Preface

Introduction to the Special Issue on the ISME-XV: Toward Sustainable Society with Natural Resources—Development of Resource Exploration Technology in the Past Thirty Years and for the Future

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As the world's demand for mineral resources is in the upward trend along with the population growth or advancement of urbanization and industrialization, the mining industry needs to discover more resources in the earth's crust in order to produce more metals and/or raw materials. On the other hand, the discovery rate of ore deposits has kept declining over the past thirty years under more difficult conditions and circumstances against mineral resource exploration, e.g., thick overburden, isolated district, ore grade decline, social and environmental issues, and so on. For that reason, technological innovation in mineral resource exploration is expected more than before to secure sustainability of nonrenewable resources.

The International Symposium on Mineral Exploration (ISME) is an international activity of Division of Exploration Technology (DETEC) of Mining and Materials Processing Institute of Japan (MMIJ), aiming to bring together researchers and professionals actively working on diverse fields in order to foster the exchanges of ideas related to the

resource exploration. ISME symposia have been held every two years since 1990 in Japan and subsequently in various parts of the world, in conjunction with annual conferences of International Association for Mathematical Geosciences (IAMG) and/or International Geological Congress (IGC) when ISME symposia could be held at the same time as those conferences. Against the adverse circumstances for mineral resource exploration mentioned above, the academic exchange such as ISME activity must assume a greater responsibility in development of resource exploration technology.

Heretofore, three special issues of Natural Resources Research (NRR), including former Nonrenewable Resources, featuring ISME symposia have been published as introduced by Singer and Kouda (1993, 2003) and Koike (2005). This fourth special issue of NRR featuring ISME symposia is a collection of one review paper and ten research papers. All these papers were selected from the presentations at the latest 15th ISME Symposium (ISME-XV) entitled “Toward Sustainable Society with Natural Resources—Development of Resource Exploration Technology in the Past Thirty Years and for the Future”. This was held at Kyoto University, Japan, during 26–28 November 2018, in commemoration of the 30th anniversary of DETEC.

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With this special issue, it is our great pleasure to celebrate the 30th anniversary of NRR. All papers in this special issue fit perfectly in NRR's original aim/scope (McCammon, 1992) to publish "*papers that report on the range of nonrenewable resources, including metals, nonmetals, coal, oil, gas, geothermal energy, and uranium, and that, in particular, emphasize multidisciplinary studies focused on land-use policy, domestic and international supply issues, and mineral and energy exploration planning*". In addition, all these papers contribute perfectly to NRR's past modified aim/scope (Merriam, 1999) to be "*an international journal devoted to promoting quantitative approaches to mineral resource exploration, assessment, extraction, and utilization*". Moreover, all papers in this special issue align perfectly with NRR's current aims/scope:

Natural Resources Research publishes peer-reviewed, quantitative geoscientific studies on the search for and development of natural resources, including associated environmental, economical, and risk-related aspects. Reports regarding petroleum or energy-mineral resources are of interest, as are investigations on the exploitation of any metallic or non-metallic mineral resource. Typical articles use geoscientific data or analyses to assess, test, or compare resource-related activities. NRR reports cover a wide variety of resources, including coal, water, vegetation, and heavy oil. Case studies are particularly welcome.

The first paper, by Okada (2021), reviews the history of advances in mineral exploration technology over the past thirty years—the 1990s, the 2000s and the 2010s. The review is divided into the following categories: (a) theoretical advances in economic geology (i.e., the target model itself); (b) breakthroughs in the methods or technologies for discovering and defining the ore deposits; and (c) advances in associated and general fields (e.g., computer science). Concerning the current technological trend, in consideration of the findings of the historical review presented in this paper, Okada (2021) emphasizes the importance of conceptual geological prediction of mineralization in greenfield exploration. This emphasis is based on sophisticated analysis and interpretation of large datasets, and recent advances in data science, especially sparse modeling providing powerful tools as solution methods using big data for a variety of geoscientific problems.

In the second paper, Shoji (2021) presents the grade-cumulative tonnage relation of Au deposits approximated by the combination of three exponential functions, which forms a gradually decreasing curve being convex downward in a semilog plot (hereinafter referred to as "the typical pattern"). The typical pattern is also found in the ore value—cumulative tonnage relation of metallic deposits in both cases including and excluding platinum-group elements (PGEs), where ore value is the sum of products of metal grades and metal prices in each deposit. The enrichment ratio—cumulative tonnage relation shows the typical pattern in the case excluding PGE, where enrichment ratio is the sum of the metal grades normalized by the corresponding crustal abundances in each deposit. In the case including PGE, however, the relation does not show the typical pattern, but has a hump (convex upwards), because the enrichment ratios of PGE deposits are extremely high. Shoji suggested that it is necessary to clarify why many cases show the typical pattern, yet there is an exception showing an atypical pattern with a hump.

The third paper, by de Sá et al. (2021), discusses identification and characterization of mineralized zones in seafloor hydrothermal areas using limited metal content data from sparse drilling sites. They applied principal component analysis to decrease the dimensionality of the metal content data. High metal content zones were delineated by application of three geostatistical methods to principal component scores: (1) spatial estimation using ordinary kriging; (2) turning bands simulation (TBSIM); and (3) sequential Gaussian simulation. The case study targeted at an active seafloor vent area in the Okinawa Trough, southwest Japan, deploying those three methods. The results show two high metal content zones: one around a sulfide mound, and the other associated with lateral flow of hydrothermal fluids from the bottom of the mound. de Sá et al. (2021) concluded that TBSIM is the most effective for scarce data conditions.

In the fourth paper, Yoneda et al. (2021) compare tri-smectite (S)–corrensite (Co)–chlorite (C) series of minerals in two epithermal Au–Ag deposits, namely Todoroki and Hishikari, both located in Japan. The S–Co–C series of minerals from the two deposits show a discontinuous stepwise sequence of different mixed-layering of chlorite and smectite layers, and there are differences in the mode of occurrence of the two deposits. The Al/Si ratios and Fe/(Fe + Mg) ratios of the S–Co–C series of min-

erals vary closely with mixed-layering and mode of occurrence. The S-Co-C series of minerals, as products of direct precipitation from ascending hydrothermal solutions, may reflect fluid chemistry that originated in water-rock interaction at deeper strata.

The fifth paper, by Scibek and Annesley (2021), presents geological and hydrogeological observations combined with results of permeability tests at spot-on unconfined drillcore, extracted along transects through the Gryphon U deposit and fault zone, located in eastern Athabasca Basin, Canada. They introduced a method to test drillcore matrix permeability, using a pressure-decay N_2 gas probe with adequate seal to the rock surface, a low detection limit, and observations of gas discharge bubble pattern for mapping macro-porosity geometry. The paper discussed the mechanism of present- and paleo-fluid flow processes and deposit formation in the study area.

In the sixth paper, Ishikawa et al. (2021) applied multiple geophysical techniques for regional geothermal exploration in the Teshikaga area, Japan, based on airborne gravity gradiometry (AGG) data from HeliFalcon® and airborne electromagnetic and magnetic data from Helitem®. They demonstrated that 3D inversion of AGG data enables detailed interpretation of deep subsurface structures related to geothermal resources (e.g., an intrusion and a caldera), and that the distribution of resistivity and magnetism in the relatively shallow subsurface revealed conductive anomaly overlapping low-magnetic anomaly, which suggest hydrothermal alteration related to geothermal resources.

The seventh paper, by Pratama et al. (2021), integrates numerical modeling of reservoir and power plant thermodynamics to assess a couple options of power plant technologies, namely (1) dry-steam cycle unit (DSCU) and (2) integrated geothermal combined cycle unit (IGCCU), for the development strategy for the Patuha geothermal field, West Java, Indonesia. Through numerical simulations with power generation scenario, it was demonstrated that IGCCU is less sustainable when hot fluid is produced only from the steam zone and that higher injection rates into the brine zone from IGCCU power plant can generate higher electrical power than DSCU.

In the eighth paper, Heriawan (2021) discusses detection of near-surface permeable zones at the Wayang Windu geothermal field in West Java,

Indonesia, based on spatial correlation between ^{222}Rn gas concentration sampled from 17 shallow drillholes and lineament density derived from a digital terrain model surveyed by using an unmanned aerial vehicle. Permeable zones, detected through collocated cokriging and a fuzzy logic approach, mainly overlap with geothermal manifestations and regional faults. The permeable indices generally correspond with ^{222}Rn concentrations from new drillholes. These demonstrate the effectiveness of the proposed method.

The ninth paper, by Asaue et al. (2021), presents a development of a variable frequency-based electric sounding system (VFES), to increase the accuracy of detecting aquifers by measuring apparent resistivity in the frequency range 1–100 Hz at intervals of 1 Hz. The paper demonstrates the effectiveness of VFES in soil–water sample and aquifer-model experiments and in three field experiments with different geologic settings by using the coefficient of variation (C_v) of the resistivity in the frequency range 21–40 Hz. It was presented that the C_v specified the locations of the groundwater table, aquifer and the doline in the limestone aquifer field. It was suggested that electrokinetically induced vibration of porous material is the most plausible mechanism for the large C_v in the 21–40 Hz frequency range.

In the tenth paper, Miyamoto and Niihara (2021) discuss simplified simulated materials of asteroid Ryugu, based on terrestrial observations of the asteroid, for Hayabusa2 spacecraft operations and scientific evaluations. By adjusting the abundance of the carbon suspension controlled by the reflectance in the wavelength region of the visible to near infrared, they achieved characteristics of the simplified Ryugu simulant developed, simulating relatively closely the materials of carbonaceous meteorites in terms of density and spectral characteristics.

The last paper, by Martín-Fernández et al. (2021), discusses two procedures for back-transformation of estimates, obtained by modeling of compositional data on coordinates with respect to a log-ratio basis, to the original data units. The two procedures were (1) a simple approach consisting of adding a residual part to the composition and (2) an approach based on the use of an auxiliary variable.

The abovementioned 11 papers in this special issue are classified into three groups: (1) exploration technologies, data analysis, spatial modeling, mineralogy, and rock physics of metal deposits (papers 1

to 5); geothermal and water resources exploration and production (paper 6 to 9); and the other resource-related topics (paper 10 and 11).

We hope that this special issue of NRR contributes to readers in various aspects of their researches and to the development of natural resource science and technology. We also hope that readers take part in the next ISME to exchange ideas in a wide range of topics on natural resources.

Kazuya Okada (Guest Editor), Katsuaki Koike (Guest Editor), and Emmanuel John M. Carranza (Editor-in-Chief).

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