APPLICATION OF SIR-C DATA FOR EXPLORATION OF MINERALIZED ZONES (HWANGGANG-RI, KOREA)

Wei W. Jiang[1,2], S.W. Choi[4], Jeong-Ho Park[3], Cahng-Won Lee[3], Duk-Jin Kim[3], Byung-Han So[3], C. S. So[4] and Wooil M. Moon[2,3]

1. Institute of Geophysics, Academia Sinica, Beijing, China, 2. Dept. of Geological Sciences, University of Manitoba, Winnipeg, Canada R3T 2N2, 3. Dept. of Earth System Science, Seoul National University, Seoul 151-742, Korea, 4. CMR, Korea University, Seoul, Korea

Abstract

This paper investigated and evaluated the NASA's Shuttle Imaging Radar-C (SIR-C) multiple frequency SAR data for differential backscattering effects of microwave from the surface geological materials overlying the skarn type mineralization. Although an integrated approach in mineral exploration is more cost effective and is well in use, there are still many technical and scientific issues to be further investigated and researched. In this study we have reprocessed several sets of previously surveyed exploration data and experimented with fuzzy logic digital fusion of the preprocessed data with respect to chosen exploration targets. Among the numerous fuzzy logic operators, which are currently available for a data driven integrated exploration strategy, we used varying combinations of fuzzy MIN, fuzzy MAX, and fuzzy SUM operators along with Gamma operator for fusion of exploration data, including the contact metamorphic zone information. The final exploration target tested was a skarn type W-Mo-F mineralization in the study area.

The fuzzy logic derived mineral potential anomaly almost exactly matched the differential backscattering anomalies on the C-band and L-band SIR_C data when overlaid on each other. Although this high degree of correlation between these two data sets is remarkable, the differential backscattering anomaly over the skarn type W-Mo-F mineralization in the study area requires further investigation.

Key words: SIR-C, SAR, Mineral exploration, Fuzzy logic application, Hwanggangri

1. Introduction

The basic concept of mineral exploration remains unchanged but the exploration methodss and subsequent processing of the data and interpretation have been changing rapidly with advancing exploration and computer processing technologyies. Even in a modest exploration project, a wide variety of spatial data with different characteristics in terms of geological, geophysical, geometric, radiometric, and spectral resolution is utilized now. Although the information content of these spatial data sets often partially overlap, the complementary aspects of each anomaly represents a valuable opportunity for identifying physical characteristics of a complex mineralized zone. In this study we have reprocessed the previously surveyed data and attempted to digitally integrate with respect to chosen exploration targets. The results were also correlated with the NASA's Shuttle Imaging Radar-C (SIR-C) image data and tested for usefulness of the multiple frequency polarimetric SAR data in mineral exploration.

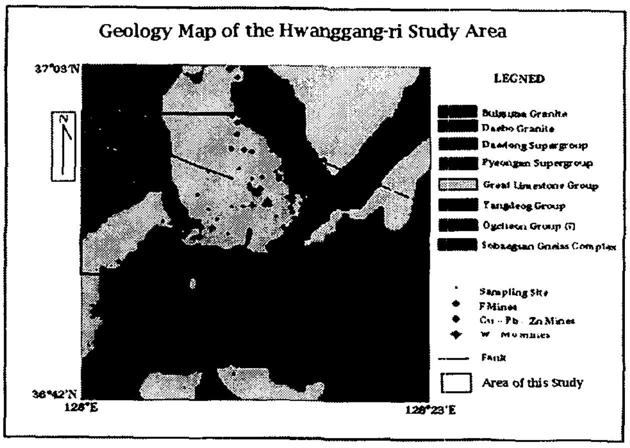


Figure 1. General geology map of the study area. The black box represents the actual data fusion limit.

The Hwanggang-ri area is located in the mountainous central-eastern part of the Korean peninsula. The region is moderately vegetated with small to medium size shrubs and trees. Most geological mapping of the study area was carried out in the 1960's (Lee and Park, 1965; Seo et al., 1970) and in the 1970's (Reedman et al., 1975). Although there are numerous abandoned mines in the area, there is not much useful geological information from these pre-WW2 mining activities. Geologically the study area is located in the Ogcheon belt, which extends for 350 km across the central part of the southern Korean peninsula as a narrow (40 - 60 km wide) northeast - southwest trending pelitic meta-sedimentary and sedimentary rocks (mainly carbonates) of Paleozoic age and Mesozoic igneous rocks.

One of the objectives of this study was to digitally compile the old data and outline favorable areas with respect to selected mineral exploration targets for further investigation. There are several quantitative ways of integrating spatial exploration data towards a specific exploration target (Moon, 1990, 1993; Steinnocher, 1997). In this study we tested the fuzzy logic approach by representing each exploration data layer with weighted fuzzy membership function and opeerators (An et al., 1991).

The SIR-C data incorporated in this study were acquired by NASA during one of its SIR-C experiments to test the multiple frequency polarimetric SAR systems. The SIR-C data characteristics and data acquisition parameters are given in Table 1.

The digital data processing algorithms used in this study are mostly commercially available packages but the fuzzy information representation steps and the fuzzy operators calculation were written by the authors. The multiple frequency and multiple polarization data sets also provided us with an opportunity to apply the hyperdimensional data fusion techniques along with auxiliary layers of exploration data (Benediktsson et al., 1997). However, this study focused only on the multiple frequency effects in the backscattering occurring over various geological materials in the study area.

2. Geology of the Study Area

The study area is situated in the Ogcheon belt which lies between the Gyeonggi and the Sobaegsan massif in a northeast direction (Fig. 1). It is divided into southwestern metamorphic and northeastern non-metamorphic areas (Kobayashi, 1953), which are named the Ogcheon zone and the Taebaegsan zone, respectively. Recently Cluzel et al. (1990) interpreted the Ogcheon belt as a stack of synmetamorphic, southward-verging nappes which resulted from the deformation of a volcano-sedimentary sequence deposited in an early single Paleozoic rift basin. Two main lithologic units are recognized in the study area: Cambro-Ordovician sedimentary rocks of the Chosŭn Supergroup, and the Late Cretaceous Muamsa Granites. The former is composed of largely of limestone and dolomites with minor intercalation of calcareous argillites. These sedimentary rocks represent transitional sedimentary facies deposited between a stable platform and deep rift zones (Cluzel et al., 1990). The Muamsa Granite intruded the sedimentary rocks, resulting in contact metamorphic halos up to the maximum of 2.5 km in width (So and Yun, 1990). The Chosun group in the Hwanggang-ri district occurs in the northeastern part where it is in fault contact with the Ogcheon Supergroup. The Pyongyang Group of mid-Carboniferous to Early Triassic age represents predominantly terrigeneous siliclastic formations.

In the study area, granitic rocks have intrudes all previously described rocks and are composed of two main units: Jurrasic (Daebo) granites and Cretaceous to early Tertiary (Bulgugsa) granites. The Wolagsanm Sogrisan, Muamsan, and Susan granites and ubiquitous small granite bodies and dikes belong to the Cretaceous granites (Kim and Kim, 1974). Overall K-Ar ages of these Cretaceous granites are 83 to 90 Ma. The Muamsan, Susan, and Wolagsan Granites show close spatial association to the metallic mineralizations in the region. Compositionally and texturally, the Wolagsan and Susan Granites are similar to the Muamsa Granite.

Metallic mineral deposits in the study area are classified into two major types: skarn-type replacement deposits; and fissure-filling hydrothermal quartz and carbonate veins. Skarn-type replacement deposits are typically developed along bedding planes of the carbonate wall rocks around the Wolagsan and Muamsa Granites and are composed of magnetite, fluorite and base metal sulfides (So and Yun, 1990). The hydrothermal vein deposits differ mineralogically in relation to distance from the Muamsa and Wolagsan Granite bodies. The W-Mo deposits are located in or near the granites, whereas Cu-Pb-Zn vein deposits occur up to 5 km from the granites. Further detailed description of the various metallic mineral deposits can be found in So and Yun (1990) and So et al., (1984).

Even though we are more concerned with the large scale mineral deposit potential, the above small scale geological features give some indication of the types of mineralization in the study area. Integrated imaging of mineral potential critically depends on the digital data sets available for the study area and imaging of specific individual mineralization along the above contact metamorphic zones is not feasible. However, approximate outlining of the mineral potential zones based on the available data sets is possible.

3. Digital Data Sets

The geological, geochemical and geophysical data sets utilized in this study are all public domain data sets and are

Geological map (Fig. 1)

Geochemcial data
- stream survey data
- soil survey data
- rock samples analysis for fluorine

Geophysical data
- regional and detailed gravity data
- aeromagnetic data
- electrical method data
- resistivity data
- SP (Self-potential) survey data
- EM survey data
- IP (Induced Potential) survey data
- radiometric survey data

Some of these data sets, such as gravity data, were already in digital format but others were available either as a geology map or as a contour map, which were manually digitized for subsequent processing.

Detailed description of the data are as follow :

Geological Map - Both the geology map and the location map of the study area, originally prepared by Reedman et al., (1975), were digitized (Fig. 1). Lithologically similar geological units are bundled together to make the later digital processing simpler. The geological units represented in the study area include Bulgugsa (Cretaceous) Granite, Daebo (Jurassic) Granite, Daedong Supergroup, Pyeongan Group, Great Limestone (Chosun) Group, Yangdeog Group, Ogcheon Group, and Sobaegsan Gneiss Complex.

Geochemcial Data - Two types of geochemical surveys: stream sediment surveys and soil surveys, were carried out in the study area for Cu, Pb, Zn, Mo, W, and F. The purpose of the soil surveys was to locate precise targets for further detailed geophysical exploration. In this study geochemical data was digitized, interpolated, and resampled for later processing and integration. Among the various element data, we have chosen W and F as our exploration target.

Geophysical Data - The geophysical surveys carried out in the study area includes gravity survey, magnetic survey, electrical (EM and IP) surveys, and radiometric survey. All the IP and VLF EM data were in line profile format across specific mineral showing and were judged to be not suitable for this type of integrated exploration study. These types of line profiles may be useful for correlation of individual final results. In this study, the original gravity and elevation data (Reedman et al., 1975) was reprocessed for Bouguer anomaly and interpolated. Irregular and sparse data points, however, provide us with a regional trend rather than detailed lithologic density variations. The magnetic data was digitized from the contour map, which was included in the report prepared by Reedman et al. (1975) and re-interpolated. Even though these data sets were not acquired for integrated exploration type of work, they were adequate for modeling of the upper crustal structure of the study area.

SAR Data - Among the SIR-C missions, we have tested the experimental data acquired during the August 1996 over Japan – Korea transect. Detailed data acquisition parameter is tabulated in the following section (Table 1).

The SIR-C data we received were fully polarimetric data and one could have evaluated Stokes matrix for specific theme classification. However, this study is limited to qualitative comparison of X-, C-, and L-band wave scattering processes with respect to the surface geological materials associated with the local mineralization. Although there is some difference in frequency between the X-band and C-band data, there is not much difference in their backscattering properties between these two bands and only the C-band and L-band data were used in this study for outlining of the mineral potential areas.

	X-band Data	**C-band Data**	**L-band Data**
Date of Acquisition	1994/04/12	1994/10/04 1996/08/	1994/10/03 1996/08/
Region	Japan-A1-1	Japan-A1	Japan-A1
No. of Looks	Multi-look	Multi-look	Multi-look
Look Direction	right	right	right
Look Angle	15^0 - 55^0	20^0 - 55^0	20^0 - 55^0
Frequency (Wavelength)	9.6 GHz (3.1 cm)	5.3 GHz (5.3 cm)	1.250 GHz (23.5 cm)
Polarization	VV	HH, HV, VV	HH, HV, VV
Orbit	Descending	Descending	Descending

Table 1. Technical Parameters of the SIR-X/C/L Data

4. Data Processing

During the preprocessing step, the exploration data sets with different resolution can be re-interpolated, re-sampled and geocoded. In the case of the SIR-C data, we applied an adaptive filter to smooth and enhance the image data, in addition to geocoding. The ERMapper and public domain GRASS GIS package were used for most processing. Some of the processing steps which were not available publicly were developed in the laboratory and applied to the respective data sets, one of which was the adaptive filter (Ristau and Moon, 1998).

Original gravity data were in point data form in a digital format and magnetic data were digitized from the contour maps. These data sets were interpolated and resampled to a regular grid data. Then the upward and downward continuations were computed to investigate the deep crustal structures beneath the study area. Both upward and downward continuation were carried out using the numerical programs written in this study by Jiang et al. (1996).

5. Data Fusion using fuzzy Logic

There are a number of possible ways of quantifying survey data (or spatial information) with respect to a chosen exploration hypothesis. In this study, we chose a data driven approach, which makes the whole process simpler (Moon, 1993). In a data driven approach, there are several mathematical approaches one can employ, such as pixel based probability (Schistad-Solberg et al., 1993, 1994), evidential belief function (Moon, 1990), or fuzzy logic (An et al., 1991). When there are un-surveyed and/or areas with no data inside the exploration boundary, evidential belief function has an advantage because unknowns and/or un-surveyed areas can be more adequately represented with plausibility and ignorance functions (Moon, 1990). In this study, the data coverage of all available data layers is complete and fuzzy logic representation was judged to be adequate.

A fuzzy set is characterized by a membership (characteristic) function which assigns to each spatial object (pixel in raster format) a grade of membership ranging between zero and one. Basic algebraic relationships of inclusion, union, intersection, complement, convexity, etc. are also extended to fuzzy sets, making application of fuzzy set theory easier to real problems (Zadeh, 1987; An et al., 1987; An et al., 1991; Bonham-Carter, 1994).

1992). For this reason the highest fuzzy membership function classification for flourite mineralization has broader pattern than the W-Mo mineralization.

Digital fusion of the exploration data layers with respect to each mineral deposit hypothesis was experimented with five fuzzy operators, previously tested by An et al. (1991) and An (1992): fuzzy MIN, fuzzy MAX, algebraic sum, algebraic product, and Gamma operators. The Gamma operator is basically a combination of the algebraic sum and algebraic product operator with varying γ parameter (An et al., 1991; Moon, 1993).

For the skarn type replacement mineralization, systematic application of available exploration data toward the final proposition does require several types of fuzzy operators. For example, if the proposition is "there is an economically viable W-Mo deposit", geochemical analysis anomaly of W and Mo can be

Fuzzy operator	Data layers operated	Comments
Fuzzy MIN : $\mu_{fp} = MIN(\mu_A, \mu_B, \mu_C, \ldots)$	Geophysical (potential field) data including indirect anomalies with respect to the exploration hypothesis	Mineral deposit model has to be considered.
Fuzzy MAX : $\mu_{fp} = MAX(\mu_A, \mu_B, \mu_C, \ldots)$	Geochemical data for W, Mo, F, etc.	Mineral deposit model has to be considered.
Fuzzy SUM : $\mu_{fp} = 1 - \prod_{l=1}^{n} (1 - \mu_i)$	Complimentary information such as geochemical data directly associated with the target hypothesis and the contact metamorphic zone.	Detailed field information required in this case.
Gamma operator : $\mu_{fp} = (1 - \prod_{l=1}^{n} (1 - \mu_i))^{\gamma} * (\prod_{l=1}^{\infty} \mu_i)^{(1-\gamma)}$	Geological data and other (non-potential field) geophysical data	Case dependent.

Table 2. Fuzzy operators and the data layers

For the target hypotheses of F-W-Mo mineralization, the constituent data sets include geology map, mineralized zone polygons, geochemical analysis data, and geophysical data. Assignment of fuzzy membership function in each data is such that the maximum likelihood (anomaly) corresponds to 1.0 and the minimum (or zero likelihood) to 0.0 in a normalized scale. In most cases, linear classification of anomalies, preprocessed field measurements, is adequate as long as one is consistent through the digital fusion process. Therefore, each data layer can be represented with fuzzy membership values and the different data layers are weighted with respect to the mineral deposit theory or the ore deposit model adopted.

On the geological map, the W-Mo occurrences are assigned with highest fuzzy membership values along the granite intrusion contacts. The Cu-Pb-Zn mineralization is cut by the late flourite-calcite-pyrite veinlets. Thus the skarn type replacement mineralization formed early and quartz-carbonate veins formed later by hydrothermal fluid injection. The different mineralogies of the metallic deposit formation is a function of distance from the granites (So and Yun,

combined with the algebraic sum operator. However, if the proposition is "there is an economically viable F deposit", and if we consider aeromagnetic data and geochemical analysis data of F, it becomes clear that application of the fuzzy MAX operator more logical. In this study, fuzzy Min, fuzzy MAX and algebraic sum operators are applied in combination and the result is shown in Fig. 2 for the combined proposition that there exists a W-Mo-F mineralization.

6. Discussion

There are basically two types of digital data made available for this study: the conventional mining exploration data, including the geological, geochemical, and geophysical survey data, including the potential field data such as magnetic and regional gravity survey data, and the space-borne SAR data. In this study, the magnetic and regional gravity data were first processed for residual anomaly maps, and upward and downward continuation maps to investigate the deep downward extension of the surface geological formations. Most other geological exploration data was first preprocessed, utilizing such steps as interpolation, resampling, geocoding, which were followed by fuzzy representation and digital information fusion. Geological Structural Features - It is well known that the Ogcheon belt in the study area forms the basement with respect to the various younger lithostratigraphic units, associated with diverse mineralization (Kim and Kim, 1974; So et al., 1983). Results of the regional gravity data processed in this study, including the MOHO depth (Fig. 7), clearly indicate that the general trend of the Ogcheon belt. The basement topography confirms with the new gravity data result, even though the precise depth profile of MOHO depths in the area requires detailed seismic study. The regional magnetic anomaly map does not appear to have the regional trend, which is so clear in Bouguer gravity data, but when it is upward continued to 5 km, the clear trend appears. The result also concurs with the analysis of the regional Indosinian tectonic structure (WNW-ESE compression and NNE-SSW extension) along the Korea peninsula reported by Cluzel et al. (1991). MOHO depths estimated from the regional gravity data are approximately 33 km in the northwest corner of the study area and increases to 35 km in the southeast.

The other geological features identified and mapped in this study are the two local faults and an extension of an existing fault. These are the east-west striking fault, the extension of the NW-SE trending fault, and a short NW-SE trending fault in the west. The near vertical faults B and C are clearly visible on all three SIR-X/C/L images and also confirmed in field during the recent field survey. The amount of displacement along the fault B varies, but it is a strike slip fault and is interpreted to be an extension of the previously mapped fault north of the fault A. Both these faults require further field confirmation and the numerous small faults mapped in various local mines require further investigation.

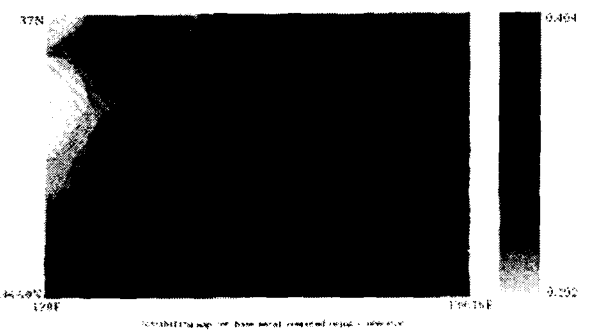
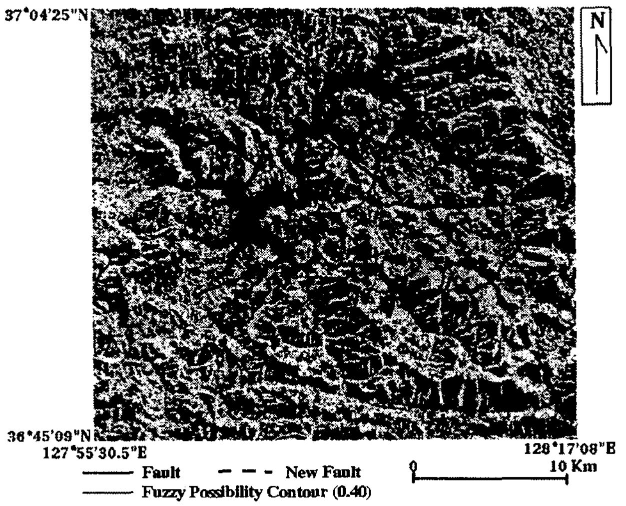


Figure 2. Flourite mineral potential map obtained using fuzzy fusion of the geochemical and geophysical data.

Digital Fusion of the Exploration Data - The basic method employed in the study is straightforward, however, there are a couple of points which require clarification. In the earlier work using fuzzy logic by An et al. (1991) and An (1992), the gamma operator was effectively and extensively used for integration of various mineral exploration data with respect to the hypothesis on the existence of base metal deposits. However, it become clear that the application of the same approach using the same gamma values resulted in unsatisfactory results in this study. There may be several reasons for this. One of the more important reasons may be the different type of deposit studied. The study area investigated by An et al. (1991) and An (1992) dealt with a base metal mineralization along a Greenstone belt in the Precambrian shield environment whereas in this paper W-Mo deposits and F skarn type mineralization. Another reason could be due to different assemblage of exploration data.

Utility of SIR-L/C/X Data - SIR-C mission was initially planned as a polarimetric SAR mission. However, for geological applications, the backscattering characteristics of the microwave at the surface play important role even over heavily vegetated areas. The SAR data acquired with C-band and the longer wavelength L-band signal over the exactly same study area exhibit characteristically different responses over different geological materials, such as granite plutons, limestone and contact alteration zones. Each individual X-band, C-band, or L-band SAR image of the study area shows most surface geographic features. However, subtle differences in backscattering occurs over different surface geological material and it is clearly shown in Fig 3. When the C-band and the longer L-band data are overlaid in different colors, the areas with different surface scattering appears as a distinct color pattern. In Fig. 3, there two important geological features are shown: (1) newly discovered faults (in dashed lines) which are also verified from field mapping, and (2) the higher than average mineral potential area (relatively flat area southeast of the reservoir). The pink areas in Fig. 3 (when the imae is shown in colour) basically represents the area with less or smaller trees growing over thick soil beds, in comparison to the green area which is covered with tall pine trees with very thin top soil. It is however interesting to notice that the area outlined as higher than average mineral potential area in Fig. 2 coincides with the large flat pink area in Fig. 3. The higher than average mineral potential area outlined in Fig. 2 is overlaid on the composite C-band and L-band SAR image as shown in Fig. 3. Of course, one cannot quantitatively state how the differential backscattering characteristics in SIR-C/L image (Fig. 3) are related to the high mineral potential area outlined in Fig. 2. Without further detailed research, one cannot draw any definite conclusions, however, it is evident that the correlation between the anomalous differential backscattering and the higher than average mineral potential area imaged using fuzzy logic reasoning process is excellent.

The skarn type mineralization of W-Mo and also of F in the study area along the limestone - granite contact area is relatively well studied (So et al., 1983; So and Yun, 1992). According to these studies it appears that the skarn mineral assemblages, the metallic deposit forming sequence, (i.e. the polyascending hydrothermal fluids from nearby plutons, and the pressure -depth conditions), are all indirectly expressed as an anomalous differential backscattering phenomena. However, there has been no previous study of skarn type mineralization in view of SAR image interpretation and will also require further detailed investigation.



Fuzzy Possibility Contour overlaid on composit SIR-C image

Figure 3. SIR-C L-band and C-band composite image showing the mineralized alteration zones. The dark outline represents the fuzzy mineralization potential area.

7. Conclusions

The two main objectives of this study were first to test the digital fusion of exploration data and outline the most probably area of specific mineral deposit occurrences and to evaluate the SIR-X/C/L data for such mineral exploration application. Although the number of data sets were large probably because of numerous old mines, the number of data sets which were actually useful for effective digital data fusion was very limited. Based on the results obtained in this study, the following conclusions can be made:

(1) although selective application of fuzzy operators required careful testing with each data set, the fuzzy logic approach of digital data fusion employed was effective and accurate,

(2) the estimated MOHO depths indicate that the general trend of the Ogcheon belt follows the deep crustal trends at the MOHO discontinuity (this study may be confirmed by a future seismic survey),

(3) SIR-X/C/L data, for each frequency band, provides valuable structural geological information in their own right, and

(4) the areas outlined by the digital data fusion results exactly coincide with an area outlined in the composite C- and L-band data. This particular area outlined in the composite C-band and L-band image probably represents an area with differential backscattering over the skarn mineralization zone.

Although this research has unveiled a new potential for the multiple frequency polarimetric SAR in the mineral exploration projects, it also warrants considerable further research.

8. Acknowledgments

This study was partially support by an NSERC of Canada operating grant #7400 to W. M. Moon and a CMR fund, Korea University. Authors would like to thank Ellen O'Leary (JPL) for the SIR-C data. Some of the geophysical processing software was developed at the Institute of Geophysics, Academia Sinica (China) by W. W. Jiang.

8. References

An, Ping, 1992, Spatial Reasoning and Integration Techniques for Geophysical and Geological Exploration Data, Unpublished Ph.D. thesis, University of Manitoba, Canada, 280 p.

An, P., W.M. Moon, A. Rencz, and C.F. Chung, 1991, Integration of geological, geophysical and remote sensing data using fuzzy logic, Journ. Can. Explor. Geophys., 27, 1-11.

Benediktsson, J. A., J. I. Ingimundarson, J.R. Sveinsson , 1997, Classification and Feature Extraction of Hyperdimensional Data using LOOC Covariance Estimation, IGARSS'97 Proceedings - B10.03.

Bonham-Carter, G.F., 1994, Geographic Information System for Geoscientists, Pergamon Press (Elsevier) (London), 1 - 398.

Campbell, B.A., and M.K. Shepard, 1996, Lava flow surface roughness and depolarized radar scattering, Jour. of Geophysical Research (Green), Vol. 101, pages 18,941-18,951.

Cluzel, D., B. J. Lee, and J. P. Cadet, 1991, Indosinian dextral ductile fault system and synkinematic plutonism in the southwest of the Ogcheon belt (South Korea), Tectonophysics, 194, 131-151.

Jiang, W.W., 1996, Computer Algorithms for Potential Field Data Processing, (Technical Report, Academia Sinica, 1 - 42.

Jiang, W.W., W.M. Moon, and L. N. Feng, 1997, Data fusion research for mineral exploration data from

Hwanggang-ri region, Korea, Technical Report # 17, Geophysics, University of Manitoba, Winnipeg (Canada), 1 - 62.

Kim, Ok Joon, and K.H. Kim, 1974, The Study of Structure and Petrology of the Area between Susan-ri and Hwanggang-ri, Mining Geology, Vol. 7, No. 3, 101-122.

Kobayashi. T., 1953, Geology of South Korea, Tokyo University Press, 1-293.

Lee, Moon Sup, and B.S. Park, 1965, Open File Report on Hwanggang-ri Map Sheet (Sheet-6824-IV) (Scale 1: 50,000), Geological Survey of Korea, 1-43.

Moon, W.M., 1990, Integration of multiple sets of geophysical information using evidential belief function, IEEE Trans. Geosci. Remote Sensing, 28, 272-278.

Moon, W.M., 1993, Mathematical Basis for geophysical information representation and integration, Can. Journ. Remote Sensing, 19, 63-67.

Reedman, A. L., K.S. Yoon, C.J.N. Fletcher, H.S. Rhyu, R.B. Evans, S.H. Jeong, D.R. Workman, and J.N. Park (Anglo-Korean Mineral Exploration Group), 1975, Geology of the Hwanggang-ri Mining District (Korea), Monograph, 1-118.

Ristau, J., and W. M. Moon, 1999, Application of adaptive filtering to 2-D geophysical data, Geophysics, (submitted).

Seo, Hyo Joon, J.S. Cho, N.E. Hong, and J.Y. Lee ,1970, Geochemical Reconnaissance in the Hwanggang-ri Sheet, Geophysics Survey Report, Geological Survey of Korea, Vol. 4, No. 1, 105-140.

So, C.S., D.M. Rye, and K/L/ Shelton, 1983, Carbon, Oxygen, and Sulfer Isotope and Fluid Inclusion Study of the Weolag Tungsten-Molybdenum Deposit, Republic of Korea: Fluid Histories of Metamorphic and Ore Forming Events, Economic Geology, 78, 1551-1673.

So, C.S., and S.T. Yun, 1992, Geochemistry and Genesis of Hydrothermal Au-Ag-Pb-Zn Deposits in the Hwanggang-ri Mineralized District, Korea, Economic Geology, 87, 2056-2084.

Schistad Solberg, A.H., A. K. Jain, and T. Taxt, 1993, Fusion of multi-temporal satellite images and GIS data for land-use classification, Proceedings of the 8th Scandinavian Conference on Image Anlysis, 691-697. (May 1993).

Schistad Solberg, A.H., A. K. Jain, and T. Taxt, 1994, Multisource Classification of Remotely Sensed Data: Fusion of Landsat TM and SAR images, IEEE Transactions of Geoscience and Remote Sensing, 32, 768-778.

Steinnocher, K., 1997, Application of Adaptive Filters for Multisensor Image Fusion, IGARSS'97 Proceedings - B10.02.

Zadeh, L.A., 1987, Fuzzy Sets, In Fuzzy Sets and Applications: Selected papers by L.A. Zadeh, Tager, R.A., Ovchinnikov, S., Tong, R.M., and Nguyen, H.T. (eds.), 29-44.

Zadeh, L.A., 1987, Probability Measures of Fuzzy Events, In Fuzzy Sets and Applications: Selected papers by L.A. Zadeh, Tager, R.A., Ovchinnikov, S., Tong, R.M., and Nguyen, H.T. (eds.), 45-51.