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論文内容の要旨

The North China Craton is one of important regions for precious metal resources in China. Eastern Hebei Province in the craton has a long history regarding supply of gold for royal dynasties for thousands of years. The exploration of gold resource has been focused on the granite porphyry for a long time in the North China Craton. The Xiayingfang mining area is located in Yanshan district of the Craton. It is located in the northeast part of Beijing with about 210 km away from the Beijing. There are the Xiajinbao and Dongliang gold deposits in the mining area. In the Xiajinbao deposit, granite porphyry (Ilmenite-series) and diorite are present. The orebody predominantly is hosted in the granite porphyry. On the other hand, acidic tuff, diorite and porphyry dike are present in the Dongliang deposit which is about 1km apart from the Xiajinbao deposit. The orebody predominantly is hosted in the diorite. The diorite in the Dongliang deposit and the diorite dike in the Xiajinbao deposit shows similar characteristics. Previous researches suggested that the granite porphyry in the Xiajinbao deposit is the source of the gold mineralization based on the similar ages between the granite porphyry and mineralization. However, the age of the granite porphyry, diorite dike in the Xiajinbao deposit and Dongliang deposit are determined using Zircon U-Pb age dating method by LA-ICP-MS analysis. The morphology of the

zircon suggests that the zircon in those rocks is mainly magmatic zircon with typical oscillatory zoning. The concordant age of the zircon of the granite porphyry and diorite in Xiajinbao deposit are $163\pm 0.9\text{Ma}$ and $163\pm 1.7\text{Ma}$, respectively. The concordant age of tuff; diorite and porphyry dike in the Dongliang deposit are $162.5\pm 1.7\text{Ma}$, $164.5\pm 3.1\text{Ma}$ and $163.4\pm 0.7\text{Ma}$, respectively. This result suggests the igneous rocks in the Xiajinbao deposit and Dongliang deposit were emplaced almost same time. These age values suggest that the diorite is a candidate of igneous activity for the gold mineralization of the Xiajinbao deposit.

The orebodies of the Xiajinbao deposit that is composed of aggregates of large number of veins and veinlets having width from 5cm to 1mm occur mainly in the granite porphyry within area of 800m by 300m. Base on the cross-cutting relationship, the veins are classified into pyrite-quartz veins, pyrite-chalcopyrite quartz veins and sphalerite-galena quartz veins from earlier to later. Pyrite quartz veins are composed of large amounts of quartz and pyrite with trace amounts of chalcopyrite and electrum. Pyrite-chalcopyrite quartz veins are composed of large amounts of quartz, pyrite and chalcopyrite. Sphalerite-galena quartz veins are composed of large amounts of quartz, sphalerite and galena, small amounts of pyrite and chalcopyrite, and trace amounts of native bismuth, tetrahedrite and electrum. Quantity of electrum in sphalerite-galena quartz veins is larger than that of electrum in the pyrite quartz vein and pyrite-chalcopyrite quartz veins.

The granite porphyry consists of quartz, orthoclase, plagioclase and biotite as phenocrysts with trace amounts of ilmenite, zircon, rutile and apatite without magnetite. On the other hand, the diorite consists of plagioclase, amphibole and biotite with small amounts of apatite, magnetite, hematite, ilmenite and pyrite. The magnetic susceptibility of granite porphyry is generally lower than 0.1×10^{-3} SI unit while the diorite has much higher magnetic susceptibility from 30 to 60×10^{-3} SI unit in the Xiajinbao deposit. The igneous activity of Xiajinbao mining area is characterized by bimodal igneous activity. The distribution of diorite dike accords with the distribution of area having high Au content. Au rich part (approx. 220ppm) present near the diorite dike in the underground workings of the Xiajinbao deposit. These geological features indicate that mineralization has intimate relation with those diorite dikes in space.

The SiO_2 and TiO_2 contents of granite porphyry are around 70wt% and 0.2wt%, respectively. The Al_2O_3 contents of granite porphyry range from 13.9 to 14.3wt%. The $\text{T-Fe}_2\text{O}_3$ contents of granite porphyry range from 1.9 to 2.5wt%. The Na_2O and K_2O contents of granite porphyry range from 2.3 to 2.9wt% and 4.6 to 6.1wt%, respectively. The aluminum saturation index of granite porphyry is range from 1.12 to 1.28. These

features suggest that the granite porphyry belongs to the ilmenite-series granitic rocks. The granite porphyry was formed by the reduced magma. On the other hand, the SiO₂ and Al₂O₃ contents of diorite dikes are 49.1 to 51.1wt% and 13.7 to 16.3wt%, respectively. The TiO₂ content of diorite dikes ranges from 1.0 to 3.1wt%. The T-Fe₂O₃ content of diorite dikes is 7.3 to 11.5wt%. The Na₂O and K₂O contents of diorite dikes are 3.3 to 4.1wt% and 2.4 to 2.9wt%, respectively. The Zr/TiO₂ ratios of granite porphyry and quartz porphyry dikes are both around 770 while the Zr/TiO₂ ratios of diorite dikes in the underground and outcrop are approximately 150 and 60, respectively. These ratios indicate that the characteristics of magma of granite porphyry and quartz porphyry dikes are similar and are different from the characteristics of magma of diorite dikes.

The sulfur fugacity of sphalerite-galena quartz vein is estimated to be around 10⁻¹² atm. The formation environment of the sphalerite-galena quartz vein of the Xiajinbao deposit is similar to the environment of zoned base metal veins associated with oxidized magma. The δ³⁴S values of sulfide minerals of the Xiajinbao deposit range from -3 to +8 ‰ with the mode of +4 ‰. The distribution of sulfur isotopic ratios of the sulfide minerals of the Xiajinbao deposit are similar to the distribution of δ³⁴S of ores associated with oxidized magmas. The formation environment of gold-bearing sphalerite-galena-quartz veins of the Xiajinbao deposit is different from formation environment of hydrothermal activities associated with reduced granitic magma. The oxygen and hydrogen isotopic ratios of hydrothermal solution in equilibrium with quartz from the sphalerite-galena quartz vein range from +3.3 to +5.5 ‰ and -38 to -41‰, respectively. The oxygen and hydrogen isotopic ratios suggest hydrothermal solution of the pyrite quartz veins, pyrite-chalcopyrite quartz veins and sphalerite-galena quartz veins was magmatic origin. Based on the geological, geochemical and isotopic data, Au-mineralization of the Xiajinbao deposit is thought to have intimate relation with oxidized magma such as diorite.

論文審査結果の要旨

中国北東部には多くの金鉱床が存在する。これまで中国では金鉱化作用と火成活動の関連性については、マグマの酸化状態よりもマグマ発生の構造的環境や発生プロセスが重要と考えられ、議論されてきた。また、多くの金鉱床が帯磁率の低いチタン鉄鉱系の火成岩類に胚胎されることやチタン鉄鉱系の火成岩類と金鉱床形成の年代が近いことから、金鉱化作用に関連する火成活動はチタン鉄鉱系のマグマであると考えられてきた。しかしながら、金鉱床の分布やチタン鉄鉱系火成岩類の分布と調和的に小規模ではあるが帯磁率が高い磁鉄鉱系の火成岩類も分布している。これまでこれらの小規模な磁鉄鉱系火成岩類と金

鉍化作用の関係は検討されたことがほとんどなく、金鉍化作用をもたらした火成活動は不明で、未解決な問題であった。

本研究では、野外地質調査に基づく下金宝（Xiajinbao）鉍床と東梁（Dongliang）鉍床とこれらの鉍床周辺の地質、これらの岩石の産状・構造・組織、鉍物組合せ、ジルコンのU-Pb年代値、全岩化学組成や安定同位体比等の地球化学的データに基づき、火成活動の酸化度と金鉍化作用の関連性について検討を行った。その結果、以下のような結論が得られた。

1) 下金宝鉍床地域の火成活動の変遷

野外での岩石と鉍石の産状、岩石の構造と組織に基づき、下金宝鉍床地域のジュラ紀の火成活動は、花崗斑岩、閃緑岩、石英斑岩岩脈の順に進んだことが示された。閃緑岩が金鉍脈により切られることから、金鉍化作用は閃緑岩形成後に起こったことが示された。

2) 下金宝鉍床地域の火成活動の放射年代

金鉍化作用がこれらの岩石のジルコンのU-Pb年代値から、いずれの岩石も160Ma頃の時期に形成されたことが明らかにされ、閃緑岩も金鉍化作用をもたらした火成岩の候補の一つであることが示された。また、これらの年代が、本地域の鉍化作用と同じ年代であることを確認された。

3) 下金宝鉍床地域の火成岩類の特徴

本鉍床地域の花崗斑岩、閃緑岩、石英斑岩岩脈は、帯磁率の高い閃緑岩と帯磁率の低い花崗斑岩と石英斑岩岩脈に区分され、前者がI-タイプ、後者がS-typeに対応することが示された。そして、スカルン鉍床や斑岩銅鉍床の火成岩類と比較を行い、本地域の閃緑岩が金鉍化作用に関連する火成岩類の特徴を持っていることが示された。

3) 金鉍化作用鉍化流体の特徴

鉍脈構成鉍物組合せと鉍物化学組成に基づき、鉍床の鉍床生成温度や硫黄フィガシティー等の生成環境を推定し、下金宝鉍床の生成環境が酸化的なマグマから形成される銅鉍化作用、亜鉛銅鉍作用の生成環境と類似し、下金宝鉍床の金鉍化作用が酸化的なマグマに関連して形成されたことが指摘された。また、下金宝鉍床の鉍石の硫黄同位体比を、酸化的な環境と還元的な環境で形成された花崗岩類と鉍石の硫黄同位体比とそれぞれ比較し、下金宝鉍床の金鉍化作用に伴う硫黄が酸化的なマグマ由来である可能性が示された。また、下金宝鉍床の含金石英脈の石英の酸素同位体比、同石英脈近傍の母岩中の粘土鉍物（イライト）の水素同位体比、同石英脈近傍の母岩の全岩の酸素同位体比のデータから、鉍化流体がマグマ水起源であることが示され、下金宝鉍床の金鉍化作用がマグマ由来の流体により形成されたことが明らかにされた。

本研究では、下金宝鉍床の岩石および鉍石の産状、鉍物組合せ、U-Pb年代値、全岩化学組成、安定同位体比等の地球化学的データに基づき、同鉍床における火成活動と鉍化作用

の関連性を明らかにし、金鉱化作用が酸化的なマグマ活動により形成されたことを推定した。得られた成果は、これまでの中国北東部の金鉱化作用に関して、酸化的な火成岩類と金鉱化作用の密接な関連性を提案するものであり、これまで還元的な火成岩類と金鉱化作用の関連性をもとに金鉱床探査を行ってきた中国北東部の今後の資源探査に大きく貢献するものである。

従って、本論文は博士（工学）の学位論文として十分価値のあるものと判断した。