Mesozoic gold deposits of Eastern Zabaykalye: relationship to magmatism, isotopic composition

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Abstract. It is noted that the formation of Mesozoic gold mineralization in Eastern Zabaykalye is associated with magmatic formations of the Amudzhikansky (J<sub>2-3</sub>), Shakhtaminsky (J<sub>2-3</sub>), and Sokhondinsky (J<sub>1</sub>) complexes formed during collisional and post–collisional processes. The nature of these magmatic formations has both mantle (87Sr/86Sr < 0.0706) and crustal components (87Sr/86Sr < 0.0706). Calculation of isotopic composition of oxygen from the ore veins of Aleksandrovsky and Lyubavinsky gold deposits revealed that fluids of magmatic nature were involved in their formation. These data indicate a magmatic source of the Mesozoic gold mineralization in Eastern Zabaykalye.

Mesozoic gold deposits are widespread in Eastern Zabaykalye. Their formation is generally associated with collisional and post-collisional processes at the boundary of the Late Jurassic and Early Cretaceous periods. A close spatial confinement of gold ore deposits to the seam zone of the Mongol-Okhotsk deep-seated fault (figure 1) is observed [1].

Figure 1. Layout of the Mesozoic ore-bearing magmatic complexes and gold ore deposits of Eastern Zabaykalye. 1 – Gold-bearing magmatic complexes: a) Amudzhikansky (J<sub>2-3</sub>), b) Shakhtaminsky, c) Sokhondinsky; 2 – Mongol-Okhotsk suture: a) the main branch, b) the Onon branch; 3 – deposits: 1 – Lyubavinsky, 2 – Darasunsky, 3 – Baleysky, 4 – Verkhne-Aliinsky, 5 – Kariysky, 6 – Klyuchevsky, 7 – Aleksandrovsky, 8 – Itakinsky.
Magmatic formations of the magnetite series are developed in the closest margins of the Mongol-Okhotsk fault; further away from the suture zone, igneous rocks of the magnetite series are replaced by igneous rocks of the ilmenite series. Deposits and occurrences of tin, tungsten and rare metals are associated with the ilmenite rock series; gold ore deposits are associated with the magnetite rock series. Gold mineralization in the Zabaykalye sector of the Mongol-Okhotsk deep fault is paragenetically related to the intrusions of the Amudzhikansky (J₃), Shakhtaminsky (J₃) and Sokhondinsky (J₁) complexes [2].

The Amudzhikansky complex is developed in the central and eastern part of Zabaykalye. Intrusions of the complex are represented by stock- and laccolith-shaped bodies confined to the zones of large faults. Terminal dyke formations of the complex are characterized by elevated gold concentrations.

Intrusions of the Shakhtaminsky complex are widespread in the interfllue of the Shilka and Argun Rivers. The rocks of this complex are represented by stocks, laccoliths, and dyke like bodies. Molybdenum, polymetallic and gold mineralization is associated with the dyke complex series.

The Sokhondinsky complex forms volcanic plutonic formations along the Onon-Tura branch of the Mongol-Okhotsk Suture [2]. Some researchers associate the formation of Lyubavinsky gold ore deposit with the dyke series of the Sokhondinsky complex [2].

The formation of the Mesozoic intermediate intrusive rocks is associated with mantle-crustal interaction. The $^{87}$Sr/$^{86}$Sr ratios are used to establish the mantle or crustal nature of the magmatites. $^{87}$Sr/$^{86}$Sr values less than 0.706 are typical for mantle sources, values more than 0.706 – for crustal sources. In the ore fields of gold-ore deposits magmatic formations, which are probable sources of mineralization, magmatites of both mantle and crustal nature are developed (table 1).

**Table 1.** $^{87}$Sr/$^{86}$Sr ratio in the Mesozoic intrusive formations of the Eastern Zabaykalye gold deposits [3].

| Rock             | $^{87}$Sr/$^{86}$Sr | Deposits          |
|------------------|---------------------|-------------------|
| Granite          | 0.70669             | Lyubavinsky       |
| Granite          | 0.70785             | Lyubavinsky       |
| Granite          | 0.70666             | Lyubavinsky       |
| Granite          | 0.70647             | Lyubavinsky       |
| Groleudite       | 0.70733             | Kariysky          |
| Granite-porphyry | (0.70575–0.7059)    | Darasunsky        |

Previous research of isotopic composition of quartz in the ore veins of productive stages of Lyubavinsky [4] and Aleksandrovsky [5] gold deposits indicates the presence of magmatic source of gold mineralization (table 2).

**Table 2.** Isotopic composition of quartz and coexisting fluid of the Eastern Zabaykalye gold deposits.

| Sample no. | Ore composition | $\delta^{18}$O,‰ | Fluid isotopic composition at different temperatures, $\delta^{18}$O$_{H2O}$ |
|------------|-----------------|------------------|---------------------------------------------------------------|
|            | Mineral formation temperatures | Lyubavinsky deposit | 260°C  | 205°C  |
| 781        | Pr$_3$, Ars$_3$ (to 5%) | 16.4             | 7.96   | 5.09   |
| 782        | Pr (to 1%)       | 16.5             | 8.06   | 5.19   |
| 791        | Pr (to 1%)       | 15.6             | 7.16   | 4.29   |
| 794        | Pr, Ars, Mo (to 3%) | 16.7             | 8.26   | 5.30   |
| 795        | Pr (>5%)         | 17.9             | 9.46   | 6.59   |
| 796        | Pr (>5%)         | 17.7             | 9.26   | 6.39   |
| 862        | Pr (to 1%)       | 17.3             | 8.86   | 5.99   |
| 864        | Pr (to 4%)       | 16.6             | 8.16   | 5.29   |
| 865        | Pr (to 3%)       | 16.6             | 8.16   | 5.29   |
| 866        | Pr, Ars (to 1%)  | 18.1             | 9.66   | 6.79   |
| 668        | Pr (to 1%)       | 18.7             | 10.26  | 7.39   |
Isotopic composition of oxygen in hydrothermal fluid calculated in quartz-water system with the equation \( \delta^{18}O_{\text{quartz}} - \delta^{18}O_{\text{H}_2O} = 3.34 \left( 10^6 / T^2 \right) - 3.31 \), where \( T \)–temperature in Kelvin [6] showed that most values correspond to the corresponding fluid of magmatic nature [4, 5, 7]. Oxygen isotopic composition values of less than 5.0 ‰ can be explained by the involvement of meteoric water in ore formation.

The calculated oxygen isotopic composition in the fluid in equilibrium with quartz of productive stage of Itakinsky deposit (220–300°C) varies from 2.77‰ to 7.24‰. Some of the calculated values fall within the interval from + 6.34‰ to +7.24‰, which corresponds to an aqueous fluid of magmatic nature [7] (table 2).

To establish potential ore-bearing capacity of granites, petrogeochemical trend classification of granite formations, associated with the formation of the main types of ore deposits, was used (figure 2, table 2).
Gold deposit granitoids developed in the deposit areas are characterized by elevated alkaline content (table 3). They are confined to the fields of subalkaline and alkaline granitoids (figure 2). Such a sustained uniformity may indicate a probable common source.

Given close genetic relationship between gold and molybdenum mineralization in Eastern Zabaykalye, it can be stated that intrusive formations of the Amudzhikansky and Shakhtaminsky complexes of gold deposits mainly correspond to the gold-molybdenum mineralization trend.

Table 3. Content of petrogenic components (wt. %) and impurity elements in granitoids of the Amudzhikan-Shakhtaminsky complex of ore fields of the Mesozoic gold ore deposits of Eastern Zabaykalye (g / t) a.

| Sample no. | 489b | 489-1 | 548 | 548-3 | 694 | 694-1 | 695 | 684 | 684-1 | 685 |
|------------|------|-------|-----|-------|-----|-------|-----|-----|-------|-----|
| SiO₂       | 69.00| 69.00 | 67.80| 67.30 | 69.10| 69.00 | 72.00| 71.00| 69.60 | 70.50 |
| TiO₂       | 0.62 | 0.61  | 0.35 | 0.33  | 0.27 | 0.42  | 0.35 | 0.28 | 0.32  | 0.32 |
| Al₂O₃      | 14.40| 14.00 | 15.00| 14.70 | 15.60| 14.80 | 13.30| 15.10| 15.50 | 15.60 |
| Fe₂O₃      | 0.64 | 0.78  | 1.28 | 1.23  | 0.86 | 1.16  | 1.01 | 0.77 | 0.74  | 0.69 |
| FeO        | 2.16 | 1.84  | 1.68 | 1.68  | 1.37 | 2.11  | 1.68 | 1.33 | 1.48  | 1.52 |
| MnO        | 0.03 | 0.04  | 0.03 | 0.04  | 0.04 | 0.06  | 0.04 | 0.04 | 0.04  | 0.04 |
| MgO        | 1.66 | 1.49  | 1.40 | 1.06  | 1.18 | 2.23  | 1.90 | 0.57 | 0.89  | 0.80 |
| CaO        | 2.09 | 1.83  | 2.68 | 2.49  | 0.92 | 1.83  | 1.56 | 0.92 | 1.02  | 1.02 |
| Na₂O       | 3.39 | 3.88  | 4.53 | 4.19  | 3.86 | 4.39  | 4.00 | 4.54 | 4.86  | 4.75 |
| K₂O        | 4.55 | 4.58  | 3.57 | 4.10  | 6.15 | 3.20  | 3.18 | 3.98 | 3.92  | 4.00 |
| P₂O₅       | 0.17 | 0.17  | 0.13 | 0.13  | 0.11 | 0.16  | 0.12 | 0.17 | 0.17  | 0.16 |
| Ignition loss | 1.08 | 1.06  | 1.25 | 2.36  | 0.65 | 0.85  | 0.73 | 0.79 | 0.74  | 0.90 |
| Total      | 99.79| 99.28 | 99.70| 99.48 | 100.11| 100.21| 99.87| 99.49| 99.28 | 100.30 |
| Zn         | 40   | 33    | 75   | 27    | 79   | 52    | 58   | 79   | 52    | 35   |
| As         | 110  | 100   | 39   | 99    | 81   | 140   | 56   | 400  | 220   | 105  |
| Pb         | 65   | 61    | 35   | 21    | 30   | 15    | 17   | 27   | 36    | 19   |
| Rb         | 190  | 200   | 64   | 80    | 160  | 119   | 105  | 127  | 110   | 109  |
| Sr         | 410  | 360   | 560  | 550   | 480  | 434   | 410  | 780  | 920   | 940  |
| Zr         | 280  | 280   | 110  | 110   | 88   | 130   | 114  | 160  | 145   | 150  |


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