GEOCHEMICAL PATTERN OF ORE SYSTEMS FROM REGIONAL TO LOCAL-BASED ON IONEX TECHNOLOGY

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Introduction

- In current practice, geochemical exploration of mineral deposits is directed at verifying the presence of anomalous (above background) concentrations of ore elements. These concentrations are a result of the primary process of ore formation and/or the disintegration of deposits in the form of haloes of secondary dispersion.
Introduction

In “Geochemistry in Mineral Exploration” by Rose et al., (1979) these are presented as four general criteria for appraising favorable areas: “(i) the magnitude of the values metal above background; (ii) the size and shape anomalies areas; (iii) geological setting and; (iv) the extend to which the local environment may have influenced the metal content and the pattern of the anomaly”.

Introduction

Problems of appraising a favourable anomaly could be largely overcome by considering another criterion which is currently almost ignored: the presence of depletion zones in ore regions, which are manifest in pairs with enrichment zones. Such pair patterns can be outlined as unified polar geochemical systems.
The fundamental features of a polar geochemical ore system include:

- polar zoning of distribution of ore-forming elements,
- polar zoning of distribution of iron group elements

Geochemical systems are fractal (self-similarity) and occur at all scales.
Areas of investigation

Australia
Canada
China
Kazakhstan
North America
Russia
Spain
There are 97 different types of gold deposits with resources of more than Au 20 t (4500 t in total).
LOCATION OF GOLD REPOSIT AND DISTRIBUTION OF GOLD IN STREAM SEDIMENTS

1 M samples per 8 M sq km

after Xie, 2008
LOCATION OF GOLD REPOSIT AND DISTRIBUTION OF GOLD IN STREAM SEDIMENTS

Enriched zones > 3 ppb
Area – 1.7 M sq km.

Depleition zones < 1.5 -0.75 ppb
Area – 2.7 M sq km.

The geochemical system areas – n*100,000 sq km
DISTRIBUTION OF GOLD IN SOIL
NORTH PROVINCE
150,000 sq km

After Wang et al. 1997
GOLD PROVINCE
NORTHERN GREAT BASIN NEVADA U.S.A

Geological map  1 : 1,500,000
S - 165,000 sq.km

Distribution of Gold  1 : 1,500 00
Enrichment zones of Au – 20,000 sq.km
Open-File 02-0227, USGS, Coombs et al 2002
Fig. Distribution of As in soil and stream sediments. Great Basin, Nevada & Oregon, USA.
Carlin–Trend Ore –Region scale

Area – 7 000 sq. km

After Teal and Jackson, 1997; Ressel
Scale 1: 500 000
Henry, 2006)
CARLIN-TREND GOLD DEPOSITS
USA
Distribution of gold

Enrichment zones of Au -2320 sq km
CARLIN-TREND GOLD DEPOSITS
USA

Distribution of As

Cumulative distribution plot of As

Enrichment zones of As -2320 sq km
Depletion zones As -2324 sq.km
CARLIN-TREND GOLD DEPOSITS
USA

Distribution of Ag

Cumulative distribution plot of Ag

Enrichment zones of Ag -1580 sq km
Depletion zones of Ag -2324 sq km
ORE REGION OF VASYLKOVSKOE GOLD
PORPHYRY DEPOSIT
NORTH KAZAHSTAN

Area (S) 15 500 sq km
Number of samples - 1100
Detection limit of Au – 0.2ppb
Enrichment zones (> 25 ppb) S = 800 sq km
Depletion zones (< 0.5 ppb) S = 4500 sq km
Background 1.5 -2 ppb

After rafalovich and Los 2007
Area – 4000 sq.km.
Scale 1:500 000,
Density rock sampling - 1s/25 km.
134 rock samples.

Geological map of Bendigo gold field
GEOCHEMICAL SYSTEMS OF BENDIGO GOLD FIELD

Cumulative distribution plot of Au

Analysis at ALS Chemex. Brisbane

GEOCHEMICAL SYSTEMS:
1. BENDIGO  2. MALDON  3. CASTEMAINA  4. FOSTERWILL
MASS BALANCE CALCULATION OF GOLD

<table>
<thead>
<tr>
<th>Zones</th>
<th>S, km²</th>
<th>H_{depth}, km</th>
<th>V, km³</th>
<th>Au_{average}, ppb</th>
<th>Au_{enrich}, ppb</th>
<th>Au_{loss}, ppb</th>
<th>R, t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enrichment zone</td>
<td>100</td>
<td>1.4</td>
<td>100</td>
<td>14</td>
<td>12.71</td>
<td></td>
<td>~3500</td>
</tr>
<tr>
<td>Background</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depletion zone</td>
<td>800</td>
<td>2</td>
<td>1600</td>
<td>0.5</td>
<td></td>
<td>0.79</td>
<td>~3000</td>
</tr>
</tbody>
</table>

Model of geochemical system of Bendigo gold deposit
The link between the size of Au depletion zones and Au reserves in the gold deposits of the Bendigo region.
Wiluna Archaean orogenic gold deposit. Northernmost Norseman-Wiluna Belt in the Yilgarn Craton, Australia

Distribution of Au in drill core

After P. Eilu & D. Groves, 2001

Western Australia
Ni-Cu deposit Kambalda Norseman-Wiluna Belt
the Yilgarn Craton, Australia

Western Australia

Distribution of Au in drill core

After Raid R. Keays, 1982)
The Alaska Zn deposits are located within a metallogenic belt extending along North–American Cordillera.
Alaska Territory covers the northern part of the North American Cordillera. It is formed by a series of terranes which are attached to North-West edge of the North American platform by right-lateral faults in Mesozoic
On data of American geologists of USGS (Nokleberg et al., 1971; Nokleberg et al., 1972) different types of Alaska zinc deposits are combined into eleven metallogenic belts in accordance with their geodynamic and geological setting.

Metallogenic belts (after W. Nokkleberg 1997)
DISTRIBUTION OF ZINK. ALASKA

Cumulative distribution plot of Zn. 175 samples
DISTRIBUTION OF ZINK. ALASKA

Northern geochemical system (along Bruks Rahge)
- Enrichment zone – 110,000 sq km
- Depletion zone – 130,000 sq km

Central Geochemical system (along Alaska Range)
- Enrichment zone – 110,000 sq km
- Depletion zone – 91,000 sq km
DISTRIBUTION OF ZINK IN THE NORTHERN CHEOCHIMICAL PROVINCE

Geochemical systems of ore region scale
1. Ruby Creek 2. Michigan Creek
DISTRIBUTION OF ZINK IN THE CENTRAL GHEOCHEMICAL PROVINCE

Geochemical systems of ore region scale
1. WTF, Red Maunt,
2. Delta District (26 VMS Kuroko type of deposits)
Deficit of zinc in the depletion zone (91 000 sq km) on 1 m of depth is 8.3 million tons, and the accumulation of Zn in the enrichment zone (110 000 sq km) is 18.5 million ton, respectively.

Therefore, the depletion zones can be consider as the areas of mobilization.
RUDNY ALTAY METALLOGENIC PROVINCE
KAZAKHSTAN
VMS DEPOSITS

Geological map of Leninogorsky and Zyryanovsky ore regions (20 000 sq km)
Down to depth of ~10 km the regions have a two-layer structure:

- **S₂-D₁** layer – sandstone, phyllites and greenschist
- **D₁-D₃** layer – volcanogenic-sedimentary formations with main VMS mineralization.

Area – 20 000 sq.km. 1s/25 sq.km. 800 rock samples.
Distribution of Zn & Ti in Different Rocks of Leninogorsky and Zyryanovsky Regions


On the base of petrographic study area there are seven main types of rock: gabbro – diorite, andesite – basalt, dacite – rhyolite, granitoids, sandstone, shale and hornstone.

For each of the rock types the cumulative distribution plots of zinc and titanium were made.
Distribution of Zn & Ti in Different Rocks of Leninogorsky and Zyryanovsky Regions

There are three populations: medium – background, tops - enrichment anomaly, bottom – depletion anomaly.

Due to the great variety of rock composition the metal concentrations in each sample were normalized to their backgrounds. The boundaries of anomalies and backgrounds were drown according to this data.

DISTRIBUTION OF Zn AND Ti IN LENINOGORSKY AND ZYRYANODSKY ORE REGIONS

Leninogorsky geochemical system
- Enrichment zone - 1200 sq km
- Depletion zone - 1000 sq km

Zyryanovsky geochemical system
- Enrichment zone - 1500 sq km
- Depletion zone - 1250 sq km

Nucleous parts of systems
IRTYSHKY VMS DEPOSITS in RUDNY ALTAY METALLOGENIC PROVINCE, KAZAKHSTAN

Simplified geological map
IRTYSHKY VMS DEPOSITS
RUDNY ALTAY. KAZAKHSTAN

DISTRIBUTION OF Pb

Cross-section A-B
1. Highland (Canada) 2. Dexing (China) 3. Duoboshan (China).
(After W.D. Sinclair, 2007)
Cu PORPHYRY DEPOSITS
Highland ore region (Canada)

16 Cu-porphyry deposits hosted by Guichon Creek Batholit. The main deposits:
Valley Copper,
Lorenex, Higmont
Bethlehem.

The total reserves:
8 Mt Cu (Cu 0.42%)
Cu PORPHYRY DEPOSITS
Highland ore region (Canada)

Distribution of Cu, 1500 sq.km, 352 s. (After Brabec and White, 1971)

Guichon Creek Batholit
(Old and Flether, 1976)
DISTRIBUTION OF Cu
Guichon Creek Batholit

Depletion zone < 50 ppm.

S - 820 sq km
Degree of Cu relies – 46%
Total deficit of Cu – 25 Mt
(250 m of depth)

(Modified after Brabes, 1971 G.Govett 1983)
Cu PORPHYRY DEPOSITS
Dexing, SE China

Reserves of Tongchang deposit -5.2 Mt Cu, 190 t Au (Ji Kejian et al., 1992, )

Distribution of Cu

Cu (ppm )
1. > 150.
2. 100 -150,
3. 50-100
4. < 50
5. Deposits
Cu PORPHYRY DEPOSITS
Dexing, SE China

Reserves of Tongchang deposit - 5.2 Mt Cu, 190 t Au

Cu (ppm)
1. > 150
2. 100 - 150
3. 50 - 100
4. < 50

Enrichment zone - 40 sq km
Depletion zone – 480 sq km
Cu deficit – 15.4 Mt

(Estimated by 500 m of depth)
(Ji Kejian et al., 1992, 195 p)
Cu PORPHYRY DEPOSITS
Duobaoshan, NE China

1. Cu-porphyry ore body
2. Enrichment zone of Cu > 200 ppm.
3. Background - 200-70 ppm
4. Depletion zone Cu < 70 ppm

O – Andesite
Gd - Granodiorite
Gr - Granite
Gdp – Granodiorte-porphyry
**Cu PORPHYRY DEPOSITS**  
**Duobaoshan, NE China**

**Reserves**

2.4 Mt Cu, 73 t Au

**Enrichment zone** 3.6 sq km.

**Depletion zone** 15 sq km.

**Enriched of Cu** - 1.3 Mt

**Deficit of Cu** - 3.4 Mt

(Estimated by 1 km of depth)

(Ji Kejian et al., 1992, 195 p)
SEDIMENT-HOSTED STRATIFORM COPPER DEPOSITS
DZHESKAZGAN ORE REGION. KAZAKHSTAN

Geology

Cross-section

1 Terrigenous carbonate deposits (D- C1). 2. Dzheskaizgan suite: red and grey bed sandstone , siltstone, conglomerate ( C2-3 – P1) 3. Argilite ( P2) 4.Ore body. 5 Enrichment zone of sulfate (1-0.5%). 6. Salt bearing deposits 7.Drill holes  8. Shaft

Modified after A.V. Kyslitzyn and V.O. Glebovsky (1983)

1 Carbonate rock ( P2).
2. Red bed sandstone strata (P1)
3. Dzheskaizgan suite ( C2- 3 – P1)
DISTRIBUTION OF Cu. 
DZHESKAZGAN ORE REGION. KAZAKHSTAN

Reserves: 22 Mt Cu. 
Background of Cu 30 -100 ppm 
Enrichment zone of Cu, Pb, Zn – 45 sq.km. Cu > 100 ppm 
Depletion zone – 20 -25 ppm 
Area- 1000 sq. km.

Cu deficit - 25 Mt 
(Estimated by 500 m of depth)
BABEL and NEBO Ni-Cu PGE deposit
Central Australia

Ultramafic rock hosted in amphibolite (Middle Proterozoic).
Area of geochemical mapping - 1700 sq km. (Grid 1 km X 0.5 km. Total – 1700 samples)
Thickness of cover - 10 m. Area of Ni and Cu less than 20 ppm – 100 sq. km
Ni DEPOSIT AVBURY
IN ULTRAMAFIC ROCK
WESTERN TASMANIA

S-D Sediments
Cm Sediments
Cm Serpentinizied Ultramafic intrusion
Cr granites
Ni in ore bodies – 1.5 -1.8%
Ni in dunite (background) – 1500 – 2500 ppm
Depletion zone (in dunite) Ni - 200 – 500 ppm
Mo-U ORE DEPOSITS. ZABAYKALIE. RUSSIA

GEOLOGY OF STRELTZOVSKY ORE REGION


Uranium ore deposits are localized into basalt-rhyolite caldera
STRELTZOVSKY ORE REGION. ZABAYKALIE

DISTRIBUTION OF U

- Cumulative distribution plot of U
- Enrichment zone > 8.9ppm
- Depletion zone < 1.28 ppm
- Background - 3.28ppm

S – 15 000 sq. km. Rock samples -550. 1s/25-30
Reserves U - 250 000 t
Enrichment zone - 650 sq km.
Depletion zone - 2020 sq km.

Enriched U – 3.2 Mt
Deficit U -5 Mt
(Estimated by 500 m of depth)
1-9 Sn deposits

DISTRIBUTION OF Sn
Area – 500 sq km, 6000 rock samples (Mz turbidity)
Clunes turbidity hosted gold deposit under basalt

- The ore bodies of saddle-shaped form are located in the Ordovician sequences and are overlapped by basalts of 20-60 meters.
- In this area for mapping we used a selective extracting method (TMGM)

Bendigo-Ballarat gold province, Australia
Clunes turbidity hosted gold deposit under basalts

1s/1 sq km
200 sq.km

100s/1 sq km
4 sq.km

Geochemical system

Au, ppb
3.0
5.0
20.0
Depletion
Background
Enrichment

Ore deposit
Ore body
Quaternary basalt
Paleozoic sandstone
Discussion and Conclusion

1. Polar geochemical ore systems have been established at different scales from regional to local and different types of mineralization.

2. The geochemical pattern of these systems indicates a universal mechanism of formation. This includes the spherical or ellipsoidal form of the systems. It can be assume the frontal migration of ore elements from the boundaries of systems to the centres of ore precipitation.

3. Such structure we explain on base of geoelectrochemical model.
In Earth's crust to exist different types of sources electrical energy (E). For example: fluid movements lead to electrical potential. There are other sources (self-potential – SP) of electrical energy, including SP, when stressed blocks of rock in active geo-dynamic environments and etcetera.

Electrical energy in Earth’s crust inevitable provokes a redistribution of chemical elements in electrical fields, forming geochemical systems of polar structure. Studies of the electrochemical kinetics of the extraction and redistribution of elements conducted in the development of the CHIM geo-electrochemical method.

The inclusion of an electrochemical mechanism in ore formation processes gives us greater freedom in discussing aspects of the genesis of ore deposits, include formation polar geochemical systems.
GEOELECTROCHEMICAL MODEL OF ORE FORMATION

Convection cell sub-seafloor hydrothermal systems and Steaming potential electrical field (as example)
On base of empirical and theoretical data of redistribution ore-forming and associated elements within a particular geological space with forming polar geochemical systems was created IONEX TECHNOLOGY
IONEX TECHNOLOGY

IONEX Technology is usually employed in sequence of stages from a regional survey to progressively more-detailed follow-up.

The basic model of IONEX’s Technology is carried out in four stages with density of sampling:

- Stage I - 1 sample/25 sq.km (area ~n.1000 sq km)
- Stage II – 1 sample/1 sq.km (area ~n.100 sq km)
- Stage III - 16 samples/1 sq.km (n.10 sq km)
- Stage IV - 100 samples/1 sq.km (n.1 sq km)

Available geological and geophysical data is incorporated in the interpretation of the geochemical results.
GOLD EXPLORATION ON COVER AREA IN NSW
AUSTRALIA
BY IONEX TECHNOLOGY

RECOGNISION STAGE

Au-Cu mineralization prediction
GOLD EXPLORATION ON COVER AREA IN NSW
BY IONEX TECHNOLOGY

In the Dandalo area four stages of geochemical exploration were carried out in scales of 1:500,000 to 1:10,000 by MPF selective extraction method.

**Stage IV**

- **S=2,300 sq km**
  - EL 7022 Stage I
  - 1 s/25 km²

- **S=200 sq km**
  - EL 7022-A1 Stage II
  - 1 s/1km²

- **S=56 sq km**
  - Site 1
  - Stage IV
  - 100 s/1km²

- **1.25 sq km**
  - Site 3
  - Stage III
  - 100 s/1km²

- **3 sq km**
  - Site 2
  - Stage IV
  - 100 s/1km²

**Distribution of Au/C in Soil (MPF)**

Depletion  | Background  | Enrichment
Distribution of Au and Ni (siderophile element)

Stage I

Stage IV

Nuclei part of system

Au/C*10^4% 0.07 0.18 0.60

Au/C*10^4% 0.22 0.55 1.00
THE EHD