The Journal of GIS Association of Korea, Vol.7, No.2, pp.159-173, October 1999

GIS를 이용한 지질자료 기반 통합 주제정보의 다중 버퍼 영역분석

이기원* · 박노욱** · 권병두**

Multi-Buffer Zone Analysis of Geo-Based Integrated Thematic Mappable Information by Using GIS

Kiwon Lee* · No-Wook Park** · Byung-Doo Kwon**

요　　약

GIS는 다양한 지구과학분야의 응용에 중요한 방법 중 하나로 인식되고 있으며 최근 지구과학정보의 공간 통합을 위한 다양한 방법들이 개발되고 있다. 그러나, 현재 공간분석 통합결과에 대한 정량화 분석에 대해서는 그다지 많이 연구되고 있지 않으며, 이러한 측면에 일부 기인하여 GIS에서 제공하는 분석기법들을 자연과학분야에의 그대로 적용하는 데는 부족한 면이 있다. 본 연구에서는 GIS 공간분석 측면에서 "다중버퍼 영역분석"이라는 간단한 방법을 소개하고, 실제 자료를 이용하여 광물부존 지역 예측 문제에 본 제안 방법을 적용하였다. GIS 측면에서 볼 때, 본 방법은 격자기반 버퍼링 혹은 근접성분석 기법을 지구과학 자료의 해석을 위해 확장하여 응용한 것이다. 본 방법은 GIS의 가장 기본적인 도형 모델인 점, 선, 면으로 표현할 수 있는 중요한 지질학적 지표 특징에 대하여 지구과학적 현상이나 양상이 주로 원형 상으로 나타나는 경우에 대하여 적용이 가능하다. 이러한 방법을 적용하여 하나의 지질학적 현상을 설명하는 데 있어서 항공물리탐사, 지표탐사, 지질조사, 위성 영상 자료 등과 같은 복합적인 지구과학자료들이 어떻게 영향을 미치고 있는 가를 정량적으로 밝혀내는 데 이용할 수 있다. 결론적으로 GIS에서 제공하는 분석기법의 적용은 공간 통합에 의한 주제도 작성 문제와 연계되어 제한적인 공간 영역 내에서 복합적인 입력 자료들에 대한 상호 영향을 추론하는 데 활용될 수 있을 것으로 생각된다.

주요어 : 다중버퍼 영역분석, 공간분석, 공간통합, 지질정보, 복합자료

ABSTRACT : GIS has been regarded as one of important tools or methodologies for various geoscience applications. Recently, spatial data integration schemes for site-specific or field-specific thematic mapping are newly developed and utilized. However, these kinds of approaches are somewhat insufficient quantitative assessment of integrated layers towards known targets in-detailed. Moreover, GIS analysis scheme is rarely extended to scientific approaches. In this study, simple approach of 'Multi-Buffer Zone Analysis', related to GIS analytical aspect, is addressed and an actual application for predicting or favorable mapping of mineral occurrences, one of GIS-based geoscientific approaches, is performed. As for geo-processing in GIS itself, this scheme can be regarded as extension or adaptation of cell-based buffering or proximity analysis to geoscientific data interpretation. This study is based on rationale that surface geological pattern around primitives such as a point, a line, or a polygon in GIS, representing

---

* 한국전자통신연구원 GIS연구팀(ETRI/CSTL-GIS, E-mail : Kilee@etri.re.kr)
** 서울대 지구과학교육과(Dept of Earth Sciences, Seoul National Univereity)

significant geological features, can be efficiently utilized to delineate complex geological behaviors or events, especially handling multiple data sets originated from multiple sources such as airborne geophysical/radiometric exploration, field survey, and even a classified image of remote sensing. Conclusively, this methodology associated with GIS is thought to be helpful to analyze the spatial pattern of multiple data, pointing given sources, and is expected to effectively utilize for exploratory analysis of cell-based resultant layer integrated with complex or different data sources.

Key words : GIS Analysis, Geological Information, Multiple Data Sets, Multi-Buffer Zone Analysis, Spatial Integration

1. Introduction

GIS(Geographic Information System) is very useful methodology or tool for various field-specific applications, and it is widely utilized at both geo-based data processing and interpreting in geosciences, when applied to multiple data sets (Burrough, 1986 ; Agterberg and Bonham-Cater, 1990 ; Bonham-Cater, 1994 ; Goodchild et al., 1996). However, its functionality, composed of generic stages of data entry/updating, conversion, storage and management, modeling, analysis, presentation/display, shows somewhat limited availability in scientific approaches; most spatial analysis methodologies in GIS focus on spatial data modeling and attribute query, in some extents, in vector-based GIS handling object or feature-based geoprocessing. While, cell-based or raster-based GIS, handling field-based geoprocessing, often applies to cell-based operation containing attribute information itself in the form of logical value, linked with image processing technology. Furthermore, digital geocoding of geoscientific data faces with its intrinsic complexity; Consequently, specialized scheme beyond typical modeling or representing process in GIS is necessary.

Despite of above limitation, GIS application to geoscientific approach has been gradually increased; in relation to this trend, spatial integration in the GIS environment is one of main issues related to it. Spatial integration terms the whole GIS process for generation of fused decision supporting layer using multiple data sets. Its meaning and application is somewhat different from data overlay or superimposition, because it normally needs special integration rule, scheme, or function towards site-specific or field-specific application. Furthermore, it needs to generalization or formalization of applied methodology for data fusion. Conjugated GIS with geoscience, spatial integration methodologies have been mainly developed at the perspectives of mathematical geology and geostatistical approach since the late 1980s and applied to site-specific researches such as nonrenewable natural resources exploration, geo-environmental suitability analysis, geo-hydrologic modeling or thematic representation of geological data. As its implementation level, it can be performed with several mathematical/probability-based approaches and deterministic approaches, towards GIS-based interpretation of complex multiple data sets; Conditional probability, Weight of evidence method, Evidential belief function method, Certainty factor estimation, Multivariate statistical data analysis, Neural network analysis, Fuzzy set approach and so forth (Moon, 1990 ; Fabbri and Chung, 1996 ; Rostirolla et al., 1998). Therefore, mappable information, spatially integrated layer, usually provides decision-making information for a given target application. However, quantitative or exploratory analysis with respect to newly generated layer by those methodologies, in consideration of additional supporting evidences, have not been studied deeply. Moreover, as for this additional information, its scope and covering discipline are currently not well defined. Furthermore, it is difficult to establish the generalized scheme for these reasons: sophisticated aspect contained various types of data sets, handling error propagation, data accuracy /quality level, heterogeneity of multi-source data model and target-oriented parameterization for multiple data fusion methodologies.

This study doesn't deal with these whole topics fully; whereas, it focuses on provision of useful evidences for interpretation of integrated layer within GIS. Mineral Potential Mapping (MPM) using multiple data sets, one of geoscience applications of GIS, is attempted in this study, especially in consideration of multi-buffer zone analysis, newly proposed geo-processing scheme. The discipline of solid geoscience for MPM is the field of studying the physical and natural aspects of subsurface/surface feature and history of the earth by using various data sets such as catchment geochemistry, geological map, and ore deposit site location. In general, MPM in the solid geoscience handles large data sets containing field-, airborne-, and space-borne data. Airborne data is mainly airborne radiometric and total intensity magnetic data, and space-borne data is remotely sensed imagery or classified /post-processing data using imagery. Therefore, these data sets can be represented with GIS's main primitive types: point, line, and polygon. However, pure vector-based geo-processing usually shows somewhat limitation of spatial analysis, despite of its powerful functionality for data storage/management, and spatial analysis in engineering perspectives. Therefore, a kind of hybrid-typed spatial analysis in the side of scientific approach is necessary, and this study is also categorized into this scope for GIS-based geoscientific application with the case study by using actual data sets.

In this study, firstly, spatial integration scheme was applied to real multiple geoscientific data sets and quantitative assessment methodology was applied. Also, a simple and easily applicable GIS scheme names 'Multi-buffer Zone Analysis' was proposed to provide additional supporting evidences.

2. Mineral Potential Mapping (MPM) and Multi-buffer Zone Analysis

2.1. Data Sets for the Case Study

For the case study of this proposed scheme for MPM, multiple geoscientific data sets of 15 types covering the Ogdong area, were used (Table 1(a)). The main reason of area selection was the data availability. Actually, in these days, digitally processed or GIS-typed geoscience data sets are not enough provided to public level; however, field or airborne surveyed data sets is in the middle of geocoding in the exchangeable

Table 1. (a) Used geo-based data sets and classified GIS layers

Type / Class		Airborne Radiometric Data Sets * (unit : cpu^1, gamma^2)					Catchment Geochemical Data Sets ** (unit: ppm)						DEM (unit : degree)		Satellite Imagery	Geological map***
		γ ray^1	K^1	Th^1	U^1	Mag.^{2}	Ag	Cd	Cu	Pb	U	Zn	Slo.	Asp.	Image Class	
1	min	200	10	5	4	-60	0.10	0.02	10.00	10.00	1.70	17.00	0	0	Water	Alluvium
	max	250	15	6	5	-35	0.17	0.50	13.50	20.90	5.50	36.22	10	45		
2	min	251	16	7	6	-34	0.18	0.51	13.51	20.91	5.51	36.23	11	46	Forest	Daedong system
	max	350	26	10	7	-20	0.81	0.98	35.10	49.00	12.90	59.57	20	90		
3	min	351	27	11	8	-19	0.82	0.99	35.11	49.01	12.91	59.58	21	91	Allu.	Pyeongan supergroup
	max	450	36	13	9	5	2.09	4.20	93.30	114.80	29.50	133.10	30	135		
4	min	451	37	14	10	6	2.10	4.21	93.31	114.81	29.51	133.11	31	136	Agri.	Joseon supergroup (Ordovician)
	max	550	47	17	11	20	3.09	10.40	151.40	175.80	44.70	184.00	40	180		
5	min	551	48	18	12	21	3.10	10.41	151.41	175.81	44.71	184.01	41	181		Joseon supergrup (Cambrian)
	max	650	58	21	14	80	7.21	14.80	239.10	267.30	67.00	252.95	50	225		
6	min	651	59	22	15	81	7.22	14.81	239.11	267.31	67.01	252.96	51	226		Pegmatitic migmatite
	max	750	68	24	16	140	15.96	17.21	699.00	5695.00	69.48	495.00	60	270		
7	min	751	69	25	17	141							61	271		Precambrian schist & quartzite
	max	850	78	28	18	200							70	315		
8	min	851	79	29	19	201							71	316		Granitic gneisses
	max	950	90	30	22	300							80	360		
9	min												81			Acidic dike
	max												90			
10	min															Granite
	max															
11	min															Porphyrite
	max															

Data Sources :

* Aerial gamma ray and magnetic survey map at Jungseon, samcheok, Yemi, Jangsung(1:50,000), KIER(Korean Institute of Energy and Resources), 1988

** Geochemical Maps for Ogdong Sheet in the Taebaegsan Mineralized Belt, KIER, 1984

*** Geological map of Ogdong area scaled by 1:50,000, Geological Survey of Korea, 1966

(b) Known eight mines and rich element ore deposit of mines at this study area

ID number	Name	Rich element in Ore Deposit
1	Oyang	Fe
2	Jeougyang	Pb, Zn
3	Gari	Fe
4	Ogdong	Fe
5	Nokjeon	Sericite
6	Imok	Pb, Zn
7	Yujeon	Pb, Zn
8	Dohwadong	Pb, Zn

style to GIS environment. Therefore, most data sets in this study was originally text or raw format, and pre-processing for geocoding and geo-registering process was carried out.

As for geophysical and geochemical data sets, airborne surveyed data composed of magnetic anomaly (designated as Mag) and radiometric anomaly of gamma-ray, K(Potassium), Th(Thorium), and U(Uranium) and ground surveyed data of Pb(Lead), Zn(Zinc), Cu(Copper, Cuprum), Ag (Argentum, normally silver), Cd(Cadmium), and U were used respectively. In U, both airborne and surface data sets were obtained, but they were separately processed. Geophysical data sets in originally vector format were converted to raster format, and geochemical data sets, ground surveyed data from widely distributed stream rock samples were interpolated to obtain grid data.

As for topographic data sets represented as DEM(Digital Elevation Model), DEM-driven slope /aspect map sets and classified image of Landsat TM imagery were used. DEM was produced by vector to raster conversion process, and supervised classification Landsat TM imagery was used. While, geological map, one of basic data sets for this approach, was fully geo-registered into GIS with geometric features and their database attributes.

After this pre-processing, all data sets were built at cell-based database with resolution 30 meter and were reclassified with respect to the feature of each data set. Cell-based re-codes range of data sets is also shown at Table 1 (a). Also, known eight mines at this study area (Table 1 (b)) were used as prior evidences in spatial integration and sources in multi-buffer zone analysis. These contents and locations were acquired from research report and geological map of KIER (1988) and GSK (1966). This temporal inconsistence may affect interpretation of integrated layer at decision-supporting level, but this severe problem and its effect was excluded in this study. However, this problem is not unusual case in GIS application, so it was assumed that geological transition time of this MPM and used data sets was preserved.

2.2. Spatial Integration by Certainty Factor Estimation (Lee et al., 1999)

Among various integration methodologies, spatial integration using certainty factor estimation was performed using the whole data sets towards favorable mapping of mineral occurrences. The main purpose of this study is not just spatial integration, but the hybrid-type spatial analysis, so experimentally certainty factor estimation was applied.

Certainty factor (CF) estimation is a measure of certainty of conditional probability with respect to the priori probability and is based on the probabilistic relationships between known evidence and input layers. CF is equal to zero if the conditional probability is equal to the priori probability; the absolute value of CF increase if the conditional probability is far from the priori probability.

At certainty factor estimation result represented as probability (Figure 1), the result of spatial integration was well fitted to actual ground truth representing actual mine or mineral deposit location. To assess quantitatively the result of spatial integration, main classes of all input layers corresponding to selected zones over 95% by certainty factor were masked, and then this masked zones were reproduced as a binary map. Through this processing, Yule(α) and odds ratio(OR), were computed, for the purpose of revealing the most dominant class value within classified zones over 95% of CF estimation layer, and its result (Table 2) could be regarded as a kind of post-processing or assessment of modeling results of spatial integration task with respect to spatially integrated layer for mineral

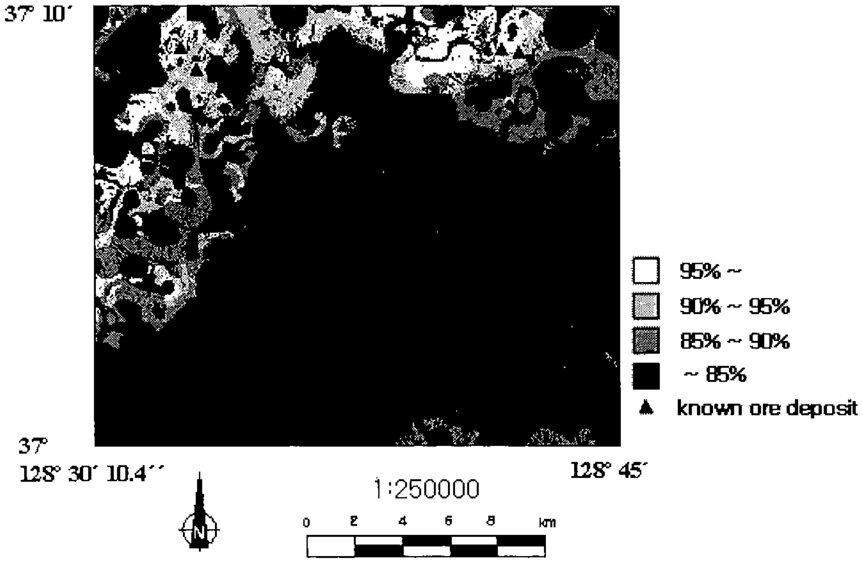

Fig 1. Spatially integrated layer showing potential mapping for mineral occurrence using whole data sets of Table 1(a), excerpted from Lee et al.(1999).

Table 2. Main classes of all input layers corresponding selected zones over 95% by certainty factor and Yule and odds ratio with respect to integrated layer of figure 1

Input Layers		Class	α	OR
Airborne Radiometric Data	γ ray	7	0.350	4.313
	K	2	0.260	2.903
	Th	5	0.393	5.269
	U	6	0.399	5.414
	Magnetic.	7	0.607	16.739
Catchment geochemical Data	Ag	2	0.822	105.295
	Cd	5	0.572	13.500
	Cu	3	0.335	4.036
	Pb	6	0.618	17.972
	U	2	0.488	8.460
	Zn	4	0.551	11.938
Geology		Granite	0.518	9.909
Image class		Alluvium	0.158	1.894
DEM	Slope	1	0.097	1.474
	Aspect	2	0.117	1.599

potential mapping. As shown at Table 2, statistics of airborne magnetic anomaly, Ag, Pb and Zn showed relatively high value, and its meaning was that spatial pattern on these 4 data sets was strongly affected to newly integrated layer for prediction of mineral occurrences. However, the large coefficient value of Ag might be caused by the non-diagonal deviation. The dominant influence of granite zone geologically attributed to the high class value of airborne data sets (except potassium). Therefore, overall assessment of this integrated result is considered as decision-supporting layer in the viewpoint of GIS with quantitative additional evidences. But, these general statistical approaches have difficulties to explain input layers' behavior and spatial pattern, given ground truth; in this case, known mineral ore deposits are regarded as ground truth. Moreover, final integrated layer is sometimes insufficient to explore data themselves. Therefore, other scheme to carry out this task is necessary to attempt in the same GIS environment with spatial database including the whole data sets. While, this approach was previously performed at Lee et al.(1999), but its main result is quoted in this study for further explanation of multi-buffer zone analysis in the case of MPM.

2.3. Multi-buffer Zone Analysis and Its Result

General schematic view for multi-buffer zone analysis is outlined at Figure 2. This approach is not technical improvement of GIS processing algorithm, but somewhat practical approach based on a GIS buffering operation. An buffering operation is one of basic and easily applicable spatial analysis method in GIS to provide buffered zone which surrounds source features. A buffer is a newly generated polygon enclosed an area within specified distance from a certain primitive source and expression of influence zone with respect to certain distance (Chou, 1996); however, multi-buffer zone analysis focuses on the change of spatially distributed pattern in buffered zones or buffering boundaries along with equi-interval or distance. In a multi-buffering, the dominant circular pattern with respect to a given source can be incrementally determined by cell-counting. Therefore, through this scheme, spatial behaviors of multiple data layers around given source primitives can be extracted.

Geo-based source primitives in this scheme are compatible to 'point' as ore deposit, seismic epicenter, or various types of point source causing natural hazards, 'line' as surface fault line or drainage networks, and 'polygon' as mineral occurrence zone, alteration zones, and geological pattern. In this study for MPM, the location of mineral occurrences is mainly dealt with to associate with previous spatial integration task. Each clump in buffered zone with interval of every 300 meters from known ore deposit can be represented as plot-style shown at Figure 2. The whole buffered zone of each layer was obtained at circular range to 1800 meters from point source location; in this concept, 'clump' stands for the most dominant class value and it is regarded as a representative value for a buffered zone.

Figure 3 represents buffered zones with interval of every 300 meters from known ore

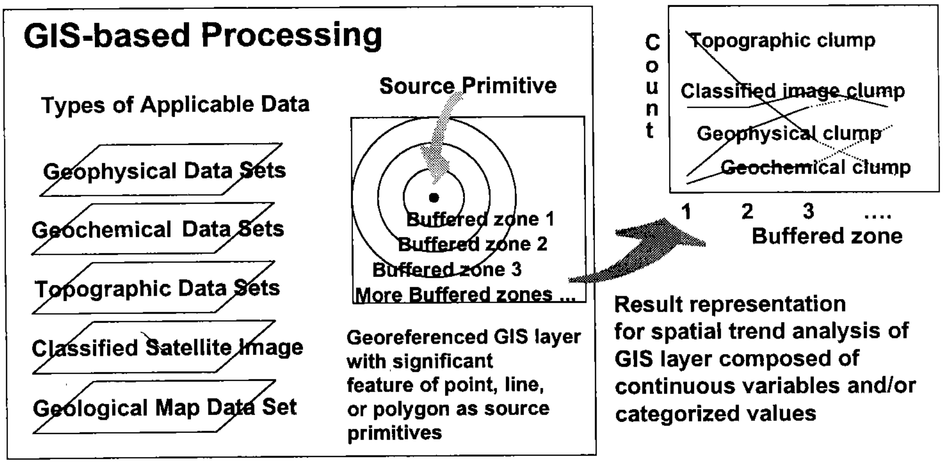

Fig 2. Applied scheme of multi-buffer zone analysis with point source.

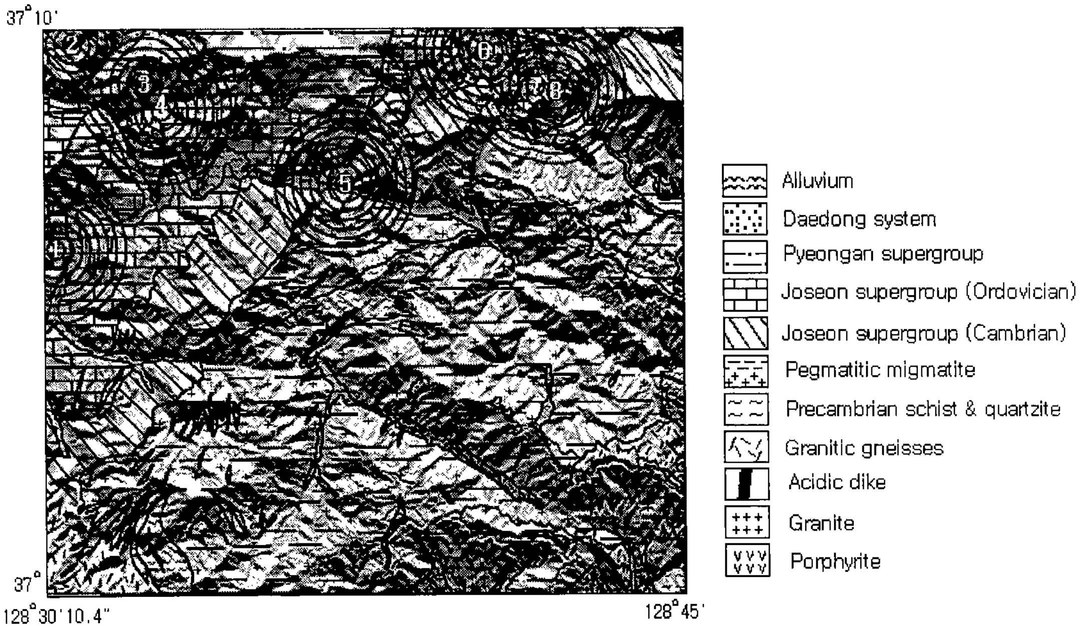

Fig 3. Buffering zones on DEM-based surface relief image draped over geological map.

deposits: mine 1 to 8. In consideration of proximity of mines, the interval of buffered zone was selected. Mines 1 and 3 are Fe rich ore deposit, and mines of 5 and 8 are sericite and (Pb, Zn)-rich ore deposits, in turn. In figure 3, DEM superimposed with geological features boundaries is shown as additional information for visual interpretation.

As these results (Figure 4~Figure 7), in most cases, topographic data sets (slope and aspect)

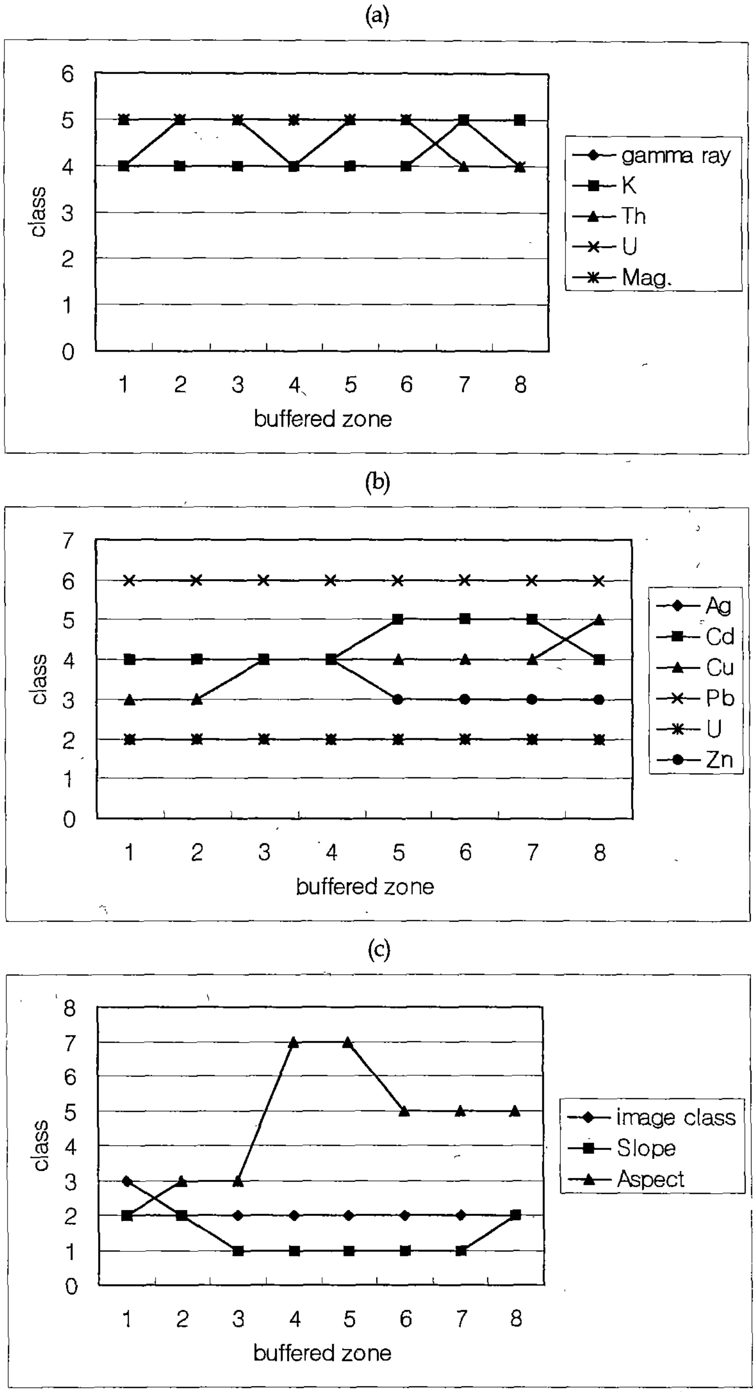

Fig 4. Multi-buffer zone analysis results by cell-counting with respect to mine 1 : (a) airborne radiometric data sets, (b) catchment geochemical data sets, (c) topographic data sets

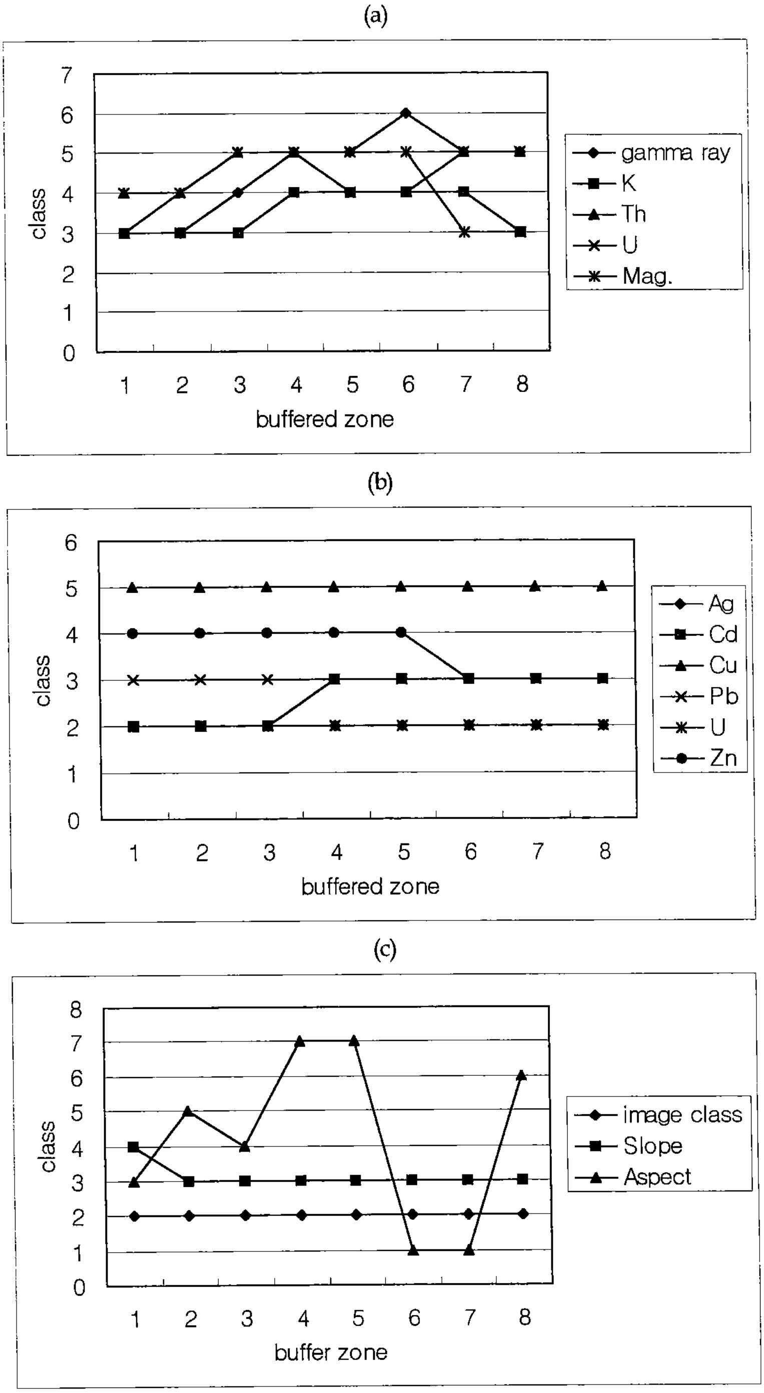

Fig 5. Multi-buffer zone analysis results by cell-counting with respect to mine 3 : (a) airborne radiometric data sets, (b) catchment geochemical data sets, (c) topographic data sets

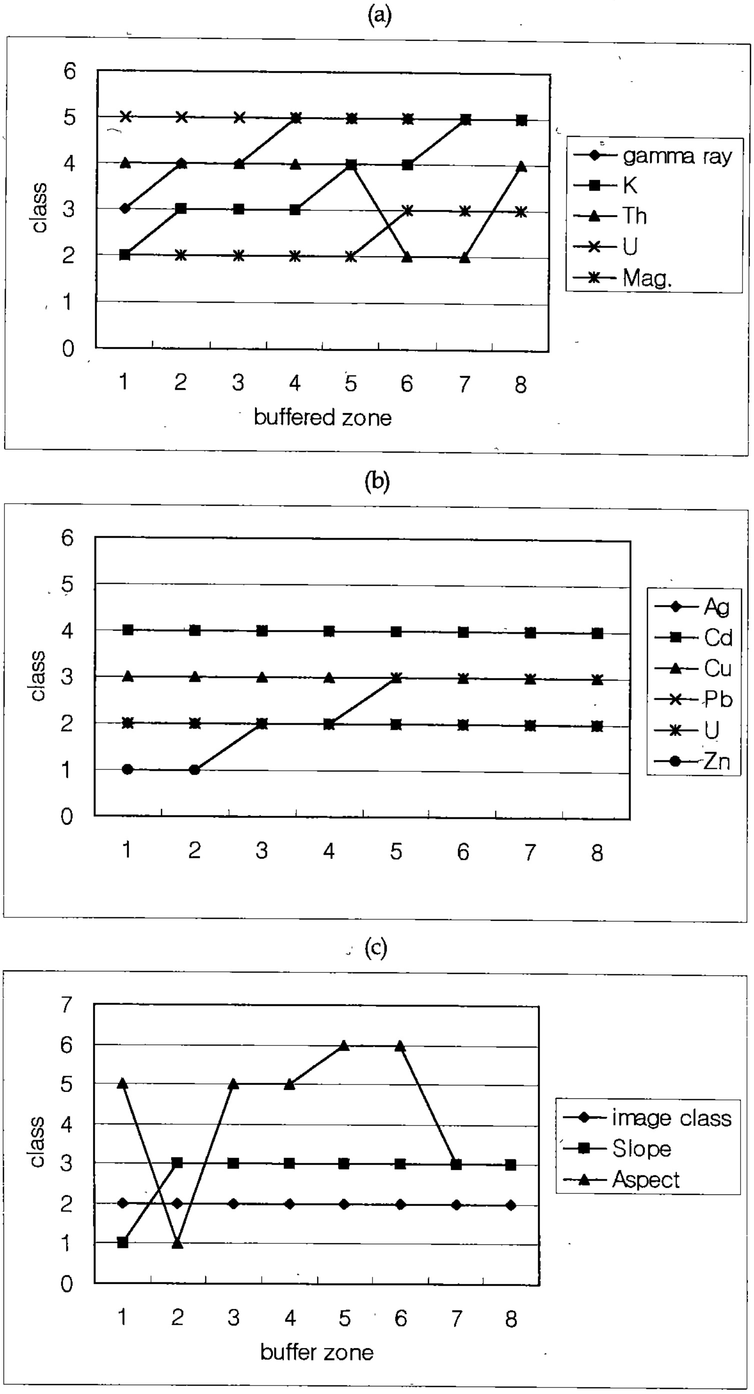

Fig 6. Multi-buffer zone analysis results by cell-counting with respect to mine 5 : (a) airborne radiometric data sets, (b) catchment geochemical data sets, (c) topographic data sets

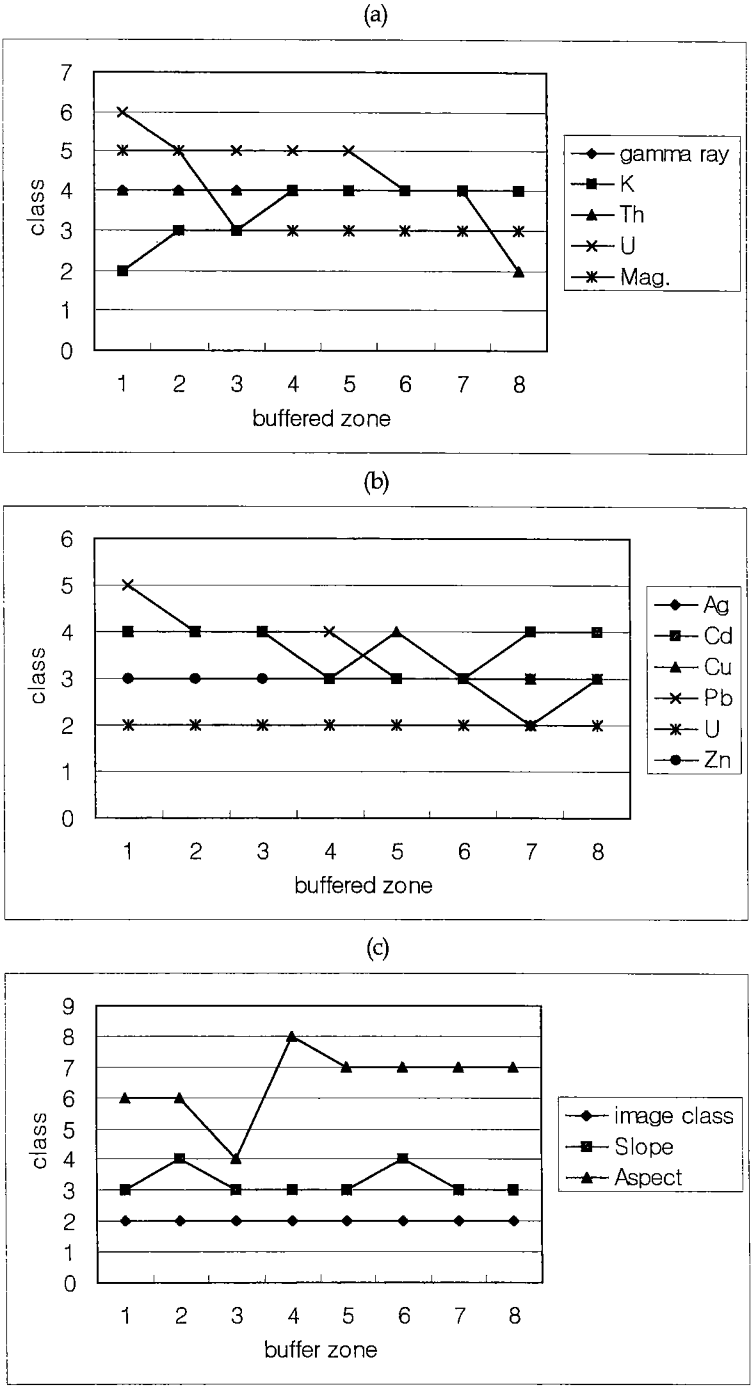

Fig 7. Multi-buffer zone analysis results by cell-counting with respect to mine 8 : (a) airborne radiometric data sets, (b) catchment geochemical data sets, (c) topographic data sets

showed much variation. In the case of mine 1 (class 4 in geology, Figure 4), spatial trend in airborne data sets appeared to be same class in airborne data sets : class 5 of airborne magnetic anomaly. But, catchment geochemical data sets showed relative variations : class 4 to 5 of Cd, class 3 to 5 of Cu, class 3 to 4 of Zn, except class 2 of Ag, and class 6 of Pb. Range of each class can be referred from Table 1. In the case of mine 3 (class 3 in geology, Figure 5), some different distributed patterns were shown: airborne data sets varied relatively much than catchment geochemical data sets : class 3 to 5 of airborne magnetic anomaly, class 3 to 6 of gamma ray, and class 3 to 5 of airborne uranium. It was thought that these patterns resulted from class 3 in geology: Airborne radiometric data usually shows large response in coal seam or black shale. Though class 3 was the representative value, the heterogeneity of geology in buffered zone resulted in the variation of airborne radiometric data.

While, as shown at figure 6, important circular trend in mine 5 was class change of 2 to 5 of airborne potassium, class 3 of Cu, or class 5 of airborne uranium, compared to change of geological background with class 4, 5, and 6. High value of U resulted from the sericite in buffered zone.

Finally, in mine 8 (class 3 in geology, Figure 7), in spite of a point source of Pb and Zn-rich ore deposit, classified pattern of Zn was invariant, on the contrary of class change of 3 to 5 of Pb. Furthermore, clumped trend on most layers was slightly changed, class 5 to 3 of airborne magnetic anomaly, class 6 to 4 of airborne uranium, class 2 to 4 of K, expect gamma ray and U.

In comparison with quantitative assessment result with respect to the integrated layer(Table 2), main classes of input layers influence on the integrated layer, was not fully fitted to the spatially clumped class. : Main class of Ag, Cd, U, and Zn in catchment geochemical data sets was fitted to the spatially clumped class. However, other data sets were not directly fitted. That results from the fact that this result may not be directly oriented to rich-element; as reasons, areas of mineral deposit, modeled with points in GIS, does not normally appear wide spatial pattern, and a spatial resolution of cell is not appropriate at detailed ore deposit model.

Actually, this changed pattern and circular clumped trend extracted by these example case studies in this area may not be fully explained through traditional geological investigation. But it is regarded as the informative supporting evidences towards spatial integrated and newly generated layer such as Figure 1, in the viewpoint of GIS's application to prediction- related thematic mapping of mineral occurrences. Some advantages over traditional interpretation at non-GIS environment can be described as follows: provision of supporting information to build knowledge base around target for geo-based expert system ore deposit model for mineral exploration, and delineation of generalized model for given source features.

3. Concluding Remarks

In this study, spatial integration with

post-processing step of statistical assessment and multi-buffer zone analysis handling multiple geo-based data sets were performed toward the case study of MPM. In spatial integration task using certainty factor estimation, statistics with respect to the whole range of the study area was relatively well fitted to integrated result and actual ground truth.

In application of multi-buffer zone analysis with real data sets, several aspects need to be further discussed regardless of its result: selection problems of representative value of each data layer within buffered zones and its uncertainty or accuracy level caused by limitation of cell-based processing, and mis-understanding problems according to intrinsically complex interactions between used data. Nevertheless, this proposed scheme can be developed as supplementary information for result interpretation and shows possibilities for further extended approaches, especially handling other types of geo-based features; it is helpful to analyze the spatially clumped pattern of multiple data oriented to given sources whatever any type of primitives are applied, although only one case study related to thematic mapping for mineral occurrences concerned with MPM is presented.

As well, it is expected to effectively utilize for exploratory analysis to quantitatively interpret an appropriate merged model of spatial data, especially when this approach is applied to the data sets of geoscientific field and those of other fields simultaneously. In addition, this approach can be utilized to reveal inter-relationship on spatial pattern between multiple data sources at site-specific spatial integration application. Though this applied methodology is not development of new technology but that of practical scheme using basic GIS function of application level, it is thought that it is available at various types of GIS applications handling geoscience-based hybrid data model.

4. References

Agterberg, F.P. and Bonham-Carter G. F., 1990, Statistical Applications in the Earth Sciences, Geological Survey of Canada Paper 89-9, p.588.

Bonham-Carter, G. F., 1994, Geographic Information Systems for Geoscientists: Modelling with GIS, Pergamon, p.398.

Burrough, P. A., 1986, Principles of Geographical Information Systems for Land Resources Assessment, Oxford Science Publications, p.194.

Chou, Y.-H., 1996, Exploring Spatial Analysis in Geographic Information Systems, Onward Press, pp. 474.

Fabbri, A. G. and Chung, C.-J. F., 1996, Predictive Spatial Data Analysis in the Geosciences, In Spatial Analytical Perspectives on GIS, eds M. Fischer, H. J. Scholton, and D. Unwin, Tayor & Francis, pp. 147-159.

Goodchild, M. F., Steyaert, L. T. and Parks, B. O. (Eds.), 1996, GIS and Environmental Modeling : Progress and Research Issues, GIS World Books, p.486.

Lee, K., Park, N. W., Chi, K. H., and Kwon, B. D., 1999, GIS-based Spatial Integration and Statistical Analysis using Multiple Geoscience Data Sets: A Case Study for Mineral Potential Mapping, *Jour. Korean Society of Remote*

showed much variation. In the case of mine 1 (class 4 in geology, Figure 4), spatial trend in airborne data sets appeared to be same class in airborne data sets : class 5 of airborne magnetic anomaly. But, catchment geochemical data sets showed relative variations : class 4 to 5 of Cd, class 3 to 5 of Cu, class 3 to 4 of Zn, except class 2 of Ag, and class 6 of Pb. Range of each class can be referred from Table 1. In the case of mine 3 (class 3 in geology, Figure 5), some different distributed patterns were shown: airborne data sets varied relatively much than catchment geochemical data sets : class 3 to 5 of airborne magnetic anomaly, class 3 to 6 of gamma ray, and class 3 to 5 of airborne uranium. It was thought that these patterns resulted from class 3 in geology: Airborne radiometric data usually shows large response in coal seam or black shale. Though class 3 was the representative value, the heterogeneity of geology in buffered zone resulted in the variation of airborne radiometric data.

While, as shown at figure 6, important circular trend in mine 5 was class change of 2 to 5 of airborne potassium, class 3 of Cu, or class 5 of airborne uranium, compared to change of geological background with class 4, 5, and 6. High value of U resulted from the sericite in buffered zone.

Finally, in mine 8 (class 3 in geology, Figure 7), in spite of a point source of Pb and Zn-rich ore deposit, classified pattern of Zn was invariant, on the contrary of class change of 3 to 5 of Pb. Furthermore, clumped trend on most layers was slightly changed, class 5 to 3 of airborne magnetic anomaly, class 6 to 4 of airborne uranium, class 2 to 4 of K, expect gamma ray and U.

In comparison with quantitative assessment result with respect to the integrated layer(Table 2), main classes of input layers influence on the integrated layer, was not fully fitted to the spatially clumped class. : Main class of Ag, Cd, U, and Zn in catchment geochemical data sets was fitted to the spatially clumped class. However, other data sets were not directly fitted. That results from the fact that this result may not be directly oriented to rich-element; as reasons, areas of mineral deposit, modeled with points in GIS, does not normally appear wide spatial pattern, and a spatial resolution of cell is not appropriate at detailed ore deposit model.

Actually, this changed pattern and circular clumped trend extracted by these example case studies in this area may not be fully explained through traditional geological investigation. But it is regarded as the informative supporting evidences towards spatial integrated and newly generated layer such as Figure 1, in the view-point of GIS's application to prediction- related thematic mapping of mineral occurrences. Some advantages over traditional interpretation at non-GIS environment can be described as follows: provision of supporting information to build knowledge base around target for geo-based expert system ore deposit model for mineral exploration, and delineation of generalized model for given source features.

3. Concluding Remarks

In this study, spatial integration with

post-processing step of statistical assessment and multi-buffer zone analysis handling multiple geo-based data sets were performed toward the case study of MPM. In spatial integration task using certainty factor estimation, statistics with respect to the whole range of the study area was relatively well fitted to integrated result and actual ground truth.

In application of multi-buffer zone analysis with real data sets, several aspects need to be further discussed regardless of its result: selection problems of representative value of each data layer within buffered zones and its uncertainty or accuracy level caused by limitation of cell-based processing, and mis-understanding problems according to intrinsically complex interactions between used data. Nevertheless, this proposed scheme can be developed as supplementary information for result interpretation and shows possibilities for further extended approaches, especially handling other types of geo-based features; it is helpful to analyze the spatially clumped pattern of multiple data oriented to given sources whatever any type of primitives are applied, although only one case study related to thematic mapping for mineral occurrences concerned with MPM is presented.

As well, it is expected to effectively utilize for exploratory analysis to quantitatively interpret an appropriate merged model of spatial data, especially when this approach is applied to the data sets of geoscientific field and those of other fields simultaneously. In addition, this approach can be utilized to reveal inter-relationship on spatial pattern between multiple data sources at site-specific spatial integration application. Though this applied methodology is not development of new technology but that of practical scheme using basic GIS function of application level, it is thought that it is available at various types of GIS applications handling geoscience-based hybrid data model.

4. References

Agterberg, F.P. and Bonham-Carter G. F., 1990, Statistical Applications in the Earth Sciences, Geological Survey of Canada Paper 89-9, p.588.

Bonham-Carter, G. F., 1994, Geographic Information Systems for Geoscientists: Modelling with GIS, Pergamon, p.398.

Burrough, P. A., 1986, Principles of Geographical Information Systems for Land Resources Assessment, Oxford Science Publications, p.194.

Chou, Y.-H., 1996, Exploring Spatial Analysis in Geographic Information Systems, Onward Press, pp. 474.

Fabbri, A. G. and Chung, C.-J. F., 1996, Predictive Spatial Data Analysis in the Geosciences, In Spatial Analytical Perspectives on GIS, eds M. Fischer, H. J. Scholton, and D. Unwin, Tayor & Francis, pp. 147-159.

Goodchild, M. F., Steyaert, L. T. and Parks, B. O. (Eds.), 1996, GIS and Environmental Modeling : Progress and Research Issues, GIS World Books, p.486.

Lee, K., Park, N. W., Chi, K. H., and Kwon, B. D., 1999, GIS-based Spatial Integration and Statistical Analysis using Multiple Geoscience Data Sets: A Case Study for Mineral Potential Mapping, *Jour. Korean Society of Remote*