Late Cenozoic Metallogeny of Southwest Hokkaido, Japan

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1. Introduction

Southwest Hokkaido (Sapporo-Iwanai district) in the Northeast Japan arc (Fig. 1) is one of the best places to test the correlation among tectonic regime, stress field, magmatic style and hydrothermal mineralization. This paper reviews the Miocene to Pleistocene tectonic framework, geology, magmatic style and stress field of southwest Hokkaido, and correlates them with different types of deposits (Kuroko, epithermal base-metal and precious-metal). This correlation allows the tectonic factors that resulted in economic deposits including intermediate and high sulfidation epithermal gold deposits to be identified.

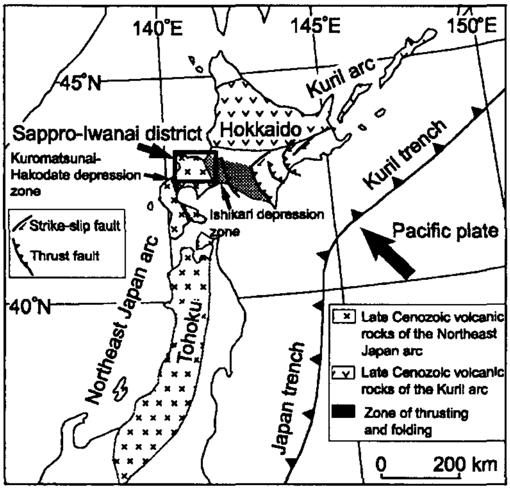

Fig. 1 Tectonic framework of the Northeast Japan arc and location of the Sapporo-Iwanai district. Box shows the location of Figure 2.

2. Tectonic Framework

Since the Middle Miocene, the tectonic regime of southwest Hokkaido has been related to the orthogonal convergence rate (OCR) between the Northeast Japan arc and the Pacific plate. The OCR is related essentially to the subduction direction of the Pacific plate (Jackson et al., 1975), and secondarily due to the change of absolute convergence rate (Engebretson et al., 1985). This paper divides the late Cenozoic era into five periods as follows. Period 1 (15.0-12.1 Ma) was characterized by an oblique-subduction setting with a relatively low, and rapidly changing orthogonal convergence rate of 51-81 mm/y; Period 2 (12.1-6.2 Ma) by normal subduction with a relatively high and constant OCR of 81-94 mm/y; Period 3 (6.2-3.6 Ma) by oblique subduction with an OCR of 73-99 mm/y; Period 4 (3.6-1.5 Ma), a normal-subduction setting marked the highest OCR of between 99-103 mm/y; and Period 5 (1.5-0 Ma), an oblique-subduction setting was characterized by a decrease in the OCR, from 99 to 57 mm/y, due to rapid clockwise rotation of the Pacific plate.

3. Magmatic Style and Stress Field of southwest Hokkaido

Period 1 is characterized by widespread submarine volcanism consisting of andesite in the east, and bimodal volcanism of rhyolite and basalt in the western part of the district. Andesite of this period commonly forms polygenetic volcanoes, whereas rhyolite and basalt on the backarc (west) side tend to form monogenetic lava domes. At the beginning of Period 2, the volcanic front of the arc retreated westward (Fig. 2), and bimodal rhyolite and basalt volcanism in the western part of the district was replaced by andesitic volcanism. During the Period 3, dacite and rhyolite lavas became dominant, in addition to less abundant andesite lavas, and these dacites and rhyolites frequently formed monogenetic volcanoes or small polygenetic volcanoes, mainly in the eastern part of the district. Periods 4 and 5 were characterized by the mixed occurrence of large and small polygenetic volcanoes of andesite composition.

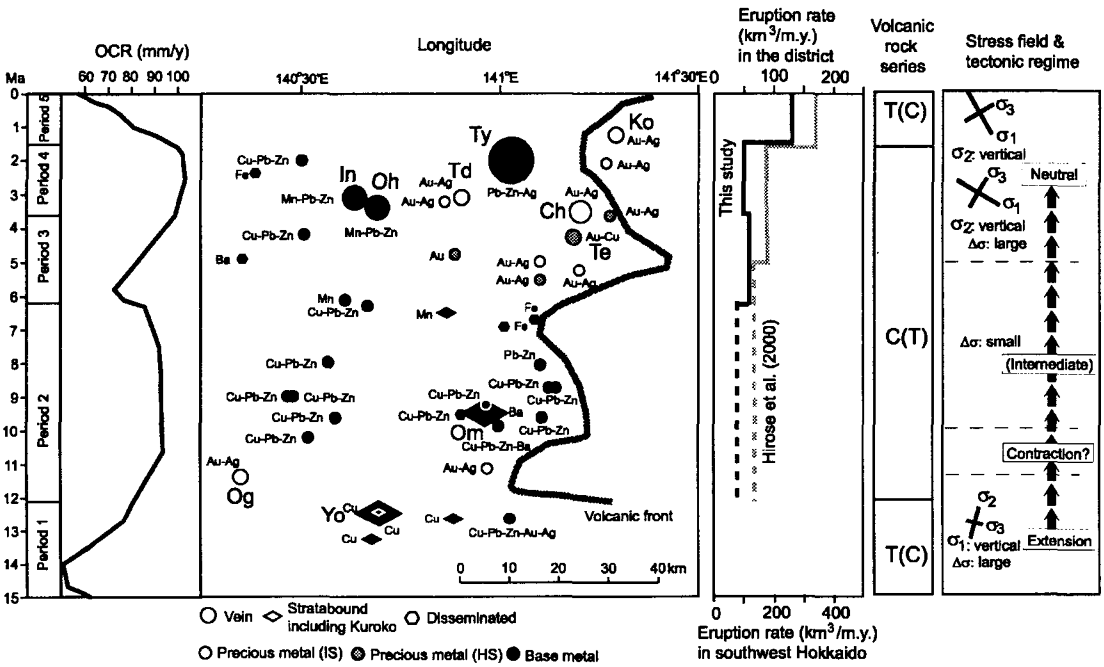

Fig. 2 Relationship among tectonic periods, OCR, longitudinal distribution of hydrothermal deposits, location of the volcanic front, volume of volcanic rocks per million years (km^3/m.y.), and volcanic rock series, and stress field in the Sapporo-Iwanai district. Eruption rate calculated by Hirose et al. (2000) for the whole southwest Hokkaido also is indicated. C(T): calc-alkaline series dominant (minor tholeiitic), T(C): tholeiitic series dominant (minor calc-alkaline). Abbreviations for productive deposits are Ch: Chitose (18 t Au and 83 t Ag), In: Inakuraishi and Oh: Ohe (1.6 Mt Mn, 90,000 t Zn, 26,000 t Pb), Ko: Koryu (no data), Og: Ohgane (1.4 t Au), Om: Otaru-Matsukura (0.3 Mt $BaSO_4$), Td: Todoroki (2.6 t Au), Te: Teine (9 t Au and 130 t Ag), Ty: Tohoha (1.8 Mt Zn, 0.5 Mt Pb, 3000 t Ag), and Yo: Yoichi (8,700 t Cu, 8,900 t Pb and 59,000 t Zn).

The eruption rate of volcanic rocks of Periods 2, 3, 4 and 5 is 40, 60, 50, and 130 km^3/ million years, respectively (Fig. 2). The value for Period 2 is significantly underestimated, because the volcanic rocks of this period are covered commonly by volcanic rocks of the younger periods. The estimated eruption rate of Period 4 is smaller than that of Period 3, despite the likelihood that there is less erosion of Period 4 volcanic rocks than those of the older Period 3.

Period 1 andesites and basalts have chemical compositions of tholeiitic series, poor in K_2O. The volcanic rocks of Periods 2 to 4 and Period 5 are dominated by calc-alkaline and tholeiitic series, respectively (Hirose et al., 2000). Major chemical compositions of the volcanic rocks in the district are related apparently to the OCR; tholeiitic-series rocks dominated during the periods of relatively low OCR (Periods 1 and 5) and calc-alkaline series rocks dominated during the period of relatively high OCR (Periods 2 to 4; Fig. 2).

The dike patterns and modes of faulting indicate that the stress field in the district changed from vertical σ_1 and horizontal σ_3 during Period 1 to horizontal σ_1 and σ_3 during Period 4, suggesting that tectonic regime also changed from extension during Period 1 to neutral during Period 4 (Fig. 2). Lack of significant faulting and folding, and the radial pattern of dikes during Period 2, suggest that the tectonic regime during this period was intermediate between those of Periods 1 and 4. The lowest OCR during Period 1 and highest OCR during Period 4 characterize arc-normal σ_3 and σ_1, respectively (Fig. 2).

4. Hydrothermal Mineral Deposits

Period 1 is characterized by the occurrence of Kuroko deposits. Precious metal veins formed during Period 2 to 5, with most deposits formed during Periods 3 to 5. Base-metal veins formed during Periods 1 to 4, with most deposits formed during Periods 2 and 4 (Fig. 2). Epithermal precious-metal deposits in the district are classified into high (HS) and intermediate sulfidation (IS) types, based on assemblages of ore and alteration minerals and the deduced sulfidation state (Hedenquist, 2000; John, 2001). Among the 19 precious-metal deposits in the district, three are classified as HS, and 14 deposits have IS characteristics. Two deposits are unclassified due to lack of data. One deposit (Teine) is classified as a composite HS-IS. These precious metal deposits are located primarily near the volcanic front (Fig. 2), where small polygenetic-monogenetic volcanoes are dominant.

HS precious-metal deposits in the district are characterized by the occurrence of enargite and luzonite with advanced argillic alteration, represented by alunite, quartz and dickite. These deposits formed during Period 3. IS precious-metal deposits (Chitose, Koryu, Todoroki and Ohgane) are characterized by an ore assemblage of pyrite, chalcopyrite, sphalerite, galena, electrum and tetrahedrite in a gangue of quartz, adularia, calcite and sericite. These deposits lack pyrrhotite and arsenopyrite, characteristic of LS deposits, but include sphalerite with a low Fe content, consistent with intermediate sulfidation states (John, 2001). Some deposits (Misono, Chitose) are rich in base metals in the deeper parts of veins. Silver/gold ratios of the IS deposits are 5-50. A spatial coincidence of HS and IS types is recognized in the Teine Au-Cu deposit and Harukayama (IS)-Ohtoyo (HS) Au-Ag deposits formed during Period 3.

Base-metal deposits of Period 2 are located in both backarc and volcanic front regions, whereas those of Period 4 are distributed mainly in the backarc region (Fig. 2). These base-metal deposits are characterized by ore assemblages of pyrite, sphalerite, galena, chalcopyrite and rhodochrosite ± tennantite ± tetrahedrite, with an alteration halo of quartz and sericite, fringed by chlorite and smectite ± adularia alteration. The Toyoha deposit, and the Inakuraishi and Ohe deposits, are associated with barren lithocaps of quartz-alunite-dickite ± pyrophyllite and quartz-pyrophyllite-diaspore, respectively. Some base-metal deposits (Otaru-Matsukura Ba, Sannai Ba, Akaiwa Cu-Pb-Zn-Ba, Tsuchiya-Bikuni Cu-Pb-Zn and Shigeta-Bikuni Cu-Pb-Zn) formed in the high-sulfidation environment. These deposits are associated with enargite and luzonite ± electrum and with advanced argillic alteration. Silver/gold ratios of the base-metal deposits are >10, typically 40-400.

5. Discussion

5.1. Tectonic regime for Kuroko and epithermal vein deposits

Metallogeny in the district is divided mainly into Period 1 Kuroko and Periods 2-5 epithermal vein-type deposits. The Kuroko deposits were accompanied by submarine monogenetic rhyolite volcanism that was associated with tholeiitic basalt in the backarc. These deposits formed in an extensional tectonic regime with large horizontal differential stress. In contrast, epithermal vein-type deposits during Periods 2-5 were associated mainly with polygenetic andesite and monogenetic rhyodacite volcanism of calc-alkaline series. The tectonic regime for these deposits is inferred to be intermediate between extensional and neutral (Periods 2 and 3) or neutral (Period 4).

The change of the tectonic regime, composition of volcanic rocks and stress field in the district is related to the OCR. Relatively low (<80 mm/y) and high OCR (>80 mm/y) resulted in tholeiitic versus calc-alkaline volcanic rocks as well as extensional versus non-extensional tectonic regimes during Period 1 and Periods 2-4, respectively. The increase in horizontal stress normal to the arc during Periods 2 to 4 was caused by an increase of OCR. This resulted in the bimodal volcanism of rhyolite and tholeiitic basalt on the backarc side changing to polygenetic calc-alkaline andesitic volcanism. The correspondence between the OCR and the stress field suggests that the stress field of the district was related to the subduction mode of the Pacific plate. The influence of the arc-parallel component of the convergence rate is not detected in the district.

5.2. Tectonic factors for successful vein-type mineralization

During Periods 2 to 5, productive base-metal (Toyoha, Inakuraishi and Ohe) and precious-metal deposits (Chitose) formed during Period 4, and two other productive precious-metal deposits, Teine and Koryu, formed in late Period 3 and early Period 5, respectively (Fig. 2). In contrast, the base-metal deposits that formed during Period 2 are mostly non-economic. The period of productive mineralization from late Period 3 to early Period 5 corresponds to the highest OCR (90-103 mm/y; Fig. 2). This suggests that these deposits formed in a relatively contractional tectonic regime in the district since the Middle Miocene, due to an increase of arc-normal horizontal stress. The relatively intense regional stress may have formed subvolcanic intrusions without magmatic extrusion more frequently than the less intense regional stress of Period 2.

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References

Engebretson, D. C., Cox, A. and Gordon, R. G. (1985) Relative Motions between Oceanic and Continental Plates in the Pacific Basin. Geol. Soc. Amer., Spec. Pap., 206, 59p.

Hedenquist, J. W., Arribas, A. R. and Gonzalez-Urien, E. (2000) Exploration for epithermal gold deposits. Rev. Econ. Geol., 13, 245-277.

Hirose, W. Iwasaki, M. and Nakagawa, M. (2000) Transition of Neogene arc volcanism in Central-Western Hokkaido, viewed from K-Ar ages, style of volcanic activity, and bulk rock chemistry. Jour. Geol. Soc. Japan, 106, 136-150 (in Japanese with English abstr.).

Hokkaido Development Agency (1960) Report on the Mineral Exploration Survey in the Shakotan Peninsula during the Fiscal Year Showa 34. Hokkaido Development Agency, Tokyo, 64p. (in Japanese).

Jackson, E. D., Shaw, H. R. and Barger, K. E. (1975) Calculated geochronology and stress field orientations along the Hawaiian chain. Earth Planet. Sci. Lett., 26, 145-155.

John, D. A. (2001) Miocene and Early Pliocene epithermal gold-silver deposits in the northern Great Basin, western United States: Characteristics, distribution, and relationship to magmatism. Econ. Geol., 96, 1827-1853.