The genesis of the Mesozoic alkaline intrusions of the Khokhoi ore field (Upper Amga gold-mining district, Aldan Shield, North Asian Craton)

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Abstract. The article discusses petrography and features of the chemical composition of the Mesozoic alkaline intrusions of the Khokhoi ore field located within the Upper Amga gold-mining district in the Aldan Shield. This gold-mining district is located in the Aldan-Stanovoy Province rich in gold. Tectonic position and magmatic events of this Province are close to those positions and events of Shandong Gold Province of Sino-Korean Craton. The investigation of the genesis of the magmatic rocks and comparison of the Provinces can shed light on the genesis and regularity of location of the gold deposits in them. Intrusions of the Upper Amga gold-mining district passed through the metamorphic rocks of the Precambrian and intruded into the Cambrian carbonate rocks and the Jurassic sandstones. Petrographic observations found that large intrusive massifs of the ore field consist mainly of potassic feldspar and plagioclase. Blocks of melanocratic rocks – presumably tephrites are rare on the surface. Several generations of feldspar and dark-colored minerals are observed within all these rocks, indicating melt fractionation. High Sr and K contents were identified in the rocks. Contents decrease in the series of tephrite-syenite-monzonite. This feature, judging by other petrochemical data, can be associated not only with magmatic differentiation, but also with the melting and interaction of the lithosphere. In sienites, ovoids of quartz and the first-generation potassic feldspar melting margin were found. It could be possibly resulted from the capture of surrounding rock material and changes in the thermodynamic conditions of crystallization. It is found out that potassium and silicon contents in rocks depend inversely on calcium content. Interaction of melts and the host carbonate rocks with removal of silicon and potassium and formation of gold-bearing sericite-quartz and feldspar-quartz metasomatites is assumed. The loss of potassium probably has led to potassium metasomatism at the contacts of intrusions. This metasomatism produced the gold ores.

1. Introduction
The researches of the mineral and chemical compositions of the igneous rocks are important to define the tectonic and thermodynamic settings at the moment of the intrusion. A comparison with the similar and more studied objects can shed the light on the poorly interpreted features of the rocks under
research. The objects of this study were the petrography and geochemistry of alkaline igneous rocks of the South-East of the North Asian Craton to determine the genesis of the alkaline rocks and the reasons for their ore potential. In order to determine the quantitative mineral composition of the Mesozoic igneous rocks of the studied objects, 60 petrographic sections were examined using the MIN-8 polarization microscope. Photos of thin sections are made on an electronic polarization microscope Olympus BX 50, at magnification 25, 40, 100 camera Zeiss Axio Cam ICc 3. Chemical analysis of rocks was performed by the method of wet chemistry at Diamond and Precious Metal Geology Institute of the Siberian Branch of the RAS. Analysis of the contents of rubidium and strontium was carried out by the ICP-MS method at the Sobolev Institute of Geology and Mineralogy of the Siberian Branch of the RAS. The results of the research are given below. Concentrations of rock-forming oxides and trace elements given in the article correspond to the true contents.

2. Geological setting

The Upper Amga gold-mining district is located in the South-East of the North Asian Craton (figure 1) in the North of the Aldan Shield within the meridional Amga tectonic zone (figure 2). This zone divides two large Precambrian structural units: the West Aldan granite-greenstone and Nimnyr granulite-orthogneisses terranes. Gold ores and intrusives in the area are located in the faults, coinciding with the strike of the zone. The alkaline and subalkaline intrusions under consideration were formed as the result of the Mesozoic tectonic-magmatic activation of the zone. Greater part of the intrusions formed near the contact of the crystalline basement and elastic-carbonate sediments on the periphery of the Yamalakh Horst. Intrusive bodies have different shapes: laccoliths, sills and similar intrusions, stocks and dikes. The intrusions regarded in this article were named Northern Boskho, Western Boskho and Upper Khokhoi.

![Figure 1. Location of the regarded Mesozoic intrusions on the scheme of the North Asian Craton and adjacent areas [1], with changes](image-url)
Figure 2A [2]. 1 - contours of Precambrian metamorphic complexes: WA, Nm, St, Uch - terranes (West Aldan, Nimnyr, Sutam, Uchur); am, kl, tr - zones of melange (Amgin, Kalar, Tyrkanda); 2 - Proterozoic and Cambrian sedimentary rocks; 3 - Jurassic and Cretaceous sedimentary rocks; 4 - faults; 5 - thrusts; 6 - Cretaceous plagioporphyrtes, dacitic, andesitic porphyries, quartz porphyries, felsites and their tuffs, tuff breccias, Jurassic-Cretaceous and Cretaceous granodiorites, granites, granodiorite-porphyrty; 7 - Jurassic-Cretaceous syenite-porphyrty, granosienite-porphyrty, pseudoleucite and nepheline syenite, grorudite, orthophyre, aegirine granite, quartz porphyry, etc.; 8 – the boundary separating the zone of gold deposits related with MZ alkaline magmatism (to the North) from zone of gold deposits related with MZ granitoids (to the South); 9 – gold-mining districts (UT – Upper Toko, UA – Upper Amga, Ev – Evota, CA – Central Aldan, Lo – Lomam, Tr – Tyrkanda, KK – Ket-Kap) with gold fildes (1 – Khokhoi and Khatyrkhay, 2 – Kuranakh, 3 – Lebedinoe, 4 – Ryabinovoe, 5 – Inagli, 6 – Uguy, 7 – Sivagli, 8 – Perevalnoe, 9 – Ekhyunda, 10 – Mayskoe, 11 – Tchaidakh); 10 – border of the Republic of Sakha (Yakutia). **Figure 2B** (data of the Yakutskgeologiya state company). 1 - alluvial deposits. 2 - monzonite-syenite intrusions which are considered in the article. 3 – Jurassic sandstones, lenses and interlayers of gravelites, conglomerates, aleurolites. 4 - Vendian-Cambrian dolomites with layers of marls, nodules and flint lenses, stromatolite dolomitic limestones. 5 – Archean-Proterozoic quartzite with packs of gneisses and crystalline schists. 6 - main fractures. 7 – subordinate fractures. 8–the points with gold mineralization. 9–the areas with a gold content (ppm)

### 3. Petrography

#### 3.1. Northern Boskho intrusion

The rocks of the Northern Boskho intrusion are syenite-porphyrtes. They are leucocratic, porphyric or hypidiomorphic without facies transitions. The feature of these rocks is the predominance of the potassic feldspar (52%) over the plagioclase (35%). Dark-colored minerals in the rocks up to 7% (hornblende 4%, augite 2%, biotite 1%). The presence of quartz inclusions up to 3% in the Western chilled contact zone was found (figure 3A). The xenoliths of the quartz 3x1,5 cm in size are present too (figure 3B, C). The accessories are presented by the single grains of Apatites and ores. The latter (up to 3%) replace dark-colored minerals.
The two generations of the main rock-forming minerals (of the potassic feldspar, plagioclase and pyroxene) exist. Potassic feldspar of the first generation is distinguished by porphyry crystals of irregular, prismatic and rectangular forms. Potassic feldspar grain boundaries are corroded and have sutural texture (figure 3D) often with perthitic texture (intergrowths of albite in the orthoclase (figure 3E). Inclusions of dark-colored minerals, particularly pyroxene, were found. Peripheral and/or nuclear parts of grains are partially or completely replaced by products of secondary changes (pelitization) and have brownish and dark brownish color. The second generation of potassic feldspar (KFS) is in the groundmass. This KFS is represented by the small elongated grains interspersed with the small grains of plagioclase. Plagioclase of the first generation is represented by independent porphyry rectangular and prismatic crystals (figure 3F). These crystals are characterized by simple and polysynthetic twins, with traces of sericitization in both central and peripheral areas. crystals of this plagioclase have corrosion rim of the melting. The second generation of plagioclase is irregularly shaped crystals with polysynthetic twins. They are present in the form of the groundmass along with the second generation of KFS. Every crystal was altered with local sericitization. Monoclinic pyroxene is present in the form of single phenocrysts (first generation) and in the form of inclusions (second generation) in the first generation of KFS (figure 3G). Two types of pyroxene crystals were identified. One is represented by rare elongated-prismatic crystals (augite). The other one is represented by long-prismatic (needle-shaped) crystals with the obtuse ends (presumably aegirine). Interference color from pink to blue-green tones, depending on the cut. The extinction angle up to 43°. The mineral is strongly changed or replaced by a hornblende almost to complete pseudomorphs. Hornblende crystals are often of irregular shape rarely similar to a prism. They often form monomineral aggregates. Extinction angle up to 25°, the angle between the directions of cleavage 120°. Pleochroism from pale green and green to pale brown. Apatite is extremely rare. It is observed in the rock in the form of xenomorphic, rounded grains. This mineral was diagnosed due to a small birefringence, direct extinction, elevated relief. Quartz is present in the form of irregularly rounded grains mostly with an inherent to its cloud extinction. And it is also present in the form of aggregates with a "shirt" and rare inclusions of dark-colored minerals. Ore mineral of irregular shape replaces the mafic minerals (opacitization of hornblende and biotite).

**Figure 3.** Thin section A17-1. Western chilled contact zone (a) of the North Boskho Intrusion; Quartz aggregate (b, c) in syenite-porphyry. Magnification 40, crossed nicol. Thin section A17-1. KFS syenite porphyry of the Northern Boskho intrusion. Sutural texture (d) and perthite texture (e). Magnification 40, crossed nicol. Thin section A17-10. Phenocrysts of plagioclase (f) and KFS (g) with corroded boundaries and microinclusions of dark-colored minerals. Syenite porphyry of the Northern Boskho intrusion. Magnification 40, crossed nicol

3.2. Western Boskho intrusion

Petrographic composition and texture of the rocks of the Western Boskho intrusion allow us to refer them to monzonites. Rocks are characterized by the homogeneity of the composition. They are leucocratic and contain a significant amount of the feldspar. The rocks have a monzonite texture. Occasionally found fragments of hypidiomorphic and porphyry texture, which was caused by the presence of inclusions of KFS, plagioclase and pyroxene, were rarely observed (figure 4A). Mineral composition of the rocks of the Western Boskho intrusion has a noticeable difference from the North
Boskho intrusion. It is characterized by a high content of plagioclase to 65% at low content of potassic feldspar up to 20%. Dark-colored minerals more (up to 10%). Pyroxene 7% prevails over hornblende 3%. The composition of the rocks also includes a small amount (up to 2%) of ore mineral been formed by replacement of the amphibole grains. Late magmatic quartz up to 3% is also present in the rocks.

KFS, plagioclase and pyroxene crystals contain two generations of minerals. The first generation of KFS in the rocks of Western Boskho intrusion is represented by the porphyry grains of irregular shape. Grains contain the idiomorphic plagioclase crystals (figure 4B) and small inclusions of dark-colored minerals. The first generation of KFS is slightly pelitized and rarely has perthite structure. KFS of the second generation is represented by grains of irregular shape, forming the groundmass together with plagioclase of the second generation. The KFS amount prevails over the plagioclase amount. The second generation of KFS is subject to secondary changes (peliticization) and that is why it has a dark brown color. Plagioclase of the first generation is represented by idiomorphic porphyry crystals of rectangular and prismatic shapes, which are characterized by simple and polysynthetic twins, as well as zonal aggregates (figure 4A). The second generation is represented by rectangular, prismatic with rough outlines crystals with a simple twinning in the groundmass with the second generation of the KFS, and in the form of inclusions in the border parts of the early generation of the KFS. Pyroxene of the first generation is represented by porphyry crystals of prismatic appearance. Grains of pyroxene are subject to secondary changes. The second generation of plagioclase is in the form of small crystals of prismatic and irregular shapes. Their extinction angle is up to 45°. Their color of the interference is of the lowest order. The second generation performs the monomineral aggregates and aggregates with hornblende. Hornblende in groundmass is presented as the rare grains of irregular shape (figure 4B). The angle of extinction of hornblende - up to 30°, pleochroism is green, dark green to brown colors. It replaced the pyroxene with the formation of the ore mineral inclusions on the border. Inclusions and aggregates of ore mineral have a round and irregular shape. The quartz grains are represented by small rounded forms in the interstices between the plagioclase, KFS and mafic minerals.

3.3. Upper Khokhoi intrusion
The rocks of Upper Khokhoi intrusion are leucocratic monzonites with the predominant felsitic and monzonitic textures. The rocks record the certain isomorphism of plagioclase relative to KFS, idiomorphic crystals of plagioclase included in grains of potassic feldspar (figure 5A), porphyry grains of KFS, plagioclase and dark-colored minerals. Content of KFS - up to 30%, plagioclase - up to 50%. The distribution of dark-colored minerals in them is not homogeneous. There is a significant predominance of the hornblende 10% over the augite 5%. The cement aggregate consists of difficult to diagnose feldspar and small biotite 2%. The rocks also contain quartz, up to 2%. The amount of ore mineral is up to 1%.

Figure 4. Thin section A17-17. Phenocrysts of plagioclase and first-generation dark-colored minerals, against the background of the cement aggregate (a) of the Western Boskho intrusion. Magnification 40, crossed nicol. Porphyric polysynthetic plagioclase crystals in the KFS (b), monzonites of the Western Boskho intrusion. Magnification 40, crossed nicol. Porphyric grains of pyroxene and hornblende (c) in the monzonites of the Western Boskho intrusion. Magnification 40, uncrossed nicol
There are two generations of potassium feldspar. The first generation of KFS is presented by prismatic, irregularly shaped porphyritic grains, with the inclusions of the second sericitized plagioclase. Grains of KFS were the subject of peliticization. The border changes are found in rare grains. KFS of the second generation is represented by irregular small grains of the cement aggregate. It is subject to products of secondary changes and has a dark brown color in places of change. The first generation of plagioclase is represented by rectangular and prismatic phenocrysts, which are characterized by simple and polysynthetic twins (figure 5B), as well as the rare presence of zonal individuals. Plagioclase crystals of early generation are characterized by the presence of inclusions of second plagioclase and KFS on the edge. The second generation of plagioclase along with second KFS is also present in the cement aggregate in the form of the rectangular, prismatic, irregularly shaped crystals with polysynthetic twinning. Pyroxene is represented by rare porphyry crystals of prismatic and short-prismatic shape, sometimes with rounded edges. Pyroxene is unevenly distributed in the rock and is subject to secondary changes. Extinction angle - up to 45°. Interference colors are of lower order. Hornblende is represented by prismatic crystals and grains of irregular shape (figure 5 B-E). In some samples, hornblende is developed in the pyroxene with the formation of the edges of the ore mineral, and contains inclusions of accessory minerals. Extinction angle - up to 30°. Quartz is presented as small rounded grains (in amphibole) and larger xenomorphic particles and rounded grains in the interstices between the plagioclase, KFS and mafic minerals. Ore mineral of irregular, round shape, is developed in the dark-colored minerals edges and in the independent aggregates.

Figure 5. Thin section A17-23. Plagioclase crystals in KFS phenocrysts (a), monzonites of the Upper Khokhioi intrusion. Magnification 40, crossed nicol. Thin section A17-26. Porphyric grains of plagioclase of the first generation (b), against the background of the felsitic cement aggregate of the Upper Khokhioi intrusion. Magnification 20, crossed nicol. Hornblende (c, d) in the monzonites of the Upper Khokhioi massif. Magnification 40, crossed nicol

Within the Northern Boskho and Upper Khokhioi intrusions during the field observations, we have found fragments of strongly weathered and altered rocks which were referred by us to tephrites (?). The rock texture is pilotaxitic and porphyric, due to the phenocrysts of pyroxene. Mineral composition of the rock: plagioclase-20%, pyroxene – 40%, apatite – 3%, volcanic glass – 7%, products of secondary changes – 20%, ore minerals – 10%.

4. Geochemistry
According to the content of petrogenic oxides in the rocks of the Northern Boskho intrusion, the rocks belong to syenites [3]. The rocks contain SiO2 64.46-65.35%, TiO2 0.25-0.33%, Al2O3 17.23-17.65%, Fe2O3 1.48-2.27%, MgO up to 0.82%, CaO up to 6%. The total content of alkalies (Na2O + K2O) is close to that of alkaline rocks 10.47–11.32%, with K2O prevailing 5.41–6.47% over Na2O 4.38–5.33% (table 1). By the ratio (Na2O+K2O)-SiO2 rocks of the massif belong to alkaline quartz syenites (table 1). Figurative points of rock compositions in relation to R1-R2 (R1 = 4Si-11 (Na + K); R2 = 6Ca + 2Mg + Al) [4] occupy an intermediate position between syenites and quartz syenites (figure 6A). By K2O-SiO2 ratio the compositions of rocks of the Northern Boskho intrusion form a secant trend in the field of the shoshonite series (figure 6B).
Table 1. The chemical composition of igneous rocks of the Khokhoi ore field (wt. %) and concentration of Rb & Sr (in ppm)

|          | 1   | 2   | 4   | 5   | 7   | 8   | 9   | 11  | 14  | 16  | 17  | 18  | 20  | 21  | 23  | 24  | 25  | 26  | 12  | 12  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| SiO₂     | 64  | 65  | 65  | 65  | 65  | 65  | 66  | 66  | 66  | 66  | 67  | 66  | 67  | 67  | 67  | 67  | 67  | 49  | 48  |
| TiO₂     | 0.3 | 0.3 | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.8 | 0.7 |
| Al₂O₃    | 17  | 18  | 18  | 18  | 17  | 17  | 17  | 17  | 17  | 17  | 17  | 17  | 18  | 18  | 18  | 18  | 14  | 13  |
| Fe₂O₃    | 1.8 | 2.3 | 2.3 | 1.9 | 2.0 | 1.5 | 2.0 | 1.9 | 2.1 | 2.1 | 2.2 | 2.0 | 1.9 | 1.0 | 1.3 | 1.1 | 0.9 | 6.7 | 6.5 |
| FeO      | 1.2 | 0.6 | 0.8 | 0.8 | 1.0 | 1.4 | 0.9 | 1.0 | 0.9 | 1.0 | 0.9 | 0.9 | 1.2 | 0.8 | 1.1 | 1.3 | 1.4 | 1.3 |
| MnO      | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| MgO      | 0.0 | 0.6 | 0.4 | 0.6 | 0.3 | 0.8 | 0.0 | 0.2 | 0.2 | 0.6 | 0.4 | 0.1 | 0.3 | 0.0 | 0.0 | 0.3 | 0.2 | 3.1 | 3.0 |
| CaO      | 2.7 | 1.7 | 1.5 | 2.0 | 2.6 | 2.3 | 2.8 | 2.0 | 3.2 | 2.6 | 3.0 | 2.9 | 2.5 | 2.0 | 1.4 | 1.8 | 2.3 | 9.0 | 9.8 |
| Na₂O     | 5.1 | 4.4 | 4.5 | 5.0 | 5.3 | 5.3 | 5.1 | 5.2 | 4.9 | 4.7 | 4.8 | 5.2 | 4.9 | 5.4 | 5.4 | 5.8 | 5.4 | 0.7 | 0.7 |
| K₂O      | 5.7 | 6.5 | 6.9 | 5.5 | 5.4 | 5.3 | 5.7 | 6.0 | 4.4 | 4.2 | 4.2 | 4.6 | 4.5 | 4.6 | 4.6 | 4.9 | 9.5 | 3.1 | 3.7 |
| H₂O      | 0.4 | 0.5 | 0.4 | 0.4 | 0.2 | 0.6 | 0.4 | 0.6 | 0.4 | 0.5 | 0.4 | 0.3 | 0.3 | 0.5 | 0.5 | 0.3 | 0.8 | 0.8 |
| H₂O’     | 0.2 | 0.4 | 0.5 | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.4 | 0.7 | 0.6 | 0.5 | 0.3 | 0.7 | 0.7 | 0.4 | 2.3 | 2.6 |
| P₂O₅     | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 1.0 | 1.0 |
| CO₂      | 0.2 | 0.4 | 0.2 | 0.2 | 0.2 | 0.2 | 0.8 | 0.2 | 0.3 | 0.3 | 0.3 | 0.1 | 1.1 | 1.1 | 0.0 | 0.0 | 3.3 | 3.6 |
| S        | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 |
| F        | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 |
| Total    | 100 | 101 | 101 | 100 | 100 | 101 | 101 | 101 | 99.8| 101| 100| 99.7| 100| 101| 101| 100| 101| 101| 101|
| Sr       | 980 | 1200| 1100| 1100| 910 | 1000| 990| 890| 800| 880| 960| 910| 740| 740| 830| 1000| 1300| 1800 |
| Rb       | 101 | 115 | 117 | 107 | 105 | 106 | 109| 115 | 90 | 85 | 86 | 85 | 86 | 77 | 77 | 76 | 74 | 147| 138 |

Notes. Intrusions and sample numbers: Northern Boskho 1 - 11; Western Boskho 14 - 18; Upper Khokhoi 23 - 26; tephrites 12.

Monzonites of the Western Boskho intrusion in contrast to the rocks of the previous intrusion are characterized by a slightly higher content of SiO₂ 65.5-67.06%, relatively low values of TiO₂ 0.23-0.29%, Al₂O₃ 16.94-17.19%, Fe₂O₃ 1.89-2.19%, MgO 0.12-0.56%, CaO 2.52-3.15%. They have lower total alkalinity (Na₂O+K₂O) 8.92-9.41%, with the prevalence of Na₂O 4.68-5.18% over K₂O 4.18-4.56% (table 1). According to the contents (Na₂O+K₂O)-SiO₂, K₂O-SiO₂, the rocks of the intrusion occupy an intermediate position between alkaline and sub-alkaline quartz syenites and belong to the high-potassium calc-alkaline series of igneous rocks. The ratio of R₁-R₂ compositions [4] in them varies from quartz syenites to quartz monzonites (figure 6A). Monzonites forming an Upper Khokhoi intrusion with the SiO₂ content of 65.62-66.71% are close to those of Western Boskho (figure 6B), but differ from the latter by a relatively high content of Al₂O₃ 17.76-18.05% and low TiO₂ 0.19-0.24%, Fe₂O₃ 0.86-1.3%, MgO up to 0.34%, CaO 1.44-2.34%, with the higher alkalinity of the rock of 9.94-10.35% where Na₂O 5.41-5.75% predominates over K₂O 4.50-4.64% (table 1). According to the contents of (Na₂O + K₂O) and SiO₂, the rocks correspond to quartz syenites. The ratio of K₂O/SiO₂ in them corresponds to rocks of the high-potassium calc-alkaline series. According to the [4] method, composition points are localized in the field of quartz monzonites (figure 6A). The content of SiO₂ 48.07-48.6% and TiO₂ up to 0.74%, Al₂O₃ 13.28-13.55%, Fe₂O₃ 6.54-6.72% MgO 3.03-3.14%, CaO 9.21-of 9.77% (table 1) in the tephrites is close to plagiobasalt[3]. At the same time, according to high K₂O content 9.21-9.46% prevailing over Na₂O 0.74%, the rocks shall be referred to the leucite-phonotephrite[3]. The composition of rocks according to (Na₂O+K₂O)-SiO₂ classification refers to basic alkaline rocks, and the ratio of K₂O/SiO₂ in them corresponds to those of the shoshonite.
series. According to the [4] method, figurative points of composition occupy the fields of the basic rocks (figure 6A).

Figure 6. Discrimination charts for igneous rocks. For the figure 6A: \( R_1 = 4Si - 11(Na+K) \), \( R_2 = 6Ca + 2Mg + Al \). Classification fields after [4], fields I-III after [5]: I - alkaline magma differentiation field, II - mantle magma field, III – field of the rocks of the orogenic stage. Points are: 1 – tephrites, 2 – Northern Boskho intrusion, 3 – Western Boskho intrusion, 4 – Upper Khokhoi intrusion. Colored fields are the fields for the chemical composition of the alkali rocks of the Aldan Shield gold-mining districts: red – Central Aldan, blue – Tyrkanda, green – Evota (figure 2A). For the figure 6B fields after [6]: I – the field of the low potassium tholeiitic series, II - the field of the middle potassium calc-alkaline series, III – the field of the high-potassium calc-alkaline series, IV – the field of the shoshonite series.

Points of the composition of all Khokhoi ore field rocks in the \( R_1-R_2 \) coordinates form the secant trend, from the field of the differentiates of the alkaline magmas to the field of syncollisional rocks. This trend is typical for the Mesozoic alkaline igneous rocks of the Aldan Shield (figure 6A). The tendency of the chemical composition change in the rocks is not typical for magmatic differentiation and classic magmatic series (figure 6A, B). This phenomenon can be explained by the contamination processes. For the plutons, the variations of the contents of \( SiO_2 \) and \( K_2O \) are observed with an inverse relationship to the \( CaO \) content (figure 7). These features probably indicate the removal of \( SiO_2 \) and \( K_2O \) from the melt during contamination with carbonate material. \( CaO \) and \( Na_2O \) show a direct relationship. The Upper Khokhoi intrusion which is located in the sandstones has minimal variations (figure 7). But for the Northern and Western Boskho intrusions located in the carbonate rocks, the variations are significant (figure 7). Rb/Sr relation is greater in these intrusions and can depend on the contamination by the crustal material. Instability of the first generation of the potassic feldspar and the presence of quartz rarely observed in the rocks can be the evidence of the undersaturation and oversaturation of the melt by the potassium and silicon during the changes in magma composition.
Figure 7. Depending on silica and alkalis concentration from the calcium concentration in the rocks of the Khokhoi ore field intrusions.

Gold-bearing metasomatites of the Upper Amga gold-mining district are found on the contact of the basement (gneiss) and cover (dolomite), as well as in the cover on the contact of carbonate (dolomite) and detrital (sandstone) rocks. The Khokhoi ore field is confined to the last contact (figure 2). Metasomatites consist of quartz or carbonates in association with pyrite, potassic feldspar and less often sericite. Subordinate quantities of other ore minerals occur. Ore occurrences of gold are spatially associated with the Northern and Western Boskho intrusions (figure 1). It can be the evidence that potassium and silicon were removed from alkaline magmatic rocks to form the gold-bearing metasomatism.

5. Results and discussions
Within the Sino-Korean Craton in Shandong Province (figure 1), the gold ore metasomatic deposits Jiaojia and Liujapuzhi[1] are close to the Khokhoi ore field by tectonic position, age and alterations[7]. These deposits are associated with granites, diorites, and syenite porphyres intruded in the Archean metamorphic and Neoproterozoic-Ordovician carbonate sedimentary complexes. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratio in MZ alkaline igneous rocks of Shandong Province is 0.706-0.7087 [8] close to that of 0.704-0.709 for similar rocks of the Aldan Shield [9] and the Mesozoic lithospheric mantle of the Sino-Korean Craton [10]. This may suggest that the source of alkaline melts in both Gold Provinces could be the lithospheric mantle. On the seismic tomography sections [11] in both areas of alkaline magmatism and gold mineralization, a decrease in the depth of the base of the lithosphere is observed (figure 8). These features can be the evidence that these two gold reach regions are comparable in the genesis of the mesozoic magmatic rocks and gold mineralization. The further researches with comparison are needed to understand in detail the processes of the ore formation.
6. Conclusions

Melts for the Mesozoic igneous rocks of the Khokhoi ore field were formed by melting of the lithospheric mantle. During the rising, the melts experienced fractionation and at the level of the crust were contaminated with crustal material. Contamination caused the redistribution of elements with the removal of potassium and silicon and the formation of gold-bearing metasomatites. According to the tectonic position, age and genesis of Mesozoic intrusive alkali rocks the Khokhoi gold field is close to the Shandong gold-mining Province of the Sino-Korean Craton. Further study of the evolution of Mesozoic alkaline igneous complexes and gold-mining districts of the southern part of the North Asian Craton should be carried out taking into account the geological history and metallogeny of the Shandong province.

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