts are inherited a linear form from the oceanic trench to which they are connected.

In case of a magmatic melts crystallize in the continental crust without reaching a surface, igneous plutonic and subplutonic bodies of various size and composition are formed. They favors to formation of the metallic mineralization of different types from deep-seating Cu-Porphyry to shallowest hydrothermal deposits. The deposits of Cu, Au, Ag and others metals containing thousand tons of metals are

revealed a close relation between subduction zone and occurrence of precious mineralization (Sillitoe, 1994 and White, 1995).

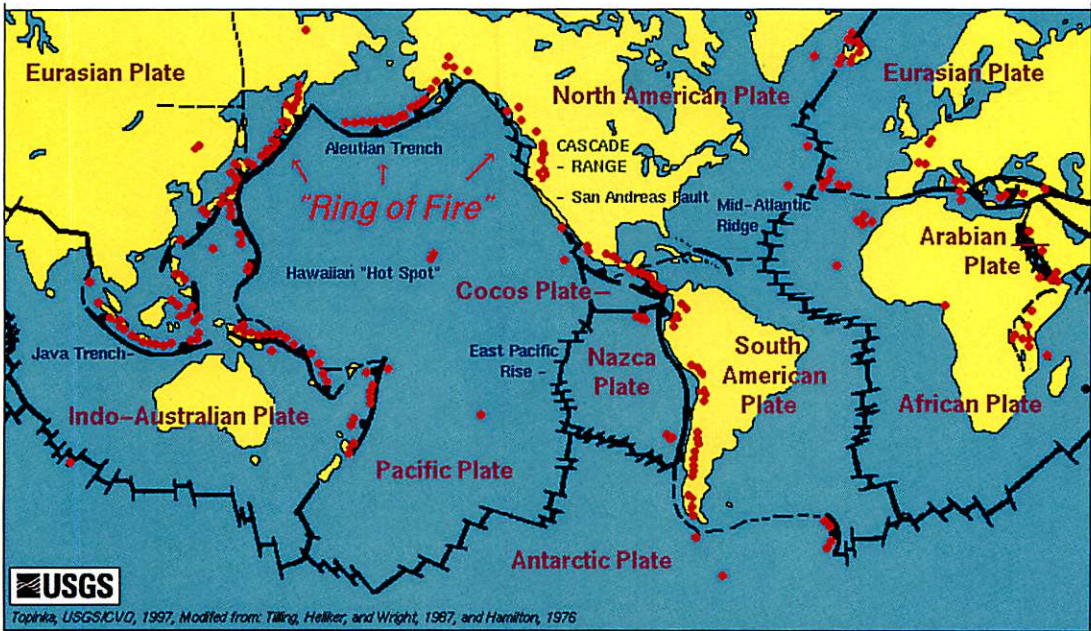


Fig. 2.1.1. A map of different style of plates' boundaries. A map was taken from a web site: http://www.gweaver.net/techhigh/projects/period1_2/Yellowstone/Plate%20Tectonics.html

2.1.1. General introduction to the magmatism originated in the subduction zone

The subduction zone occurring along the continental margins in the Pacific Rim of Fire presents a complex mechanism of modern magma generation (Fig. 2.1.1.). Number of papers was written to explain a process that lead to a production of the magmatic melts (Tatsumi *et al.*, 1986; Hall and Smyth, 2008 and etc.). In general speaking, a cold ocean plate, carrying sediments, subducts under the continental crust and sinks into the mantle influenced on increasing of the temperature and pressure. Those island arcs that formed from one source of magma are primitive. They usually produce High-Mg and Low-K basalts (Plechov, 2011). Evolution of subduction zone affects on the growth of the continental overriding crust. Magmatic melts migrating from a sinking oceanic plate through the thick overriding continental plate is mutated due to mixing with other melts of different composition. As results, basaltic, andesitic, dacitic and rhyolitic volcanic rocks are formed from mixed magmatic melts. Those arcs, consisting of different composition

volcanic rocks, are named mature arcs. In fact, the mature arcs are more common than the primitive ones. In 1974 Ringwood proposed a model of magma generation on example of primitive arc lavas (Fig. 2.1.1.1.). Basaltic lavas of the primitive island arcs may be originated by the dehydration of the hydrated ocean crust at depth of 100km due to enriched in amphibolites. Mobile fluids are rising up into the peridotite mantle wedge forcing the melting of surrounding cold rocks with later crystallization of Mg-rich olivines and pyroxenes basalts. Calc-alkaline rocks composing the mature arcs are originated through melting of eclogite. Different composition volcanic rocks, composing mature island arcs, reflects variety of magma source, enrichment of mantle wedge in the fluids, supplement of sediments and melting degree of mantle (<http://www.le.ac.uk/geology/art/gl209/lecture6/lecture6.html>).

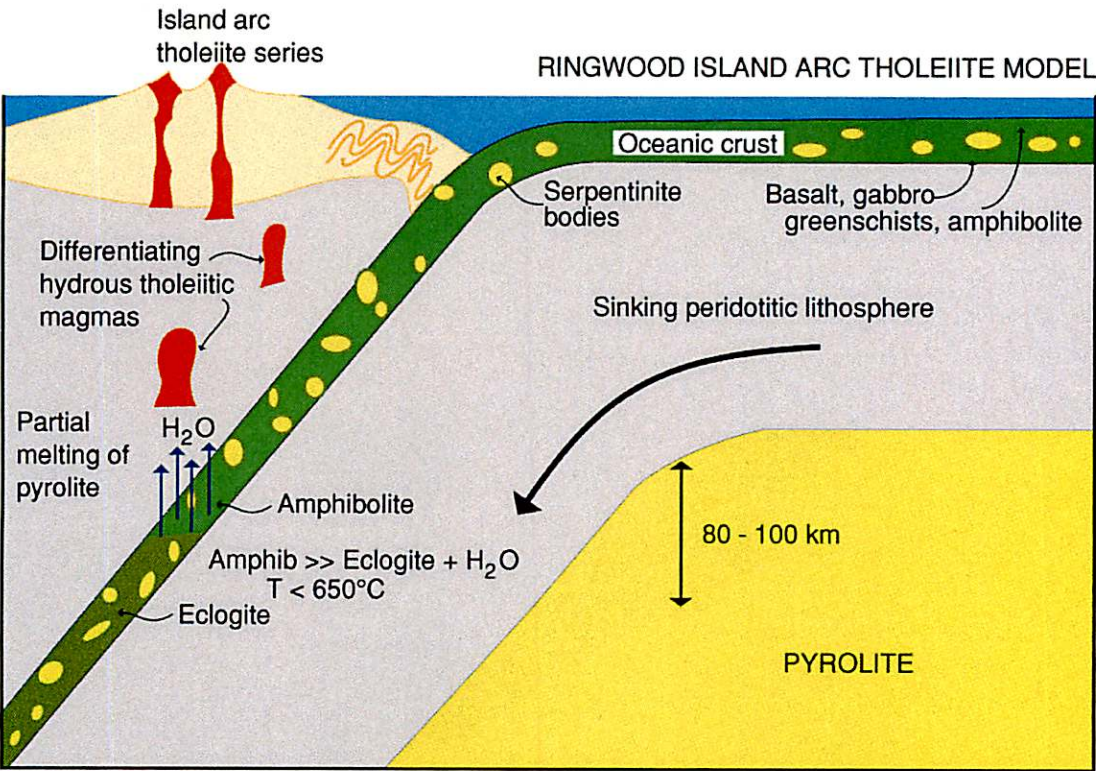


Fig.2.1.1.1. The cartoon illustrating Ringwood’s subduction zone model for a primitive island arc composed of basalt. A model includes major elements: subducted oceanic crust, release of H₂O from amphibolite, formation of tholeiitic magma and a volcanic front. Photo is taken from website: <http://www.le.ac.uk/geology/art/gl209/lecture6/lecture6.html>

2.1.2. *The Kuril-Kamchatka volcanic arc*

The Kuril-Kamchatka island arc, extending from the north-east of the Kamchatka peninsula to down north-east of the Hokkaido island, consists of two main segments: Kamchatka volcanic arc and Kuril volcanic island arc (Fig. 2.1.2.1.). While the Kuril segment of island arc includes a single volcanic belt, the Kamchatkan segment is build up by four parallel volcanic belts, which were active in different geological time. However, currently active volcanoes are located in the youngest the Central Kamchatka Oligocene-Quaternary and Eastern Kamchatka Pliocene-Quaternary volcanic belts. Geochemical difference between volcanic rocks of the Central and Eastern volcanic belts of Kamchatka will be detailed described in the subsequent sections. Herein, only general characteristics of the Kuril-Kamchatka island arc are given.

The Kuril-Kamchatka is a mature 2,200 km long island arc composed mainly of calc-alkaline volcanic rocks. It has appeared in Late Oligocene or Early Miocene time, however, a present configuration of arc system was formed in Late Miocene-Early Pliocene Time. The arc was developed as result of migration of the ancient subduction zone, localized along the Central Kamchatka volcanic belt in the Oligocene-Miocene time. There are hundreds of volcanoes occurred in Late Cenozoic time. In the Eastern Kamchatka volcanic belt 29 volcanoes are in active stage. In the Kuril arc 39 volcanoes are active now. Moreover, around 104 marine volcanoes are located to the west from the Kuril archipelago (Martynov *et al.*, 2007, 2010; Chudaev *et al.*, 2008). The Kuril-Kamchatka island arc was intensively studied by numerous researchers, but mostly these studies were targeted on volcanic rocks of Pliocene-Quaternary. The results of studies were published in Russian literatures mainly. An ocean plate dips at angel of 36-40° with rate of 10 cm/year under the Kuril segment of the arc, and under the Kamchatka segment at angel of 45-50° with rate of about 8-9 cm/year (Volynech, 1991; Avdeiko *et al.*, 2007). The Emperor seamounts are subducted in north of the Kamchatka arc. Chemical composition of Late Cenozoic volcanic rocks is broadly ranging from basalt to rhyolite. In terms of potassium content, volcanic rocks are generally subdivided into Low-K, medium-K

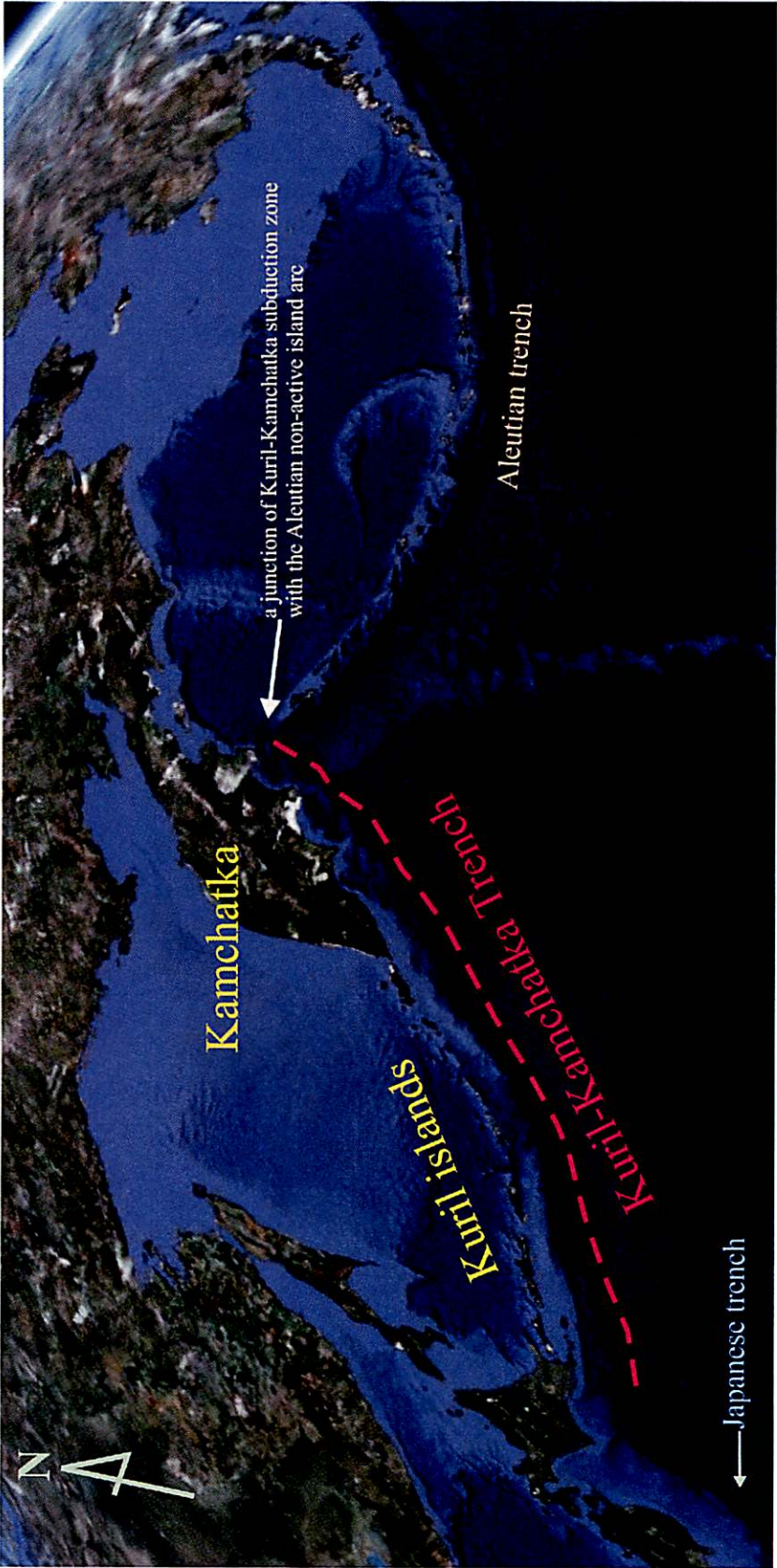


Fig. 2.1.2.1.1. A satellite image of the North-West area of the Pacific Ocean. The Kuril-Kamchatka island arc is connected to the Aleutian non-active arc in the north-east and to the Japanese active arc in the south-east. A map was created by author using Google map satellite image.

and high-K and in terms of alkaline content the shoshonite-latitude series into normal and alkaline lava series, which are also subdivided on FeO/MgO into tholeiitic and calc-alkaline varieties. However, generally volcanic are of intermediate-K calc-alkaline types in both Kuril and Kamchatkan segments of the arc. Within plate volcanics are also found in the Kuril-Kamchatka island arc. They are subdivided into subalkaline and alkaline types and distributed across modern volcanic belts and in rear zone of the Central Kamchatka volcanic belt.

2.1.3. Descriptions of the Kamchatkan Volcanic Belts and the present location of the subduction zone

It was mentioned in the previous section that Kamchatka consists of four volcanic belts, which became younger toward the Pacific Ocean. They are Okhotsko-Chukotsky (Cretaceous-Paleogene), Koryaksko-Western-Kamchatsky (Eocene-Oligocene), Central Kamchatsky (Oligocene-Quaternary) and Eastern Kamchatka (Pliocene-Quaternary) volcanic belts (Petrenko, 1999). The former two belts are not active in present and only fragments of them are recognized in the north of Kamchatka mainland and the western coast of the Kamchatka isthmus. It is needed to be noted that only a few published data available on geology, geochemistry and petrology of these belts. Most of geologists are interested in the Eastern Kamchatka volcanic belt and the Central Kamchatka Depression zone, where magma is generated in the present time. Large volcanic calderas, associating with a long-term magmatism, are predominantly localized in the Central and Eastern volcanic belts (Bindeman *et al.*, 2010). A mechanism explaining formation of Kamchatkan volcanic belts is a “jumping” of subduction zone has been adopted by many Russian geologists (Volynets, 1991; Bindeman *et al.*, 2010). The present ocean trench is located in 200-250 km to the east from the Eastern Kamchatka volcanic belt (Fig. 2.1.2.1.). From Oligocene to Miocene an oceanic trench was located about 200 km to the west from the present location. In Middle Miocene a trench has migrated to the east. Thus, the Central Kamchatka volcanic belt has lost a direct connection with a trench; however, a volcanic activity was continued until Late Holocene with formation of a number of composite and shield volcanoes upon on Oligocene-

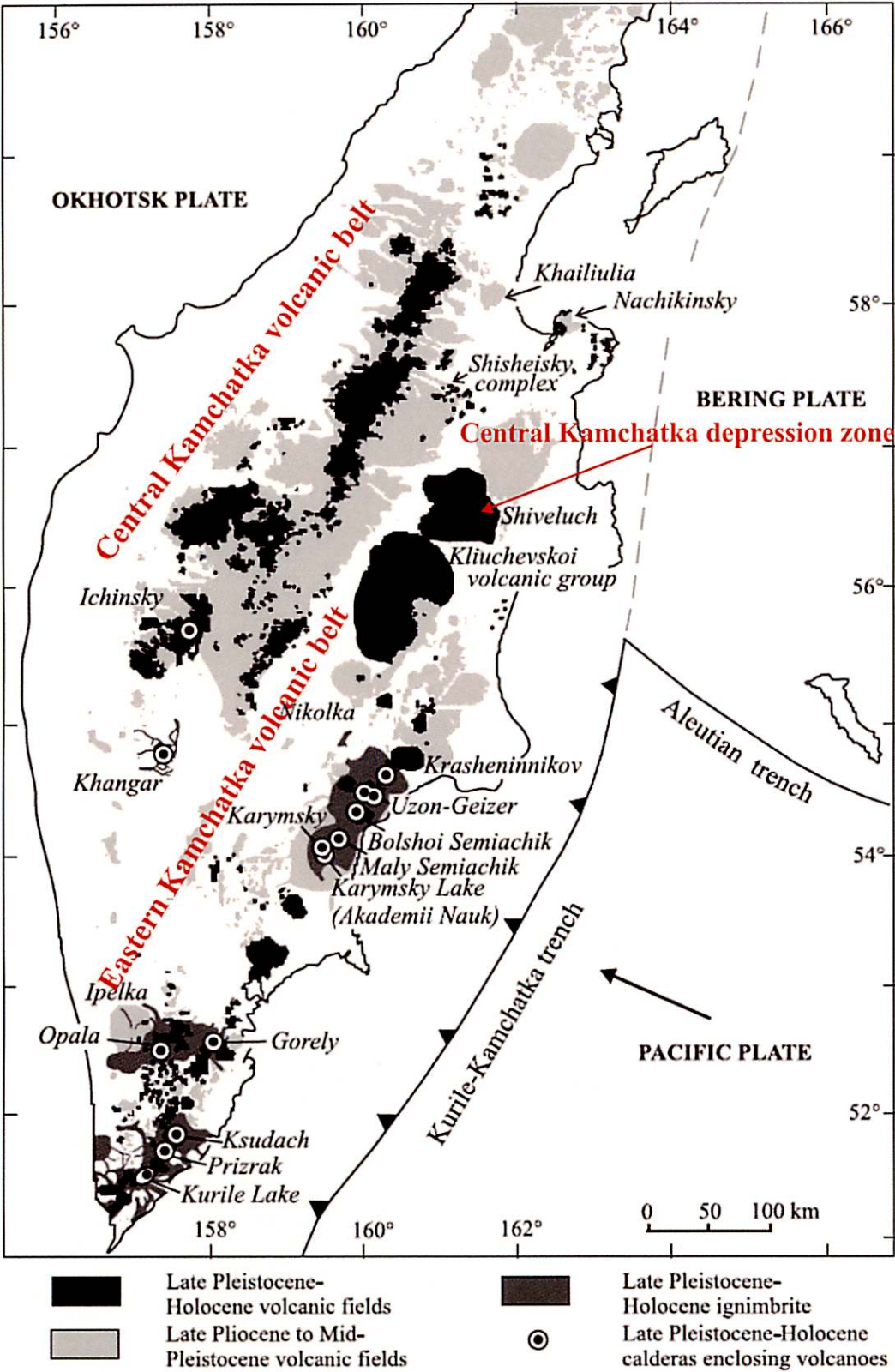


Fig. 2.1.3.1. A sketch map showing occurrence of Late Pleistocene volcanoes and their eruption products in the Central and Eastern volcanic belts and the Central Kamchatka depression zone. A map is taken from Ponomareva *et al.*, 2007.

Miocene volcanoes (Fig. 2.1.3.1.). In Middle Miocene the Eastern Kamchatka volcanic belt has started to form. This period is characterized by most intensive magmatic activity with catastrophic volcanic eruptions. A reason of trench migration is explained by a collision (Volynets, 1991) or complete subduction an ancient oceanic Kula plate under the continental plate (Konstantinovskaia, 2000 and Bindeman *et al.*, 2010). The depth of the seismofocal zone is increased toward the Central Kamchatka volcanic belt from 100-140 km up to 400 km (Fig. 2.1.3.2.).

The Central Kamchatka volcanic belt is a main orogenic element of Kamchatka stretching from the Koryak upland in the north to south of Peninsula, where it is adjusted to the Southern Kamchatka (Fig. 2.1.3.3.). Intensive igneous activities, reproducing metallic mineralization, were occurred through late Cretaceous to Late Miocene. Second stage of magmatic uplifts along with volcanic eruptions has occurred in Pliocene-Holocene time, however, precious metallic mineralization associating with second stage volcanism is not found. Although, majority of volcanoes are dead, two volcanoes (Ichinsky volcano and Khangar volcano) are still show off moderate fumarolic activity and occasionally occurrence of fresh lava flows. Based on that evidence, the Central Kamchatka volcanic belt was classified as in the active stage by Melekestsev in 2002. These two volcanoes are located close to the occurrence of metallic mineralization in the Central Kamchatka volcanic belt.

The Ichinsky volcano with high of 3,631 m is a typical composite volcano of Late Pleistocene age has erupted numerous times during Holocene. Earliest eruption occurred about 10,000-15,000 years, 4,000-4,200 and

latest 1,800 years ago (Bindeman *et al.*, 2010). Eruption products are varying from basalt to rhyodacite, characterizing by high-K₂O content.

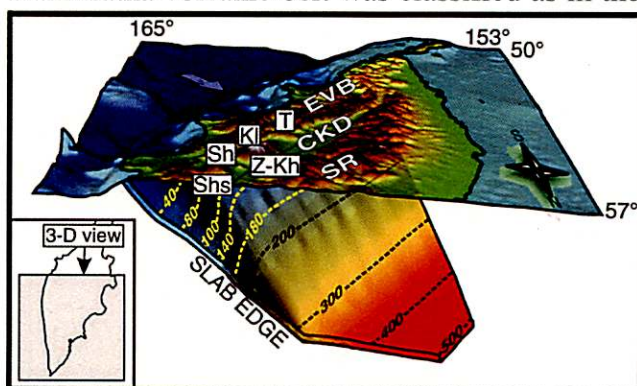


Fig. 2.1.3.2. The 3-D model of Kamchatkan subduction zone illustrating a increasing of the depth of seismofocal zone towards to the Central Kamchatka volcanic belt (Central Range here). EVB – Eastern volcanic belt, CKD – Central Kamchatka Depression and SR – Sredinnyi Range. A 3-D model is borrowed from Gorbatov *et al.*, 1997.

The Khangar volcano of 2,000 m high is located in 2 km wide lake filled caldera in southernmost area of the Central Kamchatka volcanic belt. Khangar volcano has erupted twice in Pleistocene and once in early Holocene. Sequence of eruptions led to formation of volcanic caldera of size 12 x 16 km.

The Eastern Kamchatka volcanic belt hosts most active in terms of eruptions volcanoes caused by near location of the subduction zone. Violent volcanic eruptions were occurred during last 30,000 – 40,000 years (Braitseva *et al.*, 1995). The Central Kamchatka volcanic belt is separated from the Eastern Kamchatka volcanic belt by the Central Kamchatka depression zone with the Northern Kamchatka Group Volcanoes. The volcanoes of the northern group display strong explosive eruptions with high value outputs of pyroclastic materials and lava flows. The Central depression zone is formed under the triple junction of the Pacific oceanic plate and the Pacific oceanic plate and the Eurasian plate.

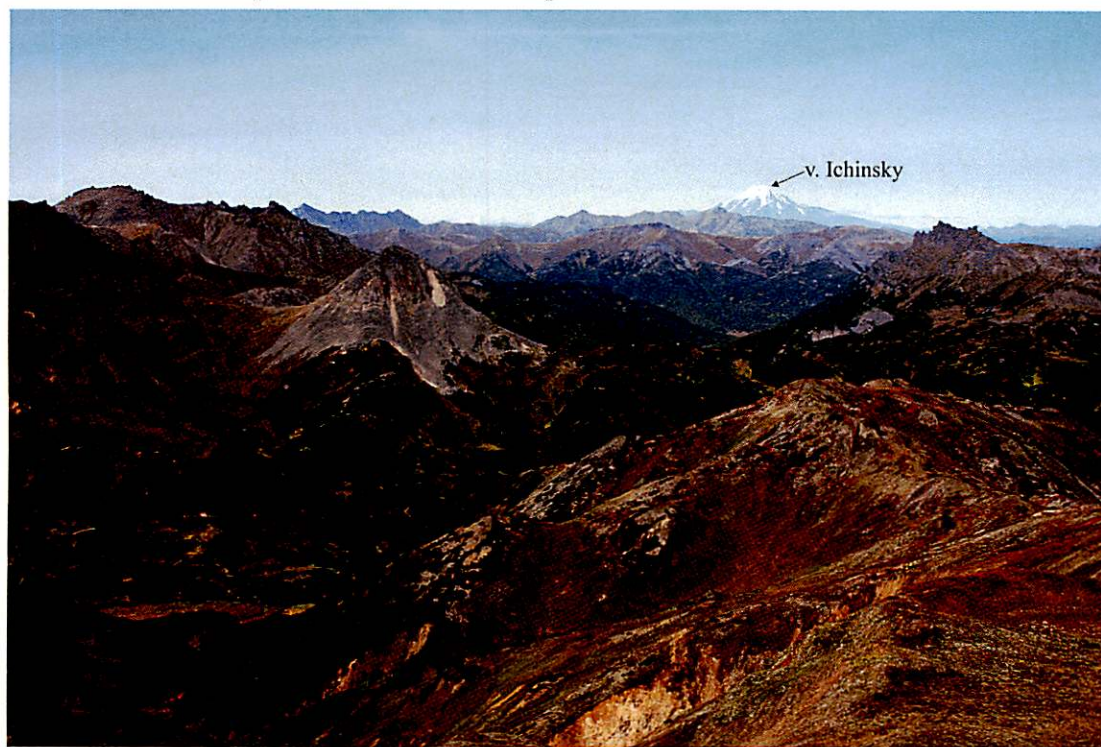


Fig.2.1.3.3. View on the Central Kamchatka volcanic belt looking to the North-West. Quarternary volcanic rocks are covering destroyed volcanic calderas of Oligocene-Miocene. On the background of the photo is the Ichinsky composite volcano. The photo was taken by undergraduate student Pereygin Alexei during the geological prospecting works in the Central Kamchatka mining district in 2011.

Although, igneous activities was continued in Kamchatka arc segment from the Upper Cretaceous until present time, most active stage of volcanism has appeared

from upper Pleistocene to Holocene. At that time volcanoes were erupted with high-volume outputs in the Central Kamchatka volcanic belt, the Central Kamchatka depression zone and the Eastern Kamchatka volcanic belt (Ponomareva *et al.*, 2007; Bindeman *et al.*, 2010). Most significant character of the Kamchatka segment of the arc-system is that being subducted an oceanic plate does not carry any sediments (Volyne, 1991; Pineau *et al.*, 1999; Avdeiko *et al.*, 2007; Churikova, *et al.*, 2010).

Many researchers studied geochemistry of volcanic rocks of Kamchatka agreed that rocks composing the Eastern and Central volcanic belts and the Central Kamchatka depression zone are generally low-K series. Some high-K rocks are found in the Central Kamchatka volcanic belt. The data on volcanic rocks composition taken from various literature sources are complicated in Fig. 2.1.3.4. Churikova with co-workers (2010) reported that majority of rare earth elements and some oxides as NaO, and K₂O positively correlates with depth of the subducted plate. Thus, concentration of rare earth elements is increasing with increasing of depth of the subducted plate. This evidence was also confirmed in the Kuril arc segment and Japanese islands (Churikova *et al.*, 2010).

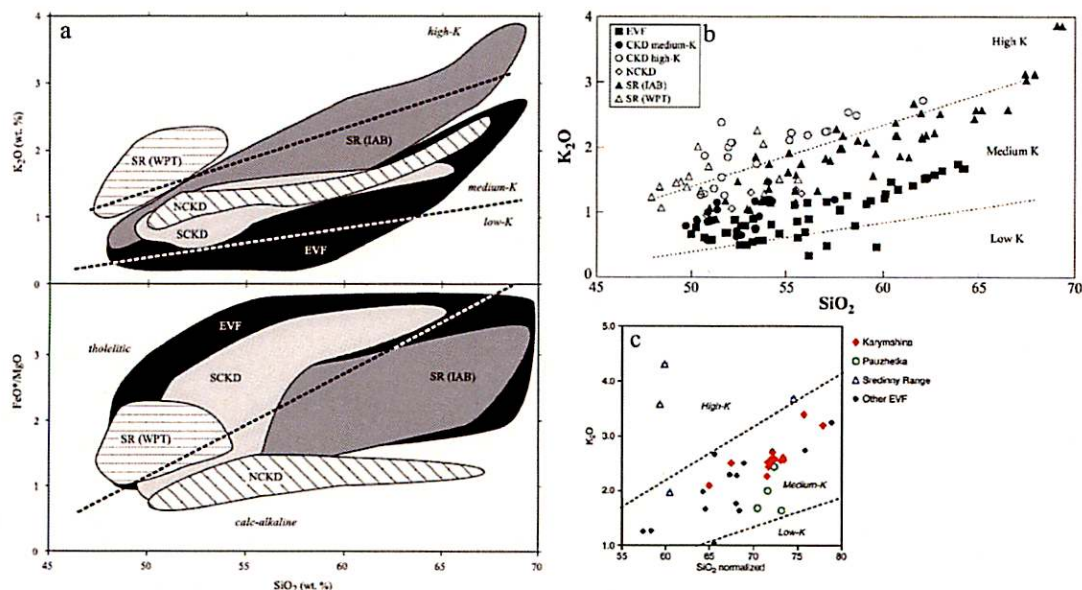


Fig.2.1.3.4. Various K₂O (wt%) vs. SiO₂ (wt%) diagrams showing division of Kamchatkan volcanic rocks into high-K, medium-K and low-K varieties. Diagrams are borrowed from: a – Ponomareva *et al.*, 2007: EVE – Eastern Volcanic Front, SCKD – volcanics from the south of the Central Kamchatka Depression Zone and NCKD – from north of the Central Kamchatka depression zone, SR (IAB) – island-arc type basalts from the Sredinny Range, SR (WP) – within-plate type rocks from the Sredinny Range. Lower diagrams FeO/MgO vs. SiO₂.

b – Churikova *et al.*, 2001 and c – Bindeman *et al.*, 2010. Abbreviation is same as in Fig. 2.1.3.4a.

Typical for island arc an isotopic imbalance of ^{238}U - ^{230}Th was not observed in volcanics of Kamchatka. Churikova with co-authors (2010) proposed a model of magma generation in the Kamchatka island arc. According to them the magma source generated under the Eastern Kamchatka volcanic belt and the Central Kamchatka depression zone is enriched in the fluid component compare to the Central Kamchatka volcanic belt. The degree of rock melting is changed from high degree of melting under the Eastern volcanic belt (20 %) toward the low degree of melting under the Central Kamchatka volcanic belt (9 %).

2.2. Volcanic hosted epithermal deposits

The precious metal deposits associating with volcanic rocks are commonly classified on depth of occurrence on mesothermal and epithermal. On mineralization type and association with intrusive rocks they are usually subdivided into porphyry, massive sulfide and vein-type deposits. On mineral components they are also subdivide into gold-silver, polymetallic and Cu-Mo and etc. In this chapter the classification of epithermal deposits and distribution map within the circum Pacific region are given below.

2.2.1. Classification of epithermal deposits

The epithermal deposits were discovered and firstly described by Lingred in 1922. He found these deposits in similarity to the hot springs and argued that they were deposited at shallow depth from the low-temperature fluids at the moderate pressure (Lindgren, 1933). Most intensive exploitation and rising of mining interest to the epithermal gold-silver deposits have began in late of XX century. Until now epithermal deposits are the main source of gold in some areas. Great studies on the epithermal deposits were done by N. White, D. Cooke, R. Sillitoe, J. Hedenquist, G. Coberth and others. Although there are enormous numbers of epithermal deposits they are all grouped into two large and distinct types: Low-Sulfidation and High-Sulfidation deposits. A classic classification of the epithermal deposits into Low-Sulfidation (LS) and High-Sulfidation type is based on structural controls, depth, alteration and vein mineralogy, ore texture and geochemical signature (Lindgren,

1933; White & Hedenquist, 1997). Commonly the epithermal deposits are young in age and hosted by Tertiary volcanic rocks. Older epithermal deposits are supposedly existed, however, they are may be completely destroyed and presented as placer gold or metamorphized (Heald *et al.*, 1987). Epithermal deposits of both type and broad range of precious metals are predominantly distributed in the South-West Pacific Rim Circum: Japan (Koryu, Sado, Hishikari and etc.), Philippines (Acupan), Indonesia (Kelian), Papua New Guinea (Porgera). Some of them are also occurred in North and South America (Lake City I, Eureka etc. and Colqui, respectively). In Kamchatka epithermal deposits are also common (Sergeevskoe, Ametistovoe, Rodnikovoe etc.). Cartoon model, created by Corbett and Leach (1997), is illustrated in Fig. 2.2.1.1., showing localization of LS, HS and porphyry deposits in the continental crust and relations to the intrusive body. Although, first classification of epithermal deposits were made by Lindgren in 1933 and since then many researchers attempted to improve the classification of the epithermal deposits, diversities of mineralization styles make difficult to further classification than simple HS and LS types, associating with volcanics. This section is summarized main distinct features between two end-member types of epithermal deposits.

A Low-Sulfidation type is vein-filling lodes occurring within volcanic calderas and spatially associating with the intrusive bodies of grandodiorites in general. A second name of LS deposits is a sericite-adularia, frequently appears in the geological literature. Although, there are a great variety of LS deposits depending on ore minerals assemblage, herein, generalization is given. To LS ore system author refers deposits of following mineralization style: gold-silver, some gold-silver-telluride and gold-polymetallic.

A term Low-Sulfidation means abundant presence of low-sulfidation state sulfides such pyrite, sphalerite, galena in ores (White & Hedenquist, 1991; Corbett & Leach, 1997). LS veins are basically composed of quartz-adularia-carbonate with typical ore textures of banded, colloform, crustiform and brecciated (Fig. 2.2.1.2.). Grade of economic metals are highly variable. Common feature is bonanza – rich part of ore body in metals. In ores free gold is common, sometime associates with various sulfides and tellurides. Extensive studies of adularia-sericite deposits has shown that they were deposited from low-temperature and low to moderate salinity

hydrothermal fluids, which are originated from reduced meteoric water rich fluid circulated in upper crust (White, 1974; Matsuhisa *et al.*, 1985 etc.).

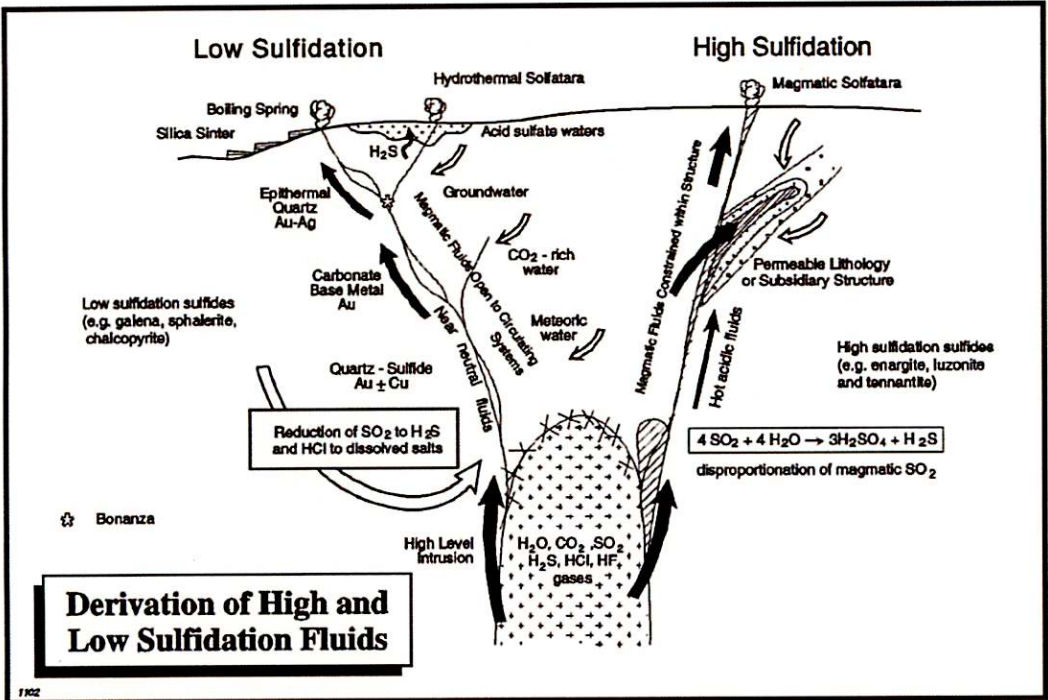


Fig.2.2.1.1. Corbett's cartoon model explaining the origin of the epithermal LS and HS deposits (Corbett & Leach. 1997).

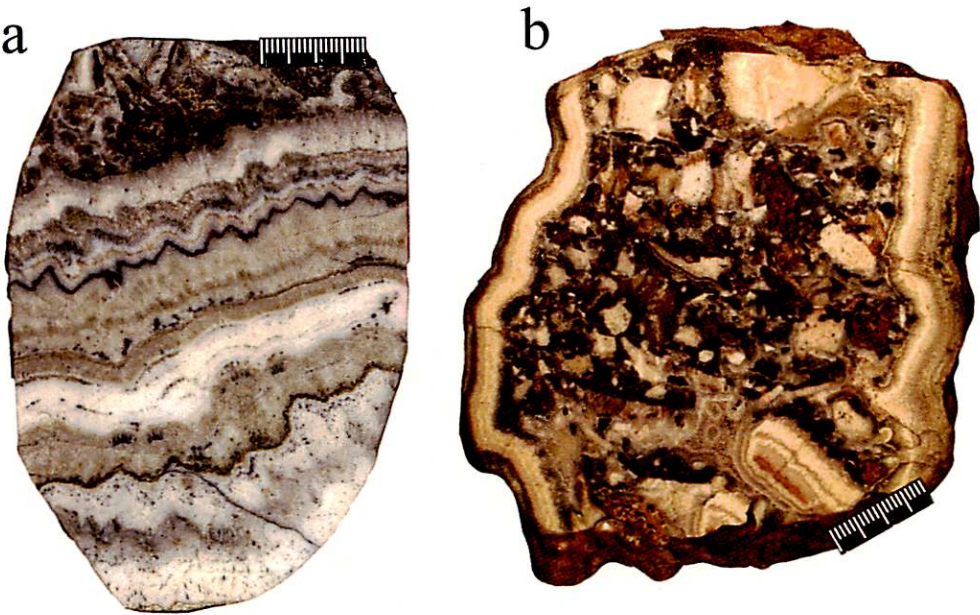


Fig.2.2.1.2. Colloform-banded (a) and brecciated (b) textures of ores from the Aginskoe deposit, Central Kamchatka.

A high-sulfidation type of epithermal deposits is less common than a Low-Sulfidation variety. It is also occurred in margins of the volcanic calderas and distinguished from LS deposits by the presence in ores of high sulfidation state minerals such as enargite and luzonite and acidic type of alteration minerals, for example, alunite (Heald *et al.*, 1987; White & Hedenquist, 1991; Arribas, 1995 etc.). Although, HS deposits generally consists of low-grade ores (gold grade around 1-3 ppm), gold reserves are large enough allowing exploitation for years. The HS ores are proofed to be deposited from the oxidized fluids enriched in magmatic components. Characteristic feature of this type deposits is vuggy silica occurring as a result of reaction between acidic fluid and host rocks (Arribas, 1995; Panteleyev, 2005).

2.2.2. Distribution of Au-Ag epithermal deposits in South-Western part of Pacific Fire Rim

In previous section general characteristics of epithermal deposits were highlighted. Herein, author give a distribution map of gold-silver epithermal deposits in the south-west of Pacific Circum (Fig. 2.2.2.1.) with systematization of gold-silver mineralization and gold-silver mining production in some countries. Detailed geological, mineralogical and geochemical data is published by follows authors: D. Cooke, N. White, R. Sillitoe, J. Hedenquist and etc.

South-west area of Pacific Ocean is complicated by wide occurrence of subduction zones forming primitive and mature island arcs. They exhibit aggressive volcanic eruptions, provoking by magma uplifting from a sinking plate. As results enormous numbers of the epithermal deposits were occurred in those island arcs. Despite that, the epithermal adularia-sericite deposits commonly are small in term of gold reserves and compare to the porphyry systems, however, some giant world-class LS Au-Ag deposits are known in South-West of Pacific Circum.

Japan is located in East Asia. It has produced gold since historical time from placer and underground deposits. Approximately 100 epithermal LS and HS deposits genetically related to a Japanese subduction zone are found there (Fig. 2.2.2.2.). HS type is predominant in southern island Kyushu and occurs as a group of Nansatsu

deposits (Iwate, Kasuga). Epithermal deposits of LS type are ranging from base-metal to strictly gold-silver

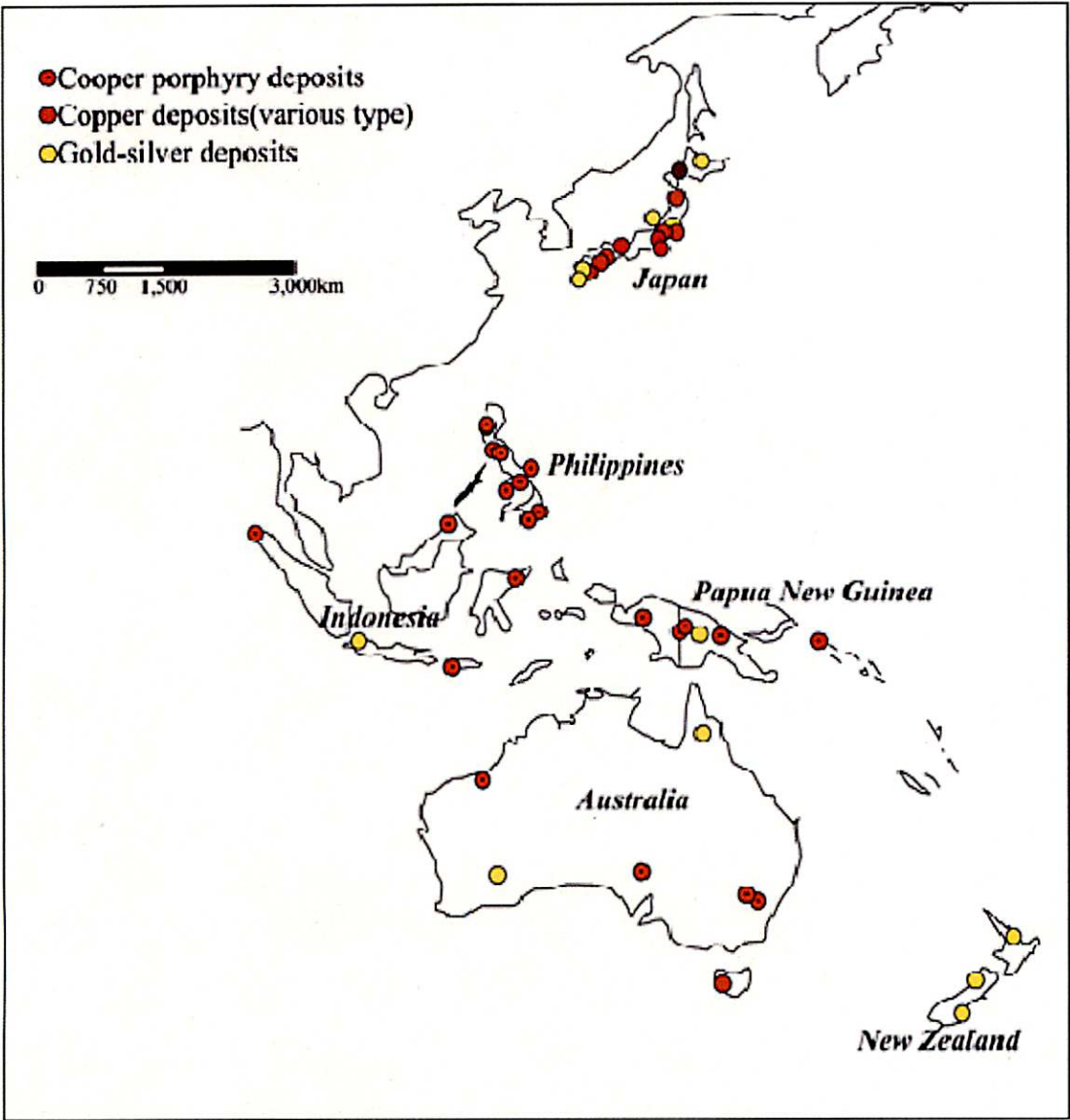


Fig.2.2.2.1. A map showing distribution of copper porphyry, copper of various types and epithermal gold-silver deposits in the south-west of Pacific region. Modified after USGS report, 2005

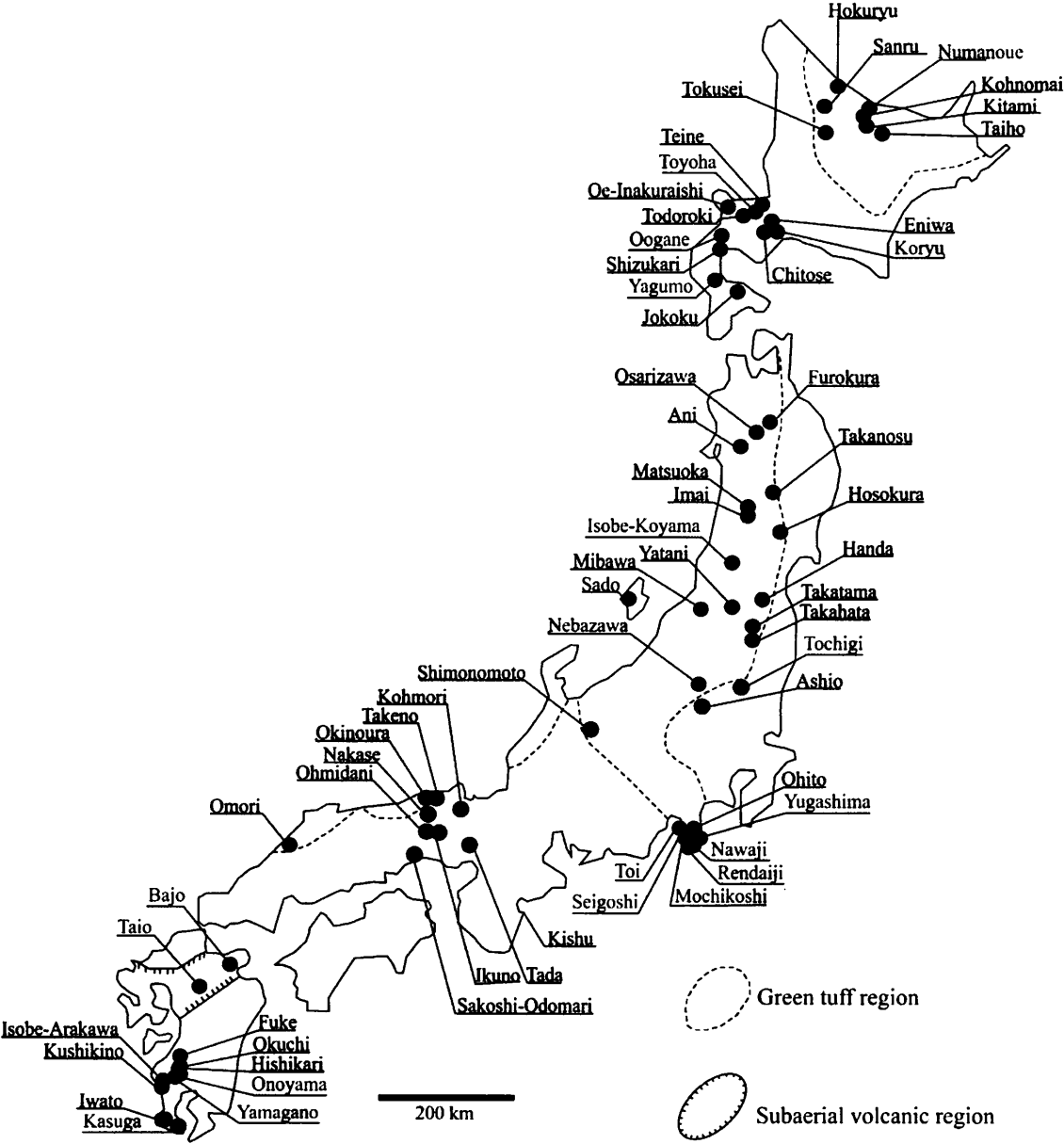


Fig.2.2.2.2. A map of distribution of gold-silver and base metal vein and disseminated type epithermal deposits in Japan. Most of mines were closed due to exhaustions of mineral resources from late 50s to 80s. A map is taken from Shikazano, 1986.

variety. They are widely distributed in all largest Japanese islands. Most of mines were closed in past century due to decreasing of precious metal reserves. Only a few mines are still operated at the Iwate HS deposit and LS giant Hishikari mine in the southern Kyushu. Detailed information on gold tonnage, vein mineralogy, alteration styles and other features of the epithermal deposits in Japan are described in Shikazono 1978, 1985, 1986 and 1988; Nakayama, 1986; Shoji, 1986; Shiga & Urashima, 1988; Shimizu *et al.*, 1998; Shimizu, 2011 and etc.

Philippines archipelago situating to the south-west from Japan is a famous area for the large production of gold from Au-Cu porphyry deposits, however, epithermal LS and HS are also know in Philippines. LS deposits are showed distinct differences from other LS lodes occurring in south-west of Pacific Circum. They are characterized by high base metal content, crystalline quartz and absence of adularia (White *et al.*, 1995). Most intensive period of gold mining has happened in 1949 – 2009 (Cook *et al.*, 2011). Despite 73 metallogenic provinces in Philippines, gold has been mainly produced in Baguio and Paracale in Luzon; and Masbate, Surigao and Masara in Mindanao (Fig. 2.2.2.3.). Acupan mine, which located in Baguio district, is a classic example of large epithermal LS system, containing interconnected veins and breccias (Cooke *et al.*, 1996).

Indonesian archipelago is located to the east from the Philippines and consists of 13,000 islands, hosting world-class porphyry Cu system and low-sulfidation gold deposits of Miocene-Pliocene age (Fig.2.2.2.4.). Indonesia ranks the 8th place among gold-producing countries in the world. Over 70 % of gold is mined as a by-product from the copper-porphyry, which located within Irian Jaya, North Sulawesi and Sumbawa islands. Grasberg in Irian Jaya and Batu Hija in Sumbawa are large Au-Cu porphyry deposits in the south-west Pacific region containing 600 Mt grading at 1.13% copper, 1.05 g/t gold and 3.8 g/t silver and 564.72 Mt grading at 0.52% copper and 0.4 g/t gold, respectively. Porphyry systems of Indonesia exhibit similar characteristics to those in Philippines and Papua New Guinea (Sillitoe, 1994). Epithermal gold deposits of both LS and HS types are also widespread in Indonesia; however, LS gold deposits are predominant. Kelian LS gold deposit is classified as a giant with Au reserves of >200 t. Volcanogenic massive sulfide deposits are found

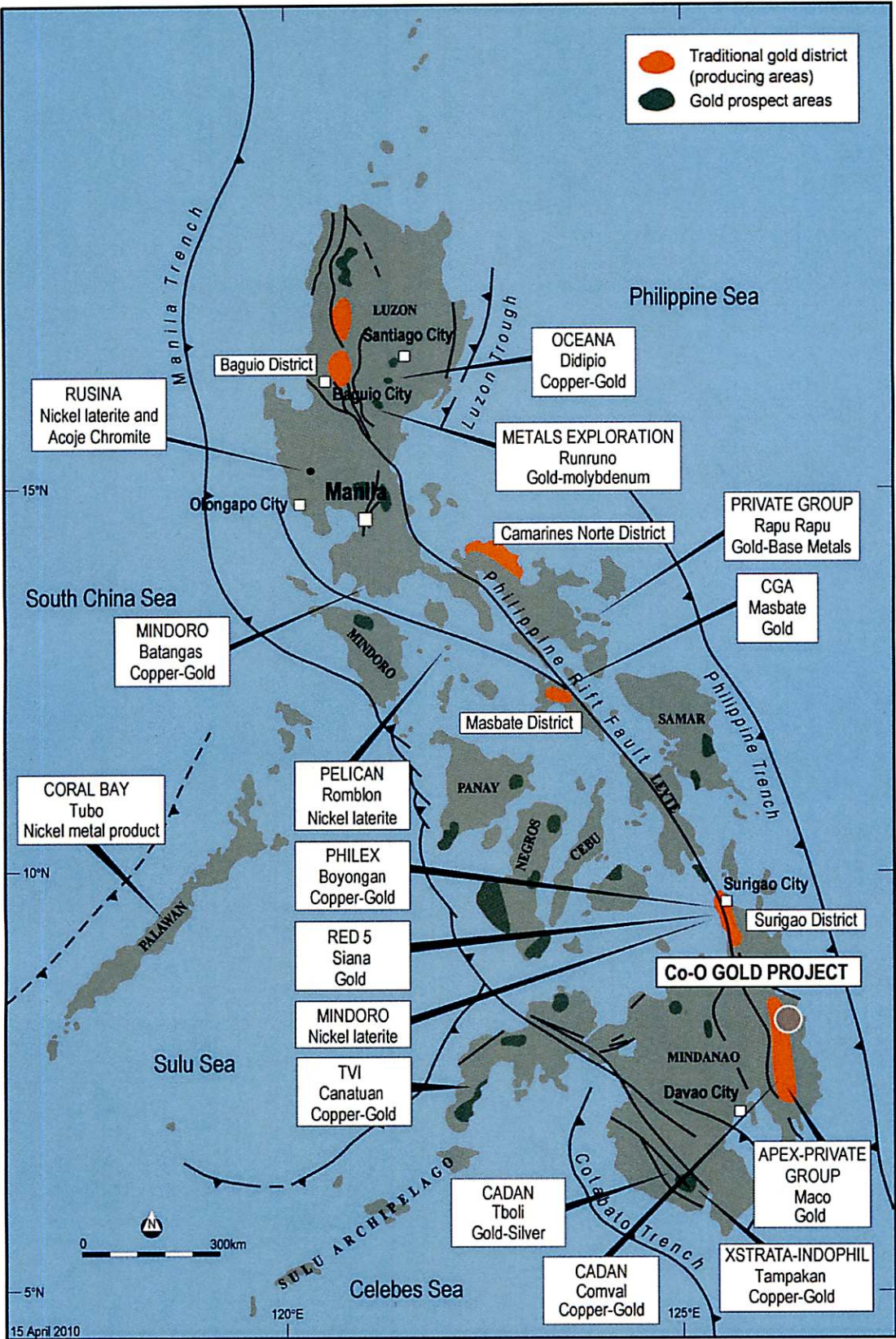


Fig.2.2.2.3. A map of gold-silver deposits in Philippines. Location of Baguio and Mindanao districts are shown. A map is borrowed from a website philippinemaps.

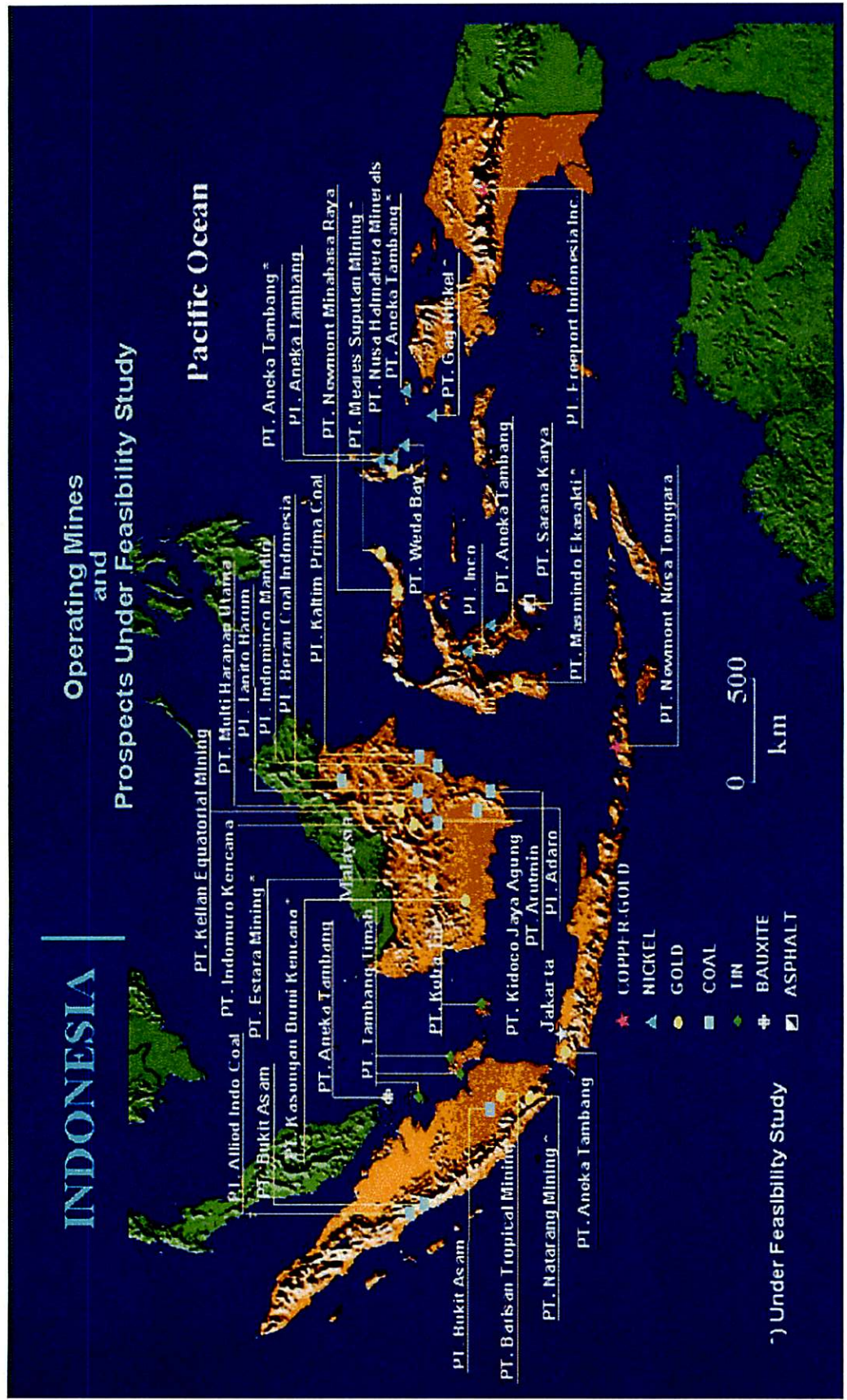


Fig.2.2.2.4. Mineral prospects and mining in the Indonesia. A map is obtained from the website http://okghiqwiy.blogspot.jp/2013/01/pertambangan_6.html

in Wetar island of Banda arc.

Papua New Guinea is sharing an island with Indonesia and includes large number of islands in the south-east area of the Pacific Ocean to the north of Australia. Gold and copper are the main metals mining in the country, concentrated in low-sulfidation and porphyry type deposits genetically related to the Miocene dioritic intrusions in the mountain range of South-West, Central and North-East tectonic provinces (Fig. 2.2.2.5.). Exploration and mining activities has started in the 1960s targeting on the porphyry copper deposits. Discoveries of huge Porgera and Lihir gold deposits with summary gold tonnage of over 200 t and range of smaller deposits made PNG promising region on the gold mineralization (Kawagle, 2005). Currently PNG ranks the 13th place in the world gold production. Gold and copper are produced at large porphyry Ok Tedi, Porgera and Lihir deposits, and medium-scale Tolukuma and Kainantu deposits. On the territory of PNG alluvial gold deposits and lateritic nickel-cobalt are also known.

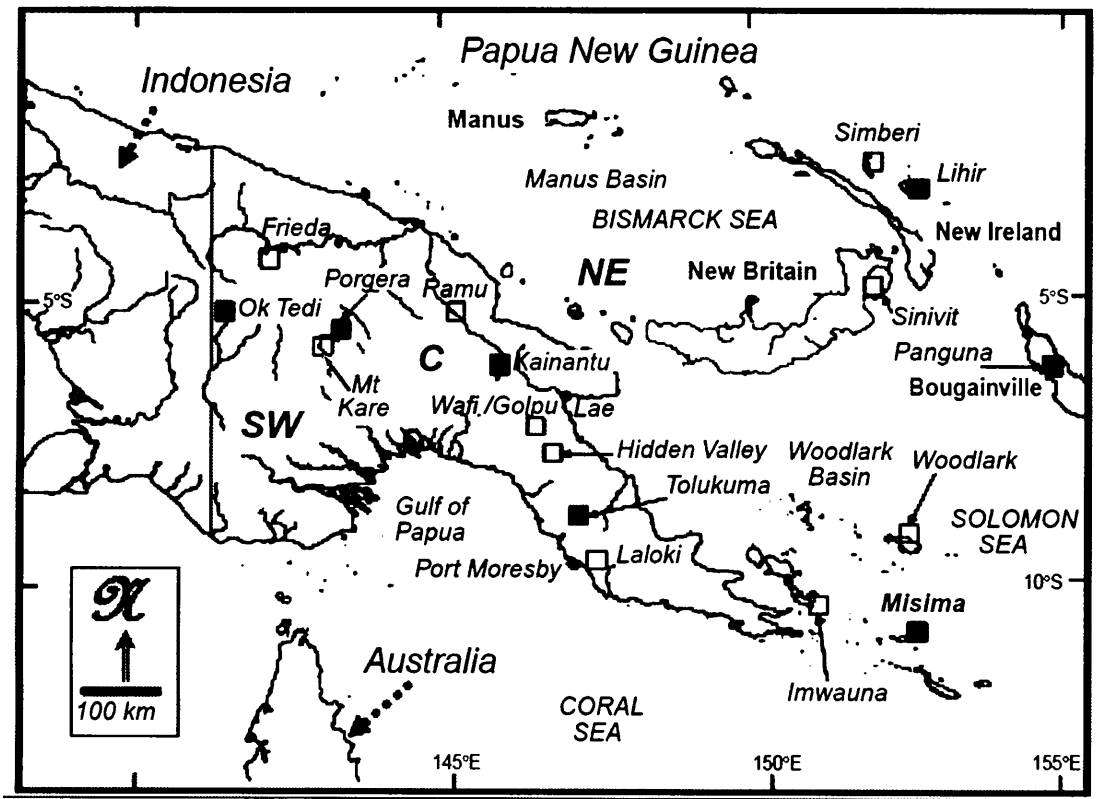


Fig.2.2.2.5. Distribution of gold-silver and gold-copper deposits within South-West, Central collisional and North-East geological provinces of Papua New Guinea. A map is adopted from Kawagle, 2005.

New Zealand consists of several islands representing similar features of other island arcs occurring in Pacific Circum Rim. Epithermal gold-silver mineralization occurs within three volcanic zones: Northland, Coromandel and Taupo (Fig. 2.2.2.6.). Most famous for a gold production is a Coromandel zone includes 50 independent gold-silver deposits, occurring in 200 km long the Hauraki Goldfield (Christie *et al.*, 2007). The Huaraki Goldfield belt is composed of Miocene-Pliocene calc-alkaline volcanics, hosting quartz-calcite-sericite-illite LS deposits basically. World-known large deposits in New Zealand are Waihi with most famous mine Marta Hill produced around 202 t of Au, Golden Cross (37.1 t of Au) and Karangahake (29.4 t of Au) and the Thames field (21.8 t of Au). Although, gold mineralization widely spread within the Northland and the Taupo volcanic zones significant gold deposits have not been discovered yet (White *et al.*, 1995). The Taupo volcanic zone is however interesting for the geothermal flows circulated in the thin-crust is caused to the modern precipitation of gold-enriched materials, for instance at the Ohaake and the Waiotapu geothermal fields. Hot spring spots are basically occurred at the eastern side of the Taupo volcanic zone, while extinct geothermal systems are situated in the western side of the zone.

Fiji islands is situated in the south-eastern part of Pacific Rim and consisted of 332 volcanic islands, which were formed through volcanic activity. Most famous LS gold-bearing deposit is the Emperor Au-Ag-Te mine, which is located in Viti Levu island.

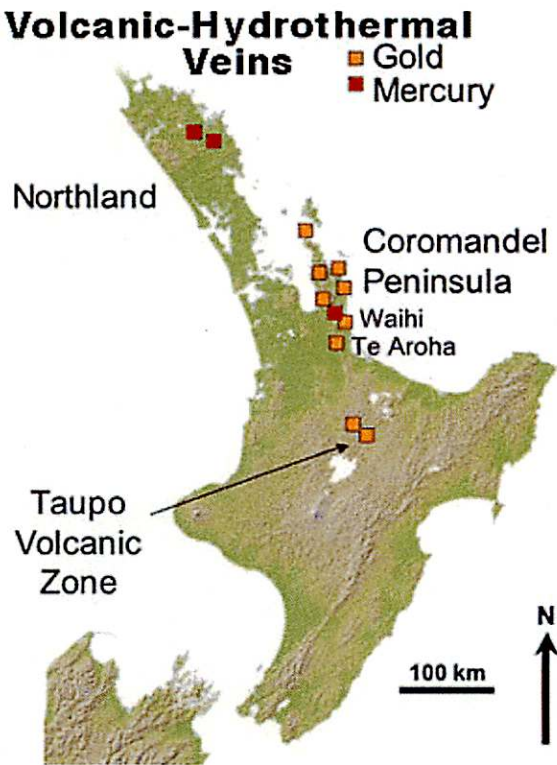


Fig.2.2.2.6. A map of Northland, Coromandel and Taupo volcanic zones hosting major gold-silver deposits of New Zealand. A map is taken from a website of the University of Otago.

2.2.3. Descriptions of epithermal deposits occurring in Kamchatka

Various kinds of mineral deposits are known in all four volcanic belts existing in Kamchatka (Fig. 1.1.). They are placer (PGM and Au), primary (epithermal, Au-Ag-Polymetallic), precious metals, Cu-Ni, Sb-Hg deposits. The deposits are confined to each volcanic belt and tend to show the almost same formation age.

The Sergeevskoe gold-silver deposit with total Au reserves of 100 t is an older lode occurring in the Okhotsko-Chukotsky Cretaceous-Paleogene volcanic belt in the north-west of the Kamchatka mainland. Major part of this belt is spreads in Magadan and Chukotska areas, where many of large gold deposits are localized: Nataalka, Vetrenskoe, Shkol'noe, Juliet, Kvarcevaya, Lunnoe, Arylah, Dukat, Karamken, N'yavlenga, Agatovoe in Magadan and Maiskoe, Kupol, Valunistoe. Sovinoe, Karal'veem, Dvoinoe, Klen in Chukotka (Andreeva *et al.*, 2010).

Second largest Au-Ag Kamchatkan deposit is Ametistovy and some ore manifestations are located within the Ichigin-Unneivayamsky ore-mining region in the Koryaksko-Western-Kamchatsky Eocene-Oligocene volcanic belt. Okrugin (2010) argued that this region is a promising large silver province like Dukatskya one (Magadan region). Many Ag-Pb, Ag-Zn manifestations and two Ag-Pb-Zn deposits are located in this place (Okrugin *et al.*, 2010).

The longest one and the richest in mineral deposits is Central Kamchatka Oligocene-Quaternary volcanic belt, extending from Koryaksky highland to Southern Kamchatka. It is the main orogenic belt hosting many epithermal ore deposits and ore manifestations, which are divided into three ore-mining regions such as the Northern, the Central and the Southern. The last ore-mining region occupies the special position in the structure of Central-Kamchatsky volcanic belt. It is limited to overprint zone of Eastern Kamchatsky volcanic belt on Central-Kamchatsky volcanic belt, complicated by Malkinsko-Petropavlovskoi faulted area. There is Mutnovskaya geothermal area, which includes three epithermal gold-silver deposits (Rodnikov, Mutnovsky and Asachinsky) and more than 25 ore manifestations. Concentration of such quantities of gold and silver deposits is result of paleohydrothermal ore-forming system activity. Magmatic (volcanic) and hydrothermal activity continues nowadays (Okrugin, 2001).

Chapter III. Geology and metal mineralization of the Central Kamchatka Volcanic Belt

3.1. Regional geology and tectonic settings of the Central Kamchatka Volcanic Belt

3.2. Characteristics of precious metal deposits distributed within the Central Kamchatka Volcanic Belt

3.3. The Central Kamchatka Mining District

3.3.1. Geological background

3.3.2. Tectonics

3.3.3. Precious metal deposits

Chapter III. Geology and metal mineralization of the Central Kamchatka Volcanic Belt

3.1. Regional geology and tectonic settings of the Central Kamchatka Volcanic Belt

The Central Kamchatka volcanic belt is around 800 km long the north-east-south-west orientated mountain range with highest pick of 3,607 m (Ichinsky volcano). For long time this belt was classified as non active, thus, it also often called as a Sredinny Range or Central (Mountain) Range in the literature. Only in 2002 Melekestsev has proofed that two volcanoes in the Central Mountain Range (Ichinsky volcano and Khangar volcano) are still active (Fig. 2.1.3.1.). The Central volcanic belt was form in Oligocene-Quaternary by the surface volcanism mainly and marine volcanism rare. The belt is consisted of more than 100 composite volcanoes and shield volcanoes, which erupted with high-value volcanics outputs in Oligocene-Late Miocene (first stage of igneous activity) and Late Miocene-Late Holocene (second stage of igneous activity). In present volcanoes exhibit moderate fumarolic activities. Much more detailed petrographic and geochemical characteristics of this belt are given in Chapter II, sub chapter 2.1.3. and also in papers of following authors: Volynech, 1991; Avdeiko *et al.*, 1991; Ponomareva *et al.*, 2007, Melekestsev, 2009; Bindeman *et al.*, 2010.

The Central Kamchatka weakly altered volcanic belt is running throughout the peninsular part of Kamchatka and links to Southern Kamchatka. Linear arranging of volcanoes along with geophysical data allows arguing the existence of a deep-seated fault underneath the Central Range. This regional northwest-east fault is named as a Main Blind Kamchatka fault. It is also a main channel for magma uplifts and spatially relates to the hydrothermal deposits.

During past 30 years a number of high economic potential deposits were discovered there. Basically epithermal deposits are occurred within volcanic calderas of Oligocene-Miocene, i.e. the deposits were formed in the First stage of igneous activities during localization of the subduction zone along the eastern coast of the Central Kamchatka volcanic belt. Number of age dating conducted by Okrugin (2001,

2010) are also relieved that age of ore mineralization is coincided with age of volcanic rocks produced during a first stage of volcanism.

3.2. Characteristics of precious metal deposits distributed within the Central Kamchatka Volcanic Belt

Majority of all-known Kamchatkan precious metal deposits of both HS and LS types are scattered within the Central Kamchatka volcanic belt. The epithermal Au-Ag lodes in common and Au-Ag-Te-(Se) rarely are associated with volcanic calderas of andesitic-basalt or andesite-diorite in composition in north, central and south areas. The Au-Cu deposits are associated with intrusions of granodiorite and preferentially occurred on the western slope in the south area of the Central Range. Based on the distribution of the significant metallic mineralization in the Central Kamchatka volcanic belt the deposits could be simple grouped into three ore and mining districts: the North Kamchatka ore district, the Central Kamchatka mining district and the Southern Kamchatka mining district (Fig. 1.1.). Present mining are operated in the Central and the Southern mining districts. For that reason they are called as mining district, in those districts there are non active stage of mining they are called as an ore district. Genetic relationship between the Central volcanic belt and the Southern Kamchatka is still a hot question of many discussions, thus, deposits localized in the southern Kamchatka will not be mention in this chapter. Southern Kamchatka is limited to overprint zone of Eastern Kamchatsky volcanic belt on Central Kamchatsky volcanic belt, complicated by Malkinsko-Petropavlovskoi faulted area.

The Northern ore district includes large in term of Au reserves Maletiovayam and Vetrovayam high-sulfidation deposits and number of small scale Au-Ag manifestations. Central mining district consists of Aginskoe Au-Ag-Te mine, Baranevskoe, Zolotoe, Kungurcevskoe Au-Ag deposits and etc.

3.3. The Central Kamchatka Mining District

The Central Kamchatka mining district with a square of around 90 km² is mapped on the southernmost area of the Central Kamchatka volcanic belt (Fig. 1.2.).

The district contains more than 30 deposits and ore manifestations of epithermal genesis and some of probably mesothermal deposits.

3.3.1. Geological background

The geological structure of the Central Kamchatka mining district was investigated by many Russian geologists, who distinguished two structural levels: Mesozoic folded basement (the lower structural level) and Cenozoic volcanic sediments (the upper structural level). Both structural levels are multiply deformed by numerous faults. The local folded basement of the district is Paleozoic-Mesozoic crystalline schist and gneiss of the Kamchatka and the Malki formation overlying by Upper Cretaceous volcanogenic-siliceous sediments of the Iruneiskoi formation (Fig. 3.3.1.1.). Sredinny-Kamchatka anticlinorium had occurred in result of Upper Cretaceous to Paleogene intensive folding processes. Simultaneously, numerous granite and peridoite intrusions had been injected. Cenozoic igneous rocks of the upper structural level of the Central Kamchatka mining district unconformable overlie on the eroded surface of the folded basement. The main strato-volcanoes such as Irakansky, Balkhach, Kreruksky etc., and polygenetic volcanoes as Levinson-Lessing, Karakovsky, Aginsky etc. are associated with the gold-silver and gold-silver-telluride mineralization had been developed there in Neogene. The volcanoes of both types are composed primarily by andesitic-diorite, andesitic-basalt and andesitic-dacite volcanic rocks. Whereas, andesitic-diorite rocks are dominated at the bottom of the volcanoes, while, andesitic-basalt and andesitic-dacite rocks occupy middle part and top of the volcanoes (Fig. 3.3.1.1.).

3.3.2. Tectonics

The regional north-east trending major potential (blinded) Kamchatka fault, accompanied with fault bounded the Central Kamchatka depression, plays the most important role in tectonic and magmatic life of the Central Kamchatka volcanic belt entire. Another major fault is Kirganiksky one strikes to the north-north-west and divide the Sredinny-Kamchatka anticlinorium with Central Kamchatka volcanic belt.

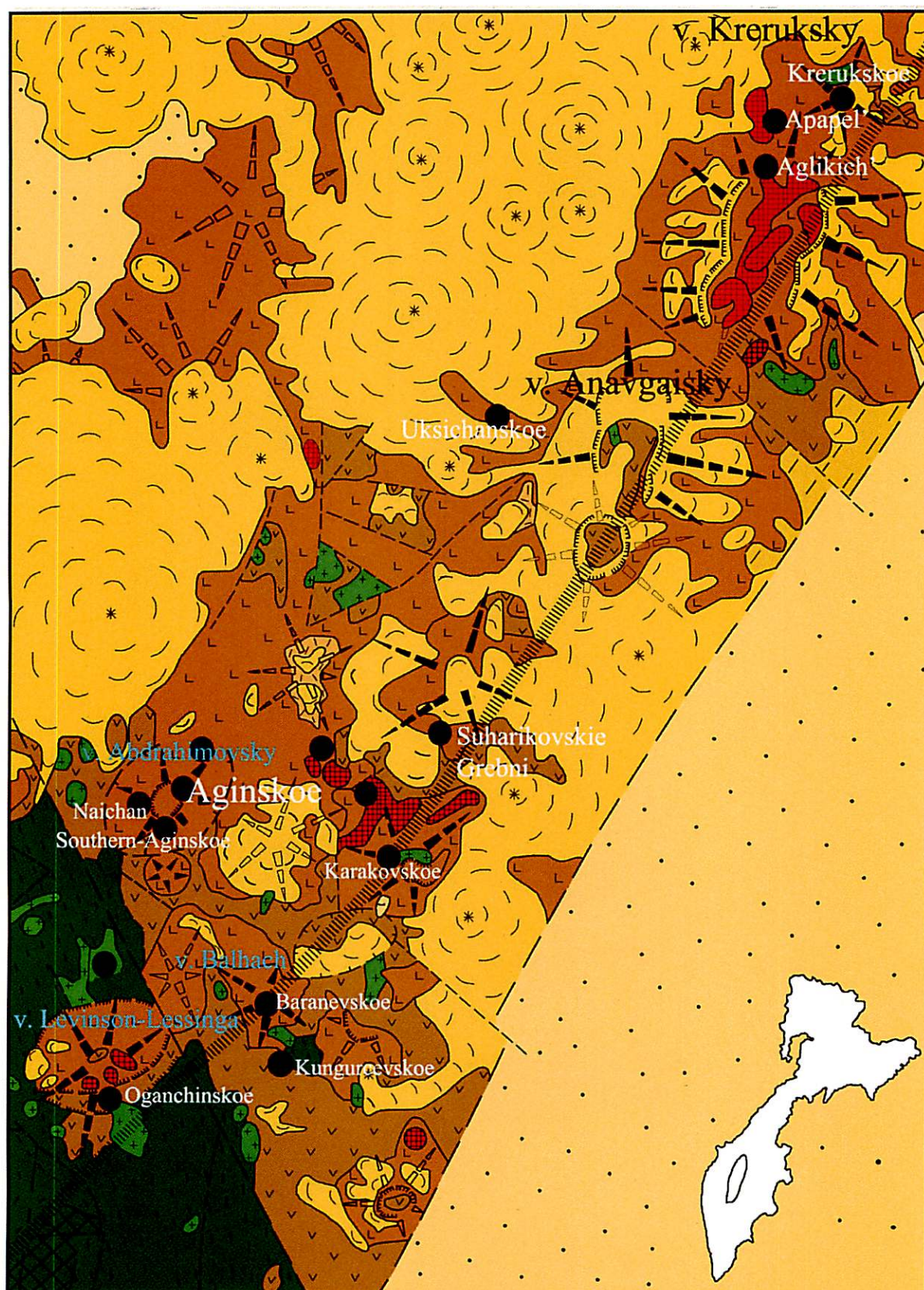
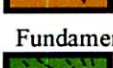


Fig.3.3.1.1. A simplified geological map, showing localization of volcanoes composed by basaltic, andesitic, dacitic and rhyolitic volcanics, hosting the metallic mineralization in Central Kamchatka mining district. Shaded lines displace approximate orientation of the Major Kamchatka Blind fault, controlling the localization of Au-Ag mineralization in the district.

Legenda:

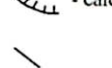
Effusive magmatic facies:

-  - Pleistocene-Holocene basaltic rocks;
-  - Pliocene rhyolite;
-  - Upper Miocene_Pliocene basalt-andesite-dacite-rhyolite formation;
-  - Neogene volcanic rock masses;
-  - Paleogene-Quaternary sandy shale formation;
-  - Miocene andesitic-diorite;

Fundament of the area:

-  -Cretaceous volcanic rock;

Intrusive magmatic facies:

-  - Upper Miocene-Pliocene basalt-andesite-dacite-rhyolite;
-  - Miocene andesite-diorite.
-  - volcanoes of central type;
-  - volcanoes of polygenic type;
-  - caldera;
-  - fracture;
-  - the Main Kamchatka deep-seated potential fracture.

Among East-West direction faults the largest is Zolotoi one. The faults describe above are the biggest faults in Kamchatka. The local faults of the Central Kamchatka mining district the north-east trending Aginsky and Essovsky fractures are splays of the Major Kamchatka potential fault. The Oganchinsky, Kopylinsky and etc. north-north-west trending faults are subparallel to Kirganisky one. Bystrinssky and Ketachansky faults trend to the east-west direction. Main mineralization of the area occurs in the intersecting of the Major potential fracture with local regional faults (Fig. 3.3.1.1.).

3.3.3. Precious metal deposits

The Central Kamchatka mining district lies on the contact between the Sredinny-Kamchatka anticlinorium and the Central Kamchatka volcanic belt, controlling the patterns of gold-silver and gold-copper (?) veins distribution. Synorogenic Upper Cretaceous to Paleogene gabbro-plagiogranitic granitoids are responsible for the formation of gold mineralization and alluvial deposits in the district. Postorogenic andesitic-diorite granitoid intrusions of Miocene are source for the gold-copper-porphyry type deposits. The gold-silver deposits are related to the Late Neogene subvolcanic bodies. The main characteristics of epithermal Au-bearing deposits located in the Central Kamchatka mining district could be characterized by

the shallow depth of deposition, approximately 50-100 and 500-1000 m from the present surface, relationship to the subvolcanic bodies of basalts and occurrence within volcanic calderas.

Upon on ore mineral assemblages epithermal deposits were classified into three types: polysulfide (sulfide) (Oganchinskoe, Lazurnoe), gold-silver-telluride (Aginskoe, South-Aginskoe), gold-silver (Karakovskoe, Apapel' etc.) sulphosalt (Kreruuskoe, Aglikichskoe).

The Aginskoe gold-silver-telluride deposit is located within the Aginsky volcano occurring within the Central Kamchatka mining district (Fig. 2.2.3.1.). Baranevskoe, Zolotoe and Kungurcevskoe deposits are situated in the south-east area of the Central Kamchatka mining district.

Chapter IV. Gold-silver-telluride mineralization at the Aginskoe deposit

4.1. Exploration and investigation history

4.2. Geology of the Aginskoe deposit

4.2.1. Magmatic units and faults

4.3. Structure of the Aginskoe deposit

4.3.1. Mineralization stages

4.3.2. Age of ore mineralization

Chapter IV. Gold-silver-telluride mineralization at the Aginskoe deposit

The Aginskoe lode is one of the three known Au-Ag-Te deposits of the Abdrakhimovskoe ore field. It occurs in a mid-part of the Central Kamchatka mining district within so-called the Aginsky volcano. Abdrakhimovskoe ore field, including Aginskoe and Southern Aginskoe deposits and Naichan ore manifestation, is covering approximately 90 km² of the area (Fig. 4.2.1.). Nachain ore manifestation is not investigated in terms of exploration. The Aginsky volcano of Pliocene age is a polygenetic type volcano with an oval shaped caldera mainly composed by volcanic rocks of basalt to andesite in composition corresponds to the Alneiskaya formation in a regional scale. The size of caldera is 15x20 km.

4.1. Exploration and investigation history

By the middle of the XX century active geological works have been begun at Kamchatka. By the reason of little erosion in the Central Kamchatka volcanic belt many of veins are not exposed on the surface. And only long term geological prospecting works eventually bring benefits on the finding economic value deposits. As a consequence a Central Kamchatka geological survey was organized in 1964. Senior geologist Dmitry A. Babushkin had mapped outcrops of a gold-quartz vein at the upstream of the Aga River. Later, samples of vein quartz have been sent to the Central Analytic Laboratory in Kamchatka. The obtained results showed concentration of gold 20 g/t, silver 100-300 g/t, and lead 0.1 g/t. This concentration of elements was under the conditioning led to stopping the prospecting geological works. But one of geologist became interested in the discovering of gold-bearing quartz-adularia vein and provoked the intensive prospecting works in this area. In consequence his name, Abdrakhimov, was given to the ore field mapped within Aginsky volcano. The first geological prospecting work was started by the government mining geology organization Kamchatgeology in 1968. Several cross-strike trenches were done along the gold-quartz vein, which was mapped by D.A. Babushkin. Eventually, geologists had got outline of vein: width ranges from 0.2 to 7.2 m with total expansion of 420 m and average concentration of gold 166 g/t and 48 g/t of silver.

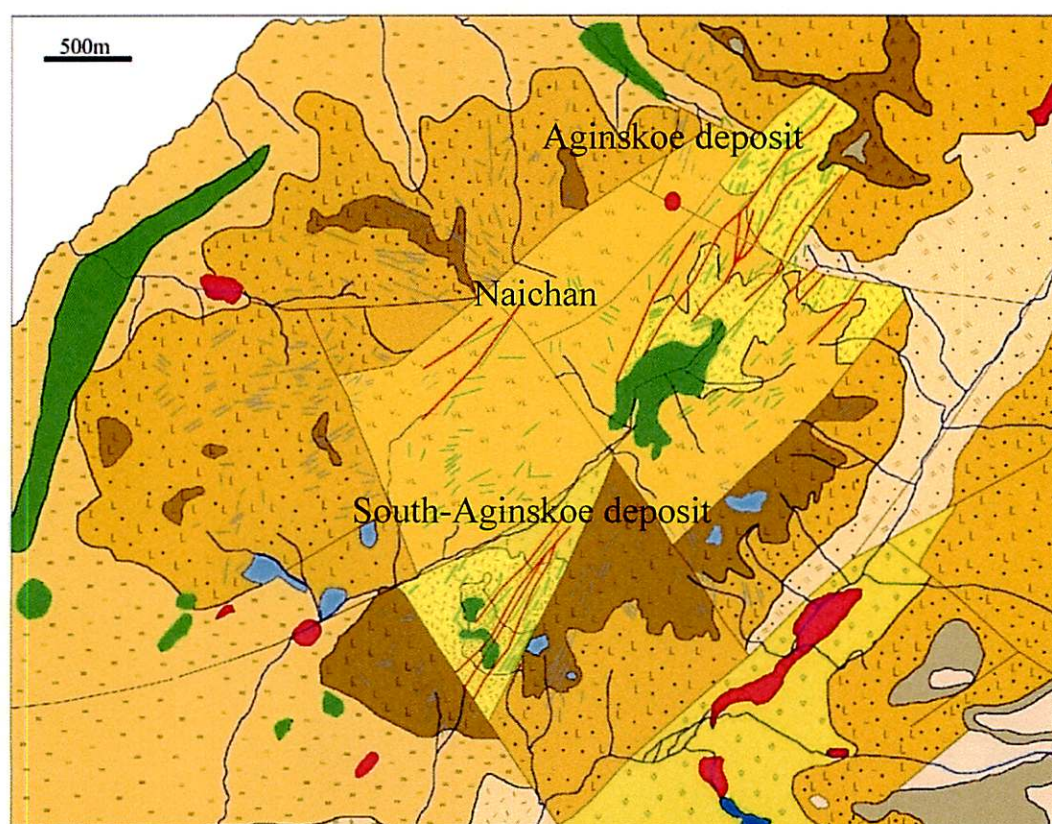
In 1971 geological survey took place in order to re-study an area. By that time along the Aginskaya veins the first underground tunnel at level of 1210 m was done. The preliminary exploration of the Aginskoe deposit was included map composition of ore field in scale of 1:10,000 and preliminary exploration of Aginskaya, Valery and Tumannaya veins. By results of last geological work Aginskaya vein has been exposed along 960 m, also, two new blind ore bodies, confined to Surprise and Noyabor'skaya veins have been discovered that time. The recourse of deposit was estimated by categories of proven and predicted resources. The detailed exploration of lode was started in 1976.

However, almost all geological prospecting works (hard heading work) had been done towards to beginning of 80s. Mining began in early 90s and divided in two stages. The earliest operation activity took place in 1990. The Magadanskaya Company explored the richest ore body Aginskaya by the open-pit method. In 1994 a joint venture of Canada's Kinross Gold Corporation, U.S.-based Grynberg Resources Inc. and Russia's Kamgeo, Kamgold won the rights to mine Aginskoe deposit. In 2005, Aginskoe mine (operated by the KamGold Company) has utilized the underground mining method.

4.2. Geology of the Aginskoe deposit

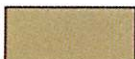
The geology of mine, predominantly, consists of a thick sequence of Miocene volcanic rocks belonging to the Alneiskaya Formation. Previously mining geologists divided the lithostratigraphy of a mine area into three units of volcanic rock showing a circular sequence: the deeper part – alkaline rocks; the medium part - intermediate rocks; the upper part – alkaline rocks. The intrusion of gabbro-diorite named as the Aginskaya intrusion crops out in central part of caldera (Petrenko, 1999). Petrenko had done some research on the wall rocks petrology of the Aginskoe deposit. He argued that the Aginsky volcano has been created in two cycles of the magmatic activity. The first of all, Aginsky volcano was formed as a shield volcano with the magmatic chamber in the shallow part. After formation of basalt rocks of the lower unit of Alneiskaya Formation with thickness is about 400-500 m the intermediated magmatic chamber was formed. The composition of rocks range from andesitic dacite to dacite. In the same time numerous accessory (subordinate) eruption centers

have been developed in a periphery of the caldera. The eastern accessory eruption center was recognized by tuff deposition of the intermediate unit and net of dikes. The exposed pyroclastic products are covered the central part of the caldera. Subvolcanic bodies of basalts and intrusions of diorite and gabbro-diorite (Aginskaya intrusion) intruded in the overlying sequence of volcanic rocks correspond to second period of the magmatic activity. The intermediated magmatic chamber was consolidated due to the short breakdown of the igneous activity. The Aginskaya intrusion has plugged the central volcanic channel that reduces to numerous excentric eruptions. Places of excentric eruptions are marked by nekks and various subvolcanic bodies. During the last period of the volcanic-magmatic activity the upper unit of basalts was formed. This model could be applied for the previously geology of mine area. The present prospecting works have done by mine geologists of the KamGold company show the two stratigraphic units namely the Lower Alneyskay Formation and the Upper Alneiskaya Formation (Fig. 4.2.1.). The basement of area manly composed by Miocene tuff sundstones, tuff siltstones and tufaceous argillite. It overspreads in vicinity of Aginsky volcano. The oldest and most abundant volcanic rocks are the Lower Alneiskaya Formation characterized by brecciated basaltic lava flows, andesitic and dacitic rocks and their tuffs. The most overspread volcanic deposits of the Lower Alneyskaya Formation are two-pyroxene andesite, which cover the central and the north-eastern flanks of the caldera. The fragments of psephitic and psammitic tuffs have been recognized in the central part of the volcanic caldera and peripheral areas. Andesitic basalts with lenses of tuff breccias build up the south-eastern sector of a caldera. The deposits of andesite, biotitic and hornblend dacites are exposed on the western direction from the caldera of the Aginsky volcano (Fig. 4.2.1.). The description of rocks belonging to the Lower Alneiskaya Formation could be corresponded to lower and intermediated units of the previously local stratigraphic geology. Pliocene rock masses of the Upper Alneyskaya Formation represent as basaltic and andesitic lava flows. The basaltic lava flows are marked by majority of pyroxene and presence of plagioclase in the middle part and dominance of olivine in



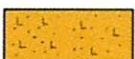
Legend:

Quaternary

	Andesite;		Olivinic basalt.
---	-----------	---	------------------

Miocene

The Alneiskaya Formation. The Upper Unit

	1. Basalt; 2. Andesite, andesitic dacite.		Brecciated lava of basalt, psammitic psephitic tuffs, tuff breccia.
---	--	---	--

The Alneiskaya Formation. The Lower Unit

	1. Dacite; 2. Andesitic dacite, tuff siltstone.		1. Two pyroxene andesitic basalt; 2. Psammictic tuff.
	Psephitic and psammitic tuff		1. Andesite; 2. Two pyroxene andesitic basalt with lenses of tuff breccia

Volcanic sediments Unit

	Tuffaceous sandstone, tuff siltstone
---	---

Subvolcanic bodies, dikes

Pliocene

	Subvolcanic bodies, intrusions and dikes of basalt.
---	--

Miocene-Pliocene

	1. Subvolcanic bodies, dikes of dacite; 2. intrusions of diorite; 3 dikes of andesine.
---	---

 Faults

 Mineralized veins

 Rivers

Fig. 4.2.1. A geological map of Aginsky volcano with location of Aginskoe and South Aginskoe deposits and Naichan ore manifestation.

the upper part of lava flows. The overlying Quaternary volcanic depositions of porphyritic andesite and olive-pyroxene basalts and tuffs have subordinate value (Fig. 4.2.1.).

4.2.1. Magmatic units and faults

Despite the enormous numbers of the intrusive bodies injected from Miocene to Quaternary time at the side of the Aginskoe deposit only intrusive body of gabbro-diorite occurring in the center of caldera is somehow related to the metallic mineralization. As it was mentioned above this intrusion is named as the Aginskaya intrusion and was emplaced during first cycle of the magmatic activity. The Aginskaya intrusion is a little eroded. From the surface only a small part of size 4x1 km could be observed.

Others subvolcanic bodies of dacite, andesite-dacite, andesite and andesitic-basalt in composition are occurred in the area supposedly referred to accessory magmatic activity and presumably post-date ore mineralization.

The Aginsky volcano has been appeared on the crosscut of two major faults of NE and NW directions. The NE trending fault is called Aginsky and the NW trending fault is called the Kirganiksy. They are reflected a deep-seated blind fault called as Kamchatka fault. The latest strikes to NE throughout a whole peninsular. An oval shaped caldera was formed due to collapsing of surface rocks into an empty magma chamber. Southern area of the volcanic caldera, hosting the South-Aginskoe deposit, is lower down in 80-100 m than a north area with the Aginskoe deposit along a fault running through a caldera.

4.3. Structure of the Aginskoe deposit

Abdrahimovskoe ore field covering an area of 90 km² includes Aginskoe and South-Aginskoe gold-silver-telluride deposits and Naichan ore manifestation. The Aginskoe mine consists of two vein systems: Aginsky and Vuin, respectively. The Aginskaya vein system involves two major mineralized faults hosted by volcanic rocks of the upper unit of the Lower Alneiskaya Formation (andesite rocks unit). Three different fracture types, involving high grade ore, crosscut an interlayered

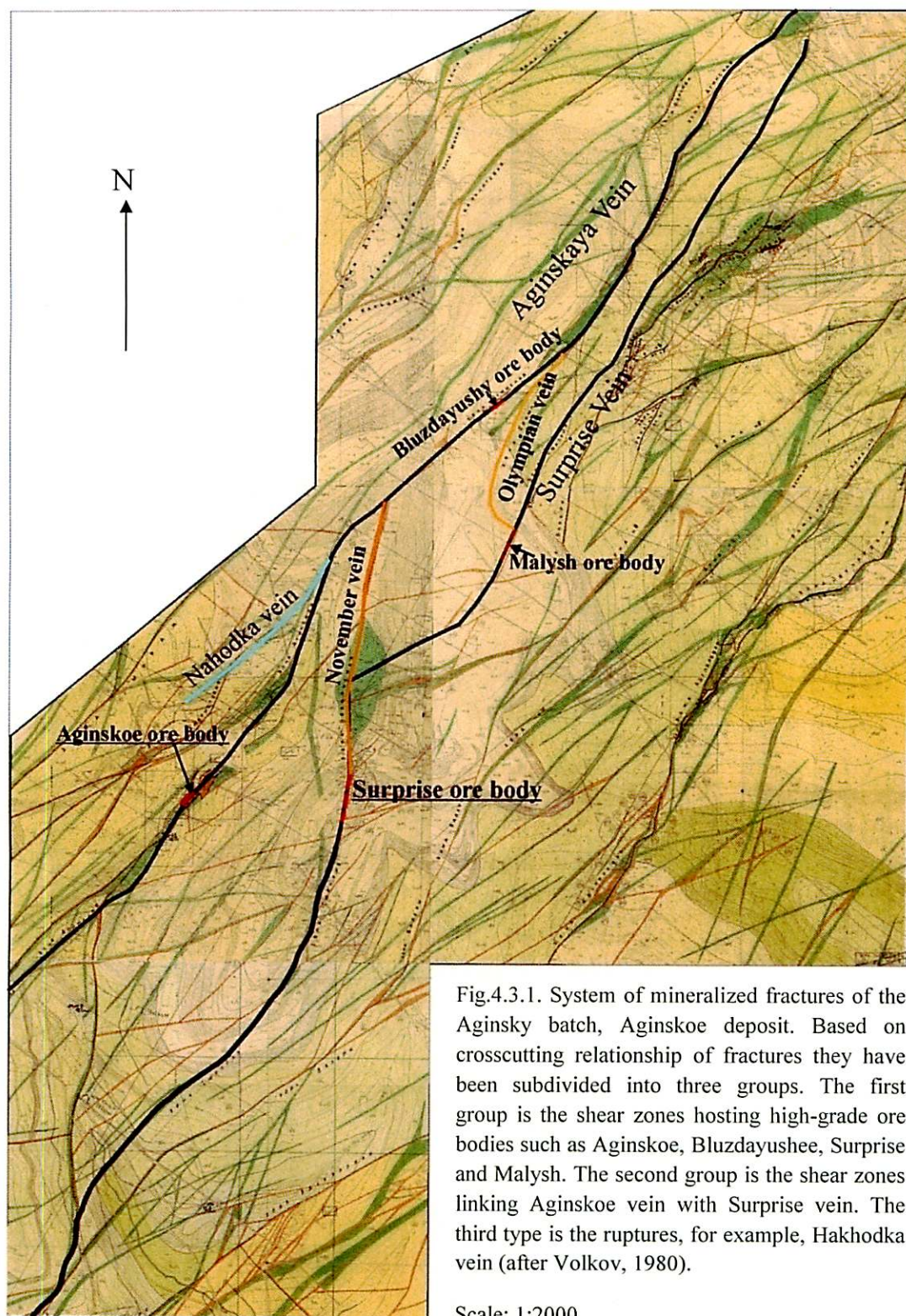
sequence of Miocene volcanic rocks have been mapped (Fig. 4.3.1.). The first type of fractures is the large steep to the southwest and the northwest shears, hosting such high-grade ore bodies as Aginskoe, Surprise, Bluzdayushee and Malysh. The shears are characterized by simple morphology. The second type represents shears, playing role as a link between main shear zones. Linkage shears of submeridional orientations dip at angle of 40-70° to northwest includes Olympiskoe and Noyabr'skoe ore bodies. Although, ore bodies of linkage shear generally host insignificant mineralization, the side wall in place where it links to the main vein zones includes high-grade ores. The third and last type of mineralized fractures is ruptures, for instance, Nakhodka vein (Fig. 4.3.1.). Subvertical small-scale ruptures trending to northeast and east-west directions. The ruptures are branches of the main Aginskoe and Surprise shears, characterized by small-scale in length and lower thickness. In place where ruptures are feathering-out, they form numerous veinlets having a form of horsetail. Nakhodka and Kulisy Valiry ore bodies with uniform distribution of the gold concentration occupy the ruptures (Petrenko, 1999).

4.3.1. Mineralization stages

Aginskoe and Surprise veins are the largest veins in the mine involving 90% of gold resources of the mine. General paragenetic sequence of mineral assemblages and detailed classification of mineralization stages combined with the macroscopic sketching of ore structure were done basically for the ore specimens collected along Aginskoe ore body, Bluzdayushee ore body and Yasnoe ore body from Aginskaya vein and Surprise ore body, Noyabr'skaya ore body, Malysh ore body and Olimpiskoe apophyse from Surprise vein; Valeri ore body from Valeri vein. In fact only Aginskaya vein exhibits banding ores from host rock to center of vein suitable for establishing layers' sequence and visible time gap between stages. Ore bodies localized in Surprise vein are intensive brecciated, thus not all stage recognized in Aginskaya vein were found in Surprise vein. However, evidences of stages were found.

Due to impossible of the observation morphology of veins in the underground tunnels during the field work author had classified the mineralization stages by using the specimens of veins taken from different horizontal levels. The determination of

hydrothermal stages based on the detailed macroscopic sketch of the ore samples, crosscutting relationships of quartz-adularia veinlets within specimens and



assemblages of opaque and vein minerals. The first and the fifth stages refer to pre- and post-mineralization stages through a whole hydrothermal activity. The second stage is characterized by a productive Au-Ag-Te mineralization. The third and fourth stages have recorded brecciation events followed by filling free spaces between blocks of host rocks, and early stage massive quartz by coarse violet colored quartz aggregates. The last sixth stage is classified as a supergene, where various secondary minerals have been formed (Fig. 4.3.1.1.).

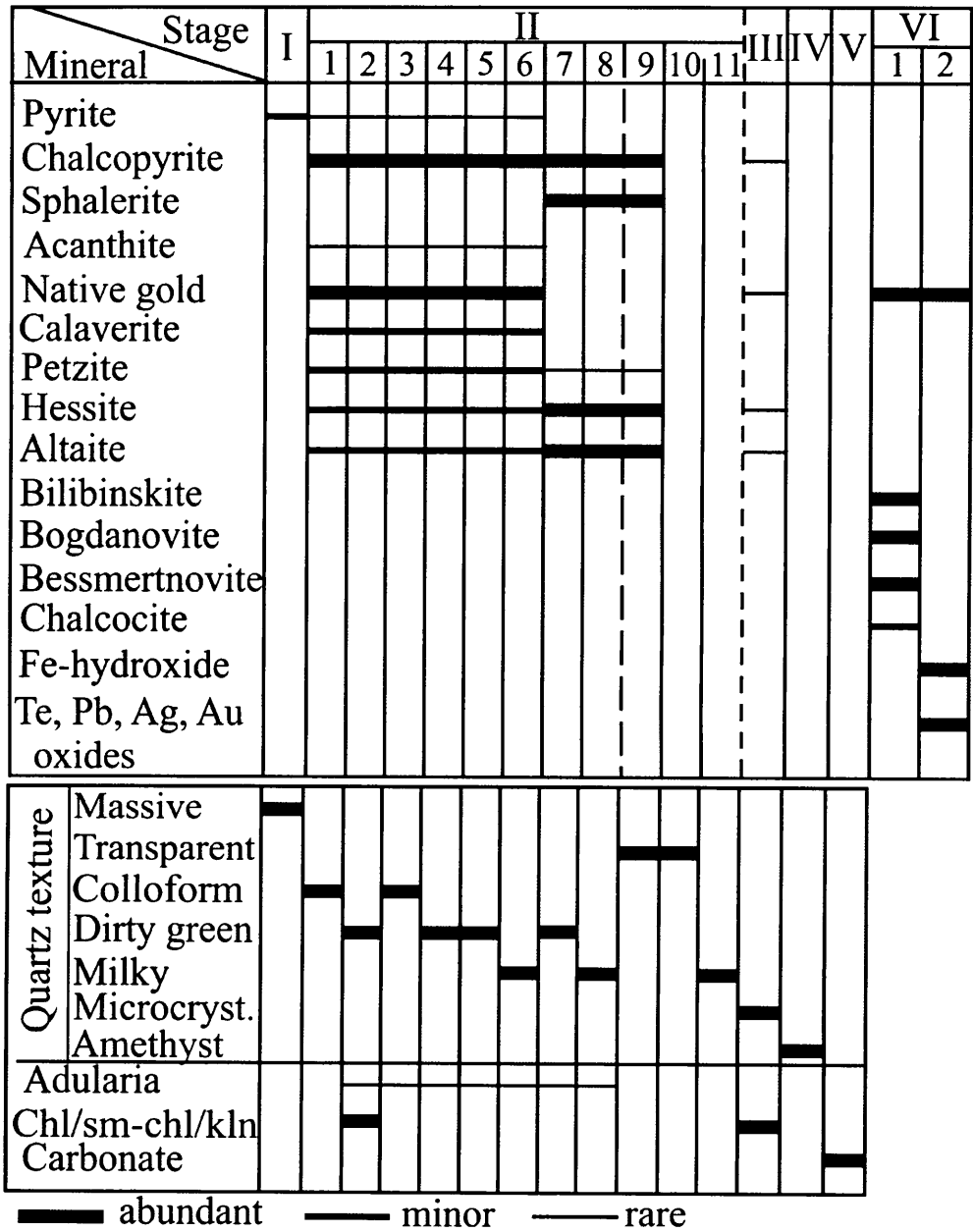


Fig.4.3.1.1. General sequence of mineralization stages distinguished in the Aginskoe ore body mainly.

Stage I represents prior to main mineralization, slightly banded massive quartz with impregnation of fine-graded pyrite. This stage is developed at the contact of ore and host-rocks and characterized by almost lack of the precious metals. Andrusenko & Shchepot'yev (1974) reported that some amount of gold was deposited in this stage; however, Petrenko (1999) confirmed this stage as a prior to main metal-carrying stage and barren in concentration of any metals.

Stage II is a major mineralization stage distinguished in Aginskoe and Bluzdayushee ore bodies combined Au-Ag-Te and Ag-Au-Te-sulfide mineralization (Fig. 4.3.1.1. & Fig. 4.3.1.2.). This stage shows milky colored colloform and banded quartz units adjusted to semitransparent quartz with pseudo-acicular texture. The Au-Ag-Te mineralization type with Au-bearing tellurides such as calaverite and few Au-free tellurides (altaite and hessite) are scattered within the unit of the rhythmically-repeated banding quartz. Those quartz bands are marked by the presence of adularia pseudomorphs replaced by quartz defined by typical shape of the adularia crystals (Fig. 4.3.1.2a.). Some of gold-silver minerals in association with Au-bearing tellurides and chalcopyrite grow along pseudomorphs of adularia crystals forming dendritic texture (Fig. 4.3.1.2a.). The Ag-Te-sulfide mineralization presented by altaite, hessite and petzite accompanied with chalcopyrite and sphalerite is occurred in semi-transparent (colloidal) quartz band of the 9th sub-stage in stage II (Fig. 4.3.1.2a.). The careful observation of specimens revealed rough boundary between unit containing Au-Ag-Te minerals and quartz layer carrying Au-poor Ag-Te minerals. It is clear that most tellurides have been precipitated in the decomposition of previous unit forming locally Te-rich one. The time relationship between two different mineralization types is still ambiguous. Those ore specimens carrying visible gold-telluride mineralization are usually showing discontinuous depositions between units of banded quartz-adularia layers and semitransparent quartz (Fig. 4.3.1.2 a, b.). Instead of that, barren samples or including only Ag-Te-sulfide mineralization display continuous deposition of quartz-adularia banded vein.

Stage III is recognized in the central parts of the ore shoots. It is constructed of the intensively brecciated ores structure probably formed in the consequence of boiling of the hydrothermal water. The hydrothermal breccias involve early

generation quartz blocks cemented by mixture of microcrystalline quartz, adularia and clays (Fig. 4.3.1.2c and Fig. 4.3.1.3b.).

Stage IV is represented by aggregates of amethyst-like quartz occupying free spaces among breccias formed in the previous stage. This stage barren for any precious metals was distinguished in each studied ore body. Generally amethyst quartz grows in available free spaces still remaining between early crystallized minerals (Fig. 4.3.1.4.).

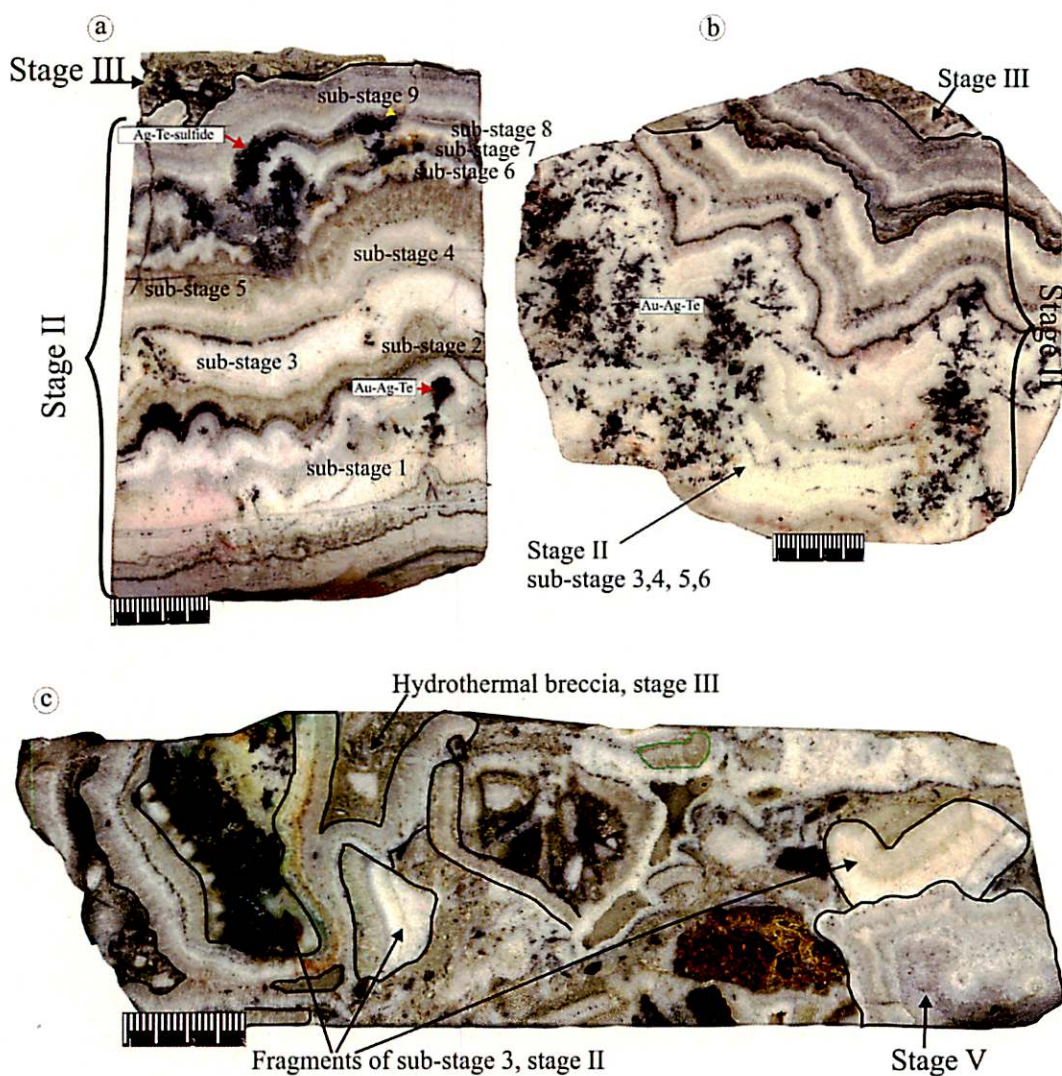


Fig.4.3.1.2. Ore specimens from Aginskoe ore body showing sequence of the mineralization stages: a) rhythmically colloform-banding ore combines Au-Ag-Te, occurring within milky quartz bands and Ag-Au-Te-sulfide occurring in semitransparent quartz; b) dendritic mode occurrence of native gold, Au-bearing tellurides and chalcopyrite within quartz-adularia aggregates; c) a hydrothermal breccia showing time relationship between stages II, III and IV.

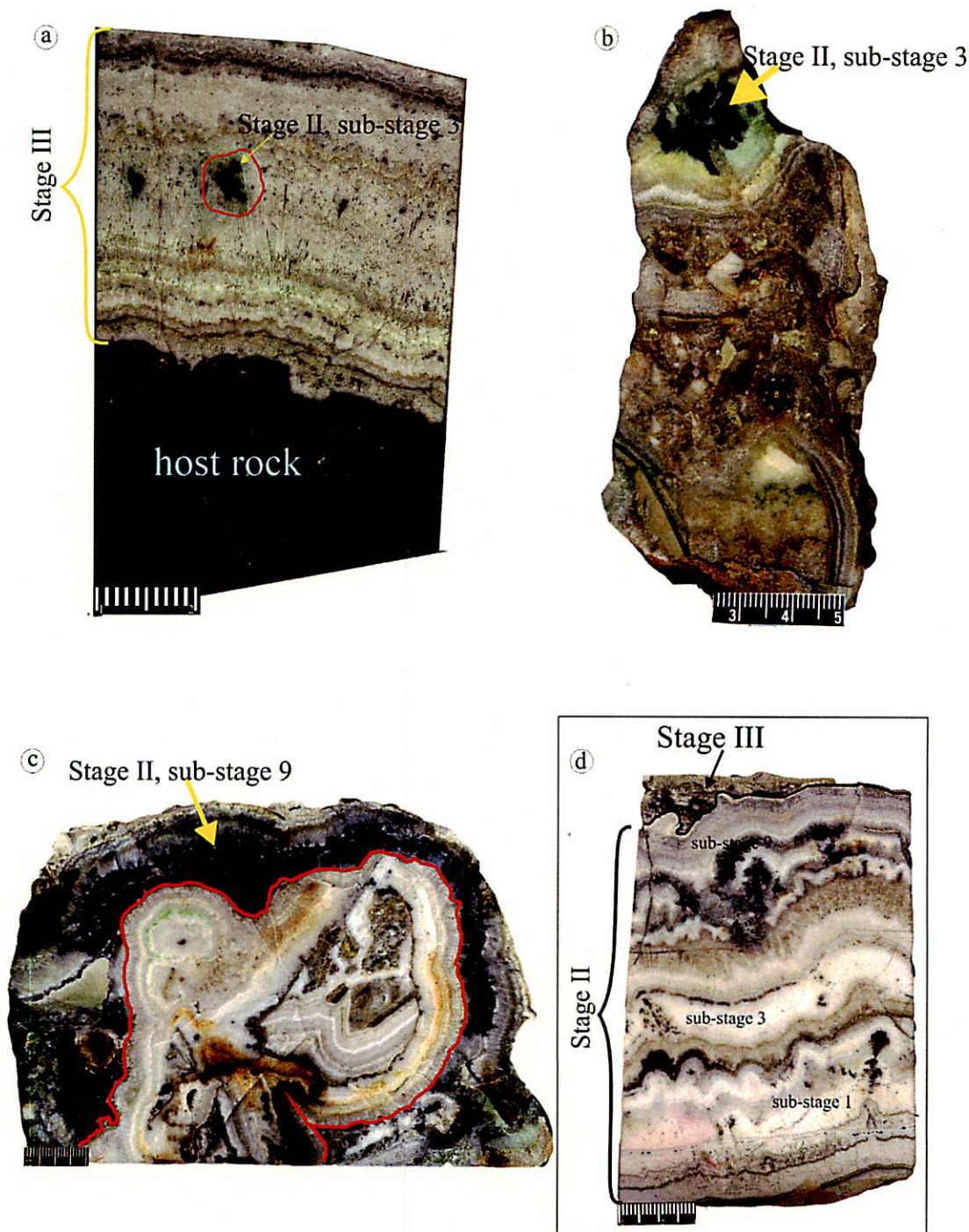


Fig.4.3.1.3. Ore specimens from Bluzdayushee ore body showing sequence of the mineralization stages: a) colloform-banding ore hosting Au-Ag-Te within milky quartz growing from a wall of host rocks. Remnants of adularia crystals are recognizable macroscopically; b) fragment of quartz hosting Au-Ag-Te mineralization of stage II in hydrothermal breccia of the stage III; c) bands of quartz referring for sub-stages through 9 to 11 of the stage II with rich Ag-Te-sulfide mineralization are coating brecciated fragments of sub-stages 1-6 of the stage II; d) specimen from Aginskoe ore body used as a standard for the comparison of the mineralization stages.



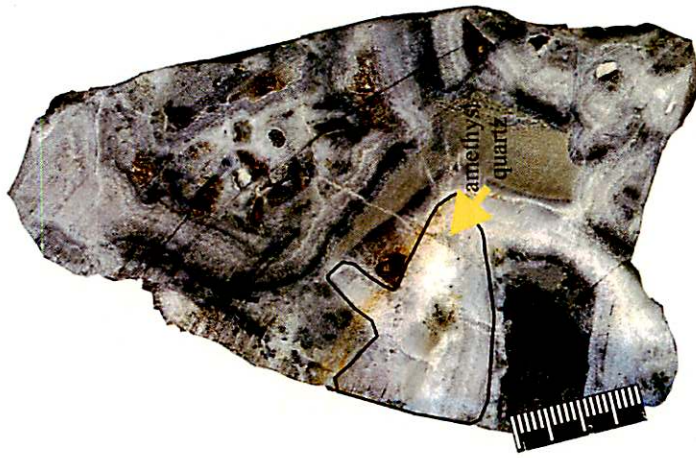
ore body Bluzdayushee,
Aginskaya vein



ore body Aginskoe,
Aginskaya vein



ore body Malysh,
Surprise vein



ore body Surprise,
vein Surprise

Fig.4.3.1.4. Occurrence of amethyst quartz in ore bodies Bluzdayushee, Aginskoe, Malysh and Surprise. Amethyst is filled free spaces in breccias.

Stage V is relegated to the deposition of calcite. The carbonates are showing local abundance, thus, the relationship between calcite with early stages has been not indentified yet. Due to abundant occurrence of carbonates in central part of veins, Petrenko (1999) referred them to post-ore stage. In this study calcite was observed as overgrowing amethyst quartz in Malysh ore body mainly. Thus, it agrees with Petrenko's statement that calcite crystallized during the post ore stage.

Stage VI has been classified as supergene one. The stage is recognized mainly in the stage II ore, in which most significant mineralization occurred. Supergene mineralization includes the weathering products of primary ore phases (stage VI-1) and oxidized minerals (stage VI-2) (Fig. 4.3.1.1.). The weathering in caused on overgrowing of primary Au-Ag tellurides by rare known metallic alloys containing of Cu, Pb, Au, Te, Ag with mustard gold, which are highly unstable under oxidized conditions and tend to be easily oxidized. Among others secondary minerals chalcocite and Fe-hydroxides are recognized. They commonly replace chalcopyrite of the stage II. This stage widely occurs throughout whole veins systems. Tendency of the prevailed of distribution of secondary minerals in upper horizons were not always noticed.

The comparison of Aginskoe ore body with the ore shoots occurring on the upper mining levels shows the similar gangue bands, however, characterized by exponentially decreasing of amount of visible ore minerals impregnation upward to the surface. In Aginskoe vein visible gold-telluride and silver-telluride-sulfide mineralizations were observed in ore bodies Aginskoe and Bluzdayushee only. Yasnoe ore body occupying shallowest horizons in Aginskaya vein are free of impregnation of ore minerals. Also, no any ore mineral was observed in the Valery ore body laid on the eastern most upper mining levels.

Bluzdayushee ore body is occurred in Aginskoe vein at levels between 1150-1410 m. Highest grades of Au are prevalent to the central part of ore body. Classification of mineralization stages is shown in Fig. 4.3.1.3. It is composed of similar quartz-adularia bands, which were observed in Aginskoe ore body (Fig. 4.3.1.2.). Some bands are hosting gold-silver-telluride mineralization. It is recognized in banded ore as well as in brecciated (Fig. 4.3.1.3 a.b.). Silver-

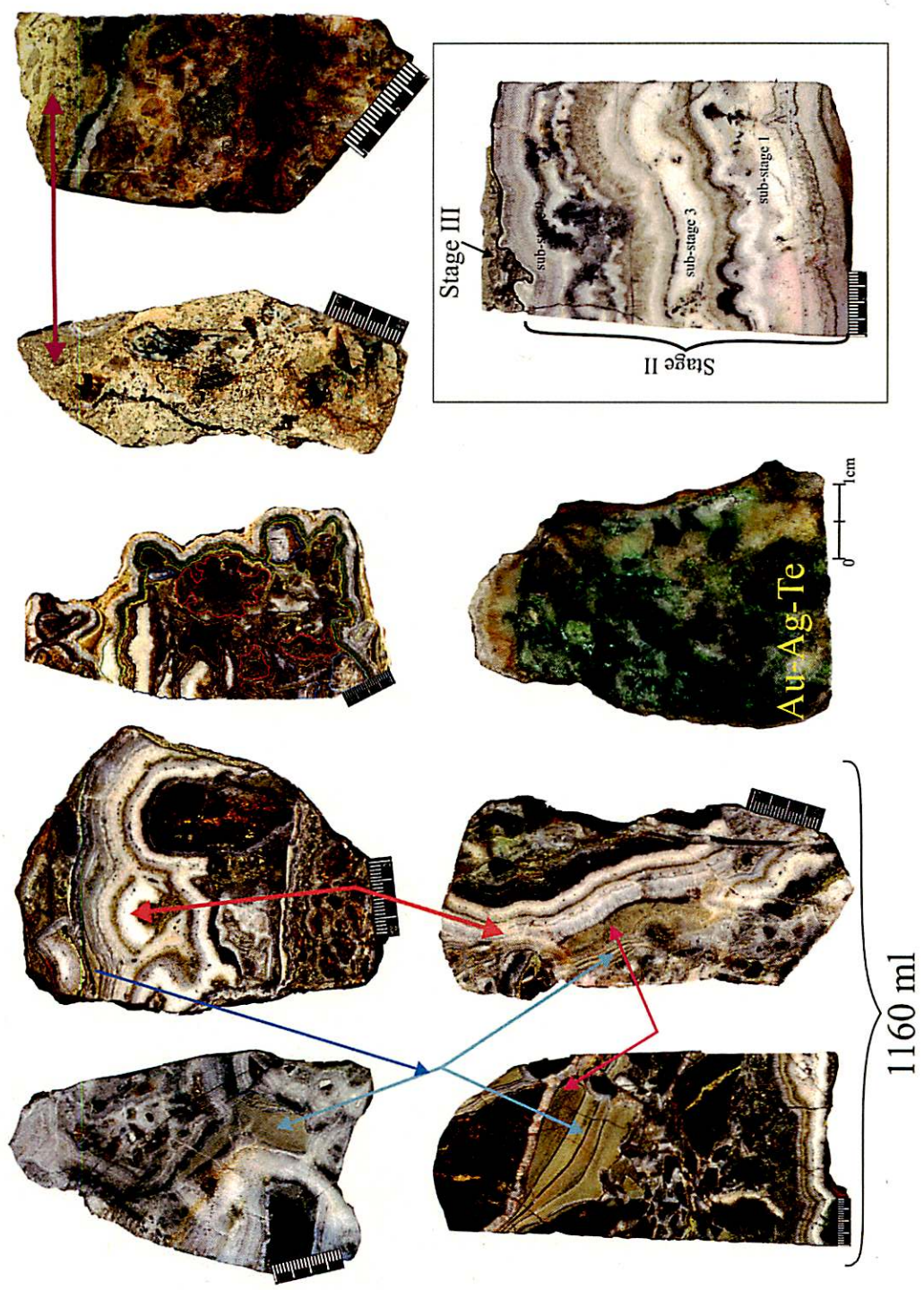


Fig.4.3.1.5. Ore specimens collected along Surprise ore body. Most of samples are hydrothermal breccias, hosting Au-Ag-Te mineralization. Specimen in the square is from Aginskoe ore body used as a standard for the comparison of the mineralization stages.

telluride-sulfide mineralization was rarely observed in samples from Bluzdayushee ore body. Basically those samples are hydrothermal breccias, and mineralization is tends to show close relation with brecciation (Fig. 4.3.1.3c.). Generally Bluzdayushee ore body is showing same mineral paragenesis as Aginskoe ore shoot.

Surprise ore body, occurring in Surprise vein, is filled a shear fracture. Surprise vein hosts two major ore bodies Surprise and Malysh and number of minor ore bodies. Surprise ore body is complicated by various brecciated events happened during the formation of the vein. Some independent mineralization stages distinguished in Aginskoe ore body could be observed in Surprise ore body, commonly latest shows distinct difference in compound (Fig. 4.3.1.5.).

Malysh ore body is shear link between Aginskoe and Surprise veins. Malysh ore body grades into Olimpiskoe apophyse, occurring at level of 1190-1370 m. It consists of banding and brecciated ores. Mineralization stages recognized in Aginskoe ore body were also distinguished in Malysh ore body and Olimpiskoe apophyse (Fig. 4.3.1.6.). It is needed to note that in Surprise ore body and in Malysh ore body aggregates of well- developed quartz crystals are found (Fig. 4.3.1.7.). They are spatially related to gold mineralization. Spatial and time relation to stages recognized in Aginskoe ore body is still under consideration. In Aginskoe ore body only single crystals of similar nature with quartz aggregates from Surprise and Malysh ore bodies were found in the hydrothermal breccias (Fig. 4.3.1.7.).

A few samples were collected from Yasnoe ore body, Noyab'rskoe ore body and Valery ore body (Fig. 4.3.1.8.).

Previously mineralization stages in ores of Aginskoe deposit were classified by Andrusenko and Shepot'ev (1974) and I.D. Petrenko (1999); however, the stages were basically distinguished based on mineral paragenesis. The collective of colleagues of the Central Geological Research Institute for Nonferrous and Precious Metals (Petrenko, 1999) had done the detailed mineralogical study of the Aginskoe deposit in 1979. As a result of that study several mineral complexes have been defined. The briefly description of the mineral complexes translated from original source are given below.

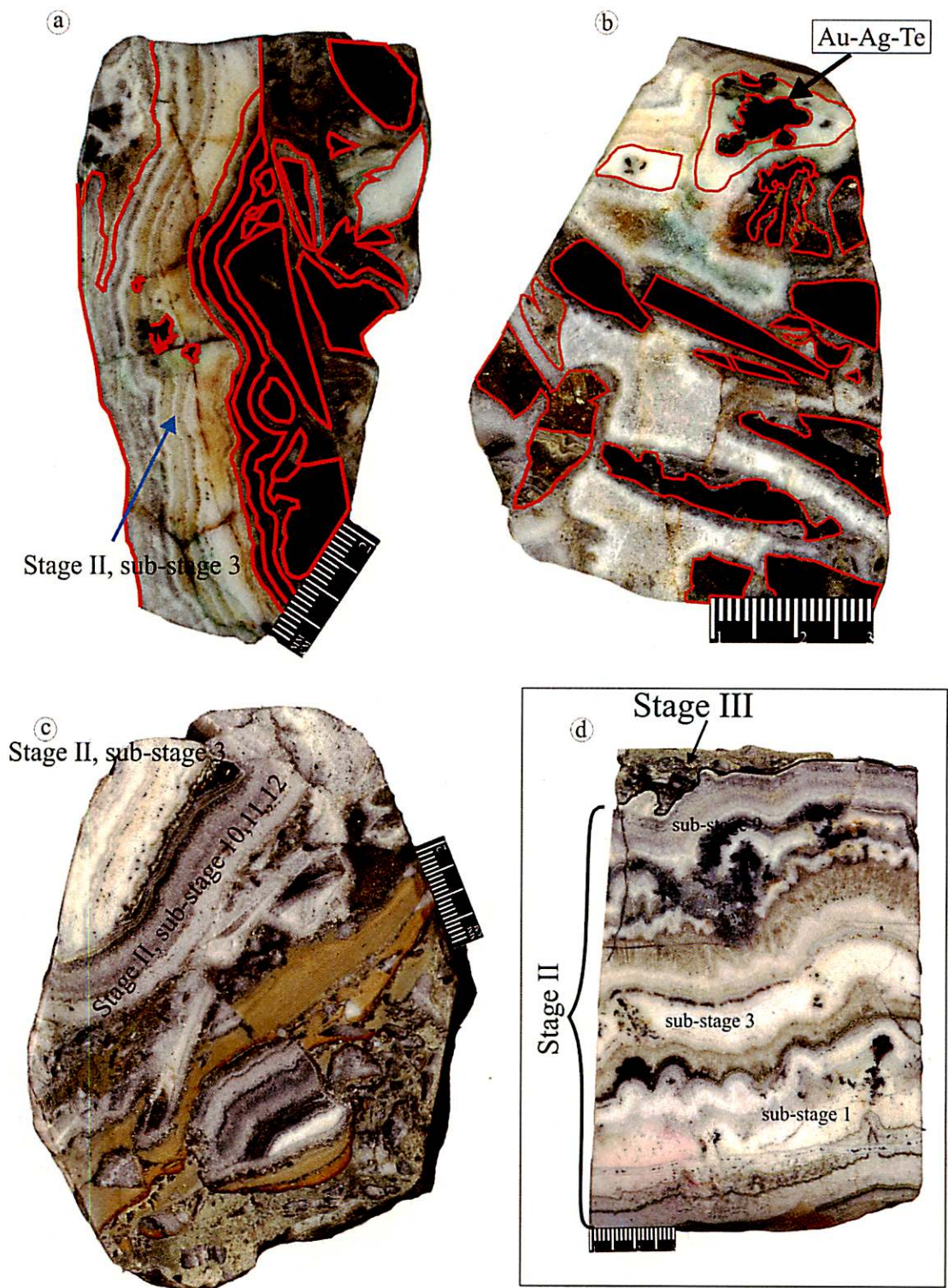


Fig.4.3.1.6. Ore specimens collected along Olimpiskoe apophyse and Malysh ore body. a,b) ore samples of the Olimpiskoe apophyse showing preserved fragments of the stage III with Au-Ag-Te mineralization in breccias of the stage II; c) hydrothermal breccias from Malysh ore body hosting quartz fragments resemble for a stage II; d) specimen from Aginskoe ore body used as a standard for the comparison of the mineralization stages.



Fig.4.3.1.7. Occurrence of euhedral quartz aggregates from Malysh ore body (upper left); Surprise ore body (upper right). Similar appearance is showing single quartz crystals in hydrothermal breccias of Surprise ore body (lower left) and Aginskoe ore body (lower right).

1. **Quart-pyrite pre-mineralization complex** widely distributes in the ore. It presents white slightly banded massive quartz with invisible impregnation of pyrite. The pre-mineralization complex occurs on the margin of the ore shoots or could be recognized as fragments in breccias.

2. Gold-pyrite-adularia-corrensite-quartz complex represents dirty green radiate-banded fine and coarse-grained aggregates of quartz, adularia and corrensite. A thin layer of the gold-sulfide mineralization with minor tellurides occurs in crustiform-banded vein selvages. Although, the complex was generally observed in lower levels of Aginskoe and Surprise ore shoots, the sufficiently large blocks may be found in breccias in upper levels.

3. Gold-silver-quartz complex is related to the periodically recurring layers of quartz and adularia without any visible mineralization. The complex occupies central parts of ore shoots or forms individual bodies. It is characterized by the light degree of mineralization with gold as a main mineral.

4. Gold-calaverite-quartz complex occurs within banded porcelaneous quartz aggregates intergrown with adularia. The ore mineralization consists of gold, gold and silver tellurides, sulfides. It locally distributes within Aginskoe and Surprise ore shoots.

5. Gold-hessite-corrensite-quartz mineral complex consists of the banded colloidal quartz, adularia and corrensite with semitransparent pale-gray quartz carrying significant metallic mineralization. Opaque minerals predominantly are gold, hessite, altaite and chalcopyrite. This complex is most common for each ore body of the deposit. It corresponds to central parts of ore bodies at the level of 1200 m. However, tellurides restrict below the level of 1200 m. Concentration of minerals is decreased upward.

6. Gold-zeolite-quartz-carbonate mineral complex locally distributes within ore bodies of Aginskoe and Surprise veins. It had been observed as small scale veinlets branching from main ore bodies. It is most typical for Nakhodka vein and vein № 6. Among zeolite minerals were determined desmine as a main mineral and laumontite as a trace one. Among opaque minerals most common is native gold with minor pyrite, chalcopyrite, galena and acanthite. The relationship between the gold-zeolite-quartz-carbonate mineral complex with described above mineral complexes is unclear. Generally, it occurs on the upper part of veins.

7. Quartz-zeolite-calcite post-mineralization mineral complex makes up the central part of veins. Also, it is cement for the hydrothermal breccias. No any ore minerals were determined in this complex.



Fig.4.3.1.8. Ore specimens collected from Yasnoe ore body (a), Valeri ore body (b), Noyabr'skoe ore body (c).

4.3.2. Age of precious mineralization

Previously age dating was reported by Petrenko (1999) and Okrugin (2001). K/Ar dating was done for host rocks and ore samples of the Aginskoe shoot, basically. The result of K/Ar dating is given in Table 4.3.2.1., which have been adopted from Petrenko (Petrenko, 1999).

The K-Ar and Ar-Ar dating for the precious mineralization at Aginskoe and South-Aginskoe deposits have been reported by Petrenko (1999) and Okrugin (2001). They showed ages of mineralization $7.48 (\pm 0.30)$ Ma for Aginskoe deposit and $7.45 (\pm 0.30)$ Ma for South-Aginskoe deposit (Petrenko, 1999) and $6.9 (\pm 0.2)$, $7.1 (\pm 0.7)$, $7.4 (\pm 0.1)$, $7.48 (\pm 0.3)$ Ma for Aginskoe deposit (Okrugin, 2001; Okrugin *et al.*, 2010). Host rocks and nearby emplaced intrusive body revealed ages from $7.64 (\pm 0.31)$ to $7.71 (\pm 0.24)$ Ma for volcanic rocks, from $7.40 (\pm 0.20)$ Ma for the intrusive body of gabbro-diorite spatially related to the mineralization, and $7.90 (\pm 0.24)$ Ma for the subvolcanic andesitic basalt body emplaced in the periphery part of the caldera (Petrenko, 1999), respectively.

Adularia was chosen as a K-bearing mineral closely associating with precious mineralization in quartz veins. Additionally, adularia is abundant gangue mineral occurring in through veins systems from early to late stages of mineralization allowing the estimation of timing of vein formation and also analyzing of time gap during a ore formation.

Table 4.3.2.1. K-Ar dating for ore and host rocks samples of Aginskoe deposit
(after Petrenko. 1999).

№	Type	Age, Ma
383	Adularia-Quartz vein	7.48 ± 0.30
385	Adularia-Quartz vein № 2 the South Aginskoe deposit	7.45 ± 0.30
384	Basalt (the lower unit)	7.64 ± 0.31
956	Andesitic-Basalt (the upper unit)	7.71 ± 0.24
396	Andesitic-basalt, subvolcanic body	7.90 ± 0.24
968	Diorite	7.40 ± 0.20

In polished thin sections adularia was observed as acicular-shaped crystals of about 2-3 cm in length and rhombic-shaped crystals. Both varieties of adularia are occurred together with Au-Ag-Te mineralization. K-Ar age dating showed that adularia occurring in a gouge of Bluzdayushee ore shoot has apparent age of 7.10±0.2 Ma, and adularia occurring in central part of ore shoot has apparent age of 6.93±0.2 Ma (Table. 4.3.2.2.). Thus, Bluzdayushee ore shoot was formed in Late Miocene in age range of 170,000 years. K-Ar age dating of vein adularia from Valeri ore body yields a Late Miocene age of about 6.70±0.5 Ma.

Table 4.3.2.2. K-Ar age of Bluzdayushee orebody.

No.	Sample	Mineral	⁴⁰ Ar _{air}	40Ar _{rad}	% K	K/Ar age (Ma)
1	B6/1	adularia	82.9	0.975±0.012	1.98±0.02	7.10±0.2
2	B6/3	adularia	70.8	0.938±0.007	1.95±0.02	6.93±0.2

Age was calculated using constants: $\lambda_K=0.581 \cdot 10^{-10} \text{ year}^{-1}$, $\lambda_\beta=4.962 \cdot 10^{-10} \text{ year}^{-1}$, $^{40}\text{K}=0.01167$ (at. %).

Chapter V. Mineralogy of mineralized veins and hydrothermal altered rocks at the Aginskoe deposit

5.1. Geochemistry of host rocks and ores

5.2. Alteration mineralogy

5.3. Vein mineralogy

5.4. Quartz texture

Chapter V. Mineralogy of mineralized veins and hydrothermal altered rocks at the Aginskoe deposit

Aginskoe mine is a leader gold producer in the Kamchatsky Krai entire. Mining has started in December, 2006. A total reserve of gold is 39 t and silver is 20 t. The end product is a gold-silver dore. The ore consists of different tellurides, including their secondary products, gold-silver minerals and sulfides. Grades of Au and Te are highly variable in quartz-adularia-carbonate epithermal veins. The ore are not exposed at the present surface. This allows a detailed investigation of mineral associations and their changing in vertical extension of veins from deeper to shallowest horizons.

5.1. Geochemistry of ore and REE

Due to strong ore oxidation and wide occurrence of secondary minerals only a few hypogene minerals were identified in this study. Among them major vein minerals are native gold, calaverite, altaite, hessite, petzite, chalcopyrite and sphalerite. However, previous investigators have reported various kinds of gold-silver tellurides in Aginskoe deposit (Nekrasov, 1991; Petrenko, 1999; Okrugin, 2001). They are sylvanite, krennerite, calaverite and coloradoite. Tennantite-tetrahedrite minerals, bornite, pearceite and Se-bearing galena were also reported (Andrusenko & Shepot'ev, 1974; Okrugin, 2001). Moreover Nekrasov (1991) and Okrugin (2001) have determined rare oxide gold-telluride minerals in ores of Aginskoe deposit, some of them are still unknown due to impossibility measuring the chemical composition by the EPMA. The temporal chemical formulas of unknown oxide gold minerals were provided by Nekrasov in "Geochemistry of gold-silver deposit" (Nekrasov, 1991). Also, Nekrasov has reported a mustard gold in ores from Aginskoe deposit.

In this study Au-Ag-Te and Ag-Te-sulfide mineral assemblages are found. The former type is occurred in sub-stages 1-3 of the stage II consisting of native gold, gold-bearing tellurides, chalcopyrite, petzite and some amount of altaite, hessite and

pyrite. Ag-Te-sulfide mineralization is occurred in the sub-stage 9 of stage II consisting of hessite, altaite, chalcopyrite and sphalerite.

Five samples of andesite and andesitic basalt host rocks were also analyzed by ICP method. Table 5.1.2. presents ICP data for host rocks. The ICP analysis had been done for more than 40 representative ore samples, obtained from Aginskoe ore body, Bluzdayushee ore body, Noyabr'skoe ore body, Surprise ore body, Malyshe ore body and Olimpiskoe apophyses. The analytical results are given in Table 5.1.2. Epithermal veins are marked by high concentration of Au, Te, Pb and Cu. Scattered diagrams of correlation of Au vs. Ag, Te, Cu, Pb and As and Te vs. Se are shown in Fig. 5.1.1. In Aginskaya vein gold grades are highly variably showing a positive correlation with Ag, however, decreasing upward: in Aginskoe ore body Au grade varies from highest 7403 ppm to lowest 99.5 ppm, in Bluzdayushee ore body Au grades from highest 1040 ppm to lowest 7.1 ppm. In Surprise vein gold grade is also showing irregular distribution with a positive correlation with Ag: in Surprise ore body Au grades from 7437 ppm to 3.8 ppm, in Malyshe ore body from 3109.5 to 15.1 ppm. No any positive or negative trends were observed from diagram of Au vs. As (Fig. 5.1.1.). Also, Au shows a positive correlation with Te and Cu with some exceptions (Fig. 5.1.1.). Te content is much higher than Au in Aginskoe deposit ranging from 367.3 ppm to 7679 ppm in Aginskoe ore body; from 55 ppm to 8766.2 ppm in Bluzdayushee ore body; from 9.0 ppm to 20767.2 ppm in Surprise ore body and from 12.9 ppm to 1553.7 ppm in Malyshe ore body. Diagram Te vs. Se shows a random distribution without any good correlation (Fig. 5.1.1.). Se content rarely exceeds concentration of 50 ppm.

Concentrations of REE were measured by ICP analysis in both host rocks and ore samples. REE compositions are given in Tables 5.1.3. and 5.1.4. Eu/Eu^* were calculated using formula $Eu/Eu^* = Eu_N / (Sm_N * Gd_N)^{1/2}$ and Ce/Ce^* calculated from the formula $Ce/Ce^* = Ce_N / ((2La_N + Sm_N) / 3)$ taken from reference (Anan'ev, 2012).

A chondrite normalized spider diagram shows an equal abundance on incompatible elements in host rocks with a clear positive anomalous of Ba and negative anomaly of Nb and Ta. Primitive mantle normalized REE patterns of host rocks are almost flat, however, slight enrichment in LREE could be noticed (Fig. 5.1.2.). Eu/Eu^* is varying in narrow range from 0.8-1.0 with lowest value of 0.79

Table 5.1.1 Bulk composition of host rocks of Aginskoe deposit.

	Ahr1	Ahs2	Ahs3	Ahs4	Ahs5
SiO ₂	52.15	52.02	52.29	50.96	55.49
Na ₂ O	2.61	2.87	2.88	3.16	0.96
MgO	3.62	3.54	3.46	4.70	3.66
Al ₂ O ₃	17.23	18.74	19.46	17.59	14.22
P ₂ O ₅	0.27	0.21	0.22	0.32	0.12
K ₂ O	3.21	1.67	1.59	1.59	6.71
CaO	6.26	8.33	8.43	7.43	3.22
TiO ₂	0.73	0.75	0.75	0.89	0.69
MnO	0.20	0.14	0.15	0.19	0.22
Fe ₂ O ₃	8.29	7.78	7.87	9.40	8.58
Be	2	<1	<1	2	<1
Sc	18	19	18	24	27
V	177	194	197	242	212
Co	19.1	19.5	19.8	23.5	24.0
Ni	9.4	7.0	7.2	11.6	28.2
Cu	58.40	41.0	59.8	112.1	91.5
Zn	59	50	52	52	56
Ga	15.4	15.5	15.8	17.6	13.5
As	3.7	1.5	0.8	1.9	5.1
Se	0.6	<0.5	<0.5	<0.5	0.5
Mo	0.3	0.3	0.3	1.4	0.2
Ag	<0.1	<0.1	<0.1	<0.1	0.3
Cd	0.1	<0.1	<0.1	<0.1	0.6
Sb	0.1	0.1	0.1	<0.1	0.5
Au	12.3	6.6	7.2	50.5	12.5
Hg	0.02	0.01	<0.01	0.01	0.83
Tl	<0.1	<0.1	<0.1	<0.1	<0.1
Pb	5.2	2.3	2.0	2.4	3.2
Bi	<0.1	<0.1	<0.1	<0.1	<0.1

Table 5.1.2 Bulk composition of quartz-adularia ores: Aginskoe ore body.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Na ₂ O	0.050	0.059	0.072	0.046	0.050	0.049	0.049	0.049	0.074	0.052
MgO	0.063	0.156	0.031	0.048	0.035	0.074	0.028	0.356	0.060	0.752
Al ₂ O ₃	0.913	3.237	1.256	1.043	0.910	1.227	2.534	1.261	1.308	2.611
P ₂ O ₅	0.013	n.d	n. d.	n. d.	n. d.	0.014	0.010	n.d.	n.d.	0.012
S _{total}	0.076	0.006	0.010	0.021	0.094	0.173	0.123	0.012	0.015	0.063
K ₂ O	0.257	2.302	0.643	0.338	0.298	0.510	1.194	0.073	0.394	0.843
CaO	0.093	0.102	0.077	0.230	0.074	0.121	0.123	0.471	0.230	0.163
TiO ₂	0.001	0.001	0.002	0.005	0.003	0.007	0.002	0.002	0.007	0.037
MnO	0.006	0.009	0.003	0.007	0.004	0.007	0.002	0.016	0.006	0.039
Fe ₂ O ₃	0.980	0.647	0.587	0.659	0.711	0.874	0.899	1.032	0.655	1.291
Li	130	59.2	153	110	138	89.5	36.0	62.8	142	67.4
Be	0.2	0.1	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.6
Sc	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.9
V	16.4	11.4	9.2	4.1	3.4	10.6	3.7	12.8	12.3	23.8
Cr	568	483	492	452	510	496	420	569	519	320
Co	2.8	2.7	2.4	2.0	2.1	2.3	1.8	2.8	2.7	3.1
Ni	21.2	12.4	15.6	10.8	13.8	12.7	n.d.	20.1	14.8	13.6
Cu	926	80	117	230	802	1646	2328	149	101	144
Zn	266	66	110	108	506	433	58.1	97.2	60.8	105
Ga	0.5	1.4	0.6	0.6	0.5	0.6	0.8	2.0	0.5	3.3
As	2.9	1.7	n.d.	4.1	n.d.	3.5	n.d.	n.d.	n.d.	5.8
Se	6.1	1.9	4.1	4.0	33.4	51.1	6.5	3.2	2.1	5.5
Mo	6.1	5.5	4.9	5.4	6.5	5.0	5.3	6.9	5.1	3.7
Pd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ag	264	197	156	328	443	717	215	399	208	147
Cd	54.6	28.0	45.5	33.8	157	119	10.6	17.4	43.3	11.8
In	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sn	1.3	0.9	0.8	1.1	2.0	1.6	1.3	2.8	0.9	1.2
Sb	8.1	19.8	9.4	6.9	19.6	16.1	11.8	29.5	7.0	7.7
Te	852	423	722	525	3815	3264	2789	7679	790	367.3
W	43.2	29.0	27.6	32.1	34.2	27.7	32.7	27.3	26.6	24.8
Re	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ir	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pt	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Au	307	139	172	99.5	777	3241	4899	7403	254	916
Hg	0.5	0.7	0.5	0.3	0.6	1.8	1.2	1.8	1.0	0.6
Tl	0.2	0.7	0.4	0.2	0.3	0.4	0.5	0.1	0.2	0.3
Pb	897	367	725	427	2930	3168	282	394	573	486
Bi	2.2	1.1	1.2	0.9	8.0	6.9	0.3	0.4	1.2	0.5

Table 5.1.2 Continued: Bluzdayushee ore body (B1.2.3) and Noyabr'skaya ore body (N1.2.3).

	B1	B2	B3	N1	N2	N3
Na ₂ O	0.049	0.048	0.048	0.050	0.076	0.064
MgO	0.240	0.090	0.237	0.137	0.173	0.076
Al ₂ O ₃	1.433	2.110	2.300	1.491	4.768	1.527
P ₂ O ₅	n.d.	0.008	0.021	0.007	0.025	0.007
S _{total}	0.006	0.602	0.126	0.344	0.009	0.007
K ₂ O	0.511	0.538	0.698	0.361	1.181	0.550
CaO	0.523	0.078	0.149	0.157	0.320	0.076
TiO ₂	0.004	0.024	0.034	0.051	0.247	0.038
MnO	0.011	0.005	0.011	0.011	0.009	0.005
Fe ₂ O ₃	0.882	2.125	0.593	1.992	1.502	0.762
Li	73.7	142	148	146	133	194
Be	0.3	0.2	0.3	0.2	0.4	0.3
Sc	n.d.	0.7	1.0	0.8	5.1	0.8
V	5.6	16.3	20.8	24.2	71.5	12.7
Cr	504.6	n.d.	n.d.	326.9	412.9	422.3
Co	2.0	7.3	1.2	2.6	2.3	2.4
Ni	12.6	0.8	1.1	11.8	16.6	9.2
Cu	15.3	7790.3	130.7	111.3	61.7	20.8
Zn	59.4	587.1	158.2	45.8	10.1	27.6
Ga	1.2	1.2	1.8	1.4	5.7	1.4
As	n.d.	n.d.	1.0	22.9	35.5	6.2
Se	1.7	52.0	2.1	4.6	n.d.	n.d.
Mo	5.0	1.3	0.2	6.0	3.5	4.1
Pd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ag	51.3	230.0	43.6	42.2	13.8	20.4
Cd	2.7	185.3	16.4	0.6	0.3	0.5
In	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sn	0.9	2.1	0.4	2.4	1.2	1.0
Sb	7.1	35.7	7.8	10.2	5.5	6.2
Te	55.1	8766.2	491.9	67.2	25.1	35.2
W	29.5	64.6	2.5	22.5	23.6	27.0
Re	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ir	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pt	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Au	172.0	1040.1	127.8	94.1	7.1	36.5
Hg	< 1.5	n.d.	n.d.	< 1.4	< 1	0.2
Tl	0.2	0.2	0.2	0.1	0.4	0.2
Pb	48.0	5257.5	256.3	130.9	32.1	26.2
Bi	n.d.	16.0	0.4	1.3	0.4	0.2

Table 5.1.2 Continued: Surprise ore body.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Na ₂ O	0.166	0.042	0.041	0.024	1.434	0.047	0.050	0.029	0.074	0.040	0.048	0.111	0.050
MgO	0.855	0.477	1.029	1.129	1.704	0.216	0.157	0.010	0.182	0.063	1.127	0.470	0.013
Al ₂ O ₃	2.541	2.772	1.630	1.878	10.074	1.214	0.919	0.502	1.393	1.776	1.793	2.779	0.727
P ₂ O ₅	0.036	0.039	0.015	0.010	0.140	0.025	0.066	0.071	0.070	0.006	0.032	0.027	0.038
S _{total}	0.127	0.048	0.161	0.106	0.105	0.491	0.826	1.022	0.501	0.030	0.051	0.183	0.511
K ₂ O	0.779	0.401	0.159	0.074	1.480	0.211	0.277	0.049	0.326	0.453	0.409	1.465	0.172
CaO	0.217	0.323	0.196	0.133	4.350	0.123	0.121	0.211	0.368	0.135	0.204	0.161	0.081
TiO ₂	0.086	0.082	0.026	0.005	0.372	0.013	0.007	0.002	0.035	0.016	0.043	0.059	0.001
MnO	0.041	0.033	0.031	0.057	0.115	0.018	0.010	0.003	0.034	0.006	0.060	0.023	0.003
Fe ₂ O ₃	1.709	1.310	1.850	2.241	4.784	1.651	1.384	2.641	2.865	0.852	1.618	1.560	2.272
Li	147.7	121.5	86.0	105.4	39.8	150.0	144.3	94.2	190.8	67.9	58.0	107.1	170.6
Be	0.2	0.4	0.2	0.4	0.9	0.3	0.3	0.2	0.2	0.3	0.2	0.3	0.1
Sc	2.1	2.4	0.6	0.3	8.6	0.3	0.2	n.d.	0.7	0.3	0.8	1.2	n.d.
V	29.6	56.2	21.5	40.2	143.7	26.0	3.7	n.d.	9.7	12.0	24.5	36.2	14.7
Cr	506.9	205.8	423.8	359.7	281.3	625.2	545.4	656.9	748.7	630.0	543.9	515.6	617.8
Co	4.3	3.0	4.3	2.2	8.0	3.7	2.8	3.9	5.9	2.5	2.8	3.9	3.3
Ni	17.8	10.6	13.6	13.6	22.0	20.8	12.1	19.1	20.1	12.1	13.6	15.5	16.8
Cu	1177.0	104.3	231.0	1003.4	9046.0	994.3	4710.9	16705.0	11556.5	28.0	331.2	397.9	11374.8
Zn	621.2	129.2	196.8	445.1	60.9	4347.8	5004.8	1301.4	236.1	21.5	209.2	159.1	1259.4
Ga	2.8	3.1	2.6	3.2	9.3	1.3	0.8	0.5	1.0	2.3	2.4	2.1	0.3
As	n.d.	17.4	6.5	9.7	4.8	14.6	n.d.	5.9	3.6	n.d.	5.0	15.0	6.7
Se	8.7	3.0	7.0	12.3	n.d.	196.5	309.9	112.7	13.8	n.d.	7.1	4.6	101.6

Mo	5.2	4.4	3.6	3.6	13.2	23.7	5.9	9.0	8.4	4.8	4.8	5.3	7.3
Pd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ag	298.2	196.9	331.0	299.2	23.2	415.7	225.0	1255.2	178.3	11.1	342.6	197.2	1355.4
Cd	74.7	8.6	24.9	55.3	0.4	457.5	466.0	241.4	45.3	0.5	45.3	17.0	344.0
In	n.d.	n.d.	n.d.	n.d.	n.d.	< 1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	< 0.4
Sn	2.8	2.2	1.3	1.6	2.0	4.6	2.9	7.8	1.6	0.7	1.6	1.7	3.7
Sb	19.3	10.8	7.6	13.1	1.4	28.9	26.9	75.3	7.6	6.6	7.1	6.3	41.3
Te	3497.7	403.5	1215.9	1861.6	9.0	6137.3	6779.1	20767.2	855.8	13.5	975.8	445.6	10398.0
W	34.3	23.5	23.3	24.3	17.2	37.6	35.9	33.2	39.4	35.1	33.5	26.7	35.5
Re	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ir	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pt	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	< 0.09	n.d.	n.d.
Au	4187.8	340.1	699.3	822.9	3.8	1740.4	6025.0	7437.1	263.0	40.6	1304.0	277.7	2123.2
Hg	0.5	0.6	1.3	2.1	< 1	0.8	0.4	0.7	0.7	< 1.3	< 1.6	0.9	1.1
Tl	0.4	0.2	0.1	0.2	0.3	0.7	0.5	0.4	0.2	0.1	0.3	0.5	0.4
Pb	1373.1	443.8	683.0	2002.0	12.7	13886.9	9930.5	6640.7	1089.2	26.4	1279.2	635.2	7232.6
Bi	1.5	0.4	2.0	1.1	0.1	11.8	11.2	5.8	1.8	0.1	0.9	0.6	27.8

Table 5.1.2 Continued: Malysh ore body.

	M1	M2	M3	M4	M5	M6	M7	M8	M9
Na ₂ O	0.011	0.046	0.046	0.049	0.056	0.034	0.058	0.055	0.035
MgO	0.308	0.434	0.724	0.698	0.219	0.237	0.232	0.080	0.024
Al ₂ O ₃	0.399	2.411	1.847	1.938	2.148	2.182	2.511	1.146	1.230
P ₂ O ₅	n.d	0.122	0.020	0.034	0.016	0.015	0.225	0.005	0.004
S _{total}	0.045	0.146	0.044	0.032	0.018	0.020	0.016	0.151	0.003
K ₂ O	0.011	0.696	0.316	0.417	0.594	0.862	0.647	0.386	0.647
CaO	0.076	0.321	0.202	0.223	1.736	0.194	0.466	0.087	0.062
TiO ₂	0.002	0.033	0.060	0.073	0.050	0.047	0.141	0.012	0.002
MnO	0.020	0.026	0.024	0.024	0.018	0.012	0.009	0.013	0.004
Fe ₂ O ₃	1.198	1.931	1.693	1.591	0.957	1.422	1.616	1.402	0.589
Li	22.4	107.2	101.4	110.4	117.7	92.4	124.0	146.3	58.8
Be	0.1	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.6
Sc	n.d	1.3	1.5	1.7	1.2	1.4	3.7	0.4	n.d
V	5.9	81.5	27.9	31.0	18.0	14.1	41.0	5.0	2.7
Cr	618.8	500.9	523.1	506.2	373.5	315.7	296.9	860.9	330.7
Co	3.1	3.7	4.6	4.1	2.7	4.3	4.1	4.3	2.0
Ni	19.3	19.0	15.9	15.3	14.9	28.3	13.1	22.3	14.4
Cu	31.4	180.3	284.4	60.6	39.9	27.2	68.4	458.1	12.3
Zn	599.8	231.5	230.2	79.3	42.0	172.9	40.9	1595.5	9.8
Ga	0.9	7.4	3.3	3.2	2.0	1.6	4.9	0.7	0.8
As	5.4	6.2	3.1	4.7	6.3	2.4	18.3	2.6	2.2
Se	1.6	6.0	1.6	3.3	n.d	n.d	3.0	5.6	n.d
Mo	4.8	4.9	5.8	7.4	13.6	6.5	3.2	7.2	4.6
Pd	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ag	170.7	19.9	57.1	99.5	20.3	5.1	4.7	28.7	5.1
Cd	33.0	2.9	3.8	5.1	1.0	2.2	0.6	23.2	0.3
In	0.3	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Sn*	2.0	1.2	2.0	1.0	1.0	1.1	0.7	3.3	0.9
Sb	15.6	9.1	8.3	9.9	7.5	5.1	7.3	7.3	7.0
Te	1553.7	106.3	94.7	171.9	22.7	16.1	18.6	235.2	12.9
W	45.7	32.9	45.4	38.6	27.2	47.1	19.1	54.1	33.8
Re	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ir	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Pt	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Au	3109.5	122.6	132.4	384.8	17.0	27.9	15.9	69.7	15.1
Hg	0.7	0.7	0.3	0.3	0.2	< 1.2	< 1	< 1.2	0.2
Tl	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.4
Pb	256.9	480.7	165.4	270.0	32.9	128.0	40.8	1621.4	10.8
Bi	0.3	5.0	0.6	0.6	0.1	0.1	0.1	0.6	n.d

obtained from sample Ahr5 showing a negative Eu anomaly on the diagram. Ce/Ce^* is also varying in narrow range from 1.0 -1.1.

REE patterns for ore samples are shown in Figs. 5.1.3, 5.1.4, 5.1.5 and 5.1.6. Ore samples from Aginskoe and Bluzdayushee ore bodies are showing progressive depletion in REE (Fig. 5.1.3.). Much of REE in samples from Aginskoe and Bluzdayushee ore bodies were under detection limits (Table 5.1.3.). Eu/Eu^* value equal to 1.01 was calculated for only one sample A10 from Aginskoe ore body. Eu/Eu^* for samples from Bluzdayushee ore body ranges from 0.65-1.04 and Ce/Ce^* from 0.31-2.87. On basis of REE's pattern ore samples from Surprise ore body were divided into two groups. First group of samples inherit the REE's behavior from hosts rocks with enrichment in Ba and depletion in Nb and Ta (Fig. 5.1.4a.). Pattern of sample S5 exhibits a clear negative Eu anomaly. Negative anomalies of Eu also could be read from other samples, except S9, which is showing slightly positive anomaly (Fig. 5.1.4.b.). A negative Ce anomaly is recoded in sample S1 and S2. Eu/Eu^* is broadly ranging from 0 to 1.2 and Ce/Ce^* is ranging from 0.1 to 1.0. REE behavior of second group samples is similar to Aginskoe and Bluzadayushee ore bodies (Fig. 5.1.4b.). Ore samples from Malysh ore body exhibits elevated REE concentrations resemble with Surprise ore body's REE patterns of first group samples. All samples turned on to be slightly enriched in LREE (Fig. 5.1.5a.). Samples M2 and M7 have a pronounced Eu anomaly, while others showing flat or negative Eu anomaly (Fig. 5.1.5b.). Same as sample from Surprise ore body, all samples from Malysh ore body revealed a negative Ce anomaly (Fig. 5.1.5b.). Eu/Eu^* is varying from 0.6-1.6 and Ce/Ce^* from 0.5-1.9. REE patters for samples from Noyabr'skoe ore body are similar to ore samples from Surprise and Malysh ore bodies (Fig. 5.1.6a.), however, characterized by lower REE concentrations. Behavior of Eu and Ce was not clear from the REE patterns (Fig. 5.1.6b.).

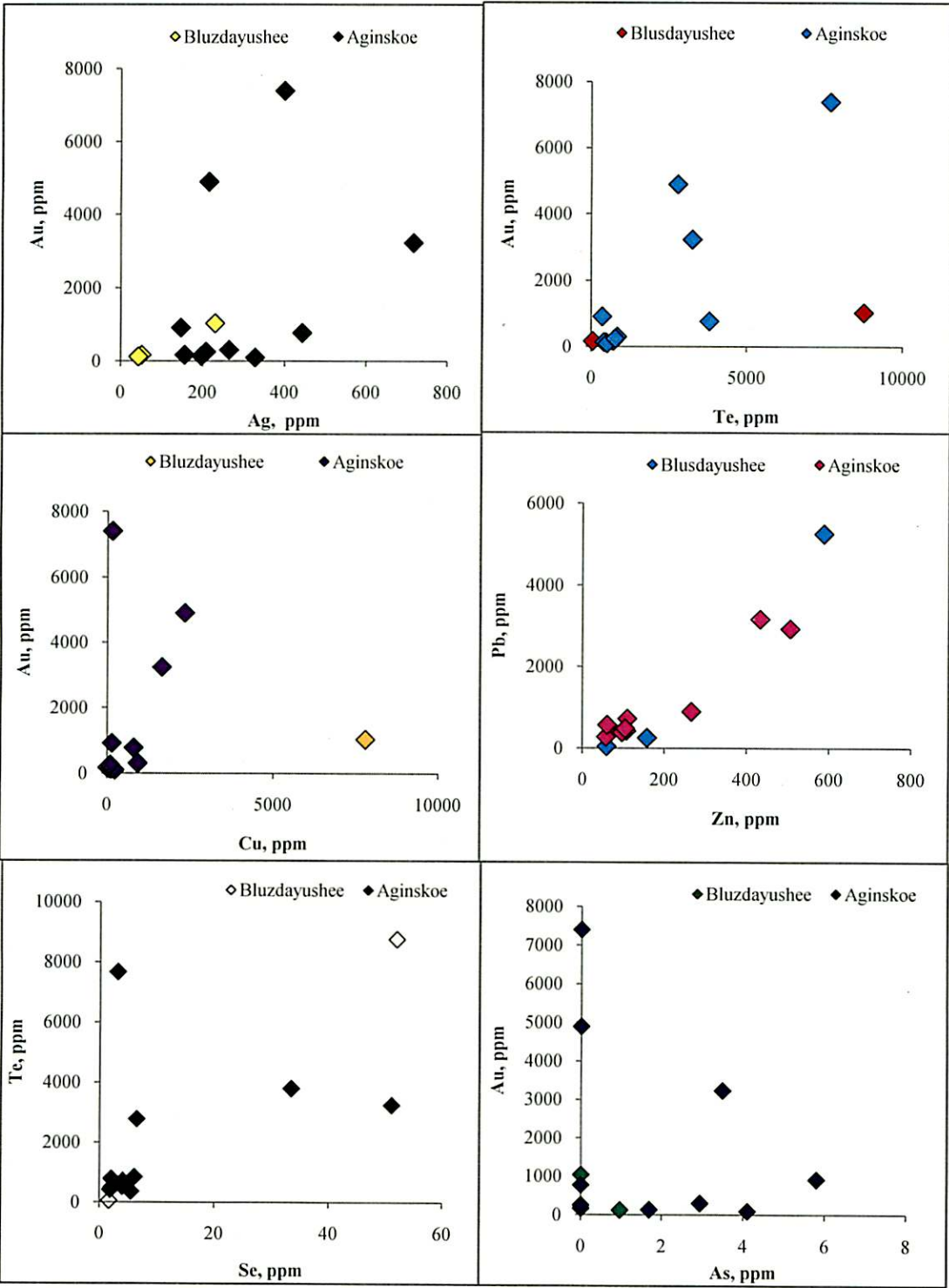


Fig.5.1.1. Scattered diagrams of Au vs. Ag, Te, Cu and As; Pb vs. Zn; Te vs. Se made for Aginskoe and Bluzdayushee ore bodies.

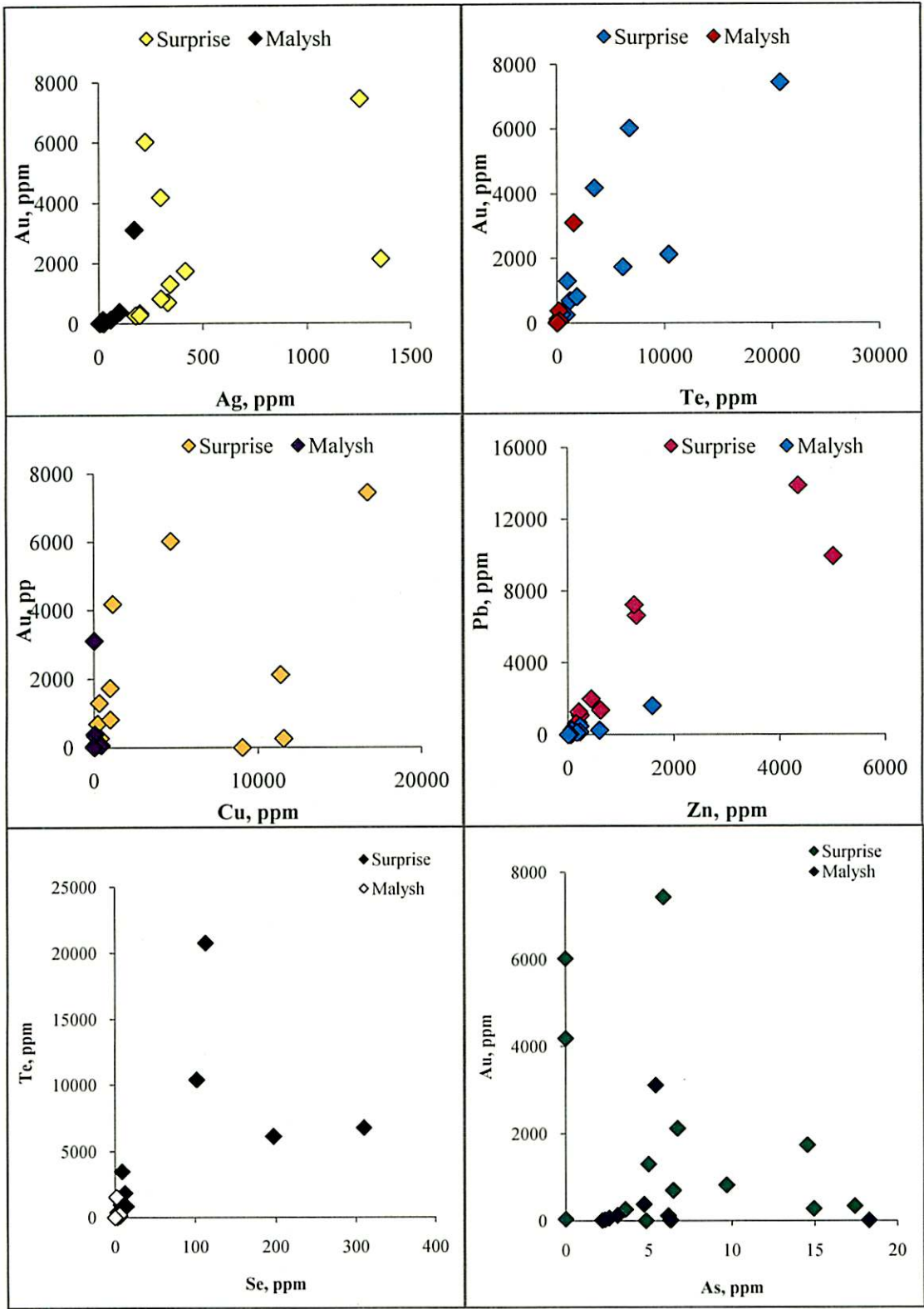


Fig.5.1.1. Continued. Scattered diagrams of Au vs. Ag, Te, Cu and As; Pb vs. Zn; Te vs. Se made for Surprise and Malysh ore bodies.

Table 5.1.3 ICP data for trace and REE for host rocks.

	Ahr1	Ahr2	Ahr3	Ahr4	Ahr5
Cs	0.80	0.40	0.40	0.10	1.00
Rb	53.30	22.70	22.30	20.30	119.90
Ba	479.0	387.0	371.0	538.0	386.0
Th	1.70	1.40	1.30	1.60	0.80
U	0.80	0.70	0.70	0.90	0.30
Nb	2.60	2.10	2.50	3.10	1.30
Ta	0.10	0.10	0.10	0.10	0.10
La	11.90	9.60	9.90	13.90	6.70
Ce	28.50	23.50	23.30	32.10	16.00
Pb	5.20	2.30	2.00	2.40	3.20
Pr	3.93	3.30	3.27	4.68	2.28
Sr	525.9	600.9	620.9	534.0	214.6
Nd	15.30	14.50	14.10	20.20	10.10
Zr	98.30	81.00	80.80	120.10	51.20
Hf	2.80	2.30	2.40	3.60	1.50
Sm	3.89	3.52	3.36	4.92	2.60
Eu	1.15	1.08	1.09	1.24	0.83
Gd	3.49	3.32	3.36	4.61	2.57
Tb	0.60	0.56	0.58	0.78	0.43
Dy	3.30	2.99	3.15	4.49	2.52
Ho	0.69	0.70	0.67	0.91	0.52
Er	1.98	1.89	2.02	2.77	1.46
Yb	1.98	2.07	1.89	2.57	1.37
Y	18.90	17.90	17.60	25.50	14.40
Lu	0.31	0.30	0.30	0.39	0.22
Eu/Eu*	0.95	0.96	0.99	0.79	0.98
Ce/Ce*	1.10	1.11	1.07	1.04	1.06

Table 5.1.4 ICP data for trace and REE: Aginskoe ore body.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Cs	1.40	1.70	1.80	1.80	1.40	1.30	1.40	1.20	1.70	1.40
Rb	5.60	47.80	14.70	9.30	6.90	12.40	24.90	2.70	9.20	18.00
Ba	8.90	31.60	13.20	11.90	7.00	14.90	13.50	3.00	9.00	26.50
Th	0.03	n.d.	n.d.	n.d.	n.d.	n.d.	0.60	0.07	n.d.	0.11
U	0.04	0.04	0.04	0.03	0.04	0.04	0.18	0.06	0.03	0.11
Nb	0.11	0.08	n.d.	0.17	0.14	0.15	0.20	0.16	0.15	0.25
Ta	n.d.	0.02	n.d.	n.d.	0.03	0.03	n.d.	n.d.	n.d.	0.02
La	0.10	0.15	0.05	0.09	0.05	0.15	0.21	0.13	0.08	0.53
Ce	0.18	0.13	0.07	0.15	0.09	0.23	0.24	0.16	0.15	1.20
Pb	897	367	725	427	2930	3168	282	394	573	486
Pr	0.03	0.04	0.01	0.02	0.03	0.05	0.05	0.05	0.03	0.17
Sr	17.10	53.80	20.40	24.60	19.30	18.90	68.40	18.40	19.90	18.70
Nd	12.00	0.22	n.d.	0.09	0.27	0.28	0.31	0.37	0.18	0.74
Zr	0.40	0.20	n.d.	0.79	0.39	1.10	0.30	0.24	0.71	6.90
Hf	n.d.	n.d.	n.d.	n.d.	n.d.	0.05	n.d.	0.03	0.03	0.18
Sm	0.03	0.04	n.d.	n.d.	n.d.	0.05	n.d.	n.d.	n.d.	0.18
Eu	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	n.d.	n.d.	0.06
Gd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.09	n.d.	n.d.	0.19
Tb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03
Dy	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.08	n.d.	n.d.	0.20
Ho	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	n.d.	n.d.	0.04
Er	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	n.d.	n.d.	0.11
Yb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	n.d.	n.d.	0.10
Y	0.11	0.14	0.07	0.12	0.08	0.21	0.47	0.25	0.18	0.88
Lu	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03

Table 5.1.4 Continued: Bluzdayushee ore body.

	B1	B2	B3	N1	N2	N3
Cs	1.60	1.00	1.10	1.60	5.30	1.30
Rb	11.50	11.00	14.30	6.90	27.00	10.70
Ba	14.20	14.70	23.80	11.80	24.60	13.90
Th	n.d	0.03	0.07	0.08	0.41	0.05
U	0.01	0.03	0.13	0.09	0.32	0.03
Nb	0.11	0.05	0.13	0.25	1.30	0.32
Ta	0.02	n.d.	n.d.	0.10	0.08	0.03
La	0.42	0.16	0.54	0.64	2.00	0.26
Ce	0.37	0.35	1.30	1.40	4.00	0.52
Pb	48	5258	256	131	32.1	26
Pr	0.10	0.06	0.20	0.24	0.67	0.09
Sr	29.00	17.70	19.50	14.50	17.10	16.50
Nd	0.31	0.20	0.85	0.97	2.50	0.48
Zr	0.60	2.70	4.70	8.20	34.60	4.30
Hf	n.d	0.08	0.16	0.25	0.83	0.14
Sm	0.10	0.05	0.20	0.22	0.64	0.09
Eu	0.02	0.02	0.07	0.07	0.15	0.02
Gd	0.08	0.05	0.19	0.17	0.50	0.08
Tb	0.02	0.01	0.03	0.02	0.06	n.d.
Dy	0.07	0.05	0.16	0.10	0.47	0.10
Ho	n.d.	0.01	0.03	0.04	0.11	0.03
Er	0.05	0.04	0.11	0.11	0.32	0.07
Yb	0.05	0.03	0.09	0.12	0.42	0.09
Y	0.60	0.26	1.00	0.68	2.80	0.51
Lu	n.d.	0.01	0.01	0.02	0.06	0.01
Eu/Eu*	0.65	1.04	1.02	1.06	0.81	0.79
Ce/Ce*	0.76	0.31	2.87	0.99	0.92	0.91

	S1	S2	S5	S9	S11	S12	S3	S4	S6	S7	S8	S10	S12
Cs	0.90	0.93	0.20	0.66	1.20	1.10	0.94	0.82	0.92	0.90	0.77	2.00	1.10
Rb	13.20	9.40	21.50	7.50	8.00	32.50	3.70	2.00	5.20	5.40	1.70	10.40	32.50
Ba	30.10	24.20	1004.00	24.40	36.60	60.20	5.00	8.70	10.80	7.00	2.30	12.50	60.20
Th	0.20	0.21	0.70	0.11	0.14	0.08	n.d.	n.d.	n.d.	0.04	0.04	0.04	0.08
U	0.34	0.18	1.20	0.24	0.14	0.11	0.11	0.19	0.20	0.01	0.45	0.02	0.11
Nb	0.55	0.73	1.90	0.34	0.48	0.40	0.19	0.14	0.22	0.21	0.24	0.22	0.40
Ta	0.04	0.06	0.12	0.03	0.03	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
La	1.00	1.50	6.00	0.84	0.80	0.67	0.54	0.22	0.58	0.21	0.05	0.29	0.67
Ce	2.40	2.60	13.70	2.60	1.90	1.50	0.85	0.30	0.98	0.40	0.18	0.45	1.50
Pb	1373	444	12.7	1089	1279	635	683	2002	13887	9930	6641	26.4	635
Pr	0.43	0.54	2.20	0.45	0.30	0.20	0.16	0.68	0.21	0.05	0.13	0.06	0.20
Sr	25.00	23.30	53.10	16.60	18.30	26.90	12.20	16.20	15.30	13.10	14.20	19.40	26.90
Nd	2.10	2.50	9.80	2.30	1.70	0.94	0.75	0.24	1.30	0.40	0.17	0.23	0.94
Zr	13.00	16.10	63.50	5.80	8.40	8.90	3.50	1.30	2.80	0.80	n.d.	1.80	8.90
Hf	0.35	0.39	1.40	0.12	0.21	0.17	0.14	0.00	0.08	n.d.	n.d.	0.07	0.17
Sm	0.47	0.57	2.70	0.56	0.40	0.23	0.15	0.06	0.24	n.d.	n.d.	0.06	0.23
Eu	0.17	0.17	0.49	0.22	0.11	0.08	0.06	0.02	0.06	n.d.	n.d.	n.d.	0.08
Gd	0.48	0.66	2.80	0.59	0.38	0.23	0.18	0.09	0.22	0.05	n.d.	0.05	0.23
Tb	0.06	0.09	0.47	0.08	0.05	0.04	0.02	0.01	0.02	n.d.	n.d.	0.01	0.04
Dy	0.47	0.51	2.70	0.43	0.28	0.16	10.00	0.08	0.16	0.05	n.d.	n.d.	0.16
Ho	0.09	0.10	0.65	0.10	0.07	0.04	0.03	n.d.	0.04	0.02	n.d.	n.d.	0.04
Er	0.23	0.28	1.80	0.28	0.19	0.11	0.07	0.03	0.08	0.02	n.d.	0.02	0.11
Yb	0.24	0.27	1.80	0.18	0.16	0.11	0.05	0.03	0.06	n.d.	n.d.	0.04	0.11
Y	1.90	2.10	14.30	2.30	1.40	1.30	0.77	0.41	0.99	0.23	0.07	0.21	1.30
Lu	0.05	0.04	0.24	0.03	0.03	0.02	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02
Eu/Eu*	1.09	0.84	0.89	0.54	-	0.86	-	-	1.17	1.09	1.17	1.09	-
Ce/Ce*	1.01	0.77	0.65	0.97	0.77	0.98	-	0.12	0.75	0.74	1.17	1.02	-

Table 5.1.4 Continued: Surprise ore body.

Table 5.1.4 Continued: Malysh ore body.

	M1	M2	M3	M4	M5	M6	M7	M8	M9
Cs	n.d.	1.30	1.50	1.70	1.20	1.40	3.70	1.30	1.60
Rb	0.31	14.80	9.00	9.40	14.30	23.30	16.80	9.32	15.5
Ba	1.60	24.30	12.50	19.90	26.90	31.10	18.30	7.25	9.50
Th	0.04	0.11	0.15	0.18	0.12	0.09	0.23	0.04	n.d.
U	0.09	0.10	0.06	0.11	0.07	0.05	0.15	0.02	n.d.
Nb	0.14	0.27	0.32	0.44	0.28	0.31	0.88	0.25	0.11
Ta	n.d.	0.03	0.05	n.d.	0.04	0.12	0.06	n.d.	n.d.
La	0.49	1.10	0.87	1.10	0.79	0.61	1.40	0.27	0.09
Ce	0.53	2.10	1.70	1.90	1.50	1.10	3.90	0.41	0.18
Pb	257	481	165	270	33	128	40.8	1621	11
Pr	0.15	0.31	0.30	0.37	0.32	0.19	0.63	0.05	0.01
Sr	4.40	16.40	18.20	21.10	33.10	29.90	17.10	24.47	34.30
Nd	0.89	1.50	1.50	1.80	1.40	0.82	2.80	0.26	n.d.
Zr	n.d.	6.00	10.50	12.60	8.90	9.30	37.90	1.78	n.d.
Hf	n.d.	0.15	0.32	0.33	0.26	0.23	0.70	0.07	n.d.
Sm	0.15	0.36	0.27	0.41	0.33	0.19	0.74	0.05	n.d.
Eu	0.10	0.18	0.07	0.14	0.10	0.05	0.40	n.d.	n.d.
Gd	0.24	0.35	0.31	0.41	0.34	0.20	0.89	0.08	n.d.
Tb	0.04	0.05	0.07	0.05	0.04	0.03	0.12	n.d.	n.d.
Dy	0.18	0.29	0.25	0.44	0.26	0.17	0.66	0.11	n.d.
Ho	0.04	0.06	0.06	0.06	0.02	0.05	0.15	n.d.	n.d.
Er	0.13	0.12	0.16	0.23	0.19	0.13	0.35	0.03	n.d.
Yb	0.08	0.12	0.15	0.18	0.19	0.14	0.34	0.03	n.d.
Y	1.50	1.40	1.10	1.60	1.50	1.30	4.00	0.43	0.064
Lu	0.01	0.01	0.02	0.03	0.02	0.02	0.04	0.01	n.d.
Eu/Eu*	1.61	0.55	0.74	1.04	0.91	0.78	1.50	-	-
Ce/Ce*	0.58	0.83	0.91	0.77	0.83	0.84	1.88	-	-

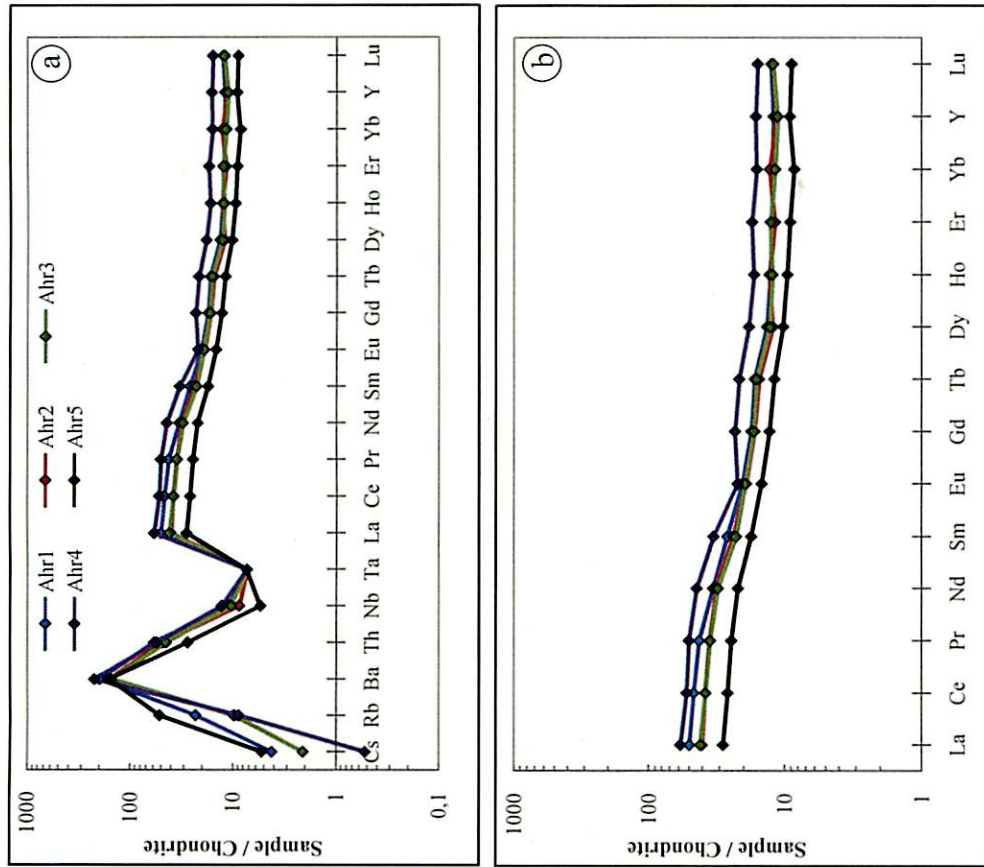


Fig.5.1.2. Chondrite normalized incompatible element diagram (a) and rare earth element abundance for host rocks of Aginskoe deposit. Chondrite REE compositions from Mcdonough and Sun (1995).

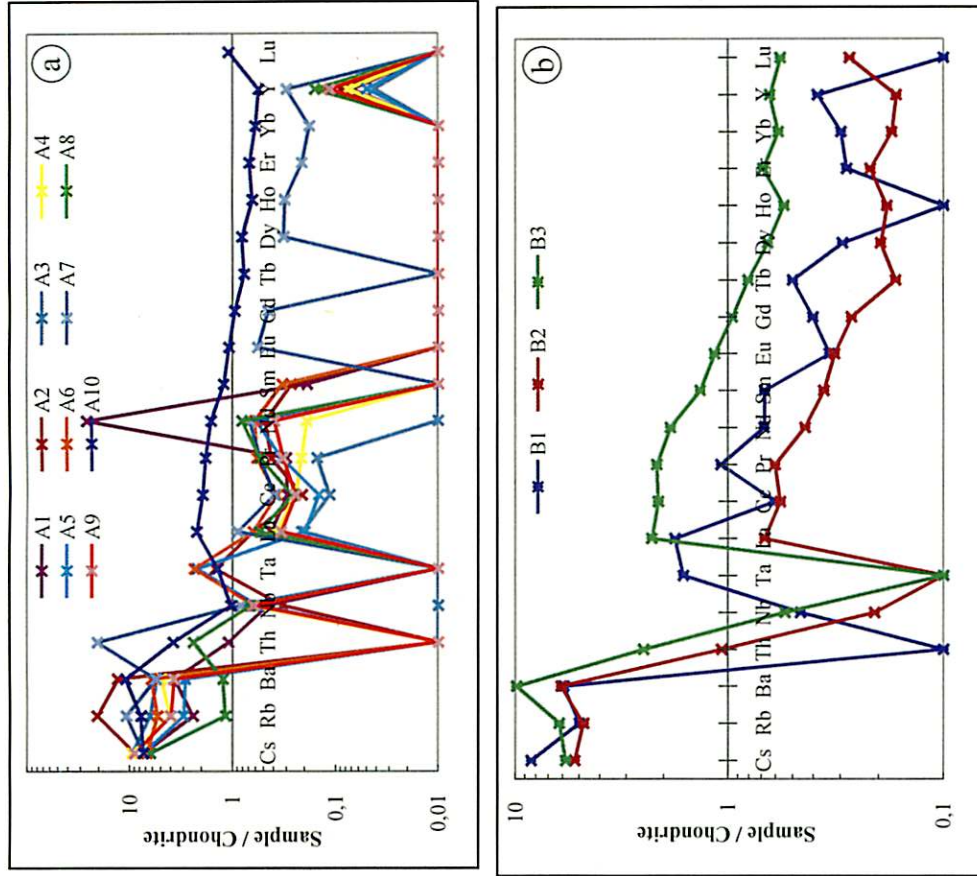


Fig.5.1.3. Chondrite normalized incompatible element diagram for Aginskoe ore body (a) and Bluzdayushee ore body (b). Chondrite REE compositions from Mcdonough and Sun (1995).

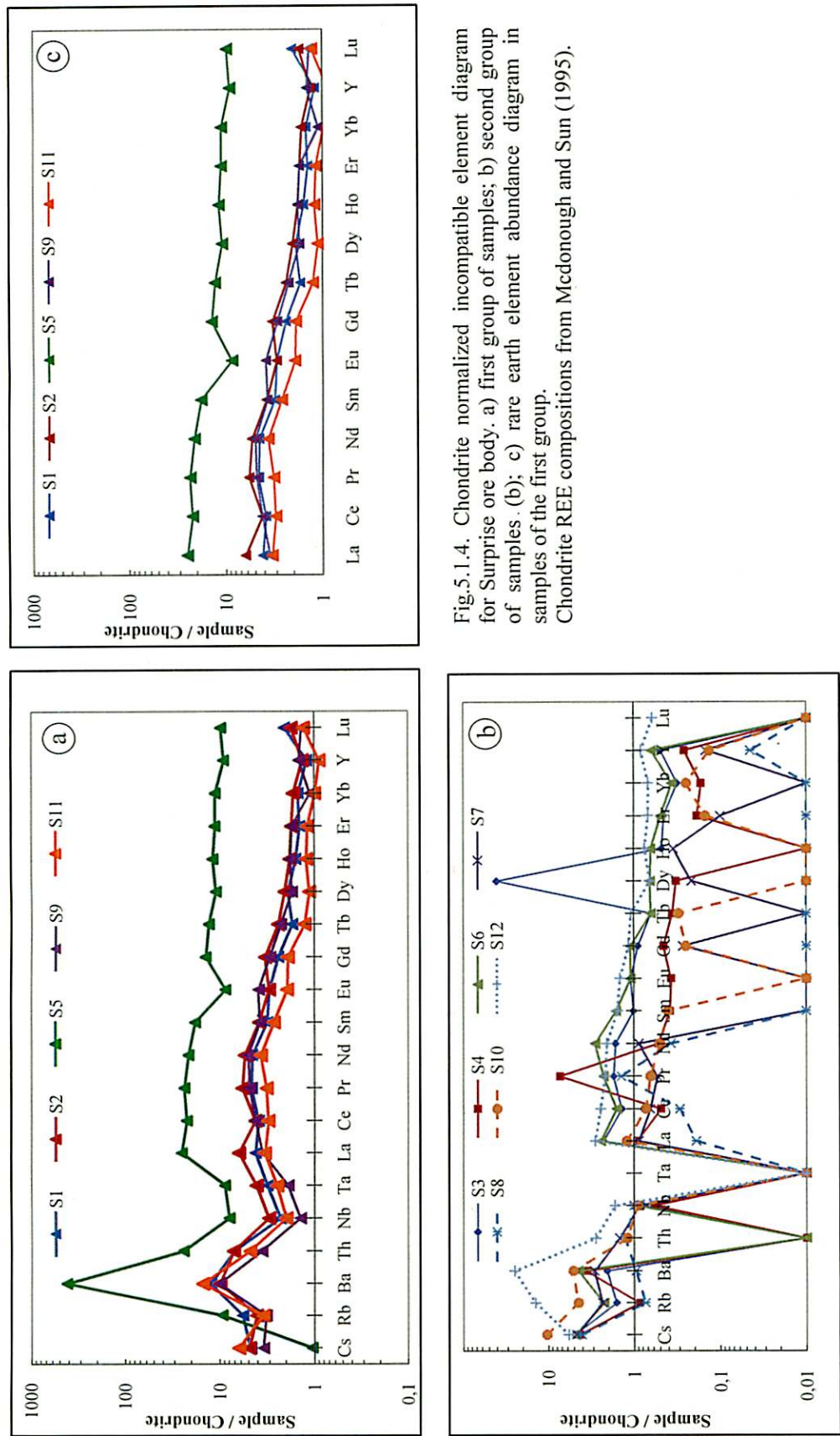


Fig.5.1.4. Chondrite normalized incompatible element diagram for Surprise ore body. a) first group of samples; b) second group of samples. (b); c) rare earth element abundance diagram in samples of the first group.
Chondrite REE compositions from Mcdonough and Sun (1995).

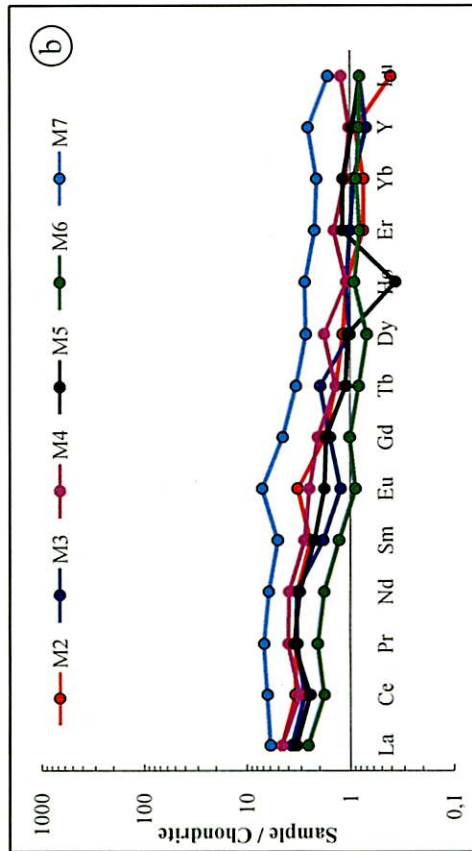
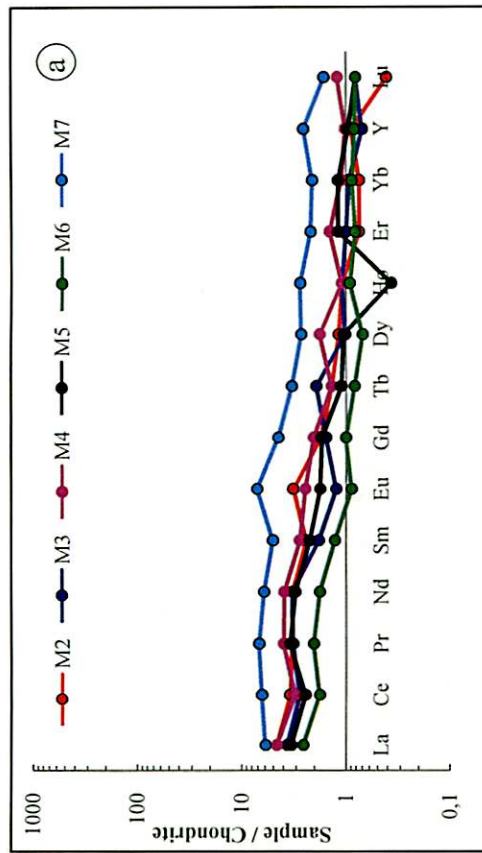


Fig.5.1.5. Chondrite normalized incompatible element diagram (a) and rare earth element abundance diagram (b) for Malysk ore body. Chondrite REE compositions from Mcdonough and Sun (1995).

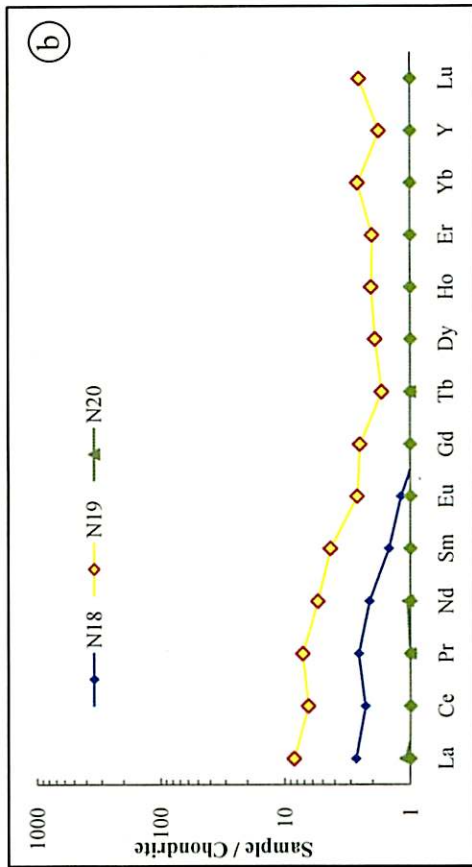
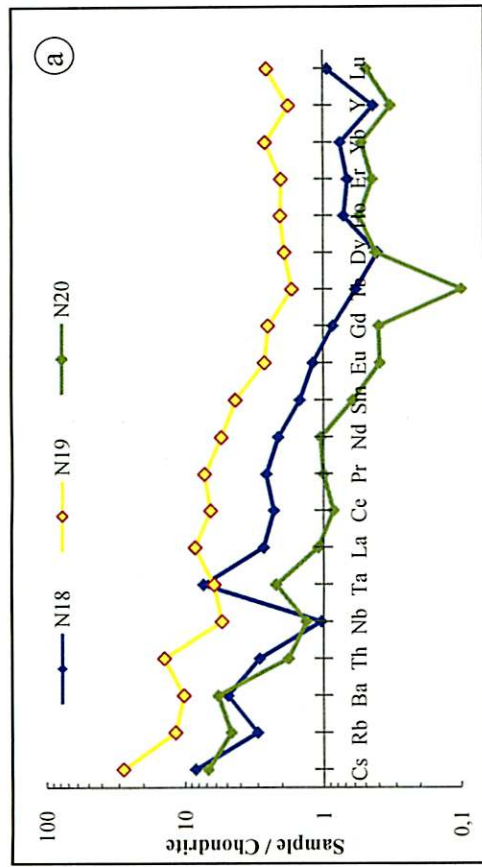


Fig.5.1.6. Chondrite normalized incompatible element diagram (a) and rare earth element abundance diagram (b) for Noyabr'skaya ore body. Chondrite REE compositions from Mcdonough and Sun (1995).

5.2. *Alteration mineralogy*

Alteration patterns at Aginskoe deposit were studied by Petrenko mainly in late 70s. Petrenko (1999) described sequence of alteration zones developed in host rocks with respect to the quartz veins: silification, sericitic, argillic and a blanket of propylitic alteration. Typical for epithermal system lateral and vertical zonation of propylitic alteration have been observed at Aginskoe deposit. High temperature epidote-chlorite minerals are predominant in deeper horizons below level of 1200 m grading upward into low temperature chlorite-carbonate assemblages in shallowest parts of vein system. Sericitic and argillic alterations are adjusted to veins and various in thickness from 1-10 m. Rare assemblage of kaolinite and alunite, which is typical for more acid conditions, was diagnosed in the central part of a caldera and probably genetically related to the intrusive body of gabbro-diorite.

In this study host rocks samples were taken from host-rocks and vein contact in the underground tunnels, core of exploration drill holes and surface. Wall-rock alteration graded from intensive at veins to moderated and weak in peripheral areas.

Host rocks are andesitic basalt in composition with Si_2O content up to 50-53 wt% and relatively high $\text{Na}_2\text{O}+\text{K}_2\text{O}$ content (Fig. 5.2.1.). Negative correlation of $\text{CaO}+\text{Na}_2\text{O}$ vs. K_2O is presented in Fig.5.3.2. suggests potassic and propylitic alteration (Shikazono, 1988). Vein cleavage and fragments of host rocks in ores are intensively silicified. Smectite, chlorite, kaolinite, K-feldspar and quartz were diagnosed in clays separated from altered host rocks by the X-ray diffraction (Fig. 5.2.3.). In thin sections outline of phenocrysts of plagioclase, pyroxene and hornblende are still recognizable, but they are partially replaced by chlorite, chlorite-kaolinite, smectite, sericite and pyrite (Fig. 5.2.4.). Samples taken from vein cleavage are showing strong alteration dominated by chlorite-kaolinite series minerals completely replacing crystals of plagioclase, pyroxene and hornblende and developed in groundmass. Sericite is overgrowing plagioclase crystals mainly.

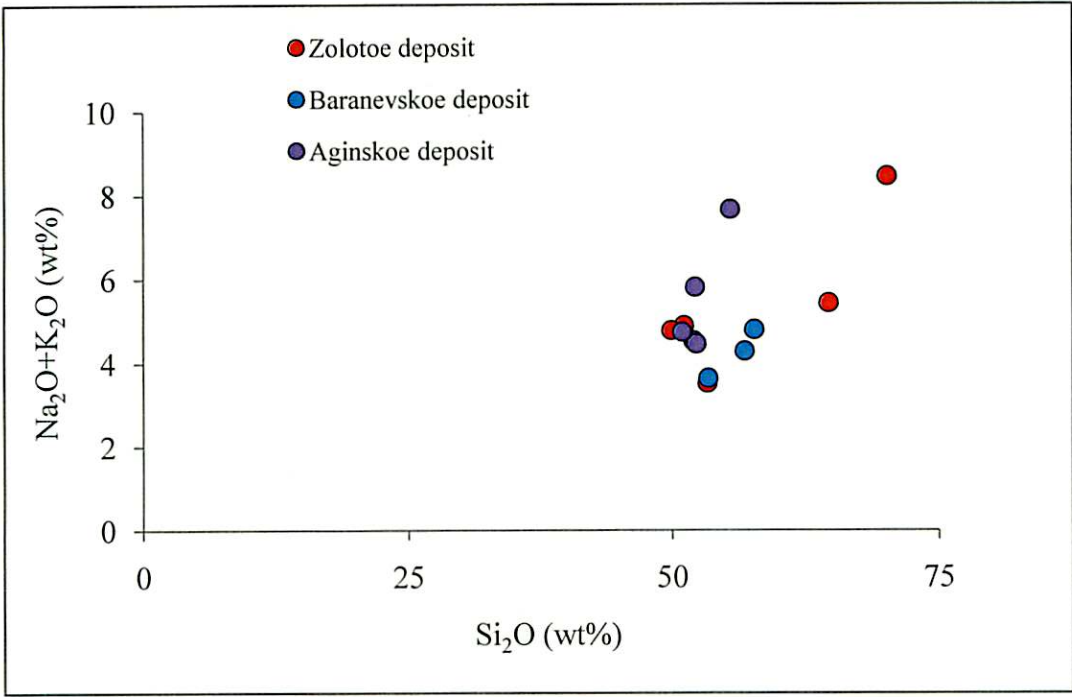


Fig.5.2.1. $\text{Na}_2\text{O} + \text{K}_2\text{O}$ vs. Si_2O in host rocks of Aginskoe, Baranenskoe and Zolotoe deposits.

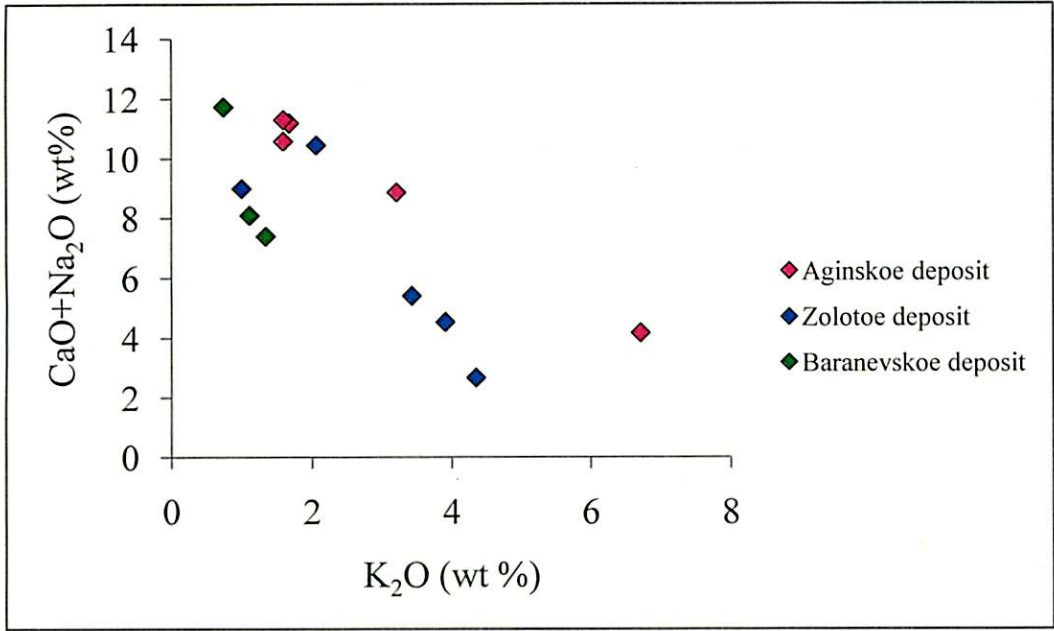


Fig.5.2.2. Typical patterns of propylitic and potassic alteration of $(\text{CaO} + \text{Na}_2\text{O})$ vs. K_2O in host rocks of Aginskoe, Baranenskoe and Zolotoe deposits.

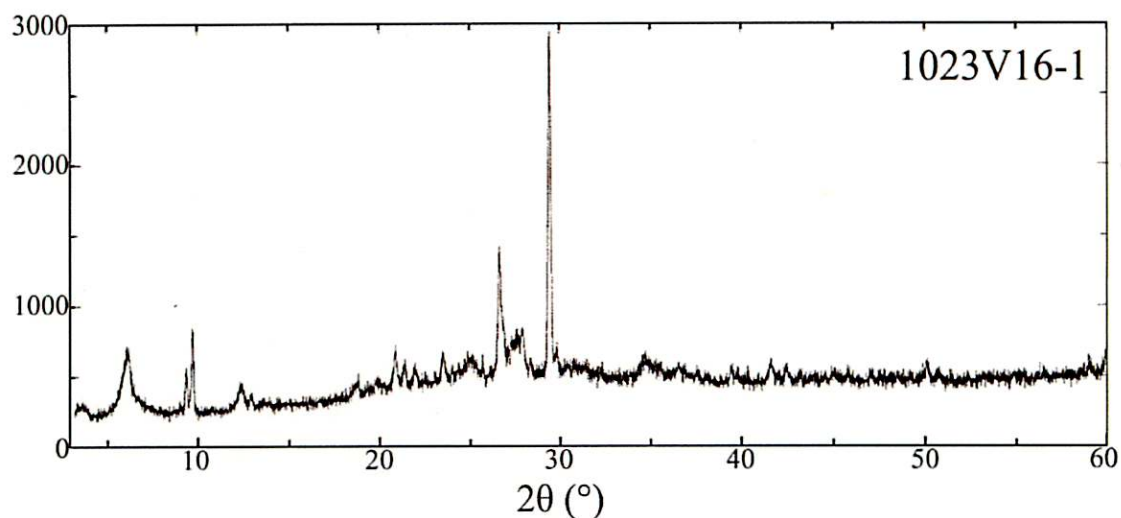


Fig.5.2.3. X-ray diffraction patterns of chlorite, chlorite-kaolinite mixed layer, K-feldspar (adularia and albite) and quartz from Valery ore body, Aginskoe deposit.

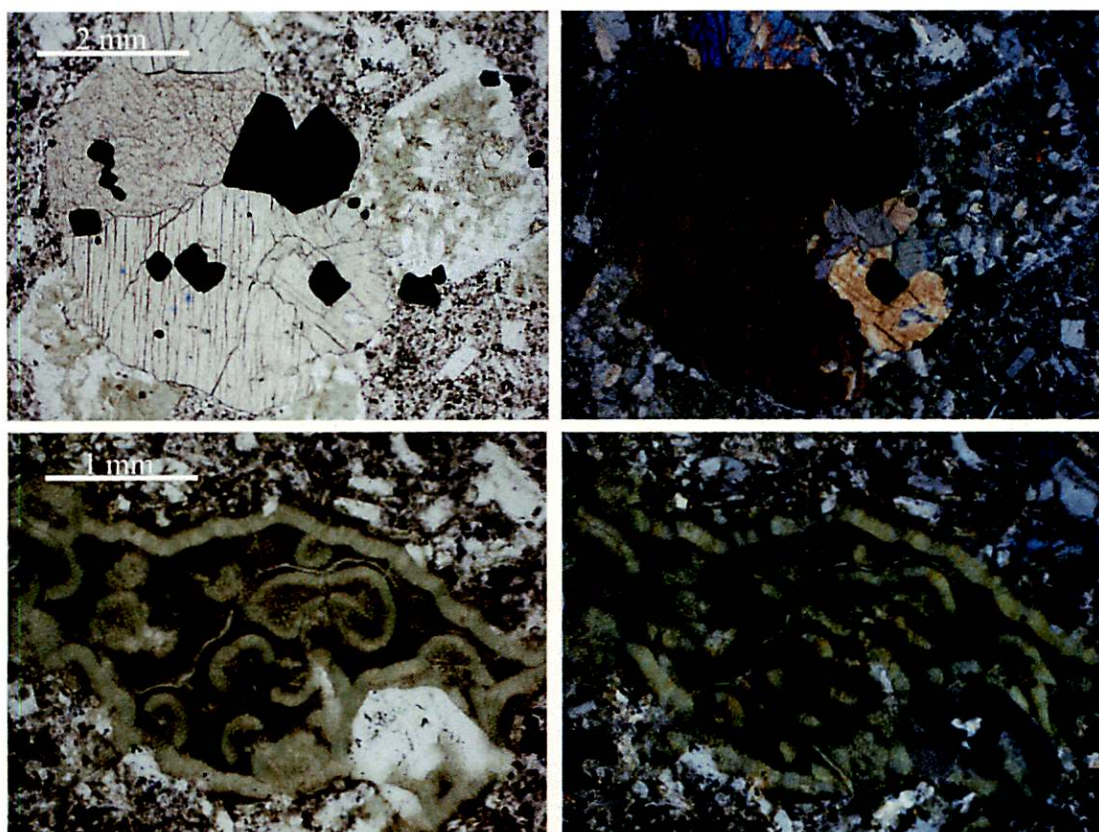


Fig.5.2.4. Microphotographs illustrating type of alteration in host rocks of Aginskoe deposit. a,b) partially replacement of pyroxene phenocrysts by chlorite-kaolinite mixed layer mineral (greenish) and pyrite (black); b,c) development of chlorite-kaolinite mixed-layer mineral in groundmass.

5.3. *Vein mineralogy*

Predominantly epithermal veins consist of quartz, adularia, clays, minor calcite and zeolite hosting tellurides, sulfides and gold-silver minerals. Quartz and adularia texture are given in subsequent chapter. Vein mineralogy is described below.

Tellurides

Altaite (PbTe) is by far the most abundant telluride in epithermal veins of Aginskoe deposit. Basically altaite was observed in the sub-stage 9 of Stage II in Aginskoe ore body as individual grains, inclusions in chalcopyrite and in contact with chalcopyrite, sphalerite, petzite and hessite (Fig. 5.3.1a,b,j and k). In sub-stages 1-3 of the stage II altaite is intergrown with tellurides of gold and silver, chalcopyrite and occurs as isolated grains. Rarely altaite is occurred as inclusions in chalcopyrite, frequently being intergrown with hessite (Fig. 5.3.2a.). Altaite grains vary in size from 50 to 200 μm . In Bluzdayushee ore body altaite was observed in intergrown with tellurides, calaverite in particular (Fig. 5.3.1g.).

In Surprise ore body altaite forms various individual grains and mutual contact with hessite and native gold (Fig. 5.3.1c & l.). It is noteworthy, that altaite tends to be closely associated with native gold in Surprise ore body. Altaite is also enclosed in chalcopyrite. Size of altaite varies from few microns up to 400 μm . In Malysh ore body altaite was found in multitype contact with native gold, calaverite, petzite and chalcopyrite (Fig. 5.3.1i.) and as inclusions in native gold (Fig. 5.3.2g.). Small grains dispersed in quartz-adularia matrix were also observed.

The chemical composition of altaite is close to pure theoretic chemical formula. Some altaite contains impurities of silver and selenium. Analyses obtained by EPMA are given in the Table 5.3.1. Se-content has been detected only in altaite occurring in the Surprise ore body. Se concentration varies from 0.16 to 0.40 wt%. Frequently, single grains of altaite and some in mutual intergrowth include small concentration of silver (Ag 0.67-2.64 wt%). The impurities of silver commonly occur in altered or decomposed altaite grains, i.e. rim of deep gray color develops on the margin of altaite grains. To those altaite crystals is typical gray-white color and

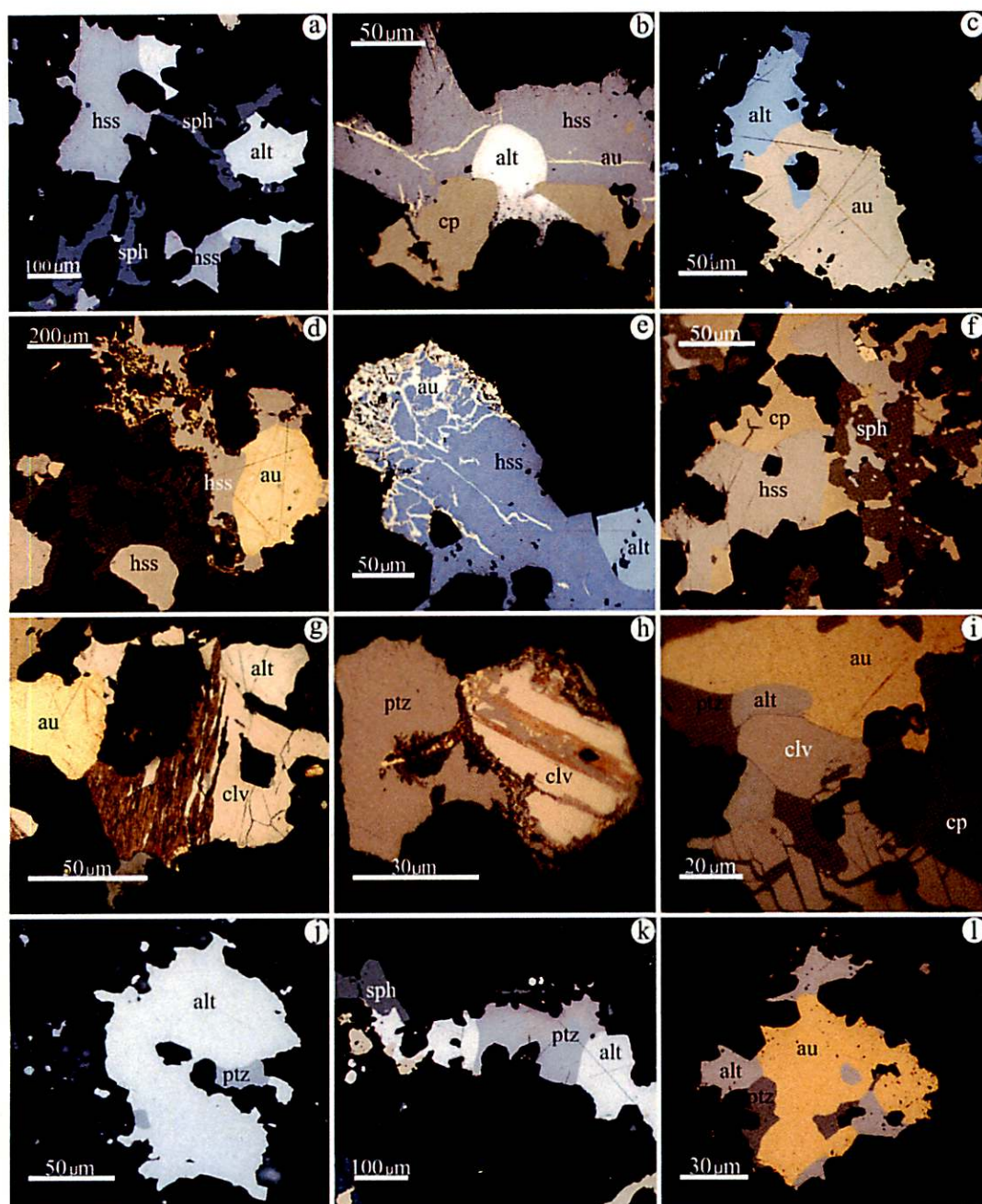


Fig.5.3.1. Microphotographs of tellurides from Aginskoe deposit. a) association of hss, alt and sph in the sub-stage 9 of the stage II from Aginskoe ore body; b) intergrowth of alt, hss and cp in the sub-stage 9 of the stage II from Aginskoe ore body; c) intergrowth of au and alt in the Surprise ore body; d) au in contact with hss in Bluzdayushee ore body; e) association of hss and alt in the sub-stage 9 of the stage II from Aginskoe ore body; f) early association of cp, hss and au is replaced by late sph in the sub-stage 2 of stage II from Bluzdayushee ore body; g) decomposed clv in intergrown with alt and au in the sub-stage 2 of stage II from Bluzdayushee ore body; h) primary tellurides clv and ptz are slightly decomposed in the sub-stage 2 of stage II from Bluzdayushee ore body; i) mutual contact of alt, cp, ptz and au in the sub-stage 2 of stage II from Bluzdayushee ore body; j) small patches of ptz is adjusted to anhedral alt in the sub-stage 9 of the stage II from Aginskoe ore body; k) sph, ptz and alt association in the sub-stage 9 of the stage II from Aginskoe ore body; l) primary tellurides alt and ptz in intergrown with au in Surprise ore body.

Abbreviations; alt: altaite, hss: hessite, clv: calaverite, ptz: petzite, cp: chalcopyrite, sph: sphalerite, py: pyrite, au: gold, etm: electrum.

tarnished surface might be occurred due to decomposition of altaite. Afifi proposed that altaite decomposes during cooling stage of deposition (Afifi, 1988). Applying this hypothesis, it is likely that cooling of hydrothermal solution had happened during formation of Aginskoe deposit.

Hessite (Ag_2Te) is next most abundant telluride in the Aginskoe deposit. In polish thick sections color of hessite is changed from deep blue to light gray and is marked by intensive anisotropism. Hessite is a most abundant mineral in the Ag-Te-sulfide sub-stage in Aginskoe, Bluzdayushee and Malysh ore bodies. It co-exists with sphalerite, altaite and chalcopryrite (Fig. 5.3.1b & f.). Some individual grains of hessite illustrate complex internal texture of gold exsolution. This suggests the essential intergrowth of hessite and petzite (Fig. 5.3.1e.). According to Afifi continuous intergrowth of hessite and petzite are formed due to break-down of μ phase below 120 °C (Afifi, 1988). In Au-Ag-Te sub-stage hessite occurs as individual grains or in contact with native gold (Fig. 5.3.1d.). Initial association of hessite with native gold was denoted in the Surprise vein, where hessite hosts inclusions of gold and is in contact with altaite and gold. Electrum occurs in border between hessite and native gold. EPMA data are shown in Table 5.3.2. Generally, hessite is stoichiometric in chemical composition with small amount of Au (less than 1-2 wt%) that could be a residual Au of previous petzite.

Calaverite (AuTe_2) is the only one Au-bearing telluride is remaining as a primary phase of Au-bearing telluride in Au-Ag-Te sub-stage of Stage II. Mostly tellurides were altered in the weathering and oxidation zones. Non-decomposed calaverite was observed in polish thick sections from Bluzdayushee and Malysh ore bodies (Fig. 5.3.1g, h and i.). It occurs as an individual grains up to 100 μm , as small patches on margin of chalcopryrite and in mutual contact with altaite, native gold, petzite and chalcopryrite. However some grains show the textures of replacement or pseudomorphous of supergene minerals. All calaverite are presumed to be completely replaced by secondary minerals during stage VI in Aginskoe and Surprise ore bodies. Calaverite was not found in Ag-Te-sulfide stage nor in the Surprise ore body. Chemical composition of calaverite is given in Table 5.3.3. Calaverite contains trace amount of Ag 0.59-4.57 wt%.

Petzite (Ag_3AuTe_2) was observed very rare; otherwise it was identified by the qualitative or the micro-probe analysis as well. In the polish sections mineral shows similar microscopic characteristics (i.e. color, anisotropy) with hessite that make difficult to identify it by microscopic observation. As it was mentioned before, conceivably, most of primary petzite was being in contact with hessite gradually decomposed with formation of gold (electrum) exsolution (Fig. 5.3.1d & e.) in sub-stage 9 and Surprise ore body. Initial petzite was determined as small patches on the margins of altaite in Aginskoe ore body (Fig. 5.3.1j.), in contact with altaite and sphalerite (Fig. 5.3.1k.). In Surprise ore body petzite was also observed in intergrown with native gold and altaite (Fig. 5.3.1l.). Representative the EPMA data is given in Table 5.3.4. Generally petzite is stoichiometric in chemical composition. Only some of petzite contains impurities of Se up to 2.86 wt%.

Sulfides

Chalcopyrite (CuFeS_2) is a most common sulfide mineral in the deposit. It closely associates with native gold in sub-stages 2, 3, 4 of the stage II and occurs together with altaite in the sub-stage 9 of the stage II in Aginskoe, Bluzdayushee and Malysh ore bodies. It is also very common sulfide mineral in Surprise ore body. In the gold-rich sub-stage majority of chalcopyrite grains are intensively replaced by Fe hydroxides and some grains are slightly replaced along the margins by chalcocite (Fig. 5.3.2a.). Frequently chalcopyrite involves numerous tiny inclusions of hessite, altaite and rare micron size gold and acanthite (Fig. 5.3.2b.). In Surprise ore body, chalcopyrite was observed in association with native gold and in contact with hessite (Fig. 5.3.2c.).

Sphalerite (FeS) was identified in Aginskoe, Surprise and Malysh ore bodies and Olimpiskoe apophyse. In Aginskoe ore body sphalerite was observed in the sub-stage 9 of the stage II in association with petzite, altaite and chalcopyrite and as individual grains (Fig. 5.3.1k & Fig. 5.3.2e.). In Surprise ore body sphalerite is intergrown with native gold, chalcopyrite and altaite (Fig. 5.3.2f.). It also associates with pyrite and gold in sulfide rich ores of Surprise ore body.

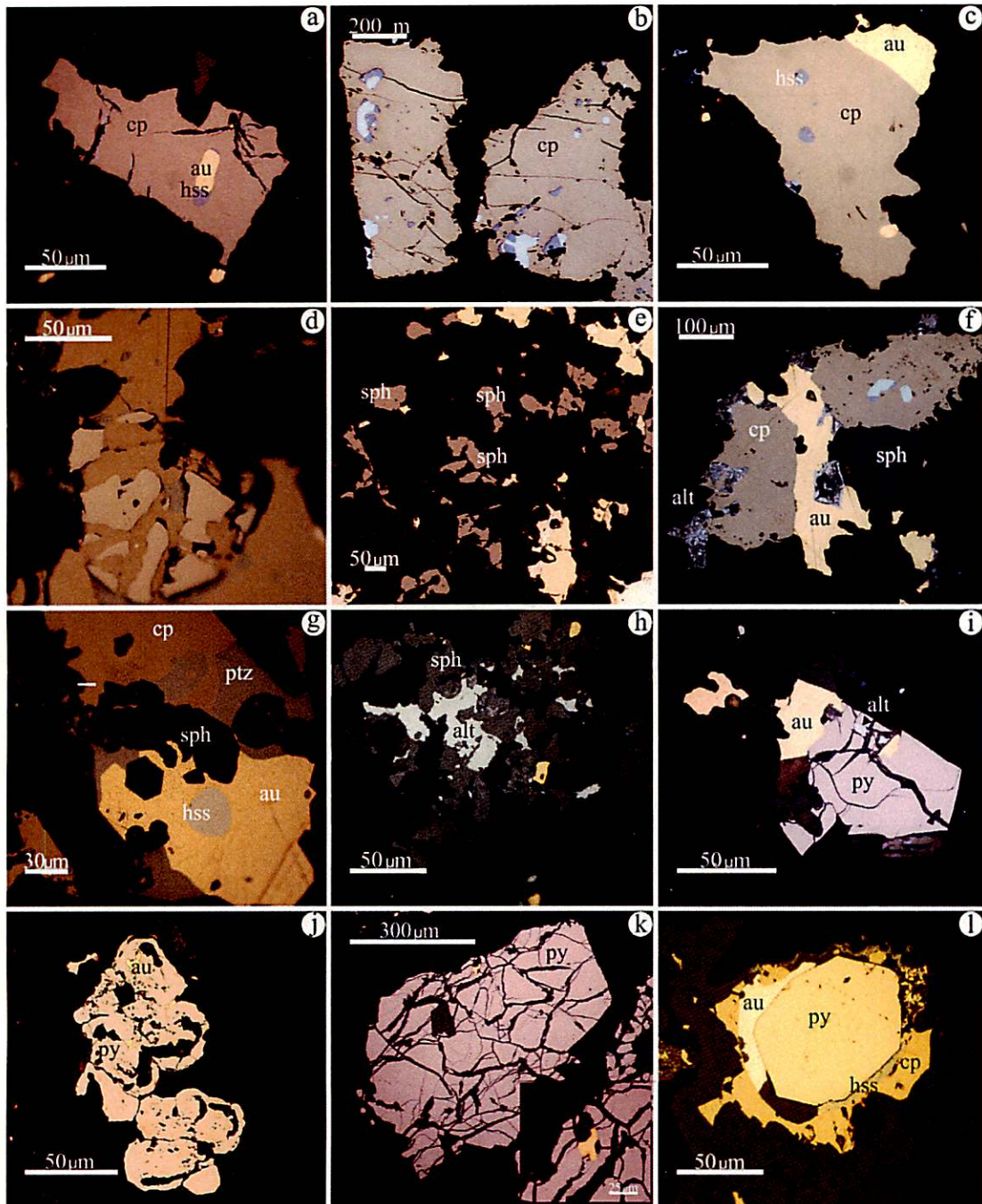
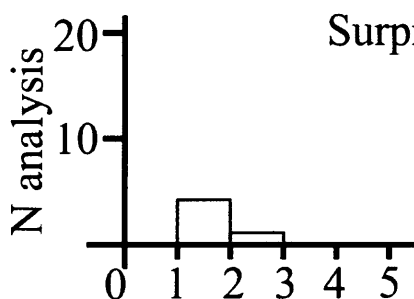
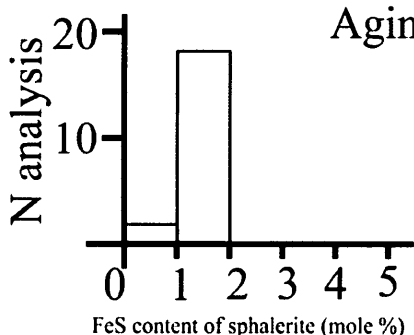


Fig.5.3.2. Microphotographs of sulfides from Aginskoe deposit. Abbreviations listed in Fig. 5.3.1.
a) au in intergrown with hss enclosed in cp from sub-stages 1-3 of the stage II in Aginskoe ore body;
b) cp hosting inclusions of alt and hss from the sub-stage 9 of the stage II in Aginskoe ore body;
c) au in contact with cp hosting inclusions of hss in Surprise ore body;
d) inclusions of py in cp from sub-stages 1-2 of the stage II in Malysh ore body;
e) anhedral sph from the sub-stage 9 of the stage II in Aginskoe ore body;
f) mutual contact of sph, cp and dissolved alt (?) in Surprise ore body;
g) association of au, cp, ptz, alt and late sph in sub-stages 1-3 of the stage II in Malysh ore body;
h) sph replaces alt in sub-stages 1-3 of the stage II in Olimpiskoe apophyse;
i) cataclased py in intergrowth with au and supergene minerals in sub-stages 1-3 of the stage II in Aginskoe ore body;
j) fractured py with au inclusions in Surprise ore body;
k) au inclusions in py in Surprise ore body;
l) pyrite enclosed in cp in intergrown with au and hss in sub-stage 1-2 of the stage II in Malysh ore body.

In the Malysh ore body sphalerite likely replaces hessite and alatite (Fig. 5.3.1f & Fig. 5.3.2g.). Yet sphalerite occurs as need-shaped crystals, reminding relicts of adularia. In the Olimpiskoe apophyse sphalerite was also observed replacing altaite (Fig.



Surprise



Aginskoe

Fig.5.3.3. FeS content in sphalerite from Aginskoe and Surprise ore bodies.

5.3.2h.). Fe and Cd were detected in sphalerite from Aginskoe and Surprise ore bodies and Cd in sphalerite from Malysh ore body and Olimpiskoe apophyse by mean of EPMA (Table 5.3.5.). Variations of FeS and CdS contents in sphalerite are plotted in Figs. 5.3.3. and 5.3.4. FeS content in sphalerite from Aginskoe ore body varies from 0.5 to 2 mole % with mean of 1.3. CdS varies from 0.2 to 2.9 mole % with a mean of 1.3. A few sphalerite grains from Surprise ore body analyzed by EPMA revealed FeS variation from 1 to 3 mole % with almost constant value of CdS. FeS in sphalerite from Malysh ore body and Olimpiskoe apophyse was not detected in this study. CdS content ranges

from 2 to 3 mole % in sphalerite of Malysh ore body and from 3 to 8 mole % in sphalerite of Olimpiskoe apophyse (Fig. 5.3.4.). No other minor elements were detected in sphalerite.

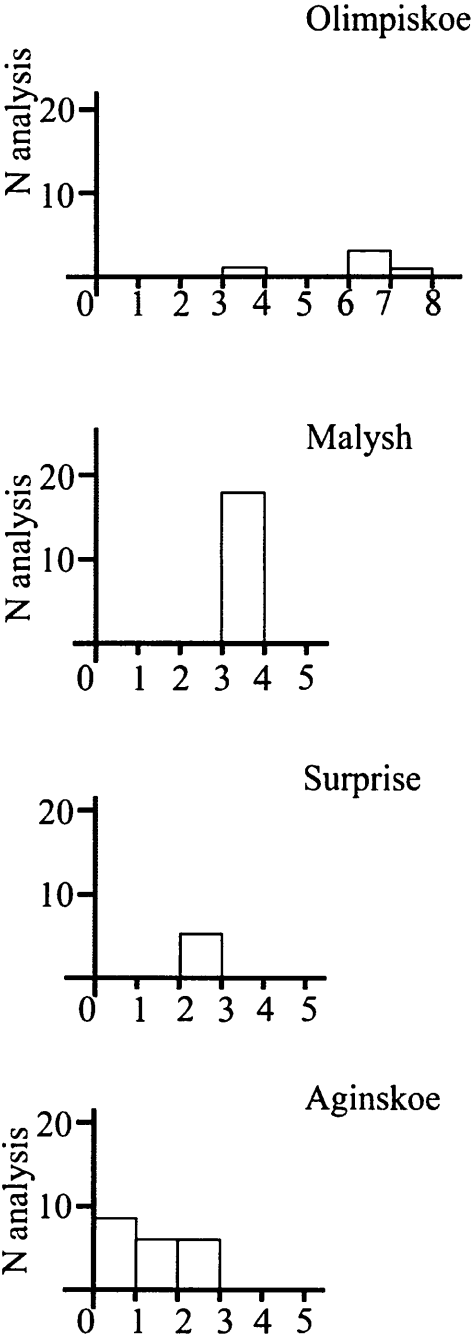
Pyrite is very rare sulfide mineral in the ores of Aginskoe deposit. It is locally abundant in Surprise ore body, where occurs together with electrum and sphalerite (Fig. 3.3.5h.). Also fractured pyrite from Surprise ore body hosts micron-size gold inclusions (Fig. 5.3.2j & k.). In Aginskoe ore body rare pyrite was observed in intergrown with native gold and presumable decomposed telluride (Fig. 5.3.2i.). In Malysh ore body pyrite occurs as inclusion in chalcopyrite (Fig. 5.3.2d.) and sometimes is intergrown with native gold and hessite (Fig. 5.3.2l.).

Acathite is trace minerals in ores, usually occurs as invisible inclusions in chalcopyrite.

In this study galena was not found. Okrugin reported on Se-bearing galena (Se 1.5-2.0 wt%).

Gold-silver minerals

The native gold is ubiquitous and was observed in each ore body. Moreover, native gold is considered to be deposited directly from hydrothermal fluid and also to



CdS content of sphalerite (mole %)

Fig.5.3.4. CdS in sphalerite from Aginskoe deposit.

be reprecipitated in the supergene stage. Gold has been precipitated in sub-stages 1-3 of the stage II simultaneously with Au-bearing tellurides. Due to strong ore oxidation the intergrowth of gold with Au-bearing tellurides could be observed only in Bluzdayushee and Malysh ore bodies (Fig. 5.3.1g,n,i and 5.3.5e.). In Aginskoe and Surprise ore bodies all Au-Ag tellurides have been completely transformed into the supergene minerals (Fig. 5.3.5c&i.). Free gold crystals of rounded shape frequently host inclusions of hessite (Fig. 3.3.5b.). In addition, most of fine-grained gold occurs along cockade texture of clay bands and/or dispersed grains in clay matrix and grows along adularia crystals. Another typical mode of gold occurrence is gold myrmekites within hessite suggesting breakdown of primary petzite-hessite intergrowth.

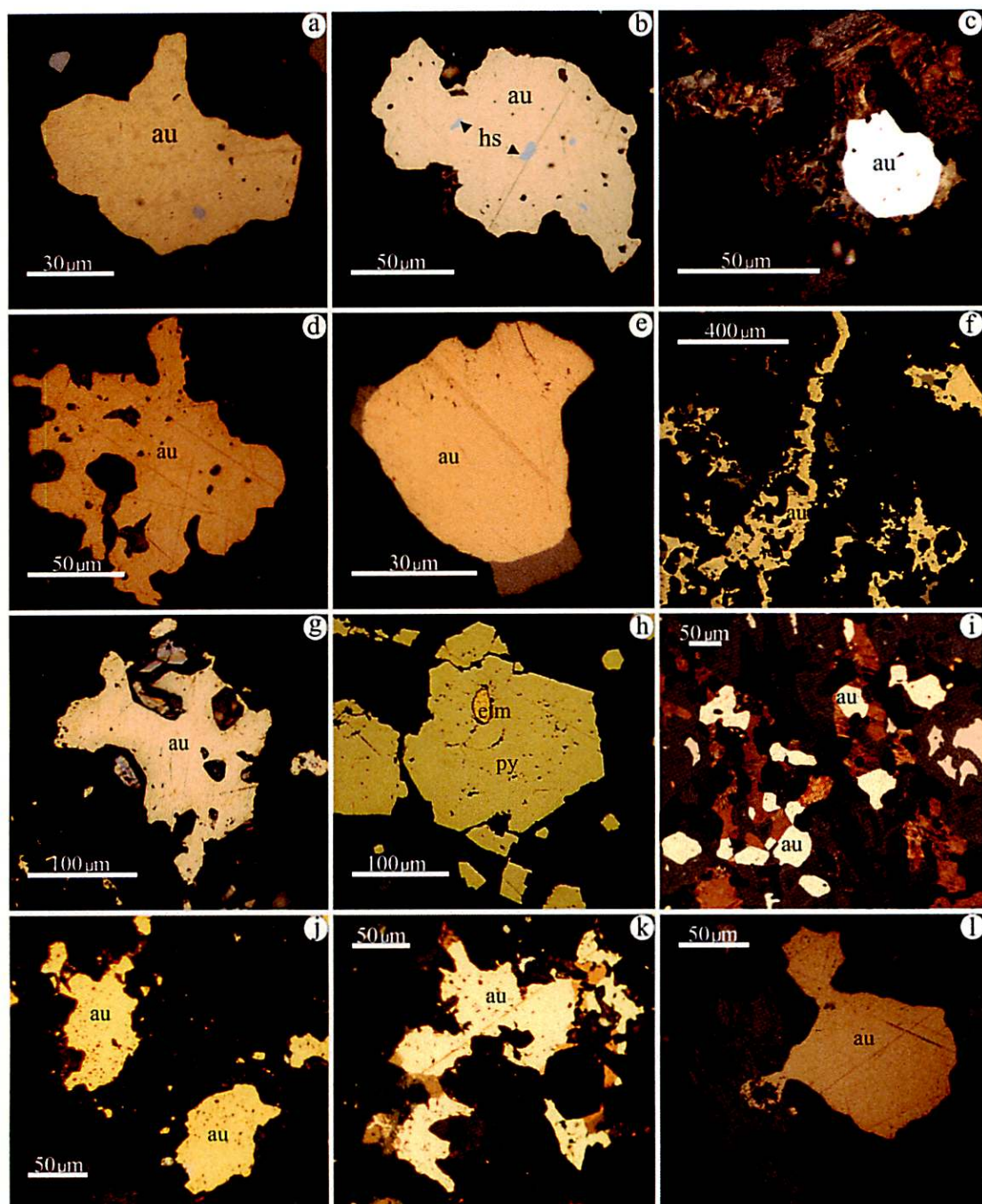


Fig.5.3.5. Microphotographs of native gold and electrum from Aginskoe deposit. Abbreviations listed in Fig. 5.3.1. a) & b) individual au crystals hosting inclusions of hss in sub-stages 1-3 of the stage II in Aginskoe ore body; c) intergrowth of au with secondary minerals in sub-stages 1-3 of the stage II in Aginskoe ore body; d) & e) au from sub-stages 1-3 in Bluzdayushee ore body; f) elongated au crystals associate with cp in sub-stages 1-3 of the stage II in Bluzdayushee ore body; g) free au from Surprise ore body; h) etm enclosed in pyrite in Surprise ore body; i) association of au with secondary minerals in Surprise ore body; j) free au in sub-stage 1-3 of the stage II in Malysh ore body; k) au in intergrown with secondary minerals in Malysh ore body; l) decomposed tellurides in contact with au. Secondary phase are still contain primary telluride.

In Surprise ore body, native gold was frequently observed as individual isolated large-size grains (up to 100-150 μm) and as inclusions in chalcopyrite and pyrite and intergrown with sphalerite and chalcopyrite (Figs. 5.3.1c & 5.3.2b.).

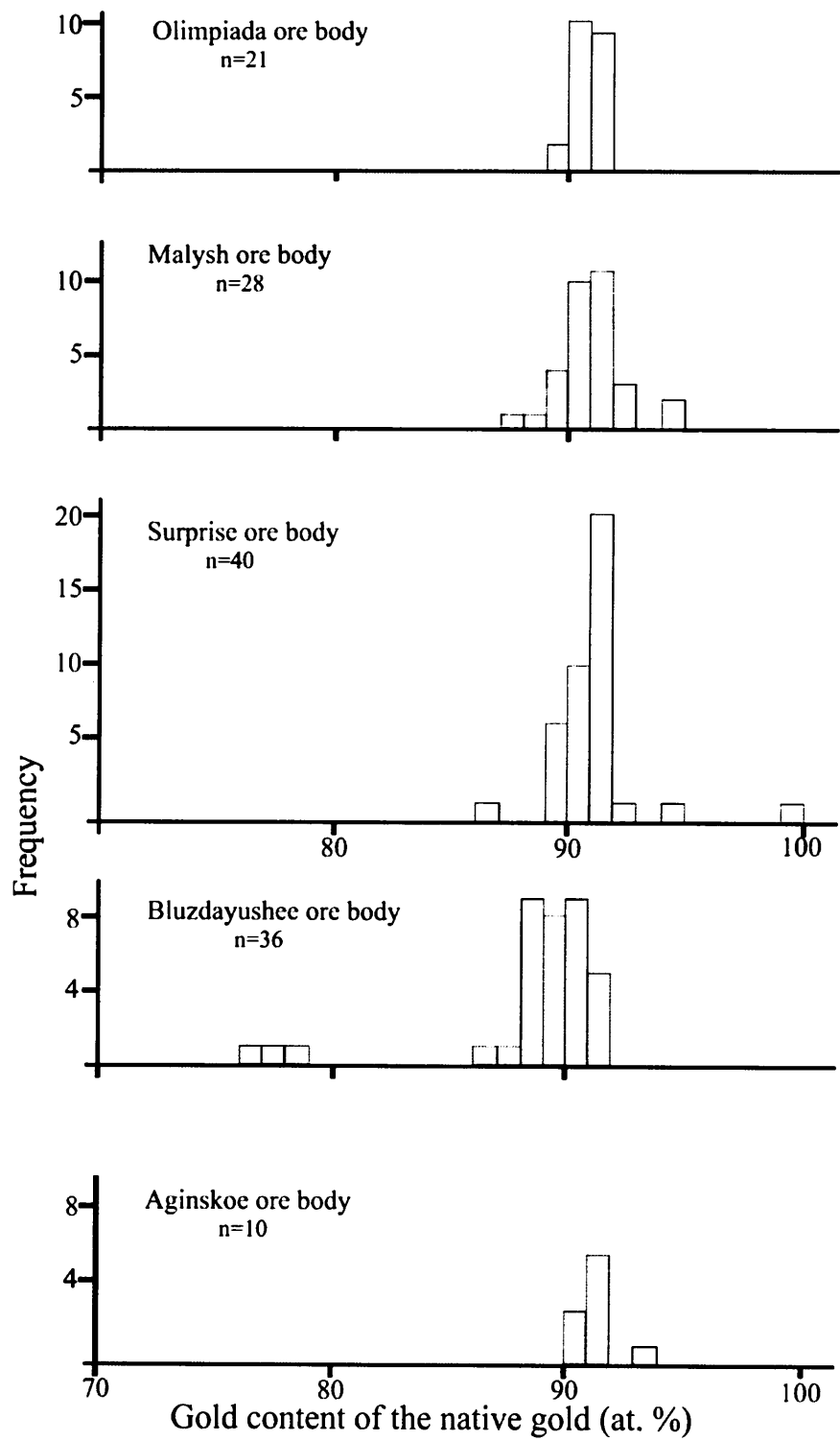


Fig.5.3.4. Au content in native gold from Aginskoe deposit.

Table 5.3.6. presents the micro probe analysis of native gold. The chemical composition of gold is extremely similar throughout entire deposit. Au content in gold ranges from 89-92 at%, however, some gold grains are closed to 99 at% Au (Fig. 5.3.4.). Gold from Bluzdayushee ore body is characterized by slightly lower Au content (Fig. 5.3.4.). Gold is characterized by a weak internal zonation. Au content tends to be higher in core of grains.

Electrum is very rare mineral typically occurring in contact between native gold and hessite and associates with pyrite and sphalerite in Surprise ore body (Fig. 5.3.5h.). Electrum occurring in contact between hessite and native gold contains 37-52 at% of Au. Rare electrum from sulfide rich bans contains 62 at% of Au.

Secondary gold accumulates on surface of the decomposed primary Au-bearing tellurides in Aginskaya vein and develops as tiny veinlets in Fe hydroxides replacing chalcopyrite bands in Surprise vein (Fig. 5.3.7.). Latest mode of occurrence was observed only in Surprise ore body.

Secondary (supergene) minerals

Various kinds of secondary minerals have been distinguished in the polish thin sections by the microscopic observation. Some of them are unknown ones. Almost all secondary minerals tend to show mixture of different minerals or alteration products of the origin minerals. As it was noted before, supergene minerals are closely associated with native gold.

Some researchers reported metallic alloys such as bilibinskite $\text{Au}_3\text{Cu}_2\text{PbTe}_2$, bessmertnovite $\text{Au}_4\text{Cu}(\text{Te}, \text{Pb})$ and bogdanovite $\text{Au}_5(\text{Cu}, \text{Fe})_3(\text{Te}, \text{Pb})_2$ formed in the weathering zone of some known Te-bearing deposits are widely occurred in Aginskoe mine. They usually replace such Au-bearing tellurides as calaverite, krennerite, sylvanite and nagyagite (Spiridonov, 2008 and 2011). Optical characteristics of these minerals are similar to each other. Microscopally they could be distinguished by distinct bright red, brown and purple colors with strong anisotropic effects. In the zone of the oxidation and secondary enrichment those minerals are highly unstable and tend to be decomposed with releasing of free gold.

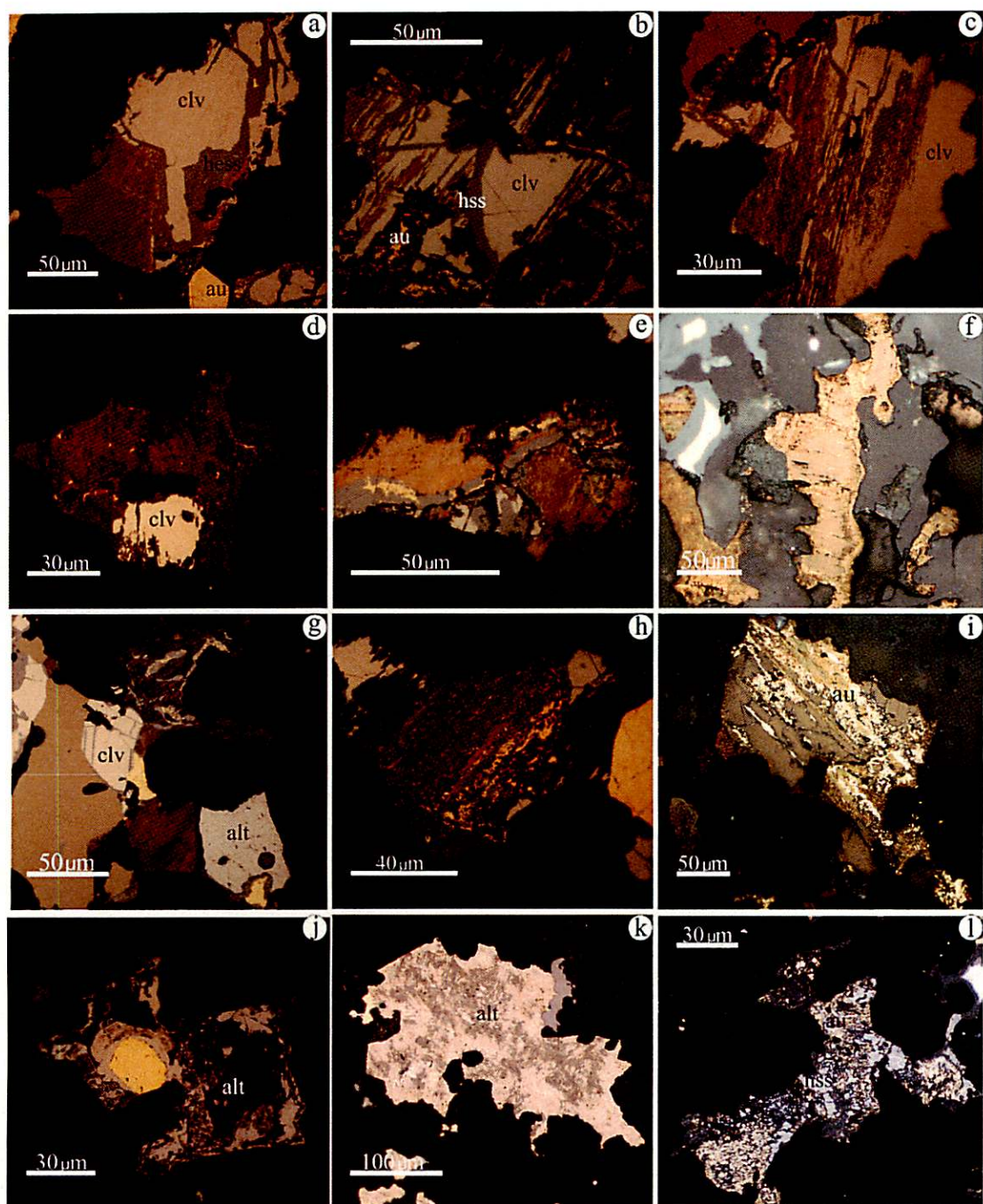


Fig.5.3.5. Microphotographs of secondary and altered minerals from Aginskoe deposit. Abbreviations listed in Fig. 5.3.1. a), b) & c) development of secondary minerals on the surface of primary tellurides from Bluzdayushie ore body; d) & e) relicts of hypogene tellurides in the secondary minerals in Bluzdayushee ore body; f) completely altered tellurides in Aginskoe ore body. Au is accumulated along fractures of decomposed primary tellurides; g) altaite intergrown with secondary minerals from Bluzdayushee ore body; h) & i) release of or reprecipitation of au on the surface of the secondary minerals in Bluzdayushee and Aginskoe ore bodies, respectively; j) au presumably intergrown with altaite in Surprise ore body; k) altered altaite from Aginskoe ore body; l) altered hss with au from Surprise ore body.

5.4. Quartz texture

Quartz texture carries important information on fluid chemistry, boiling, mixing and cooling processes during vein growth (Dong *et al.*, 1995). Generally quartz texture is classified on primary growth (massive, crustiform, cockade, colloform, moss, comb and zonal), recrystallization (mosaic, feathery, flamboyant and ghost sphere) and replacement (pseudo-banded, pseudo-acicular and saccharoidal).

Banded ore of Aginskoe deposit is showing colloform-crustiform banded, moss, flamboyant, ghost-sphere and pseudo-acicular textures. Only rare comb quartz was found in Surprise ore body. Colloform-crustiformed banded and moss texture is recognized in macro-scale in samples from Aginskoe, Bluzdayushee and fairly in Malyshev ore bodies (Fig. 4.3.1.2., 4.3.1.3. and 4.3.1.6.). Crustiform-colloform texture reflects such hydrothermal processes as cooling, mixing and wall rock-fluid interaction and boiling (Dong *et al.*, 1995). Cockade texture was observed in Surprise ore body. Large fragments of host rocks is coating by few layers of crystalline quartz. In thin sections mosaic, flamboyant, ghost sphere and pseudo-acicular textures were observed. Microcrystalline quartz of mosaic texture is composed majority of quartz-adularia veins of Aginskoe deposit. Flamboyant texture exhibits radial extinction of individual quartz crystals in banded ores of Aginskaya vein (Fig., 5.4.1.a, b.). Ghost-sphere is also one of common quartz texture in Aginskoe vein, generally. Ghost-spheres are found in microcrystalline quartz of mosaic texture (Fig. 5.4.1.c, d.). Flamboyant and ghost-sphere textures are indicators of recrystallization from amorphous silica and chalcedony. Acicular adularia intergrown with microcrystalline quartz is notably in specimens collected at Aginskaya vein mainly. In thin sections adularia is showing complete replacement by quartz (Fig. 5.4.1.e, f.). Adularia is still recognizable by outline of crystals. Replacement of initial calcite by adularia and quartz led to formation of pseudo-acicular texture. Thus, deposition of calcite in beginning of vein growth is confirmed.

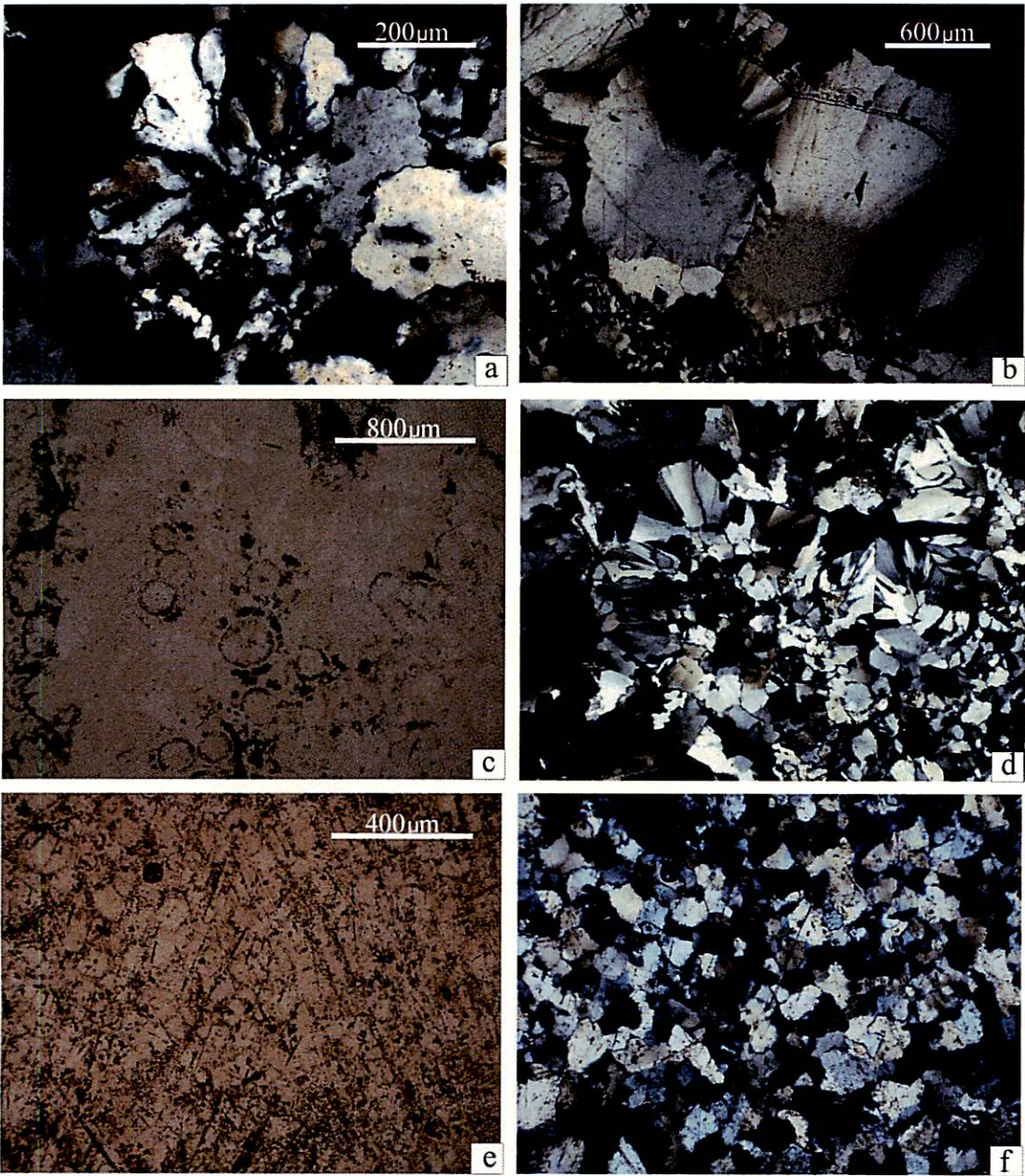


Fig.5.4.1. Textures of quartz observed in Aginskoe deposit. a) flamboyant texture of quartz; b) flamboyant texture developed on margin of quartz crystals; c,d) ghost sphere texture in mosaic quartz. Left photo is taken with open nicols, right – closed nicols; e,f) pseudo-acicular quartz texture. In groundmass of microcrystalline quartz outlines of needle-shaped adularia crystals are preserved. Left photo is taken with open nicols, right – closed nicols.

Table 5.3.1. Representative micro-probe analysis of altaite from Aginskoe, Bluzdayushie, Surprise and Malysh ore bodies.

	Aginskoe ore body			Surprise ore body			Malysh ore body		
wt%	1	2	3	7	8	9	10	11	12
Te	38.33	37.47	37.06	36.50	35.18	35.71	37.11	37.18	36.11
Pb	61.00	59.88	62.04	62.15	64.03	61.66	62.89	62.82	63.89
Ag	0.67	2.64	0.90	1.35	0.79	-	-	-	-
Sum	100.00	99.99	100.00	100.00	100.00	97.37	100.00	100.00	100.00

	Aginskoe ore body			Surprise ore body			Malysh ore body		
at%	1	2	3	7	8	9	10	11	12
Te	49.98	48.36	48.55	47.79	46.55	48.47	48.92	49.00	47.93
Pb	48.98	47.61	50.05	50.12	52.20	51.53	51.08	51.00	52.07
Ag	1.04	4.03	1.40	2.09	1.25	-	-	-	-

Table 5.3.2. Representative micro-probe analysis of hessite from the Aginskoe ore body.

wt %	1	2	3	4	5	6
Au	0.16	0.05	0.33	-	-	0.26
Ag	62.45	62.54	61.43	62.80	62.10	62.09
Te	36.86	37.03	36.66	37.64	36.23	36.85
Se	-	-	1.63	-	-	-
Sum	99.47	99.62	100.05	100.44	98.33	99.55

at%	1	2	3	4	5	6
Au	0.09	0.03	0.19	-	-	0.36
Ag	66.49	66.48	64.81	66.53	66.13	66.94
Te	33.42	33.49	32.64	33.47	33.87	32.70
Se	-	-	2.36	-	-	-

Table 5.3.3. Representative micro-probe analysis of calaverite from Bluzdayushee and Malysh ore bodies.

	Bluzdayushee ore body						Malysh ore body			
wt%	1	2	3	4	5	6	7	8	9	10
Au	42.13	41.81	40.77	41.43	41.96	42.89	41.40	38.39	33.96	33.39
Te	58.23	56.79	56.24	57.40	57.39	57.69	58.60	56.51	47.46	50.00
Ag	0.69	-	0.74	0.78	0.59	0.80	-	4.57	16.01	16.06
Sum	101.05	98.60	97.75	99.61	99.94	101.38	100.00	100.01	97.43	99.45

	Bluzdayushee ore body						Malysh ore body			
at%	1	2	3	4	5	6	7	8	9	10
Au	31.61	32.39	31.62	31.52	31.88	32.15	31.40	28.95	24.89	24.16
Te	67.45	67.71	67.33	67.41	67.30	66.75	68.60	64.85	53.69	54.96
Ag	0.95	-	1.05	1.08	0.82	1.10	-	6.21	21.42	20.88

№ 9 analysis is sylvanite.

Table 5.3.4. Representative micro-probe analysis of petzite from Aginskoe, Bluzdayushie, Surprise and Malysh ore bodies.

	Aginskoe ore body			Bluzd.	Surprise ore body		Malysh ore body		
wt%	1	2	3	4	7	8	9	10	11
Au	23.26	25.66	25.86	23.13	36.75	41.65	26.20	23.40	26.35
Ag	43.30	40.22	40.91	44.83	39.89	39.39	40.19	41.84	41.05
Te	33.05	32.14	33.23	31.97	19.38	18.97	33.61	34.76	34.05
Se	-	2.87	-	-	-	-	-	-	-
Sum	99.61	100.87	100.00	99.93	96.03	100.01	100.00	100.00	101.45

	Aginskoe ore body				Surprise ore body		Malysh ore body		
at%	1	2	3	4	7	8	9	10	11
Au	15.38	16.64	16.83	14.99	26.34	29.16	17.30	15.25	17.13
Ag	51.43	47.61	48.79	53.04	52.21	50.34	48.44	49.77	48.56
Te	33.18	32.13	33.39	31.97	21.45	20.50	34.26	34.97	34.31
Se	-	4.64	-	-	-	-	-	-	-

Table 5.3.5. Representative micro-probe analysis of sphalerite from Aginskoe, Bluzdayushie, Surprise and Malysh ore bodies.

at%	Aginskoe ore body			Bluzdayushee ore body			Surprise ore body			Malysh ore body		
	1	2	3	4	5	6	7	8	9	10	11	12
Zn	63.79	63.84	64.77	63.01	64.25	65.18	61.16	62.06	62.85	57.07	58.08	58.33
S	34.22	33.89	34.17	33.60	33.57	33.79	33.61	33.53	33.40	38.07	38.19	38.15
Fe	0.71	0.71	0.82	0.82	0.64	0.64	1.41	0.89	1.01	-	-	-
Cd	2.09	2.16	0.21	3.05	2.40	0.37	2.72	3.29	2.14	3.48	2.74	3.52
Sum	100.80	100.59	99.96	100.52	100.88	100.04	98.90	99.77	100.40	98.62	99.01	100.00

wt%	Aginskoe ore body			Bluzdayushee ore body			Surprise ore body			Malysh ore body		
	1	2	3	4	5	6	7	8	9	10	11	12
Zn	47.03	47.28	47.80	46.93	47.65	48.25	46.02	46.51	46.92	41.74	42.05	42.22
S	51.44	51.17	51.40	51.02	50.75	50.99	51.55	51.24	50.84	56.78	56.38	56.30
Fe	0.62	0.62	0.71	0.72	0.55	0.55	1.25	0.80	0.88	-	-	-
Cd	0.90	0.93	0.09	1.32	1.03	0.16	1.18	1.45	1.36	1.46	1.57	1.47

Table 5.3.6. Representative micro-probe analysis of native gold from Aginskoe ore body.

wt%	1	2	3	4	5	6	7	8	9	10
Au	95.54	94.55	96.63	94.87	94.60	94.85	94.20	94.98	94.12	94.93
Ag	4.75	5.33	5.12	5.19	4.99	5.15	5.22	5.02	5.19	5.07
Sum	100.29	99.88	101.75	100.06	99.59	100.00	99.42	100.00	99.31	100.00

at%	1	2	3	4	5	6	7	8	9	10
Au	91.62	90.84	91.17	90.98	91.21	90.99	94.59	91.20	90.84	90.21
Ag	8.38	9.16	8.83	9.02	8.79	8.79	5.41	8.80	9.16	8.79

Table 5.3.6. Continued: representative micro-probe analysis of native gold from Bluzdayushie ore body.

wt%	1	2	3	4	5	6	7	8	9
Au	85.70	86.74	93.97	93.41	92.76	94.81	85.99	93.20	90.12
Ag	14.29	13.26	6.03	6.29	6.84	5.16	4.57	5.87	5.80
Sum	99.99	100.00	100.00	99.70	99.60	99.96	90.56	99.07	95.92

at%	1	2	3	4	5	6	7	8	9
Au	76.65	78.16	89.51	89.09	88.20	90.97	91.15	89.69	89.49
Ag	23.35	21.81	10.49	10.91	11.80	9.03	8.85	10.31	10.51

Table 5.3.6. Continued: representative micro-probe analysis of native gold from Surprise ore body.

wt%	1	2	3	4	5	6	7	8	9	10	11	12
Au	94.53	94.47	94.76	94.94	95.21	94.92	92.67	95.31	94.46	94.69	74.41	74.26
Ag	5.47	5.53	5.24	5.06	4.79	5.08	5.34	4.69	5.54	5.31	25.59	25.75
Sum	100.00	100.00	100.00	100.00	100.00	100.00	98.01	100.00	100.00	100.00	100.00	100.00

at%	1	2	3	4	5	6	7	8	9	10	11	12
Au	90.45	90.35	90.82	91.14	99.56	91.09	90.52	91.77	90.33	90.24	60.94	60.14
Ag	9.55	9.65	9.18	8.86	0.40	8.91	9.48	8.23	9.67	9.76	39.06	39.86

Table 5.3.6. Continued: representative micro-probe analysis of native gold from Malysk ore body.

wt%	1	2	3	4	5	6	7	8	9	10	11	12
Au	94.62	95.92	96.24	94.44	93.92	92.61	94.68	93.07	94.19	94.44	95.26	93.94
Ag	5.80	4.08	4.37	5.56	5.68	6.28	5.32	5.25	5.81	4.95	4.74	6.06
Sum	100.42	100.00	100.61	100.00	99.60	98.89	100.00	98.32	100.00	99.39	100.00	

at%	1	2	3	4	5	6	7	8	9	10	11	12
Au	89.93	92.79	92.35	90.31	90.06	88.97	90.70	90.66	89.86	91.27	91.66	89.46
Ag	10.07	7.21	7.66	9.69	9.94	11.03	9.30	9.34	10.14	8.73	8.34	10.54

Chapter VI. Characteristics of hydrothermal fluids

6.1. Fluid inclusions

6.1.1. Nature of fluid inclusions

6.1.2. Melting and homogenization temperature

6.2. Gas composition of fluid inclusion

6.3. Stable isotopes

Chapter VI. Characteristics of hydrothermal fluids

Characteristics of hydrothermal fluids such as temperature, salinity, pressure and compositions are important factors for the estimation of the physicochemical environment of ore deposition. Data on fluids nature may be drawn from fluid inclusions, stable isotopes and Raman spectroscopy studies. Although, sphalerite, adularia and calcite are also used for fluid inclusions and Raman spectroscopy studies, in this study quartz was the one mineral hosting large enough fluid inclusions. Adularia is ubiquitously replaced by quartz in ores of Aginskoe deposit, and calcite is free of inclusions. Sphalerite is rare and tiny in size regarding for the fluid inclusion studies. Gangue quartz and calcite were also used for stable isotope studies.

6.1. Fluid inclusions

Fluid inclusions are the preserved small portions of hydrothermal solutions provide information on temperature, salinity, composition and pressure of the mineralized solutions. Droplets of fluids vary from homogeneous liquid or gas to inclusions containing two or three phases including solid and various gases. Depending on trapping mechanism three types of inclusions are recognized: primary, secondary and pseudosecondary (Mel'nikov *et al.*, 2008; Roedder, 1984). Primary inclusions are characterized by large size of hosting cavity, negative crystal shape and occurrence along growth zones of parent mineral, and in central or upper zone of crystals. Primary inclusions are trapped by growth imperfection on crystal surface representing the initial solution. Secondary inclusions are generally trapped along fractures formed due to deformation of crystals. These inclusions are also carrying important information on fluid temperature and salinity, but on the estimation of the geochemical environment they have minor importance. Pseudosecondary inclusions were classified as intermediated type between primary and secondary. Those inclusions are trapped while crystal growing, however, debut of origin of pseudo-secondary inclusions are still actual now.

The measuring of ice-melting and homogenization temperatures of fluid inclusions in quartz was applied to estimate salinity, temperature and pressure of the original hydrothermal water-steam mixture, and fluid evolution during mineralization.

6.1.1. Nature of fluid inclusions

About 40 underground samples of quartz from different localities of Aginskoe and Surprise veins were made into thin sections for the fluid inclusion studies. Extra vein samples were taken from South-Aginskoe deposit.

Quartz of Aginskaya vein is mainly fine-graded flamboyant, mosaic, ghost-sphere, pseudo-acicular or saccharoidal in texture suggesting recrystallization from primary silica gel, adularia and calcite (Dong *et al.*, 1995). Fluid inclusions were observed in clear euhedral quartz crystals in breccias from ore bodies Aginskoe and Surprise, banded quartz from Bluzdayushie and Malysh ore bodies, post-ore stage amethyst from Malysh ore body. In South-Aginskoe deposit fluid inclusions were found in quartz veins interbedded andesitic tuff.

Microscopic observation of double-polished thin sections showed mess of primary, secondary and pseudo-secondary inclusions. Generally all of observed fluid inclusions contain two phases at the room temperature. Primary inclusions of negative crystal shape and size of about 2-8 μm tend to be occurred along growth zones and upper part of quartz crystal (Fig. 6.1.1.1.). Based on vapor phase, varying from 10 to 90 vol% of cavity, generally two types of primary inclusions are recognized. Type I - liquid-rich inclusions with 10-30 % of vapor volume two phase inclusions. Type II - vapor dominated inclusions with 50-100 % vapor volume single and two phase inclusions. Groups of gaseous and gas- and liquid-rich inclusions were frequently observed in singly quartz crystals fairly in each ore body (Fig. 6.1.1.2.). Daughter minerals and presence of liquid CO_2 was not found in inclusions. Secondary inclusions are characterized by linear mode of occurrence, highly variable size and shape. Among secondary inclusions liquid-rich type with liquid phase up 70 vol% is dominant. Primary fluid inclusions in amethysts quartz from Malysh ore body are small in size and negative crystals form in shape. Type I and type II are frequently observed in co-

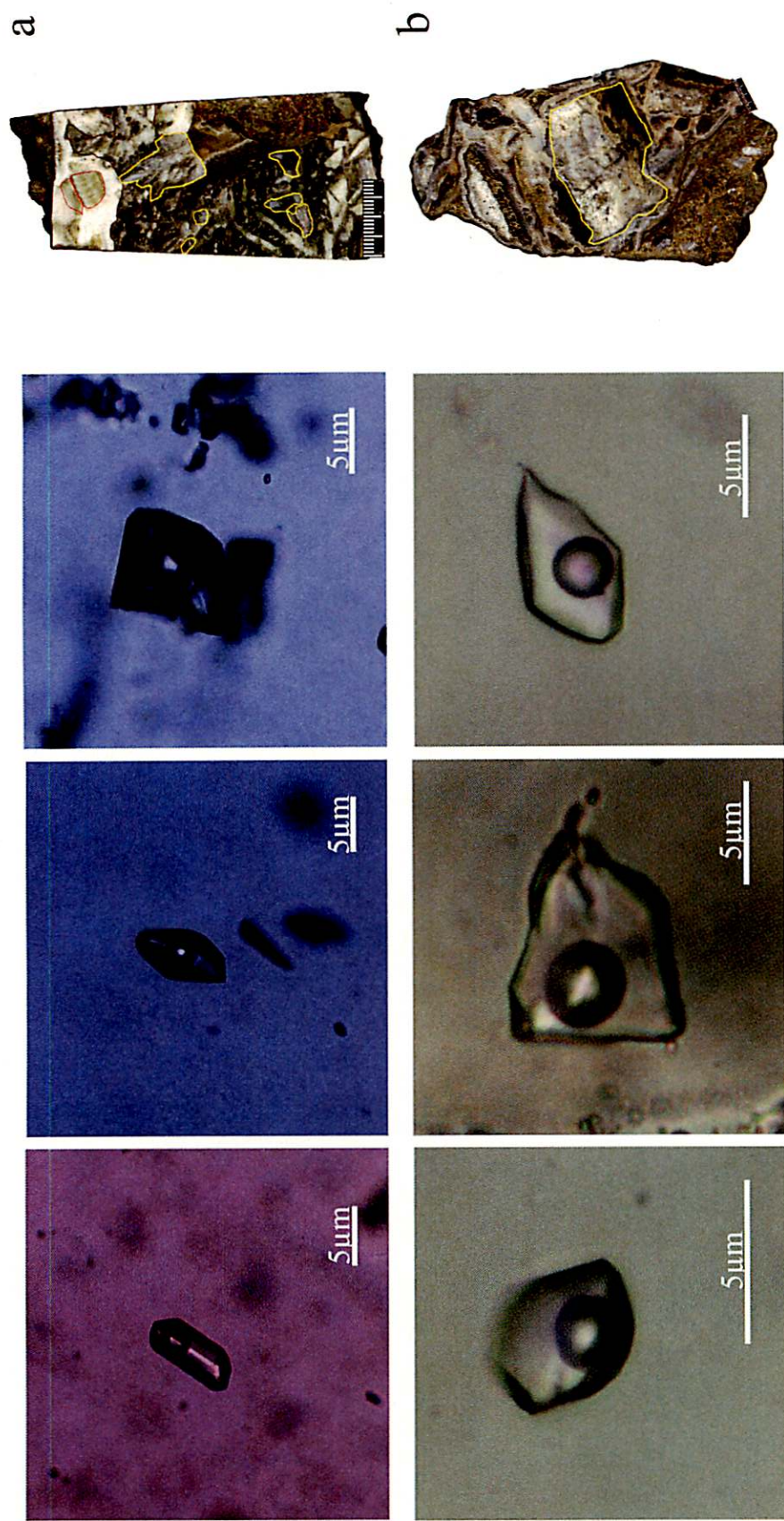


Fig.6.1.1.1. Mode of occurrence of primary fluid in inclusions in Aginskaya vein: a) primary two-phase fluid inclusions in Aginskoe ore body. Liquid-rich inclusions display variety of morphology; b) primary individual liquid-rich inclusions of negative crystal shape in quartz from Bluzdayushee ore body. Specimens on right side of a figure show quartz crystal used for fluid inclusions study.

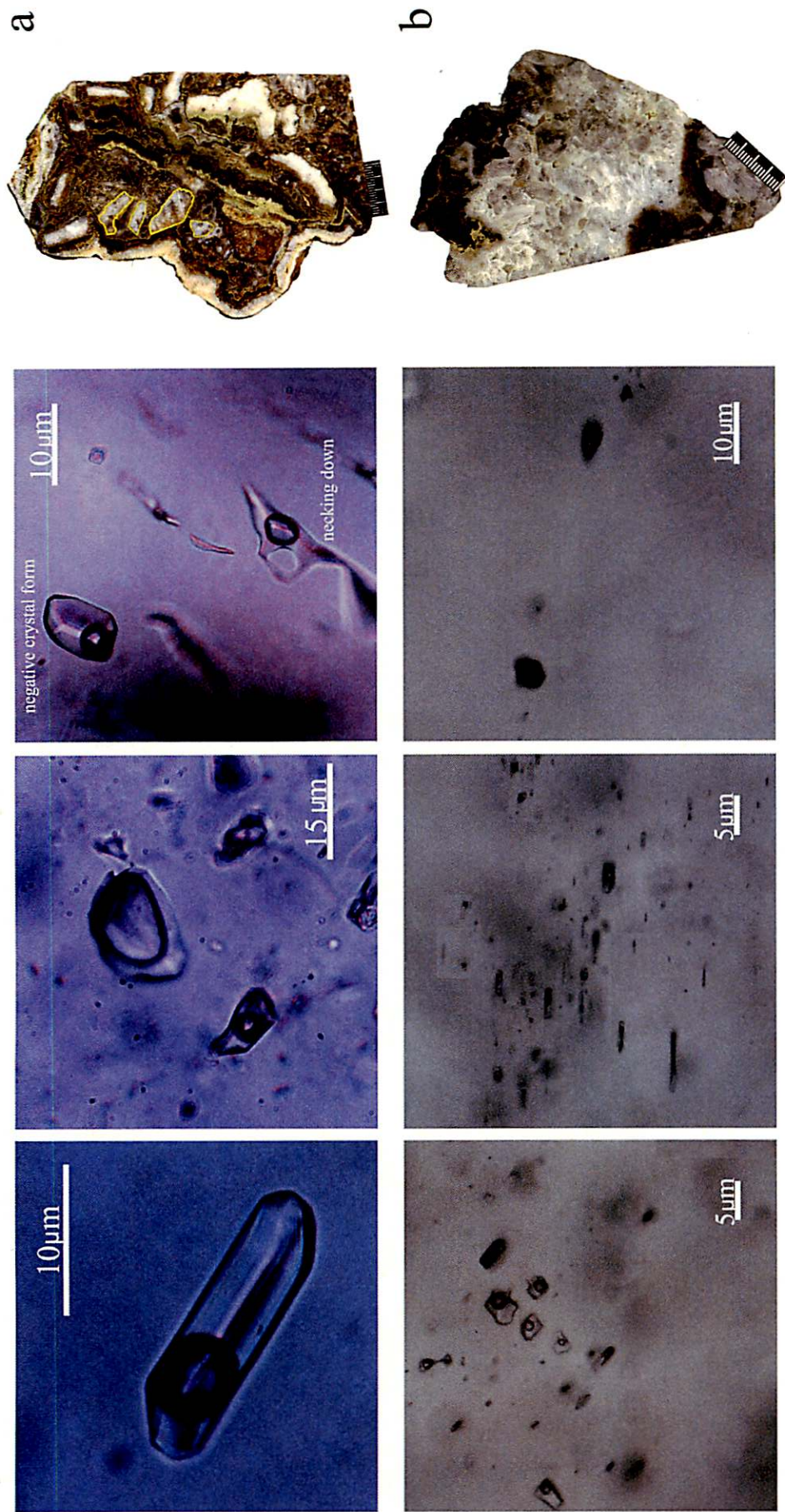


Fig.6.1.1.2. Mode of occurrence of primary fluid in inclusions in Surprise vein: a) primary two-phase liquid-rich fluid inclusions of typical tube and negative crystal shape co-existing with two-phase vapor-dominated inclusions. Necking-down fluid inclusions were also observed; b) occurrence of minute size primary fluid inclusions in quartz aggregates of Malysk ore body. Specimens on right side of figure show quartz crystal used for fluid inclusions study.

existing, however, aqueous inclusions of Type I are dominant (Figs. 6.1.1.1. and 6.1.1.2.).

Type I inclusions in co-existing with Type II inclusions were found in euhedral quartz aggregates from South-Aginskoe deposit (Fig. 6.1.1.3.). However, type inclusions are minor compare to type I inclusions. Primary inclusions are basically negative crystals with size varying from 2 to 20 μm randomly occurred in upper and central part of quartz crystals. Secondary inclusions are tiny Type I inclusions crosscut crystals. In quartz from South-Aginskoe deposit fluid inclusions tend to be bigger in size with irregular shape (Fig. 6.1.1.3.).

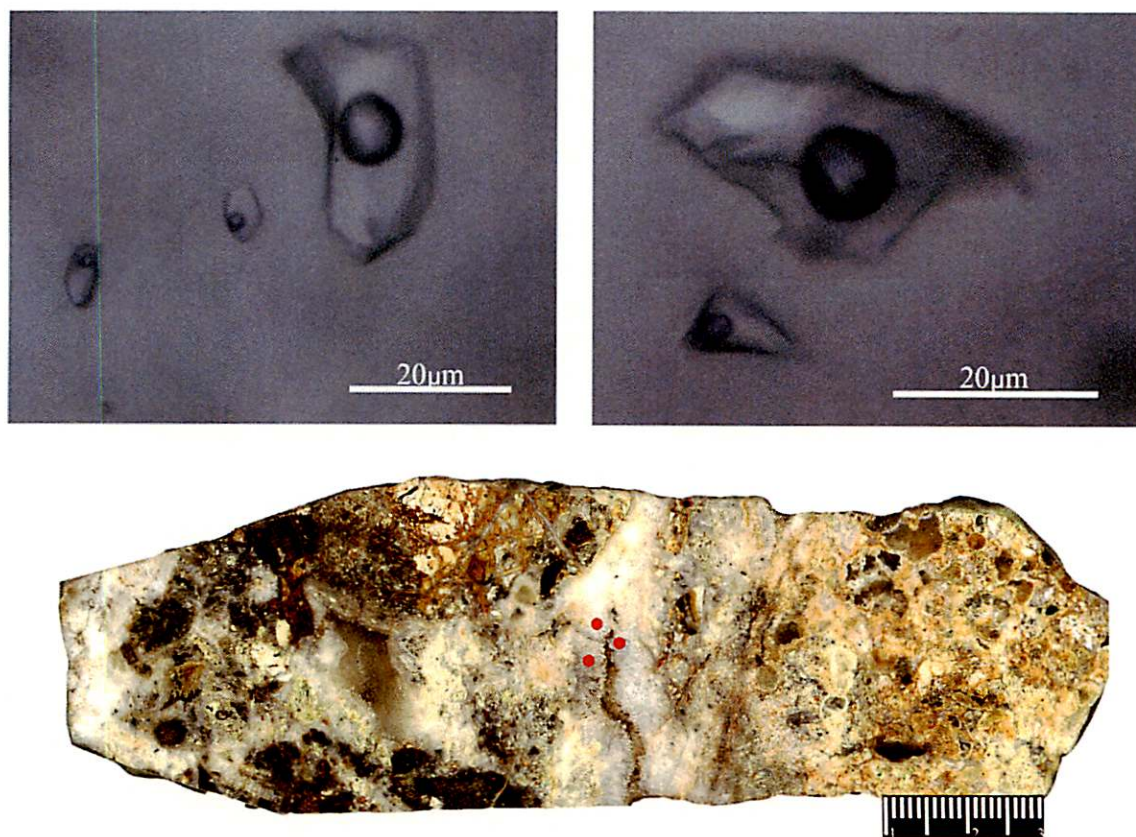


Fig.6.1.1.3. Mode of occurrence of primary fluid in inclusions in quartz vein of South-Aginskoe deposit. Fluid inclusions are mainly consisted of two-phase with dominant aqueous. Specimen of tuff with quartz veins show quartz crystal used for fluid inclusions study.

6.1.2. Melting and homogenization temperature

The homogenization temperatures of the primary fluid inclusions vary over large range in Surprise vein, and within narrow range of temperatures in Aginskoe vein. Salinity of fluid inclusions, however, varies insignificantly in both veins. Data on homogenization temperatures, melting temperature and salinity of Stage II for each ore body in Aginskoe deposit are listed in Table 6.1.2.1, 6.1.2.2., 6.1.2.3., 6.1.2.4., 6.1.2.5., and 6.1.2.6. Table 6.1.2.6 presents the homogenization and melting temperature for the fluid inclusions in quartz from South-Aginskoe deposit. Histograms of primary and secondary fluid inclusions homogenization temperatures from euhedral quartz crystals of the ore stage II and amethysts of the post-ore stage IV are shown in Fig. 6.1.2.1. and 6.1.2.3. Fluid inclusions of both types homogenize in vapor phase. Type I and type II primary fluid inclusions in quartz from brecciated ores of Aginskoe ore body homogenize within temperature range of 230-270 °C. Primary fluid inclusions in banded quartz of Bluzdayushee ore body homogenize from 250-280 °C (Fig. 6.1.2.1.). Secondary inclusions are generally showing lower temperature of homogenization. Primary inclusions in quartz of brecciated ores from Surprise ore body homogenize from 200 to 290 °C. Primary inclusions of type I mainly from quartz aggregates of Malysh ore body homogenize between 240-300 °C (Fig. 6.1.2.1.). Homogenization temperatures of secondary inclusions were measured only for secondary inclusions in the Surprise ore body. The T_h values range from 240 to 300 °C. The mean of homogenize temperature for both veins is about 250-260 °C. Fluid inclusions in amethysts quartz from Malysh ore body homogenize from 240 to 280 °C mainly (Fig. 6.1.2.3.). Temperatures of ice melting range from 0 to - 0.8 °C in fluid inclusions from quartz of the Aginskoe deposit. The salinity calculated from melting data varies from 0.4 to 1.4 wt% NaCl for Aginskoe vein, and from 0 to 1.6 wt% NaCl equiv. for Surprise vein, respectively (Fig. 6.1.2.2.). Melting temperatures of fluid inclusions in amethysts quartz is -0.7 and salinity 1.2 wt% NaCl equiv.

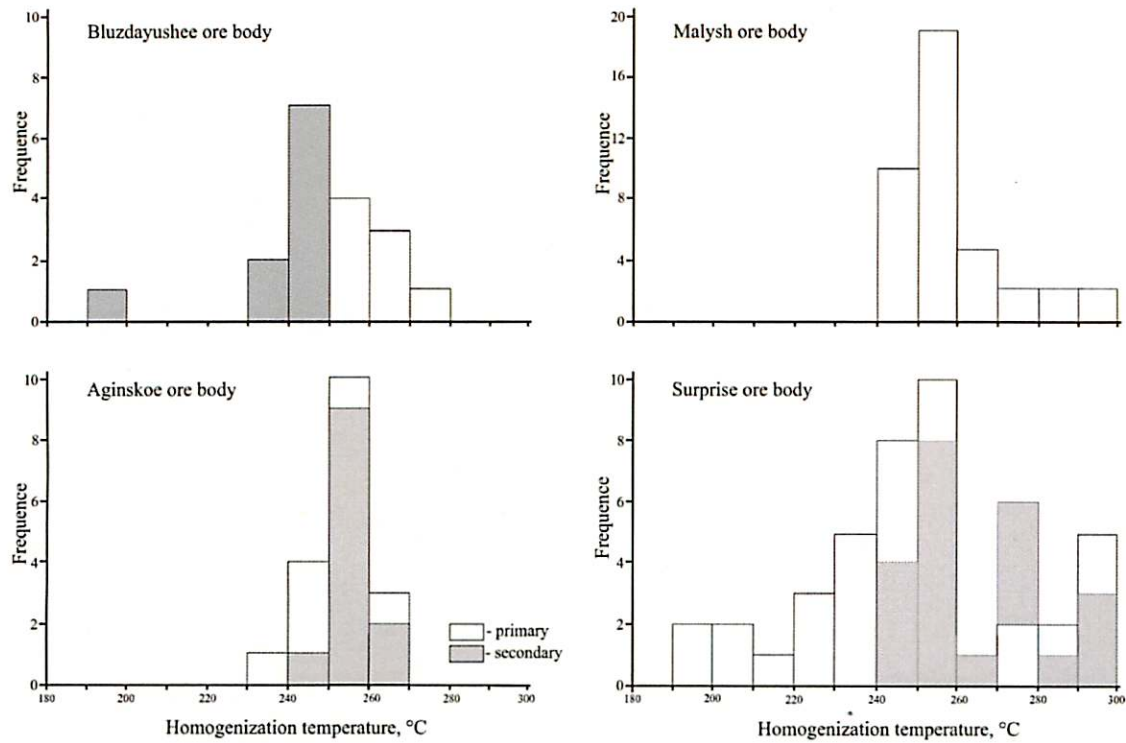


Fig.6.1.2.1. Histograms of homogenization temperatures for fluid inclusion in Aginskoe deposit.

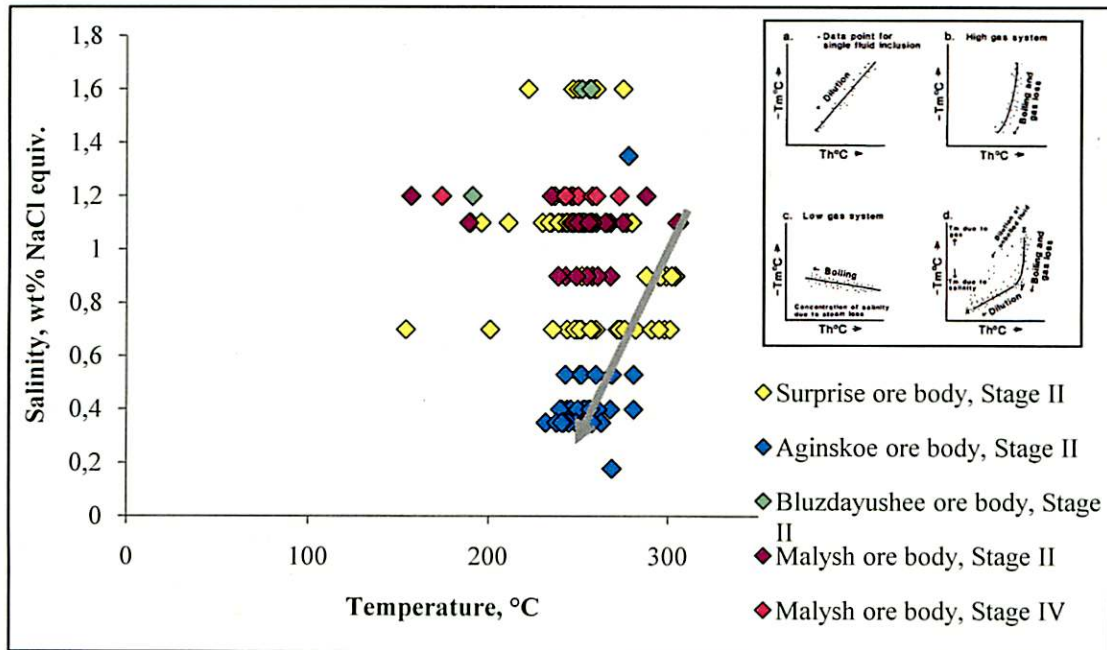


Fig.6.1.2.2. A scattered diagram of salinity vs. homogenization temperature for primary inclusions in Aginskoe deposit. Diagrams in left upper part are showing different trends between melting and homogenization temperatures of the fluid inclusions. Diagrams are taken from Hedenquist and Henley, 1985.

Primary fluid inclusions in clear quartz from South-Aginskoe deposit homogenize under low-temperature (170-200 °C) and high-temperature (240-290 °C). A scattered diagram of primary fluid inclusions homogenization temperatures vs. salinity is shown in Fig. 6.1.2.4. Melting temperatures of fluid inclusions ranging from -0.5 to 0.9 °C. Salinity is about 0.9-1.4 wt% NaCl equiv., respectively (Fig. 6.1.2.4).

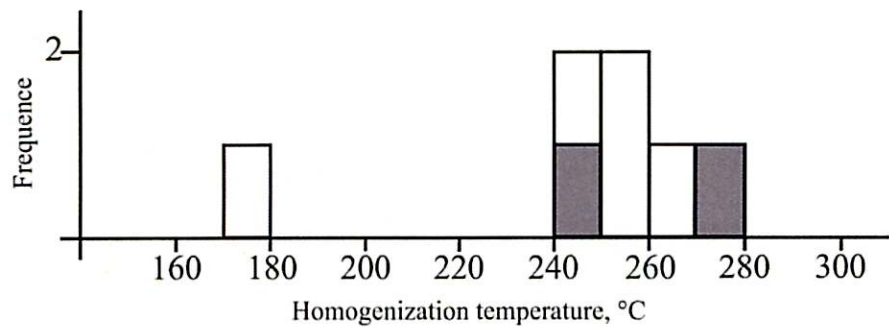


Fig.6.1.2.3. A histogram of homogenization temperatures for fluid inclusion in amethysts quartz of stage IV from Malyshev ore body, Aginskoe deposit

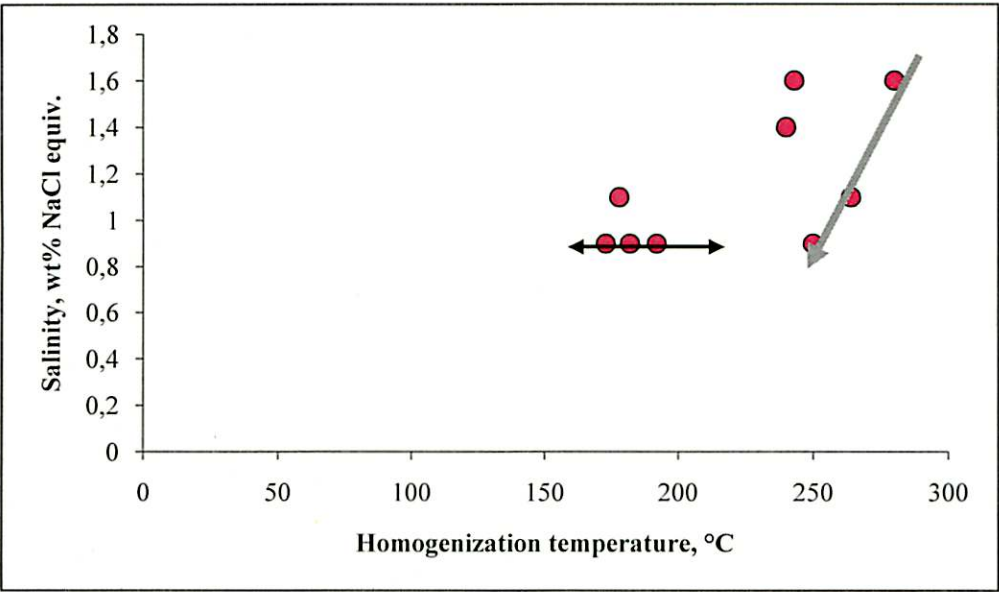


Fig.6.1.2.4. A scattered diagram of salinity vs. homogenization temperatures for primary inclusions in quartz from South-Aginskoe deposit.

Table 6.1.2.1 Fluid inclusions data on vein quartz from Aginskoe ore body.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _m	Calib. T _m	NaCl wt%
1	23AJ12	Quartz	pr.	250	244	-0.1	-0.4	0.7
2	23AJ12	Quartz	pr.	260	253	-0.1	-0.4	0.7
3	23AJ12	Quartz	pr.	263	256	-0.1	-0.4	0.7
4	23AJ12	Quartz	pr.	275	268	-0.1	-0.4	0.7
5	23AJ12	Quartz	pr.	247	241	-0.1	-0.4	0.7
6	23AJ12	Quartz	pr.	252	246	-0.1	-0.4	0.7
7	23AJ12	Quartz	pr.	252	246	-0.1	-0.4	0.7
8	23AJ12	Quartz	pr.	246	240	-0.1	-0.4	0.7
9	23AJ12	Quartz	sd.	260	253	-0.1	-0.4	0.7
10	23AJ12	Quartz	sd.	260	253	-0.1	-0.4	0.7
11	23AJ12	Quartz	sd.	261	254	-0.1	-0.4	0.7
12	23AJ12	Quartz	sd.	261	254	-0.1	-0.4	0.7
13	23AJ12	Quartz	sd.	261	254	-0.1	-0.4	0.7
14	23AJ12	Quartz	sd.	261	254	-0.1	-0.4	0.7
15	23AJ12	Quartz	sd.	256	250	-0.1	-0.4	0.7
16	23AJ12	Quartz	sd.	268	261	-0.1	-0.4	0.7
17	23AJ12	Quartz	sd.	268	261	-0.1	-0.4	0.7
18	23AJ12	Quartz	sd.	264	257	-0.1	-0.4	0.7

Table 6.1.2.2 Fluid inclusions data on vein quartz from Bluzdayushee ore body.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _m	Calib. T _m	NaCl wt%
1	B3	Quartz	pr.	264	256	-0.6	-1	1.7
2	B3	Quartz	pr.	260	252	-0.6	-1	1.7
3	B3	Quartz	pr.	270	257	-0.6	-1	1.7
4	B3	Quartz	pr.	266	257	-0.6	-1	1.7
5	B3	Quartz	pr.	266	260	-0.6	-1	1.7
6	B3	Quartz	pr.	269	261	-	-	-
7	B3	Quartz	pr.	270	261	-	-	-
8	B3	Quartz	pr.	281	271	-	-	-
9	B3	Quartz	sd.	250	191	-0.4	-0.8	1.4
10	B3	Quartz	sd.	254	237	-0.4	-0.8	1.4
11	B3	Quartz	sd.	254	237	-0.4	-0.8	1.4
12	B3	Quartz	sd.	254	242	-0.4	-0.8	1.4
13	B3	Quartz	sd.	257	242	-0.4	-0.8	1.4
14	B3	Quartz	sd.	257	246	-0.4	-0.8	1.4
15	B3	Quartz	sd.	195	246	-0.4	-0.8	1.4
16	B3	Quartz	sd.	244	246	-0.4	-0.8	1.4
17	B3	Quartz	sd.	244	249	-0.4	-0.8	1.4
18	B3	Quartz	sd.	250	249	-0.4	-0.8	1.4

Table 6.1.2.3 Fluid inclusions data euhedral quartz from Surprise ore body.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _m	Calib. T _m	NaCl wt%
1	23SJ5	quartz	pr.	315	306	-0.3	-0.6	1.1
2	23SJ5	quartz	pr.	250	244	-0.1	-0.4	0.7
3	23SJ5	quartz	pr.	288	280	-0.3	-0.6	1.1
4	23SJ5	quartz	pr.	194	190	-0.3	-0.6	1.1

5	23SJ5	quartz	pr.	200	196	-0.3	-0.6	1.1
6	23SJ8	quartz	pr.	296	288	-0.2	-0.5	0.9
7	23SJ8	quartz	pr.	296	288	-0.2	-0.5	0.9
8	23SJ8	quartz	pr.	313	304	-0.2	-0.5	0.9
9	23SJ8	quartz	pr.	308	299	-0.2	-0.5	0.9
10	23SJ8	quartz	pr.	308	299	-0.2	-0.5	0.9
11	23SJ8	quartz	pr.	311	302	-0.2	-0.5	0.9
12	23SJ8	quartz	pr.	311	302	-0.2	-0.5	0.9
13	23SJ8	quartz	pr.	303	295	-0.2	-0.5	0.9
14	23SJ8	quartz	pr.	305	296	-0.2	-0.5	0.9
15	23SJ8	quartz	pr.	305	296	-0.2	-0.5	0.9
16	23SJ8	quartz	pr.	261	254	-0.3	-0.6	1.1
17	23SJ8	quartz	pr.	261	254	-0.3	-0.6	1.1
18	23SJ8	quartz	pr.	261	254	-0.3	-0.6	1.1
19	23SJ8	quartz	pr.	261	254	-0.3	-0.6	1.1
20	23SJ8	quartz	pr.	261	254	-0.3	-0.6	1.1
21	23SJ8	quartz	pr.	236	230	-0.2	-0.5	1.1
22	23SJ8	quartz	pr.	241	235	-0.3	-0.6	1.1
23	23SJ8	quartz	pr.	247	241	-0.3	-0.6	1.1
24	23SJ8	quartz	pr.	240	234	-0.3	-0.6	1.1
25	23SJ8	quartz	pr.	249	243	-0.3	-0.6	1.1
26	23SJ8	quartz	pr.	216	211	-0.3	-0.6	1.1
27	23SJ12	quartz	pr.	290	282	-0.1	-0.4	0.7
28	23SJ12	quartz	pr.	205	201	-0.1	-0.4	0.7
29	23SJ12	quartz	pr.	205	201	-0.1	-0.4	0.7
30	23SJ12	quartz	pr.	262	252	-0.2	-0.5	0.9
31	23SJ12	quartz	pr.	262	252	-0.2	-0.5	0.9
32	23SJ12	quartz	pr.	265	258	-0.1	-0.4	0.7
33	23SJ12	quartz	pr.	242	236	-0.1	-0.4	0.7
34	23SJ12	quartz	pr.	242	236	-0.1	-0.4	0.7
35	23SJ12	quartz	pr.	259	252	-0.3	-0.6	1.1
36	23SJ12	quartz	pr.	245	239	-0.3	-0.6	1.1
37	23SJ12	quartz	pr.	254	248	-0.3	-0.6	1.1
38	23SJ12	quartz	pr.	250	244	-0.3	-0.6	1.1
39	23SJ4	quartz	pr.	266	259	-0.6	-0.9	1.6
40	23SJ4	quartz	pr.	259	252	-0.6	-0.9	1.6
41	23SJ4	quartz	pr.	227	222	-0.6	-0.9	1.6
42	23SJ4	quartz	pr.	227	222	-0.6	-0.9	1.6
43	23SJ4	quartz	pr.	253	247	-0.6	-0.9	1.6
44	23SJ4	quartz	pr.	253	247	-0.6	-0.9	1.6
45	23SJ4	quartz	pr.	266	259	-0.6	-0.9	1.6
46	23SJ4	quartz	sd.	267	260	-0.6	-0.9	1.6
47	23SJ4	quartz	sd.	283	275	-0.6	-0.9	1.6
48	23SJ4	quartz	sd.	256	250	-0.6	-0.9	1.6
49	23SJ4	quartz	sd.	264	257	-0.6	-0.9	1.6
50	23SJ8	quartz	sd.	311	302	-0.2	-0.5	0.9
51	23SJ8	quartz	sd.	311	302	-0.2	-0.5	0.9
52	23SJ8	quartz	sd.	311	302	-0.2	-0.5	0.9
53	23SJ8	quartz	sd.	311	302	-0.2	-0.5	0.9
54	23SJ8	quartz	sd.	311	302	-0.2	-0.5	0.9
55	23SJ8	quartz	sd.	296	288	-0.2	-0.5	0.9
56	23SJ8	quartz	sd.	296	288	-0.2	-0.5	0.9
57	23SJ12	quartz	sd.	261	154	-0.1	-0.4	0.7
58	23SJ12	quartz	sd.	255	249	-0.1	-0.4	0.7

59	23SJ12	quartz	sd.	307	298	-0.1	-0.4	0.7
60	23SJ12	quartz	sd.	267	260	-0.1	-0.4	0.7
61	23SJ12	quartz	sd.	310	301	-0.1	-0.4	0.7
62	23SJ12	quartz	sd.	299	291	-0.1	-0.4	0.7
63	23SJ12	quartz	sd.	281	274	-0.1	-0.4	0.7
64	23SJ12	quartz	sd.	303	295	-0.1	-0.4	0.7
65	23SJ12	quartz	sd.	256	250	-0.1	-0.4	0.7
66	23SJ12	quartz	sd.	279	272	-0.1	-0.4	0.7
67	23SJ12	quartz	sd.	254	248	-0.1	-0.4	0.7
68	23SJ12	quartz	sd.	280	273	-0.1	-0.4	0.7
69	23SJ12	quartz	sd.	284	276	-0.1	-0.4	0.7
70	23SJ12	quartz	sd.	259	252	-0.1	-0.4	0.7
71	23SJ12	quartz	sd.	257	251	-0.1	-0.4	0.7
72	23SJ12	quartz	sd.	264	257	-0.1	-0.4	0.7
73	23SJ12	quartz	sd.	285	277	-0.3	-0.6	1.1
74	23SJ12	quartz	sd.	264	257	-0.3	-0.6	1.1
75	23SJ12	quartz	sd.	264	257	-0.2	-0.5	1.1
76	23SJ12	quartz	sd.	273	266	-0.3	-0.6	1.1
77	23SJ12	quartz	sd.	263	246	-0.3	-0.6	1.1
78	23SJ12	quartz	sd.	258	252	-0.3	-0.6	1.1
79	23SJ12	quartz	sd.	259	253	-0.3	-0.6	1.1
80	23SJ12	quartz	sd.	288	280	-0.3	-0.6	1.1

Table 6.1.2.4 Fluid inclusions data on gold-associated quartz from Malysk ore body.

№	Sample	Host mineral	Type	Meas.T _h	Calib.T _h	Meas. T _m	Calib.T _m	NaCl wt%
1	M1	Quartz	pr.	256	249	-0.1	-0.5	0.9
2	M1	Quartz	pr.	277	268	-0.1	-0.5	0.9
3	M1	Quartz	pr.	266	258	-0.1	-0.5	0.9
4	M1	Quartz	pr.	250	243	-0.1	-0.5	0.9
5	M1	Quartz	pr.	250	243	-0.1	-0.5	0.9
6	M1	Quartz	pr.	269	261	-0.1	-0.5	0.9
7	M1	Quartz	pr.	256	249	-0.1	-0.5	0.9
8	M1	Quartz	pr.	256	249	-0.1	-0.5	0.9
9	M1	Quartz	pr.	263	255	-0.1	-0.5	0.9
10	M1	Quartz	pr.	256	249	-0.1	-0.5	0.9
11	M1	Quartz	pr.	246	239	-0.1	-0.5	0.9
12	M1	Quartz	pr.	256	249	-0.1	-0.5	0.9
13	M1	Quartz	pr.	256	249	-0.1	-0.5	0.9
14	M1	Quartz	pr.	201	197	-0.1	-0.5	0.9
15	M1	Quartz	pr.	201	197	-0.1	-0.5	0.9
16	M1	Quartz	pr.	282	273	-0.2	-0.6	1.1
17	M1	Quartz	pr.	285	276	-0.2	-0.6	1.1
18	M1	Quartz	pr.	259	251	-0.2	-0.6	1.1
19	M1	Quartz	pr.	252	245	-0.2	-0.6	1.1
20	M1	Quartz	pr.	254	247	-0.2	-0.6	1.1
21	M1	Quartz	pr.	252	245	-0.2	-0.6	1.1
22	M1	Quartz	pr.	251	244	-0.2	-0.6	1.1
23	M1	Quartz	pr.	255	248	-0.2	-0.6	1.1
24	M1	Quartz	pr.	220	215	-0.2	-0.6	1.1
25	M1	Quartz	pr.	259	251	-0.2	-0.6	1.1
26	M1	Quartz	pr.	197	193	-0.2	-0.6	1.1
27	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1

28	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
29	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
30	M1	Quartz	pr.	268	260	-0.2	-0.6	1.1
31	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
32	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
33	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
34	M1	Quartz	pr.	316	305	-0.2	-0.6	1.1
35	M1	Quartz	pr.	277	268	-0.2	-0.6	1.1
36	M1	Quartz	pr.	254	247	-0.2	-0.6	1.1
37	M1	Quartz	pr.	257	250	-0.2	-0.6	1.1
38	M1	Quartz	pr.	257	250	-0.2	-0.6	1.1
39	M1	Quartz	pr.	284	275	-0.2	-0.6	1.1
40	M1	Quartz	pr.	192	189	-0.2	-0.6	1.1
41	M1	Quartz	pr.	275	266	-0.2	-0.6	1.1
42	M1	Quartz	pr.	273	265	-0.2	-0.6	1.1
43	M1	Quartz	pr.	266	258	-0.2	-0.6	1.1
44	M1	Quartz	pr.	266	258	-0.2	-0.6	1.1
45	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
46	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
47	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
48	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
49	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
50	M1	Quartz	pr.	264	256	-0.2	-0.6	1.1
51	M1	Quartz	pr.	298	288	-0.3	-0.7	1.2
52	M1	Quartz	pr.	254	247	-0.3	-0.7	1.2
53	M1	Quartz	pr.	158	157	-0.3	-0.7	1.2
54	M1	Quartz	pr.	242	235	-0.3	-0.7	1.2

Table 6.1.2.5. Fluid inclusions data on amethyst quartz from Malyshev ore body.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _m	Calib. T _m	NaCl wt%
1	M2	Quartz	pr.	258	250	-0.3	-0.7	1.2
2	M2	Quartz	pr.	266	258	-0.3	-0.7	1.2
3	M2	Quartz	pr.	268	260	-0.3	-0.7	1.2
4	M2	Quartz	pr.	188	174	-0.3	-0.7	1.2
5	M2	Quartz	pr.	250	243	-0.3	-0.7	1.2
6	M2	Quartz	pr.	250	243	-0.3	-0.7	1.2

Table 6.1.2.6 Fluid inclusions data on vein quartz from South-Aginskoe deposit.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _m	Calib. T _m	NaCl wt%
1	SAJ1	Quartz	pr.	257	250	-0.1	-0.5	0.9
2	SAJ1	Quartz	pr.	181	178	-0.2	-0.6	1.1
3	SAJ1	Quartz	pr.	181	178	-0.2	-0.6	1.1
4	SAJ1	Quartz	pr.	250	243	-0.5	-0.9	1.6
5	SAJ1	Quartz	pr.	290	280	-0.5	-0.9	1.6
6	SAJ1	Quartz	pr.	272	264	-0.2	-0.6	2.2
7	SAJ1	Quartz	pr.	185	182	-0.1	-0.5	0.9
8	SAJ1	Quartz	pr.	247	240	-0.4	-0.8	1.4
9	SAJ1	Quartz	pr.	196	192	-0.1	-0.5	0.9
10	SAJ1	Quartz	pr.	176	173	-0.1	-0.5	0.9

11	SAJ1	Quartz	sd.	160	158	-0.1	-0.5	0.9
12	SAJ1	Quartz	sd.	160	158	-0.2	-0.6	1.1
13	SAJ1	Quartz	sd.	200	196	-0.5	-0.9	1.6
14	SAJ1	Quartz	sd.	190	187	-0.5	-0.9	1.6
15	SAJ1	Quartz	sd.	186	183	-0.4	-0.8	1.4
16	SAJ1	Quartz	sd.	219	214	-0.4	-0.8	1.4
17	SAJ1	Quartz	sd.	283	274	-0.4	-0.8	1.4
18	SAJ1	Quartz	sd.	213	208	-0.4	-0.8	1.4

6.2. Gas composition of fluid inclusions

Composition of liquid and gas phases of fluid inclusions was estimated based on Raman spectroscopy method. Unfortunately, data obtained from Raman spectroscopy is controversial and needed more detailed interpretation.

6.3. Stable isotopes of quartz and carbonate

Water is proofed to be main component in the epithermal convection systems. Great number of researches on isotopic compositions of vein quartz and carbonate conclude that hydrothermal fluids responsible for formation of the majority of epithermal deposits is a mixture between gas and water with dominated role of meteoric water (O'Neil and Silberman, 1974; White, 1974; Taylor, 1974; Matsuhisa *et al.*, 1985; Faure *et al.*, 2002; Rosana and Matsueda, 2001 & 2002; Takahashi *et al.*, 2002, 2006 and 2007). Knowledge of the isotopic composition of quartz and carbonate allows us to interpret the parent source of the hydrothermal fluids and mixing with meteoric waters. Stable isotope study was applied to the Aginskoe deposit in aim to find out the isotopic composition of vein quartz and calcite.

Two samples of clear euhedral quartz and amethysts from Malysh ore body and three samples of carbonate from Aginskoe, Malysh and Valery ore bodies were analyzed for oxygen-isotope composition. Quartz $\delta^{18}\text{O}$ value of ore-stage II quartz is -3.3 ‰, and post-ore stage IV amethyst is -3.0 ‰. Table 6.3.1 shows isotopic values of quartz and calcite from the Aginskoe deposit. Calcite $\delta^{18}\text{O}$ values of post-ore stage IV calcite from Valeri, Aginskoe and Malysh ore bodies are -0.7, 1.3 and -0.6 ‰, respectively. Calcite $\delta^{13}\text{C}$ values for same samples are -3.0, -0.9 and 1.1 ‰. Isotopic

composition of H₂O was calculated using equations of Clayton *et al.* (1972) for quartz and O’Neil and Silberman (1974) for calcite.

Fluid inclusions water from 4 samples of quartz was analyzed on hydrogen-isotope composition. Ore-stage quartz of Malysh, Surprise and Aginskoe ore bodies yielded δD_{H_2O} values of -128. -105 and -128 ‰, respectively. The post ore-stage amethysts quartz has δD_{H_2O} of -99 ‰.

Table 6.3.1 Stable isotope data on quartz and calcite (‰).

Sample	Ore body	$\delta^{18}O_{\text{mineral}}$	$\delta^{13}C$	$\delta^{18}O_{H_2O}$	δD_{H_2O}
Quartz					
Q1	Malysh	-3.3	-	-8.0	-128
Q2	Malysh	-3.0	-	-10.0	-99
Q3	Surprise	-2.9	-	-5.2	-105
Q4	Aginskoe	0.9	-	-1.8	-128
Calcite					
K1	Valery	-0.7	-3.0	-	-
K2	Aginskoe	1.3	-0.9	-	-
K3	Malysh	-0.6	1.1	-	-

Chapter VII. Tellurium-bearing oxides and secondary supergene mineralization in epithermal deposits

7.1. Tellurium behavior in the hydrothermal solution: Te-bearing species and its transport in the hydrothermal solution (importance to gold deposition mechanism)

7.2. Te behavior under the oxidation conditions: formation of tellurites and tellurates under the supergene conditions

7.3. Au-Ag-Te epithermal deposits at Kamchatka

Chapter VII. Tellurium-bearing oxides and secondary supergene mineralization in epithermal deposits

Te is very rare element in the earth crust and in water; however Te is most abundant element in solar system (Bernad, 1984). Te-bearing hydrothermal deposits are major source of Te and richest class of Au in terms of gold tonnage (for example: Emperor, Fiji by Ahmad *et al.*, 1987 and Pals & Spry, 2003; Kushikino, Japan by Shiga & Urashima, 1988; Acupan and Bulawan, Philippines by Callow & Worley, 1965, Cooke & McPhail, 2001 and Maglambayan *et al.*, 2006; Tongyoung, Korea by Shelton, 1990; St. Barbara and St. Gemitrious, Greece by Voudouris *et al.*, 2006; Prasolovskoe and Ozernovskoe, Russia by So *et al.*, 1995 and Kovalenker & Plotinskaya, 2005; Kochbulak, Uzbekistan by Plotinskaya, 2006; Bilimonia, Papua New Guinea by Espi *et al.*, 2007). Although in some ores Te occurs in form of native tellurium, most frequent mode of Te occurrence is various Au-Ag-bearing and other metal-tellurides in ores. Additionally, Te may substitute Sb and As in tennantite-tetrahedrite minerals. It is noteworthy native tellurium and Te-bearing minerals are highly unstable minerals under oxidizing conditions and tend to be transformed into various new forms in the zone of weathering and oxidation at the Te-bearing deposits. This chapter is described behavior of Te in the hydrothermal solutions and in the oxidation zone.

7.1. Tellurium behavior in the hydrothermal solution: Te-bearing species and its transport in the hydrothermal solution (importance to gold deposition mechanism)

As it was mentioned above Te is rare element in the Earth's crust and there are no known Te deposits. A major source of Te is the Au-Ag epithermal deposits associating with the calc-alkaline rocks. Generally Te-bearing deposits are found in volcanic-arc setting in the Pacific Rim region. In some cases, concentration of Te in gold enriched ore-body exceeds 20,000 ppm as in the Aginskoe deposit, Kamchatka. Te occurs in form of gold-silver and lead tellurides preferentially, native tellurium and amalgams in the ore. However, a behavior of Te in the hydrothermal solution

and its initial source is still under debate. Variety of uncertainties in Au-Ag-Te system related to phase transition, similar physical properties and diversity of polymorphic phases stable under a certain temperature made these studies complicated. Experimental studies by Cabri (1965) and Esmicheva & Osadchii (2009) revealed that essential natural gold-silver tellurides undergo several inversions or phase transitions during evolving of the hydrothermal system. Additionally, Te is easy element to be oxidized. Hence, in the epithermal deposits tellurides are completely altered into tellurates.

Te belongs to same group with sulfur and selenium of the Mendeleev periodic system. On physical and chemical properties tellurium distinctly differs from sulfur and selenium. In contrast to highly mobile sulfur, which is stable in wide range of temperature and may be carried in great distance from magmatic source, tellurium is often found close to the magmatic source. Ionic radii of sulfur and selenium are almost same, subsequently Se often substitutes S in sulfides. Although, Te is from same group with S and Se, but same as rare metals as gold, silver, bismuth, mercury, platinum, and palladium has a large ionic radius consequently Te cannot replace sulfur and forms its own minerals - tellurides. Together with other rare metals with large ionic radii Te crystallized from residual fluid after all sulfides were precipitated (Telluride ores of Boulder County, Colorado, Geol. Soc. Am. Mem., 109; Watterson *et al.*, 1977).

Tellurium is found in nature in form of native tellurium, various Au-Ag tellurides and Te-bearing sulfosalts (Fig. 7.1.1.). Te may be transformed in the mineralized fluid as aqueous species and as vapor phase. Concentration of dissolved Te in hydrothermal solution is unknown; however, it may be similar to concentration of Te in rocks and water approximately 0.1, 1, and 10 ppb (Beatty and Maniel, 1973; Zhang and Spry, 1994). Twelve aqueous Te species existing in the hydrothermal fluid are established: H_2TeO_4 , HTeO_4^- , TeO_4^{2-} , Te^{4+} , HTeO_2^+ , H_2TeO_3 , HTeO_3^- , TeO_3^{2-} , Te_2^{2-} , H_2Te , HTe^- and Te^2 . Species H_2TeO_4 , HTeO_4^- and TeO_4^{2-} are stable only at very high Eh conditions, and Te^{4+} under acid conditions ($\text{pH} < 0$). Species HTeO_2^+ , H_2TeO_3 , HTeO_3^- , TeO_3^{2-} are unstable. Therefore, the main carriers of Te in the fluid of near neutral are HTe^- , Te_2^{2-} and HTeO_3^- . Te_2^{2-} became dominant with increasing of ΣTe and decreasing of temperature. HTeO_3^- is dominant in highly

oxidized fluid, HTe^- in the reduced fluid. Native tellurium is stable in hydrothermal solution upon condition same as for Te_2^{2-} by increasing of ΣTe and

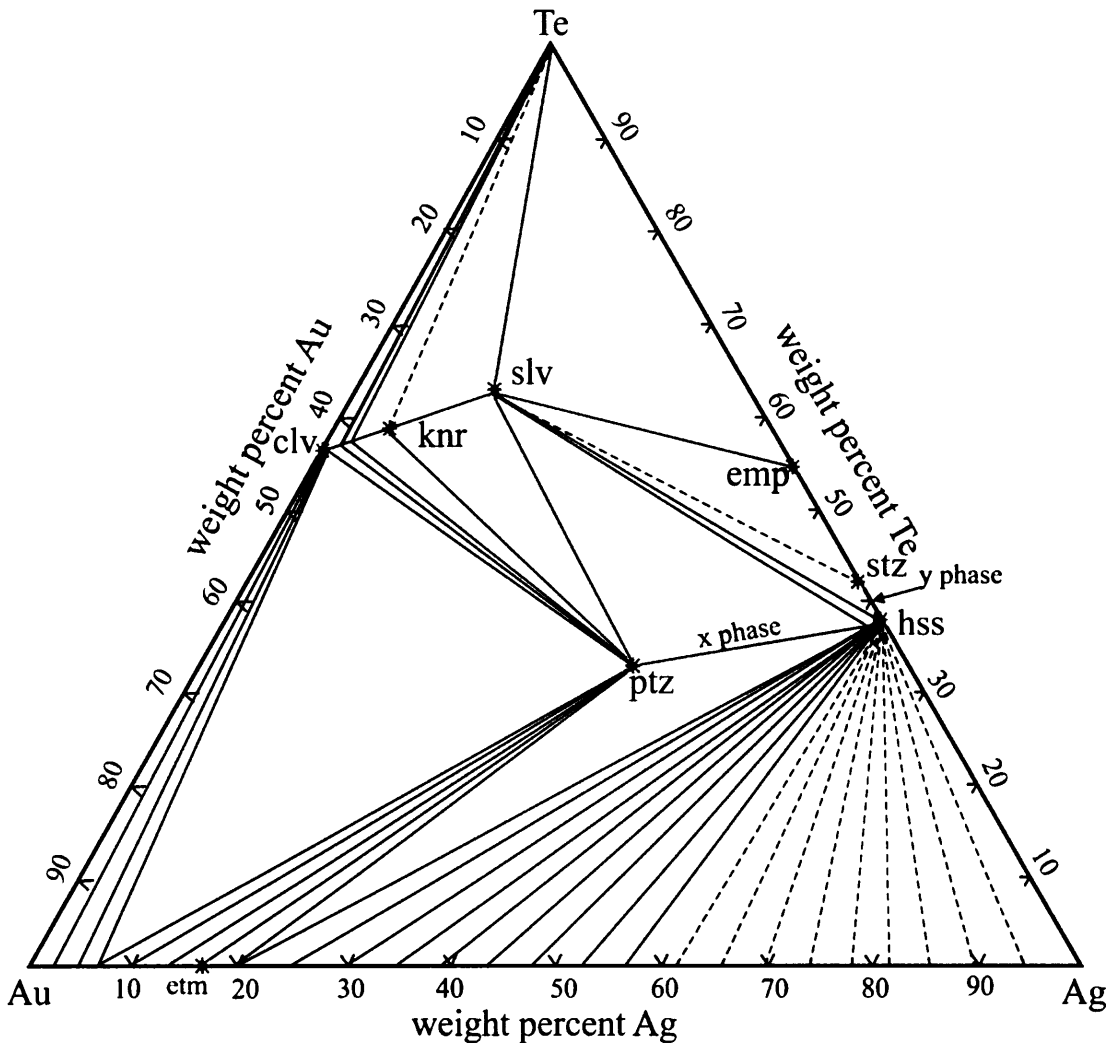


Fig.7.1.1. Ternary Au-Ag-Te diagram showing the phase relationships between Au-Ag tellurides.

temperature drops (Zhang and Spry, 1994). Stability diagrams of aqueous tellurium species and native tellurium in the hydrothermal solution could be found in Zhang and Spry, 1994.

There are fifteen known minerals in Au-Ag-Te system: native gold, native silver, native tellurium, electrum, sylvanite, petzite, calaverite, krennerite, hessite, stuetzite, empressite, muthmannite, γ phase of composition of $\text{Ag}_{1.9}\text{Te}$, a solid solution of hessite and petzite named as x phase. Muthmannite is rarely presented in natural assemblages. Phase γ and x are existed under high-temperature, and usually break down with temperature drop with formation of hessite, petzite and sylvanite.

To form Au-Ag tellurides in quartz veins Te is could be probably carried as $\text{Au}(\text{Te}_2)^-$, $\text{Au}_2(\text{Te}^{2-})^\circ$ and $\text{Au}(\text{Te}_2)_2$, although, the existing of these species are speculated.

AuCl_2^- , $\text{HAu}(\text{HS})_2^\circ$ and $\text{Au}(\text{HS})_2^-$ and AgCl_2^- and $\text{Ag}(\text{HS})_2^-$ are main Au-Ag carriers in the hydrothermal solution. Calaverite and hessite are most common and representative Au- and Ag-bearing minerals in the ores of epithermal deposits. Zhang and Spry (1994) claimed that Au in calaverite is derived from $\text{HAu}(\text{HS})_2^\circ$ and $\text{Au}(\text{HS})_2^-$ and stability of calaverite depends on variation of $f\text{O}_2$, while pH is not important factor. Increasing of $f\text{O}_2$ caused precipitation of calaverite (Fig. 2&3 in Zhang and Spry, 1994). Hessite is main Ag-bearing telluride widely occurring in the epithermal veins. Stability of hessite is much more depends on temperature, than on ΣS and ΣTe in alkaline fluid with high $f\text{O}_2$.

7.2. Te behavior under the oxidation condition: formation of tellurites and tellurates under the supergene conditions

Te is highly unstable element under the oxidation, thus, Te-bearing precious metal ores are easily oxidized in the supergene conditions. Though tellurites and tellurates are occurred in almost each Te-bearing deposit, however, mineralogical studies of them are strictly limited. Twenty seven identified tellurites and tellurates are listed in Table 7.2.1 (Yakhontova and Zverev, 2000). However, enormous numbers of secondary tellurides are still remained as unknown phases, in consideration of the reports from the epithermal deposits of Japan (the Teine mine), Australia (Kalgoorlie), Mexico (Moctezuma), Kazakhstan (Kochbulak, Jana-Tube) and Far East of Russia (Pionerskoe, Aginskoe). Tellurites are much more abundant than tellurates.

Experimental studies conducted on the behavior of Te under the hydrothermal conditions coupled with mineralogical investigation of natural tellurides showed that Te-bearing minerals are highly unstable during deposition and tend to be dissolved and break down and eventually replaced by gold or some sorts of secondary minerals. In the weathering zone under the near-surface conditions a mustard gold is formed due to intensive leaching of Te from gold tellurides. A mustard gold is gold characterized by porosity surface. In the oxidation zone primary tellurides break

down with formation of tellurites and tellurates (Zhao *et al.*, 2009). Nekrasov (1991), Spiridonov (2010 & 2011) and Okrugin (pers. comm.) argued that Au-Ag tellurides such as kostovite, krennerite, sylvanite, altaite are altered into supergene minerals in the weathering zone of some epithermal deposits in Kamchatka. They are mainly composed of Au, Cu, Fe, Ag, Te, Pb and trace amounts of Sb and Bi. Only some of them were identified as bilibinskite ($\text{Au}_3\text{Cu}_2\text{PbTe}_2$), bogdanovite ($\text{Au}_5(\text{Cu,Fe})_3(\text{Te, Pb})_2$) and bessmertnovite ($\text{Au}_4\text{Cu}(\text{Te, Pb})$) in the Aginskoe deposit by Spiridonov in 1980. Bogdanovite has three varieties: Cu-rich, Fe-rich and Cu-Fe intermediate (Spiridonov, 1981). Nekrasov & Okrugin (1991, 2001) also reported that gold oxides are common gold-bearing phases in the deposit.

7.3. Au-Ag-Te epithermal deposits at Kamchatka

Au-Ag-Te epithermal deposits are known in the Central Kamchatka volcanic belt. A great number of these deposits are located in the southern portion of the volcanic belt within the Central Kamchatka mining district. The Aginskoe is one of the representative Au-Ag-Te lodes in the district. Epithermal ores of the Aginskoe deposit are not exposed, but strongly oxidized down to 150-200 m below present surface. The oxidized gold-silver tellurides and rare intermetallic compounds are widely distributed in ores. The intermetallic compounds are bilibinskite, bessmertnovite and bogdanovite.

Table 7.2.1 Tellurite and tellurate identified (after Yakhontova and Zverev, 2000).

Pb, Cu, Zn, Bi	
<i>Mineral</i>	<i>Chemical formula</i>
Plumbotellurite (rhomb.)	$\text{Pb}[\text{TeO}_3]$
Fairbankite	$\text{Pb}[\text{TeO}_3]$
Balyakinite	$\text{Cu}[\text{TeO}_3]$
Graemite	$\text{Cu}[\text{TeO}_3] \cdot \text{H}_2\text{O}$
Choloalite	$\text{CuPb}[\text{TeO}_3]_2$
Quetzalcoatlite	$\text{Cu}_4\text{Zn}_8[\text{TeO}_3]_3(\text{OH})_{18}$
Cesbronite	$\text{Cu}_5[\text{TeO}_3]_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
Teineite	$\text{Cu}[\text{TeO}_3] \cdot 2\text{H}_2\text{O}$
Xocomecatlite	$\text{Cu}_3[\text{TeO}_4](\text{OH})_4$
Khinit	$\text{Cu}_3\text{Pb}[\text{TeO}_4](\text{OH})_6$
Parakhinite	$\text{Cu}_3\text{Pb}[\text{TeO}_4](\text{OH})_2$
Kuranakhite	PbMnTeO_6
Smirnite	$\text{Bi}_2[\text{TeO}_4]\text{O}$
Montanite	$\text{Bi}[\text{TeO}_4]\text{O}_2 \cdot 2\text{H}_2\text{O}$
Oboyerite	$\text{H}_6\text{Pb}_6[\text{TeO}_3]_3[\text{TeO}_6] \cdot 2\text{H}_2\text{O}$
Tlapallite	$\text{H}_6(\text{Ca,Pb})_2(\text{Cu,Zn})_3(\text{SO}_4)(\text{TeO}_3)_4(\text{TeO}_6)$
Tlalcite	$(\text{Cu,Zn})_{16}[\text{TeO}_3][\text{TeO}_4]_2 \text{Cl}(\text{OH})_{25} \cdot 27\text{H}_2\text{O}$
Fe, Mn, Ca	
<i>Mineral</i>	<i>Chemical formula</i>
Denningite	$(\text{Mn,Zn})[\text{Te}_2\text{O}_5]$
Emmonsite	$\text{Fe}_2^{3+}[\text{TeO}_3]_3 \cdot 2\text{H}_2\text{O}$
Mackayite	$\text{Fe}_2^{3+}[\text{TeO}_3]_3 \cdot 2\text{H}_2\text{O}$
Kinichilite	$\text{Mg}_{0.5}[\text{MnFe}(\text{TeO}_3)_3] \cdot 4.5\text{H}_2\text{O}$
Sonoraite	$\text{Fe}^{3+}[\text{TeO}_3](\text{OH}) \cdot \text{H}_2\text{O}$
Poughite	$\text{Fe}_2^{3+}[\text{TeO}_3]_2(\text{SO}_4) \cdot 3\text{H}_2\text{O}$
Rodalquilarite	$\text{H}_3\text{Fe}_2^{3+}[\text{TeO}_3]_4\text{Cl}$
Cuzticite	$\text{Fe}_2^{3+}[\text{TeO}_4]\text{O}_2 \cdot 3\text{H}_2\text{O}$
Carlfriesite	$\text{CaTe}_2\text{TeO}_8$
Mroseite	$\text{Ca}[\text{TeO}_2](\text{CO}_3)$

Chapter VIII. The cycling of historical glaciuous periods in Kamchatka and affects on the deposits

8.1. The glacial periods in Kamchatka

8.2. Affects of glacier cover on the certain deposits

Chapter VIII. The cycling of historical gracious periods in Kamchatka and affects on the deposits

In Pleistocene several periods of glaciations on the Earth are recognized. Glaciations was originated in early Pleistocene time approximately 2 Ma ago and continued untill Late Pleistocene. Glacial periods were changed in time with short-lived interglacial cycles. The main reasons of glaciations are continental positions, oceanic circulation, solar-energy fluctuations, global climate change, and the fluctuation of the Earth's orbital parameters. In Pleistocene main four glacial and three interglacial periods are known. During last glacial period large portion of Europe, North and South America, and partially Asia were completely glaciated. In this chapter glaciations in Kamchatka and relation to the ore mineralization will be discussed.

8.1. The glacial periods in Kamchatka

Exact number of glaciations in Kamchatka is not concluded yet. Data on glaciations history is random and dated to the past century. Bogdanovich I.K. was one of first researchers, who described glaciations relief in Kamchatka in 1904 (Braitseva *et al.*, 1968). However, systematic investigation of ice sheet was begun in late 30s.

Climate and tectonic are the main factors influenced on developing of the glacial cover in Kamchatka. Climate change was significant in Quarternary time. Field data support the idea of three epochs of cooling in Early, Middle and Late Pleistocene time. However, glaciations were formed only in middle and late Pleistocene time. Although ice sheet was existed on the entire Kamchatka, present absence of moraines in south Kamchatka was explained by the post-glaciations volcanic activities in this area (Braitseva *et al.*, 1968).

Early Pleistocene glaciers are not preserved in Kamchatka region. Middle Pleistocene is characterized by uplifts of Central Kamchatka, Valaginskogo, South-Bystrinsko, Kumroch, Tumrock and others mountain ranges. Thus, first stage of glacial advancing has begun. Therefore most significant glaciation has happened in

Late Pleistocene time. There are two stage of ice advancing separating by interglacial cycles. Ice drifting of the first glacial period (or phase) is not well preserved. Commonly glacial depositions are washed out and found as isolated fragments. Main area of ice developing was Central Mountain Range, Eastern and Southern Kamchatka. In the Central Kamchatka volcanic belt ice started to form at elevation of about 600-900 m, while in Eastern and Southern Kamchatka at elevation of 300-500 m. Elevation of the snowline was depended on amount of atmospheric precipitation. Earlier ice sheet was largest covering almost all of peninsular part and mainland (Bigg *et al.*, 2008; Stauch and Cialtieri, 2008). Reconstruction of ice shield based on the occurrence of marine shows that the ice was extending to the coastline reaching the ocean in many places (Fig. 8.1.1.). In contrast evidences of second stage of glaciation are widespread in Kamchatka. The icefield was a mountain limited of the Central Kamchatka volcanic belt basically. Only in few places ice was reached a coastline (Bigg *et al.*, 2008). Central Kamchatka depression zone and western lowland were free of ice in the second stage of glaciation. Length of ice sheet was generally varying from 20 to 30 km. In Central Kamchatka volcanic belt ice was extending up to 80-100 km.

Presently around 414 glaciers with different size and elevation of about 1500-1200 m are existed in Kamchatka. However, small-scale ice sheets are predominant. Most of glaciers are preserved in the Alnei-Chashakondja region in the central area of the Central Kamchatka volcanic belt (Braitseva *et al.*, 1968).

8.2. Affects of glacier cover on the certain deposits

Glaciation occurring through late Pleistocene time may have a significant effect on the certain type of gold deposits, which have been formed prior to Pleistocene time. The Central Kamchatka Range was completely covered by ice of about 400-500 m in thickness. All precious metal deposits were formed from early Miocene to Pliocene in the Central Kamchatka volcanic belt. Aginskoe deposit located in the central of the belt was occurred in Late Miocene prior to Late Pleistocene glaciation. It was also covered by the tons of ice during Pleistocene glaciation. Ice melting produced large value of water, which instantly penetrates

well-fractured volcanic rocks and reached quartz-adularia veins. Author argues that this water bearing O was a main factor of Te oxidation in the ores and formation of Au-enrichment zone. Despite the snowy winter, exotic minerals observed in the ores of Aginskoe deposit with numerous not yet identified phases, requires constantly long-term oxidation conditions, which may happen in consequence of glaciation.

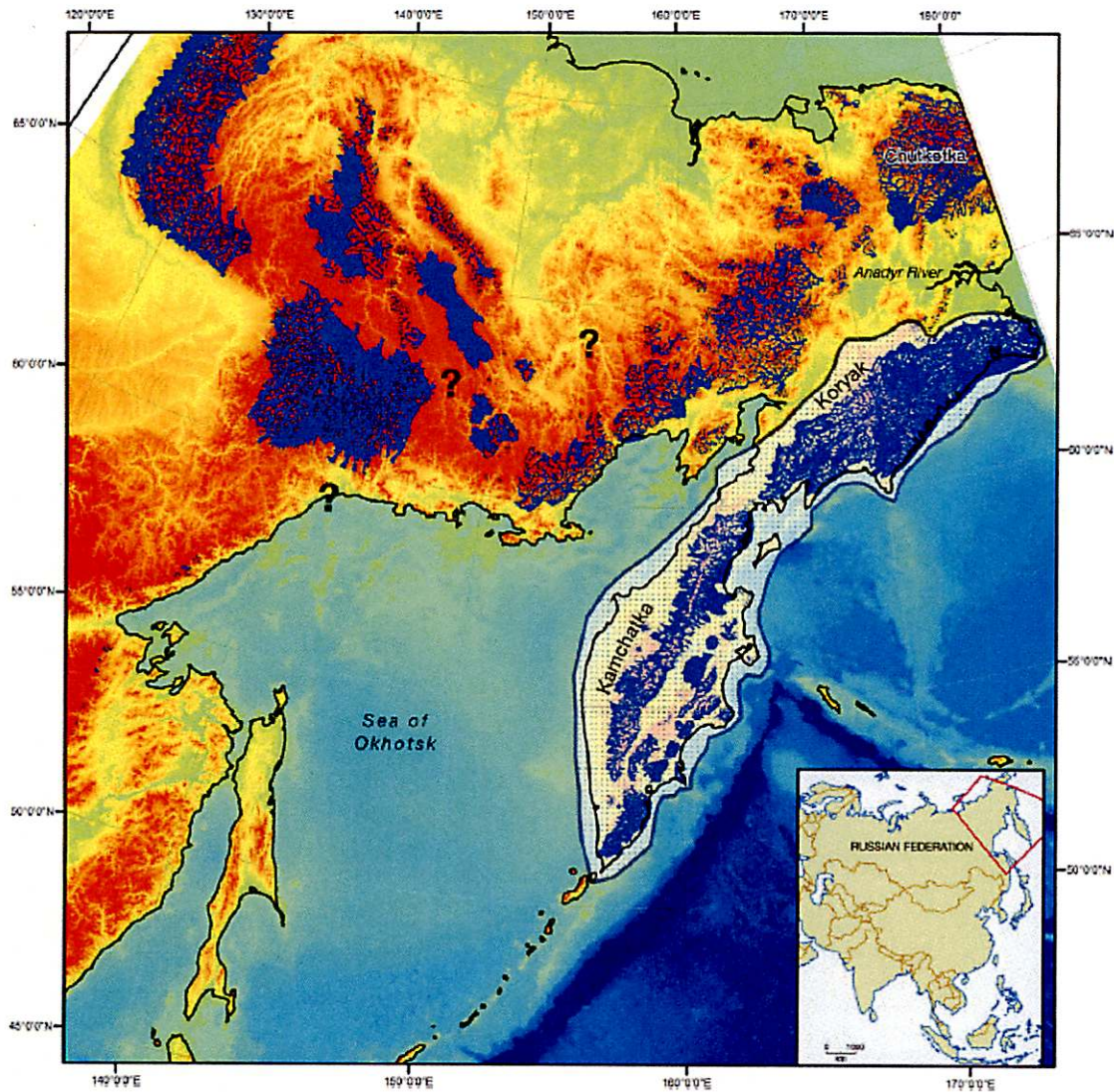


Fig.8.1.1. A map showing distribution of ice in Late Pleistocene time. Deep blue color indicates an area with intensive glaciation. A thick line surrounded Kamchaka showing the ice cover. A map is adopted from Bigg *et al.*, 2008.

Chapter IX. Discussions on source and physicochemical environment of Au-Ag-Te Aginskoe deposit

- 9.1. Source of hydrothermal fluids
- 9.2. Boiling and mixing of hydrothermal fluids
- 9.3. The physicochemical environment
- 9.4. Origin of Te-enriched veins

Chapter IX. Discussion on source and physicochemical environment of Au-Ag-Te Aginskoe deposit.

The deposition of quartz veins hosting various minerals is caused by the constancy or abrupt changes of such basic hydrothermal system parameters as T, pressure, pH, f_{S_2} , f_{O_2} , and f_{Te_2} are used to characterize the ore-forming environment, entire. These parameters were calculated from mineralogical, geochemical, fluid-inclusions and stable isotopes studies for Aginskoe Au-Ag-Te deposit. Definitions of the above mentioned characteristics help to classify Aginskoe deposit as LS epithermal class veins. Additionally, the consideration on type of deposit, gold and tellurium carriers in Aginskoe vein fluids is also discussed.

9.1. Source of hydrothermal fluids

Epithermal veins of LS and HS type deposits are originated from convection fluids circulated near magmatic source or in distinct distance from the original source (Hedenquist and White, 1991). Veins system of Aginskoe deposit is occurred on the north-eastern slope of the volcanic caldera in vicinity of intrusion body of gabbro-diorite. Contact of quartz veins and intrusions were not observed in this study due to poor outcropping of the intrusive body.

Fluid inclusions study show significant variation of the fluids temperatures and slightly variation in salinity. Te-rich veins of Aginskoe deposit have been deposited from the hydrothermal fluids of average temperature of 250-260 °C and salinity around 1-2 wt% NaCl equiv. (Figs. 6.1.1. and 6.1.2.). Salinity is extremely low and consistent for all of measured inclusions and typical for meteoric water-enriched hydrothermal fluids. Temperature range and salinity is typical for many of epithermal system occurring in the Pacific region. The Aginskoe deposit show similar characteristics of typical LS precious metal deposits in Pacific Region such as Hishikari, Kushikino and Teine in Japan, Acupan in Phillipines and Emperor in Fiji. Those deposits were formed from dilute hydrothermal fluids of low salinity (0-3 wt% NaCl equiv.) and moderate to low temperature (150-300 °C).

Styles of alteration zones and presence of adularia in ores indicate that fluids were neutral reduced and dilute. Fluid pH has been changed in time from slightly alkaline to neutral conditions. Quartz shows diversity of texture with dominant colloform, mosaic, ghost-sphere and pseudo-acicular (Fig. 5.4.1.). Colloform and moss texture is formed from recrystallization of the initial silica gel. Pseudo-acicular texture frequently observed in ores indicates the replacement of the initial carbonate by adularia and quartz as the deposition proceeds further (Dong *et al.*, 1995).

9.2. Boiling and mixing of hydrothermal fluids

Hydrothermal solution circulated in the shallow depth is suffering from high temperature and pressure eventually boils with rapid precipitation of vein and ore minerals. The boiling phenomenon is confirmed on many of epithermal deposits. Presence of coexisting vapor-rich and liquid-rich inclusions and homogenization temperatures of fluid inclusions are important indicators of boiling. However, absolutely absence of vapor-rich inclusions is not a criterion of absence of the boiling phenomena in formation process.

Aginskoe vein fluids were boiled. Fluid inclusions study show co-existing of Type I (liquid-rich) and Type II (gas-rich) and wide range of homogenization temperature (200-300 °C) over narrow range of salinity are main factors suggesting boiling phenomena in ore stage II. The trends observed on diagrams of salinity versus homogenization temperatures is also indicate boiling of hydrothermal fluids (Figs. 6.1.2. and 6.1.4.). Fluid inclusions are mostly aqueous with trace amount of CO₂. Loss of CO₂ also supports boiling. Further evidence of hydrothermal boiling is presence of abundant adularia in ores. Dendritic textures of veins minerals growing along adularia crystals indicate rapid precipitation of minerals from boiling fluids. Minor evidence of boiling is ubiquitous of breccias in ores. Unfortunately in this study bladed calcite as a major indicator of boiling in epithermal environment were not found in Aginskoe veins. But recrystallization texture of quartz serves as the evidence of the presence of igneous granular calcite in ores, precipitation under the boiling conditions (Fig. 5.4.1.). As fluid rapidly boils at the depths rhombic shape adularia is occurred. Continuously boiled fluids than deposited granular calcite, which is replaced in-site by adularia and quartz.

Preserved granular carbonate was not observed in ores, however, replacement texture of acicular adularia, associating with assemblages of native gold-calaverite of sub-stage 1-3 of Stage II suggest existing of carbonate. Additionally, precursor of silica gel and chalcedony intergrown with assemblages of altaite-hessite-sphalerite of sub-stage 9 of Stage II supports a boiling. Thus, boiling has occurred throughout Stage II and responsible for deposition of vein materials.

Stable isotope data show light isotopic composition of O and H. Mixing of Aginskoe fluids is written from stable isotope data. Isotopic composition of quartz and fluid is close to the meteoric water line suggesting that the fluids are circulating meteoric waters well reacted with host rocks in origin (Fig. 9.2.1).

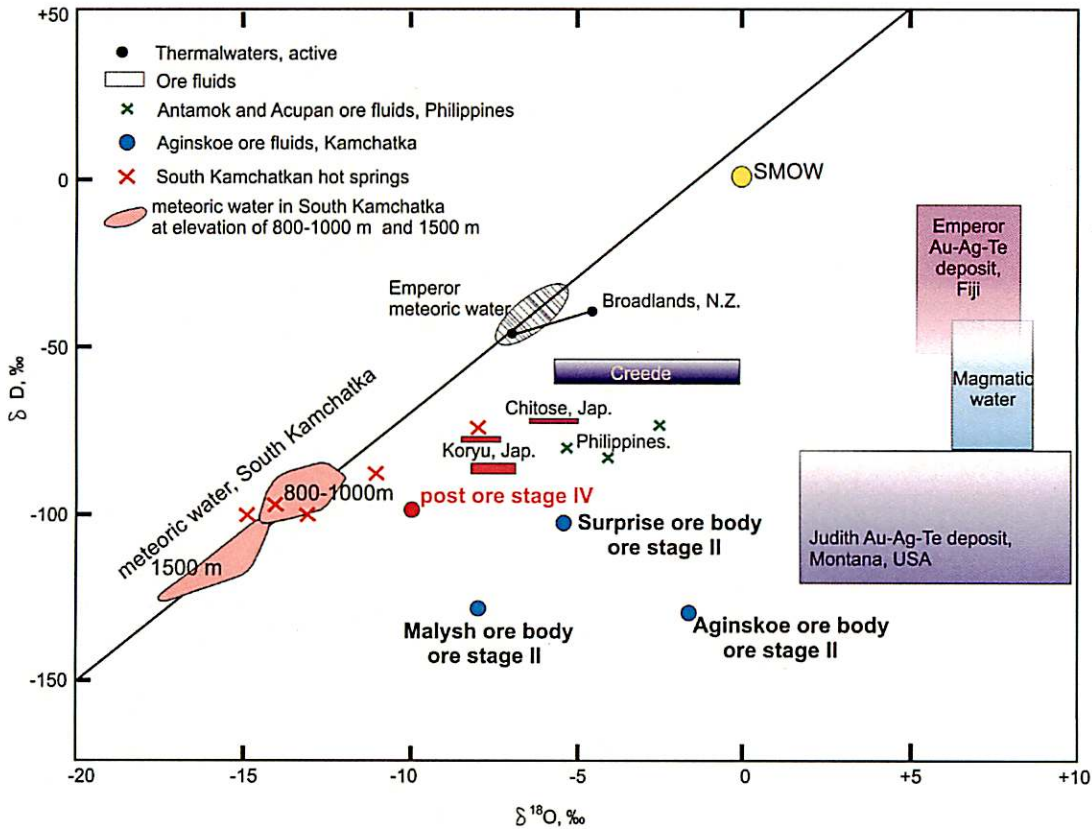


Fig.9.2.1. Isotopic composition of hydrothermal water of Aginskoe epithermal deposit in relationship to the meteoric water line. Isotopic value of H was measured directly from the fluid inclusions. Value of O was calculated using the homogenization temperature of fluid inclusions ($T=250\text{ }^{\circ}\text{C}$). Isotopic composition of present meteoric water in South Kamchatka is taken from Okrugin and Zelensky, 1997.

Data on the isotopic composition of water of Koryu and Chitose deposits in Japan, Philippines deposits, Judith deposit in USA, Emperor in Fiji and Broadlands in New Zealand is taken from Shimizu and *et al.*, 1998; Ahmad *et al.*, 1987; White, 1974.

9.3. The physicochemical environment

Wide development of exotic secondary minerals in the ores complicates the interpretation of the geochemical environment of the ore deposition. Values of $f\text{Te}_2$ and $f\text{S}_2$ were attempted to be estimated based on the remaining primary minerals and the remnants of hypogene tellurides.

The diagram of $f\text{Te}_2$ vs. $f\text{S}_2$ was constructed based on mineral assemblages for the early gold-silver-telluride and the later silver-telluride-sulfide associations with mean of fluids temperatures equal to 250 °C (Fig. 9.3.1.). The thermodynamic data for tellurides and Ag sulfides was referred from Afifi *et al.* (1988a) and Barton & Toulmin (1964). Native gold was co-genetically deposited with Au-rich tellurides such as calaverite, krennerite, sylvanite and petzite at value of $f\text{Te}_2 < -9$ (Fig. 9.3.1.). Subsequent precipitation of hessite, altaite, petzite and sphalerite with total absence of native gold or any of Au-rich tellurides indicate decrease of $f\text{Te}_2$ in mineralized fluids toward to the hessite-acanthite reaction line (Fig. 9.3.1.). Although Surprise vein display individual specific characteristics, mineral paragenesis also show decreasing of $f\text{Te}_2$ during the ore formation. Abrupt decreasing of $f\text{Te}_2$ is a typical characteristic of the Te-bearing deposits (Afifi *et al.*, 1988b), was also confirmed in the Aginskoe mine.

Sulfidation state is the most important characteristic in the hydrothermal systems used for classification of oxidation types of the gold deposits based on mineral assemblages in the ore (Einaudi *et al.*, 2003). Unfortunately, in this study no any representative sulfide minerals available for the estimation of $\log f\text{S}_2$ value were found. Sulfur fugacity has been roughly defined from the stability diagram of telluride and sulfide minerals (Fig. 9.3.1.). Based on rare occurrence of pyrite and FeS content of sphalerite, $\log f\text{S}_2$ range from approximately -13 in sub-stages 1, 2, 3 to -10.8 in the sub-stage 9.

Generally, Au-Ag-Te deposits are referred to high-sulfidation and/or intermediate sulfidation state type of deposits with source regarded to be magmatic in origin. Aginskoe deposit with Te content up to 20,000 ppm is classified as an epithermal low-sulfidation state deposit based on the alteration mineralogy and vein minerals assemblages. Wall-rock alteration zones consist of quartz, chlorite, smectite, kaolinite, adularia, sericite and albite are narrowly developed next to the quartz veins as

typical for the LS environment. Abundant presence of adularia in ores along with low-sulfidation state minerals and lacking vuggy texture suggests a near-neutral pH conditions.

The known examples of Te-bearing epithermal systems record that tellurides were deposited prior or simultaneously with gold. Aginskoe deposit is not exception that could be read from table of the mineralization stages (Fig. 4.3.1.1.). Among nine well known gold-silver-bearing tellurides three abundant calaverite, petzite, hessite are indentified in Aginskoe mine. Presumably sylvanite and krennerite are also common ore minerals, but they could have been broken down in the weathering zone. Au-bearing tellurides such as calaverite and petzite are predominant in Aginskaya vein; however they are not associated with Au free tellurides such as altaite and hessite. Common mineral assemblages observed in Surprise vein include gold, petzite, altaite and petzite. Although present study shows primitive ore mineral assemblages, previous investigators reported the occurrences of tetradyte ($\text{Bi}_2\text{Te}_2\text{S}$), coloradoite (HgTe), pearceite, bornite, idaite, marcasite and cinnabar (Andrusenko & Shchepot'yev, 1974), otherwise Se-bearing galena, krennerite, sylvanite, native tellurium (Nekrasov, 1991) in Aginskoe deposit.

The ternary diagrams shown in fig. 9.3.2. display synthetic assemblages of tellurides and its relationship in Au-Ag-Te system (a), natural telluride assemblages observed in Te-bearing deposits from the circum-Pacific region (b) and telluride assemblages observed in ore samples from Aginskoe deposit in this study (c). As it is shown on the ternary diagram, natural tellurides generally coincides in chemical compositions with synthetic tellurides and almost constant in various deposits. However, sylvanite at the Emperor deposit displays unusual high Ag content (Ag range 6.28 – 13.45 wt% by Pals and Spry, 2003). The Ag content detected in calaverite from Aginskoe mine is close to that determined by Cabry (1965), basically ranging from 0.3 to 1.3 wt%. Most of Au-bearing tellurides are predominant in Bluzdayushee ore body of upper level in Aginskaya vein, while Surprise vein contains Au principally in form of native gold since almost all gold-silver tellurides presumably have been decomposed. Ag-rich tellurides show variable occurrence in both Aginskoe and Surprise ore bodies (Fig. 9.3.2.).

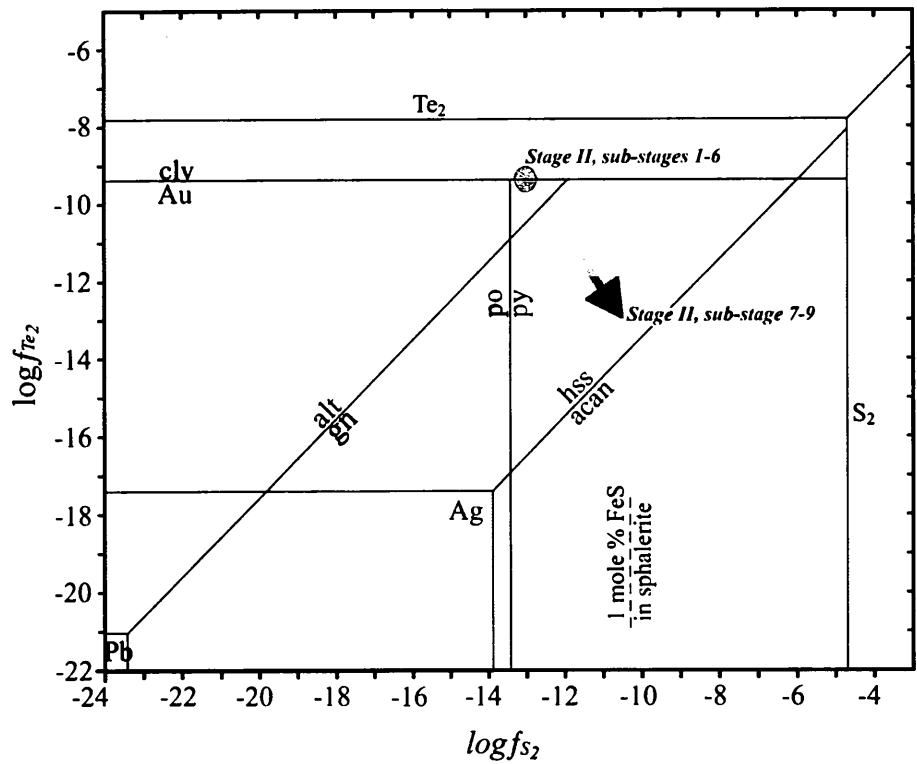


Fig.9.3.1. Estimated $\log f_{\text{Te}_2}$ vs. $\log f_{\text{S}_2}$ conditions for the Aginskoe deposit based on the mineral assemblages and FeS content in sphalerite. A black arrow indicates shifting f_{Te_2} from the sub-stage 1-6 to sub-stages 7- 9. Equilibria were calculated at 250 °C using data listed in Afifi *et al.* (1988a, b).

Abbreviations; clv: calaverite, Au: gold, hss: hessite, acan: acantite, po: pyrrhotine, py: pyrite, alt: altaite, gn: galena.

9.4. Origin of Te-enriched veins

Abundant Te mineralization occurred in the Au-Ag deposits are also recognized fater in the north Kamchatka Peninsula. Ametistovoe and Ozernovskoe precious metal deposits hosting Te mineralization is accompanied by abundant sulfide occurrence in Ametistovoe and Se mineralization in Ozernovskoe, respectively. However, paucity of published papers and the absence of detailed geochemical and mineralogical information do not allow making a compative study with Aginskoe deposit. Beside Aginskoe mine, Te-bearing Au-Ag deposits are mapped in the north and south areas of the Central Kamchatka mining district. There is a little geochemical information of those deposits is present.

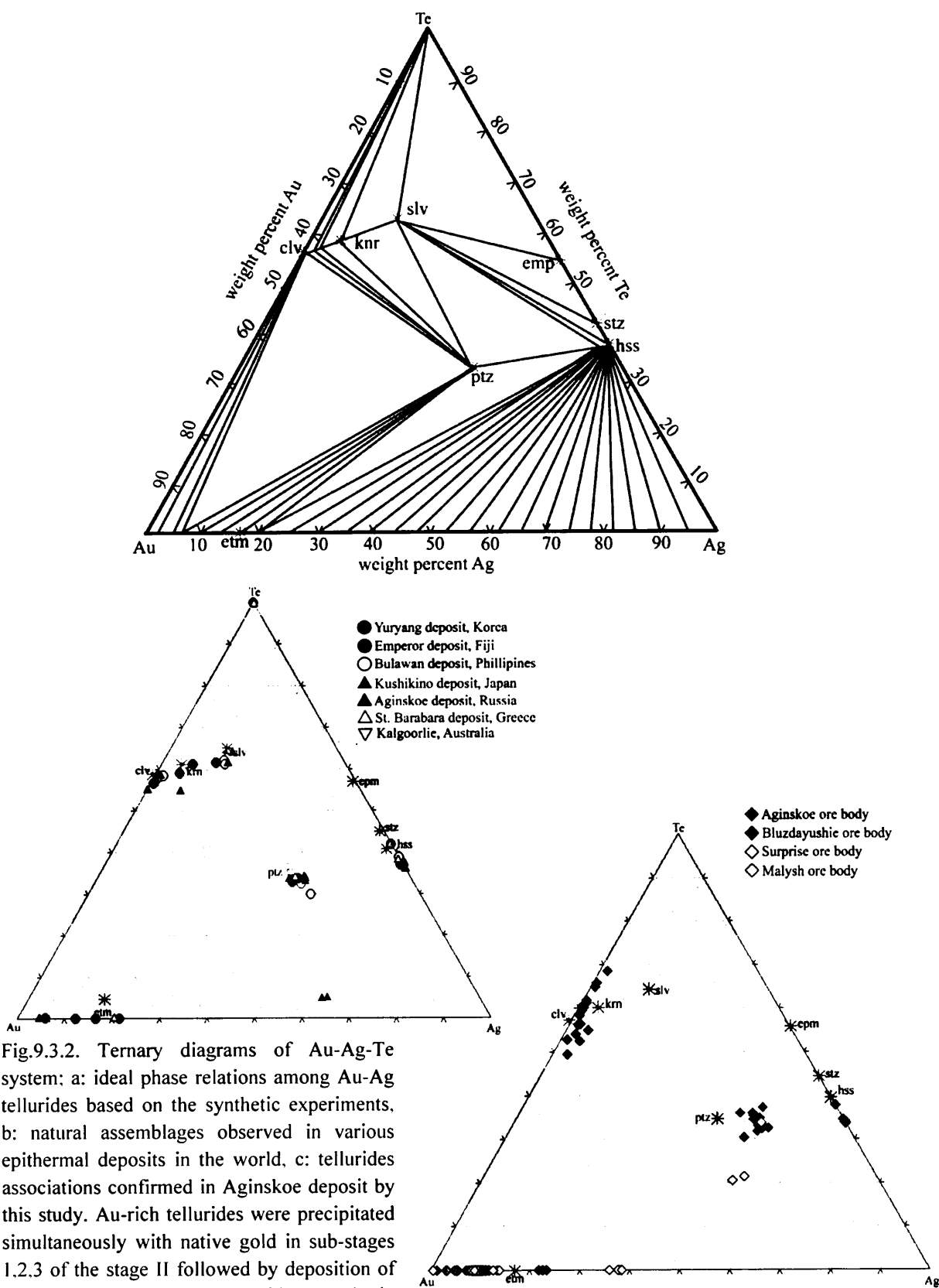


Fig.9.3.2. Ternary diagrams of Au-Ag-Te system; a: ideal phase relations among Au-Ag tellurides based on the synthetic experiments, b: natural assemblages observed in various epithermal deposits in the world, c: tellurides associations confirmed in Aginskoe deposit by this study. Au-rich tellurides were precipitated simultaneously with native gold in sub-stages 1,2,3 of the stage II followed by deposition of Ag-bearing and Au-free tellurides mostly in sub-stage 9 of the stage II. Diagrams are plotted in wt%.

Abbreviations: clv: calaverite, knr: krennerite, slv: sylvanite. emp: empressite, stz: stuzite, hss: hessite. ptz: petzite, etm: electrum.

Chapter X. Gold-silver epithermal mineralization at the Balkhach volcanic-tectonic structure

10.1. Exploration and investigation history

10.2. Geology of the Balkhach volcanic-tectonic structure

10.3. Magmatic units and major faults

10.4. Vein systems of precious metals deposits at the Balkhach ore cluster

10.4.1. Ore occurrence

10.4.2. Age of ore mineralization

Chapter X. Gold-silver epithermal mineralization at the Balkhach volcanic-tectonic structure

The Balkhach volcanic-tectonic structure is mapped on the south-eastern area of the Central Kamchatka mining district in approximately 40 km to the south-east from the Aginskoe Au-Ag-Te deposit. The occurrence of gold mineralization within the Balkhach structure was defined during the geological survey in 1964. Since that time this area has been investigated by prospecting and preliminary exploration geological hard heading works. Eventually, several economically significant and range of non economically attractive deposits and ore manifestations were mapped. Recently, alluvial gold had been discovered at Baranevskoe and Kungurcevskoe deposits. The precious metals deposits are basically of gold-silver type with high Au/Ag ratio. The deposits are currently being explored with future mining planned in the incoming years. Age of precious mineralization various from Paleocene occurring along outer fault to Pliocene-Pleistocene in center of structure. Precious mineralization is coherent with main igneous periods.

10.1. Exploration and investigation history

In this area first gold occurrence was discovered during the geological mapping in 1964 (Novoselov, 1964). Ten years later the outcropping of gold-bearing quartz veins with Au grade of 53.1 ppm were mapped at area of present Kungurcevskoe deposit (German, 1975). Trenching and sampling of exploration works in 1975-1976 have resulted in the finding of 10 gold-bearing quartz veins. In early 80s years geological works on the estimation of probable and potential resources of deposits have been begun. High economic potential of the deposits are forced to continue more detailed exploration works in 1986-1988.

In 1991-1994 four deposits with perspective economic reserves were mapped within the Balkhach volcanic-tectonic structure. They are Baranevskoe, Zolotoe, Kungurcevskoe and Uglovoe Au-Ag deposits.

Mineralogy of veins and alteration zones were studied by Okrugin V.M. and Stepanovym I.I. in 1985-1989 in the Institution of Volcanology and Seismology, Kamchatka.

Since Soviet Union was dissolved the rights on the exploration and the mining is owned by the Zoloto Kamchatki Mining Company. In 2002 Company provided exploration works on the deluvium gold distributed at Baranevskoe deposit and Kungurcevskoe deposit.

10.2. Geology of the Balkhach volcanic-tectonic structure

The Balkhach volcanic-tectonic structure is mapped on the south-eastern area of the Central Kamchatka mining district in around 40 km away from the Aginskoe deposit (Fig. 1.2.). It is a round-shaped tectonic block cut off by external ring faults (Fig. 10.2.1.). The Au mineralization is basically occurred inside volcanic calderas formed in different geological time. In early Miocene along outer ring fault series of volcanoes have been occurred. Volcanic activities continued for short time and by the Late Miocene those volcanoes were half eroded. In place where those volcanoes were existed the subvolcanic bodies and the intrusive rocks of dacite and andesite are cropped out. Most significant and economically important gold-silver mineralization (Zolotoe and Kungurcevskoe deposits and Uglovoe ore manifestation) is occurred within volcanoes at the southern fault border (Fig. 10.2.1.). In Late Miocene time Balkhach volcano has appeared in the central part of structure. The devastation of the magmatic chamber led to the collapsing of the volcano with a formation of a caldera (Fig. 10.2.1.). The third significant Au deposit Baranevskoe is occurred within Late Miocene Balkhach volcano occupying a central part of the ore cluster. Despite several other gold-bearing ore manifestations, occurring within the Balkhach volcanic-tectonic structure, the economically interesting are only Baranevskoe, Zolotoe and Kungurcevskoe deposits along with Uglovoe ore manifestation. To this reason they are grouped into the Balkhach ore cluster with total area of 150 km².

In the lithography following volcanic rocks sequence are recognized: the Upper Cretaceous Iruneiskaya Formation, the Middle Miocene Kimitinsky Complex, the Upper Miocene-Lower Pliocene Kakhtunsky Complex, the Upper Pliocene Kreruksky Complex and Quarternary glacial and alluvial sediments.

The Iruneiskaya Formation of Cretaceous is the oldest rocks at the deposit, composing the basement of Central Kamchatka mining district. Within the Balkhach volcanic-tectonic structure the Iruneiskaya Formation is recognized at the basement of the Balkhach volcano. Outcrops of these rocks are mapped in the southern area of the volcanic-tectonic structure at Zolotoe and Kungurcevskoe Au-Ag deposits and Uglovoe ore manifestation (Fig. 10.2.2.). Contacts with underlying rocks with the Iruneskaya Formation rocks masses are not indentified yet. The Iruneiskaya

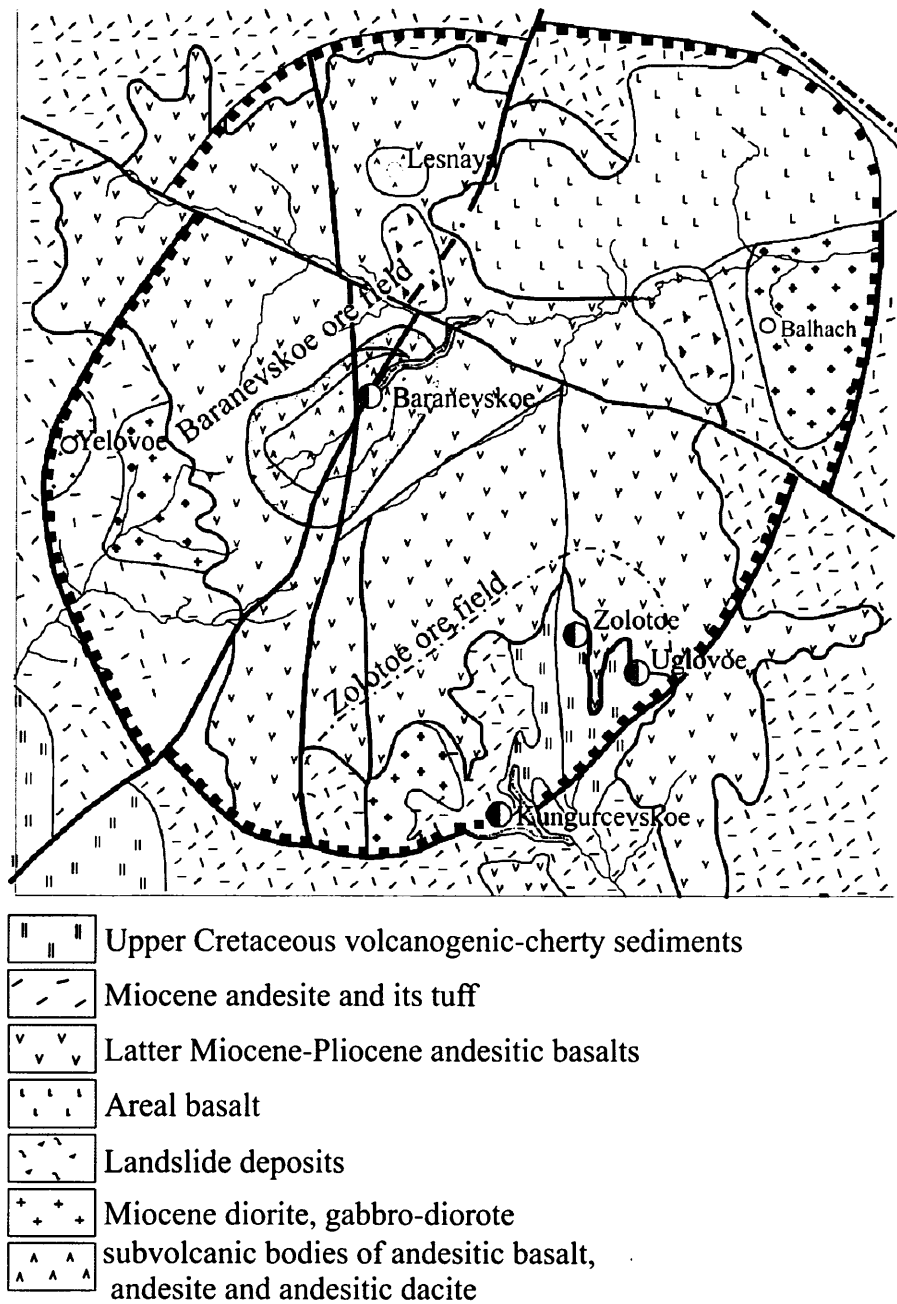


Fig.10.2.1. A schematic sketch of the Balkhach volcanic-tectonic structure with location of main gold-silver deposits (Bol'shakov *et al.*, 2010).

Formation with average thickness of 1,000-1,200 m is composed of tuffs, sandstone and siltstone tuffs. Tuffs are colored in olive-brown colouring due to the regional metamorphism of greenschists. They are easily distinguished from younger volcanic rocks depositions. As result of regional metamorphism following secondary minerals were formed: albite, chlorite, actinolite, epidote, carbonate and zeolite. Xenoliths of the Iruneiskaya Formation are often found in the breccias pipes at Kungurcevscoe and Zolotoe deposits.

The Kimitinsky Complex of Middle Miocene is next older unit of volcanic rocks after the Iruneiskaya Formation at the Balkhach volcanic-tectonic structure. It units explosive and effusive rocks of intermediate in composition, covering an area of 15 km². They are unconformably overlying volcanics of the Iruneiskaya Formation. Outcrops of the Kimitinsky complex composed of propylitized tuffs and andesitic and andesitic basalt lava flows is mapped at the south of the Balkhach ore cluster (Fig. 10.2.2.). Apparent thickness of the Complex is around 600 m.

The Kakhtunsky Complex with thickness around 700 m is widespread at the Balkhach volcanic-tectonic structure (Fig. 10.2.2.). Rocks masses of the Kakhtunsky Complex are weakly propylitized and argillized unconformably, covering volcanics of the Kimitinsky Complex. It is composed of tuffs, andesite and andesitic dacite.

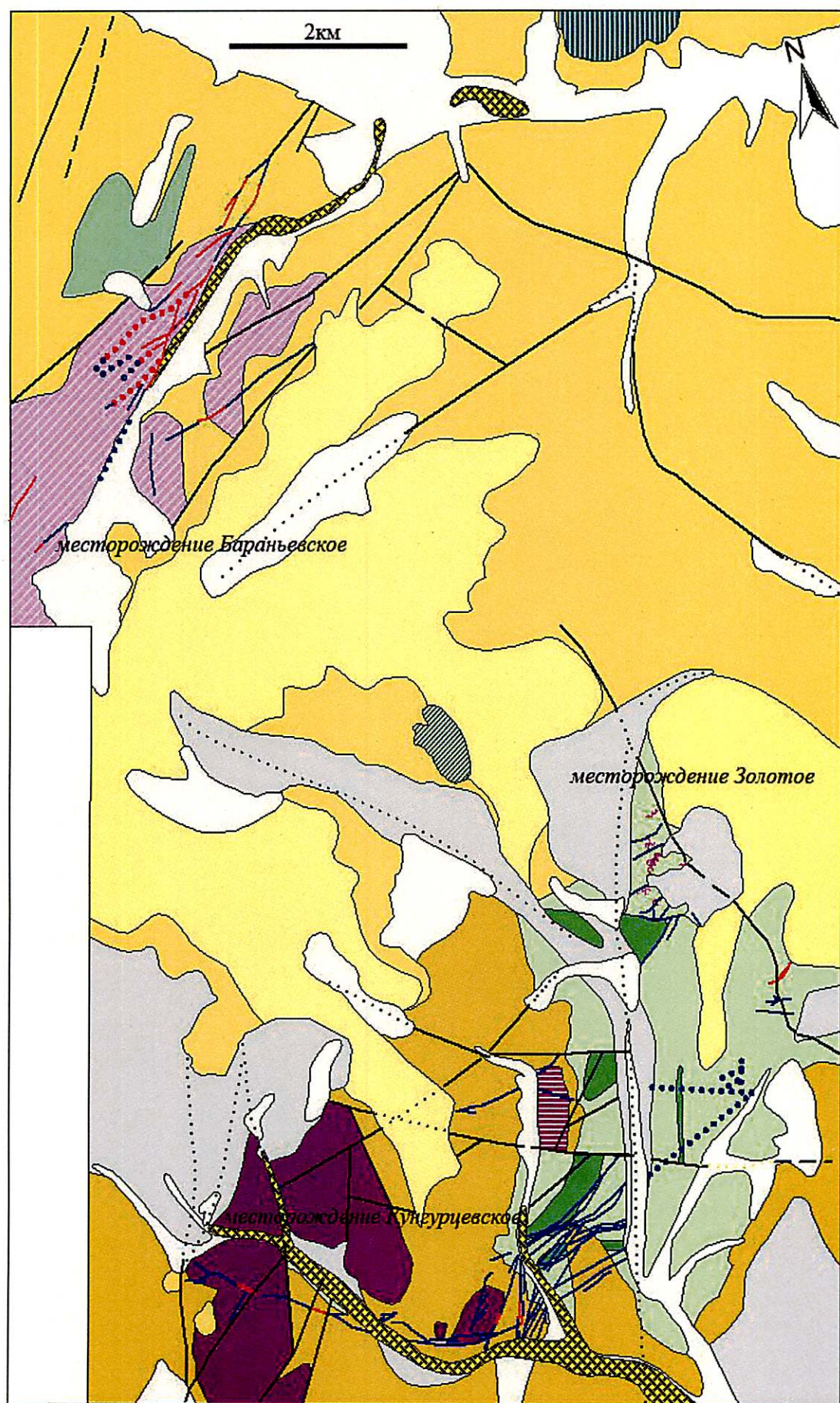
The Kreruksky Complex is occurred on the top the mountains and dividing range in the central and eastern areas of the Balkhach ore cluster (Fig. 10.2.2.). This complex is presented by andesitic and olivine basalts lava flows and tuffs. Apparent thickness is about 550 m.

Quaternary rocks are alluvial, colluvial and glacial sediments are not related to the precious mineralization covering fairly of the oldest rocks (Fig. 10.2.2.).

10.3. Magmatic units and major faults

Intrusive bodies of various compositions were intruded in Late Cretaceous, Early Miocene, Late Miocene-Early Pliocene, Late Pliocene and Quaternary in north-west and south areas mainly (Fig. 10.2.2.).

Intrusive bodies and dikes of Late Cretaceous and Early Miocene have been injected into rocks masses of the Iruneiskaya Formation prior to the ore mineralization. Intrusive bodies of the Kimitinsky Complex are divided into two



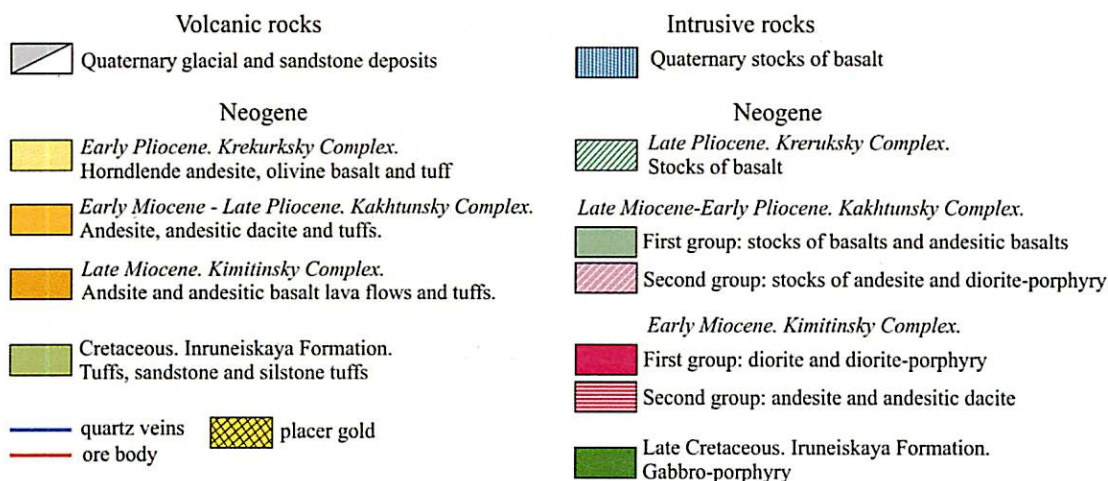


Fig. 10.2.2. A geological map of Balkhach ore cluster, compose by the exploration team.

variety and probably spatially related to gold mineralization occurred at the Balkhach ore cluster. The first group consists of diorite and diorite-porphyry, which have been intruded by andesite and andesitic dacite of the second group. The diorite and diorite-porphyry are predominant; however, ore mineralization is showing spatially relationship mostly with the second group of the intrusive bodies.

Late Miocene-Early Pliocene dikes of basalt and andesite of the Kakhtunsky Complex and Late Pliocene stocks of basalt of the Kreruksky Complex are very rare and not related to ore mineralization.

Among Quarternary intrusive stocks of basalts intruding the Kakhtunsky rock masses in the north of the Balkhach ore knot are recognized (German, 1975 and Chernecov, 1980).

The Balkhach volcanic-tectonic structure was distinguished by exploration geologists (Bol'shakov *et al.*, 2010). It is cut off by external ring faults (Fig. 10.2.1.). The north-west trending fault, running through a whole Balkhach volcanic structure, visually separates an ore cluster into the north sector with a few occurrences of insignificant metallic mineralization and the south area hosting main gold deposits.

10.4. Vein systems of precious metals deposits in the Balkhach ore cluster

The Balkhach ore cluster with total area of 150 km² units three deposits (Baranevskoe, Zolotoe and Kungurcevskoe) and one ore manifestation (Uglovoe).

Among others the Baranevskoe deposit is largest and most geologically well-understood precious lode in the Balkhach ore cluster. It is located in central area of the cluster in approximately 10 km to north-east from Zolotoe and Kungurcevskoe deposits (Fig. 10.2.1.). Baranevskoe deposit consists of over 100 epithermal veins with variable gold grades (Au is up to 459.9 ppm and Ag from 0.3 to 160.1 ppm), distributed within the caldera of the Balkhach volcano. The Balkhach volcanic caldera is north-east orientated with size of 6 x 2.5 km and relative elevation of 1100 m. Gold grades along the zone of alteration rocks and limited by caldera forming faults. The main tectonic structure of the deposit is a deep setting left-lateral strike-slip fault trending to the north-east and dipping to the north-west. This fault hosts main vein – Rhzavaya, which is surrounded from the hanging wall by series of smaller veins trending to the south-west: Central vein, Yuznaya vein, Severyanka vein, Severnaya vein, №7 and apophyses 1, 2, 3, 4 of Rhzavaya vein. Rhzavaya vein is cut by the left-lateral, strike-slip Amto fault. In place of cross-section of two faults Stockwork body is mapped (Bol'shakov *et al.*, 2010).

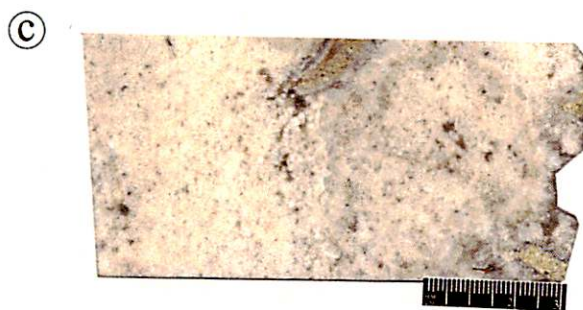
Zolotoe deposit is located in the south east area of the Balkhach ore cluster (Fig. 10.2.2.). This deposit comprises numerous vein groups hosting 100 veins. Thickness of veins varying from 1 to 20 m with length approximately 60-300 m. Gold grade varies from 11.5 to 32.9 ppm.

Kungurcevskoe deposit consists of a large near east-west (sublatitudinal) gold-bearing quartz-adularia vein surrounding by numerous with near north-south (submeridional) smaller veins (Fig. 10.2.2.). The major vein named as Glavnaya (Main) is extending for 6 km with average thickness of 5 m. Average gold grade is about 20 ppm decreasing with depth. Ore bodies are localized in contact of main vein with branches and closely associating with intrusive bodies of the Kimitinsky Complex (stocks and diatreme). Glavnaya vein is a main ore-bearing vein occurred in west side of Glavnaya vein. It hosts ore body 3 and ore body 6. Interesting characteristic of Glavnaya vein is the post-ore magmatic activities influenced on vein's configuration.

10.4.1. Ore occurrence

As it was mentioned above Baranevskoe deposit hosts over 100 epithermal veins, which differ in textures and principal commodities. In this study representative

ore samples were collected from Central vein, Stockwork Ore Body, Rhzavaya vein and Yuznaya vein of Baranevskoe deposit. Based on ore structure and mineral composition of veins following ore types were recognized: quartz-carbonate-adularia fissure filling veins, quartz-carbonate-adularia stockwork, carbonate-quartz vein and cupriferous veins (Fig. 10.4.1.1.). Quartz-carbonate-adularia veins of typical crustiform-colloform, cocarde, banded and brecciated ore structure are formed by open-space filling along SW trending faults (for example, Central vein) distributed in west side of the deposit (Fig. 10.4.1.1a.). Principal vein minerals in this ore type are native gold, electrum, pyrite, chalcopyrite, sphalerite, galena accompanying with minor amount of tellurides and sulfosalts.



Stockwork ore body is a small individual body with thickness of 100-150 m mapped between Central vein and Rhzavaya vein. It consists of numerous quartz-carbonate-adularia and sulfide veinlets, which are occurred in propylitized andesite host rocks (Fig. 10.4.1.1b.). Sulfide veinlets are mainly composed of pyrite. They are narrower and older cut by later relatively wider quartz-carbonate-adularia veins, hosting gold, pyrite and hessite. Carbonate-quartz ores occur in Yuznaya mineralized fracture, extending up to 3 km to NE

Fig.10.4.1.1. Macrophotographs of gold-silver and cupriferous ores from Baranevskoe deposit. a) a hydrothermal breccia consists of fragments of massive quartz and andesite host rocks cemented by translucent quartz, Central vein; b) crosscutting relationship between quartz-carbonate-adularia veins hosting gold and some sulfides in Stockwork ore body; c) carbonate-quartz ore hosting invisible gold mineralization from Yuznaya vein; d) brecciated cupriferous ores from Rhzavaya vein.

with width changing from 0.4 to 1.3 m. Ore is composed of calcite intergrown with whitish brown and translucent massive, cockade quartz hosting pyrite, chalcopyrite, sphalerite, marcasite and native gold. Gold and silver grades varies from vary trace to 22.5 and 9.3 ppm, respectively (Bol'shakov *et al.*, 2010). Field geologists distinguished three major mineralization stages, which consist of several sub-stages (Fig. 10.4.1.2.). Cupriferous ores occurs in left-lateral strike-slip fault of Rhzavaya vein trending to the north-east and dipping to the north-west. Cupriferous ore is showing distinct difference in mineral composition and alteration mineralogy (Fig. 10.4.1.1d.). The main vein minerals are chalcopyrite, tetrahedrite-tennantite and bornite. Minor and trace minerals are Cd-rich sphalerite, electrum, native bismuth, molybdenite, enargite and stibnite (Bol'shakov *et al.*, 2010).

Minerals	Pre-ore stage			Ore stage			Post-ore stage
	Propylitization	Ad-Q	Py-Q	Au-Q	Au-Te	Au-Ag	Q-Car
Chlorite	██████████						
Epidote	██████████						
Mica		██████████		██████████	██████████		
Quartz		██████████	██████████	██████████	██████████	██████████	██████████
Adularia		██████████					
Carbonate							██████████
Pyrite		██████████	██████████	██████████	██████████		
Arsenopyrite		██████████					
Chalcopyrite				██████████			
Sphalerite				██████████			
Galena			██████████	██████████			
Gold				██████████	██████████	██████████	
Native Ag				██████████		██████████	
Kustelite					██████████	██████████	
Hessite					██████████	██████████	
Acanthite						██████████	
Ag sulfosalt						██████████	

Fig.10.4.1.2. Mineralization stages and mineral sequence in Baranevskoe deposit.

According to the Table of the mineralization stages, presented in Fig. 10.4.1.2., quartz-carbonate-adularia ores have been formed in three large stages. First stage is a

pre-ore stage characterized by the alteration of host rocks and follows deposition of pyrite, arsenopyrite and some galena. Ore stage consists of three sub-stage differs in vein minerals. Sulfide such as galena, sphalerite and chalcopyrite were precipitated prior to tellurides and Ag-bearing minerals. Gold is most abundant metallic mineral has been continuously deposited through the Ore stage. Post-ore stage consists of carbonate and quartz.

Two principally different ore phases are recognized at Zolotoe deposit: sulfide-rich ore and sulfide-poor ore (Fig. 10.4.1.3.). The sulfide-rich ore is consisted of pyrite, locally comprises more than 80% of total ore. Sulfide-poor ore is consisted of white quartz with minor amount of adularia, mica and chlorite. Metallic mineralization is appeared as narrow sulfide bands in quartz gangue mainly (Fig. 10.4.1.3b.). Sulfide bands less than 1 cm in width consist of pyrite, chalcopyrite, sphalerite and galena mainly. Minor amount of tennantite-tetrahedrite, Ag-bearing minerals, altaite, hessite, native Te, arsenopyrite, bornite, cinnabar, molybdenite and realgar have been reported by Okrugin (1980, mining report). Idealized crustiform banding ore was not observed in ores from Zolotoe deposit. Both ore types are intensively brecciated.

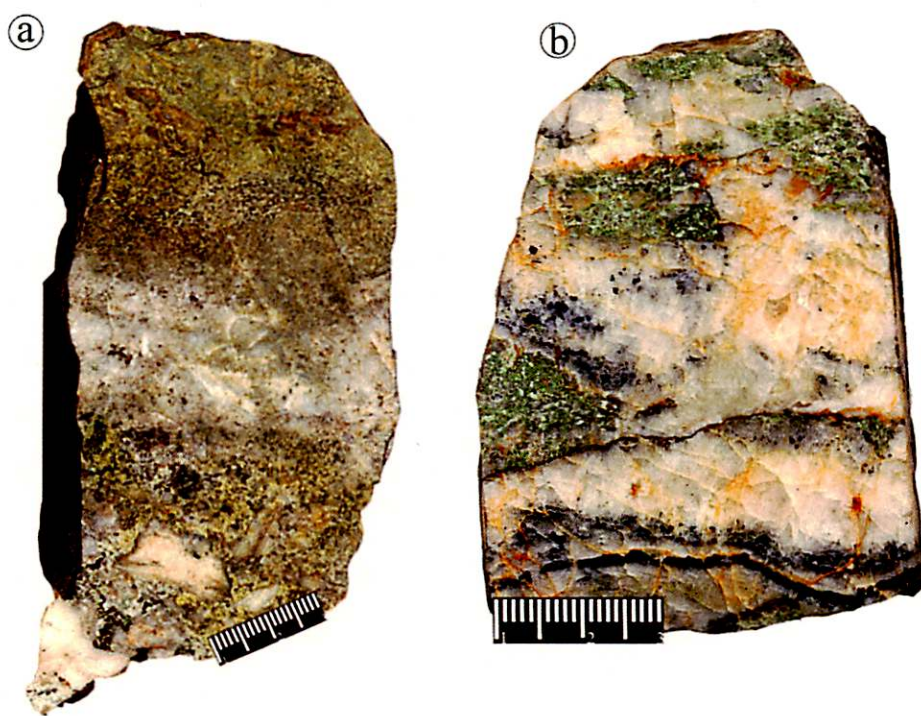


Fig.10.4.1.3. Macrophotographs of gold-silver ores from Zolotoe deposit. a) sulfide-rich ore with pyrite comprising 90 % of total ore; b) sulfide-poor ore consists of fragment of host rocks and massive quartz hosting metallic mineralization.

Vein samples collected from Main ore body, vein 14 and vein 17 at the Kungurcevskoe deposit are shown in Fig. 10.4.1.4. Main ore body is represented by hydrothermal breccias of andesite host rocks fixed by crystalline quartz (Fig. 10.4.1.4a.). Well rounded fragments of host rocks are surrounded by chalcopyrite and native gold and/or smectite-chlorite series minerals. Mineralization stage sequence was not classified due to lack of samples and complicating factor as an intensive brecciation. In this study only gold was observed as major vein minerals in Main ore body. Samples obtained from vein 17 also exhibits breccias in common. Bands of massive white and brown quartz and clays are recognizable. Metallic mineralization is dispersed in quartz-clay gangue (Fig. 10.4.1.4b.). Among vein minerals chalcopyrite and gold in association with unknown Ag-rich phase were identified. Samples from vein 14 consist of breccias, followed by deposition of clays and comb quartz (Fig. 10.4.1.4c.). Gold is found in clays layers in association with pyrite.

10.4.1. Age of ore mineralization

Age dating of host rocks and ore mineralization was borrowed from literature source in this study. Okrugin (2001) dated by K/Ar method variety of altered host rocks, and veins samples at precious metal deposits of Balkhach ore cluster. Results of K/Ar dating showed that ore mineralization at Baranevskoe deposit has occurred 3.57-3.11-2.65-2.37 Ma (Okrugin, 2001). Zolotoe and Kungurcevskoe revealed apparent age of 17.6 Ma and 21.3 Ma, respectively.

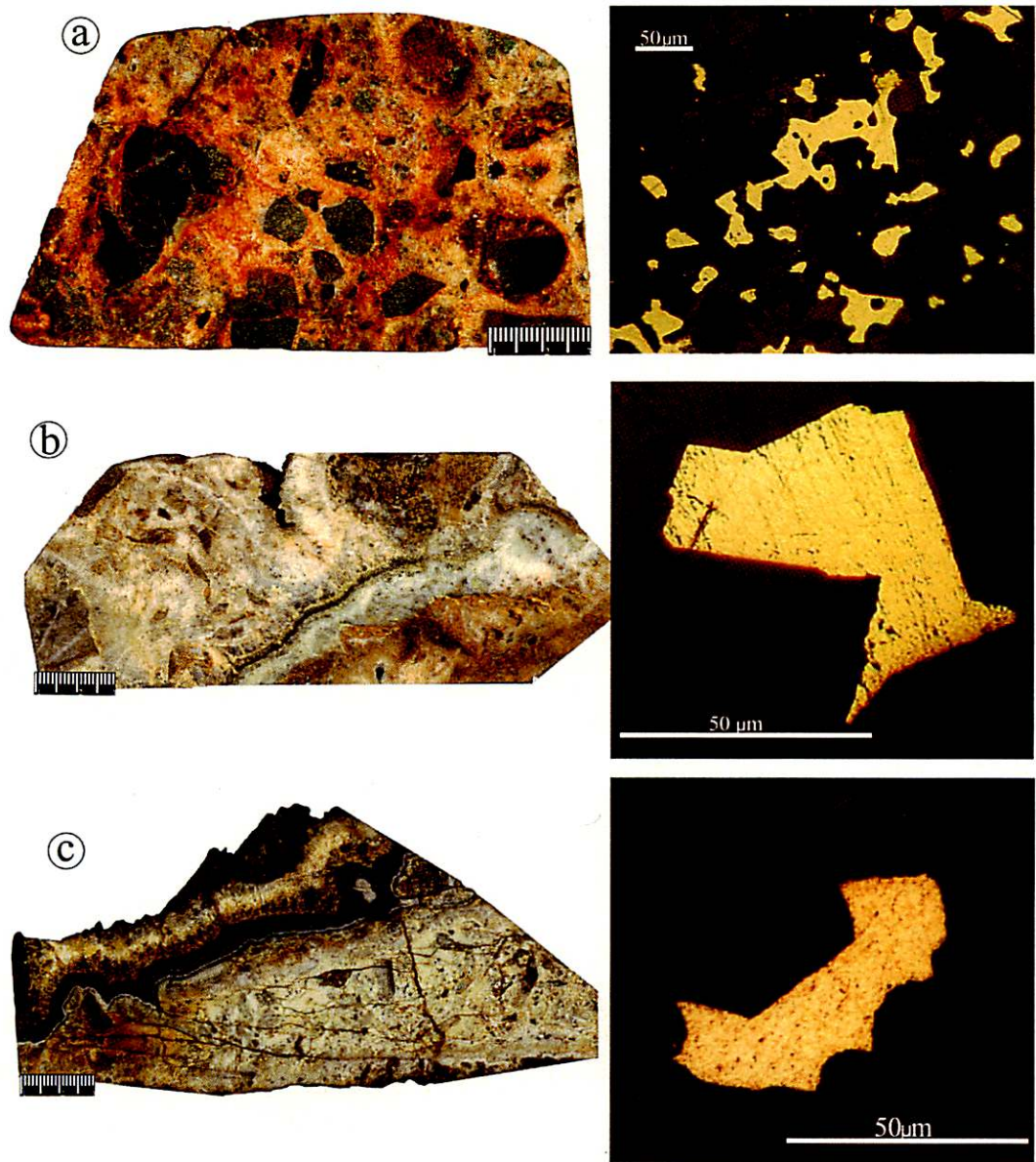


Fig.10.4.1.4. Marco- and microphotographs of gold-silver ores with typical mode of gold occurrences from Kungurcevscoe deposit. a) breccias from Main ore body (left) with occurrence of gold (right); b) quartz-carbonate-clays ores from vein 17 (left) and gold occurring in quartz interstices (right); c) hydrothermal breccias from vein 14 (left) and typical gold occurring in quartz-clay gangue (right).

Chapter XI. Geochemistry and mineralogy of veins and hydrothermally altered rocks at the Balkhach ore cluster

11.1. Geochemistry of host rocks and ores

11.2. Alteration mineralogy

11.3. Vein mineralogy

Chapter XI. Geochemistry and mineralogy of veins and hydrothermally altered rocks at the Balkhach ore cluster

Relatively fresh wall rock samples and characteristic vein specimens were analyzed for whole rock major and trace element contents. Host rock samples were collected from Baranevskoe and the Zolotoe deposits only, while vein samples were available from Baranevskoe, Zolotoe and Kungurcevscoe deposits.

11.1. Geochemistry of host rocks and ores

Baranevskoe deposit

Baranevskoe deposit consists of three different ore types carrying gold mineralization: gold-silver-quartz-adularia, copper and carbonate ores. The former ore type is presented by filling veins and stockwork of tiny veinlets occurred in propylitized andesite host rocks. Copper ore type occurs in metasomatite. The last ore type is carbonate constrained upper horizons of the epithermal system, also, contains some amount of gold.

Free slightly altered host rocks and four veins samples were analyzed for major and trace elements from Baranevskoe deposit. Analytical results are listed in Table 11.1.1 and 11.1.2. The REE elements concentration in host rocks and ores are given Table 11.1.3 and 11.1.4. Analytical data are graphically expressed in Figs. 11.1.2. for the wall rocks and for veins.

Geochemical assay for main metals plotted in Fig. 11.1.1. revealed distinct difference in concentration of Au, Ag and Cu in two principally different ore facies. Au-sulfide ore is characterized by positive correlation of Au and Ag with high Au/Ag ratio. Compare to cupriferous ores Cu content in Au-sulfide ores is very low, but generally increase with increasing of Au concentration (Table 11.1.2). Lack of geochemical data for the cupriferous makes any consideration on behavior of Au, Ag and Cu insufficient. In general, cupriferous ores is likely characterized by high Cu concentrations, which exceed concentration of Au and Ag in 10 times. Te content is higher in Au-sulfide ore facies, than in cupriferous ones (Fig. 11.1.2.).

Table 11.1.1 Bulk chemical composition of host rocks for Zolotoe (Z1-Z5) and Baranevskoe (B1-B3) deposits.

	Z1	Z2	Z3	Z4	Z5	B1	B2	B3
SiO ₂	51.11	53.34	49.91	70.17	64.68	53.43	56.84	57.74
Na ₂ O	2.84	2.53	.44	5.03	1.53	2.91	3.19	3.47
MgO	5.81	6.07	9.48	0.52	3.02	6.98	4.14	4.47
Al ₂ O ₃	16.11	15.57	14.88	14.58	12.37	14.48	14.80	15.27
P ₂ O ₅	0.11	0.13	0.24	0.15	0.20	0.14	0.18	0.19
K ₂ O	2.06	1.00	4.35	3.43	3.91	0.74	1.11	1.34
CaO	7.62	6.47	2.24	0.39	3.02	8.83	4.91	3.93
TiO ₂	0.61	0.69	0.73	0.50	0.61	0.80	0.63	0.65
MnO	0.14	0.21	0.34	0.14	0.36	0.18	0.10	0.18
Fe ₂ O ₃	8.39	9.15	8.34	3.15	6.49	8.33	5.86	8.29
Be	<1	<1	<1	2	<1	<1	<1	2
Sc	32	26	31	6	17	35	15	17
V	261	237	256	23	191	232	123	129
Co	31.6	32.8	33.6	4.5	18.1	24.0	17.8	16.7
Ni	21.9	62.1	91.9	1.2	11.8	11.7	43.0	44.3
Cu	114.4	62.7	107.2	97.1	179.4	18.2	43.3	38.3
Zn	47	83	94	51	46	52	61	63
Ga	15.7	16.7	12.6	14.0	12.3	13.2	14.0	12.9
As	4.8	18.3	301.7	16.3	3.4	2.1	69.0	42.4
Se	<0.5	<0.5	0.6	<0.5	<0.5	0.5	1.0	1.2
Mo	0.2	0.5	0.3	1.4	1.7	0.4	1.0	1.5
Ag	<0.1	<0.1	0.5	0.2	0.3	<0.1	<0.1	<0.1
Cd	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sb	0.2	0.4	1.1	0.8	0.2	0.2	0.4	0.3
Au	3.3	2.9	852.5	9.7	22.0	1.7	2.6	3.6
Hg	<0.01	<0.01	0.03	0.01	0.02	<0.01	0.01	0.02
Tl	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pb	1.2	5.3	5.7	4.0	3.3	2.6	5.0	6.2
Bi	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1

Table 11.1.2 Bulk chemical composition of quartz-carbonate-adularia veins of Kungurcevscoe (K1-K4), Zolotoe (Z6-Z9) and Baranevskoe (B4-B7) deposits.

	K1	K2	K3	K4	Z6	Z7	Z8	Z9	B4	B5	B6	B7
Na ₂ O	0.036	0.035	0.023	0.090	0.026	0.086	0.015	0.020	0.020	0.017	0.013	0.076
MgO	0.353	0.075	0.038	0.354	2.444	0.367	0.138	0.019	0.952	0.518	0.062	0.096
Al ₂ O ₃	3.382	5.777	1.620	11.274	1.742	2.328	1.259	4.326	2.175	1.725	0.417	3.376
P ₂ O ₅	0.018	0.309	0.067	0.043	0.010	0.021	0.010	0.085	0.211	0.012	n.d.	0.241
S _{total}	0.320	0.062	0.044	0.195	0.890	0.031	9.868	3.109	0.083	0.059	0.117	5.047
K ₂ O	1.246	1.090	0.270	6.150	0.901	0.861	0.063	0.037	0.284	0.547	0.082	2.236
CaO	0.043	0.439	0.149	0.103	8.453	0.057	0.091	0.040	6.046	0.080	29.127	0.105
TiO ₂	0.054	0.043	0.024	0.073	0.030	0.068	0.012	0.051	0.005	0.024	0.004	0.116
MnO	0.016	0.002	0.010	0.009	0.138	0.018	0.056	0.001	0.138	0.018	0.166	0.005
Fe ₂ O ₃	1.289	0.452	0.806	1.166	2.252	1.564	14.452	4.781	0.911	1.397	0.304	9.911
Li	164.5	66.3	82.1	42.4	66.2	153.6	49.4	29.5	51.1	105.8	38.4	51.5
Be	0.2	0.3	0.2	0.3	0.4	0.2	0.7	0.1	0.3	0.1	0.6	0.4
Sc	1.5	19.6	1.7	6.2	3.6	2.0	14.4	3.7	0.8	1.3	0.2	2.9
V	23.4	113.1	19.2	64.5	13.6	20.8	28.0	53.7	21.6	18.4	n.d.	16.1
Cr	17.8	12.6	6.3	2.7	420.6	525.0	473.3	590.4	320.9	470.1	193.9	463.9
Co	4.4	2.3	8.1	3.5	3.9	2.7	1.7	4.0	1.5	2.4	1.1	6.5
Ni	1.2	1.0	3.3	1.0	17.0	14.2	11.4	22.3	16.6	16.6	9.8	32.5
Cu	1970.5	51.1	32.6	55.0	1002.5	266.6	15.1	5034.2	9.5	107.5	19.0	53283.8
Zn	518.3	41.0	64.7	62.7	5631.1	63.1	91.5	76.3	681.1	59.1	379.4	844.7
Ga	1.7	9.9	1.3	6.3	1.5	1.8	3.2	18.1	4.7	2.6	0.7	3.8
As	n.d.	4.7	31.6	1.8	11.3	5.9	1475.4	586.6	n.d.	28.3	6.1	25.2
Se	53.1	< 3	< 1	14.3	43.3	23.3	4.9	683.2	2.3	4.9	n.d.	51.2

Mo	0.3	33	7.6	0.9	11.2	5.2	22.9	92.1	2.9	15.1	1.7	4.9
Rh	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.9	112.0	34.1	210.0
Ag	40.9	10.8	5.8	202.6	19.2	93.3	26.7	35.4	3.5	0.5	3.3	22.6
Cd	6.7	0.5	0.3	0.5	97.7	0.5	0.9	1.4	n.d.	n.d.	<0.3	n.d.
Sn*	0.5	0.6	0.3	1.0	0.69	0.76	0.48	4.2	0.6	2.5	0.6	1.0
Sb	15.2	12.7	12.6	6.6	7.7	11.7	19.9	458	17.5	5.6	14.9	109.2
Te	33.8	43.1	6.1	149.3	12.1	37.0	2.1	671.5	1.7	25.4	3.4	2.0
W	48.7	70.0	52.1	55.1	33.5	37.1	28.7	42.1	25.0	30.2	14.5	29.2
Re	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	<0.1	n.d.	n.d.	n.d.	n.d.
Ir	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pt	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Au	20.9	17.3	0.2	148.6	9.5	246.0	60.4	7.2	n.d.	663.8	191.7	109.4
Hg	n.d.	n.d.	n.d.	n.d.	1.0	0.5	0.5	1.2	n.d.	0.5	0.2	n.d.
Tl	0.5	0.3	0.1	2.1	0.5	0.5	0.2	0.2	0.2	0.3	0.1	1.3
Pb	1889.4	289.6	73.2	1016.2	3902.8	787.7	35.1	77.1	816.8	555.9	163.3	71.2
Bi	2.1	8.7	0.7	2.8	3.5	2.7	n.d.	26.5	0.7	0.9	0.1	3.4

Table 11.1.3 ICP data for trace and REE elements for host rocks of Zolotoe (Z1-Z4) and Baranevskoe (B1-B3) deposits.

	Z1	Z2	Z3	Z4	Z5	B1	B2	B3
Cs	2.80	1.20	6.50	0.70	0.60	0.40	1.10	0.80
Rb	50.10	16.30	64.80	50.10	62.80	6.20	12.10	14.10
Ba	392	700	1054	539	489	223	745	892.00
Th	1.10	2.10	1.60	15.40	1.20	0.80	1.90	2.00
U	0.50	0.80	0.70	3.80	1.20	0.30	1.30	1.20
Nb	1.00	2.60	1.70	7.90	3.20	1.30	2.80	3.00
Ta	n.d.	n.d.	n.d.	0.20	n.d.	0.01	0.01	0.01
La	6.20	8.70	9.00	30.40	7.30	5.60	10.20	11.40
Ce	14.40	20.60	19.50	63.90	17.90	15.00	22.80	24.60
Pb	1.20	5.30	5.70	4.00	3.30	2.60	5.00	6.20
Pr	2.07	2.87	2.71	7.55	2.48	2.21	3.03	3.22
Sr	473.50	522.50	71.70	158.20	252.80	489	937	429
Nd	9.40	12.40	12.70	27.60	11.10	10.30	11.60	13.70
Zr	60.90	85.30	45.30	189.70	64.20	68.70	94.00	94.40
Hf	2.10	2.10	1.30	5.40	2.10	2.10	2.20	2.40
Sm	2.39	2.92	3.47	5.95	2.47	2.86	2.62	2.72
Eu	0.77	0.95	1.27	1.22	0.84	0.92	0.81	0.80
Gd	2.41	2.89	3.53	4.39	2.58	2.92	2.32	2.38
Tb	0.41	0.49	0.61	0.73	0.42	0.51	0.38	0.40
Dy	2.23	2.80	3.46	4.16	2.47	2.96	2.14	2.24
Ho	0.49	0.57	0.71	0.81	0.48	0.63	0.42	0.44
Er	1.33	1.66	2.02	2.51	1.45	1.87	1.20	1.23
Yb	1.27	1.65	2.04	2.53	1.47	1.82	1.23	1.31
Y	12.60	15.80	19.80	21.00	13.50	17.90	12.50	12.30
Lu	0.21	0.26	0.30	0.38	0.22	0.28	0.19	0.19
Eu/Eu*	0.98	1.00	1.11	0.73	1.02	0.97	1.00	0.95
Ce/Ce*	1.03	1.08	0.96	1.05	1.12	1.10	1.08	1.05

Table 11.1.4 ICP data for trace and REE elements for ores of Kungurcevskoe (K1-K4), Zolotoe (Z6-Z9) and Baranevskoe (B4-B7) deposits.

	K1	K2	K3	K4	Z6	Z7	Z8	Z9	B4	B5	B6	B7
Cs	0.94	1.70	0.40	2.90	0.86	0.69	0.69	0.78	0.54	0.35	0.29	1.47
Rb	22.90	24.10	7.00	139.00	17.85	18.33	2.47	0.79	6.57	12.20	1.59	38.80
Ba	161.00	70.80	16.50	1068.00	472.74	144.81	14.71	556.84	31.30	74.47	11.00	155.20
Th	0.04	1.39	0.07	0.10	0.09	0.11	0.16	0.06	n.d.	0.06	n.d.	0.35
U	0.05	0.17	0.05	0.19	0.13	0.06	1.18	0.02	0.04	0.09	0.01	0.20
Nb	0.12	0.18	0.07	0.21	0.36	0.41	0.35	0.41	0.13	0.20	0.11	0.74
Ta	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02
La	0.59	4.80	0.95	2.00	7.36	0.43	16.74	1.17	2.02	0.53	0.43	2.52
Ce	1.30	7.30	1.57	5.50	15.83	1.06	30.62	3.96	3.32	0.62	0.69	5.68
Pb	1889	2.90	73	1.16	3903	788	35	77	817	556	163	71
Pr	0.19	1.20	0.27	0.95	1.68	0.20	2.76	0.23	0.52	0.08	0.09	0.64
Sr	7.50	140.00	10.60	48.90	107.77	9.63	9.61	239.29	82.93	9.99	274.15	46.29
Nd	0.82	5.60	1.20	4.70	7.31	0.85	11.50	1.36	1.87	0.35	0.51	2.52
Zr	2.00	4.10	2.40	4.40	3.23	2.88	2.31	1.49	0.59	2.92	0.57	11.33
Hf	0.09	0.18	0.09	0.22	0.23	0.14	0.06	n.d.	n.d.	0.08	n.d.	0.40
Sm	0.20	1.60	0.28	0.86	2.16	0.29	2.79	0.46	0.47	0.11	n.d.	0.67
Eu	0.05	0.74	0.11	0.27	0.81	0.10	0.91	0.14	0.12	0.02	n.d.	0.25
Gd	0.21	1.36	0.29	0.54	2.78	0.28	3.05	0.32	0.45	0.17	0.09	0.52
Tb	0.03	0.17	0.04	0.08	0.51	0.05	0.43	0.02	0.10	0.02	0.02	0.09
Dy	0.21	0.71	0.23	0.43	3.30	0.35	2.58	0.10	0.44	0.11	0.09	0.58
Ho	0.04	0.12	0.05	0.08	0.61	0.06	0.51	0.02	0.07	0.03	0.02	0.09
Er	0.13	0.29	0.12	0.23	1.57	0.16	1.29	0.07	0.21	0.11	0.03	0.24
Yb	0.10	0.27	0.09	0.19	1.08	0.17	1.23	0.13	0.13	0.12	0.03	0.26
Y	1.20	2.70	1.30	2.90	16.20	1.15	16.35	0.57	2.16	0.92	0.40	2.08
Lu	0.01	0.04	0.01	0.03	0.14	0.02	0.19	0.02	0.02	0.02	n.d.	0.05
Eu/Eu*	0.74	1.53	1.18	1.21	1.01	1.07	0.95	1.08	0.83	0.56	-	1.27
Ce/Ce*	1.00	0.70	0.76	1.19	0.34	0.31	0.32	0.50	0.27	0.19	-	0.36

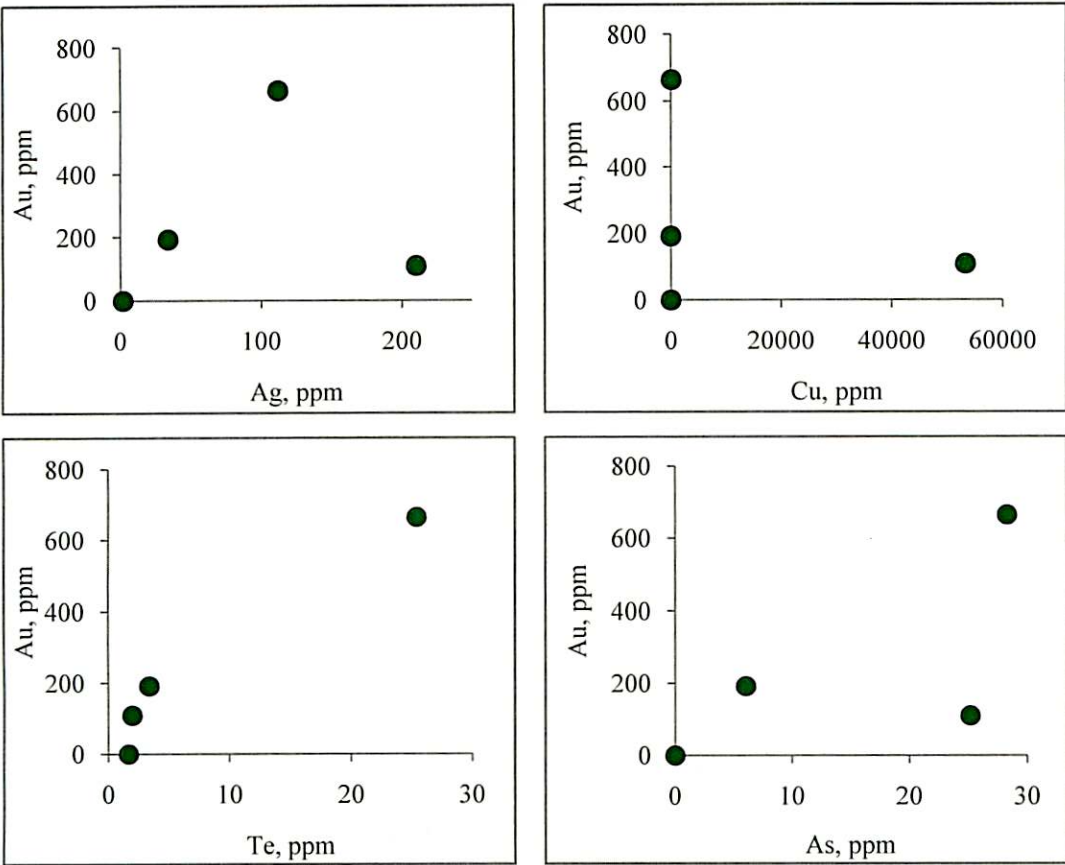


Fig.11.1.1. Scattered diagrams of Au vs. Ag, Te, Cu and As; Pb vs. Zn; Te vs. Se plotted for ores of Baranenskoe deposit.

Altered andesite shows high concentrations of large ion lithophile elements (LILE) and low high field strength elements (HFSE) (Fig. 11.1.2.). REE patterns of sample B2 and B3 are identical, showing a gentle slope, while sample B1 displays flat REE pattern (Fig. 11.1.2.). No any significant anomalies of Ce or Eu were seen in host rocks. Eu/Eu^* is about 0.9-1.0 and Ce/Ce^* 1.0-1.1.

REE were analyzed in gold-sulfide-quartz-carbonate-adularia ores (samples B4-B5), in stockwork (sample B6) and in cupriferous ores (sample B7). REE patterns for vein samples revealed progressive depletion in REE in contrast to the host rocks (Fig. 11.1.2.), however, generally repeats LILE and HSFE patterns of host rocks (Fig. 11.1.2.). Sample B7 of cupriferous ore shows a distinct positive Eu anomaly without Ce anomaly (Fig. 11.1.2.). Instead, sample B4 of gold-sulfide ore shows moderate negative anomalies of both Ce and Eu. Eu/Eu^* varies 0.6-1.3 and Ce/Ce^* 0.2-0.4.

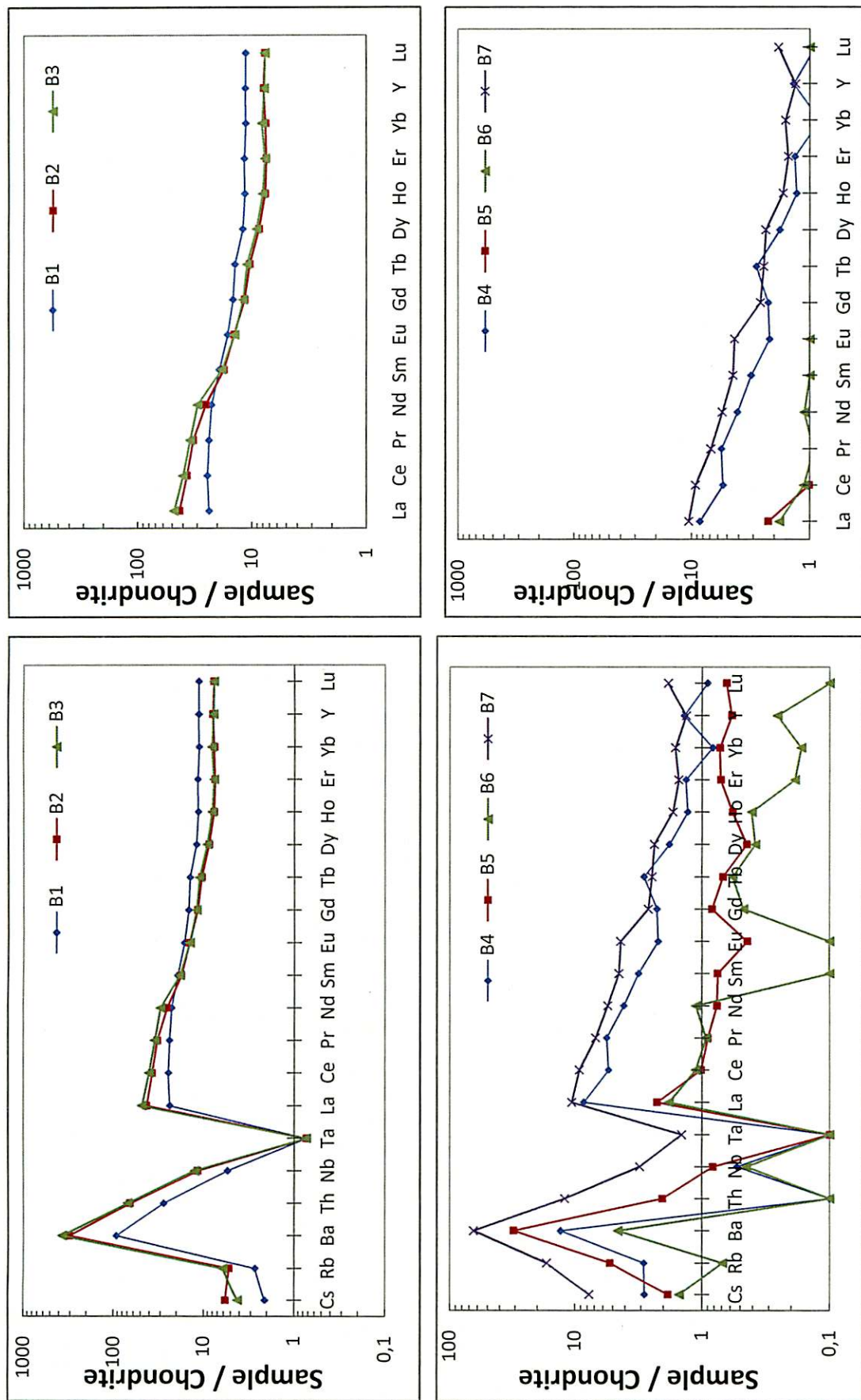


Fig.1.1.1.2. Chondrite normalized incompatible element diagram (left side) and rare earth element abundance (right side) for host rocks (two upper plots) and ores (two lower plots) of Baranovskoe deposit. Chondrite REE compositions from Mcdonough and Sun (1995).

Zolotoe deposit

Zolotoe Au-Ag deposit consists of two principally different ore types: sulfide-poor and sulfide-rich. Genetic relation of these two ore types is still under consideration and will not be discussed in this paper. Characteristics of ores are given in Chapter IX.

Major and trace elements were measured in five samples of slightly altered andesite host rocks and four veins samples. Analytical results for host rocks and veins are listed in Tables 11.1.1., 11.1.2, 11.1.3 and 11.1.4. Graphically data are expressed in Figs. 11.1.3 and 11.2.1.4.

Au shows a positive correlation with Ag in ores and negative with Te and Cu (Fig. 11.2.1.1.). Scattered diagrams of Au vs. As clearly shows a positive and negative trends. In sulfide-poor ore Au negatively correlates with As, while in sulfide-rich, in which Au tends to be occurred as tiny inclusions in As-bearing pyrite, Au has a positive trend with As (Fig. 11.2.1.1.).

The chondrite-normalized REE patterns for host rocks from Zolotoe deposit are relatively identical with REE patterns of host rocks from Baranevskoe deposit (Fig. 11.1.3.). Sample Z4 exhibits a small different pattern regarding to higher concentration of Ba, and Ta. REE patterns of host rocks show a gradual change from flat to slightly enriched pattern in light REE without anomalies of Ce and Eu (Samples Z1, Z2, Z3 and Z5) to relatively high LREE enriched pattern with pronounced negative Eu anomaly (sample Z4). Eu/Eu^* for host rocks varies from 0.7 – 1.1 and Ce/Ce^* varies from 0.9 to 1.1. REE concentration in epithermal veins has a wide variation from intensively depleted REE patterns (sample Z7 and Z9) to REE-enriched patterns (Z6 and Z8). However, REE pattern are flat without any visible Ce or Eu anomalies in all four samples (Fig. 11.2.1.2). Eu/Eu^* for veins ranges from 0.9-1.1 and Ce/Ce^* from 0.3 to 0.5.

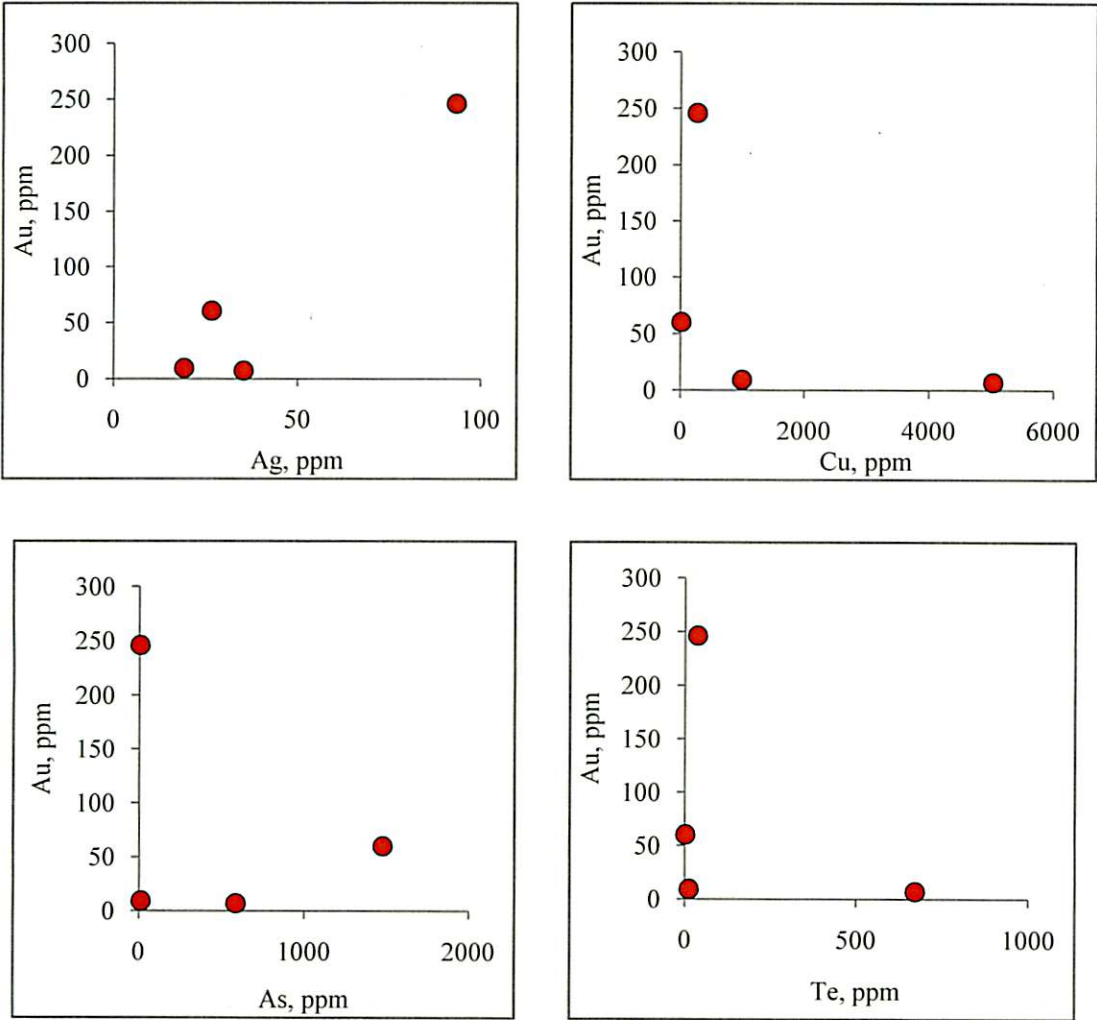


Fig.11.1.3. Scattered diagrams plotted for main commodity in gold-silver ores from Zolotoe deposit.

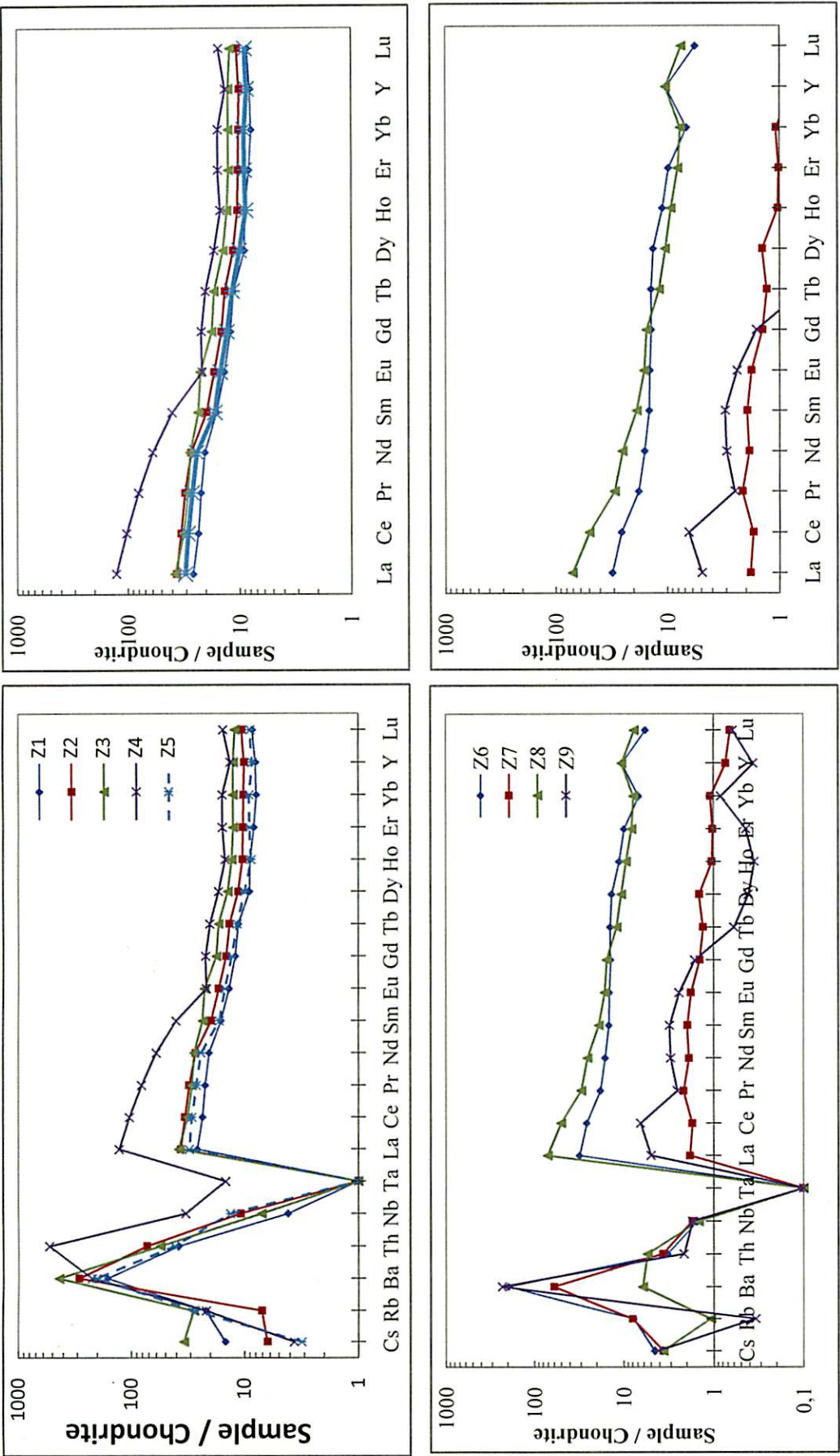


Fig.1.1.1.4. Chondrite normalized incompatible element diagram (left side) and rare earth element abundance (right side) for host rocks (two upper plots) and ores (two lower plots) of Zolotoe deposit. Chondrite REE compositions from McDonough and Sun (1995).

Kungurcevskoe deposit

Kungurcevskoe Au-Ag deposit is located in about 3 km to south-west from Zolotoe deposit. Although, host rock samples were not collected from Kungucervskoe deposit, consider similar geology, formation age and near location with other deposits of the Balkhach ore cluster, host rocks chemistry must be similar with Zolotoe deposit. Brecciated and banded quart-adularia ores from Kungurcevskoe deposit contains gold in association with sulfide. Unfortunately, only a few samples were collected for this study.

Major and trace elements obtained by ICP analysis listed in Table 11.1.2. REE data for ores is given in Table 11.1.4.

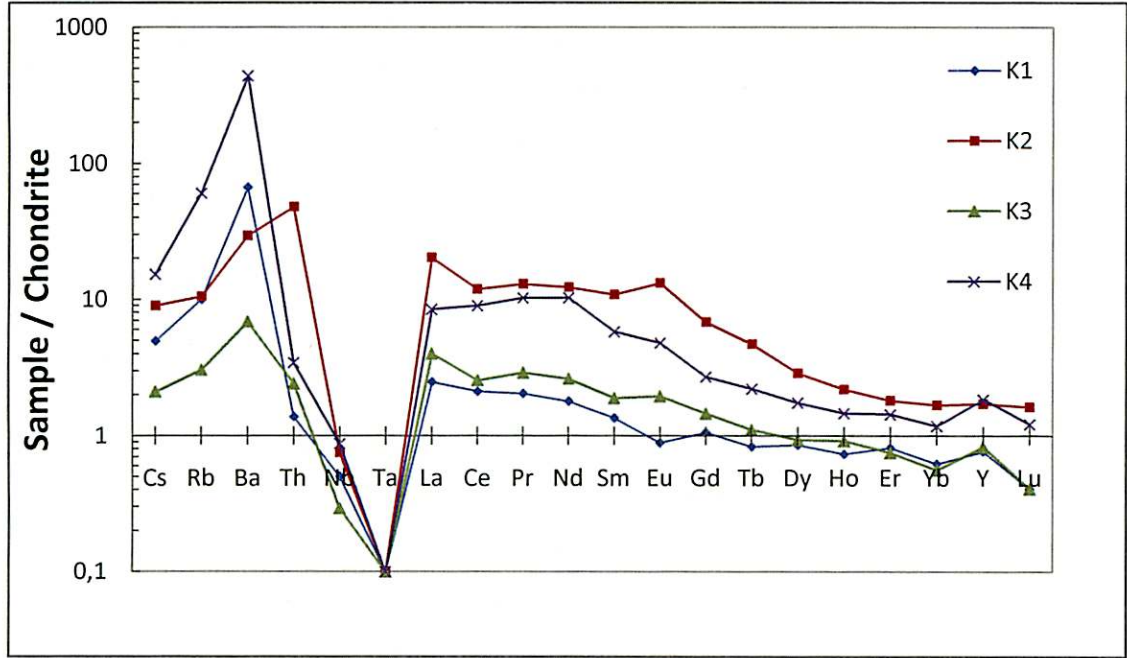


Fig.11.1.5. Chondrite normalized incompatible element diagram and rare earth element abundance for gold-silver ores of Kungurcevskoe deposit. Chondrite REE compositions from McDonough and Sun (1995).

Ore samples are mainly breccias, hosting fragments of altered host rocks, thus, veins are enriched in REE (Fig. 11.1.5) with distinct positive Eu anomaly and negative Ce anomaly. Eu/Eu^* ranges from 0.7 – 1.5 and Ce/Ce^* ranges from 0.7 to 1.2.

11.2. Alteration mineralogy

Baranevskoe deposit

Gold-bearing quartz-carbonate-adularia and cupreous veins are hosted by propylitized andesite and different types of metasomatites. In the north flank of the deposit veins are hosted by low-temperature quartzite and monoquartzite with thickness around 1-10 m. Most intensive wall rocks alteration is occurred in the central flank. Metasomatites are graded from inner of pyrite-hematite-magnetite-sericite(alunite)-quartz types and pyrite-sericite-illite-quartz composition to outer alkaline type metasomatites of adularia, illite, carbonate, clays and pyrite. Blanket of argillic alteration is covered on the south-western portion of the deposit (Bol'shakov *et al.*, 2010).

Negative correlation of K_2O vs. $CaO+Na_2O$ suggests that host rocks undergo potassic and propylitic alteration (Fig. 5.3.2.). In thin section phenocrysts of plagioclase are replaced by sericite (Fig. 11.2.1), development of chlorite and chlorite-kaolinite in groundmass is observed. XRD analyses show presence of chlorite, chlorite-kaolinite mixed layer, adularia and quartz (Fig. 11.2.2.).

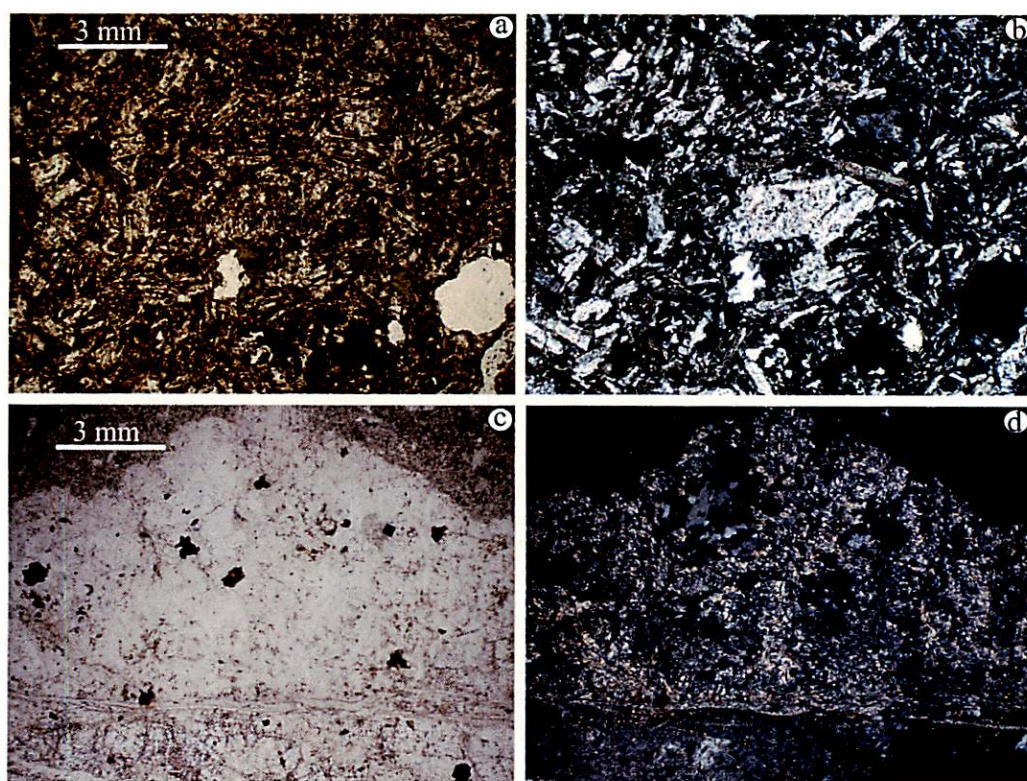


Fig.11.2.1. Microphotographs of alteration types in host rocks of Baranevskoe deposit:
a) chlorite in groundmass; b) plagioclase crystals are replaced by sericite.

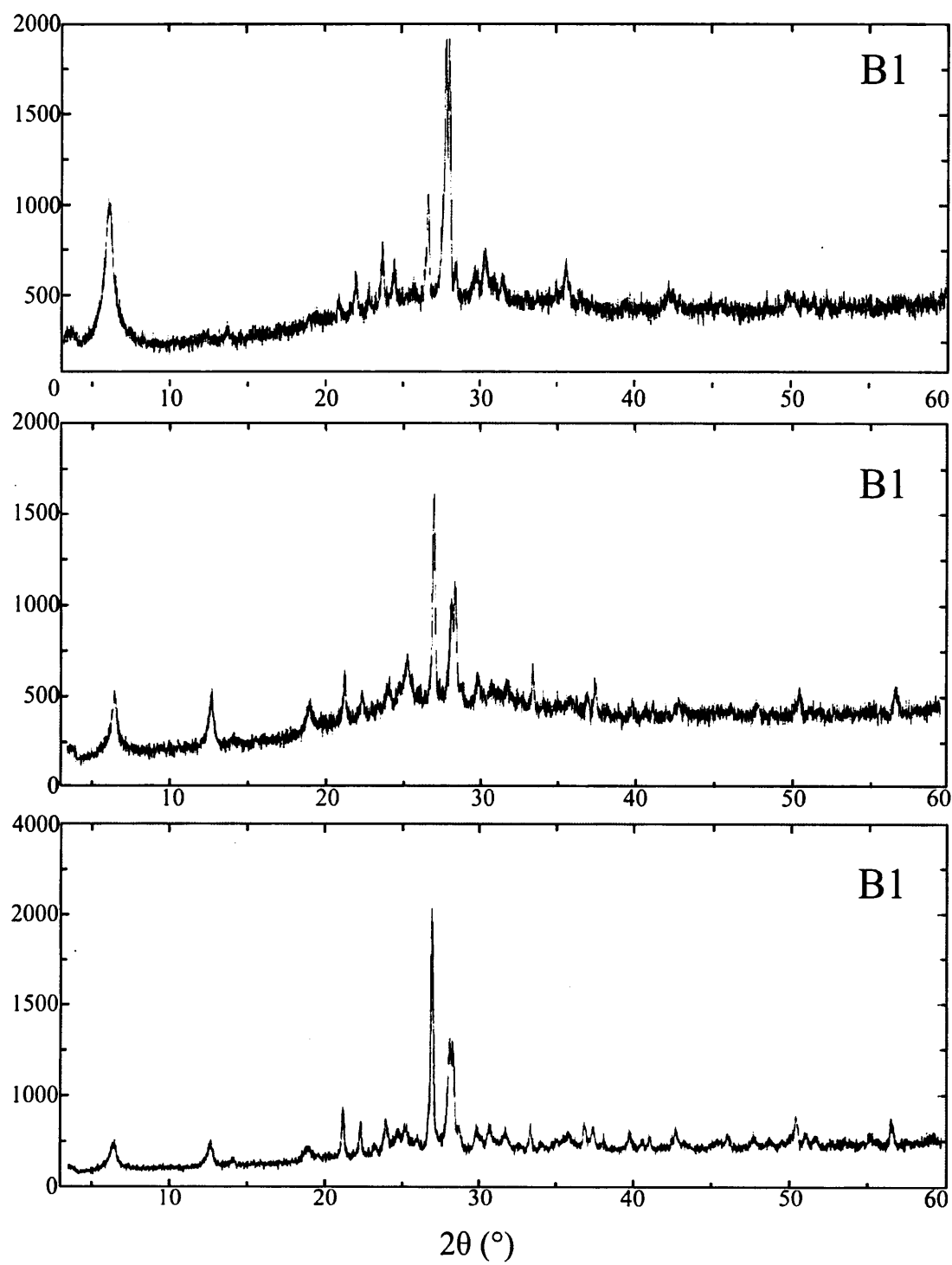


Fig.11.2.2. XRD spectrum of chlorite (chl), chlorite-smectite (chl-sm), chlorite-kaolinite (chl-kl), quartz (q), adularia and albite (ad-alb).

11.3. Vein mineralogy

Baranevskoe deposit

Main ore minerals in the brecciated quartz-carbonate-adularia vein and stockwork body are pyrite, chalcopyrite, gold, sphalerite and galena. Minor minerals are hessite, petzite and altaite. In carbonate-quartz veins only gold was found. Impregnation of metallic minerals is less than 1 volume % in those ore types. Cu-rich ore consists of pyrite, chalcopyrite, bornite, tetrahedrite-tennantite, Cd-rich sphalerite and trace amount of gold. Previous investigators reported minor amount of native bismuth, molybdenite, enargite and stibnite (Bol'shakov *et al.*, 2010). In total sulfide mineralization comprises 1.5-3 volume % of Cu-rich ore.

Sulfide

Pyrite is most abundant mineral in Baranevskoe deposit. It was found in each ore types as isolated grains, in contact with other sulfides and native metals. In the brecciated quartz-carbonate-adularia ores some individual grains host tiny inclusions of gold and/or galena (Fig. 11.3.1b.). In Stockwork ore body pyrite was frequently observed in contact with gold and tellurides such as hessite, altaite and petzite (Fig. 11.3.1a.). Typical feature of this pyrite is impurities of As with highest value of about 3-5 at%. In Cu-rich ores catalysed pyrite forms massive aggregates and associates with chalcopyrite mainly. Cracks in mineral are filled by chalcopyrite. Impurities of As was not detected by electron micro probe analysis in pyrite from the cupriferous ores. Chemical composition of pyrite is given in Table 11.3.1.

Chalcopyrite is also ubiquitous in all ore types, coexisting with sphalerite, galena and pyrite in brecciated quartz-carbonate-adularia ores (Fig. 11.3.1a-c.) and with pyrite, bornite and tetrahedrite-tennantite in cupriferous ores (Fig. 11.3.1e-g.). Some chalcopyrite of Cu-rich ore hosts inclusions of gold and tetrahedrite (Fig. 11.3.1i.). Most abundant mode of occurrence is intergrowth with bornite and tetrahedrite-tennantite group minerals (Fig. 11.3.1e & f.). Typical micrographic texture of exsolution chalcopyrite from bornite was often observed (Fig. 11.3.1g.). In the cupriferous ore

chalcopryrite is also filling small cracks in fractured pyrite, which has been deposited formerly.

Sphalerite occurs as individual grains and intergrown with pyrite, chalcopryrite and galena in the brecciated quartz-carbonate-adularia ores mostly (Fig. 11.3.1c & d).

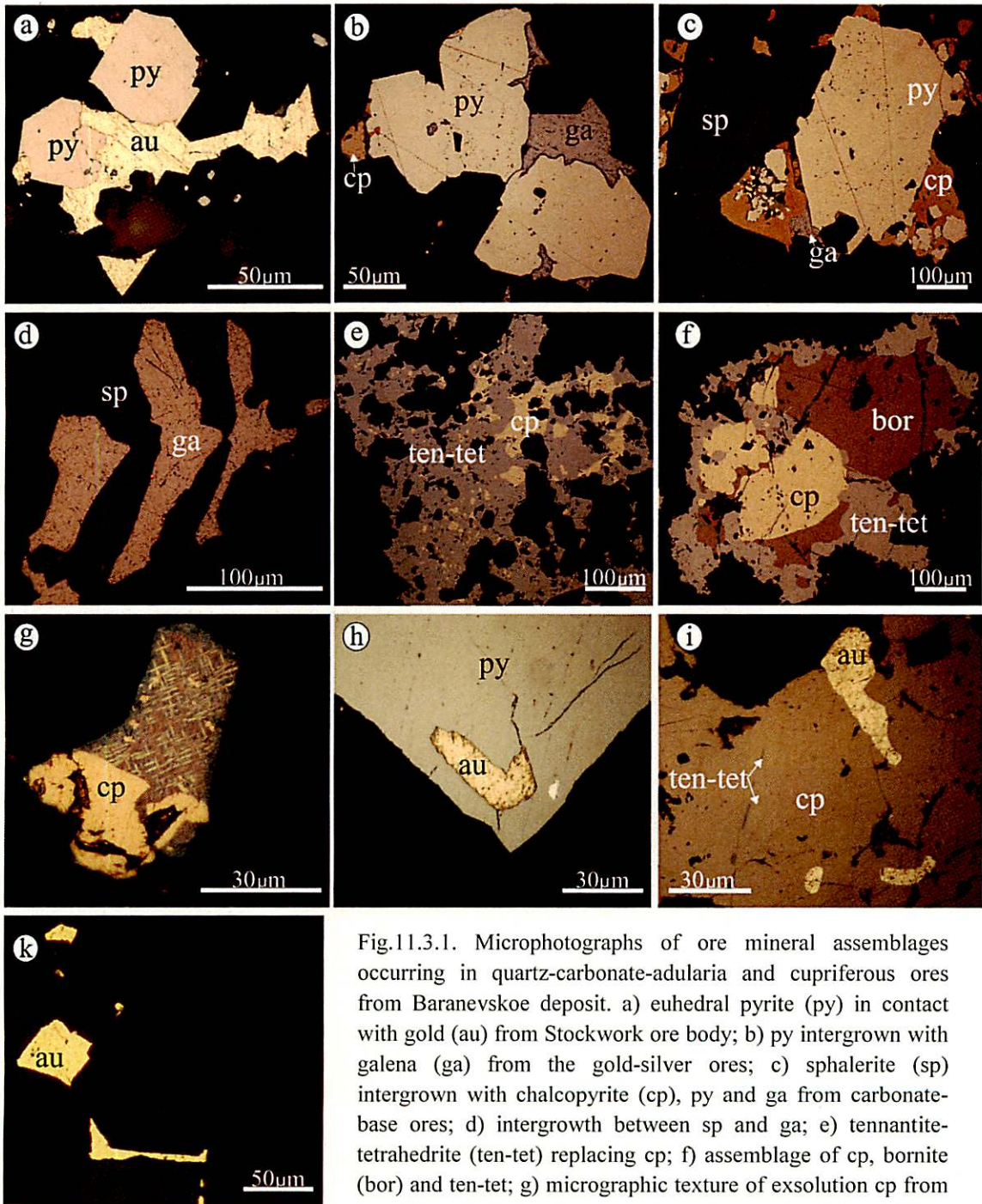


Fig.11.3.1. Microphotographs of ore mineral assemblages occurring in quartz-carbonate-adularia and cupriferous ores from Baranevskoe deposit. a) euhedral pyrite (py) in contact with gold (au) from Stockwork ore body; b) py intergrown with galena (ga) from the gold-silver ores; c) sphalerite (sp) intergrown with chalcopryrite (cp), py and ga from carbonate-base ores; d) intergrowth between sp and ga; e) tennantite-tetrahedrite (ten-tet) replacing cp; f) assemblage of cp, bornite (bor) and ten-tet; g) micrographic texture of exsolution cp from bor; h) au inclusion in euhedral py; i) au enclosed in cp; k) au crystals from the carbonate-quartz ore facies.

It frequently shows chalcopyrite disease. FeS content in sphalerite ranges from 0.1 to 6.2 mole % (Fig. 11.3.2.). MnS and InS contents were not detected by mean of the EPMA. In this study sphalerite was not observed in the cupriferous ores. Rare sphalerite with impurities of Cd up to 23 wt% was reported in previously published papers. Chemical composition of sphalerite is given in Table 11.3.2.

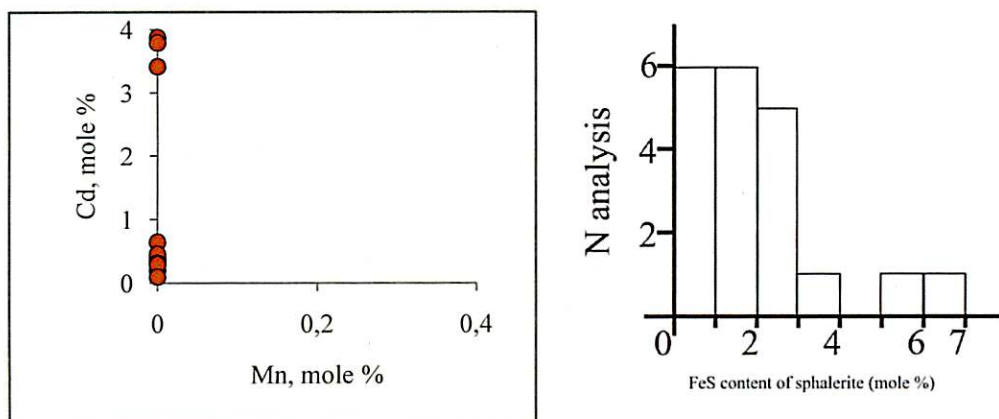


Fig.11.3.2. Impurities of Cd and Fe in sphalerite from brecciated quartz-carbonate-adularia-gold-silver ores. Left plot: scattered diagram of Cd vs. Mn content of sphalerite. Right plot: diagram of FeS content in sphalerite.

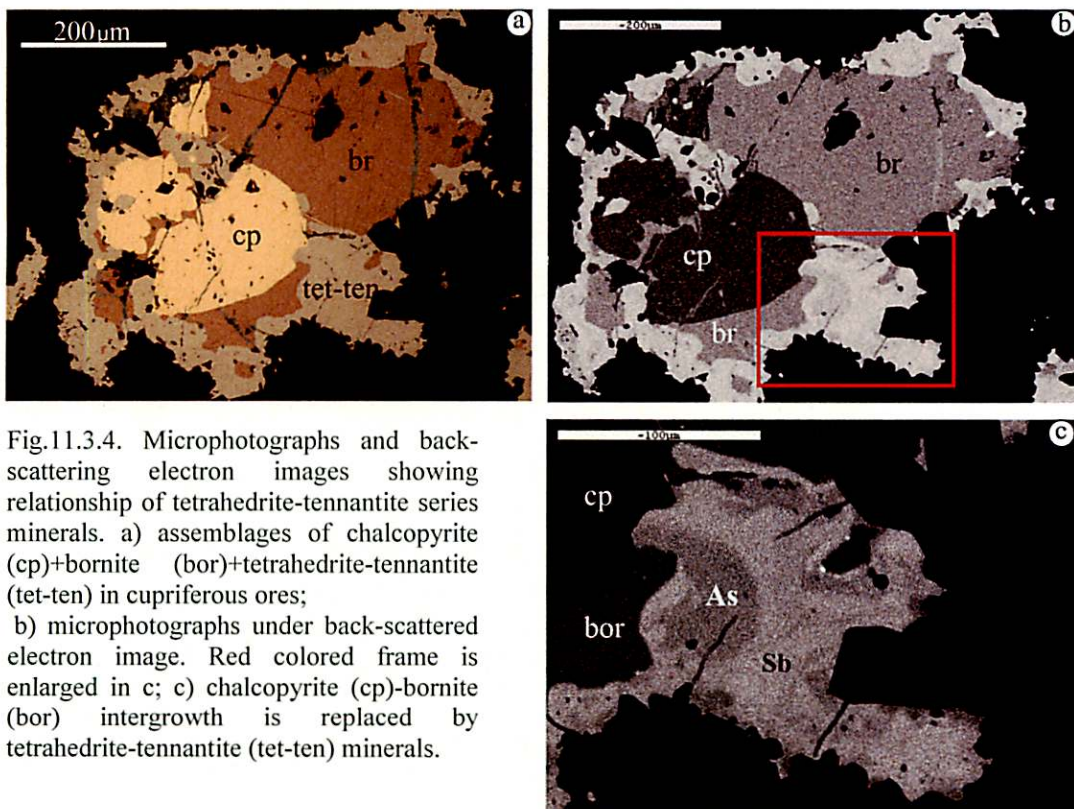
Apart from previous described sulfides galena was much rare observed in vein samples. Usually it was found in intergrown with pyrite and sphalerite in the quartz-carbonate-adularia ores (Fig. 11.3.1b, c & d). In Cu-rich ore type galena was not found in this study. Representative micro probe analysis of galena is written in Table 11.3.3.

Bornite was mainly observed in intergrown with chalcopyrite and tetrahedrite-tennantite solid solution in the cupriferous ore type (Fig. 11.3.1f.). As it mention before, bornite frequently exhibits a micrographic texture (Fig. 11.3.1g.), suggesting a hypogene genesis of bornite.

Sulfosalts

Tetrahedrite group minerals tend to be strictly occurred in Cu-rich ores. Only rarely fahlore was observed in the quartz-adularia-carbonate breccias occurring in Central vein. Tetrahedrite group minerals are the solid solution between tetrahedrite and tennantite. In ores they appear to be replacing chalcopyrite or/and intergrown with

chalcopyrite and bornite (Fig. 11.3.1e & f.). A two-hundred electron micro-probe analysis relieved a continuous intergrading of tetrahedrite and tennantite. Investigation of internal structure using back-scattered electron images showed random distributions of Sb and As within tetrahedrite-tennantite regarding to a mixed composition or replacing tennantite by tetrahedrite (Fig. 11.3.4.). Representative EPMA analysis of tetrahedrite-tennantite series with calculated chemical formulas are listed in Table 11.3.4. and graphically expressed in Fig 11.3.5. An average Ag substitution in tetrahedrite-tennantite is 0.09 at%, thus, Ag was eliminated from the formula calculating. Basically all tetrahedrite-tennantite is characterized by low Zn content (less than 1 a.p.f.). The Fe content in tennantite is generally higher than in tetrahedrite. Ratio of $(Sb/(Sb+As))$ and $(Zn/(Zn+Fe))$ in tetrahedrite-tennantite is ranging from 0.1-0.8 and 0.4-0.8, respectively. Generally, tetrahedrite-tennantite from Baranevskoe deposit are closed to the ideal formula, containing approximately 11 a.p.f of Cu, 2 a.p.f. of Zn+Fe, 4 a.p.f of Sb+As and 13 a.p.f. of S. Another varieties such goldfieldite and annivite were not identified in this research.



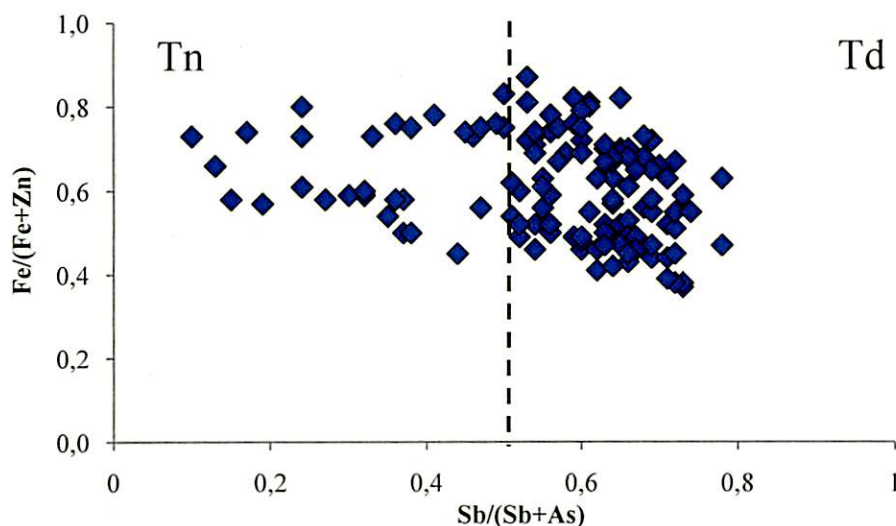


Fig.11.3.5. Chemical variation of tetrahedrite–tennantite fahlore from Baranenskoe deposit as a function of $\text{Fe}/(\text{Fe}+\text{Zn})$ and $\text{Sb}/(\text{Sb}+\text{As})$.

Native metals

Au-rich electrum is main Au-bearing phase in Baranenskoe deposit. It is a major ore mineral in stockwork, brecciated quartz-carbonate-adularia and carbonate-quartz ores. In cupriferous ores, however, electrum refers to a trace mineral. Additionally, well-development octahedral gold crystals and their dendritic branches were found in vugs of metasomatites (Fig. 11.3.6.).

In the brecciated quartz-adularia ores of the Central vein gold is coexisting with both As-bearing and As-free pyrite, chalcopyrite, sphalerite and galena (Fig. 11.3.1a, h.). The Au content varies from 68-72 at% in general (Fig. 11.3.4.). Much of the gold in stockwork occurs in contact with pyrite and hessite (Fig. 11.3.1a.). Au content is ranging from 60 to 72 at%.

Fig.11.3.6. Typical euhedral single gold crystal is grown on aggregates of euhedral quartz in vug of metasomatite. Single gold crystals are rare. Clear growth steps are seen on the surface of crystal.



In cupriferous ore, gold enclosed mainly in chalcopyrite (Fig. 11.3.1i.) contains Au from 59 to 64 at%. In carbonate ores elongated-shaped gold occupies the interstitial positions between carbonate crystals (Fig. 11.3.1k.). The Au content is about 68-72 at%. Chemical composition of gold from gold-silver ores and Stockwork ore body is identical (Fig. 11.3.7.). Unique single euhedral gold crystals, their dendritic branches and single elongated sheet-like gold crystals lying on comb quartz aggregates display well-development shapes of crystals with growth steps on surface meaning the free growing conditions (Fig. 11.3.6.). Au content of native gold is widely ranging from 64 to 74 at%. Chemical composition of gold for gold-silver ores, stockwork and carbonate ores is given in Tables 11.3.5, 11.3.6 and 11.3.7.

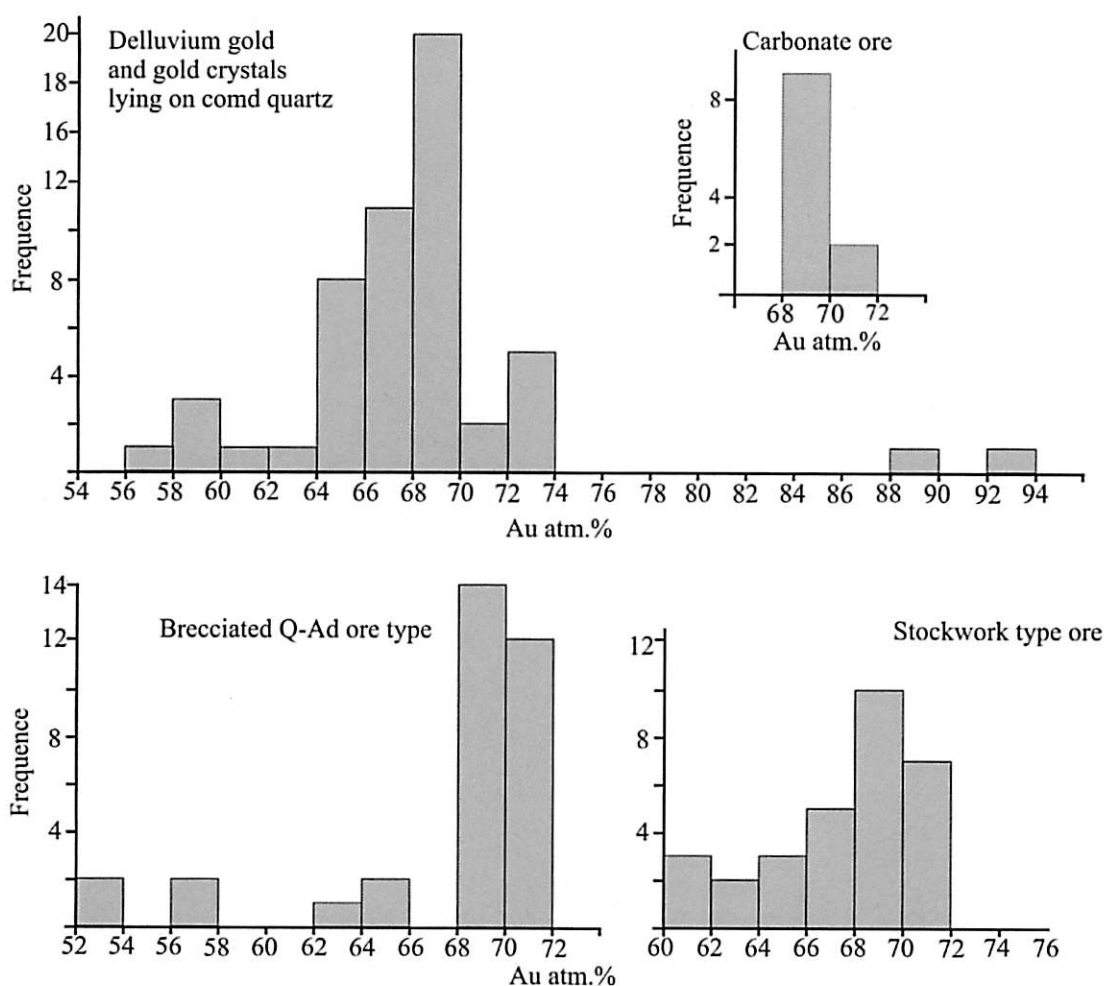


Fig.11.3.7. Au content in gold from different ore types of Baranevskoe deposit.

Zolotoe deposit

Sulfide poor ores is consisted of electrum, native gold, sphalerite, galena, chalcopryte, pyrite and trace amount of tellurides and sulfosalts. Sulfide rich ore is composed on 90% of pyrite, hosting micron size gold inclusions. Definition on sulfide-poor and sulfide-rich ores is tentative based on occurrence of pyrite. As it was outlined in Chapter IX total sulfides with other ore minerals comprises around 3 % of vein fill.

Sulfide

Pyrite is most abundant sulfide in both sulfide-rich and sulfide-poor ores. In sulfide-rich ores pyrite comprises more than 90 percent of the vein fill. Euhedral pyrite hosts micron-size inclusions of gold, which could be seen under the high-resolution microscope or in the back-scattered electron images. Frequently this pyrite contains minor impurities of As. In sulfide poor ores pyrite was observed as cubic and sub-rounded grains in quartz and enclosed in chalcopryte (Fig. 11.3.8a.).

Chalcopryte was observed in sulfide-poor ores in association with sphalerite and galena mainly (Fig. 11.3.8b-d.).

Sphalerite is also one of most common sulfides in the sulfide-poor ores. Anhedral sphalerite occurs as isolated grains and in contact with chalcopryte and galena. Frequently sphalerite is crossed by late quartz veins, bearing sphalerite, chalcopryte and galena. All sphalerite grains observed in this study showed chalcopryte disease (Fig. 12.3.8b, d.). Micro-probe analysis data revealed moderate quantities of Fe and relatively high of Cd (Fig. 11.3.9.). Chemical composition is given in Table 11.3.8.

Galena co-exists with chalcopryte and sphalerite in sulfide-poor ores (Fig. 12.3.8b, c, d.). Small quantities of Se were detected by mean of EPMA. Chemical composition is presented in Table 11.3.9.

In this study gold was observed in sulfide-rich and sulfide-poor ores, however, due to extremely small size of gold inclusions in pyrite the micro-probe analysis were not available for gold from sulfide-rich ore. A few micro-probe analyses showed Au content of 59.64 at%. In sulfide-poor ores gold occurs as free grains in quartz-adularia

gangue. Based on Ag content in gold two group of gold were distinguished (Fig. 11.3.10.). First group includes gold with relative high Ag content (Ag – 68-78 at%) and second group of gold with low Ag content (Ag – 82-88 at%). Chemical composition is given in Table 11.3.10.

Other sulfides and sulfosalts mentioned in this chapter were reported previously by other researchers.

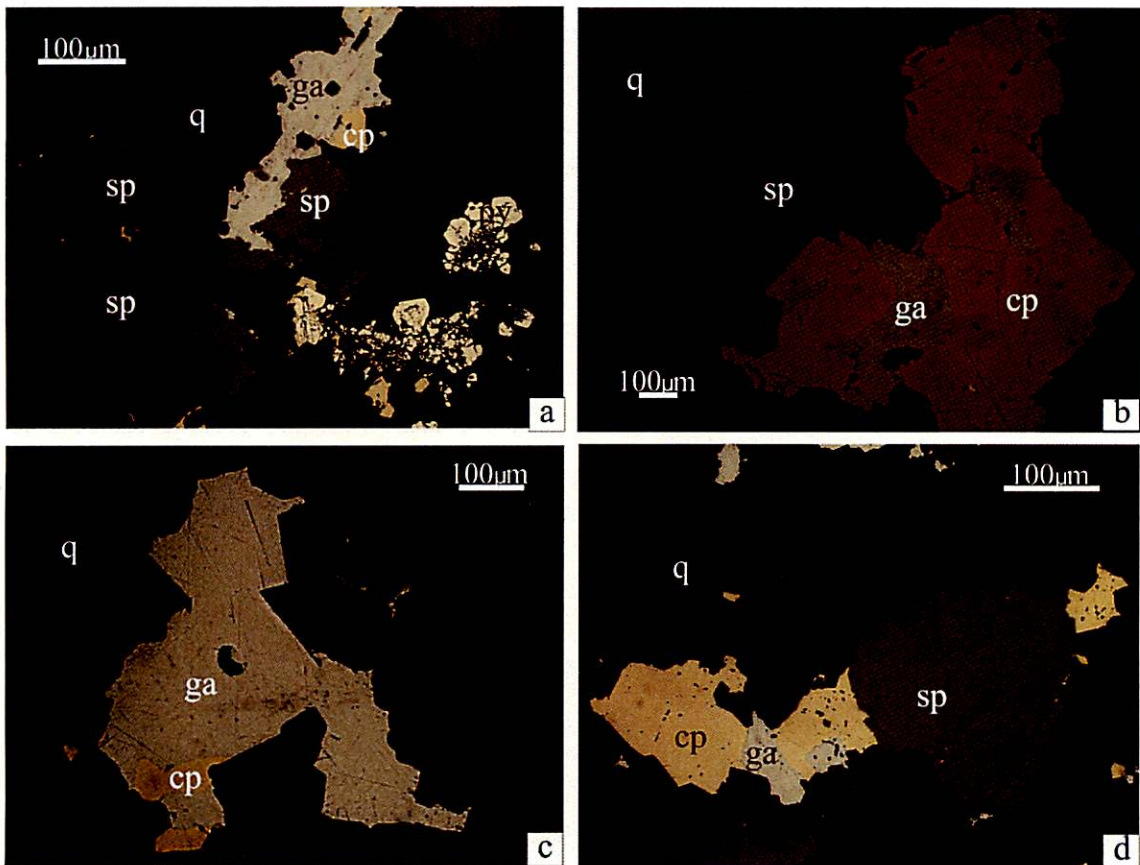


Fig.11.3.8. Mode of occurrence of sulfide in sulfide-poor ores from Zolotoe deposit. a) euhedral pyrite (py) in association with galena (ga) and sphalerite (sp); b) chalcopyrite (cp) hosting galena (ga) and intergrown with sphalerite (sp); c) galena (ga) with chalcopyrite (cp) inclusions; d) intergrowth between chalcopyrite (cp), sphalerite (sp) and galena (ga).

Kungurcevskoe deposit

Main vein mineral in ores from Kungurcevskoe deposit is gold associated with pyrite, sphalerite and galena. The principal gold mineral in ores is a silver-rich native gold with Au content around 80 wt% and Ag up to 20 wt%, respectively. Gold was found in Main ore body, veins 14 and 17. Irregular shape gold occurs at the margin of

host rocks subrounded blocks sealed in hydrothermal breccias of Main ore body (Fig.10.4.1.4 a.). This gold is often seen megascopally. Subhedral gold crystals

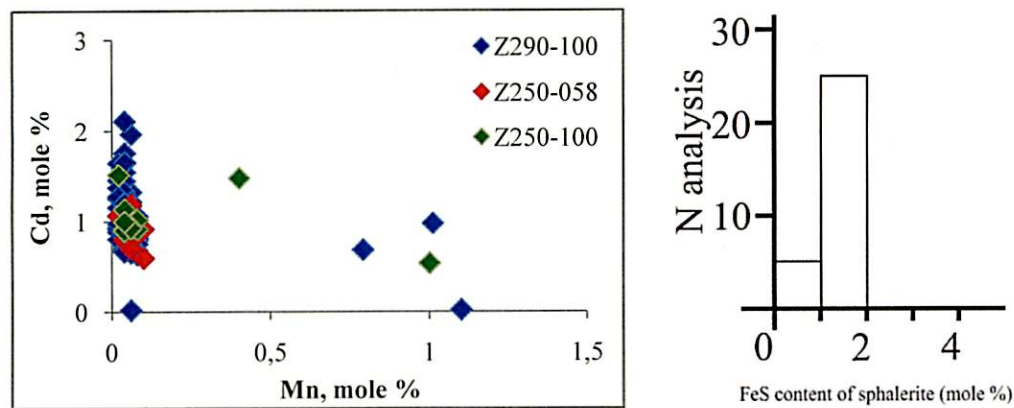


Fig.11.3.9. Impurities of Cd and Fe in sphalerite from brecciated quartz-carbonate-adularia-gold-silver ores from Zolotoe deposit. Left plot: scattered diagram of Cd vs. Mn content of sphalerite. Right plot: diagram of FeS content in sphalerite.

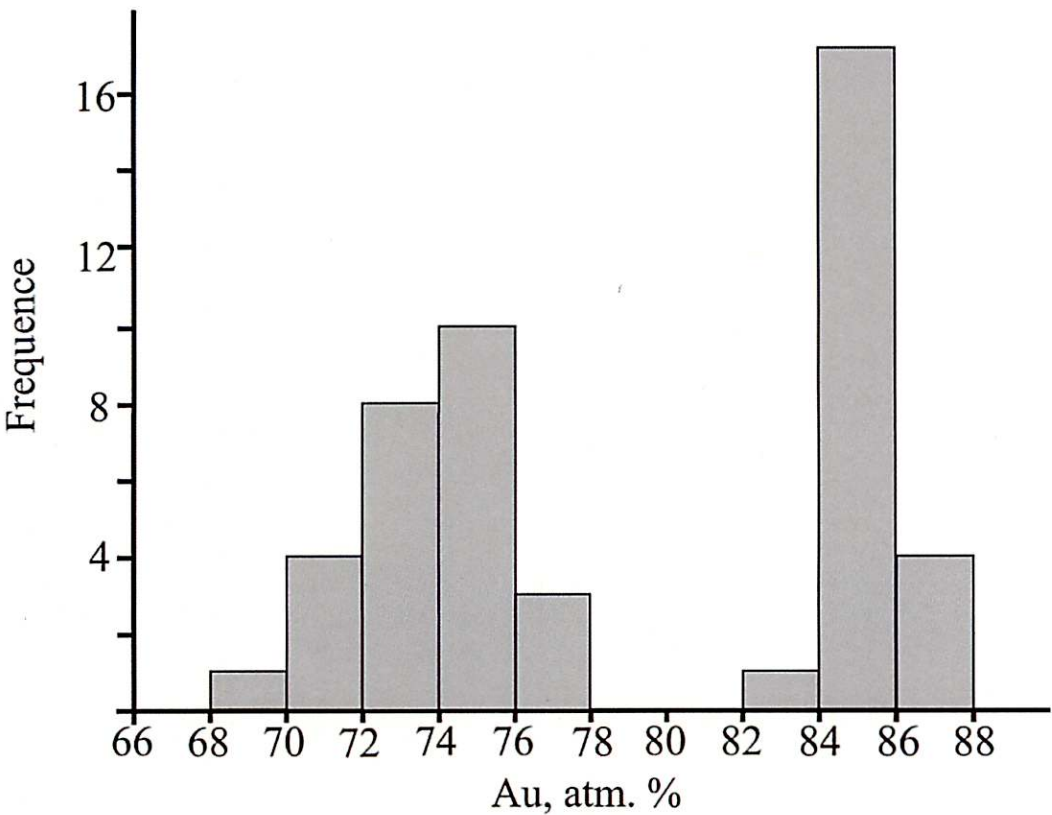


Fig.11.3.10. Au content in gold from Zolotoe deposit.

are filled up free spaces among quartz crystals in vein 17 (Fig.10.4.1.4b.). Gold occurs as isolated isometric and elongated crystals in clays of vein 14 (Fig. 10.4.1.4c.). Silver is a single impurity determined in the gold by electron-micro probe analysis. Highest amount of Ag with 19 at% were detected in gold from Main ore body. In contrast, gold occurred in clays of vein 14 contains Ag from 30 to 14 at%. Ag in gold from vein 17 is usually below 30 at% of Ag. Variations of Ag in gold are shown in Fig. 11.3.11.

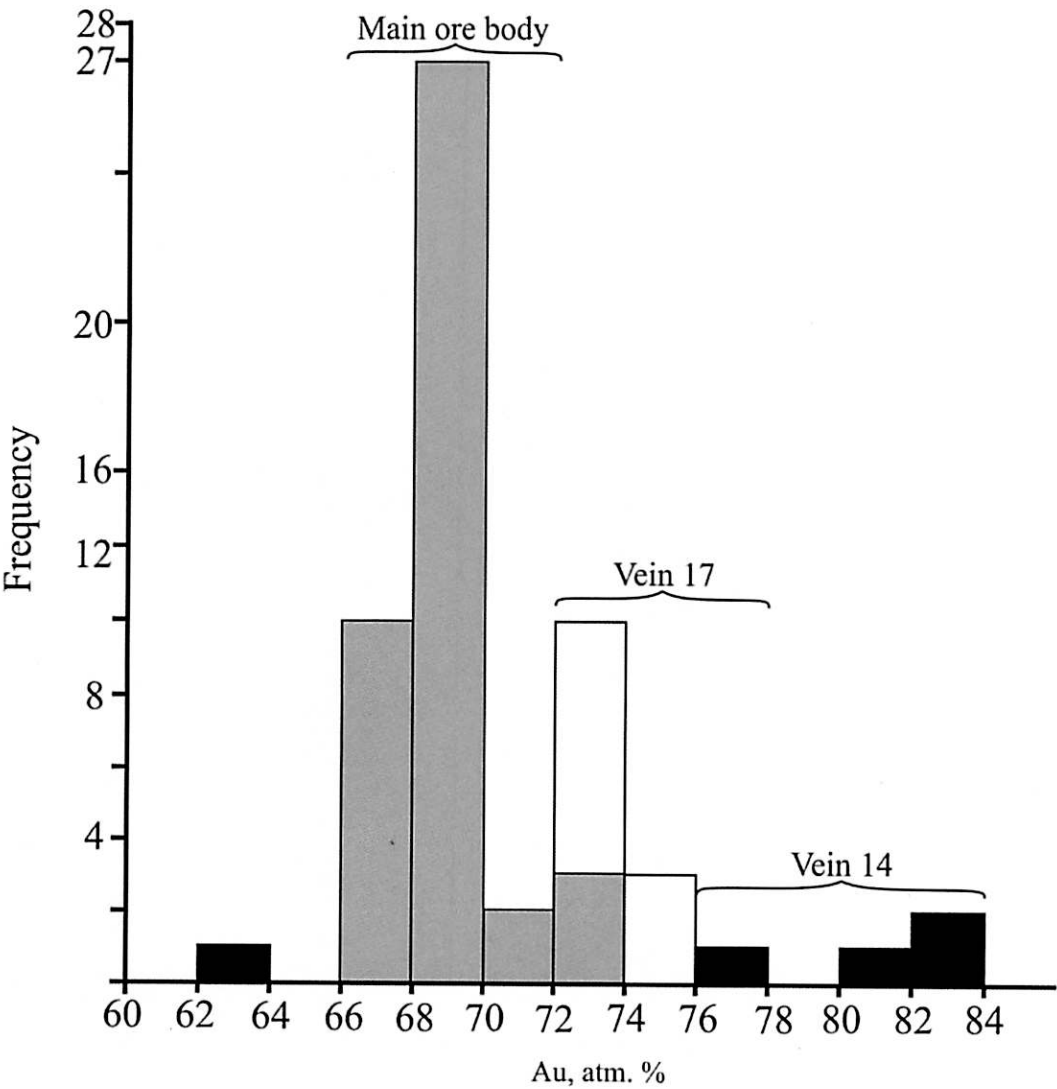


Fig.11.3.11. Au content in gold from Kungurcevscoe deposit.

Table 1.3.1. Representative micro-probe analysis of pyrite from gold-silver quartz-carbonate-adularia ores of Baranevskoe deposit.

№	1	2	3	4	5	6	7	8	9	10	11	12
Fe	46.65	46.41	45.44	46.17	47.09	46.12	46.72	46.08	47.06	45.61	46.78	45.71
S	53.55	54.04	53.30	53.70	52.31	51.73	53.36	53.17	51.64	49.18	51.78	50.48
As	0.55	0.66	0.99	0.69	-	-	-	-	-	1.92	2.64	1.77
Sum	100.75	101.10	99.73	100.56	99.40	97.85	100.08	99.25	98.70	96.71	101.20	97.96

№	1	2	3	4	5	6	7	8	9	10	11	12
Fe	33.29	32.90	32.69	32.91	34.09	33.87	33.55	33.38	34.35	34.38	33.68	33.87
S	66.42	66.75	66.78	66.72	65.91	66.13	66.45	66.62	65.65	64.54	64.91	65.15
As	0.29	0.35	0.53	0.37	-	-	-	-	-	1.08	1.41	0.98

Table I 1.3.2. Representative micro-probe analysis of sphalerite from gold-silver quartz-carbonate-adularia ores of Baranevskoe deposit.

№	1	2	3	4	5	6	7	8	9	10	11	12
Zn	64.93	63.68	64.17	64.71	64.14	65.06	64.88	62.76	63.13	61.40	62.53	64.48
S	33.43	34.23	31.84	31.59	31.26	32.43	31.81	37.78	31.55	33.99	34.32	31.69
Fe	1.19	1.68	0.08	0.11	0.31	0.10	0.24	0.95	1.53	4.28	2.64	0.65
Cd	0.40	0.41	0.99	0.40	0.41	0.45	0.12	0.46	0.65	0.13	0.35	0.49
Sum	99.95	100.00	97.08	96.81	96.12	98.04	97.05	101.95	96.86	99.80	99.84	97.31

№	1	2	3	4	5	6	7	8	9	10	11	12
Zn	48.20	46.96	49.45	49.97	49.92	49.45	49.84	48.68	48.71	47.170	45.99	49.60
S	50.61	51.44	50.03	49.75	49.60	50.26	49.82	50.25	49.62	48.42	51.46	49.59
Fe	1.03	1.43	0.08	0.10	0.29	0.09	0.22	0.87	1.38	4.28	2.40	0.59
Cd	0.16	0.17	0.44	0.18	0.19	0.20	0.12	0.20	0.29	0.13	0.15	0.22

Table 1.3.3. Representative micro-probe analysis of galena from gold-silver quartz-carbonate-adularia ores of Baranevskoe deposit.

№	1	2	3	4	5	6	7
Pb	86.95	88.38	89.00	88.39	88.53	86.06	88.23
S	12.34	12.21	12.38	12.44	12.38	12.31	12.75
Sum	99.29	100.59	101.38	100.83	100.91	98.37	100.98

№	1	2	3	4	5	6	7
Pb	52.69	53.11	52.66	52.37	53.47	52.91	52.14
S	47.31	46.89	47.34	47.63	46.53	47.09	47.86

Table I 1.3.4. Representative micro-probe analysis of tetrahedrite-tennantite series minerals from cupriferous ores of Baranevskoe deposit.

Wt%	1	2	3	4	5	6	7	8	9	10
Cu	43.19	44.20	41.81	42.14	45.3	43.19	42.02	42.52	44.49	41.17
Ag	0.12	0.04	0.14	0.08	0.04	0.12	0.14	0.19	0.06	0.12
Fe	2.88	3.41	2.35	2.35	4.38	3.20	2.82	2.81	3.33	3.92
Zn	3.32	2.77	3.80	3.92	1.93	2.98	2.73	3.10	2.82	3.74
Sb	17.53	9.69	19.93	19.03	3.31	18.21	22.59	17.47	5.05	18.25
As	8.35	13.78	6.77	7.18	18.84	9.17	5.39	8.73	17.57	7.29
S	25.61	27.10	26.04	25.66	27.94	25.63	25.26	25.80	26.97	25.84
Sum	101.00	100.99	100.84	100.36	101.74	102.5	100.95	100.62	100.29	100.33

No of atoms	29	29	29	29	29	29	29	29	29	29
Cu	10.727	10.571	10.449	10.571	10.484	10.626	10.652	10.582	10.571	10.266
Ag	0.017	0.006	0.020	0.023	0.006	0.017	0.020	0.026	0.009	0.020
Fe	0.815	0.928	0.670	0.670	1.151	0.896	0.812	0.798	0.896	1.114
Zn	0.800	0.644	0.925	0.954	0.432	0.711	0.673	0.748	0.650	0.748
Sb	2.274	1.212	2.598	2.491	0.403	2.337	2.990	2.271	0.638	2.375
As	1.760	2.799	1.436	1.528	3.698	1.911	1.16	1.844	3.541	1.543
S	12.606	12.841	12.902	12.763	12.821	12.502	12.693	12.731	12.696	12.775

Table I 1.3.5. Representative micro-probe analysis of native gold from gold-silver quartz-carbonate-adularia ores of Baranevskoe deposit.

№	1	2	3	4	5	6	7	8	9	10	11	12
Au	80.55	81.61	81.69	79.95	79.67	79.74	75.52	82.20	82.13	80.12	76.13	76.72
Ag	19.10	18.39	18.30	20.05	20.33	19.89	24.83	17.80	17.88	19.88	23.88	23.28
Sum	99.65	100.00	99.99	100.00	100.00	99.63	100.35	100.00	100.01	100.00	100.01	100.00

№	1	2	3	4	5	6	7	8	9	10	11	12
Au	69.79	70.86	70.97	68.58	68.22	68.70	62.81	71.67	71.55	69.41	64.49	65.78
Ag	30.21	29.14	29.03	31.42	31.78	31.30	37.19	28.33	28.45	30.59	35.51	34.23

Table 11.3.6. Representative micro-probe analysis of native gold from stockwork of Baranevskoe deposit.

№	1	2	3	4	5	6	7	8	9	10	11	12
Au	78.55	80.35	78.57	79.48	80.07	79.17	78.56	78.06	78.02	78.34	77.87	77.62
Ag	18.20	18.79	18.86	18.72	18.37	18.65	19.14	18.85	18.73	17.75	18.67	18.68
Sum	96.75	99.14	97.43	98.20	98.44	97.82	97.70	96.91	96.75	96.09	96.55	96.30

№	1	2	3	4	5	6	7	8	9	10	11	12
Au	70.27	70.08	69.52	69.92	70.48	69.93	69.21	69.39	69.53	70.73	69.55	69.48
Ag	29.73	29.92	30.48	30.08	29.52	30.07	30.79	30.61	30.48	29.27	30.45	30.52

Table I.3.7. Representative micro-probe analysis of native gold from carbonate ores of Baranevskoe deposit.

№	1	2	3	4	5	6	7	8	9	10	11
Au	80.00	80.78	78.87	81.16	80.89	80.69	80.73	80.79	79.76	79.33	79.22
Ag	19.71	19.27	20.00	18.26	19.40	20.50	19.71	19.94	20.43	20.67	20.37
Sum	99.71	100.05	98.87	99.42	100.29	101.19	100.45	100.73	100.19	100.00	99.59

№	1	2	3	4	5	6	7	8	9	10	11
Au	69.51	70.04	68.76	71.17	69.84	68.68	69.42	69.21	68.85	68.44	68.45
Ag	30.49	29.96	31.24	28.83	30.16	31.32	30.58	30.79	31.25	31.56	31.55

Table11.3.8. Representative micro-probe analysis of sphalerite from gold-silver quartz-carbonate-adularia ores of Zolotoe deposit.

№	1	2	3	4	5	6	7	8	9	10	11	12
Zn	64.16	64.39	64.16	64.39	64.36	64.46	64.79	64.88	65.13	64.40	64.69	64.66
S	32.78	32.51	32.44	32.50	32.75	32.58	32.91	32.58	32.92	31.66	32.74	31.64
Fe	0.84	0.49	0.46	0.44	1.00	0.51	0.67	0.59	0.53	0.55	1.21	1.07
Mn	0.04	0.01	0.02	0.02	0.04	0.02	0.02	0.01	0.02	-	0.03	0.04
Cd	0.97	1.65	1.75	2.01	0.92	1.50	1.58	1.31	1.38	1.13	0.82	0.80
Sum	98.79	99.04	98.81	99.35	99.07	99.08	99.56	99.37	99.99	97.74	99.50	98.21

№	1	2	3	4	5	6	7	8	9	10	11	12
Zn	48.39	48.70	48.65	48.64	48.44	48.69	48.57	48.87	48.71	49.45	48.50	49.38
S	50.41	50.14	50.16	50.07	50.25	50.18	50.31	50.03	50.20	49.56	50.05	49.27
Fe	0.74	0.43	0.46	0.39	0.88	0.45	0.59	0.52	0.47	0.49	1.06	0.96
Mn	0.04	0.73	0.02	0.02	0.03	0.02	0.02	0.01	0.02	-	0.03	0.04
Cd	0.97	0.01	1.75	0.88	0.40	0.66	0.51	0.58	0.60	0.51	0.36	0.35

Table 11.3.9. Representative micro-probe analysis of galena from gold-silver quartz-carbonate-adularia ores of Zolotoe deposit.

№	1	2	3	4	5	6	7	8	9	10	11	12
Pb	86.64	85.98	86.81	87.06	85.28	86.33	86.84	86.82	87.27	87.15	87.38	86.15
S	13.76	13.88	13.85	13.74	13.04	13.79	14.00	13.55	13.87	13.63	14.20	13.34
Se	0.48	-	-	-	-	-	-	-	-	-	-	-
Sum	100.38	99.86	100.66	100.81	98.32	100.13	100.84	100.38	101.14	100.78	101.58	99.49

№	1	2	3	4	5	6	7	8	9	10	11	12
Pb	49.79	48.94	49.23	49.50	50.30	49.20	48.98	49.78	49.34	49.74	87.38	49.95
S	50.47	51.06	50.77	50.50	49.70	50.80	51.02	50.22	50.66	50.26	12.62	49.55
Se	0.34	-	-	-	-	-	-	-	-	-	-	-

Table 11.3.10. Representative micro-probe analysis of native gold from gold-silver quartz-carbonate-adularia ores of Zolotoe deposit.

Nº	1	2	3	4	5	6	7	8	9	10	11	12
Au	91.81	91.99	91.65	90.51	90.77	75.99	78.61	77.93	78.17	79.55	78.62	79.18
Ag	8.20	8.01	8.31	9.49	9.23	24.01	21.39	20.59	22.10	20.90	20.40	20.51
Sum	100.01	99.89	99.96	100.00	100.00	100.00	100.00	98.52	100.27	100.45	99.02	99.69

Nº	1	2	3	4	5	6	7	8	9	10	11	12
Au	85.98	86.28	85.80	83.93	84.33	63.41	66.81	67.46	65.95	67.58	67.86	67.89
Ag	14.02	13.72	14.20	16.07	15.67	36.59	33.19	32.54	34.05	32.42	32.14	32.11

Table 10.3.1.1. Representative micro-probe analysis of native gold from Main ore body of Kungurcevskoe deposit.

№	1	2	3	4	5	6	7	8	9	10	11	12
Au	83.14	80.13	81.83	78.18	82.20	81.38	81.77	78.93	81.14	80.90	77.69	80.54
Ag	18.01	18.08	18.66	17.90	18.41	18.69	18.48	18.61	18.77	19.10	18.64	19.46
Sum	101.15	98.23	100.49	96.08	100.60	100.07	100.25	97.54	99.91	100.00	96.32	100.00

№	1	2	3	4	5	6	7	8	9	10	11	12
Au	71.56	70.80	70.63	70.47	70.98	70.49	70.78	69.91	70.33	69.87	69.49	69.31
Ag	28.44	29.12	29.37	29.53	29.02	29.51	29.22	30.09	29.67	30.13	30.51	30.69

Table 11.3.12. Representative micro-probe analysis of native gold from vein 17 of Kungurcevskoe deposit.

№	1	2	3	4	5	6	7	8	9	10	11	12
Au	83.15	83.63	84.03	83.05	83.65	83.22	83.81	84.46	84.46	83.40	84.04	83.62
Ag	16.91	16.38	15.97	16.27	16.35	16.77	16.19	15.54	15.54	16.60	16.34	16.38
Sum	100.06	100.01	100.00	99.22	100.00	99.99	100.00	100.00	100.00	100.00	100.38	100.00

№	1	2	3	4	5	6	7	8	9	10	11	12
Au	72.92	73.65	74.24	73.65	73.70	73.10	73.92	73.53	74.85	73.35	73.71	73.66
Ag	27.08	26.34	25.76	26.35	26.30	26.90	26.08	26.47	15.15	26.65	26.29	26.34

Chapter XII. Characteristics of hydrothermal fluids

12.1. Fluid inclusions

12.1.1. Nature of fluid inclusions

12.1.2. Melting and homogenization temperatures

12.2. Gas composition of fluid inclusion

12.3. Stable isotopes of quartz and carbonate

Chapter XII. Characteristics of hydrothermal fluids

12.1. Fluid inclusions

General outline of fluid inclusion studies are giving in Chapter VI. Herein, descriptions of fluid inclusions occurring in different ores types at the Balkhach ore cluster with results of microthermometry are given. Main aim was to find out temperature of hydrothermal solutions for each deposit and difference in temperature.

12.1.1. Nature of fluid inclusions

Baranevskoe deposit

Fluid inclusions were found in quartz of gold-silver-quartz-carbonate-adularia and cupriferous ores, and quartz druses. Quartz of both gold-silver and cupriferous ores are intensively brecciated and closely associated with ore mineralization.

In cupriferous ores inclusions with size of about 2-8 μm are very randomly distributed within quartz crystals. Aqueous inclusions with vapor bubble, occupying approximately 10-15 vol% are predominant. Vapor-dominated inclusions are rare, and usually co-existing with aqueous ones. Only one inclusion consisting of only vapor phase was observed in cupriferous ores in this study. Definition of inclusions on primary and secondary was complicated.

In gold-silver ores quartz consists of numerous inclusions of primary and secondary origin. Primary inclusions of different size and shape basically occur in central and upper parts of quartz crystals and comprise of liquid-phase mainly with vapor phase of about 2-30 vol% (Fig. 12.1.1.1a.). Vapor-dominated inclusions are very rare. Single gaseous inclusions were observed in swarm of liquid rich inclusions (Fig. 12.1.1.1b.). Secondary inclusions are widespread in gold-silver ores. They show linear occurrence crosscutting one/two or more quartz crystals.

Euhedral quartz crystals filling cavity in metasomatite host plenty of two-phase primary and secondary inclusions, which sporadically distributed in crystals. Both types of inclusions are aqueous mainly. Typically inclusions are small in size of about 5-10 μm with tube and amoeboid shapes. Some inclusions of oblong forms are exceeded 50 μm in length.

Zolotoe deposit

Quartz samples for fluid-inclusions studies were collected along drill holes and outcrops of both sulfide-poor and sulfide rich ores. Quartz of both ores is enriched in fluid inclusions. Significant differences in morphology and size of fluid inclusions from sulfide-poor and sulfide-rich ores were not noticed. Quartz of both ore types host numerous liquid-rich and vapor-dominated inclusions of elongated, rounded and negative crystals shape sporadically occurring as swarm in central parts of quartz crystals (Fig. 12.1.1.1c, d.). In contrast to Baranevskoe deposit, vapor-dominated inclusions were much more frequently observed in quartz from Zolotoe deposit. Aqueous and vapor-dominated inclusions are occurred in same group (Fig. 12.1.1c.).

Kungurcevskoe deposit

Fluid inclusions were found in clear quartz of Main ore body and veins 14 and 17 collected from outcrop at Kungurcevskoe deposit. All quartz is clear transparent comb euhedral crystals in close contact with gold mineralization.

Quartz of vein 14 shows inclusions are concentrated along growth zone, central and upper parts of quartz crystals. They are rounded, negative crystals, tube or irregular in shape with liquid-vapor ration of about 20-30 vol% (Fig. 12.1.1.1e.). Size varies from a few microns up to 20 μm . Vapor-dominated and gaseous inclusions occur individually and presented among aqueous inclusions.

Fluid inclusions hosted in quartz of vein 17 are typically submicron in size characterized by diversity of shapes. Inclusions are liquid-rich (vapor comprise 10-40 vol% of cavity) and vapor-dominated (vapor exceed up to 100 vol%). However, latest were rarely observed.

Aggregates of comb quartz of Main ore body consist of classic primary inclusions of negative shape and micron size occurring individually or as group of two and more inclusions in central part of crystals (Fig. 12.1.1.1f.). Mainly inclusions are two-phase type consisting on 70-80 % of liquid and on 30-20 % of vapor. Single phase vaporous inclusions are rare.

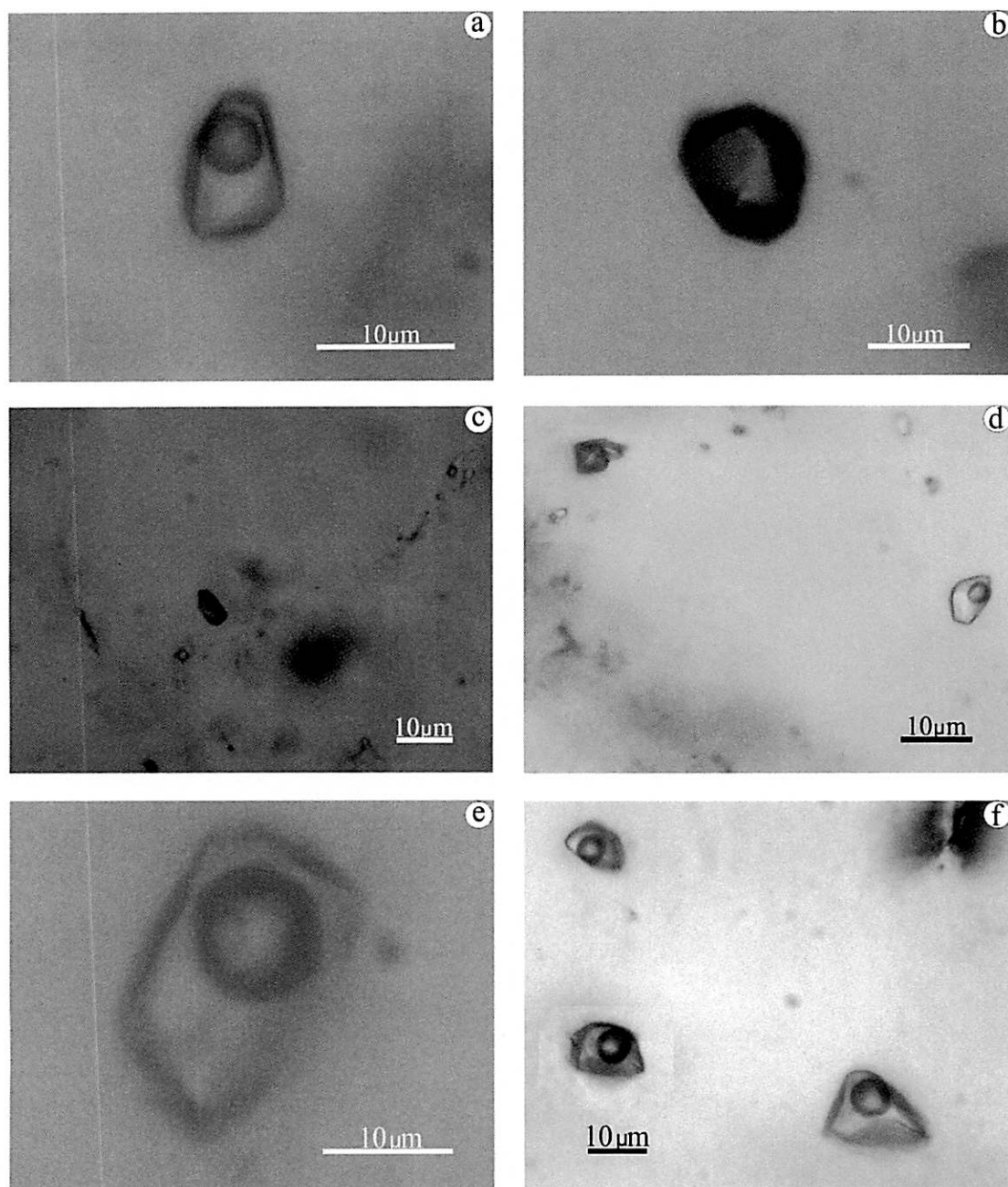


Fig.12.1.1.1. Mode of occurrence of primary fluid inclusions in Baranevskoe (a,b), Zolotoe (c,d) and Kungurcevscoe (e,f) deposits: a) two-phase liquid-rich primary fluid inclusion with negative crystal outlines in gold-silver ores of Baranevskoe deposit; b) rare vapor-dominated primary fluid inclusion in gold-silver ores of Baranevskoe deposit; c) vapor primary fluid inclusion in sulfide-poor ore of Zolotoe deposit; d) co-existing of primary liquid-rich fluid inclusion with primary vapor fluid inclusion in sulfide-rich ore of Zolotoe deposit; e) primary two-phase fluid inclusion in quartz from vein 14 of Kungurcevscoe deposit; f) group of liquid-rich primary fluid inclusions with typical negative crystal shape in quartz from Main ore body of Kungurcevscoe deposit.

12.1.2. Melting and homogenization temperatures

Style of quartz occurrence along with optic characteristics suggests that quartz of Main ore body, vein 14 and 17 of Kungurcevskoe deposit belongs to one stage of generation and similar to quartz in metasomatite of Baranevskoe deposit. Gold-bearing quartz of Central vein and Stockwork ore body of Baranevskoe deposit is similar to the vein quartz of Zolotoe deposit. Microthermometric measurements were performed on vein quartz. Primary inclusions were preferentially measured. Tables 12.1.2.1, 12.1.2.2 and 12.1.2.3 is summarized data on homogenization temperatures for each deposit.

Baranevskoe deposit

Histograms of primary and secondary fluid inclusions homogenization temperatures from cupriferous, gold-silver ores and quartz druses are shown in Fig. 12.1.2.1. All of inclusions homogenize into vapor phase. Melting temperatures and salinity were not always measured, because of very small size.

Presumably primary fluid inclusions of cupriferous ores homogenize in extremely low temperature range of 154-232 °C (Fig. 12.1.2.1a.). Melting temperature of last ice ranges from -0.4 to -0.6 °C, and subsequently salinity of fluid inclusions varies from 0.7 to 1.1 wt% NaCl equiv. Homogenization temperatures of fluid inclusions in quartz of gold-silver ores are higher than in cupriferous ores. Primary inclusions homogenize from 190-280 °C (Fig. 12.1.2.1b.). Melting temperature ranges broadly from -0.4 to -1.0 °C. Salinity is varying from 1.2 to 1.7 wt% NaCl equiv. (Fig. 12.1.2.3.). Secondary inclusions homogenize over wide range of temperatures 150-280 °C generally showing lower temperature than primary inclusions. Range of melting temperatures and salinity are same as for primary inclusions. Primary inclusions in quartz druses are high-temperature ones. Majority of inclusions homogenize from 230-300 °C. Some inclusions homogenize under temperature higher than 300 °C (Fig. 12.1.2.1c.). Final melting temperature occurs at -0.5 and -1.0 °C. Salinity ranges from 0.9 to 1.7 wt% NaCl equiv. (Fig. 12.1.2.3.). Secondary inclusions of quartz druses homogenize at temperature from 150 to 280 °C. Melting temperatures and salinity are same as for primary ones.

Zolotoe deposit

Primary fluid inclusions show wide range of homogenization temperatures from 160-280 °C (Fig. 12.1.2.2.). At level of from 80 to 120 m below surface fluid inclusions have highest homogenization exceed to 270-280 °C (Fig. 12.1.2.2.). Upper and below fluid inclusion homogenization temperatures tend to be cooler with maximum of 260 °C. From fluid inclusions studies two population of fluid inclusions are distinguished: low-temperature (160-210 °C) and relatively higher (230-280 °C). Temperature of ice melting and salinity varies from -0.6 to -0.9 °C and 1.1-1.6 wt% NaCl equiv., respectively (Fig. 12.1.2.3.). Secondary inclusions homogenize under lower temperatures of 170-240 °C with ice melting temperatures of -0.7 to 0.9 °C and salinity 1.2-1.6 wt% NaCl equiv., respectively.

Kungurcevscoe deposit

Primary two-phase inclusions in comb quartz of Main ore body homogenize at temperatures from 194 to 251 °C, however some individual inclusions homogenize at temperatures 301, 339 and 369 °C (Fig. 12.1.2.2.). Secondary inclusions homogenize under low temperature range from 177 to 232 °C. Melting temperatures of primary and secondary inclusions vary from -0.6 to -1.0 °C, and salinity ranges from 1.1-1.7 wt% NaCl equiv. Fluid inclusions in quartz from vein 17 revealed lowest homogenization temperatures varying from 161 to 226 °C (Fig. 12.1.2.2.). Melting temperatures range from -0.4 to -0.9 °C, and salinity varies from 0.7 to 1.6 wt% NaCl equiv., respectively (Fig. 12.1.2.3.). Homogenization temperatures of secondary inclusions are in range of 137-211 °C. Melting temperatures and salinity are equal with the primary inclusions. Homogenization and melting temperatures of primary fluid inclusions in quartz from vein 14 range between 220 to 280 °C and -0.6 to - 1.0 °C. Secondary fluid inclusions homogenize under lower temperatures from 160-250 °C. Melting temperatures are same as in primary vary from -0.6 to -1.0 wt% NaCl equiv. Salinity of both primary and secondary inclusions is ranging from 1.1-1.7 wt% NaCl equiv.

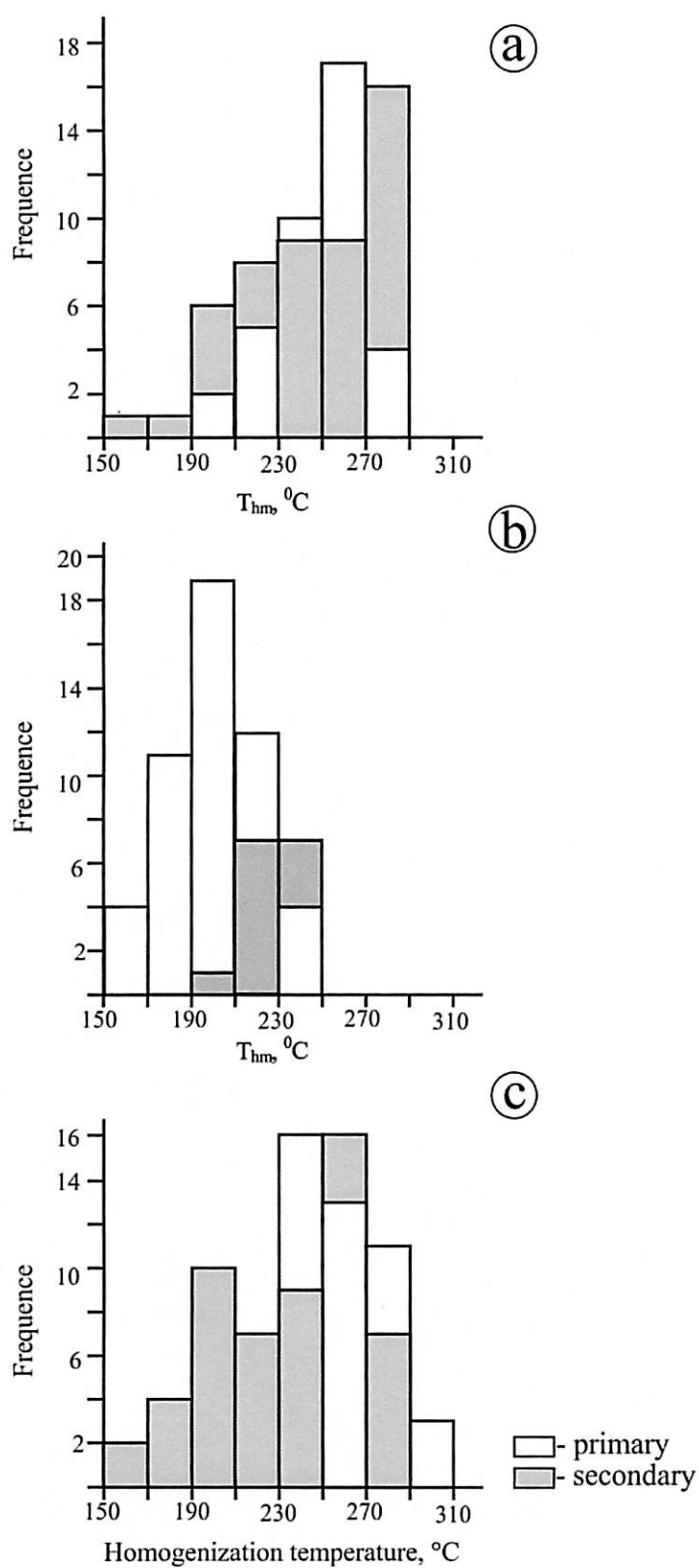


Fig.12.1.2.1. Homogenization temperatures obtained from fluid inclusions for quartz from brecciated quartz-carbonate-adularia ores (a), cupriferous ores (b) and quartz from metasomatites (c) of Baranenskoe deposit.

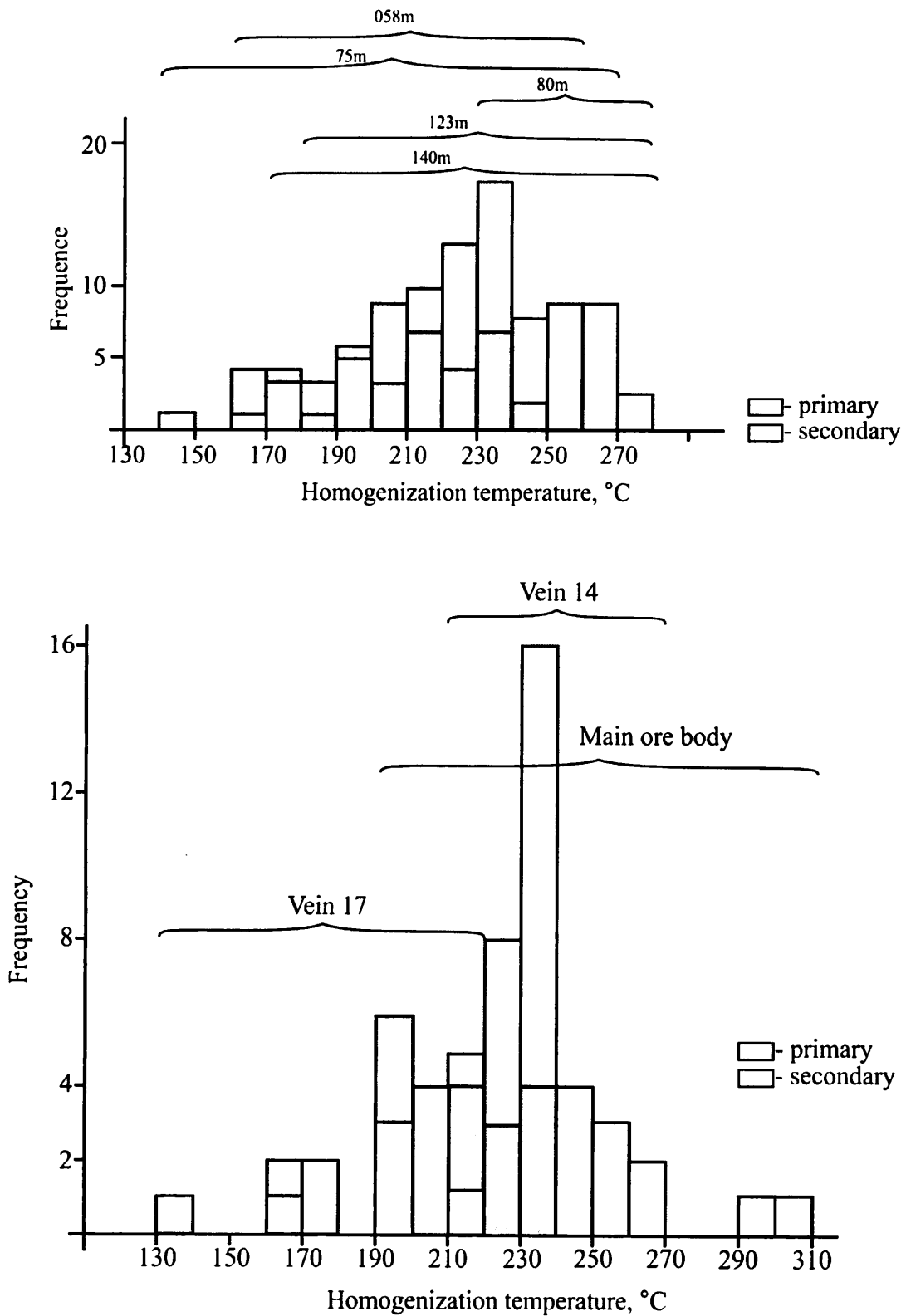


Fig.12.1.2.2. Homogenization temperatures obtained from fluid inclusions for quartz from Au-Ag quartz-carbonate-adularia ores from Zolotoe deposit (upper diagram) and Au-Ag ores from Kungurcevskoe deposit (lower diagram).

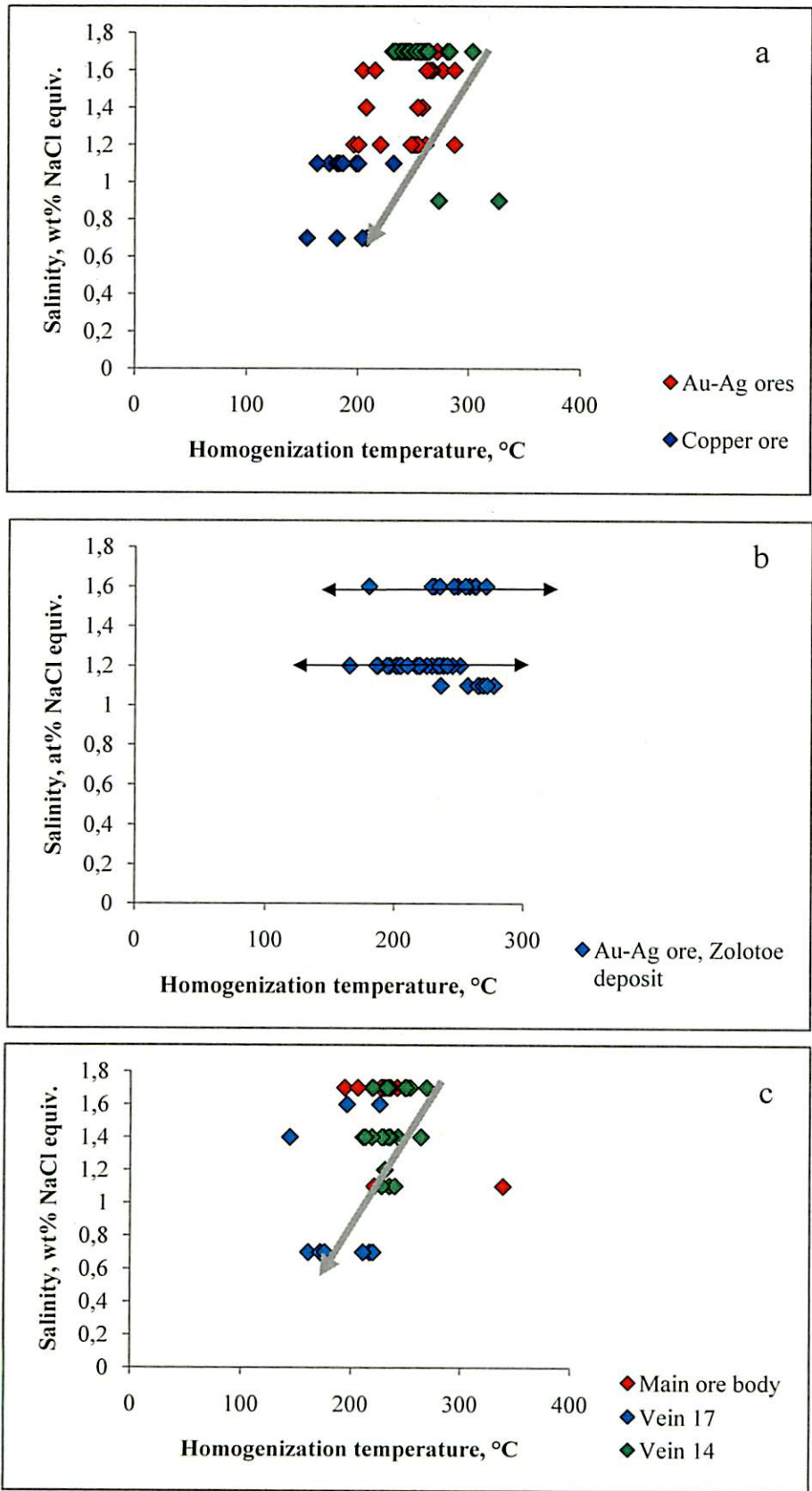


Fig.12.1.2.3. Salinity vs. homogenization temperatures: a) Baranaevskoe deposit; b) Zolotoe deposit; c) Kungurcevsckoe deposit.

Table 12.1.2.1 Fluid inclusions data on gold-silver quartz-carbonate-adularia ores from Baranevskoe deposit.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _h	Calib. T _h	NaCl wt%
1	B102	Quartz	pr.	286	276	-0.5	-0.9	1.6
2	B102	Quartz	pr.	208	204	-0.5	-0.9	1.6
3	B102	Quartz	pr.	276	267	-0.5	-0.9	1.6
4	B102	Quartz	pr.	273	265	-0.5	-0.9	1.6
5	B102	Quartz	pr.	220	215	-0.5	-0.9	1.6
6	B102	Quartz	pr.	270	262	-0.5	-0.9	1.6
7	B102	Quartz	pr.	270	262	-0.5	-0.9	1.6
8	B102	Quartz	pr.	297	287	-0.5	-0.9	1.6
9	B102	Quartz	pr.	240	234	-1.0	-1.0	1.7
10	B102	Quartz	pr.	240	234	-1.0	-1.0	1.7
11	B102	Quartz	pr.	262	254	-1.0	-1.0	1.7
12	B102	Quartz	pr.	265	257	-1.0	-1.0	1.7
13	B102	Quartz	pr.	280	271	-1.0	-1.0	1.7
14	B102	Quartz	pr.	246	239	-1.0	-1.0	1.7
15	B102	Quartz	pr.	246	239	-1.0	-1.0	1.7
16	B102	Quartz	pr.	247	240	-1.0	-1.0	1.7
17	B102	Quartz	pr.	249	242	-1.0	-1.0	1.7
18	B102	Quartz	pr.	258	250	-0.3	-0.7	1.2
19	B102	Quartz	pr.	269	261	-0.3	-0.7	1.2
20	B102	Quartz	pr.	269	261	-0.3	-0.7	1.2
21	B102	Quartz	pr.	269	261	-0.3	-0.7	1.2
22	B102	Quartz	pr.	297	287	-0.3	-0.7	1.2
23	B048	Quartz	pr.	260	252	-0.3	-0.7	1.2
24	B048	Quartz	pr.	200	196	-0.3	-0.7	1.2
25	B048	Quartz	pr.	262	254	-0.3	-0.7	1.2
26	B048	Quartz	pr.	225	220	-0.3	-0.7	1.2
27	B048	Quartz	pr.	255	248	-0.3	-0.7	1.2
28	B048	Quartz	pr.	204	200	-0.3	-0.7	1.2
29	B048	Quartz	pr.	266	258	-0.4	-0.8	1.4
30	B048	Quartz	pr.	212	207	-0.4	-0.8	1.4
31	B048	Quartz	pr.	262	254	-0.4	-0.8	1.4
32	B048	Quartz	pr.	266	258	-0.4	-0.8	1.4
33	B048	Quartz	pr.	262	254	-0.4	-0.8	1.4
34	B048	Quartz	pr.	224	219	-	-	-
35	B048	Quartz	pr.	237	231	-	-	-
36	B048	Quartz	pr.	237	231	-	-	-
37	B048	Quartz	pr.	259	251	-	-	-
38	B102	Quartz	sd.	267	259	-	-	-
39	B102	Quartz	sd.	290	280	-	-	-
40	B102	Quartz	sd.	255	248	-	-	-
41	B102	Quartz	sd.	265	257	-	-	-
42	B102	Quartz	sd.	240	234	-	-	-
43	B102	Quartz	sd.	272	264	-	-	-
44	B102	Quartz	sd.	272	264	-	-	-
45	B102	Quartz	sd.	275	266	-	-	-
46	B102	Quartz	sd.	277	268	-	-	-
47	B102	Quartz	sd.	278	269	-	-	-
48	B102	Quartz	sd.	280	271	-	-	-
49	B102	Quartz	sd.	292	282	-	-	-
50	B102	Quartz	sd.	214	209	-1.0	-1.0	1.7
51	B102	Quartz	sd.	222	217	-1.0	-1.0	1.7
52	B102	Quartz	sd.	230	224	-1.0	-1.0	1.7

53	B102	Quartz	sd.	238	232	-1.0	-1.0	1.7
54	B102	Quartz	sd.	238	232	-1.0	-1.0	1.7
55	B102	Quartz	sd.	214	209	-1.0	-1.0	1.7
56	B102	Quartz	sd.	235	229	-1.0	-1.0	1.7
57	B102	Quartz	sd.	240	234	-1.0	-1.0	1.7
58	B102	Quartz	sd.	246	239	-1.0	-1.0	1.7
59	B102	Quartz	sd.	246	239	-1.0	-1.0	1.7
60	B102	Quartz	sd.	246	239	-1.0	-1.0	1.7
61	B102	Quartz	sd.	250	243	-1.0	-1.0	1.7
62	B102	Quartz	sd.	260	252	-1.0	-1.0	1.7
63	B102	Quartz	sd.	264	256	-1.0	-1.0	1.7
64	B102	Quartz	sd.	167	165	-0.3	-0.7	1.2
65	B102	Quartz	sd.	177	175	-0.3	-0.7	1.2
66	B102	Quartz	sd.	200	196	-0.3	-0.7	1.2
67	B102	Quartz	sd.	206	202	-0.3	-0.7	1.2
68	B102	Quartz	sd.	208	204	-0.3	-0.7	1.2
69	B102	Quartz	sd.	210	205	-0.3	-0.7	1.2
70	B102	Quartz	sd.	214	209	-0.3	-0.7	1.2
71	B102	Quartz	sd.	216	211	-0.3	-0.7	1.2
72	B102	Quartz	sd.	220	215	-0.3	-0.7	1.2
73	B102	Quartz	sd.	220	215	-0.3	-0.7	1.2
74	B102	Quartz	sd.	220	215	-0.3	-0.7	1.2
75	B102	Quartz	sd.	228	222	-0.3	-0.7	1.2
76	B102	Quartz	sd.	280	271	-0.3	-0.7	1.2
77	B102	Quartz	sd.	282	273	-0.3	-0.7	1.2
78	B102	Quartz	sd.	282	273	-0.3	-0.7	1.2
79	B102	Quartz	sd.	285	276	-0.3	-0.7	1.2
80	B048	Quartz	sd.	300	290	-0.3	-0.6	1.1
81	B048	Quartz	sd.	268	260	-0.3	-0.6	1.1
82	B048	Quartz	sd.	365	351	-0.3	-0.6	1.1
83	B048	Quartz	sd.	267	259	-0.3	-0.6	1.1
84	B048	Quartz	sd.	265	257	-0.3	-0.6	1.1
85	B048	Quartz	sd.	260	252	-0.3	-0.6	1.1
86	B048	Quartz	sd.	262	254	-0.3	-0.6	1.1
87	B048	Quartz	sd.	265	257	-	-	-

Table 12.1.2.1 Continued: Fluid inclusions data on copper ores from Baranevskoe deposit.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _h	Calib. T _h	NaCl wt%
1	BCJ1	Quartz	pr.	176	174	-0.2	-0.6	1.1
2	BCJ1	Quartz	pr.	184	181	-0.2	-0.6	1.1
3	BCJ1	Quartz	pr.	165	163	-0.2	-0.6	1.1
4	BCJ1	Quartz	pr.	202	198	-0.2	-0.6	1.1
5	BCJ1	Quartz	pr.	186	183	-0.2	-0.6	1.1
6	BCJ1	Quartz	pr.	165	163	-0.2	-0.6	1.1
7	BCJ1	Quartz	pr.	238	232	-0.2	-0.6	1.1
8	BCJ1	Quartz	pr.	202	198	-0.2	-0.6	1.1
9	BCJ1	Quartz	pr.	202	198	-0.2	-0.6	1.1
10	BCJ1	Quartz	pr.	204	200	-0.2	-0.6	1.1
11	BCJ1	Quartz	pr.	189	186	-0.2	-0.6	1.1
12	BCJ1	Quartz	pr.	165	163	-0.2	-0.6	1.1
13	BCJ1	Quartz	pr.	204	200	-0.2	-0.6	1.1
14	BCJ1	Quartz	pr.	184	181	0.0	-0.4	0.7
15	BCJ1	Quartz	pr.	213	208	0.0	-0.4	0.7

16	BCJ1	Quartz	pr.	209	204	0.0	-0.4	0.7
17	BCJ1	Quartz	pr.	155	154	0.0	-0.4	0.7

Table 12.1.2.1 Continued: Fluid inclusions data on quartz druses from Baranenskoe deposit.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _h	Calib. T _h	NaCl wt%
1	MBJ1	Quartz	pr.	244	237	-0.6	-1.0	1.7
2	MBJ1	Quartz	pr.	237	231	-0.6	-1.0	1.7
3	MBJ1	Quartz	pr.	250	243	-0.6	-1.0	1.7
4	MBJ1	Quartz	pr.	253	246	-0.6	-1.0	1.7
5	MBJ1	Quartz	pr.	253	246	-0.6	-1.0	1.7
6	MBJ1	Quartz	pr.	250	243	-0.6	-1.0	1.7
7	MBJ1	Quartz	pr.	250	243	-0.6	-1.0	1.7
8	MBJ1	Quartz	pr.	252	245	-0.6	-1.0	1.7
9	MBJ1	Quartz	pr.	253	246	-0.6	-1.0	1.7
10	MBJ1	Quartz	pr.	254	247	-0.6	-1.0	1.7
11	MBJ1	Quartz	pr.	259	251	-0.6	-1.0	1.7
12	MBJ1	Quartz	pr.	267	259	-0.6	-1.0	1.7
13	MBJ1	Quartz	pr.	268	260	-0.6	-1.0	1.7
14	MBJ1	Quartz	pr.	270	262	-0.6	-1.0	1.7
15	MBJ1	Quartz	pr.	272	264	-0.6	-1.0	1.7
16	MBJ1	Quartz	pr.	290	280	-0.6	-1.0	1.7
17	MBJ1	Quartz	pr.	239	233	-0.6	-1.0	1.7
18	MBJ1	Quartz	pr.	247	240	-0.6	-1.0	1.7
19	MBJ1	Quartz	pr.	251	244	-0.6	-1.0	1.7
20	MBJ1	Quartz	pr.	251	244	-0.6	-1.0	1.7
21	MBJ1	Quartz	pr.	253	246	-0.6	-1.0	1.7
22	MBJ1	Quartz	pr.	259	251	-0.6	-1.0	1.7
23	MBJ1	Quartz	pr.	259	251	-0.6	-1.0	1.7
24	MBJ1	Quartz	pr.	260	252	-0.6	-1.0	1.7
25	MBJ1	Quartz	pr.	264	256	-0.6	-1.0	1.7
26	MBJ1	Quartz	pr.	269	261	-0.6	-1.0	1.7
27	MBJ1	Quartz	pr.	271	263	-0.6	-1.0	1.7
28	MBJ1	Quartz	pr.	292	282	-0.6	-1.0	1.7
29	MBJ1	Quartz	pr.	314	303	-0.6	-1.0	1.7
30	MBJ1	Quartz	pr.	340	327	-0.1	-0.5	0.9
31	MBJ1	Quartz	pr.	282	273	-0.1	-0.5	0.9
32	MBJ1	Quartz	pr.	271	263	-	-	-
33	MBJ1	Quartz	pr.	273	265	-	-	-
34	MBJ1	Quartz	pr.	267	259	-	-	-
35	MBJ1	Quartz	pr.	273	265	-	-	-
36	MBJ1	Quartz	pr.	273	265	-	-	-
37	MBJ1	Quartz	pr.	242	235	-	-	-
38	MBJ1	Quartz	pr.	256	249	-	-	-
39	MBJ1	Quartz	pr.	273	265	-	-	-
40	MBJ1	Quartz	pr.	277	268	-	-	-
41	MBJ1	Quartz	pr.	278	269	-	-	-
42	MBJ1	Quartz	pr.	283	274	-	-	-
43	MBJ1	Quartz	pr.	300	290	-	-	-
44	MBJ1	Quartz	pr.	330	318	-	-	-
45	MBJ1	Quartz	sd.	234	228	-0.6	-1.0	1.7
46	MBJ1	Quartz	sd.	237	231	-0.6	-1.0	1.7
47	MBJ1	Quartz	sd.	236	230	-0.6	-1.0	1.7
48	MBJ1	Quartz	sd.	184	181	-0.6	-1.0	1.7

49	MBJ1	Quartz	sd.	184	181	-0.6	-1.0	1.7
50	MBJ1	Quartz	sd.	199	195	-0.6	-1.0	1.7
51	MBJ1	Quartz	sd.	207	203	-0.6	-1.0	1.7
52	MBJ1	Quartz	sd.	210	205	-0.6	-1.0	1.7
53	MBJ1	Quartz	sd.	214	209	-0.6	-1.0	1.7
54	MBJ1	Quartz	sd.	214	209	-0.6	-1.0	1.7
55	MBJ1	Quartz	sd.	224	219	-0.6	-1.0	1.7
56	MBJ1	Quartz	sd.	225	220	-0.6	-1.0	1.7
57	MBJ1	Quartz	sd.	260	252	-0.6	-1.0	1.7
58	MBJ1	Quartz	sd.	272	264	-0.6	-1.0	1.7
59	MBJ1	Quartz	sd.	290	280	-0.6	-1.0	1.7
60	MBJ1	Quartz	sd.	294	284	-0.6	-1.0	1.7
61	MBJ1	Quartz	sd.	199	195	-0.6	-1.0	1.7
62	MBJ1	Quartz	sd.	206	202	-0.6	-1.0	1.7
63	MBJ1	Quartz	sd.	236	230	-0.6	-1.0	1.7
64	MBJ1	Quartz	sd.	236	230	-0.6	-1.0	1.7
65	MBJ1	Quartz	sd.	238	232	-0.6	-1.0	1.7
66	MBJ1	Quartz	sd.	238	232	-0.6	-1.0	1.7
67	MBJ1	Quartz	sd.	257	250	-0.6	-1.0	1.7
68	MBJ1	Quartz	sd.	260	252	-0.6	-1.0	1.7
69	MBJ1	Quartz	sd.	260	252	-0.6	-1.0	1.7
70	MBJ1	Quartz	sd.	260	252	-0.6	-1.0	1.7
71	MBJ1	Quartz	sd.	266	258	-0.6	-1.0	1.7
72	MBJ1	Quartz	sd.	267	259	-0.6	-1.0	1.7
73	MBJ1	Quartz	sd.	269	261	-0.6	-1.0	1.7
74	MBJ1	Quartz	sd.	279	270	-0.6	-1.0	1.7
75	MBJ1	Quartz	sd.	267	259	-	-	-
76	MBJ1	Quartz	sd.	267	259	-	-	-
77	MBJ1	Quartz	sd.	270	262	-	-	-
78	MBJ1	Quartz	sd.	242	235	-	-	-
79	MBJ1	Quartz	sd.	250	243	-	-	-
80	MBJ1	Quartz	sd.	218	213	-	-	-
81	MBJ1	Quartz	sd.	210	205	-	-	-
82	MBJ1	Quartz	sd.	161	160	-	-	-
83	MBJ1	Quartz	sd.	166	164	-	-	-
84	MBJ1	Quartz	sd.	183	180	-	-	-
85	MBJ1	Quartz	sd.	183	180	-	-	-
86	MBJ1	Quartz	sd.	199	195	-	-	-
87	MBJ1	Quartz	sd.	199	195	-	-	-
88	MBJ1	Quartz	sd.	209	205	-	-	-
89	MBJ1	Quartz	sd.	220	215	-	-	-
90	MBJ1	Quartz	sd.	243	236	-	-	-
91	MBJ1	Quartz	sd.	250	243	-	-	-
92	MBJ1	Quartz	sd.	262	254	-	-	-
93	MBJ1	Quartz	sd.	269	261	-	-	-
94	MBJ1	Quartz	sd.	272	264	-	-	-
95	MBJ1	Quartz	sd.	272	264	-	-	-
96	MBJ1	Quartz	sd.	287	278	-	-	-
97	MBJ1	Quartz	sd.	290	280	-	-	-
98	MBJ1	Quartz	sd.	293	283	-	-	-
99	MBJ1	Quartz	sd.	314	303	-	-	-
100	MBJ1	Quartz	sd.	161	160	-	-	-

Table 12.1.2.2 Fluid inclusions data on quartz from Zolotoe deposit.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _h	Calib. T _h	NaCl wt%
1	0.58 m	Quartz	pr.	253	246	-0.5	-0.9	1.6
2	0.58 m	Quartz	pr.	245	238	-0.3	-0.7	1.2
3	0.58 m	Quartz	pr.	208	204	-0.3	-0.7	1.2
4	0.58 m	Quartz	pr.	200	196	-0.3	-0.7	1.2
5	0.58 m	Quartz	pr.	252	245	-0.3	-0.7	1.2
6	0.58 m	Quartz	pr.	210	205	-0.3	-0.7	1.2
7	0.58 m	Quartz	pr.	167	165	-0.3	-0.7	1.2
8	0.58 m	Quartz	pr.	205	201	-0.3	-0.7	1.2
9	0.58 m	Quartz	pr.	239	233	-0.3	-0.7	1.2
10	0.58 m	Quartz	pr.	235	229	-0.3	-0.7	1.2
11	0.58 m	Quartz	pr.	259	251	-0.3	-0.7	1.2
12	0.58 m	Quartz	pr.	231	225	-0.3	-0.7	1.2
13	0.58 m	Quartz	pr.	206	202	-0.3	-0.7	1.2
14	0.58 m	Quartz	pr.	209	205	-0.3	-0.7	1.2
15	0.58 m	Quartz	pr.	198	194	-0.3	-0.7	1.2
16	0.58 m	Quartz	pr.	210	205	-0.3	-0.7	1.2
17	80 m	Quartz	pr.	274	265	-0.2	-0.6	1.1
18	80 m	Quartz	pr.	286	277	-0.2	-0.6	1.1
19	80 m	Quartz	pr.	275	266	-0.2	-0.6	1.1
20	80 m	Quartz	pr.	275	266	-0.2	-0.6	1.1
21	80 m	Quartz	pr.	265	257	-0.2	-0.6	1.1
22	80 m	Quartz	pr.	274	265	-0.2	-0.6	1.1
23	80 m	Quartz	pr.	273	265	-0.2	-0.6	1.1
24	80 m	Quartz	pr.	243	236	-0.2	-0.6	1.1
25	80 m	Quartz	pr.	278	269	-0.2	-0.6	1.1
26	80 m	Quartz	pr.	281	272	-0.2	-0.6	1.1
27	123 m	Quartz	pr.	254	245	-0.3	-0.7	1.2
28	123 m	Quartz	pr.	231	225	-0.3	-0.7	1.2
29	123 m	Quartz	pr.	209	205	-0.3	-0.7	1.2
30	123 m	Quartz	pr.	242	235	-0.3	-0.7	1.2
31	123 m	Quartz	pr.	248	241	-0.3	-0.7	1.2
32	123 m	Quartz	pr.	222	217	-0.3	-0.7	1.2
33	123 m	Quartz	pr.	190	187	-0.3	-0.7	1.2
34	123 m	Quartz	pr.	189	186	-0.3	-0.7	1.2
35	123 m	Quartz	pr.	226	220	-0.3	-0.7	1.2
36	123 m	Quartz	pr.	224	219	-0.3	-0.7	1.2
37	123 m	Quartz	pr.	215	210	-0.3	-0.7	1.2
38	123 m	Quartz	pr.	266	258	-0.5	-0.9	1.6
39	123 m	Quartz	pr.	238	231	-0.5	-0.9	1.6
40	123 m	Quartz	pr.	183	180	-0.5	-0.9	1.6
41	123 m	Quartz	pr.	235	229	-0.5	-0.9	1.6
42	123 m	Quartz	pr.	270	262	-0.5	-0.9	1.6
43	123 m	Quartz	pr.	256	249	-0.5	-0.9	1.6
44	123 m	Quartz	pr.	266	258	-0.5	-0.9	1.6
45	123 m	Quartz	pr.	242	235	-0.5	-0.9	1.6
46	123 m	Quartz	pr.	271	263	-0.5	-0.9	1.6
47	123 m	Quartz	pr.	253	246	-0.5	-0.9	1.6
48	123 m	Quartz	pr.	263	255	-0.5	-0.9	1.6
49	123 m	Quartz	pr.	280	271	-0.5	-0.9	1.6
50	140 m	Quartz	pr.	264	256	-	-	-
51	140 m	Quartz	pr.	243	236	-	-	-
52	140 m	Quartz	pr.	270	262	-	-	-

53	140 m	Quartz	pr.	176	174	-	-	-
54	140 m	Quartz	pr.	196	192	-	-	-
55	140 m	Quartz	pr.	260	252	-	-	-
56	140 m	Quartz	pr.	226	220	-	-	-
57	140 m	Quartz	pr.	218	213	-	-	-
58	140 m	Quartz	pr.	218	213	-	-	-
59	140 m	Quartz	pr.	228	222	-	-	-
60	140 m	Quartz	pr.	195	191	-	-	-
61	140 m	Quartz	pr.	274	265	-	-	-
62	140 m	Quartz	pr.	205	201	-	-	-
63	140 m	Quartz	pr.	210	205	-	-	-
64	0.58 m	Quartz	sd.	182	179	-0.5	-0.9	1.6
65	0.58 m	Quartz	sd.	204	200	-0.5	-0.9	1.6
66	0.58 m	Quartz	sd.	193	199	-0.5	-0.9	1.6
67	0.58 m	Quartz	sd.	228	222	-0.5	-0.9	1.6
68	0.58 m	Quartz	sd.	174	172	-0.5	-0.9	1.6
69	0.58 m	Quartz	sd.	198	194	-0.3	-0.7	1.2
70	0.58 m	Quartz	sd.	215	210	-0.3	-0.7	1.2
71	123 m	Quartz	sd.	172	170	-0.3	-0.7	1.2
72	123 m	Quartz	sd.	240	234	-0.3	-0.7	1.2
73	123 m	Quartz	sd.	209	205	-0.3	-0.7	1.2
74	123 m	Quartz	sd.	209	205	-0.3	-0.7	1.2
75	123 m	Quartz	sd.	181	178	-0.5	-0.9	1.6
76	123 m	Quartz	sd.	218	213	-0.5	-0.9	1.6
77	123 m	Quartz	sd.	220	215	-0.5	-0.9	1.6
78	140 m	Quartz	sd.	238	232	-	-	-
79	140 m	Quartz	sd.	242	235	-	-	-
80	140 m	Quartz	sd.	166	201	-	-	-
81	140 m	Quartz	sd.	168	205	-	-	-

Table 12.1.2.3 Fluid inclusions data on quartz from Main ore body of Kungurcevscoe deposit.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _h	Calib. T _h	NaCl wt%
1	K1	Quartz	pr.	236	230	-0.6	-1.0	1.7
2	K1	Quartz	pr.	249	242	-0.6	-1.0	1.7
3	K1	Quartz	pr.	236	230	-0.6	-1.0	1.7
4	K1	Quartz	pr.	240	234	-0.6	-1.0	1.7
5	K1	Quartz	pr.	256	249	-0.6	-1.0	1.7
6	K1	Quartz	pr.	236	230	-0.6	-1.0	1.7
7	K1	Quartz	pr.	198	194	-0.6	-1.0	1.7
8	K1	Quartz	pr.	237	231	-0.6	-1.0	1.7
9	K1	Quartz	pr.	259	251	-0.6	-1.0	1.7
10	K1	Quartz	pr.	234	228	-0.6	-1.0	1.7
11	K1	Quartz	pr.	235	229	-0.6	-1.0	1.7
12	K1	Quartz	pr.	233	227	-0.6	-1.0	1.7
13	K1	Quartz	pr.	237	231	-0.6	-1.0	1.7
14	K1	Quartz	pr.	239	233	-0.6	-1.0	1.7
15	K1	Quartz	pr.	224	219	-0.6	-1.0	1.7
16	K1	Quartz	pr.	211	206	-0.6	-1.0	1.7
17	K1	Quartz	pr.	243	236	-0.6	-1.0	1.7
18	K1	Quartz	pr.	208	204	-	-	-
19	K1	Quartz	pr.	304	293	-	-	-
20	K1	Quartz	pr.	313	301	-	-	-
21	K1	Quartz	pr.	385	369	-	-	-

22	K1	Quartz	pr.	270	262	-	-	-
23	K1	Quartz	pr.	227	221	-0.2	-0.6	1.1
24	K1	Quartz	pr.	352	339	-0.2	-0.6	1.1
25	K1	Quartz	sd.	202	198	-0.6	-1.0	1.7
26	K1	Quartz	sd.	214	209	-0.6	-1.0	1.7
27	K1	Quartz	sd.	214	209	-0.6	-1.0	1.7
28	K1	Quartz	sd.	235	229	-0.6	-1.0	1.7
29	K1	Quartz	sd.	175	173	-0.6	-1.0	1.7
30	K1	Quartz	sd.	180	177	-0.6	-1.0	1.7
31	K1	Quartz	sd.	180	177	-0.6	-1.0	1.7
32	K1	Quartz	sd.	218	213	-0.6	-1.0	1.7
33	K1	Quartz	sd.	228	222	-0.6	-1.0	1.7
34	K1	Quartz	sd.	238	232	-0.6	-1.0	1.7
35	K1	Quartz	sd.	212	207	-	-	-
36	K1	Quartz	sd.	213	208	-	-	-

Table 12.1.2.3 Continued: Fluid inclusions data on quartz from vein 17 of Kungurcevscoe deposit.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _h	Calib. T _h	NaCl wt%
1	K2	Quartz	pr.	200	196	-0.5	-0.9	1.6
2	K2	Quartz	pr.	200	196	-0.5	-0.9	1.6
3	K2	Quartz	pr.	232	226	-0.5	-0.9	1.6
4	K2	Quartz	pr.	163	161	0.0	-0.4	0.7
5	K2	Quartz	pr.	163	161	0.0	-0.4	0.7
6	K2	Quartz	pr.	174	172	0.0	-0.4	0.7
7	K2	Quartz	pr.	179	176	0.0	-0.4	0.7
8	K2	Quartz	pr.	222	217	0.0	-0.4	0.7
9	K2	Quartz	pr.	225	220	0.0	-0.4	0.7
10	K2	Quartz	pr.	145	144	-0.4	-0.8	1.4
11	K2	Quartz	pr.	216	211	-0.4	-0.8	1.4
12	K2	Quartz	pr.	216	211	0.0	-0.4	0.7
13	K2	Quartz	sd.	166	164	-0.4	-0.8	1.4
14	K2	Quartz	sd.	137	137	0.0	-0.4	0.7
15	K2	Quartz	sd.	216	211	-0.4	-0.8	1.4

Table 12.1.2.3 Continued: Fluid inclusions data on quartz from vein 14 of Kungurcevscoe deposit.

№	Sample	Host mineral	Type	Meas. T _h	Calib. T _h	Meas. T _h	Calib. T _h	NaCl wt%
1	K3	Quartz	pr.	242	235	-0.2	-0.6	1.1
2	K3	Quartz	pr.	247	240	-0.2	-0.6	1.1
3	K3	Quartz	pr.	238	231	-0.3	-0.7	1.2
4	K3	Quartz	pr.	235	228	-0.2	-0.6	1.1
5	K3	Quartz	pr.	250	243	-0.4	-0.8	1.4
6	K3	Quartz	pr.	240	236	-0.4	-0.8	1.4
7	K3	Quartz	pr.	236	230	-0.4	-0.8	1.4
8	K3	Quartz	pr.	240	234	-0.4	-0.8	1.4
9	K3	Quartz	pr.	240	234	-0.4	-0.8	1.4
10	K3	Quartz	pr.	234	228	-0.4	-0.8	1.4
11	K3	Quartz	pr.	224	219	-0.4	-0.8	1.4
12	K3	Quartz	pr.	218	213	-0.4	-0.8	1.4
13	K3	Quartz	pr.	273	264	-0.4	-0.8	1.4
14	K3	Quartz	pr.	237	231	-0.7	-1.0	1.7
15	K3	Quartz	pr.	225	220	-0.7	-1.0	1.7
16	K3	Quartz	pr.	262	254	-0.7	-1.0	1.7

17	K3	Quartz	pr.	258	250	-0.7	-1.0	1.7
18	K3	Quartz	pr.	241	235	-0.7	-1.0	1.7
19	K3	Quartz	pr.	278	269	-0.7	-1.0	1.7
20	K3	Quartz	pr.	239	233	-0.7	-1.0	1.7
21	K3	Quartz	sd.	202	197	-0.2	-0.6	1.1
22	K3	Quartz	sd.	202	197	-0.2	-0.6	1.1
23	K3	Quartz	sd.	184	181	-0.2	-0.6	1.1
24	K3	Quartz	sd.	236	230	-0.5	-0.9	1.6
25	K3	Quartz	sd.	195	191	-0.4	-0.8	1.4
26	K3	Quartz	sd.	195	191	-0.4	-0.8	1.4
27	K3	Quartz	sd.	215	210	-0.4	-0.8	1.4
28	K3	Quartz	sd.	215	210	-0.4	-0.8	1.4
29	K3	Quartz	sd.	240	234	-0.4	-0.8	1.4
30	K3	Quartz	sd.	248	241	-0.4	-0.8	1.4
31	K3	Quartz	sd.	227	221	-0.4	-0.8	1.4
32	K3	Quartz	sd.	215	210	-0.7	-1.0	1.7
33	K3	Quartz	sd.	217	212	-0.7	-1.0	1.7
34	K3	Quartz	sd.	237	231	-0.7	-1.0	1.7
35	K3	Quartz	sd.	242	235	-0.7	-1.0	1.7
36	K3	Quartz	sd.	230	224	-0.7	-1.0	1.7
37	K3	Quartz	sd.	250	243	-0.7	-1.0	1.7
38	K3	Quartz	sd.	235	229	-0.7	-1.0	1.7
39	K3	Quartz	sd.	204	200	-0.7	-1.0	1.7
40	K3	Quartz	sd.	200	196	-0.7	-1.0	1.7
41	K3	Quartz	sd.	167	165	-0.7	-1.0	1.7

12.2. Gas composition of fluid inclusion

Composition of liquid and vapor phase of fluid inclusions were measured by Raman spectroscopy analysis in the Open Facility Campus of the Hokkaido University.

CO₂ peaks were noticed in some inclusions; however, concentration of CO₂ in both liquid and vapor phase is very low. Large peaks at 2942 were identified in barely each inclusion. These peaks are stretch bands in appearance were classified as C-H compounds. Some inclusions from Kungurcevscoe deposit show presence of COS and liquid water.

12.3. Stable isotopes of quartz and carbonate

One quartz sample from Baranevskoe deposit, one quartz sample from Zolotoe deposit and two quartz samples from Kungurcevscoe deposit were measured on oxygen and hydrogen isotopic composition. Table 12.3.1 shows values of oxygen and hydrogen of quartz. The $\delta^{18}\text{O}$ values of quartz from Baranevskoe deposit,

Zolotoe and Kungurcevscoe deposits are 5.5, -0.1 to -0.2 and 0.4 ‰, respectively. $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ values has been calculated using formula of $1,000 \ln a = 3.34 \times 10^6 T^{-2}$ (Matsuhisa *et al.*, 1979) and a mean of homogenization temperature obtained from the fluid inclusions. $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ is calculated to be for Baranevskoe deposit, for Kungurcevscoe deposit and for Zolotoe deposit. Value of $\delta\text{D}_{\text{H}_2\text{O}}$ is estimated to be -129 for Kungurcevscoe and -140 for Zolotoe ore deposits (Table 12.3.1.).

Table 12.3.1 Stable isotope data on quartz and calcite (‰).

Sample	Deposit	Locality	$\delta^{18}\text{O}_{\text{mineral}}$	$\delta^{18}\text{O}_{\text{H}_2\text{O}}$	$\delta\text{D}_{\text{H}_2\text{O}}$
Q3	Baranevskoe	Yuznaya vein	5.5	4	-104
Q4	Kungurcevscoe	Vein 14	-0.1	-11.3	-129
Q5	Kungurcevscoe	Vein 14	-0.2	-12.4	-132
Q6	Zolotoe	Quartz	0.4	-10.5	-140

Chapter XIII. Discussions on source and the physicochemical environment of Au-Ag mineralization at the Balkhach ore cluster

13.1. Nature and characteristics of hydrothermal fluids

13.2. The physicochemical environment

Chapter XIII. Discussions on source and physicochemical environment of Au-Ag mineralization at the Balkhach ore cluster

Baranevskoe, Zolotoe and Kungurcevskoe deposits are located within Balkhach volcanic-tectonic structure (Fig. 10.2.1.). The volcanic-tectonic structure is defined on various Kamchatkan long-lived volcanoes with probable same parent source evolved in time. Recent works on analogues of the Balkhach volcanic-tectonic structure, located in the South Kamchatka and characterized by younger formation age, has shown that these structures are the large scale volcanic calderas, which have been erupted numerous times in history (Bignman *et al.*, 2010). This study shows similarity in vein mineralogy, principally commodities, alteration styles and associated intrusive rocks for Baranevskoe, Zolotoe and Kungurcevskoe deposits.

13.1. Nature and characteristics of hydrothermal fluids

Baranevskoe deposit

Two apparent ore types are distinguished at Baranevskoe deposit: cupriferous and gold-silver ores, showing distinct differences in mineral compositions, chemistry and fluid natures. Age of Baranevskoe deposit is confirmed as Pleistocene; however, the deposit was likely formed in two large events of hydrothermal activity. The first event is related to formation of the cupriferous ores occurring in Rhzavaya vein-filling the central left-lateral strike fault. The second big event commenced with the deposition of gold-bearing quartz-carbonate-adularia veins of LS nature. Although, a relationship between these two types of ores from genetic point of view is not well-understood, the field observation concluded the overprinting of gold LS mineralization over Cu-rich one (Bol'shakov *et al.*, 2010). Cupriferous ores have been formed prior to gold-silver from probably different the fluid source (Fig. 13.1.1.). In mineral composition of cupriferous ores two distinct assemblages are recognized early pyrite-gold-chalcopyrite-bornite and later tetrahedrite-tennantite (Figs. 13.1.2 and 13.1.3.). Fluid inclusions show low-temperature fluids of about

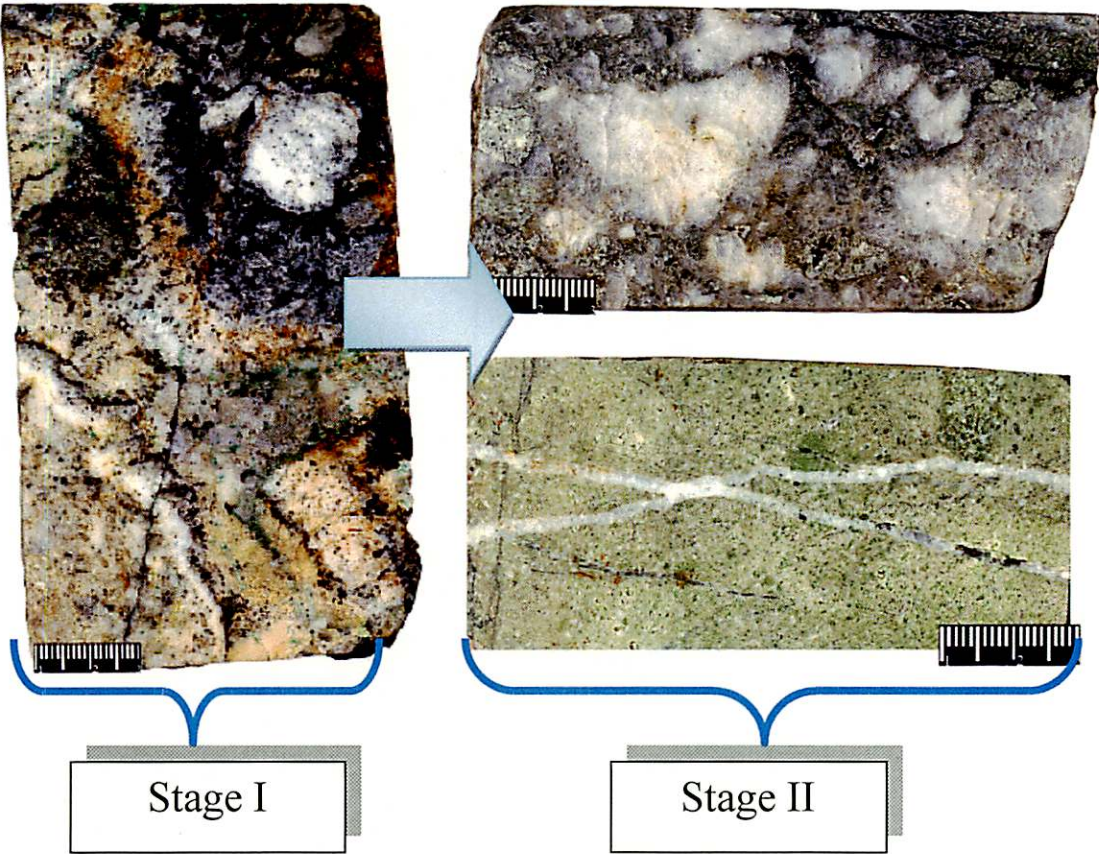


Fig.13.1.1. Cupriferous ores (left) were likely formed prior to gold-silver ores (right). Gold-silver ores consist of brecciated varieties, stockwork and carbonate-enriched ore types.

Mineral \ Stage	Stage			Rare minerals
	Early	----->	Late	
Pyrite				famatinite
Chalcopyrite				enargite
Bornite				native bismuth
Sphalerite				
Electrum				
Tet-ten				

Fig.13.1.2. Paragenetic sequence of vein minerals observed in the cupriferous ores. In left column rare minerals reported by previous researchers are listed.

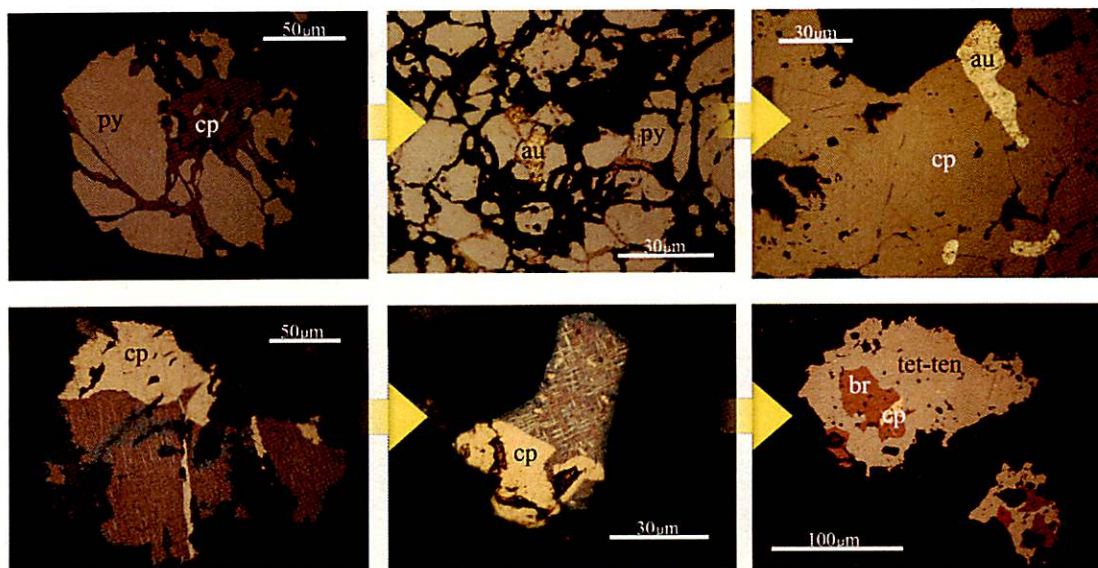


Fig.13.1.3. Microphotographs illustrating paragenetic sequence of vein minerals observed in cupriferous ores.

154-232 °C with salinity of 0.7-1.1 wt% NaCl equiv. Although, liquid-rich inclusions were observed in co-existing with gaseous inclusions, a boiling is not confirmed yet. Gold-silver ores and Stockwork ore body host electrum, sphalerite, hessite, petzite, altaite, galena, pyrite and chalcopyrite. Only gold in minor amount was found in carbonate ores. Gold in gold-silver ores, stockwork and carbonate ores show identical chemical composition ranging mainly from 68 to 72 at% (Fig. 11.3.7.). Thus, gold was likely deposited from the same fluid flow. Majority of ore minerals occur in gold-silver ores, while Stockwork and carbonate-quartz veins host insignificant amount of vein minerals. The metal-bearing hydrothermal fluids of LS nature ascended through the large, open fractures of Central vein. The widespread occurrence of breccias ores along with comparable high temperature obtained from the fluid inclusion studies indicates fluid boiling, that perhaps lead to formation of the Stockwork ore body nearby. Ascending fluids was enriched in CO₂ resulted in deposition of carbonate veins with some native gold. Based on fluid-inclusion studies the quartz-carbonate-adularia veins, stockwork and carbonate-base ores are confirmed to be deposited from the hydrothermal shallow-depth fluids of low salinity approximately 2wt% NaCl equiv., and relatively low temperature 190-280 °C. Alteration rock styles support the fluid was slightly acid-neutral to alkaline-neutral pH state. Stable isotopes of quartz from gold-silver ores show a magmatic signature.

Gold in metasomatites show well developed octahedral and polygons crystals with the growth steps implies direct deposition from the hydrothermal fluid (Fig. 11.3.6.). Fluid inclusions occurring in quartz of metasomatites homogenize in a wide temperature from 230 to 310 °C. In chemical composition gold is identical to that occurring in brecciated veins and stockwork of LS nature. Some gold grains are showing higher content of Au due to short mechanic transportation in diluvium.

Lack of age dating hides a real formation age of cupriferous ores. Previously estimated Pleistocene is age of the gold-silver ores, which formed after the cupriferous ones. Age and time gap between two different ores are needed to be discussed in future.

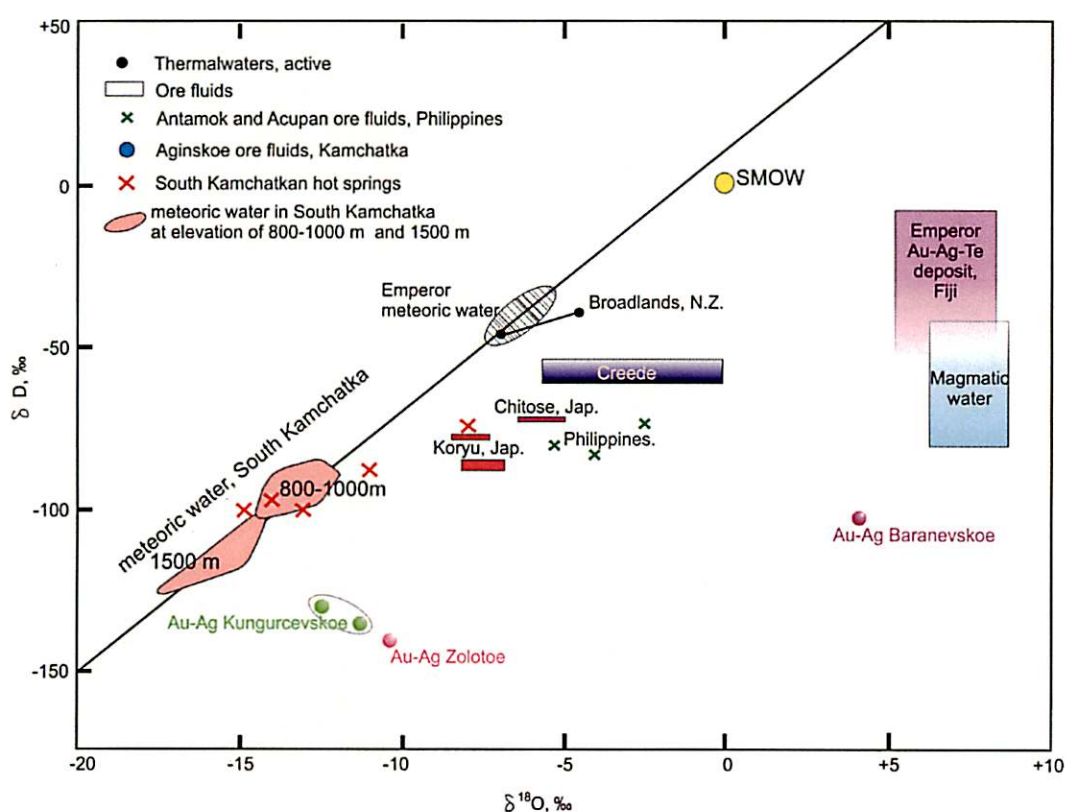


Fig.13.1.4. Isotopic composition of hydrothermal water of Baranevskoe, Zolotoe and Kungurcevscoe epithermal deposits in relationship to the meteoric water line. Isotopic value of H was measured directly from the fluid inclusions. Value of O was calculated using the homogenization temperature of fluid inclusions ($T=250\text{ }^{\circ}\text{C}$, $280\text{ }^{\circ}\text{C}$).

Isotopic composition of present meteoric water in South Kamchatka is taken from Okrugin and Zelensky, 1997.

Data on the isotopic composition of water of Koryu and Chitose deposits in Japan, Philippines deposits, Judith deposit in USA, Emperor in Fiji and Broadlands in New Zealand is taken from Shimizu and *et al.*, 1998; Ahmad *et al.*, 1987; White, 1974.

Zolotoe deposit

Homogenization temperatures and vein mineralogy of Zolotoe deposit are typical for LS epithermal environment. Homogenization temperatures range 160-280 °C with salinity around 1.1-1.6 wt% NaCl equiv. The boiling is not confirmed based on fluid inclusions studies. Ore is composed of gold, sphalerite, galena, acanthite, pyrite, chalcopyrite and minor amount of tetrahedrite-tennantite. Stable isotope studies indicate a large amount of the meteoric water involving in the hydrothermal solution (Fig. 13.1.4.).

Kungurcevscoe deposit

Fluids of Kungurcevscoe veins are relative high in temperature and low salinity. Mainly temperature ranges from 161-251 °C with some evidences of temperature over 300 °C. Salinity is consistent ranging from -0.2 to -0.8 wt% NaCl equiv. From relationship of homogenization temperature and salinity the boiling is not clear seen. Quartz morphology and fluid inclusion homogenization temperatures are similar to gold-associated quartz in metasomatite of the Baranevskoe deposit. Isotopic composition of quartz suggests enrichment of hydrothermal fluids in the meteoric water (Fig. 13.1.4.).

13.2. The physicochemical environment

Baranevskoe deposit

The tetrahedrite-tennantite series with its numerous isomorphic variations along with other ore minerals is useful mineralogical key in recording the physicochemical conditions at the site of the deposition (Feiss, 1974; Maske & Skinner, 1971; Spiridonov *et al.*, 2005). The tetrahedrite-tennantite series, crystallized under the epithermal conditions, usually exhibits complex internal zoning, which serves as evidence of changing in temperature, redox states and composition of fluids (Fadda *et al.*, 2005; Kemkina, 2007; Hernandez & Akasaka, 2010). Generally tetrahedrite-tennantite are main component minerals in epithermal polymetallic and sulfide deposits, however, they are quite common in Au-Ag Baranevskoe vein systems. Most of tetrahedrite-tennantite is hosted by Rhzavaya vein, however, trace amounts of fahlore were also found in samples obtained from other veins of the deposit. The tetrahedrite-tennantite series is predominant by

tetrahedrite (Fig. 11.3.5.). The elemental mapping showed mainly random distribution of Sb and As within tetrahedrite_{ss} (Fig 11.3.4.). This support that tetrahedrite was not directly deposited from a hydrothermal fluid rather it was occurred in replacing of chalcopyrite. The chemical composition of tetrahedrite-tennantite is closed to the ideal chemical formula with slight higher content of Cu (Table 11.3.4.). Generally, tetrahedrite is characterized by a high Cu content with a high Zn/Fe ratio. The prevalence of tetrahedrite in the ores suggests oxidized, low-temperature solution (Spiridonov *et al*, 2005). This is also supported by fluid inclusion temperature and wall-rock alteration. Fluid inclusions from Rhzavaya vein revealed relatively low temperatures in general (150-230 °C). Tetrahedrite-tennantite may be used as a geothermometer, if they co-precipitated with enargite (Feiss, 1974). Although, in this study a direct contact of tetrahedrite-tennantite and enargite was not observed, Bol'shakov with colleagues (2010) reported enargite as inclusions in other ore minerals in the cupriferous ores from the Baranevskoe deposit. In this study tetrahedrite-tennantite was mainly found in association with chalcopyrite-bornite. Existence of chalcopyrite-bornite solid solution with characteristic micrographic texture is an indicator of a high temperature initial solution (Imai & Satoshi, 2002). According to a number of experiments, exsolution of chalcopyrite from bornite was caused by rapid cooling under temperature of 270 °C (Brett & Yund, 1964). Thus, a rapidly cooling hydrothermal fluid favors deposition of tetrahedrite from a low temperature solution. Tetrahedrite is also an indicator of alkalinity, which coincides well with the alteration zones grading from inner metasomatites of pyrite-hematite-magnetite-sericite(alunite)-quartz types and pyrite-sericite-illite-quartz types to outer metasomatites of adularia, illite, carbonate, clays and pyrite. This suggest a shifting of pH of the hydrothermal solution from slightly acid-neutral to alkaline-neutral state (White & Hedenquist, 1995).

Estimation of sulfur fugacity was based on assemblages of vein minerals, ore chemistry and fluid inclusions studies. Sulfur fugacity was probably significantly changed during ore deposition (Fig. 13.2.1.). The cupriferous ores have started to precipitate from high-temperature fluid under high sulfur fugacity condition. This is supported by occurrence of bornite-chalcopyrite intergrowth with micrographic textures and rare high-temperature fluid inclusions. As the ore deposition proceeds

further the sulfur fugacity and the fluids temperature have dropped with deposition of tennantite-tetrahedrite series minerals. Precipitation of tennantite-tetrahedrite may be also related to deposition of gold-silver ores.

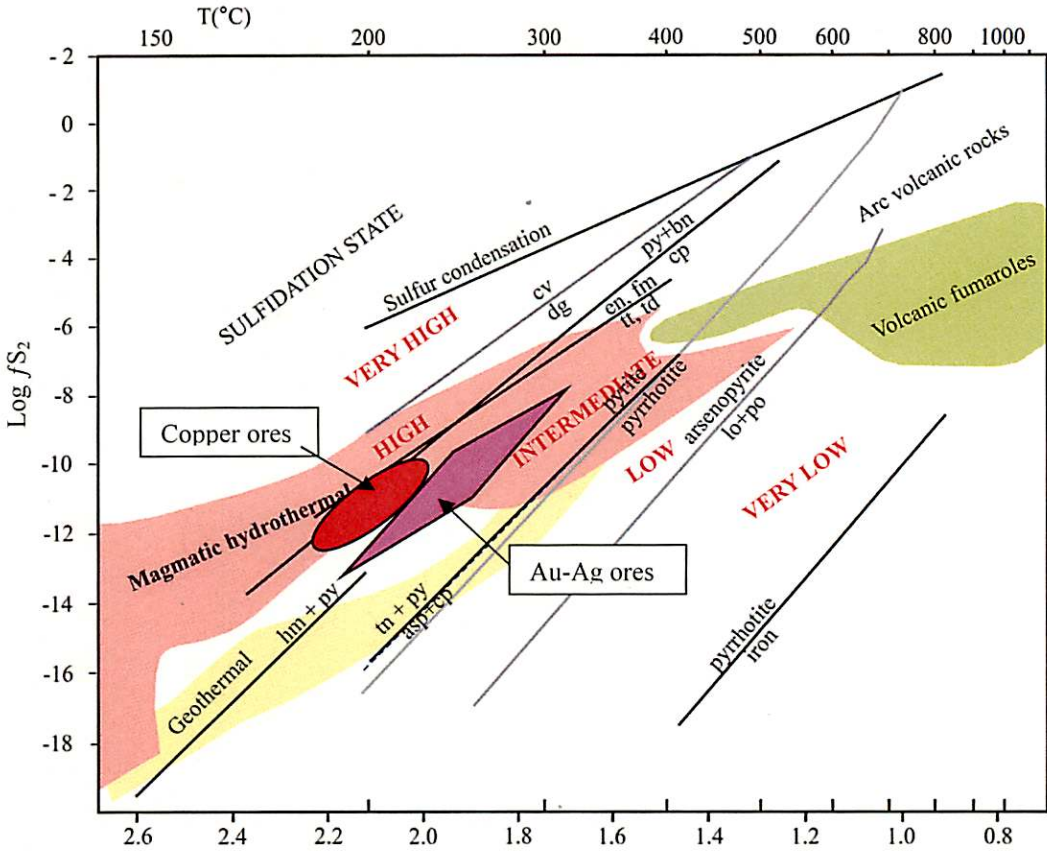


Fig.13.2.1. Plot of $\log f_{S_2}$ vs. temperature showing variation in value of the sulfur fugacity during formation of the cupriferous and the gold-silver ores.

Zolotoe deposit

In ores of the Zolotoe deposits excellent assemblage of native gold-sphalerite-acathite proposed by Shikazono (1988) to be good for the estimation of sulfur fugacity was observed. Combine with data on fluid inclusions sulfur fugacity was estimated (Fig. 13.2.2.). Using the average Ag/Au ratio of 0.2, FeS 0.2-18 mole% and homogenization temperatures of 190-270 °C value of $\log f_{S_2}$ is estimated to be in range from -17 to -10.

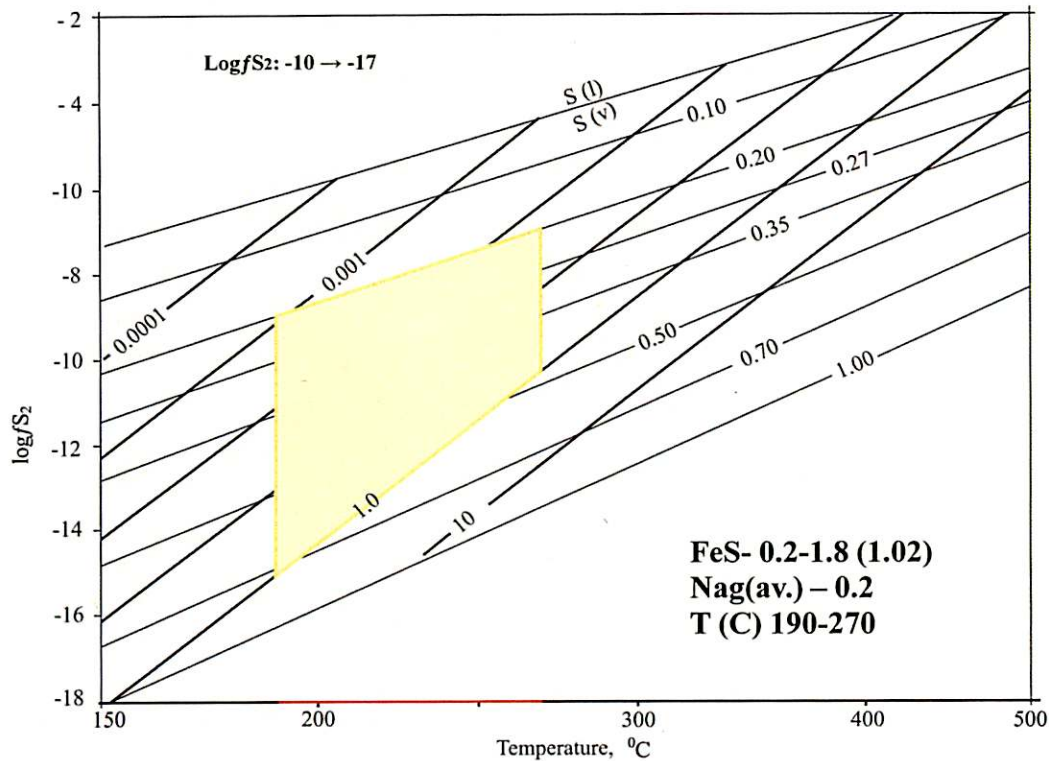


Fig.13.2.2. Plot $\log f_{S_2}$ vs. temperature showing range of sulfur fugacity of gold-silver ores of Zolotoe deposit. A plot is borrowed from Barton, 1964.

Kungurcevskoe deposit

Only gold and pyrite was observed in veins of Kungurcevskoe deposit in this study. Gold is associated with pyrite in clays of vein 14. Based on homogenization temperatures of fluid inclusions occurring in comb quartz and clays composition hosting gold (Fig. 13.2.3.) gold was deposited from the reduced hydrothermal fluid of neutral pH with temperature of 220-280 °C and salinity 1.1-1.7 wt% NaCl equiv..

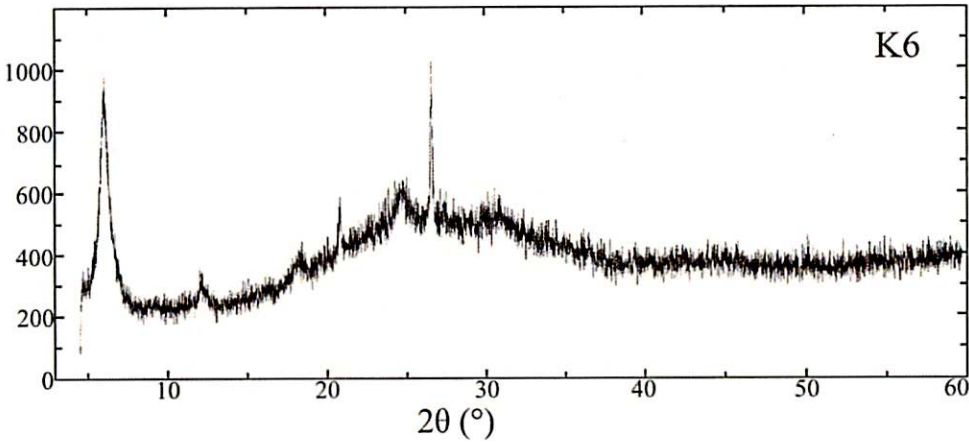
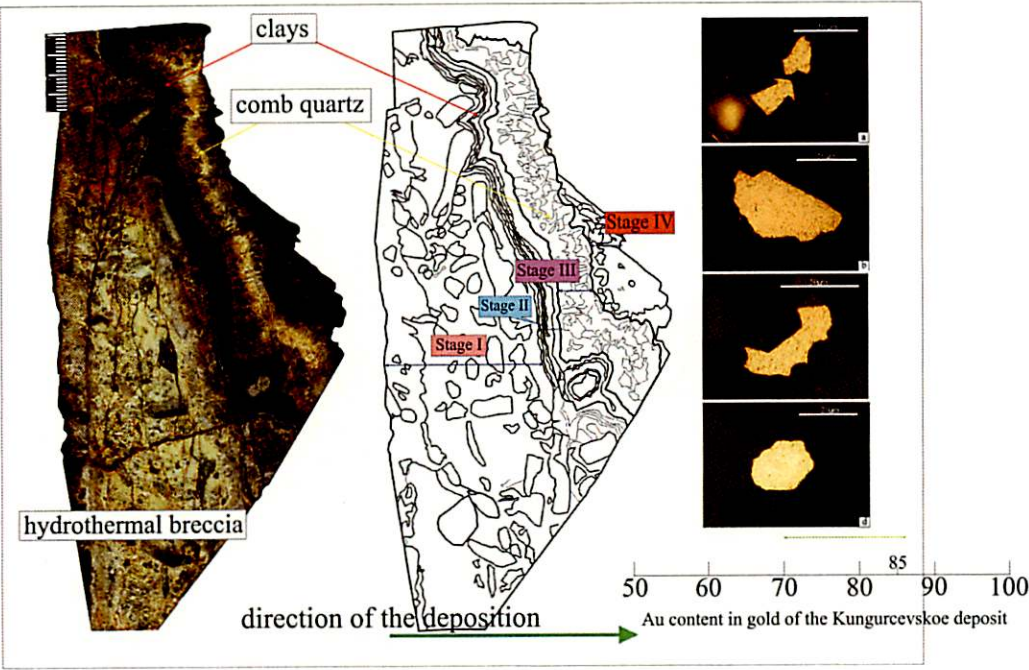


Fig.13.2.3. Hydrothermal breccias of vein 14 showing deposition sequence of clays hosting gold and comb quartz. Clays is composed of chlorite dominantly.

Chapter XIV Discussion on genesis of gold mineralization in the Central Kamchatka Mining District

14.1. Genesis of precious metal mineralization in Central Kamchatka

14.2. Factors controlling chemical composition of gold in epithermal deposits of Central Kamchatka

Chapter XIV. Discussion on genesis of gold mineralization in the Central Kamchatka Mining District

14.1. Genesis of precious metals mineralization in Central Kamchatka

The Central Kamchatka mining district, mapped on the southern area of the Central Kamchatka volcanic belt, consist of range of epithermal deposits of gold, gold-silver, gold-polymetallic and gold-silver-telluride types of mineralization with total underground recourses of gold more than 100 t. The lodes are localized within volcanic calderas composed of andesite and andesitic basalt predominantly. According to K/Ar and Ar/Ar dating, made by various researchers, several periods of magmatic activity responsible for the formation of deposits could be recognized. The age of epithermal veins change from oldest to youngest from the north to the south of the district, for instance, the deposits in the central area are occurred in Miocene (7.5.-7.4.-7.1.-6.9 Ma Aginskoe deposit and 7.4 Ma South-Aginskoe deposit) and the deposits in the southernmost area are occurred in Late Pliocene (3.57-3.11-2.65-2.37 Ma Baranevskoe deposit) (Petrenko, 1999; Okrugin, 2001). However, Zolotoe and Kunurcevscoe deposits, situated on the south-eastern area of district, shows distinct different formation age of 21.4-17.1Ma. Main magmatic activity with emplacement of various intrusive bodies was continued from Oligocene to Pliocene and from Pleistocene to Quaternary. During Oligocene-Pliocene magmatic period the subduction zone was located parallel to the Central Kamchatka volcanic belt at distance of about 200 km. As a result of migration of the subduction zone to the south-east location the distance between the sinking oceanic plate and the Central Kamchatka volcanic belt is increased up to 400 km. Although magmatic processes with injection of intrusives and rigorous volcanic eruptions have been continued untill Quarternary, none of any precious metals deposits were formed from Pleistocene to Quaternary. Metallic mineralization is showing strong relation with distance to the subduction zone in Central Kamchatka volcanic belt.

Central Kamchatkan Au-Ag deposits of different formation age differ in gangue and vein mineralogy, alteration zone patterns, temperature and composition of fluids and the physicochemical parameters. Early Miocene Zolotoe and Kungurcevscoe

deposits (21.4 -17.1 Ma), are marked by comparable low temperature of hydrothermal fluids (160-270 °C), abundant sulfides in the ores (pyrite, sphalerite, galena and chalcopyrite) accompanying with gold mineralization. Late Miocene Aginskoe and South-Aginskoe deposits (7.5.-7.4.-7.1.-6.9 Ma) are characterized by higher formation temperature (240-260 °C), high Te content and purest native gold (Au is up to 99.99 at%). Pleistocene Baranevskoe deposit is mature hydrothermal veins system hosting two distinct different type of mineralization: cupriferous and gold-silver. Cupriferous ores showing comparable low fluid temperature (150-240 °C) and salinity less than 1 wt% NaCl equiv..

Stable isotope data are plotted on Fig. 14.1.1. is showing that isotopic composition of Aginskoe fluids, Zolotoe and Kungurcevscoe ore fluids are close to isotopic composition of meteoric water of Southern Kamchatka. Thus, fluids might be a meteoric water in the origin. Besides, shifting of isotopic composition of Aginskoe water to meteoric water line during evolution of the system is observed. Baranevskoe deposit, however, shows an isotopic composition close to the area of magmatic water.

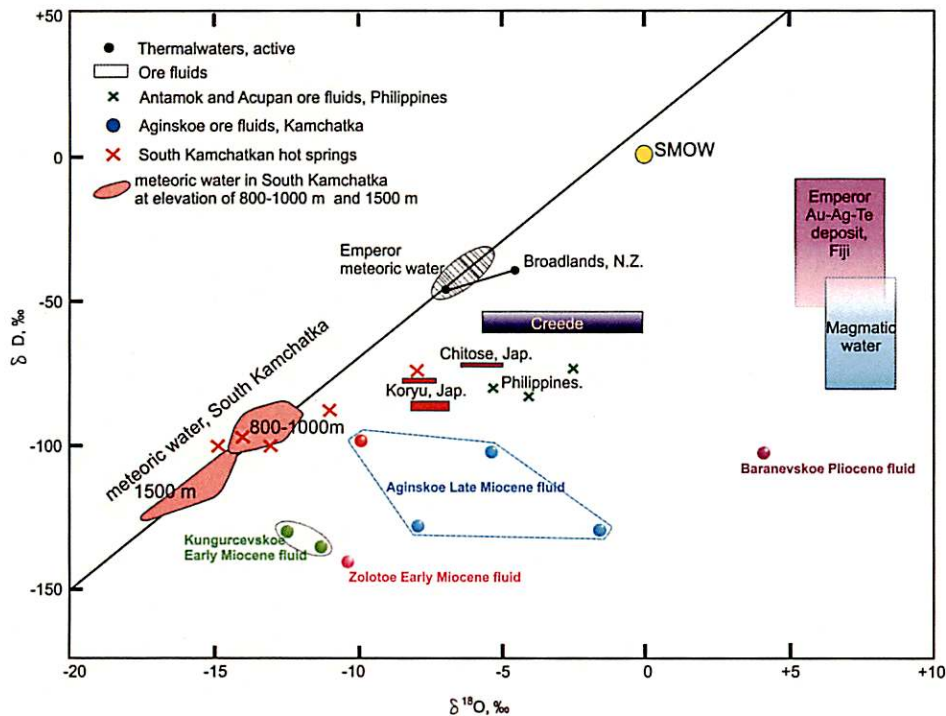


Fig. 14.1.1. Hydrogen versus oxygen isotope diagram showing isotopic composition of vein fluids, active thermal waters and meteoric waters from Pacific region. Data on Japanese, Philippines, New Zealand and USA are taken from following references: White, 1974; Ahmad *et al.*, 1987; Shimizu *et al.*, 1998.

14.2. Factors controlling chemical composition of gold in epithermal deposits of Central Kamchatka

Chemically pure native gold is not existed or presented in very little amount in nature. Term “electrum” is accepted for wide range of Ag concentration in gold-silver alloy (Shikazono, 1988). However, many researchers agree that gold with Ag content less than 20 wt% is a native gold. And gold with concentration of Ag more than 20 wt% is named as electrum (Helgeson & Garrels, 1968; Boyle, 1969; Harris, 1990; Bonev *et al.*, 2002). Chemical composition of gold occurred in epithermal ores is used for estimation of physicochemical environment of gold deposition.

The present study revealed that much of gold occurred in the epithermal deposits of the Central Kamchatka almost belong to native one with Au over than 70 wt%. In spite of wide range of chemical composition of gold in the deposits of different mineralization types and formation ages, general tendency of gold chemical composition and formation temperature is observed. The relationship between formation temperature of deposits and composition of gold pointed out by Shikazono (1988) for the Japanese deposits. In Central Kamchatka native gold with Ag content less than 10 at% occurs in Au-Ag-Te veins of Aginskoe deposit formed from fluids with average temperature of 250 °C. Gold accompanied by tellurides shows low Ag/Au (Ag 4-5 at%) than those associated with sulfide (pyrite in common). Au-enriched electrum and native gold of composition 20-30 at% in Ag occurs in Baranevskoe, Zolotoe and Kungurcevscoe with formation temperature around 170-250 °C. Gold is associated with sphalerite and characterized by high Ag/Au ratio. A tendency of increasing FeS content of sphalerite with decreasing Ag in Au-Ag minerals has been noticed.

Since relative easy solubility and abundance of S and Cl species in the hydrothermal solutions a gold accepted to be mainly transported in bisulfide and/or bichloride complexes in near-neutral pH condition (Helgeson & Garrels, 1968; Boyle, 1969; Seaward, 1973; Shikazono & Shimizu, 1987). Considering that Te and Sb frequently form independent deposits, they are avoided as potential gold-carriers in hydrothermal fluids by many researchers. Nevertheless, both elements would act as a major gold-transporter in some specific deposits. Of course complete eliminate sulfide

and chloride complexes in gold transportation during formation Te-rich deposits must be mistaken. They presumably carry significant amount of gold, however, Te might be much important variable in Te-bearing deposits than S or Cl species.

Comparing Miocene-Pliocene deposits distributed at the Central Kamchatka mining district with Pleistocene Rodnikovoe Au-Ag deposit at the Southern Kamchatka, distinct difference could be seen between both (Fig. 14.2.1.). Au-Ag minerals occur as electrum in common (Ag more than 60 wt%) closely associated with Ag-bearing minerals such as polybasite, pearciete at the Rodnikovoe deposit (Takahashi *et al.*, 2002). Gold of Rodnikovoe deposit, however, show close chemical composition of gold in epithermal deposits of Japan (Fig. 14.2.2.).

Chapter XV. Summary and Conclusion

Aginskoe Au-Ag-Te deposit of Late Miocene contains native gold, gold-silver-tellurides, sulfides and various secondary minerals much of which are still not identified. Gold-silver-telluride-bearing ores have been formed from 7.1 to 6.9 Ma based on K/Ar dating of vein adularia. Mineralization is confirmed to be formed in six stages. Stage I barren quartz, adjusted to the wall of host rocks. Stage II is characterized by a productive Au-Ag-Te mineralization. Stage III and IV are post-ore stages recorded brecciation events followed by filling free spaces amethyst quartz. stage VI is classified as a supergene, where various secondary minerals have been formed. Au-Ag-bearing tellurides of stage II were deposited from fluids of 250-260 °C temperature and salinity less than 2 wt. % NaCl at $\log f\text{Te}_2 < -9$ and $\log f\text{S}_2$ is assumed to be -13. Ratio of $f\text{Te}_2/f\text{S}_2$ is decreased as the ore deposition proceeds further. Native gold (Au 88-92 at%) was simultaneous deposited with Au-bearing tellurides such as calaverite prior to deposition of altaite-hessite-sphalerite assemblages. In oxidation zone native mustard gold was released from primary Au-bearing tellurides due to solubility of Te in zone of the oxidation. Boiling phenomena is confirmed on presence of adularia, wide range of homogenization temperature, types of inclusions and quartz texture. Vein were deposited from meteoric water-enriched hydrothermal fluids circulated at the shallow depth.

Veins system of Baranevskoe deposit consists of two principally different ore types: gold-sulfide-quartz-carbonate-adularia and Cu-bearing ores. The former type is filling a range of veins distributed in western side from a main Rhzavaya vein, hosting Cu-rich mineralization. Rhzavaya vein was formed under a different physicochemical conditions and hydrothermal source from the quartz-carbonate-adularia ores. Presence and dominance of the tetrahedrite and types of the alteration rocks suggests deposition of Cu-bearing ores from the low-temperature slightly alkaline fluid of higher sulfur fugacity. Quartz-carbonate-adularia, Stockwork and carbonate-quartz ores were probably precipitated from a same fluid source with low-temperature and low sulfur fugacity.

Proposal for future studies

In this PhD a possibility of the influence of glaciation on formation of various secondary minerals in the Aginskoe deposit was speculated, however, to conclude this theory additional detailed mineralogical and XRD studies are needed.

Baranevskoe deposit with unique features of occurrence cupriferous ores and single gold crystal provides a wide field for future investigations of various geological and mineralogical interests. As it was mentioned in paper this study was conducted on vein samples collected mainly from outcrops, trenches and few specimens were obtained from drill cores, however, they represents the upper horizons of the deposit. Future studies are needed to be aim on changing of mineral composition over vertical extensions of veins, estimation erosion level and the physicochemical conditions.

References

- Afifi, A. M., Kelly, W. C., and Essene, E. J. (1988a) Phase relations among tellurides, sulfides, and oxides I. Thermochemical data and calculated equilibria. *Econ. Geol.*, 3, 377-394.
- Afifi, A. M., Kelly, W. C., and Essene, E. J. (1988b) Phase relations among tellurides, sulfides, and oxides II. Applications to telluride-bearing ore deposits. *Econ. Geol.*, 83, 395-404.
- Ahmad, M., Solomon, M., and Walshe, J. L. (1987) Mineralogical and geochemical studies of the Emperor gold telluride deposit, Fiji. *Econ. Geol.*, 82, 345-370.
- Andreeva, E. D., Matsueda, H., Okrugin, V. M., Ono, S., and Takahashi, R. (2010) Au-Ag-Te Mineralization at the Aginskoe ore deposit, Central Kamchatka, Russia. Abstracts with programs of the 60th International Symposium «Resource geology», Tokyo, Japan, 74.
- Andrusenko, N. I., and Shchepot'yev, Yu. M. (1974) Temperatures and stages on the formation of Central Kamchatka subvolcanic Au-Ag deposits. *Geochem. International.*, 130-137.
- Arribas, A. Jr. (1995) Characteristics of high-sulfidation epithermal deposits, and their relation to magmatic fluid. *Can. Mineral. Assoc. Short Course*, 23, 419-454.
- Avdeiko, G.P., Savel'yev, D.P., Palueva, A.A., and Popruzenko, S.V. (2007) Evolution of the Kurile-Kamchatkan volcanic arcs and dynamics of the Kamchatka-Aleutian junction. *Volcanism and subduction: The Kamchatka region geophysical monograph series 172*. Am. Geophys. Union., 37-55.
- Barton, P. B., Jr., and Toulmin, P. III (1964) The electrom-tarnish method for the determination of the fugacity of sulfur in laboratory sulfide systems. *Geochim. Cosmochim. Acta*, 28, 619-640.
- Barton, P. B., Jr., and Toulmin, P. (1966) Phase relations involving sphalerite in the Fe-Zn-S system. *Econ. Geol.*, 61, 815-849.
- Bigg, G.R., Clark, C.D., and Hughes, A.L.C. (2008) A last glacial ice sheet on the Pacific Russian coast and catastrophic change arising from coupled ice-volcanic interaction. *Earth Planet. Sci. Lett.*, 265, 559-570.
- Bindeman, I.N., Leonov, V.K., Izbekov, P.E., Ponomareva, V.V., Watts, K.E., Shipley, N.K., Perepelov, A.B., Bazanova, L.I., Jicha, B.R., Singer, B.S., Schmitt, A.K., Portyagin, M.V., and Chen, C.H. (2010) Large-volume silicic volcanism in Kamchatka: Ar-Ar and U-Pb ages, isotopic, and geochemical characteristics of major pre-Holocene caldera-forming eruptions. *J. Volcanol. Geother. Res.*, 189, 57-80.
- Braitseva, O.A., Melekestsev, I.V., Evteeva, I.S., and Lupikina, E.S. (1968) Stratigraphy of quaternary deposition and glaciation at Kamchatka. M., Nauka, 227.
- Braitseva, O.A., Melekestsev, I.V., Ponomareva V.V., and Sulerzhitsky, L.D. (1995) Ages of calderas, large explosive craters and active volcanoes in the Kuril-Kamchatka region, Russia. *Bull. Volcanol.*, 57, 383-402.
- Brett, R., and Yund, R.A. (1964) Sulfur-rich bornite. *Am. Mineral.*, 49, 1084-1089.

- Bol'shakov, V. M., Florov, A. I., Mineev, S. D., Gazizov, R. B., Bezrukova, L. A., and Okrugin, V. M. (2010) Geological structure of the Baranevskoe gold ore deposits (Central Kamchatka). *Otech. Geol.*, 4, 15-22, (in Russian).
- Bonev, I. K., Kerestedjian, Th., Atanassova, R., and Colin, J. A. (2002) Morphogenesis and composition of native gold in the Chelcovech volcanic-hosted Au-Cu epithermal deposit, Srednogie zone, Bulgaria, *Mineral. Deposita*, 37, 614-629.
- Boyle, R. W., (1969) Hydrothermal transport and deposition of gold. *Econ. Geol.*, 64, 112-115.
- Cabri, L. J. (1965) Phase relations in the Au-Ag-Te system and their mineralogical significance. *Econ. Geol.*, 60, 1569-1606.
- Callow, K. J. and Worley, D. W. (1965) The occurrence of telluride minerals at the Acupan gold mine, Mountain Province, Philippines. *Econ. Geol.*, 60, 251-268.
- Christie, A.B., Simpson, M.P., Brathwaite, R.L., Mauk, J.L., and Simmons, S. F. (2007) Epithermal Au-Ag and related deposits of the Hauraki Goldfield, Coromandel volcanic zone, New Zealand. *Econ. Geol.*, 102, 785-816.
- Chudaev, O, Chudaeva, V., Sugimori, K., Kuno, A., and Matsuo, M. (2008) Composition and origin of modern hydrothermal systems of the Kuril island arc. *Indian J. Marine Sci.*, 37, 166-180.
- Churikova, T., Dorendorf, F., and Worner, G. (2001) Sources and fluids in the mantle wedge below Kamchatka, evidence from across-arc geochemical variation. *J. Petrol.*, 42, 1567-1593.
- Clayton, R.N., O'Neil, J.R., and Mayeda T. (1972) Oxygen isotope exchange between quartz and water. *Jour. Geoph. Resear.*, 77, 3057-3067.
- Craw, D. (1997) Fluid inclusions evidence for geothermal structure beneath the Southern Alps, New Zealand. *New Zealand J. Geol. Geophys.*, 40, 43-52.
- Corbett, G., and Leach, T. (1997) South-west Pacific Rim Gold-Copper systems: structure, alteration, and mineralization. *Short course manual*, 318.
- Cooke, D.R., McPhail, D.C., and Bloom, M.S. (1996) Epithermal gold mineralization, Acupan, Baguio District, Philippines: geology, mineralization, alteration, and the thermochemical environment of ore deposition. *Econ. Geol.*, 91, 243-272.
- Cooke, D. R., and McPhail, D. C. (2001) Epithermal Au-Ag-Te mineralization, Acupan, Baguio District, Philippines: numerical simulations of mineral deposition. *Econ. Geol.*, 96, 109-131.
- Cooke, D.R., Hollings, P., and Chang, Z. (2011) Philippine porphyry and epithermal deposits: an introduction. *Econ. Geol.*, 106, 1253-1256.
- Dong, G., Morrison, G., and Jaireth, S. (1995) Quartz textures in epithermal veins, Queensland – classification, origin, and implication. *Econ. Geol.*, 90, 1844-1856.
- Einaudi, M. T., Hedequist, J. W., and Inan, E. E. (2003) Sulfidation state of fluids in active and extinct hydrothermal systems: transitions from porphyry to epithermal environments. *Econ. Geol.*, Spec. publ., 10, 285-313.
- Esmicheva, E. A., and Osadchii, E. G. (2009) Determination of the thermodynamic properties of compounds in the Ag-Au-Se and Ag-Au-Te systems by the EMF method. *Geol. Ore Deposits*, 51, 247-258.

Espi, J., Hayashi, K.-I., Komuro, K., Murakami, H., and Kajiwar, Yo. (2007) Geology, walk-rock alteration and vein paragenesis of the Bilimonia gold deposit, Kainantu Metallogenic Region, Papua New Guinea. *Resour. Geol.*, 57, 249-268.

Fadda, S., Fiori, M., and Grillo, S.M. (2005) Chemical variations in tetrahedrite – tennantite minerals from the Furtei epithermal Au deposit, Sardinia, Italy: Mineral zoning and ore fluid evolution. In *Geochemistry, mineralogy and petrology, Field Workshop, Bulgaria*, 79-84.

Feiss, P.G. (1974) Reconnaissance of the tetrahedrite-tennantite/enargite-fametininite phase relations as a possible geothermometer. *Econ. Geol.*, 69, 383-390.

Gorbatov, A., Kostoglodov, V., Gerardo, S., and Gordeev, E. (1997) Seismicity and structure of the Kamchatka subduction zone. *J. Geophys. Res.*, 102, 17883-17898.

Hall, R., and Smyth H.R. (2008) Cenozoic arc processes in Indonesia: identification of the key influences on the stratigraphic record in active volcanic arcs. *Am. Geol. Soc., Spec. Paper*, 436.

Harris, D. C. (1990) The mineralogy of gold and its relevance to gold recoveries. *Mineral. Deposita*, 25, 3-7.

Heald, P., Foley, N.K., and Hayaba D.O. (1987) Comparative anatomy of volcanic-hosted epithermal deposits: acid-sulfate and adularia-sericite types. *Econ. Geol.*, 82, 1-26.

Helgeson, H. C., and Garrels, R. M. (1968) Hydrothermal transport and deposition of gold. *Econ. Geol.*, 63, 622-635.

Hernandez, A. N. G., and Akasaka, M. (2010) Ag-rich tetrahedrite in the El Zancudo deposit, Colombia: occurrence, chemical compositions and genetic temperatures. *Resour. Geol.*, 60, 218-234.

Imai, A., and Uto, T. (2001) Association of electrum and calcite and its significance to the genesis of the Hishikari low-sulfidation epithermal gold deposits, Southern Kyushu, Japan. *Proceedings of Intern. Symposium on Gold and Hydrother. System, Fukuoka, Japan*, 83-88.

Imai, A., and Satoshi, O. (2005) Primary ore mineral assemblage and fluid inclusion study of the Batu Hijau Porphyry Cu-Au deposit, Sumbawa, Indonesia. *Resour. Geol.*, 55, 239-248.

Kawagle, S.A. (2005) The mineral resources of Papua New Guinea. *Resour. Geol.*, 55, 3, 285-288.

Kemkina, R.A. (2007) Fahlores of the Prasolovka Au-Ag volcanogenic deposit, Kunashir island, Russian Far Est. *Russian J. Pacif. Geol.*, 130-143 (in Russian).

Konstantinovskaia, E.A. (2000) Geodynamics of an Early Eocene arc-continent collision reconstructed from the Kamchatka Orogenic Belt, NE Russia. *Tectonophys.*, 325, 87-105.

Kovalenker, V. A., and Plotinskaya, O. Yu. (2005) Te and Se mineralogy of Ozernovskoe and Prasolovskoe epithermal gold deposits, Kuril-Kamchatka volcanic belt. *Geochem. mineral. and petrol.*, 43, 118-123.

Lindgren, W. (1933) *Mineral deposits*, 4th ed., New York, McGraw-Hill Book Co., 930 p.

Maglambayan, V. B., Ishiyama, D., Mizuta, T., Matsubaya, O., and Ishikawa, Y. (2006) Oxygen and carbon isotope study of calcite and dolomite in the disseminated Au-Ag Telluride Bulawan deposit, Negros Island, Philippines. *Resour. Geol.*, 51, 107-116.

Martynov, Yu. A., Kimura, J.-I., Khanchuk, A.I., Rybin, A.V., Chashchin A.A., and Martynov, A.Yu. (2007) Magmatic sources of quaternary lavas in the Kuril Island arc: new data on Sr and Nd isotopy. *Doklady Earth Sci.*, 417, 1206-1211.

Martynov, Yu. A., Khanchuk, A.I., Kimura, J.-I., Rybin, A.V., and Martynov, A.Yu. (2010) Geochemistry and petrogenesis of volcanic rocks in the Kuril Island arc. *Petrol.*, 18, 489-513.

Maske, S., and Skinner, B. J. (1971) Studies of the sulfosalts of copper I. Phase and phase relations in the system, Cu-As-S. *Econ. Geol.*, 66, 901-918.

Matsuhisa, Y., Morishita, Y., and Sato, T. (1985) Oxygen and carbon isotope variations in gold-bearing hydrothermal veins in the Kushikino mining area, Southern Kyushu, Japan. *Econ. Geol.*, 80, 283-293.

Matsuhisa, Y., Metsugi, H., Mizota, C., and Hayashi, S. (2002) The Hishikari Au-Ag epithermal deposit, Japan: oxygen and hydrogen isotope evidence in determining the source of paleohydrothermal fluids. *Econ. Geol.*, 97, 481-498.

McPhail, D.C. (1995) Thermodynamic properties of aqueous tellurium species between 25 and 350 °C. *Geochem. Cosmochim. Acta*, 59, 851-866.

Melekestsev, I.V. (2009) The inflection and diagnostics of active and potentially active volcanic features in the Kuril-Kamchatka island arc and the Commander islands link of the Aleutian arc. *J. Volcanol. and Seism.*, 3, 221-245.

Mel'nikov, F.P., Prokof'ev V. Yu., and Shatagin N.N. (2008) Termobarogeochemistry. M., Akademiich. Prospekt, 215.

Mining Journal (2010) Russia. Spec. Issue, 20. www.mining-journal.com

Nakayama, E. (1986) Paragenetic and compositional variations of Au-Ag minerals in the ginguero ores from the Nebazawa mine, Gunma prefecture. *Min. Geol.*, 26, 511-522.

Nekrasov, I. Ya. (1991) Geochemistry, mineralogy and genesis of gold-bearing deposits. M., Nauka, 304 (in Russian).

Noku, S. K., Asakasa, M., and Matsueda, H. (2011) The Crater Mountain deposit, Papua New Guinea. *Resour. Geol.*, 61, 63-76.

Okrugin, V. M. (2001) Age and genesis of epithermal deposits located along north-west coast of the Pacific Ocean. In *Magmatism and metallogeny in continental margins along the Pacific Ocean*. Magadan, 39-41.

Okrugin, V.M., Andreeva, E.D., Kim, A.U., Puzankov, I.M., Shishkanova, K.O., Bukhanova, D.S., Matsueda, H., Ono, S., Takahashi, R. and Watanabe, K. (2010) Volcanic related epithermal deposits in Kamchatka and Japan. Abstracts in the International Symposium «Fundamental problems of geology of the deposit and metallogeny». Moscow, 47-49.

O'Neil, J.R., and Silberman, M.L. (1974) Stable isotope relations in epithermal Au-Ag deposits. *Econ. Geol.*, 69, 902-909.

Pals, D. W., and Spry, P. G. (2003) Telluride mineralogy of the low-sulfidation epithermal Emperor gold deposit, Vatukoula, Fiji. *Mineral. and Petrol.*, 79, 285-307.

Panteleyev, A. (2005) Epithermal Au-Ag-Cu: high sulphidation. British Columbia Geol. Survey, 6.

Patoka, M. G., Litvinov, A. F., and Petrenko, I. D. (1999) Kamchatka as a new Russian gold-mining province. Abstract in The Regional Russian Conference "Geology and mineral resources of Kamchatka", 71-72 (in Russian).

Pineau, F., Semet, M.P., Grassineau, N., Okrugin, V. M., and Javoy, M. (1999) The genesis of the stable isotope (O, H) record in arc magmas: the Kamchatka's case. *Chem. Geol.*, 135, 93-124.

Petrenko, I. D. (1999) The gold-silver deposits at Kamchatka. VSEGEI, S-Peterburg, 116 (in Russian).

Plotinskaya, O. Yu., Kovalenker, V. A., Seltmann, R., and Stanley, C. J. (2006) Te and Se mineralogy of the high-sulfidation Kochbulak and Kairagach epithermal gold telluride deposits (Kurama Ridge, Middle Tien Shan, Uzbekistan). *Mineral. and Petrol.*, 87, 187-207.

Plechov P. Yu. (2011) Island-arc magma sources and island-arc volcanism evolution.
http://www.kscnet.ru/ivs/slsecret/jkasp_2011/abstr/abs52.pdf

Ponomareva, V., Melekestsev, I., Braitseva, O., Churikova, T., Pevzner, M., and Sulerzhitsky, L. (2007) Late Pleistocene-Holocene volcanism on the Kamchatka Peninsula. Northwest Pacific region. Volcanism and Subduction: the Kamchatka Region. *Geophys. monograph series*, 172, 165-198.

Roedder, E. (1984) Fluid inclusions. *Rev. in mineral.*, 12, 646.

Rosana, M.F., and Matsueda, H. (2002) Cikidang hydrothermal gold deposit in Western Java, Indonesia. *Resour. Geol.*, 52, 341-352.

Rosana, M.F., Matsueda, H., and Sudrajat, A. (2001) Cikidang Au-Ag deposit in West Java, Indonesia: an overview. *Proceedings of Intern. Symposium on Gold and Hydrother. System, Fukuoka, Japan*, 65-71.

Seward, T. M. (1973) Thio complexes of gold and the transport of gold in the hydrothermal ore solutions. *Geochim. Cosmochim. Acta*, 37, 379-399.

Shackleton, J. M., Spry, P. G., and Bateman, R. (2003) Telluride mineralogy of the Golden Mile deposit, Kalgoorlie, Western Australia. *Can. Mineral.*, 41, 1503-1524.

Shadrin, A.G. (1999) Epithermal precious metal mineralization in Kamchatka. *Proceeding of Regional Russian Conference of the Geology and mineral resources of Kamchatka*, 74-77 (in Russian).

Shelton, K. L., So, Chil-S., Haeussler, G. T., Chi, S-J., and Lee, K-Y. (1990) Geochemical studies of the Tongyoung gold-silver deposits, Republic of Korea: evidence of meteoric water dominance in a Te-bearing epithermal system. *Econ. Geol.*, 85, 1114-1132.

Shernberg, D. M., and Barnes, H. L. (1989) Solubility of gold in aqueous sulfide solutions from 150 to 350 °C. *Geochim. Cosmochim. Acta*, 53, 269-278.

Shiga, Yo., and Urashima, Yu. (1988) Au-Ag-Te ores from epithermal quartz veins of the Kushikino Mine, Kagoshima prefecture, Japan. *Min. Geol.*, 38, 375-384.

Shikazono, N. (1978) Selenium content of acanthite and the chemical environments of Japanese vein-type deposits. *Econ. Geol.*, 73, 524-533.

Shikazono, N. (1985) A comparison of temperatures estimated from the electrum-sphalerite-pyrite-argentite assemblage and filling temperatures of fluid inclusions from epithermal Au-Ag vein-type deposits in Japan. *Econ. Geol.*, 80, 1415-1424.

Shikazono, N. (1986) Au/Ag to total production ratio and Au-Ag minerals from vein-type and disseminated-type deposits in Japan. *Min. Geol.*, 36, 411-424.

Shikazono, N., and Shimizu, M., (1987) The Ag/Au ratio of native gold and electrum and the geochemical environment of gold vein deposits in Japan. *Mineral. Deposita*, 22, 309-319.

Shikazono, N. (1988) Native gold. *Tokyo University Bul.*, 31-33, 1-88.

Shikazono, N. (1988) Hydrothermal alteration associated with epithermal vein-type deposits in Japan: a review. *Min. Geol., Spec. Issue*, 12, 47-55.

Shimizu, T., Matsueda H., Ishiyama D., and Matsubaya O. (1998) Genesis of epithermal Au-Ag mineralization of the Koryu mine, Hokkaido, Japan. *Econ. Geol.*, 93, 303-325.

Shimizu, T. (2011) K-Ar ages of adularia at the Koryu epithermal Au-Ag deposit, Hokkaido in Japan. *Jap. Geol. Sur. Bull.*, 62, 235-241.

Shoji, T. (1986) Close relationship between adularia and ruby silver in vein-type gold-silver deposits of Japan. *Min. Geol.*, 36, 439-443.

Sillitoe, R. H. (1994) Indonesian mineral deposits – introductory comments, comparisons and speculations. *J. Geochem. Explor.*, 50, 1-11.

So, C-S., Dunchenko, V.Ya., Yun, S-T., Park, M-E., Choi, S-G., and Shelton, K.L. (1995) Te- and Se-bearing epithermal Au-Ag mineralization. Pradolovskoe, Kunashir island, Kuril Island Arc. *Econ. Geol.*, 90, 105-117.

Spiridonov, E., Maleev, M., Kovachev, V., Kulikova, I., Nazmova, G., and Filimonov, S. (2005) Minerals of fahlore group: indicators of ore genesis. *Bulgarian geological society, 80th anniversary*, 79-82.

Spiridonov, E. (2008) Ferrous bogdanovite from the weathering zone of the Aginskoe (Kamchatka). *Novye dannye o mineralah*, 43, 144-146 (in Russian).

Spiridonov, E. (2011) Bilibinskite from the weathering zones of the Aginskoe (Kamchatka) and Pionerskoe (Sayany) Au-Te deposits. *Novye dannye o mineralah*, 46, 162-164 (in Russian).

Stauch, G., and Cialtieri, L. (2008) Late Quarternary glaciations on northeastern Russia. *J. Quarter. Sc.*, 23, 545-558.

Takahashi, R., Matsueda, H., Okrugin, V. M., and Shuiji, O. (2007) Epithermal gold-silver mineralization of the Asachinskoe deposit in South Kamchatka, Russia. *Resour. Geol.*, 57, 4, 354-373.

Takahashi, R., Matsueda, H., Okrugin, V. M., and Shuiji, O. (2006) Polymetallic and Au-Ag mineralizations at the Mutnovskoe deposit in South Kamchatka, Russia. *Resour. Geol.*, 56, 141-156.

Takahashi, R., Matsueda, H., and Okrugin, V. M. (2002) Hydrothermal gold mineralization at the Rodnikovoe deposit in South Kamchatka, Russia. *Resour. Geol.*, 52, 359-369.

Tatsuka, K., and Morimoto, N. (1973) Composition variation and polymorphism of tetrahedrite in the Cu-Sb-S system below 400 °C. *Am. Mineral.*, 425-434.

Tatsumi, Y., Hamilton, D.L., and Nesbitt, R.W. (1986) Chemical characteristics of fluid phase released from a subducted lithosphere and origin of arc magmas: evidence from high-pressure experiments and natural rocks. *J. Volcanol. and Geotherm. Res.*, 29, 293-309.

Taylor, H.P.Jr. (1974) The application of oxygen and hydrogen isotope studies to problems of hydrothermal alteration and ore deposition. *Econ. Geol.*, 69, 843-883.

Volynec, O. (1991) Geochemical types, petrology, and genesis of Late Cenozoic volcanic rocks from the Kurile-Kamchatka island-arc system. *Intern. geol.*, 36, 373-405.

Voudouris, P., Tarkin, M., and Arikas, K. (2006) Mineralogy of telluride-bearing epithermal ores in the Kassiteres-Sappes area, western Thrace, Greece. *Miner. and Petrol.*, 87, 31-52.

Watterson, J.R., Gott, G.B., Neuerburg, G.J., Lakin, H.W., and Cathrall J.B. (1977) Tellurium, a guide to mineral deposits. *J. Geochem. Explor.*, 8, 31-48.

White, D. E. (1974) Diverse origins of hydrothermal ore fluids. *Econ. Geol.*, 69, 954-973.

White, N.C., Leake, M.J., McCaughey, S.N., and Parris, B.W. (1995) Epithermal gold deposits of the southwest Pacific. *J. Geochem. Explor.*, 54, 87-136.

White, N.C., and Hedenquist, J.W. (1995) Epithermal gold deposits: styles, characteristics and exploration. *SEG Newsletter*, 2, 1-13.

Zhao, J., Joel, B., Grundler, P.V., Xia, F., Chen, G., and Pring, A. (2009) Mechanism and kinetics of a mineral transformation under hydrothermal conditions: calaverite to metallic gold. *Am. Mineral.*, 94, 1541-1555.

Zhang, X., and Spry, P.G. (1994) Calculated stability of aqueous tellurium species, calaverite and hessite at elevated temperatures. *Econ. Geol.*, 89, 1152-1166.

Yakhontova, L.K., and Zverev, V.P. (2000) Superenge mineralogy. Textbook, V., Dalnauka, 331.