Global tectonic settings and deep mantle control on Hg and Au-Hg deposits

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Abstract. Three main geodynamic environments are favorable for the developmemnt of ore-forming systems of Hg and Au-Hg deposits: Intracontinental rifts and aulacogens at the ancient cratons, intraplate rifting in the orogenic belts of different ages, and active continental margins of the continents. The isotope-geochemical characteristics of ore-forming systems of Hg and Au-Hg deposits, changes in $^3He/^4Hg$ ratio, and paragenetic relationship between subcrustal basite and alkaline basite magmatism suggest that mantle plumes played a significant role in their formation.

Keywords. Mercury, gold-mercury deposits, geodynamic settings, mantle plumes, helium isotopes, Ar/Ar dating

1 Introduction

Analysis of the siting of Hg and Au-Hg deposits indicates their joint deposition sites in the well- known metallogenic belts: Pacific-Ocean, Mediterranean, and Central Asia (Obolenskiy and Naumov 2003). The most ancient Precambrian Au-Hg deposits only of Canada, South America and Australia, which are localized in the separate ore districts and controlled by rifting structures of the ancient cratons, occur beyond the limits of the belts. Different geodynamic environments are typical for the Hg and Au-Hg deposits localized within the limits of recognized global metallogenic belts.

2 Global metallogenic belts

The well-known Almaden ore district in the rift structures of the ancient Iberian plate, and the Donetsk basin ore province in the Dnepr-Donetsk aulacogen in the flank of the ancient Ukraine shield, occupy separate positions in the Mediterranean belt, where Mesozoic and Cenozoic Hg and Au-Hg deposits are related to the post Jurassic subduction zones and overlying continental volcanic belts (Bailey et al. 1973; Tanelli et al. 1991). Mercury deposits of the Almaden district are the Silurian-Devonian in age, while mercury deposits of the Donetsk basin are of Permian-Triassic age.

Mercury and Au-Hg deposits of the Central Asian belt, localized in Early Paleozoic and Hercinian orogenic belts, are related to various metallogenic epochs (Table 1). The four main periods of Hg and Au-Hg deposits are distinguished in the Altai-Sayan orogenic region using Ar-Ar dating: Early Paleozoic, Middle Paleozoic, Early Mesozoic and Late Mesozoic. Industrial Hg and Au-Hg deposits of the Altai-Sayan and Tien-Shan ore provinces are related to the most productive Early Mesozoic period. Geodynamic environment of formation of these belts is caused by the intraplate riftogenesis, confined to the large scale displacements along strike-slip faults of

Table 1: Ages of Hg and Au-Hg mineralization

Geological time	Deposit type	Hg minerals in the ore	Method	Age
Late Mesozoic (J_3-K_1)	**Hg, Au-Hg, Hg-Sb-W:** Transbaikalia, West Mongolia, South-Gobi belt	Cinnabar, Hg-sphalerite, metacinnabarite, Hg-gold	Geol. age K-Ar	J_3-K_1 116-131
Early Mesozoic (T)	**Hg (Hg-Sb):** Chazadr (Tuva), Tyutyo (Altai), Kok-Uzek (Altai), Kelyanskoye (Transbaikalie) Karasug (Tien-Shan) **Au-Hg:** Hurimt-Huduk (Mongolia)	Cinnabar, Hg-tetrahedrite, Hg-sphalerite Cinnabar Hg-gold, Hg-fahlore, coloradoite	Ar-Ar - " - - " - K-Ar Ar-Ar K-Ar	227±16.3 231.5±1 234.4±1.3 240-245 235.4 238.6±2.4 246
Middle-Paleozoic (D-C_1)	**Au-Hg:** Murzinskoye (Altai), Kundat (Kuznetsk Alatau)	Hg-gold, Hg-fahlore, saukovit Cinnabar, Hg-sphalerite, Hg-gold	Ar-Ar - " -	358.3±3.8 337.8±2.9
Early Paleozoic (Є-O)	**Au-sulfide-Q:** Lysogorskoye (East Sayan), Kharalskiy district (Tuva)	Hg-gold, schwatzit, cinnabar Hg-gold, Hg-sphalerite	**Ar-Ar** - " -	512±2 486.7±8.2

Late Paleozic – Early Mesozoic age. There are no known mercury deposits of Paleozoic age, and Hg enters into the sulfides and native gold of lode gold and Au-Cu-skarn deposits, and forms complex Au-Hg occurrences related to the granitoids ($D\text{-}C_1$) (Table 1).

A large quantity of Hg and especially Au-Hg deposits are localized mainly in the back-arc rift structures of the Basin and Ranges province, occur in the global Pacific-Ocean metallogenic belt and particularly in its North American branch. The main Au-Hg deposits of the world class occur there, and since their discovery in the 1860s they became one of the major industrial types of Au deposits (Radtke 1985; Muntean et al. 2004).

Mercury deposits are localized within the limits of active continental margins of Andean and Californian types of South and North America in frontal accretion complexes of subduction zones and overlying continental volcanic belts. Mercury deposits of North-East and Far East Russia are situated in similar geodynamic environments. Au-Hg deposits in these structures are minor.

Small Hg and Au-Hg deposits occur in island-arc systems of ensialic type predominantly in the West Pacific-Ocean segment of the belt (Japan, Oceania, New Zealand). The important Au-Hg province of South-East China is situated in this part of the Pacific Ocean belt including large Sb-Hg (Vanshan) and Au-Hg deposits of Carlin type related to the structures of Mesozoic active rifting of South-China craton (Hu Rui-Zhong et al. 2002). Thus, analysis of Hg and Au-Hg deposits localization in global metallogenic belts allows us to establish the main regularities of their position.

3 Geodynamic settings

Proterozoic and Paleozoic deposits occur in rift structures or aulacogens are confined to continental rifts and related genetically to the mantle plumes. Mercury and Au-Hg deposits are located separately as a rule, although Hg mineralization coincides with Au-Hg mineralization in the South-East China province.

Mercury and Au-Hg deposits, whose formation is caused by the intraplate rifting development of anorogenic magmatism and plutonogenic ore-forming systems with complex Cu-Au-Hg ore, occur in the reactivated orogenic belts of different age in Central Asia. The intraplate riftogenesis is completed by basite and alkaline-basite magmatism as dike swarms and epithermal Au-Hg and Hg mineralization at the Permian-Triassic boundary. Mesozoic and Cenozoic Hg and Au-Hg deposits are located at active continental margins. They are known in ensialic island-arcs, accretion complexes of subduction zones, overlying continental volcanic belts, and in the back-arc rifting structures. There is a close relation between Hg and Au-Hg deposits in this geodynamic environment, with common ore-forming epithermal and volcanogenous-hydrothermal systems.

Thus, three main geodynamic environments are favorable for the development of ore-forming systems of Hg and Au-Hg deposits: intracontinental riftogenesis at the cratons, intraplate rifting related to strike-slip faults in the orogenic belts, and active continental margins of the continents. Magmatism of mantle (plume) nature, according to the isotope-geochemical characteristics, arises as volcanogenic-plutonogenic or dike complexes and magmatogenic-hydrothermal ore-forming systems in each of these geodynamic environments. Mercury and Au-Hg deposits are related to the late periods of their development. Ore-forming systems of the Hg deposits may occur separately as well.

4 Mantle plumes and ore forming processes

A mantle origin of ore-forming systems of Hg and Au-Hg deposits is proved by isotopic composition of helium from fluid inclusions in quartz at these deposits (Table 2) (Torgersen et al. 1981, 1982, Cline et al. 2003). Isotope com-

Table 2: $^3He/^4He$ values of ore-forming fluids of Hg and Au-Hg deposits

Deposits	$^3He/^4He * 10^{-6}$
Hg deposits	
Nikitovka (Ukraine)	0,12
Khaidarkan (Kyrgyzstan)	0,06
Vanshan (China)	0,38
Aktash (Altai, Russia)	0,28
Djilkidal (Altai, Russia)	1,6
Sulfur-Bank[1] (USA)	19,4 - 19,9
Uzon[2] (Kamchatka, Russia)	6 - 11,3
Au-Hg deposits	
Travyanskoe (Urals, Russia)	0,8
Novolushnikovskoe (Salair, Russia)	0,6
Lysogorskoe (Sajan, Russia)	0,37
Tereksai (Kyrgyzstan)	<0,41
Kyuchus (Yakutia, Russia)	0,32
Murzinskoe (Altai, Russia)	1,15
Kundat (Kuznetsk Alatau, Russia)	0,2
Getchell[3] (USA)	0,2 - 2
New Zealand[4]	3,1 - 7,4
Steamboat-Springs[1] (USA)	1,48 - 8,36

Data by: 1 – Torgersen & Jenkins (1981); 2 - Rozhkov (1979); 3 – Cline et al. (2003); 4 - Torgersen et al. (1982).

position of He was measured in the laboratory of geochronology and geochemistry of isotopes at the Kola Geological InstituteRAS. The lowest 3He/4He ratios (from 0.12*10-6 to 0.38*10-6) are typical for mercury deposits (Vanshan, Nikitovka). The copper-mercury (Djilkidal) and gold-mercury (Murzinskoe) deposits with the isotopes of helium varying from 1.06*10-6 to 1.6*10-6 belong to the intermediate type. Relatively high-temperature Ni-Co-As and Ag-Sb deposits (Bu-Azzer and Akdjilga) are characterized by a higher proportion of light helium isotope, average 3He/4He ratio varies from 4*10-6 to 18*10-6, respectively (Naumov et al. 2004).

We observed some inverse correlation between 3He/4He values of ore-forming fluids and resources of epithermal Au and Hg deposits from different parts of the world (Table 3).

These data suggest that in a series of deposits: mercury ? copper-mercury ? gold -mercury ? nickel-cobalt arsenide ? silver-antimony, the proportion of mantle helium increases significantly in the composition of ore-forming fluids.

In this series a marked isotope shift in the ä18OH2O of hydrothermal solutions suggests a higher concentration of magmatogenic fluids in their composition (Fig. 1).

Ore-forming systems in different geodynamic environments differ in ore productivity. The unique mercury deposits were formed by ore-forming systems of intracontinental rifts (Nikitovka, Almaden, Vanshan).

Ore-forming systems of overlying subaerial volcanic belts in the Tuscan province in Italy, Idria in Slovenia, and Huancavelica in Peru formed the world- class Hg deposits. Ore-forming systems in subduction zones (deposits of Coastal Ridge in California, USA, Tamvatney, Chukotka, SE Russia) are of the same grade. Ore-forming systems in zones of regional thrusting of the orogens are not so productive (Tien-Shan and Altai-Sayan – Aktash and Chagan-Uzun deposits).

The geodynamic environment of back-arc riftogenesis occupies a special place in formation of highly productive ore-forming systems, an example of which is the Basin and Ranges province. The Nevadan belt occurs in this province, where most of the Hg and Au-Hg deposits are concentrated.

Independent of an approach to explain the origin of tectonic structures of the Nevadan belt, evolution of Cenozoic (40 Ma) magmatism is established on the boundary of 20-15 Ma, when typical bimodal calc-alkaline magmatism gives place to the alkaline-basite, and over 5 Ma to the basite one. That is the most satisfactory explained by the influence of Yellowstone mantle plume and common reconstruction of volcanic arc geodynamic environment on the riftogenesis. The most important ore-magmatic systems of porphyry-Cu-Mo and Au-Hg epithermal deposits were formed at the boundary of 45-35 Ma, and also at 26-22 and 9-5 Ma. The intensity and duration of ore-forming processes in the Nevadan belt may be explained by the consecutive influence of mantle plumes on tectonic structure formation, magmatism, and associated ore-forming process (Pirajno 2000; Muntean et al. 2004).

Thus, mantle alkaline-basite magmatism immediately precedes the Hg and Au-Hg deposits forming in a number of ore provinces, for example Iberian (Higueras and Munha, 1993; Hernandez 1999), Donetsk, South-China (Hu Rui-Zhong et al. 2002), Tuscan (Tanelli, 1991), and Nevadan provinces (Pirajno, 2000).

Age displacements of ore-forming processes relative to the time of the main phase of plume magmatism are

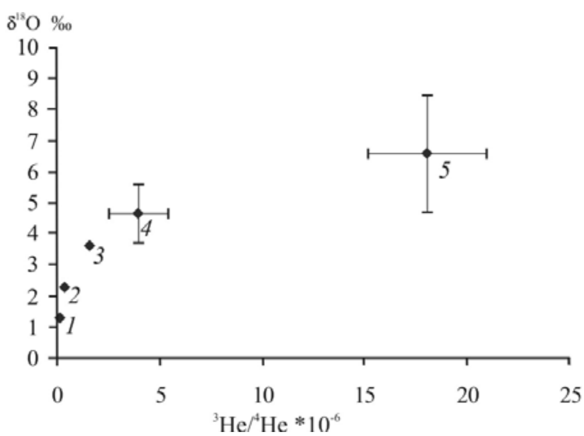

Figure 1: Isotope composition of oxygen and helium of hydrothermal solutions from epithermal deposits, according to isotope data of the O and He in fluid inclusions of minerals from the deposits: 1 – Nikitovka, 2- Vanshan, 3 – Djilkidal, 4 – Bu-Azzer, 5 – Akdjilga

Table 3: Inverse correlation between $^3He/^4He$ values of ore-forming fluids and resources of deposits

Deposit	Resources (t.roughly)	$^3He/^4He$ *10^{-6}
Au-Hg deposits		
Steamboat springs	1	1.2
Rotorua	2.5	1.2
Murzinskoe	12	1.2
Getchell	100	0.1-1.1
Hg deposits		
Uzon	10	6.0-11.3
Sulfur-Bank	15	19.4-19.9
Djilkidal	100	1.5-1.6
Vanshan	10000	0.38
Nikitovka	40000	0.12

established for the South Siberian and Tien-Shan provinces (Siberian superplume 250-244 Ma, Hg mineralization 230-235 Ma, Tien-Shan alkaline-basite magmatism 255-240 Ma, Hg deposits 236-228 Ma). This is possibly caused by specific development of the structures of intraplate riftogenesis in the orogenic belts, as well as the location of arising under-crust magmatic centers occurred generally as basite and the late alkaline basite dike swarms.

5 Conclusions

Geohistorical analysis, geodynamic environments, and spatial and temporal paragenetic relationship of ore-forming systems of Hg and Au-Hg deposits with mantle magmatism allow consideration of their formation as one of the events related to mantle plumes in the Earth's crustal structures (Pirajno, 2000). The intracontinental rifts (aulacogens) arising in the Early and Middle Paleozoic period, structures of intraplate riftogenesis in the reactivated Paleozoic orogenic belts, and subduction zones and active continental margins in Mesozoic and Cenozoic periods are the most favorable for the localization of ore-forming systems of not only Au-Hg but most of Hg deposits.

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