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SOURCES OF BASIC ORE-FORMING ELEMENTS IN THE MERCURY--ANTIMONY DEPOSITS

(Figs. 4, Tabs. 2)

Abstract: Mercury sources of mercury and mercury-antimony deposits of the planet mercury belts are connected with the abyssal parts of the upper mantle, from where mercury goes to the Earth's crust through the zones of abyssal fractions by the mechanism of degassing. Mercury degassing is responsible for metallogenetic mercury specialization of ore provinces in general, which shows itself in increased mercury bearing of deposits of different composition — ore and oil-gas deposits. Sulphur of mercury and mercury-antimony deposits is mainly of crustal origin. Sources of another ore-forming elements are considered briefly. From the analysis of the new data on the sources of ore-forming elements in mercury and mercury-antimony deposits certain conclusions referring to metallogenetic consequenses may be drawn.

Резюме: Источники ртути ртутных и ртутно-сурьмяных месторождений планетарных ртутных поясов связаны с глубокими частями верхней мантии, откуда ртуть поступает в земную кору по зонам глубинных разломов по механизму дегазации. Ртутная дегазация ответственна за металлогеническую ртутную специализацию рудных провинций в более широком плане и проявляется в повышенной ртутоносности месторождений различного вещественного состава — рудных и газонефтяных. Сера ртутных и ртутно--сурьмяных месторождений имеет преимущественно коровое происхождение. Кратко рассмотрены источники других рудообразующих элементов. Из анализа новых данных об источниках рудообразующих элементов в ртутно--сурьмяных месторождениях следуют определенные металлогенические заключения.

The present report deals with the concepts based on geochemical and geological materials on mercury and mercury-antimony deposits.

Metal sources. The problem of sources of two basic metals — mercury and antimony — in mercury and mercury-antimony deposits remains to be debatable. Presently the most satisfactory explanation to the distribution regularities of mercury deposits may be provided assuming the notion on the mantle source of mercury. This notion draws upon either genetic or paragenetic relation of mercury mineralization with deep basaltoid magmatism (V. A. Kuznetsov, A. A. Obolensky, V. P. Fedorchuk and others)), or the mercury inflow from the Earth's deep during the mantle degassing, in the A. P. Vinogradov interpretation. Hence, the mercury content in various deep rocks, basaltoid in particular, in various geotectonic provinces was studied in detail. As a result, there were established two specifics in the mercury distribution: cratons (continental and marine) feature nearly twice as less content of mercury than the linear mobile belts and, this is the most significant, only linear mobile belts are characterized by wide occurrences of abnormally

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high mercury concentrations, usually to 10/1000th portions of percent (Fig. 1). Here are three examples. Mid-Atlantic Ridge. The increased mercury content in young basaltoids in the ocean bottom and on the Iceland Island as well is established by the author showing rather great disparity of values not only for basic volcanic rocks, but also for average and acid ones. And as Iceland scientists claim the gas-hydrothermal process attending modern volcanic eruptions

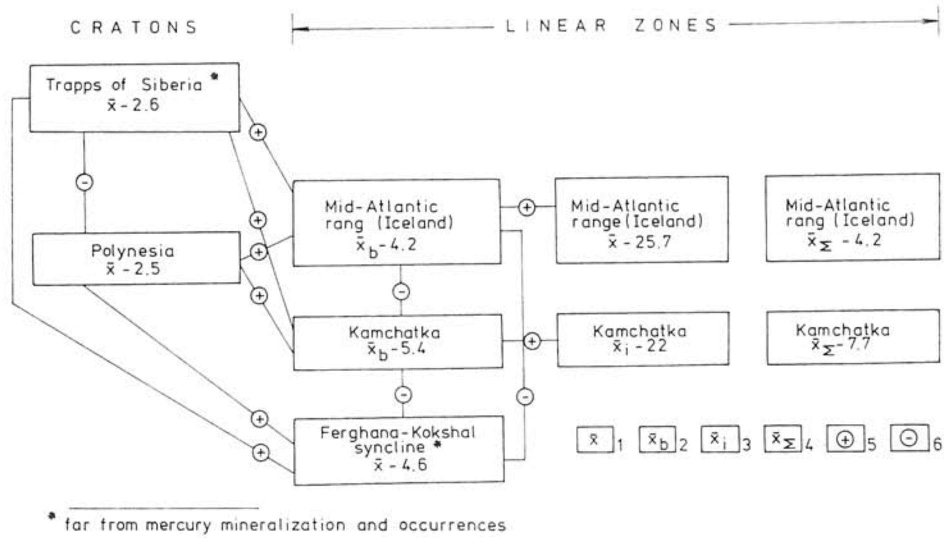

Fig. 1. Comparison of mercury content in basaltoid from various geotectonic provinces.

Explanations: 1—4 — arithmetical mean: 1 — for provinces with a single assemblage of samples; 2—4 — for provinces with two assemblages (2 — $\overline{X}$ — with background mercury values, 3 — $\overline{\overline{X}}$ — with increased, 4 — $\overline{X}$ — arithmetical mean for these provinces); 5 and 6 — similarity and difference of assemblages (5 — essentially differing with the 99.0—99.9 % reliability, 6 — not differing).

in the Iceland shows high mercury content. The second example is a Kurile—Kamchatka volcanic belt. Taking the Klyuchevskaya group of volcanoes, it has been shown by the author that by the mercury content two stable families of basaltoids (with the average low and increased content) may be identified. Similar distribution was traced in the andesites of this province. Here, similar to Iceland gas-hydrothermal process, controlling the mercury content, is associated with volcanism. The third example — a dike complex of alkali basaltoids in the zones of active deep faults preceding mercury mineralization and most close to us by age. Numerous researchers relate paragenetically mercury mineralization with these dikes. The mercury content in dikes varies widely at least by two orders. It is essential that similar increased mercury content is observed in sedimentary and metamorphic rocks and in modern marine deposits too, within such linear zones. Deep faults which control the development of mobile

Table 1

Principal parameters of mercury distribution in kimberlites and xenoliths from kimberlite pipes of the Siberian platform

Rocks	Number of samples	Arithmetical mean, 10^{-6} %	Standard error	Amplitude of values, 10^{-6} %
1	2	3	4	5
Kimberlites	122	1.0	1.2	0.2—8.0 (40)
Inclusions:	87	2.3	2.8	0.2—20 (200)
spinel peridotites	19	4.3	5.0	0.2—20
garnet peridotites	27	1.6	1.4	0.2—6.0
eclogites	34	2.2	2.0	0.5—10.0

Explanations: In column (5) figures in brackets specify maximum abnormal content; they are not taken into account while calculating the arithmetical mean since their emergence is associated with the most recent postmagmatitic processes.

belts are evidently those pathways by which mercury got from the Earth's bowels.

What possible levels of the mercury generation may be given? Low mean-arithmetic background levels of mercury in basaltoids (Clarke or below Clarke) point, in our opinion, to poor abilities of basaltoid hearths for ore generation. Similarly low mercury content is specified in various types of ultrabasites, kimberlites and, what is the most essential, in xenoliths of kimberlite pipes (peridotites and eclogites) considered to be detached masses of the upper mantle, and, thus, a direct source of information on its composition (Tab. 1). Therefore, those deep-seated strata of the Earth, on which content we judge by their representatives (rocks) on the surface, are poor in mercury. This is found in accord with the known notions on the essential differentiation of the upper mantle — to a depth of 200 km and more. The differentiation time exceeds 1 billion years. The primary mantle content is believed to be close to stone meteorites — chondrites. Data on a high mercury content in meteorites available in the publications and obtained by the author enable assumption as to generally high mercury concentrations in the mantle except for its surficial layers which, in view of differentiation processes, contain but small amounts of mercury. The depth of occurrence of asthenosphere is believed to increase during the geological evolution of the Earth. Consequently, in the Phanerozoic time mercury moved from deeper horizons of the upper mantle by the zones of planetary structures. In this case dike belts occurring in numerous mercury provinces and being close by age to mercury mineralization may be considered indicators of deep faults activity. Meanwhile, the level of magmatic melt generation in the form of dikes, and of mercury will be different. Being highly volatile, mercury obviously participates in deep emanations which, in one instances, may emerge as agents of magma formation at higher horizons, while in the others, they may get into the Earth's crust and become a source of mercury in hydrothermal solutions contributing to be shaping of mercury deposits not associated with magmatic rocks. Mercury in these fluids is obviously in the atomic and molecular forms.

Mercury degassing not only provides mercury for cinnabar deposits, but it is responsible for the metallogenic mercury specialization of ore provinces in a wider scale and manifest in the enhanced mercury content in deposits, both

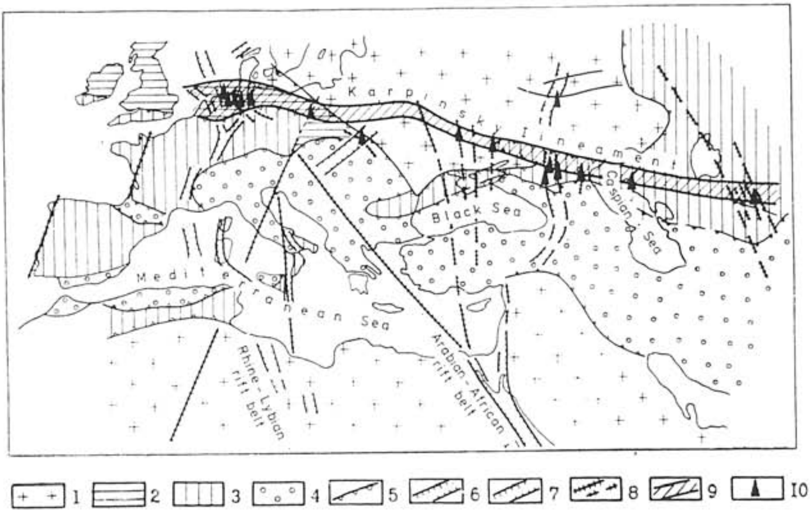

Fig. 2. Location of mercury-bearing gas and oil and gas deposits within the Karpinsky lineament.
Explanations: 1—4 — fold areas of various age: (1 — Precambrian, 2 — Caledonian, 3 — Hercynian, 4 — Alpine); 5 — boundaries between fold areas of various age; 6 — continental rift belts (Rhine-Lybian and Arabian-African); 7 — large zones of transverse dislocations; 8 — transverse deep faults; 9 — Karpinsky lineament; 10 — gas deposits and occurrences with the mercury content in gas over 1×10^{-6} g/cu. m.

ore and oil-and-gas deposits. The opposite example here is the Karpinsky lineament (Fig. 2), its western branch in particular, featuring high mercury content in ore deposits (Gortdrum, Rammerlsberg), as well as in gas and gas-and-oil fields (Groningen in the Netherlands, East-Hannover area in the F.R.G., Altmark province in the G.D.R., Ostruv Velkopolsky in Poland). In the eastern Branch the enhanced mercury content is observed in some gas and gas-and-oil fields in the Dnieper—Donets depression, Stavropol uplift and Mangyshlak—Usturt dislocations. Deposits with a high mercury content strictly confine to the crossing points of large longitudinal tectonic dislocations with zones of large transverse faults reaching the mantle level, along which mercury emerged from the Earth's mantle.

Another ore-forming element in mercury-antimony provinces is antimony which is less studied. Unlike mercury we do not know much about its behaviour in natural processes. Antimony often accompanies mercury in deposits;

it forms highly volatile compounds. But it does not mean that they have a single source. Indirect indication to this is a much wider distribution of monometallic mercury deposits than complex ones (mercury-antimony). On the other hand, antimony deposits with exceptionally low mercury content are known, thus, for instance, ore deposits in the Seinäjoki region in Finland and deposits in Yakutia. They belong to the gold-antimony (beresite) formation (acc. to V. I. Berger). They are distinguished by the confinement to the areas of the Earth's crust with granitophylic metallogeny (V. I. Smirnov) and their control by crystal faults, hence, evidently, the resultant low content of mercury there. Quite likely that the levels of mercury and antimony generation in mercury-antimony deposits are differing, but in the course of ore formation they both got involved in the hydrothermal process and occurred conjointly in the zones of deep faults. In our view mercury-antimony-tungsten deposits show the same relationships. Antimony, showing close genetic links with tungsten (stratiform or associated with granitoids), is of a crustal origin. Mercury in these ores is available, but quite seldom. It is often met in the fault zones cross-cutting the structures controlling the antimony-tungsten mineralization and it is of wider distribution in the zones of deep faults, may be as a product of degassing.

The origin of other ore elements of subordinate nature, such as lead, zinc, copper and others, takes two ways — they may be leached from country rocks and may be of an endogenous origin.

Sulphur source. Studies of the sulphur sources in mercury and mercury-antimony deposits included the analysis of a region-wide location of ore provinces, reconstruction of paleohydrogeological situation of ore formation and also the analysis of the sulphur isotopic composition. These were undertaken with the participation of V. I. Vinogradov. Studies covered deposits of major ore belts in the world — Mediterranean, Central-Asian and Pacific. It was established that the sulphur isotopic composition in ores does not show specific features associated with the location of these deposits in planetary structures of the Earth, but hinges on the obtaining geological situation. Most likely source of sulphur sulphide is the sulphur sulphate of the sedimentary cycle, whose recovery in the course of abiogenous and especially biogenous processes leads to the emergence of great quantities of hydrogen sulphide; this is also the cause of a well-known paragenesis of mercury sulphides and bitumens. The isotopic composition of the resultant hydrogen sulphide may differ greatly, and among others may be equal to the sulphur value in meteoric troilites; hence, the isotopic composition of the sulphur sulphide corresponding to the meteoric one cannot be in itself a criterion of its deep origin.

Here are some examples. Very illustrative here is the group of mercury occurrences in the south of the Siberian platform (Irkutsk amphitheatre). Mercury mineralization is observed here in the zones of major tectonic dislocations, breaking the sedimentary platform mantle with a thick salt and oil-and-gas bearing Cambrian sequence and overthrusting more ancient magnetite mineralization — Angara-Kat and Angara-Ilim iron-ore regions (Fig. 3). Data on the isotopic sulphur composition (Tab. 2) leaves no doubts as to its source — the Cambrian evaporites series. Such sulphur borrowing evidently occurred in ore deposits located in the framing of the Irkutsk amphitheatre which is proved by data pertaining to the East-Sayany and the Baikal mercury belts and Yenisei ridge. Similar situation was revealed in the Tuva salt basin and mercury deposits found in its framing, in the walls of the Verkhoyansk—Kolyma province, etc. The same sulphur source is observed in the salt-dome mercury deposits in the Dnieper-Donets depression. Caprocks and contact breccias of salt stocks contain large bodies and debris of Devonian and Permian anhydrites. Presence of bitumen and oil, which discharge in salt domes, gives rise to active hydrogen

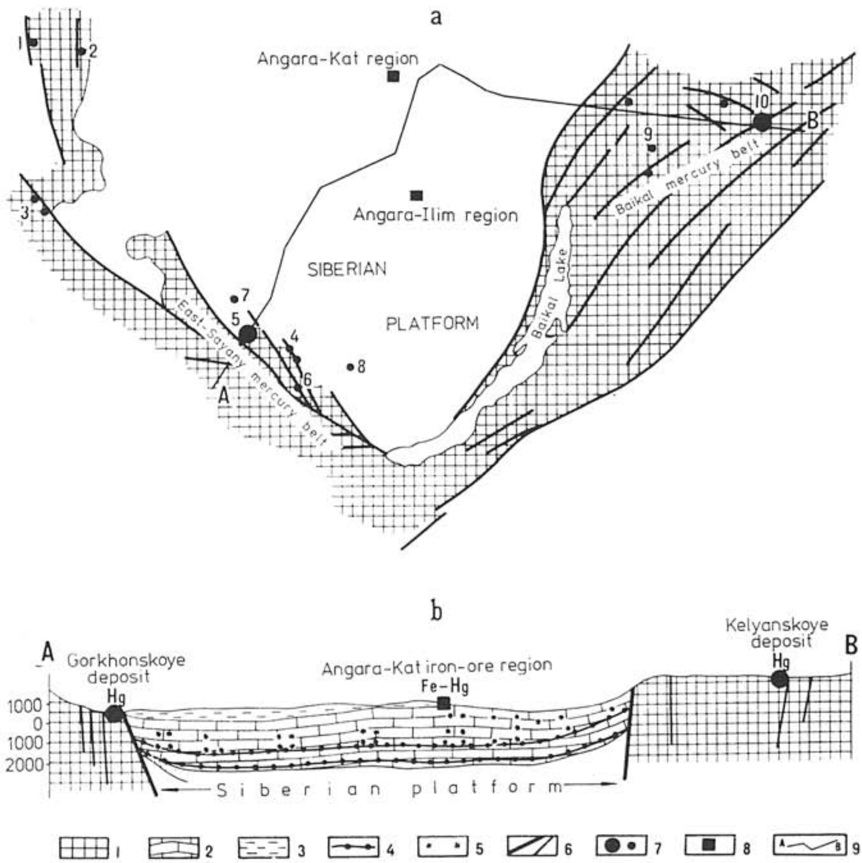

Fig. 3. Geologico-structural location of mercury deposits and ore occurrences in the south of the Siberian platform and its framing (a — scheme, b — cross section). *Explanations:* 1 — framing of Siberian platform; 2 — terrigenous-carbonate and carbonate deposits, Vendian, Cambrian, and Ordovician; 3 — terrigenous deposits, Silurian; 4 — oil and gas horizons; 5 — evaporites (rock salt, gypsum anhydrite); 6 — faults; 7 — mercury and mercury-antimony deposits and occurrences (1 — Chernorechenskoye, 2 — Mutovskoye, 3 — Senzhulskoye, 4 — Ingashinskoye, 5 — Gorkhonskoye, 6 — Ziminskoye, 7 — Udinskoye, 8 — Zalarinskoye, 9 — Ogneiskoye, 10 — Kelyanskoye); 8 — Angara-Kat and Angara-Ilim iron-ore region with mercury mineralization (Fe-Hg); 9 — geological traverse.

Table 2

Sulphur isotopic composition in mercury deposits in the south of the Siberian platform and its framing

Ore regions, deposits and ore occurrences	Mineral	^{34}S		
		from		to
South of the Siberian Platform				
Angara-Kat region:				
Chapkinskoye	Cinnabar	+12.6		+22.6
Kapayevskoye	Pyrite	+20.7		+35.4
	Pyrite	− 6.2		−12.7
Angara-Ilim region:				
Korshunovskoye	Pyrite	+17.6		+26.9
Udinskoye	Pyrite	+39.5		+39.6
Zalarinskoye	Pyrite		+33.4	
East Sayany mercury belt				
Gokhonskoye	Cinnabar		+26.7	
Gokhonskoye	Cinnabar and onofrite	+ 3.4		+ 9.4
Ingashinskoye	Cinnabar		+9.7	
Senzulskoye	Cinnabar		+4.6	
Ziminskoye	Pyrite		+4.5	
Baikal mercury belt*				
Kelyanskoye	Antimonite	−12.2		−0.9
	Cinnabar I	+ 0.3		+7.0
	Cinnabar II		+20.0	
	Barite	+24.5		
Ogneyskoe	Barite	+22.0		+27.0
Yenisei range				
Mutovskoe	Cinnabar		+17.0	
Chernorechenskoy	Cinnabar		+14.1	

* Acc. to V. I. Berger

sulphur generation. Since the dynamics of the sulphate-reduction process has its specifics in every stage passed, sulphur in hydrogen sulphur and residual sulphates differs greatly in its isotopic composition; it is usually of a heavy variety. The analysis of the isotopic composition and geological position of deposits show that the origin of sulphur in cinnabar and other sulphides may be traced to sulphates in salt domes.

A group of mercury and mercury-antimony deposits exists where the isotopic composition of sulphur sulphides approaches that of meteoric. Some features and analogy with other deposits allow an assumption that in such cases the involvement of sulphur of the sedimentary cycle in ore formation is quite likely.

But the inference is not so simple, and the involvement of juvenile sulphur cannot be neglected. Here is one example — mercury deposits in California. They are controlled by the San-Andreas regional fault (Fig. 4). Liquid oil, solid bitumen of the asphaltite family and hydrogen sulphur are found here. By isotopic ratio ($^{13}C/^{12}C$) oil here turned out similar to the oil from Cretaceous deposits of oil and gas fields located to the east of the Californian mercury

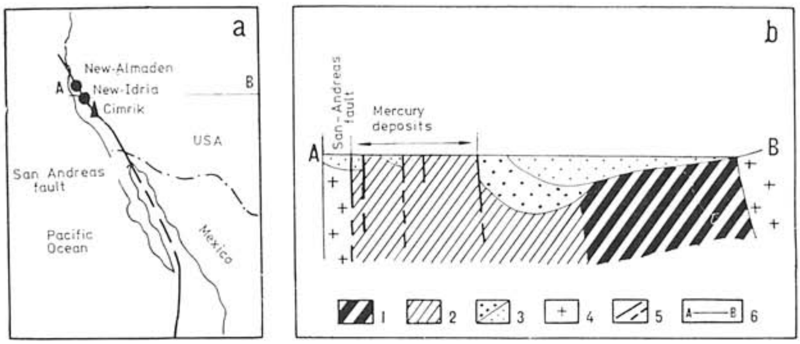

Fig. 4. Scheme of mercury deposits in California — New-Almaden and New-Idria and mercury-rich oil field Cimrik (a) and geological-geophysical cross section along 37th parallel (b). Cross section is given acc. to Carlson — Willden, 1968. *Explanations:* 1 — Paleozoic and Mesozoic metamorphic rocks; 2 — Jurassic effusive-terrigenous deposits; 3 — Cretaceous and Cainozoic sedimentary rocks; 4 — granitoids; 5 — faults; 6 — geological traverse.

belt (D. White). Studies of the isotopic composition of oxygen and hydrogen in thermal waters of California undertaken by D. White et al. have indicated that modern thermal springs including those shaping mercury mineralization Sulphur-Bank and others, are formed by mixing meteoric waters of the surface origin and oil waters. Regional structure shown in Fig. 4 had been already shaped by the time of ore formation, therefore, waters of the oil and gas field, probably, discharged along the San-Andreas fault and its feathers prior to this and might contribute to the mercury ore formation. When no hydrogen sulphur was found in oil-field waters, then a unique oil pool Cimrik was formed, the oil and gas of which are proved to contain native mercury. The isotopic data proper on the sulphur composition, i. e. closeness to meteoric composition and wide-spread negative values, might be interpreted here as a result of exchange between sulphur sulphide and sulphate realized at the expense of primary juvenile sulphur, if to take them in isolation from geological material. And only drawing upon regional geological and geochemical data it becomes possible to ascertain the involvement of hydrogen sulphur from adjoining oil gas field in ore formation.

I gave here illustrations to two basic geological situations when sulphur sulphide is generated involving sulphates of evaporite deposits and buried marine water and when it is supplied by oil and gas fields. Still more examples may be given here, many of them are published. Nowadays we have such materials for all principal mercury provinces of the world. They prove wide involvement of groundwaters in mercury-antimony ore formation. Comparison of data available on liquid gas inclusions and water extracts from minerals of mercury-antimony deposits (unfortunately, very few in number) with hydrochemical characteristics of groundwaters in respective ore regions has show that the general mineralization and macrocomponent nature of ore-forming solutions are dependent, to a great extent, on the groundwater composition in these provinces, although in the process of ore formation they undergo changes through interaction with the country rocks and deposits of selective minerals. Such comparison is made for the deposits in the Transcarpathians, Donbass, Central Asia, the Pre-Baikal area, Chukotka and others; A. S. Borisenko and A. A. Obolensky have made it for Tuva. Mercury in the ore-formation zone is available in two major forms — in monatomic dissolved form (the role of which enhanced with temperature) and in the form of a hydrosulphide complex — in solutions with the increased sulphur sulphide concentration and at temperatures less than 200 °C. These data were provided by eperimental and thermodynamic investigations carried out by the IGEM and GEOHI of the U.S.S.R. Academy of Sciences (I. L. Khodakovsky — M. Ya. Popova — N. A. Ozerova, 1977; N. D. Shikina — I. L. Khodakovsky — N. A. Ozerova, 1982).

Summing up the above it has to be said that the sources of major ore-forming elements in mercury and mercury-antimony deposits include juvenile components proper, mostly mercury, and also crustal components — antimony, tungsten, sulphur, bitumen, petrogenic and other elements.

In conclusion, I would like to emphasize that the theoretical studies of these sources are of applied significance, they allow to suggest new regional criteria of these deposits location. Well-known is also the fact that mercury belts are confined to the zones of deep faults penetrating the upper mantle. But one more factor in respect to sulphur sources should be underlined here — availability of oil and gas fields or depressions with evaporites and oil- and gas-bearing features, the walls of which are traversed by ore-controlling deep faults conveying mercury from the Earth's depths.

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