Iron-Oxide Cu-Au Mineralizing Systems: 
Eastern Yakutia Perspective

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Abstract: The GIS (geographic information system) used for predicting the associated with upper-intrusive zone of hydrothermal alteration IOCG (iron-oxide copper gold) mineralizing systems is shown by example of the northeast of Russian. IOCG ore deposits can have enormous geological resources with significant reserves of base, precious and strategic metals, are economically attractive targets for mineral exploration worldwide, but are still unknown in the northeast Russian. It was localized in Tarinskiy ore node (eastern Yakutia) field of brecciated altered rocks with sulfide and iron-oxide cement is a first in eastern Yakutia nature anomaly of IOCG-type with iron-oxide Cu-Au ± U specialization, that was formed close to the surface of Rep-Yuruinskiy pluton. It should be of interest as a new precious metals world class deposit type in northeast of Russia.

Key words: GIS, iron oxide-Cu-Au ± U, Rep-Yuruinskiy, Tarinskiy ore node.

1. Introduction

Fundamental problem of ore deposit geology is predicting and prospecting of a new large-scale commercial types precious metals deposits. One of them—the large group of IOCG (iron-oxide copper gold) hydrothermal ore deposits with Cu, Au, ±Ag, ±U, ±REE, ±Bi, ±Co, ±Nb, ±P is still unknown in the Russian Far East (Fig. 1) and prospecting perspective is obscure for the time.

The recognition of this deposit type began with the discovery in 1975, Australia’s giant Olympic Dam deposit (2 Bt of ore, containing 1.1% Cu; 0.5 g/t Au; 0.4 kg/t U3O8; 0.24%-0.45% La + Ce [1]) and in 1987, La Candelaria in Chile (470 million tons of ore with an average content of 0.95% Cu; 0.22 g/t Au; 3.1 g/t Ag [2]). Deposits are characterized by more than 20% of the content of iron oxides and low sulphides. IOCG ore bodies are typically Manto-type large-tonnage granite-associated and breccia-hosted, stacked in the exo-ore and endo-zone of plutons.

IOCG deposits are formed of near alkali type. And lime-alkaline plutons are also associated with porphyry Cu-Mo or Cu-Au deposits, Cu-Ag deposits “Manto”, U, Hematite and Au-PGE ores polymetallic Pb-Zn-Ag ±Au veins.

2. The Main Features of Known IOCG Deposits-Type

2.1 Hydrothermal Features

All regions with IOCG deposits are characterized in large areas of rocks alteration, including Na (Ca) and K-types and ranging from 10 km² to 100 km² or more [3-5]. Alteration areas usually exceed the areas of IOCG mineralization [6]. A key feature of the IOCG is association to high-K granites [7].

2.2 Mineralization

Economic mineralization is represented with chalcopyrite ± bornite and native gold, localized in
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Fig. 1  Distribution of IOCG districts and important worldwide deposits [8] (gray square boxes) and eastern Yakutia (Russia)—a new IOCG green field area (black rectangle).

Australia: Gawler district (Olympic Dam, Acropolis, Moonta, Oak Dam, Prominent Hill and Wirra Well), Cloncurry district (Ernest Henry, Eloise, Mount Elliot, Osborne and Starra), Curnamona district (North Portia and Cu Blow), Tennant Creek district (Gecko, Peko/Juno and Warrego); Brazil: Carajas district (Cristalino, Alemao/Igarapé Bahia, Salobo and Sossego); Canada: Great Bear Magmatic Zone (Sue-Dianne and NICO), Wernecke district (West Coast skarns), Central Mineral Belt and Kwyjibbo deposit; Chile: Chilean Iron Belt district (Candelaria, El Algarrobo, El Romeral, Manto Verde and Punta del Cobre); China: Bayan Obo (Inner Mongolia), Lower Yangtze Valley district (Meishan and Daye); Iran: Bafo district (Chogust, Chadoo Malu, Seh Chahoon); Mauritania: Akjoujt deposit; Mexico: Durango district (Cerro de Mercado); Peru: Peruvian Coastal Belt (Raul, Condestable, Eliana, Monterrosas and Marcona); Sweden: Kiruna district (Kiirunavaara, Loussavaara), Aitik deposit (also described as a porphyry Cu deposit); South Africa: Phalaborwa and Vergenoeog deposits; USA: Southeast Missouri district (Pea Ridge and Pilot Knob); Adirondack and Mid-Atlantic Iron Belt (Reading Prong); Zambia: Shimyoka, Kantonga, and Kitumba; Eastern Yakutia (Russia): green-field area with Nuektaminskiy, Endybalskiy, Kis-Kuelskiy and Rep-Yuruinskiy IOCG-potential districts.

Sulphides-poor deposits with large amount of iron-oxides and wide hydrothermal alteration make IOCG a good target for regional airborne magnetic and gravity research [9, 10]. Combination with field geological observations, gravity and magnetic data are useful but expensive tool in iron-oxide ore bodies prospecting.

2.3 Geophysical Features

Hematite characterizes low-level, magnetite-deep-level of mineralizing systems.

2.4 External Features at the Landsat Images

Using Landsat multispectral data is one of the most powerful tools for exploring and characterizing many aspects of the earth’s surface and is a cheap method for IOCG detecting [11-13]. Spectral analysis using red (0.63-0.69 μm), green (0.52-0.60 μm) and blue (0.45-0.52 μm) produces a true color band (3-2-1) combination, which allows to determine iron-oxide
areas (Fig. 2).

2.5 IOCG Deposits Timing

IOCG timing with respect to earth evolution is different and does not appear to be critical [14]. Deposits are known to occur from the Archean, (Salobo and Igarapé Bahia), to the Mesozoic (Chilean Iron Belt, Russian Far East) [15-17].

3. Prerequisites for the IOCG-Style Mineralization Occurrence in East Yakutia

Audit of ore collection material allowed to identify some ore types that can be assigned to IOCG and previously considered as a product of the oxidation of sulfide ores.

Ore zone “Pozolota” (65.799669°N, 129.596191°E) in Nuektaminskiy ore node [8] includes 50 m × 26 m stock-like ore body of milky drusy quartz with hematite cement and gold content from 1.2 g/t to 19.8 g/t (Fig. 3a). The field of the eruptive breccias of Endybalskiy ore node (65.673781°N, 130.132772°E) includes large bodies of breccias with hematite cement. They were not analyzed for copper and gold, but also look like IOCG type ore (Fig. 3b). Kis-Kuelskiy diorite-granodiorite intrusive (65.501242°N, 130.280125°E) includes different types of IOCG-like mineralization [18]: brecciated granodiorite with iron-oxide cement (Fig. 3c) and brecciated hornstone with iron-oxide and sulphide cement (Fig. 3d). During 2011 field season, it was assured one of the iron-oxide anomalies identified in Landsat ETM+ imagery interpretation. The anomaly is situated in Rep-Yuruinskiy ore district (Tarynskiy ore node 63.574957°N, 143.275846°E) and submitted by brecciated and horned rocks. The Rep-Yuruinskiy sub-type of IOCG consists of granodiorite-associated, breccia-hosted deposit where arsenopyrite ore is associated with iron-oxide alteration of breccias (Figs. 3e and 3f). Breccias include thick lenses of quartz-chlorite metasomatites with disseminated Cu-sulphide mineralization.

Breacha color depends on the saturation of iron-oxides and is changing in the hypergenesis from brown and dark brown to different shades of brown and yellow-brown. The breccias are commonly heterolithic and composed of sub-angular to more rarely rounded lithic and oxide clasts or fine-grained massive material. The breccia’s areal limit is about 5.16 km², density varies from 2.41 t/m³ to 3.23 t/m³ (average = 2.76 t/m³). The ore resource potential could be about 712 Mt for 50 m cut off. The grab samples assay results are presented in Table 1.
Fig. 3 IOCG ore samples from eastern Yakutia. (a) Sample 5214—gold bearing ore from Pozolota deposit (Nuektaminskiy ore node) of milky drusy quartz with hematite cement; (b) Sample 5307—eruptive breccia’s of Endybalskiy ore node with hematite cement; (c) Sample 6279—Kis-Kuelskiy pluton: brecciated granodiorite with iron-oxide cement; (d) Sample 6246-1—Kis-Kuelskiy pluton (exocontact zone): brecciated hornstone with iron-oxide and sulphide cement; (e) Sample 7117—brecciated hornstone from Rep-Yuruinskiy pluton (exocontact zone) with gold bearing cement; (f) Sample 7127—brecciated hornstone from Rep-Yuruinskiy pluton exocontact zone with Au and U bearing iron-oxide cement (Qz—quartz; He—hematite; Horn—hornstone; Ri—rhyolite; Grd—granodiorite; Fe-ox—iron-oxide cement; Fe-ox+gal—iron-oxide + galena cement).
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Table 1  Grab samples assay results of IOCG-like ore (Rep-Yuruinskiy ore node).

<table>
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<th>No.</th>
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<th>Cu (%)</th>
<th>Bi (g/t)</th>
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<td>16.03</td>
<td>0.55</td>
<td>510</td>
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NSR: no significant results; a, b, c: samples.

4. Prospecting Model for ArcGIS Analysis

Deposits of IOCG-type usually occur in the vicinity of porphyry Cu-Au or Cu-Mo deposits associated with alkaline and calc-alkaline plutons from A (anorogenic) to I (igneous) types, enriched with U, F, Mo and REE [3]. A-type granitoids are greatly enriched with Fe and refer to ferroan alkali-lime and alkaline, most part of them refer to metaluminous. I-type granitoids are mostly lime-alkaline and lime and refer to magnesian type, and as A-type granitoids are metaluminous, less often peraluminous [19].

The GIS (geogr) used to assess the ore potential of plutons is an important part of a precious metals prospecting model. Many ore deposits have a spatial relationship with the plutons, which stimulates attempts to assess their ore potential existence.

So long as nobody searched for the deposits of IOCG-type in eastern Yakutia, and their presence was not discussed in the press, this is the first attempt to assess the potential of the territory to the IOCG-type mineralization.

For this purpose, a GIS project was created, which includes:
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(1) Base geology with plutons location map and calculated geometry + related geodatabase of major-element compositions of the plutons (more than 4,000 analyses);

(2) ArcGIS online service with i-cubed 15 m eSAT;

(3) Magnetic anomalies—1 km GRID.

Interpretation of Landsat images near plutons allowed to discover a large number of areas with specific for Fe-oxides colors—from dark orange to reddish-brown.

In the first phase, the ore-potential granitoids of A and I types with Fe, Cu, Au and U mineralization are recognized. The sample obtained is compared with the local isometric magnetic anomalies for further prospecting.

4.1 A-Type Granitoids

A-Type Granitoids are characterized by a high content of alkali (Na₂O + K₂O), high (0.9 × Fe₂O₃ + FeO)/MgO ratio and low content of Al₂O₃, CaO and MgO [20] and referred to ferroan series [19]. The filtering algorithm of A-type plutons is based on the formula for the curve separating ferroan and magnesian series of magmatic rocks on a diagram plotting SiO₂ against FeO*/(FeO* + MgO), where FeO* = (FeO + 0.9 × Fe₂O₃). The dividing line formula: FeO*/(FeO* + MgO) = 0.46 + 0.005 × SiO₂, and the plutons query for geodatabase selection looks like:

\[
\frac{(FeO + 0.9 \times Fe_2O_3)}{(FeO + 0.9 \times Fe_2O_3 + MgO)} > (0.46 + 0.005 \times SiO_2)
\]

4.2 I-Type Granitoids

I-Type Granitoids are characterized by metaluminous or peraluminous. ASI index varies from 0.69 to 1.10, rarely to 1.20 [20]. Filtering algorithm of I-type plutons is based on the sample formula range:

\[
\frac{Al_2O_3}{(CaO - 1.67 \times P_2O_5 + Na_2O + K_2O)}\text{ between } 0.69 \text{ and } 1.1.
\]

In the second phase on the base of GIS-technologies, it is identified areas of iron-oxide mineralization that could potentially relate to IOCG-type. With a related geodatabase of major-element compositions, they are analyzed for the Fe, Cu, Au and U ore potential.

4.3 Uranium

As an example of Australian deposits [21], the major-element composition of rocks plays an important role in the uranium behavior, the largest concentrations are:

(1) ASI-U diagram: ASI index from 0.9 to 1.2;

(1) \((Na_2O + K_2O)/Al_2O_3-U\) diagram: Agpaicity index from 0.6 to 1.0.

4.4 Copper and Gold

In analyzing the potential of plutons for the Au-Cu and Cu-Mo mineralization, it was used the model of Mongolian copper-porphyry deposits [22] with K₂O/Na₂O ratio corresponding to Cu-Mo ore-magmatic system in interval from 0.3 to 0.7, and Au-Cu one within 0.7-1.3.

From access geodatabase, selection of Au-Cu ore-magmatic systems with high potential due to given K₂O/Na₂O ratio from 0.7 to 1.3, and their selection due to area of surface outcrop have been made with the help of the inquiry. Therefore, classifier of GIS band was made based on the feature “pluton area”, and the selected groups characterized extent of their erosional section.

To reduce the number of objects that are potentially perspective for the Au-Cu mineralization, the high potassium calc-alkaline and shoshonite series plutons were selected.

Algorithm of pluton filtration is based on formula for the curves that bound series of magmatic rocks in diagram SiO₂-K₂O, their general appearance being described by equation \(K_2O = k \times SiO_2 - b\), and inquiries are like:

for rocks of tholeiite series:
\[K_2O < (0.033462 \times [SiO_2] - 1.5);\]

for rocks of calc-alkaline series:
\[K_2O \text{ between } (0.033462 \times [SiO_2] - 1.5) \text{ and } (0.066507 \times [SiO_2] - 2.5);\]
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Fig. 4 IOCG—potential mineralizing system at Levo-Jolakagskiy, Burgaliyskiy and Verkhne-Burgaliyskiy plutons (white outline) as an example of GIS query for U and Au-Cu specialization (black outline).
The area of Cu-Au potential IOCG mineralization is about 135 km² with 166.75 Bt of probable ore resources.

5. GIS Query Results

The pluton analysis using three algorithms: ASI-U; (Na₂O + K₂O)/Al₂O₃-U and K₂O/Na₂O for U and Au-Cu mineralizing systems allowed to highlight a common group of plutons with potential Cu-Au ± U mineralizing system: Burgaliyskiy, Druza, Verkhne-Burgaliyskiy, Levo-Jolakagskiy, Verkhne-Tirekhtyakhskiy, Vostochno-Polousniy, Gornoe Ozero, Inlinianskiy, Levo-Alaseiskiy, Magan-Tasskiy, Pravo-Tuostakhskiy, Elikchanskiy, Takalkanskiy, Tarbagannakhskiy, Tommotskiy.

ArcGIS Online—i-cubed 15 m eSAT images showed the presence of iron-oxide fields nearby Burgaliyskiy, Verkhne-Burgaliyskiy, Levo-Jolakagskiy, Verkhne-Tirekhtyakhskiy, Druza, Pravo-Tuostakhskiy and Takalkanskiy plutons.

Large IOCG-potential ore magmatic systems may have three types of iron-oxide mineralization—directly to the intrusive rocks (bright yellow shades), along the path of plutons (dark yellow and brown tints) and in the horn rocks (dark brown)—that is perfectly seen at Levo-Jolakagskiy (65.650000°N, 139.229987°E), Verkhne-Burgaliyskiy (65.593794°N, 139.482345°E) and Burgaliyskiy (65.573411°N, 139.278225°E) plutons as an example (Fig. 4).

6. Conclusions

(1) The data obtained suggest that mineralization of the IOCG-type is widely manifested in the eastern Yakutia (north-east of Russia), but its potential and geological features are undiscovered till now;

(2) It is proposed on the basis of GIS-technologies prospecting model for iron-oxide Cu-Au ore mineralization type which allows detect IOCG-potential plutons and associated mineralized
areas;

(3) The magnitude of the IOCG-potential mineralization is huge—Verkhne-Burgaliyskiy pluton, as an example, has several fields of iron-oxide mineralization. The biggest is about 135.38 km² and may have about 166.75 Bt of iron-oxide ore. Even at small contents of Au, these mineralization may be of economic interest;

(4) Audit collection samples allow to identify IOCG-potential mineralization types in different ore-magmatic systems and on this basis to build a regional prospecting model, which may differ from the world-known analogues because of the particular geological history of the eastern Yakutia;

(5) On the classification of IOCG-type deposits, the first discovery of this type in eastern Yakutia is iron-oxide breccias with Au-Cu ± U (± Bi ± Mo ± W) mineralization. It is located at the roof of the alkali-lime—alkaline pluton, and corresponds to a subtype of “Olympic Dam” (Australia).

References


