別紙様式８

研　究　主　論　文　抄　録

論文題目

Geostatistical modeling and clarifying control factors of Ni grade distribution in a laterite nickel deposit

（ラテライト・ニッケル鉱床中のニッケル品位分布の地球統計学的モデリングと支配因子の解明）

熊本大学大学院自然科学研究科　　　複合新領域科学専攻　生命環境科学講座

（　主任指導　**嶋田　純**　教授　）

論文提出者 Name　　アスラン　イリアス

（by Asran Ilyas）

主論文要旨

Summary（Keep the summary within 2,000 words）

Metals are commonly found in earth's crust, but many of the most important metal-bearing minerals that disseminated in host rocks cannot be extracted until they have been concentrated by some natural processes. The natural processes include tectonic process, volcanism, weathering, erosion, and deposition. One of the natural processes, weathering process, occurs when the rocks and minerals contact directly with the atmosphere, water, and organic matters. The weathering process involves chemical, mechanical, and biological processes. Mechanical processes and chemical reactions occurring during weathering may accomplish the concentration of the metals. These processes are also occurs on the weathering and deposition of nickel (Ni), one of the most important metal-bearing mineral in modern metallurgy. The deposit of nickel that formed as a result of weathering process of ultramafic rocks in humid climatic conditions and mostly found in tropical latitudes is called laterite nickel deposit.

The need of Ni metal has been increased more and more over the last decades, particularly in the field of transportation and telecommunication industries. Accordingly, Ni has been important metal over the world, which requires essentially exploration and exploitation of new deposits. Laterite nickel deposit currently account for around 70% of Ni contained in land-based deposits but only 40% account for world nickel production. It is anticipated that increasing demand for Ni will be met largely by supply from lateritic deposit compared to sulphide deposit. Although the exploration and exploitation of Ni have been performed over long time in several parts of the world, but the economic accumulations are still in challenge. To increase the production and the exploration accuracy of Ni, especially in a laterite deposit, this study has been performed, which was focused on the modeling distribution of Ni grade.

The main purpose of this study is to develop a method for precise spatial modeling of Ni grade in a laterite deposit based on factors controlling the formation of this deposit using geostatistical method in order to improve the exploration accuracy and to investigate the genesis of Ni grade distribution based on the geostatistical modeling results.

Nickel (Ni) is a lustrous, silvery-white metal which is hard, ductile, malleable, and can take a high polish. It has fairly low thermal and electrical conductivities and can be magnetized. Properties that are important to industrial applications include resistance to oxidation and to corrosion by alkalis, strength at high temperatures, and the ability to form alloys with many other metals.

Ni deposit is produced naturally from two principal ore types; magmatic sulfide deposit and laterite deposit. Magmatic sulfide deposit formed by magmatic segregation process in ultramafic rocks (volcanic and plutonic settings) while laterite deposit formed by the intense tropical weathering process of ultramafic rocks containing ferro-magnesian minerals (olivine, pyroxene, and amphibole) rich in trace amounts of Ni, generally in humid tropical to subtropical climates area.

In general, a typical of laterite Ni deposit profile has three weathering layers: limonite zone in the upper part, saprolite zone in the middle part, and bedrock zone in the lower part, respectively. The base of the profile, the protolith, is the parent ultramafic rock, most commonly harzburgite or other types of peridotite or dunite. The initial stages of weathering process produce saprolite zone in the middle part, a zone characterized by spheroidal weathering initiated along joints and fractures, resulting in blocks of fresh parent rock surrounded by altered materials. The overlying horizon, the oxide-rich part of the profile is referred as limonite and the volume of the upper collapsed portion may be as little as ~15% of the original parent rock.

In this study, it was applied geostatistical method to infer the distribution of Ni grade in the laterite deposit. The term geostatistics is now widely applied to a special branch of applied statistics. A key concept of geostatistics is that of the regionalized variable, which has properties intermediate between a truly random variable and one completely deterministic. Typical regionalized variables are functions describing natural phenomena that have geographic distributions. Unlike random variables, regionalized variables have continuity from point to point, but the change in the variable are so complex that they cannot be described by any tractable deterministic function. In this study, the chemical concentration of Ni and the other elements and compounds are defined as regionalized variable. The thickness of laterization zone is also defined as regionalized variable. The geostatistical analysis of these variables was calculated to find out their modeling distribution.

The study area is located in the central part of Sulawesi Island, Indonesia. This area, called Sorowako area, shows extensive distribution of laterite nickel deposit and geologically suitable as a research study area. The laterite nickel deposit in this area has been mining since 1968 by an international nickel mining company, PT. INCO Indonesia. One of the mining areas of the company was selected as a suitable test site for Ni grade modeling.

The geology of the Sorowako area and its surroundings can be divided mainly into three rock units: alluvial and sedimentary lacustrine rocks of Quaternary, Tertiary ultramafic rocks such as Harzburgite, and Cretaceous sedimentary rocks. Laterite Ni deposits in this area were generated in the Tertiary ultramafic rocks, which are a part of the serpentinized peridotite zone.

Detail of study area contains 294 drillhole sites which were drilled in a lattice pattern along N-S and E-W with the spacing between adjacent drillholes is 50 m. At each drillhole, the data of metals and compounds (Ni, Fe, SiO_2, and MgO) were recorded at 1-m depth interval until the bedrocks. These data were used and analyzed to create the modeling distribution of Ni grade.

Main factors controlling the formation of this deposit are climate, topographic condition, tectonic setting, lithofacies, parent rock type, geologic structure, groundwater, organic matter content, and rates of weathering. In this study, the main factors used for Ni grade modeling are topographic condition and rates of weathering expressed by the weathering layers in this deposit: limonite, saprolite, and bedrock zones. These factors then were investigated their correlations with Ni grade distribution and the other element and compounds (Fe, SiO_2, and MgO). Topographic condition expressed in slope gradient classification may be the most predominant factor because it can affect other factors such as the groundwater system and weathering processes. This study also investigated the correlation between Ni and SiO_2 grade that should be feed into the furnace of plant mills of metallurgical processes of Ni metal related to the maintenance of refractory walls.

From the results of this study, it was found that the slope gradient has a remarkable correlation with the thickness of the limonite zone, but there was no correlation between the thicknesses of the zones. One original thing was found from this study that is the maximum Ni grade in the saprolite zone has a general relationship with the thickness of the zone. The thicker of the saprolite zone, the higher of the maximum Ni grade contain on it. Co-kriging was adopted to incorporate this correlation into estimating the maximum Ni grade in the saprolite zone. As a result, the maximum Ni grade in the saprolite zone tends to be high mainly in areas of slight slope. The Ni accumulation at this topographic feature probably originates from deep weathering by groundwater infiltrating through well-developed rock fractures. Therefore, how to trace the paleo-groundwater flow directions that carried Ni grade was also performed in this study. Geostatistical method was used to find it. From the results of this study, it was found that the paleo-groundwater flow directions can be traced through the modeling of the limonite and saprolite zones thicknesses, the modeling distribution of the maximum Ni grade in the saprolite zone, and the modeling distribution of the presence of goethite found in the saprolite zone because goethite formed by the reaction of iron oxide minerals with the hydroxyl ions of groundwater.

From the analysis results, it can be summarized that the modeling distribution of the maximum Ni grade in the saprolite zone, the modeling distribution of the averages Ni and SiO_2 grades in the limonite, saprolite, and bedrock zones, and the modeling of the paleo-groundwater flow direction that carried Ni grade can be used as fundamental basis to determine the direction of Ni grade for the mine plan and design.

Results of this study also demonstrated the usefulness of geostatistics for the prediction of Ni grade distribution in a laterite nickel deposit as can be seen from the results of this study by using the geostatistical models and tools of geostatistics to create the modeling distribution of Ni grade.