Geochemical Studies and Genesis of the Au-Ag-Cu Mineralisation Systems of the Southwestern Nansatsu District, Southern Kyushu, Japan

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論 文 内 容 の 要 旨

High-sulfidation and low-sulfidation mineralisations are collectively recognised in the fore-arc/back-arc setting of a arc-type subduction settings. These types of deposits form in response to magmatism in the shallow crust and the associated volcanic and hydrothermal activity. A consequence of these phenomena, is the generation of precious metal and semi precious to base metal deposits of the Au-Ag-Cu systems. This study focuses on the Nansatsu district of Southern Kyushu, Japan. The area is recognised as hosting major high-sulfidation mineralisations, namely; Kasuga, Iwato, Akeshi deposits and surrounding silicified bodies (Kurigano and Misome). These deposits are composed of silicified bodies encapsulating Au mineralisation, present as native gold. Peripheral to these deposits lies the Kago low-sulfidation deposit, which is located approximately 2 km from the depositional centre and hosts electrum as it's principle ore mineral. In this study I focus of the precipitation mechanisms that can be recognised by the principle ore minerals of the separate types of mineralisation. A fundamental dichotomy that defines the high-sulfidation mineralisations at Kasuga and Akeshi is the presence of extensive supergene activity in the silicified rocks that has remobilized gold bearing phases and due to the high oxygen fugacity, enriched gold at the point of re-deposition. The remobilization of Au precludes that there was a mineral precursor in the system, responsible for the production of Au from the ore bearing fluid phase. The presence of pyrite is ubiquitous throughout the genesis of the high-sulfidation type mineralisation (excluding supergene). In this study the generation of pyrite was separated into differing stages by assessing their petrographic texture in the Kasuga and Akeshi high-sulfidation deposits and the Kurigano silicified bodies. Based on identification of early stage pyrite (Pyrite I) and ore stage pyrite (Pyrite II) in the Kasuga and Akeshi high-sulfidation deposits, electron probe micro-analysis (EPMA) and laser ablation inductively coupled mass spectrometry (LA-ICP-MS) was carried out to determine the composition of pyrite in each stage of generation. EPMA analysis was used to determine whether stoichiometric or non-stoichiometric substitutions in pyrite were present and the Fe composition in pyrite. LA-ICP-MS was carried out to determine the presence of mineral inclusions in pyrite. Geological survey of the two peripheral mineralisations, the Kago low-sulfidation deposit and the Kurigano silicified bodies was carried out to determine their association with the high-sulfidation mineralisations. The presence of adularia (potassium feldspar) was detected for the first time in banded quartz veins and hydrothermal breccia ores of the Kago low-sulfidation deposit. By carrying out $^{40}Ar/^{39}Ar$ on adularia, the timing of the Kago deposition was clearly identified to a high degree of accuracy. Based on this, the temporal relationships between the differing depositional styles could be clarified. Additionally the wider mineralisations in the Hokusatsu and southeast Nansatsu districts could be contextualised in the greater mineral province.

This thesis is separated into 7 chapters. Firstly, Chapter 1 introduces the area of research, focusing on the structural and volcanic history of Kyushu Island. The arrangement of subduction related volcanism and how it is related to a change in the geological history of Kyushu over time. The methodology of experimentation and the analytical

procedures is described.

Chapter 2 introduces the Kagusa high-sulfidation deposit. This study focusess on the precipitation of pyrite in the high-grade ores of the main ore body. Petrographic analysis shows Pyrite I and Pyrite II are recognised in high-grade ores in the absence of native gold bering ore. EPMA analysis reveals that major lattice substitutions within pyrite are not recognised, whilst LA-ICP-MS indicates that gold is present in Pyrite II with a grades as high as 42 ppm. This indicates that Au is heterogeneously distributed in pyrite and is present as mineral inclusions. Ag has a very low composition, with a maximum value of 0.2 ppm. This indicates that electrum is not a likely mineral hosting precious metals. Bulk rock ICP-MS measurements show that Au has a grade of 8.0 ppm. Whilst ICP-MS measurements show that separated pyrites (Pyrite I and Pyrite II) have a grade of 4.8 ppm. Te measurements have a composition of 2.8 ppm, which suggest that gold-telluride calaverite may be present as mineral inclusions in pyrite.

Chapter 3 discusses drilling undertaken by the Metal Mining Agency of Japan below the Kasuga high-sulfidation deposit. Core 11MANU-1, at a length of 1.2 km was extracted vertically through the silicified ore body and into the underlying basement rocks of the Shimanto Supergroup. Two vein groups were identified; Type 1a – quartz-calcite-pyrite, Type 1b – druse and stockwork quartz-pyrite. Fluid inclusion microthermometry reveals that temperatures above 600 m depth at below 250°C, whilst veins below 600 m reach temperatures as high as 300°C. Salinity of the veins varies greatly with depth, with stockwork quartz veins exhibiting high salinities of 14.5 equiv. NaCl wt%. Stable isotope measurements of iliite δD and $\delta^{18}O$ suggest that shallow veins have been repeatedly overprinted by increasingly meteoric fluids, whilst the basement veins have undergone exchange with deeply located Shimanto Supergroup sediments attaining a δD composition similar to that of the deep Shimanto Supergroup.

Chapter 4 introduces the Akeshi high-sulfidation deposit which is situated distal from the main high-sulfidation and low-sulfidation deposits of the southwest Nansatsu district. The geology and mineralogy of this deposit will be discussed, followed by analysis of pyrite from the separate ore bodies. Ore bodies No. 03 and the transitional zone of the No. 01 and No. 04 ore bodies were examined in this study. $\delta^{34}S$ measurement of pyrite and native sulfur suggest that sulfur may have the product of later exchange with basement veins and magmatic fluids composed of H_2S and H_2SO_4. Both areas hosted high gold compositions, in the absence of native gold. Pyrite of ore body No. 03 is represented by Pyrite I and Pyrite II. Pyrite II has a maximum value of 10 ppm in, whilst Pyrite I is uniform at approximately 0.4 ppm. Ag content correlates well with Au exhibiting highs of 2.3 ppm. Suggesting, that high Au electrum may be present as a mineral inclusion in pyrite.

Chapter 5 discusses the Kurigano silicified bodies. The geology and alteration minerals of the silicified and surrounding host rocks will be introduced. Geochemical analysis of the silicified rocks will follow, based on EPMA and LA-ICP-MS of the hosted pyrite. Petrographically, pyrite is only single generation and is very high in Ag (9.9 ppm). Whilst Au is very low (0.3 ppm). Te measurement of goethite and pyrite suggests that Ag-Au-tellurides are present.

Chapter 6 introduces the Kago low-sulfidation deposit, with a discussion on the local geological setting, structural framework. The depositional condition, starting with the alteration and mineral assemblages are assessed. $^{40}Ar/^{39}Ar$ age dating of adularia suggests that the mineralisation period was from 3.98 Ma to 4.23 Ma. Which, indicates that Kago deposit was co-eval with the Kasuga deposit. EPMA of electrum indicates that high Au (52 to 56 at.%) was present as the principle ore mineral.

Chapter 7 is a discussion based on the previous 6 Chapters, geochemical patterns of the silicified rocks of Kasuga, Akeshi and Kurigano and contextualise the Kago low-sulfidation deposit based on its association with the surrounding deposits. Evaluating the onset of mineralisation, which likely took place along a NE-SW trend on which the Kasuga, Kurigano and Kago deposits are aligned.