Mineralogical and Geochemical Studies on Wall-Rock Alteration Zoning in the Sanjin Deposit, the Hishikari Gold Mine, Japan

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論文題名　:　Mineralogical and Geochemical Studies on Wall-Rock Alteration Zoning in the Sanjin Deposit, the Hishikari Gold Mine, Japan（菱刈鉱山の山神鉱床母岩における熱水変質帯の鉱物学的および地球化学的研究）

区　　分　:　甲

論　文　内　容　の　要　旨

The Hishikari gold mine is a world-class epithermal, low-sulfidation vein-type deposit, which is located in southern Kyushu, Japan. The mine is composed of three deposits: Honko (Main), Sanjin and Yamada, and has produced more than 250 t of gold at an extraordinarily high average grade of more than 30 g/t of gold since 1985. In the next mature mining stage, it is important to understand the thermal structure of the hydrothermal system to identify upflow zones, possibly accompany gold mineralization. This study focuses on the Sanjin deposit to establish an alteration zoning which reflects higher temperatures, which could be helpful to construct a thermal model of the Hishikari hydrothermal system. This study reports the hydrothermal alteration mineralogy, geochemistry of hydrothermal minerals, fluid inclusion microthermometry, and oxygen and hydrogen isotopic systematics on the Sanjin deposit, and discusses the significance of the higher temperature alteration zoning in the Sanjin deposit to gold mineralization and exploration implications at Hishikari.

Chapter 1 introduces the history of the Hishikari mine, contributions of previous studies at Hishikari and significance of wall-rock alteration, and mentions the purpose of the study.

Chapter 2 overviews the geological background of and previous studies on Hishikari including tectonic setting of southern Kyushu, geological units around the mining area, structure of the gold deposits. Mineralogy and banding structure of the quartz vein system, hydrothermal alteration, age-dating of the gold mineralization and physicochemical characteristics of the mineralizing fluid are also summarized.

Chapter 3 describes the alteration mineralogy of the Sanjin deposit. Identification of alteration minerals by X-ray diffractometry and the mode of occurrences are reported. The identified alteration minerals include chlorite, illite, smectite, interstratified chlorite-smectite (C/S), interstratified illite-smectite (I/S), adularia, calcite, quartz, pyrite, hematite, epidote and prehnite. In addition, intensity of alteration (i.e. weak, moderate, strong, intense) was estimated on the basis of texture of the altered volcanic rocks. Based on the identified clay minerals, the alteration zones around the Sanjin deposit are classified as Zone III (interstratified clay mineral zone) and Zone IV (chlorite-illite zone). Since the expandability of most interstratified clay minerals is quite small, Zones IIIa (50-90 % chlorite or illite) and IIIb (90-95 % chlorite or illite) are defined as part of Zone III. Epidote and prehnite occur in the southeastern part of the Sanjin deposit: these minerals have not previously been reported at Hishikari.

Chapter 4 presents the geochemistry of alteration minerals. Chemical compositions of chlorite, epidote and prehnite were determined using an electron probe microanalyzer (EPMA) and a scanning electron microscope with energy dispersive X-ray spectroscopy (SEM-EDS). In each chlorite sample, the amount of Al in tetrahedral site (Al^{IV}) is variable compared with the Fe / (Fe + Mg) atomic ratio. The formation temperature of chlorite (T_{chl}) is tested by the empirical geothermometry on the basis of Al^{IV}. The results suggest that the proportion of chlorite layers in C/S reflects the T_{chl}, and that the assemblage of chlorite-epidote/prehnite can be an index of a high temperature alteration zone in the Sanjin deposit. On the other hand, the estimated T_{chl} also depends on the alteration intensity; T_{chl} of strongly altered samples tend to be higher. Thus, the alteration intensity should be considered for application of the chlorite geothermometry. The epidote and prehnite in the Sanjin deposit are Fe^{3+}-rich and coexist with hematite, suggesting high O_2 fugacity of the hydrothermal fluid, in which Fe is present as Fe^{3+}. Thus, one of the factors to form Fe^{3+}-rich epidote and prehnite in the Sanjin deposit might be oxidation caused by mixing of the ascending hydrothermal fluids with oxidized groundwaters.

Chapter 5 focuses on the fluid inclusion of vein quartz from the Sanjin deposit. Primary, pseudosecondary and secondary inclusions were observed mainly in drusy and transparent parts of quartz crystals. Homogenization temperature (T_h) and salinity of fluid inclusions from quartz veins range from 192 to 348 °C and 1.0 to 3.1 wt.% NaCl equiv., respectively. The coexistence of liquid-rich inclusions with vapor-rich and/or vapor-inclusions and tapering tails to higher temperatures in the T_h histograms suggest that the hydrothermal fluid may have been boiling when these inclusions were trapped. Based on the mode of occurrences of fluid inclusions and the pattern of T_h histogram, trapping temperatures are estimated to range from 195 to 230 °C. The modes of T_h and the average salinity of fluid inclusions exhibit only minor variations with elevation. Based on the estimation using 0-2 wt.% NaCl boiling point depth curve, the position of paleo-water table at the Sanjin deposit might have been higher than those at Honko and Yamada.

Chapter 6 reports the oxygen and hydrogen isotope systematics of clay minerals and vein quartz in the Sanijn deposit. Oxygen and hydrogen isotopes of clay minerals from wall-rocks and veins in Zones IIIa, IIIb and Zone IV are presented. In addition, oxygen isotopes of vein quartz and hydrogen isotopes of fluid inclusions of the vein quartz are also analyzed. The averages of the fluid $\delta^{18}O$ and $\delta^{2}H$ values in equilibrium with wall-rock clay minerals are estimated as -6.9 to +0.8 ‰ and -87 to -40 ‰, respectively. The fluid $\delta^{18}O$ and $\delta^{2}H$ values from two clay samples in the veins are +4.2 ‰ and +5.6 ‰, and -75 ‰ and -61 ‰, respectively. Waters with $\delta^{2}H$ values lower than -80 ‰ suggest a contribution of water isotopically equilibrated with sedimentary basement rocks during the mineralization at Hishikari. The calculated fluid $\delta^{18}O$ and $\delta^{2}H$ values from clay minerals and quartz cannot be explained by a simple water-rock interaction or a simple fluid mixing model, since variable isotopic exchange temperature and endmembers have to be considered. It is suggested that both water-rock interaction and mixing of fluids dynamically occurred between variable end members during the mineralization.

Chapter 7 delineates the hydrothermal alteration zoning and the upflow zone in the Sanjin deposit, based on the mineralogical and geochemical signatures presented in the previous chapters. The Sanjin deposit may represent the hottest part of the upflow zone of the hydrothermal system, which was responsible for gold mineralization at Hishikari. The approach of this study can help to understand the thermal anatomy of this extraordinary high-grade mineralized system and to identify hidden upflow zones containing gold mineralized veins, which may be important in mature mining districts.

Chapter 8 is the summary of this study.