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Late Cenozoic ore deposits and their sulfur isotopic ratios of the northeastern Hokkaido, Japan

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Abstract: Sulfur isotopic ratio ($\delta^{34}S$) was determined on sulfide minerals and ores from base metal deposits (23 samples), gold-silver deposits (29 samples) and mercury deposits (9 samples), and a large number of negative $\delta^{34}S$ values were discovered. Together with the previously reported data, the base metal deposits have two groups of $\delta^{34}S$ values: -12.9 to -9.8 and -2.7 to +6.2 permil. The first group is considered genetically related to ilmenite-series granitoids, which have -6.3 permil on an average $\delta^{34}S$ value of the rock sulfur. The second group is essentially formed with magnetite-series volcanic and subvolcanic activities (Motokura-Jotoku), but locally contaminated with sedimentary sulfur from the wall rocks (Kitami).

Gold-silver deposits have a wide range of -9.0 to +9.0 permil$\delta^{34}S$. The values are especially low (-9.0 ～-0.7‰) in those of the Omu-Sanru graben and the northernmost part of the Monbetsu-Kamishihoro graben, where important ore deposits of Konomai, Hokuryu, Numano-ue and Sanru are distributed. These negative $\delta^{34}S$ values may indicate the existence of reduced-series volcanic rocks in these regions. A regional N-S variation in the $\delta^{34}S$ values of the gold-silver deposits seen in the northeastern Hokkaido is considered to reflect essentially the regional difference in the ilmenite/magnetite-series volcanic activities.

Mercury deposits have the most negative values (-14.2 to +0.4 ‰) among the three commodity groups, and could also be related to ilmenite-series volcanism.

1. Introduction

Late Cenozoic volcanism of the back-arc basins of the Japanese Islands is known associated with fruitful mineralization of mainly Kuroko and base-metal vein types that have positive $\delta^{34}S$ values of ore sulfur around 4.5 permil (Ishihara and Sasaki, 1978; Sasaki and Ishihara, 1980). Ore deposits of the Kitami province of the back-arc side of the Kuril Arc, however, are different from those of other provinces showing often negative values on the ore $\delta^{34}S$ values, in contrast to the positive values of Southwest Hokkaido (Ishihara and Matsueda, 1997). The difference is considered to reflect reduced and oxidized magmatic activities (Ishihara *et al*., 1996).

In this paper, we report additional analyses of the $\delta^{34}S$ values of ores from the Kitami province of the northeastern Hokkaido and compile all the available isotopic data of the ore sulfur. Analyzed samples were hand-picked by using a dental drilling machine, or whole rock in most of gold-quartz veins, which contain little and very fine grained sulfides in general. The isotope analyses were performed by conventional SO_2 methods at the Central Laboratory of the Mitsubishi Material Corporation, Omiya, Japan and Chinese Academy of Geological Sciences, Beijing. The analytical errors are said as ±0.2 permil.

The Kitami province is underlain by Cretaceous-Paleogene sedimentary rocks of the Hidaka Supergroup in the west and late Jurassic-Paleogene sedimentary and igneous metamorphic rocks of the Tokoro Belt in the east. They have been faulted to horst and graben blocks. Tertiary granitoids (Ishihara *et al*., 1998) intruded into the horst, while Late Cenozoic volcanism and sedimentation occurred in grabens, which strike north-south and northeast-southwest. Related ore deposits occur in and around the grabens

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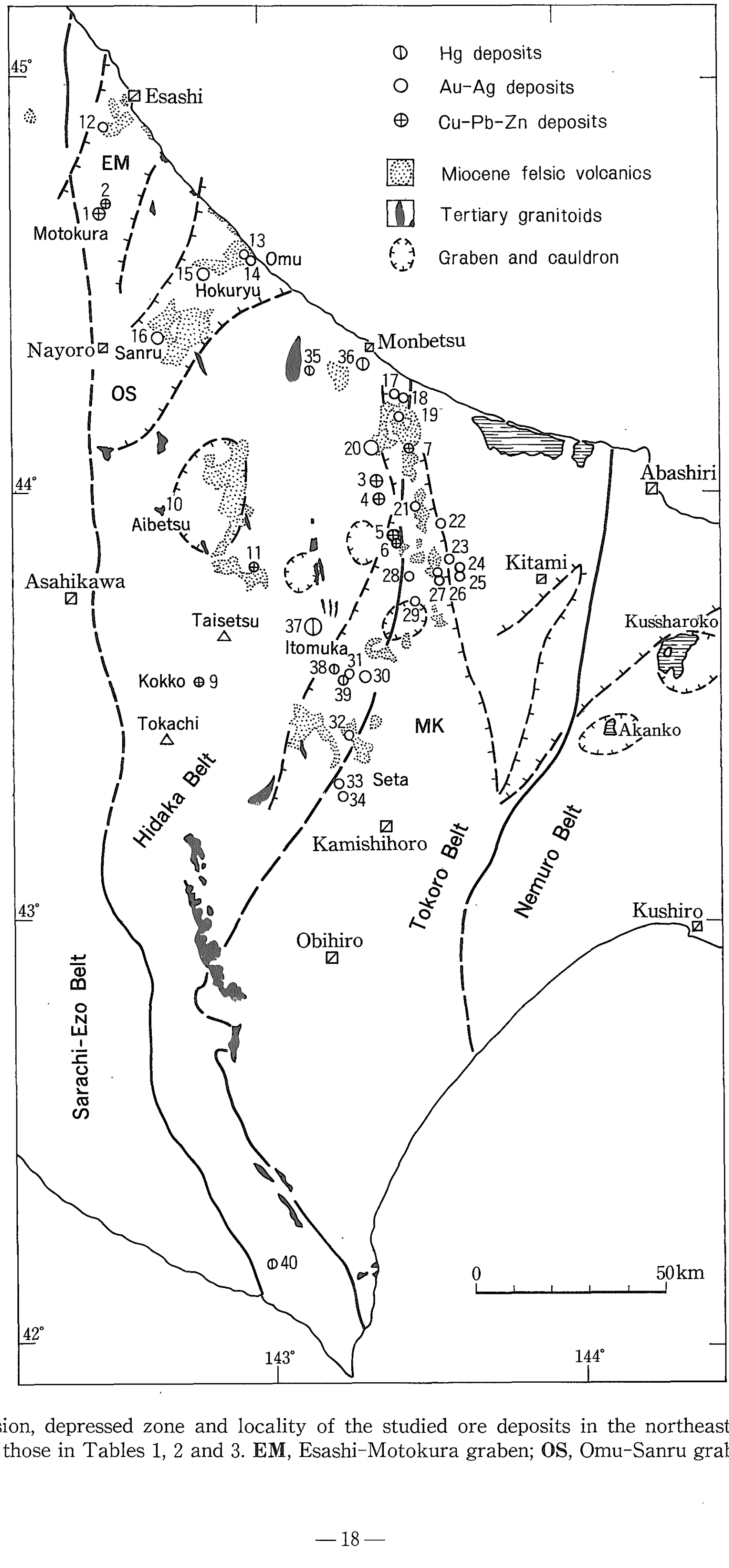

Fig. 1 Basement division, depressed zone and locality of the studied ore deposits in the northeastern Hokkaido. The numbers correspond to those in Tables 1, 2 and 3. **EM**, Esashi-Motokura graben; **OS**, Omu-Sanru graben, **MK**, Monbetsu-Kamishihoro graben.

(Fig. 1), which are here named, from north to south, as Esashi-Motokura graben, Omu-Sannru graben and Monbetsu-Kamishihoro graben (Yahata, 1997). Quaternary volcanoes are present in the southern part along the volcanic front of the Kuril-arc volcanic chain.

Metal mining was most active in 1950s in the north-eastern Hokkaido (Urashima, 1961). The ore deposits of the Kitami province are mostly hosted in the late Cenozoic volcanic and sedimentary rocks and rarely in the basement. The late Cenozoic volcanic rocks have whole-rock ages ranging from 15.1 Ma to present, and the related ore deposits have K-Ar adularia and whole-rock alteration ages of 14.4 - 0.33 Ma (Watanabe 1996; Yahata *et al.*, 1996), which have been classified into three metallogenic epochs of the middle Miocene, upper Miocene-Pliocene, and Pliocene-Quaternary (Ishihara, 1998). The ore deposits can be divided into three groups of the associated ore metals: base metal, precious metal and mercury (Fig. 1), and are described from north to south in the following paragraphs. The obtained $\delta^{34}S$ values from the ore deposits are listed in Tables 1 to 3.

2. Base Metal Deposits

Base metal deposits are rare in the Kitami province among which three ore deposits of Kitami, Motokura and Jotoku are economically important. They occur in the Esashi-Motokura depression zone and in the western rim of the Monbetsu-Kamishihoro graben, and are all vein types and rich in lead and zinc, rather than copper, which is unusual in the base metal mineralization of the back-arc zones (Ishihara and Sasaki, 1995). Kuroko type is recorded at two localities: Fumi and Nemuro (Hasegawa *et al.*, 1983).

2.1 Motokura and Jotoku deposits

The Motokura deposit was discovered in 1936 and mined during 1950-1960's decades. Total production is 150,000 tons containing Au 30 kg, Ag 14.4 tons, Cu 1,500 tons, Pb 18,600 tons, Zn 12,900 tons, pyrite 24,600 tons (Yamada *et al.*, 1980). Thus the ore deposit is rich in lead.

The Motokura deposit is underlain by Miocene andesitic and rhyolitic rocks which intercalate some conglomerate and sandstone. According to Bamba et al.(1958), the ore deposits are hosted in propylitized andesites and are composed of E-W and N50°E striking vein systems. The major ore minerals are pyrite, chalcopyrite, sphalerite and galena. Gangue minerals are mostly quartz, and some sericite and others including barite and gypsum, which are present in druse of the ore veins. K-Ar age of adularia-bearing silicified rock is 12.3 ±0.6 Ma (Yahata *et al.*, 1996) and altered rhyolite is 12.2 ±0.2 Ma (Ishihara, 1998).

Jotoku veins, located at 1.5 km northeast of the Motokura deposit, are similar in manner of the vein system to that of the Motokura deposit. The vein constituents are also similar except for the lack of sulfate minerals. The ore-forming sulfides of the Motokura deposits give $\delta^{34}S$ values of +2.8 to +1.0 permil, whereas those of Jotoku veins yield +6.2 and +3.8 permil.

2.2 Kitami deposits

The ore deposit was discoverd before 1934, and was mined most actively in the 1950's decade. The total production was 590,000 tons of crude ores containing metals of Ag 22.2 tons, Cu 4,720 tons, Pb 8,850 tons, Zn 14,750 tons and iron sulfides 53,690 tons (Yamada *et al.*, 1980).

The Kitami deposit is located in the basement at the western rim of north-south trending Miocene volcano-sedimentary, Monbetsu-Kamishihoro graben (Fig.1, Yahata *et al.*, 1988). The basement was intruded by numerous east-westerly dikes of intermediate composition (mostly SiO_2 64.4-70.5%), which are subdivided into earlier quartz-phenocryst-free granodiorite porphyry (14.4-14.2 Ma) and later quartz-phenocryst-bearing granodiorite porphyry (13.2-11.1 Ma, Watanabe *et al.*, 1999).

The veins strike in east-west and dip steeply south. The major ore minerals are pyrite, chalcopyrite, sphalerite, galena and pyrrhotite, and the gangue minerals are quartz, chlorite, sericite and calcite. Presence of pyrrhotite and sphalerite star (Yamada, 1963) indicate that this deposit formed at lower oxygen fugacity and at higher temperature than the Motokura vein deposit.

Sulfur isotopic ratios of mineral separates and composite samples of the Kitami deposit vary from -4.2 to -0.2 permil, much smaller than $\delta^{34}S$ values of Motokura and Jotoku veins. However, the Motokura and Jotoku deposits are volcanogenic, while the Kitami deposits are plutonogenic and their negative $\delta^{34}S$ values may have been effected locally by wall-rock sedimentary sulfur, similar to the ore sulfur of the Chichibu mine area (Ishihara *et al.*, 1987).

Toward the due south of Kitami mine, several base metal prospects are known to occur around the western rim of the Monbetsu-Kamishihoro graben. All are hosted in Miocene volcanic rocks and gave two different values as +1.2 permil $\delta^{34}S$ on the WNW-trending base metal veins at Yahagi-Tatsumi, and +4.5 permil $\delta^{34}S$ on the pyritized volcanic rocks at Koki.

2.3 Kuroko type ores, Fumi and Nemuro

Two Kuroko-type deposits are known to occur in the whole eastern Hokkaido. One at Fumi in the Kitami province is massive orebody occurring in argillized brecciated tuff close to rhyolitic dike (Yamada, 1963). The volcanic rocks are later

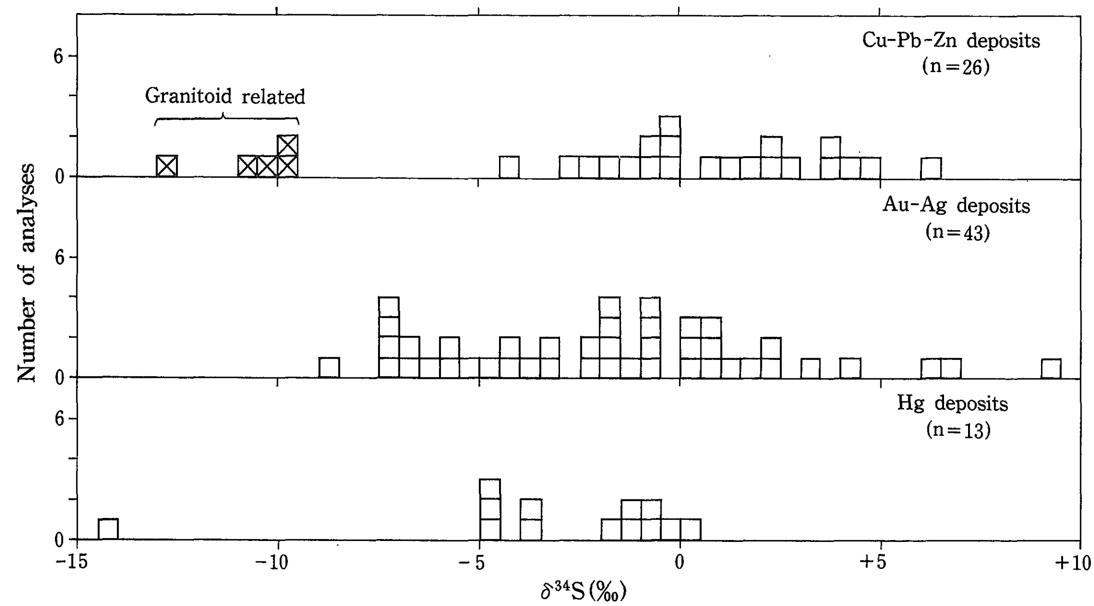

Fig. 2 Histograms of δ^{34}S values of the sulfide ores and minerals from the northeastern Hokkaido.

identified as terrestrial ash flow deposits (Yahata *et al.*, 1988). The footwall has been silicified. These features are not of typical Kuroko deposits, but similar to atypical one of Kamikita deposit in nothern Honshu (Lee *et al.*, 1974). Sphalerite-rich composite sample of this Fumi deposit give δ^{34}S values of +4.6 permil, which is very similar to the average Kuroko value of +4.5 permil (Sasaki and Ishihara, 1980)

The other example of Nemuro deposit is typical one being composed of Kuroko and Oko (yellow ore) bodies occurring in rhyolitic tuffs overlain by mudstone. Gypsum ore bodies are also present (Kinoshita, 1939). Composite sample of lead-zone ores gives +3.8 permil, which is also close to the δ^{34}S value of typical Kuroko ores (Sasaki and Ishihara, 1980).

Histogram of all the analyses are shown in Figure 2. The volcanics-related ores range from -4.2 to +6.2 permil, which are quite different from δ^{34}S values of the granitoid-related ores, mentioned below.

2.4 Ore deposits related to granitoids

Ore deposits related to ilmenite-series granitoids are very rare in central Hokkaido, but the Nakaetsu Cu-As deposit may be the one genetically connected with Tertiary granitic activity, because it occurs filling fractures of sedimentary rocks of Hidaka Supergroup at due-south of N-S trending ilmenite-series granitic pluton and the alteration age is 30 Ma, which is much older than Miocene-Pliocene volcanic activities.

The ore deposit is also unusual as volcanogenic deposit, being rich in As and In (Tsushima *et al.*, 1999). The constituent sulfides, including pyrite, arsenopyrite, and chalcopyrite, range in the δ^{34}S value from -9.8 to -12.9 permil (Table 1, nos. 10 and 11). Pyrite filling joint of Aibetsu-dam ilmenite-series biotite granite (Ishihara *et al.*, 1998) has similar δ^{34}S value of -9.8 permil. δ^{34}S values of rock sulfur of late Cenozoic granitoids are averaged as -6.3 permil (n=3, Sasaki and Ishihara, 1979), and ore sulfur is about 3 permil lower than rock sulfur (Sasaki *et al.*, 1984). Thus, the Nakaetsu and Aibetsu-dam sulfides are considered originated in the ilmenite-series granitic activities.

3. Gold and silver deposits

Gold-silver deposits are economically most important in the Kitami Province. They are essentially vein type and numerous in number (MITI, 1990a), but large ones, the production more than 100 kg Au metal, are the following ten mines (JMIA, 1968; MITI, 1990 b):

Mines	Au	Ag	Ag/Au
Konomai	73.181 tons	1243 tons	17.0
Hokuryu	2.924	11.268	3.85
Kitano-o	2.916	2.503	0.86
Numano-ue	1.405	94.149	67.0
Sanru	1.340	8.127	6.07
Ikutawara	0.505	3.938	7.80
Tokoro	0.092	2.321	25.2
Muka	0.186	0.814	4.38
Saroma	0.162	0.766	4.73
Ryuo	0.100	0.855	8.55

These Au-Ag deposits, mostly of the low sulfidation type, are hosted in the late Cenozoic volcano-sedimen-

Table 1 Sulfur isotopic ratios of base metal deposits, NE Hokkaido.

No. and Locality	$\delta^{34}S$(‰)	Analyzed minerals	Sample no . (analyst)
1 Motokura, Heian B main body	+1.0	Cp, cp-qz vein	Ishihara & Sasaki (1994)
ditto	+1.8	Sp, cp-sp-gn-py breccia vein	UR-LGK7A (MB)
ditto	+2.2	Gn, ditto	UR-LGK7B (MB)
ditto, Heian vein, drift W	+2.3	Sp, brown sp-amethyst qz	94MT01 (MB)
ditto, Heian Chudan E	+2.8	Sp, sp in clay zone	94MT07 (MB)
2 Jotoku, 1st adit 117m	+3.8	Py, py-qz vein	UR-LG1 2A (MB)
ditto	+6.2	Gn, gn-qz veinlet	UR-LG1 2B (MB)
3 Kitami, -50mL	−4.2	Composite, py-cp-po	Ishihara & Sasaki (1994)
dittto, mine dump	−0.2	Py, altered hornfels	94070212 (MB)
ditto, mine dump	−0.6	Py, py-chl-ser rock	94070213 (MB)
ditto, N240 vein, W20B	−0.7	Py, gn-sp-py vein	UR-NGF2A (MB)
ditto, N240 vein, W20B	−1.4	Sp, ditto	UR-NGF2B (MB)
ditto, N240 vein, 2nd adit	−2.1	Sp>>cp, py, latest-stage sp	94KT03 (MB)
ditto, N240 vein, +20mL, W20	−2.7	Sp, sp-py drusy qz vein in chl-py host rock	94KT02A (MB)
N550 orebody, center	−1.7	Po-sp>py-cp banded ore	94KT164 (MB)
4 3 km NE of Maruseppu	−0.3	Py,py-bearing gd porphyry	95KTM11(MB)
5 Koki, mine waste	+4.0,4.5	Py, py-diss. altered tuff	96072706A (CAGS)
6 Yahagi-Tatsumi	+1.2	Sp, sp-cp-py-qz vein in pyroclastics	GSH(MB)
7 Fumi ("Kuroko"), mine dump	+4.6	Sp>>py-cp-gn disseminated in andesitic pyroclastics	96072705 (MB)
8 Nemuro (Kuroko)	+3.8	Composite, gn-sp-py ore	Nemuro-18(CAGS)
9 Kokko	−0.4	Py>as-sp-cp-quartz vein in silicified andesite	Tokari-KKB (MB)
10 Aibetsu dam	−9.8	Py, py filling joint of granite	95092701 (MB)
11 Nakaetsu , outcrop	−9.8	Py , py-as-cp ore	97NK03 (CAGS)
ditto	−10.1	As, ditto	97NK01 (CAGS)
ditto	−12.9	Cp,	97NK02 (CAGS)
ditto	−10.8	Cp, cp>>gn -sp ore	97NKGSH-MT (CAGS)

Abbreviations : as-arsenopyrite, cp-chalcopyrite, gn-galena, py-pyrite, po-pyrrhotite, qz-quartz, sp-sphalerite, chl-chlorite, ser-sericite, comp-composite, gd-granodiorite.
Analysts: MB, Mitsubishi Central Lab.; CAGS, Chinese Academy of Geological Sciences.

tary rocks, which occur in several depression zones controlled by basement structures and regional faulting (cf., Fig. 4). Absence of the high sulfidation type is considered due to reduced type of volcanism prevailing in the Kitami province (Ishihara and Matsueda, 1997).

3.1 Konomai deposit

Konomai deposit was discovered in 1915. The production was initiated in 1917 (Sumitomo Mining Co., 1981). The mine area is underlain by Cretaceous sedimentary rocks of the Hidaka Supergroup and overlying Miocene sedimentary and volcanic rocks. The ore deposit occurs in the western part of the Monbetsu-Kamishihoro graben and is hosted by andesite and rhyolite.

The ore deposit is vein type having more than 10 veins. Their average widths vary from 10 m (e.g., Kuchan-nai No. 5) to 1 m. Single vein extends up to 2.5 km (Kuchan-nai No. 8). The vertical extent is 500 m (Kuchan-nai No. 5) to 90 m, which is Fujishima vein swarms (Kondoh *et al.*, 1967; JMIA, 1968).

The main ore minerals are native Au, native Ag, argentite, pyragyrite, pyrite and marcasite. Wall rock alteration mineralogy is characteristically quartz-sericite-adularia and calcite-pyrite in the andesite, and quartz-sericite-adularia-kaolinite-montmorillonite in the rhyolitic host rocks.

Sulfur isotopic ratios of the Konomai veins vary from -7.2 to -2.3 permil $\delta^{34}S$, which could be considered a small variation for the widespreading of the ore deposits.

Table 2 Sulfur isotope ratios of ores from Au-Ag deposits, NE Hokkaido.

	Mine	$\delta^{34}S$(‰)	Analyzed minerals	Sample no.(analyst)
12	Utanobori, outcrop	−0.9	Ag sulfides, Ginguro-qz vein	UTA-2A (MB)
	ditto, 7MAHH1 drill-core	−1.5	Py, pyritized pumice in rhyolitic tuff	UTA-138.6 (MB)
	ditto, ditto	−2.0	Py, detrital pyrite in sandstone	UTA-178.2 (MB)
13	Kami-Omu, outcrop	−3.5	Ag sulfides	Ishihara & Sasaki (1994)
14	Omu, outcrop	−9.0	Ag sulfide, in milky qz mass	95OM-4 (MB)
15	Hokuryu, waste	−7.1	Py, py-Au-qz vein	Ishihara & Sasaki (1994)
	ditto	−7.3	Py, py-Au-qz veinlets in brecciated vein	HKR-2 (MB)
16	Sanru	−7.0	Pyrargirite	Shikazono (1987)
	ditto, waste	−0.7	Py, py in drusy Au-qz vein	Ishihara & Sasaki (1994)
	ditto, ditto	−0.9	Py, py in banded Au-qz vein	ditto
	ditto, ditto	−4.5	Py, massive ore	95092705 (MB)
17	Otowa,waste of upper adit	−3.1*	Py, py-Au-qz vein	OTY9 (MB)
	ditto, that of lower adit	−3.9	Py, py disseminated in breccia matrix	OTY3 (CAGS)
18	Koudo, outcrop	−1.3	Py, occurring in silicified rock	Ishihara & Sasaki (1994)
19	Numano-ue, waste	−1.6	Py, Ag sulfides, Au-qz vein	NMY8 (MB)
20	Konomai	−2.3	Py, sp, cp, gn	Shikazono (1987)
	ditto	−7.2	Py, py-qz vein	Ishihara & Sasaki (1994)
	ditto, Sanoko-Tsudo	−5.7	Massive cp>as part of veins in tuff breccia	UR-PFG7 (MB)
	ditto, ditto	−6.1	Sp>py>cp part of veins in tuff breccia	UR-PFG8 (MB)
	ditto, 5th adit outcrop	−5.2	Py, py-Au-qz vein	96102203(CAGS)
	ditto, ditto	−6.5	Py, fine py in Au-qz vein	96102204 (CAGS)
	ditto, ditto	−7.1	Py, py in drusy Au-qz vein	96102205 (CAGS)
	ditto, South	−4.1	Py, py-mc qz vein	KY95(CAGS)
21	Ryuo	−5.8	Cp, py, sp, pol	Shikazono(1987)
	ditto	+1.9	Ag sulfides, Au-qz vein	RY8 (MB)
22	Kitano-o	+0.3	Py, in silicified tuff	Ishihara & Sasaki (1994)
	ditto	+0.6*	Py?, silica sinter	KTY5 (MB)
	ditto, north	+0.4	Py, py disseminated in rhyolite	2MAHB5, 199.2 m (CAGS)
23	Taihoku	+2.4	Py?, py-Au-qz vein	THK2 (MB)
24	Tokoro	+6.6	?, Au-qz network in breccia	TKY7 (MB)
25	Rubeshibe	+1.4*	?, Au-qz vein	RB1 (MB)
26	Muka	+3.4*	Py?, py-silicified rock	MKY6 (MB)
	ditto	−0.6	Ag sulfides, Ginguro qz vein	GSJH-6 (MB)
27	Kokka	+2.2	Py?, Au-qz vein	GSJH-5 (MB)
28	Jindai	−1.6*	Ag sulfides?, Au-qz vein in tuff breccia	JD8 (MB)
29	Onneyu	+6.5*	Py, py-Au-qz vein	ONE3 (MB)
	ditto	−1.6	Py, py disseminated silicified dacite	ONE7 (CAGS)
30	Harutomi	−2.0	Ag sulfides? in Au-qz vein	Ishihara & Sasaki (1994)
31	Akaban-nosawa, float	+4.3*	Py, py-Au-qz vein	AKB1 (MB)
32	Metou	+9.4*	Py, py-Au-qz network	MTO1 (MB)
33	Seta, 4MAHB6, 182m	+0.3	Py, py in Au-qz vein	Ishihara & Sasaki (1994)
	ditto, ditto, 182.5 m	+0.9	Py, ditto	ditto
34	Tokachi-Mitsumata	+0.9	Py, in altered rock	TM6(CAGS)

*With large error (±0.5~1.0 ‰) due to small amounts of sulfides contained. Abbreviations : ms-marcasite, pol-polybasite. For the other abbreviations of minerals and the analysts, see Table 1.

3.2 Other ore deposits

Other gold-silver deposits are mostly hosted in rhyolites and tuffaceous sediments. The rhyolites are lava flow or lava at the top but changing to dike at the bottom of the veins (e.g., Hokuryu and Sanru, JMIA, 1968). The rhyolites are considered genetically related to the gold-silver mineralizations. Sulfur isotopic ratios of these ore deposits vary generally from -9.0 to +9.4 permil $\delta^{34}S$ (Table 2, Fig. 2). They are generally low in the north and high in the south.

At Seta deposits, $\delta^{34}S$ values of pyrites from gold-quartz veins were reported to be 0.3 and 0.9 permil (Ishihara and Sasaki, 1995). Recent detailed study indicates that pyrites from gold-quartz veins have $\delta^{34}S$ values of -1.3 ～+0.1 permil, while those of the silicified host rocks have a wider range of-3.2 ～+2.6 permil (Yahata and Matsueda, 1999). Their average is -0.2 permil (n=18), which is similar to our average value of +0.6 permil (n=2).

Some large differences are observed on the ores from the same locality (Konomai, Onneyu and Ryuo). Veins at Konomai are distributed in a very wide area, but Onneyu and Ryuo veins are small in scale. We need further analyses on systematically collected samples from the latter two deposits.

4. Mercury deposits

The beginning of mercury mining goes back to 7th century in Japan for cinnabar used as vermilion to ancient architecture and also medicine. About 40 tons were spent to casting of the big Buddha of the Todai-ji temple, Nara, in 747-749 AD (Yajima, 1951, 1958). The cinnabar was mined in the southern Nara-Mie region, where the old capital Nara was located. This mining district became the second largest in the 1930s after discovery of two large and many small mercury deposits in the northeastern Hokkaido.

Mercury deposits tend to occur in the basement terranes with a little Late Cenozoic volcanic rocks (e.g., Itomuka and Ryushoden). Small ones occur very widely not only in the Hidaka Belt but also in the Sorachi-Ezo and Tokoro Belts (Hasegawa *et al.*, 1983).

The largest Itomuka deposit was discovered in 1936 and the total production was Hg 2897 tons (JMIA, 1968). It occurs in Miocene sedimentary and andesitic to rhyolitic rocks, which uncomformably overlie the basement rocks at just south of the mine. The mineralization was considered genetically related to rhyolitic dikes (JMIA, 1968).

Both native Hg and cinnabar fill fractures of sheared zones, which strike N60°E～E-W dipping N. Average width varies from 7 to 1 meter, and maximum length is 140 meters along the strike (e.g., 4th vein) and 240 meters along the dip (e.g., 7th vein). The host rocks have been pervasively altered to calcite, chlorite and quartz; the assemblage sericite-montmonrillonite occurs typically in cinnabar orebody, but kaolinite occurs with native Hg-cinnabar orebodies. Accessory sulfides are pyrite and marcasite.

Cinnabar and pyrite of the Itomuka deposits have constant values of -4.7～ -3.5 permil $\delta^{34}S$ (Table 3).

Ryushoden mine, which was discovered in 1943, then called Hokuchin mine and later changed to Ryushoden, is located much to the north of the Itomuka mine (Fig. 1). The ore deposit is stratabound-disseminated type occurring in Miocene tuffaceous sandstones (Kujirai and Kono, 1971). The mineralizations are composed of an early stage of quartz-pyrite(-cinnabar) and the later stage of chlorite-pyrite(marcasite)-calcite-cinnabar (JMIA, 1968).

Sulfur isotopic ratios vary from -1.4 to -0.6 permil $\delta^{34}S$, which are heavier than those of the Itomuka deposits, but are similar to nearby Uttsu deposit of -1.7 to -0.8 permil $\delta^{34}S$, which occurs in the basement sedimentary rocks.

$\delta^{34}S$ values of other mines are lowest at Kitabaya-

Table 3 Sulfur isotopic ratios of ores from mercury deposits, NE Hokkaido.

	Locality	$\delta^{34}S$(‰)	Analyzed samples	Sample no.(analyst)
35	Uttsu	−1.7	Cn, cn(-py)-bearing quartz vein	94 GSJH01 (MB)
	ditto, 2nd edit	−0.8	Cn, cn staining altered shale	UR-DGY01 (MB)
36	Ryushoden	−0.6	Cn, cn disseminated in argillized rock	Ishihara & Sasaki (1994)
	ditto	−1.4	Py, py disseminated in altered rock	ditto
	Hokuchin	−1.2	Cn, cn-bearing altered rock, open pit	UR-DGR (MB)
37	Itomuka, 7th edit	−3.5	Cn, euhedral xl, filling fracture of altered rock	UR-JJH07 (MB)
	ditto	−4.6	Cn, cn-Hg in altered rock	Ishihara & Sasaki (1994)
	ditto	−4.7	Cn, cn-py disseminated silicified tuff	ditto
	ditto, East	−4.6	Py, pyritized altered lava	ITM23 (MB)
	ditto, ditto	−3.7	ditto	ITM24 (MB)
38	Kitabayashi	−14.3	Cn, cn disseminated sandstone	94 GSJH02 (MB)
39	Oketo,	−4.2	Py, argillized rhyolite	94070208 (MB)
40	Hidaka	+0.4	Cn, cn disseminated in altered limestone	94 GSJH04 (MB)

Abbreviations: cn-cinnabar, Hg-Native mercury, py-pyrite, xl-crystal. For the other abbreviations and the analysts, see Table 1.

shi where cinnabar ores occur in the basement sandstone, and highest at Hidaka deposit occurring in limestone of the basement.

5. Sulfur Isotopic Variation in Time and Space

The initial proposal of southward migration of Miocene volcanism (Watanabe and Yamaguchi, 1988) in the Kitami Province was confirmed by additional data including those of the mineralized materials (see Fig. 5 of Ishihara, 1998). That is, ore deposits from Utanobori gold mine southward to the Kitami base-metal mine give middle Miocene ages, and Ryuo southward, they show late Miocene and Pliocene ages.

Figure 3 is the N20° W-S20° E profile of $\delta^{34}S$ values of the studied ore deposits. The values are different within the middle Miocene group. For example, $\delta^{34}S$ values of the Jotoku-Motokura Pb-Zn deposits are higher than those of the Kitami Pb-Zn deposits, and $\delta^{34}S$ values of Utanobori Au-Ag deposits are higher than those of the Konomai Au-Ag deposits.

Genetical relationship between the oxidized magnetite-series granitoids and positive $\delta^{34}S$ values, and the reduced ilmenite-series granitoids and negative $\delta^{34}S$ values are well established on both rock and ore sulfurs in the Japanese Islands (Sasaki and Ishihara, 1980; Ishihara *et al.*, 1988). The same may be true in the late Cenozoic volcanic fields.

The Motokura Pb-Zn veins of the Esashi-Motokura graben are hosted in propylite and related volcanic rocks to the mineralization is stricktly unknown (JMIA, 1968). Reconnaissance study indicates that volcanic rocks of the Motokura-Jotoku mineralized area along the Tokushibetsu River have magnetic susceptibility of 4.5 to 10.5 x 10^{-3} SI unit for andesites and 4.5 to 6.0 x 10^{-3} SI unit for rhyolitic rocks, which indicate they belong to magnetite series.

Rhyolites of the Utanoboriyama volcanic complex have magnetic susceptibility of 5.0~6.5 x 10^{-3} SI unit. Glassy rhyolitic dome located to the WSW of the WSW-ENE trending Au-Ag veins of the Utanobori mine, which could be related genetically to the mineralization has magnetic susceptibility of 4.0~4.5 x 10^{-3} SI unit. belonging to magnetite series. Thus, the relationship between magnetite-series volcanic rocks and positive $\delta^{34}S$ values is also seen in the Easashi-Motokura graben.

The difference between the Jotoku deposit (average of 5.0 ‰) and Motokura deposit (average of 2.0 ‰) can be explained by the presence and absence of

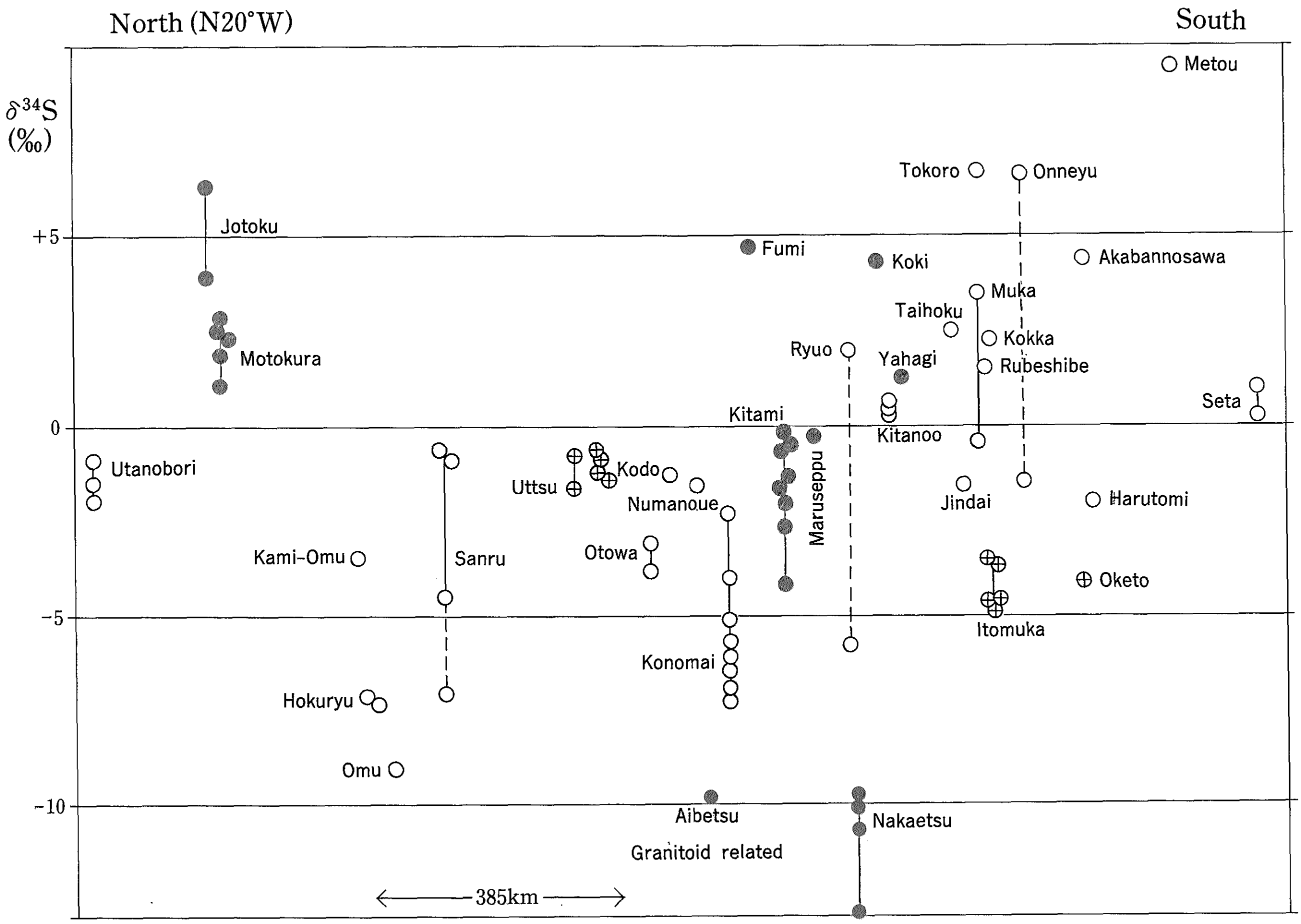

Fig. 3 North-south plots of $\delta^{34}S$ values of the sulfide ores and minerals from the northeastern Hokkaido.

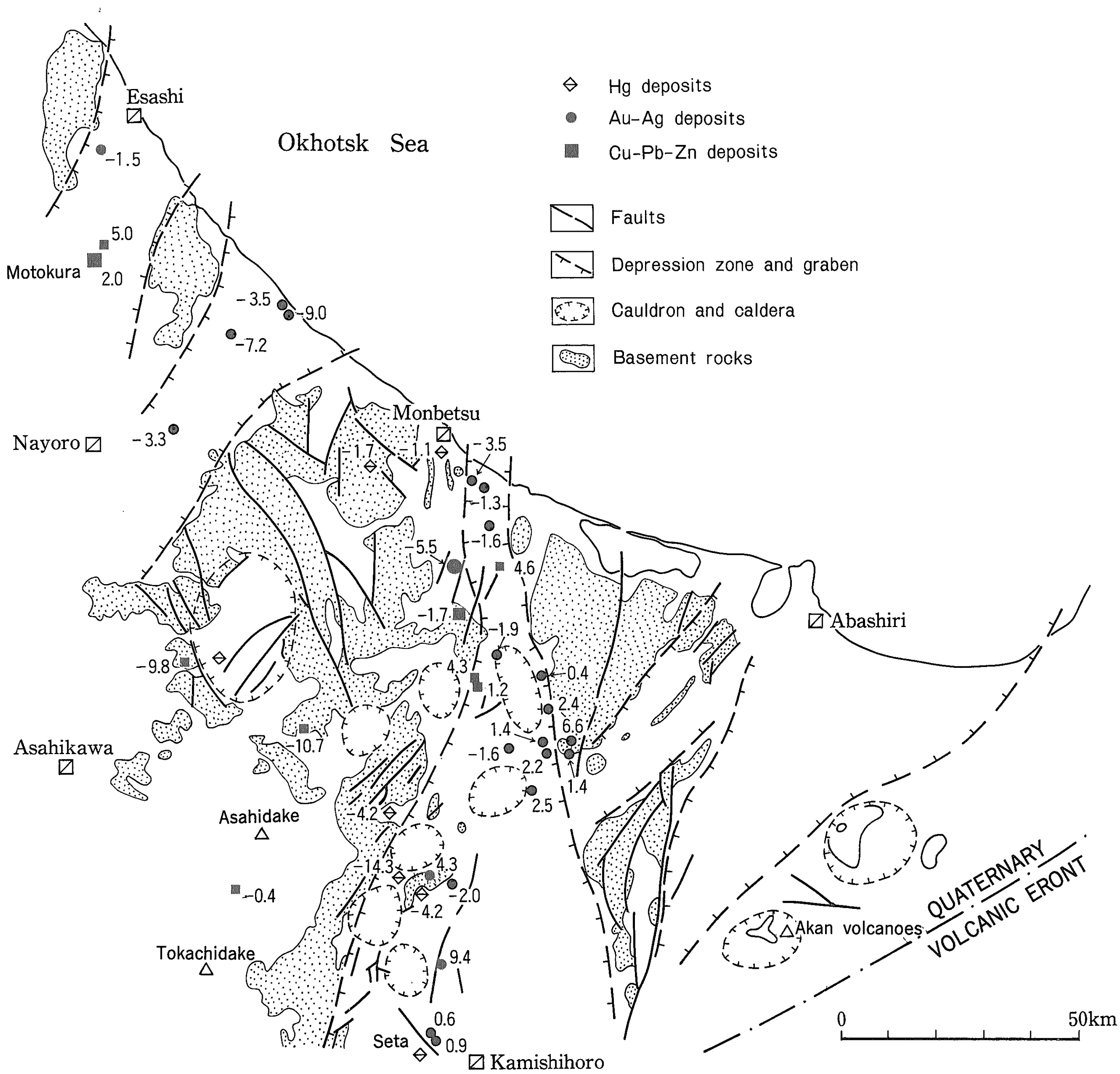

Fig. 4 Regional distribution of averaged $\delta^{34}S$ values of individual ore deposits from the northeastern Hokkaido.

sulfate minerals. $\delta^{34}S$ values of the Utanobori Au-Ag deposit are lower than the base metal deposits. This fact is widely seen on the Japanese Neogene ore deposits and can be explained by more oxidized nature of the Au-Ag-bearing ore fluid than the base metal ore solution (Shikazono, 1987).

Au-Ag deposits at Hokuryu, Sanru and Omu occur in the Omu-Sanru graben to the south (Fig. 4). They have average $\delta^{34}S$ values from -9.0 to -3.3 permil, thus depleted in ^{34}S. They are hosted in rhyolites which are considered genetically related to the mineralization (JMIA, 1968). The rhyolite could belong to ilmenite series, though we need to study the Fe-Ti oxide minerals.

In the Monbetsu-Kamishihoro graben, Au-Ag and Hg deposits of the northern part vary -5.5 to -1.1 permil in their average, while those of the southern part range from -1.6 to +6.6 permil in their average. Some of the volcanic rocks in the northern part show low magnetic susceptibility as 1.8~9.2 x 10^{-3} SI unit (see appendix V of Ishihara *et al.*, 1995). Genetically related volcanic rocks for the Konomai deposits are considered andesite and rhyolite (JMIA, 1968). Although a detailed study is necessary on the opaque minerals, we consider that the andesite and rhyolite could belong to ilmenite series or intermediate series for the $\delta^{34}S$ values.

Among base metal deposits and prospects at the western rim of the Monbetsu-Kamishihoro graben, whose average $\delta^{34}S$ values vary from -1.7 to 4.3

permil, the Kitami ores may have received some sulfur from the intruded pelitic wall-rocks and the original magnetite-series value may have been converted to the observed negative value, because of proximity of the ores to the sediments and higher temperature of their formation (cf. Ishihara *et al*., 1987), as compared with Au-Ag deposits. Base metal prospects at Koki and Yahagi-Tatsumi have positive $\delta^{34}S$ values (Table 1).

Mercury deposits have a wide range of $\delta^{34}S$ values, though the values are biased to negative side. The ore deposits occur in Miocene volcanic rocks with shallow basement or within the basement rocks. It is not clear that the mineralization could be telethermal type of ilmenite-series volcanism or occurred with meteoric water circulation with none-igneous heat extracting Hg from the basement rocks.

6. Conclusions

Sulfur isotopic ratios of the ores from late Cenozoic age in the northeastern Hokkaido have been examined and a large number of negative $\delta^{34}S$ values have been discovered. The observed $\delta^{34}S$ values are divided in two distinct groups: granitoid-related ore deposits such as the Nakaetsu having -12.9 to -9.8 permil, which is reasonable because the granitoids have -6.3 permil rock sulfur on the average (Sasaki and Ishihara, 1979), and volcanogenic ore deposits, which are most important economically in the northeastern Hokkaido. The latter group can be divided into Au-Ag, Cu-Pb-Zn and Hg ore deposits. The base metal deposits vary from -4.2 to +6.2 permil $\delta^{34}S$. Negative values of the Kitami ore deposit may have been formed by interaction of the original ore fluid with the wall-rock sedimentary sulfur. Thus, the essential value for the base metal mineralization is considered to be a positive value.

Ores of Au-Ag deposits have a wide range of -9.0 to +9.0 permil. The $\delta^{34}S$ values vary within the major middle Miocene deposits; they are most depleted in ^{34}S in those of the Sanru-Omu graben and the northern part of the Monbetsu-Kamishihoro graben. The negative values are thought of the related volcanic rocks of ilmenite and/or intermediate series and the positive values of magnetite-series volcanic rocks. Thus, the major gold-silver deposits of Konomai, Hokuryu, Numano-ue and Sanru were related to the reduced-series volcanism, while only small ones were formed with an oxidized-series volcanism in the northeastern Hokkaido.

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北海道北東部における新生代後期の鉱床と硫黄同位体比

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要　旨

標記地域のベースメタル鉱床（23試料），金銀鉱床（29試料），水銀鉱床（９試料）から得られた鉱石および硫化鉱物のδ^{34}S値を求めた。これらの結果を報告すると共に，既存データと合わせて全域の総括を行った。ベースメタル鉱床のδ^{34}S値は－12.9から－9.8パーミルのグループ，および－2.7から＋6.2パーミルのグループに２大別される。前者は北海道中軸帯のチタン鉄鉱系花崗岩類が平均して－6.3パーミルの岩石δ^{34}S値を持つことから考察して，この花崗岩類に由来する鉱液から生成した可能性が高い。後者は磁鉄鉱系の火山岩ないし浅成貫入岩相に関連して生成した鉱床であるが，北見鉱床では壁岩の堆積岩から硫黄を同化した可能性が考えられる。

金銀鉱床は－9.0パーミルから＋9.0パーミルに至る幅広い値を持ち，δ^{34}S値は雄武-珊瑠グラーベン帯，紋別-上士幌グラーベン帯北部の鉱床で特に低い（－9.0 ～－0.7‰）。ここには鴻之舞・北隆・沼の上・珊瑠などの主要鉱床が分布している。鉱床硫黄と関係火成岩の硫黄同位体比の経験則から推察して，この地方の主要金銀鉱床はチタン鉄鉱系火山岩類に関係して生成したものと考えられる。水銀鉱床は３鉱種の中で最も小さいδ^{34}S値を示し，これもチタン鉄鉱系火山岩類に関連して生じた可能性がある。