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Spatial modeling of metal contents in a kuroko-type deposit with application to estimating ore-solutions paths

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Demand for metal resources has largely increased because of constructing sustainable society and innovative technologies. This trend will continue in the future, which requires accurate characterization of ore grade in a metal deposit and deep understanding of ore generation mechanism for exploring new deposits. Based on that background, this study is aimed to (i) develop a method for highly precise spatial modeling of metal contents in a metal deposit and (ii) clarify a physical law that formed a deposit. Matsumine mine, the largest kuroko deposit in the Hokuroku district, Akita Pref., northern Japan, is selected as a case study site. Kuroko is a Japanese term that was used originally in the mining industry for massive, compact black-ore. It mainly contains sphalerite, galena, and pyrite. Kuroko deposits are massive sulfide deposits associated with felsic to intermediate submarine volcanic activity (e.g. Yamada and Yoshida, 2013).

Geological columns at 77 sites and the metal contents of Cu, Zn, and Pb (chief metals of kuroko) at 1457 measurement points were used for the spatial analyses over a region of 500 m$\times$1000 m in the horizontal direction and 300 m along the vertical direction from 0 to -300 m a.s.l. 3D geological model was produced by classifying the columns into ten main rock types and calculating their appearance probabilities at each grid point using 3D optimization principle method (Koike et al., 1998). Geostatistics, known as the best linear nonbiased estimator, was adopted for 3D modeling of metal contents. The result of variography clarified that, common to the three metals, the spatial correlation structures of the metal contents was well approximated by the spherical model. Correlation length (range) along the horizontal direction is longer by a factor of 2 to 3 than that of the vertical direction, which implies the horizontal extents of ore solutions. Ordinary kriging (OK) was selected as a spatial modeling method, because its estimation accuracy was higher than a multivariate kriging.

Through an integration of 3D geological and metal-content models, high content zones were revealed to be overlapped with the patchy kuroko zones and extend horizontally as connecting the zones. Secondary sedimentation of kuroko ores by small-scale volcanic activity and subsequent submarine landslide is one possible cause of this extent. Assuming that the transport of ore solutions and the deposition of metals are approximated by an advective-diffusion spread phenomenon, the advective velocities and the diffusion coefficients were calculated at each grid point by an combination of the metal content model and an advection-diffusion equation. One noteworthy feature detected is that the advective velocities are mainly directed upward and the grid points with this direction are continued in the distributions of silicious ore and rhyolite. This may imply the main paths of ore solutions. The biased signs of vertical diffusion coefficients, 2 to 1 is considered to originate from the general trend of metal contents, which is higher in the shallow parts than the deep parts. Our next step is to improve the metal content estimation by combining a physical law of the deposit formation, which may be expressed by the above advection-diffusion equation, and kriging.

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