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Integration of Geological Data Sets Using Fussy Logic

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Abstract: Fussy set theory provides a simple framework for integrating and analyzing qualitative and quantitative data irrespective of their sources. This study introduces fussy logic and demonstrated its application for predicting hydrothermal mineral occurrences in northwestern part of Yunnan. Three geo-variables were considered and their membership functions were determined subjectively. Combination of the three fussy evidence layers; geochemical, lineament and lithology resulted into a favorability map for the occurrences of hydrothermal Cu, Ag, Au and Pb-Zn.

Key words: Fussy logic, GIS, hydrothermal mineralization, factors, fussy sets, membership scores

INTRODUCTION

The role being played by Geographic Information System commonly known a GIS can not be over emphasized. It provides a quick access to; (a) information extraction; (b) ranking various geo-variables (c) integrating diverse information; (d) reducing data processing time; and (e) enhancing decision making processes. Most of the statistical approaches based on regression and characteristics or canonical correlation analysis transform the multi-layer to binary or ternary form. Such techniques may be limited in the type of information that can be quantified. Bayesian methods and weight of evidence may be limited by conditional independence requirements for the data used. Belief and plausibility functions may in practice, be difficult to interpret and asses. The limitations of the above approaches are that, they can be somewhat inflexible in expressing the different degrees of favorability of the mineral occurrence for each of the individual geo-variables considered.

Fussy sets provide an alternative framework that could improve upon some of the limitations in previous techniques. A fussy set-based formulation is used by An *et al.*[1] to integrate geological and geophysical data from Farley lake area, Canada. The study uses the algebraic-sum and aggregation operators to outline favorable areas for base metal and iron deposits, based on an approach also advocated by Chung and Agterberg[2]. Although a notable development, the approach use combined geo-information does not take into account the individual relative importance of geo-variables in quantifying favorability for mineral occurrence. In addition relative, the approach is knowledge-driven and as such does not include objectives data driven criteria in the combination of the geo-information used. The purpose of this study is to test the implementation of fussy logic in the northwestern Yunnan by way of predicting favorable hydrothermal mineral occurrences.

Fuzzy sets: Geological information and data interpretations in mineral exploration are inherently ambiguous. The quantitative expressions like relative high, fair, low and relatively, fairly favorable, unfavorable for the mineral occurrences as well as the grey areas between these expressions, is difficult to define. Fussy set theory[3] and[4] provides a mathematical framework to represent the linguistic and ambiguities frequently encountered in mineral exploration geological information analysis and interpretation. The theory formally associates any statement with a quantifiable measure indicating the degree of possibility of the statement.

Definition and examples:
If X is a collection of objects denoted by x, fussy set in X is the set of ordered pairs,

$$A = \{(x, \mu_A(x)| \epsilon X\}, \quad (1)$$

Where, is $\mu_A(x)$ termed the membership function or membership grade of x in A[3], $\mu_A(x)$ maps X to the membership space M. When M contains only two points 0 and 1, A is a non fussy set and $\mu_A(x)$ is identical to the characteristics function of a regular, non-membership and expresses full membership.

In mineral potential mapping, the individual spatial objects on a map are considered as members of the fussy set and the set is defined as areas containing a specific type of mineral deposit. The degree of membership is expressed with respect to some attribute of interest .The level of measurement of mapped variables can be categorical, ordinal or interval. Generally the attribute of interest is measured over discrete intervals and the membership function can be expressed as a table relating to map classes to the membership values. Thus individual objects or classes of objects can be evaluated regarding their membership in a fussy set of geologic objects.

Determining the initial fussy membership function critically depends on the exploration target and related geological deposits characteristics. In general initial fussy memberships are assigned subjectively based on the expert opinion. This may sometimes be very qualitative, however, subsequent steps, including the integration of multilayered data using various fussy operators are quantitatively precise. Grade of membership is usually represented by a membership function that need not to be linear or even continuous. Indeed many fussy sets have extremely nonlinear membership functions[4] or fussy membership can be thought of as in terms of support for proposition or hypothesis. In mineral exploration, the proposition is favorable location for mineral deposits". In this study the goal is to identify areas favorable for mineral deposits. The maps to be used as evidence to support the proposition are all expressed as a common information metric –namely fussy membership on the {0,1} scale.

Fussy sets can be combined using fussy operators. Zimmerman[4] and Zadeh[5] discuss more than two dozen fussy operators An *et al.*[1] discuss 5 of the various fussy operators as the more basic operators found to be useful for combining exploration datasets, namely fussy AND OR, fussy algebraic product, fussy algebraic sum and fussy gamma operators.

Fussy AND: This is equivalent to a Boolean AND (logical intersection) operation on classical set values of (1,0). It is defined as

$$\mu_{combination} = \mathrm{MIN}(\mu_A, \mu_B, \mu_C \ldots\ldots\ldots \mu_N) \tag{2}$$

where, μ_A is the fussy membership value for map A at particular location, μ_B is the membership of map B and so on. The effect of this rule is to make the output map be controlled by the smallest fussy membership value occurring at each location. Like the Boolean AND fussy AND results in a conservative estimate value occurring at each location. Like Boolean AND fussy AND results in a conservative estimate of set membership, with a tendency to produce small values. The AND operation is appropriate where two or more pieces of evidence for a hypothesis must be present together for the hypothesis to be true[6].

Fussy OR: Is equivalent to the Boolean OR (logical union) where the output membership values are controlled by the maximum values of any of the input maps for nay particular location. The fussy OR is defined as:

$$\mu_{combination} = \mathrm{MIN}(\mu_A, \mu_B, \mu_C \ldots\ldots\ldots \mu_N) \tag{3}$$

Using this operator, the combined membership value at any location is limited only by the most suitable of the evidence maps. This operator in some circumstances might be reasonable for mineral potential mapping, where favorable indictors of mineralization are rare and the presence of any positive evidence may be sufficient to suggest favorability.

Using the fussy AND or fussy OR, a membership of a single piece of evidence controls the output value. The following operators combine the effect of two or more pieces of evidence in a blended result so that each data source has some effect on the output.

Fussy algebraic product: The combined membership function is defined as:

$$\mu_{combination} = \prod_{i=1}^{n} \mu_i \tag{4}$$

Where, μ_i is the fussy membership function for the *ith* map and i =1,2, ... n maps to be integrated . The combined fussy membership values tend to be very small with this operator, due to the effect of multiplying several numbers less than 1. The output is always smaller than, or equal to the smallest contributing membership value and is therefore decreasive.

Fussy algebraic sum: This operator is complementary to fussy algebraic product and defined as:

$$\mu_{combination} = 1 - \prod_{i=1}^{n} 1 - \mu_i \tag{5}$$

The result is always larger (equal to) the largest contributing fussy membership value. The effect is there increasive. Two pieces of evidence that both favors a hypothesis reinforce one another and the combined evidence is more supportive than either piece of evidence taken individually. The increasive effect combining several favorable pieces of evidence is automatically limited by maximum value of 1, 0 which can never be exceeded.

Fussy gamma operation: This is defined in terms of the fussy algebraic product and fussy algebraic sum as:

$$\mu_{combination} = (\prod_{i=1}^{n} \mu_i)^{1-\gamma} \ (1\prod_{i=1}^{n} 1 - \mu_i)^{\gamma} \tag{6}$$

Where, γ is a parameter chosen in the range zero to one. When γ is 1, the combination is the same as the fussy algebraic sum and γ is 0, the combination equals the fussy algebraic product. Judicious choice of γ produces output values that ensure a flexible compromise between the increasive tendencies of the fussy algebraic sum and the decreasive effects of the fussy product (Fig. 1).

APPLICATIONS OF FUSSY LOGIC IN NORTHWESTERN YUNNAN

Yunnan province is geological complex region endowed with various forms of mineral formations.

At least five different styles of lead-zinc-silver mineralisation occur in Yunnan[7-9].

- With copper in sedimentary exhalative (Sedex) deposits (e.g., Tertiary Jingding/Lanping deposit) and Mississippi Valley Type (MVT) deposits (e.g., Carboniferous Qilinchang deposit).
- With copper in volcanic-hosted massive sulphide (VHMS) deposits (e.g., Carboniferous Laochang deposit and the recently discovered Carboniferous Dapingzhang deposit).
- With copper and tin in lead-zinc skarn deposits (e.g., Triassic Dadongchang and Hongshan deposits),
- With precious metals in veins and porphyry deposits (e.g., Beiya deposit).
- With tin and copper in Sn-W vein and skarn deposits (e.g., Mengzimao).

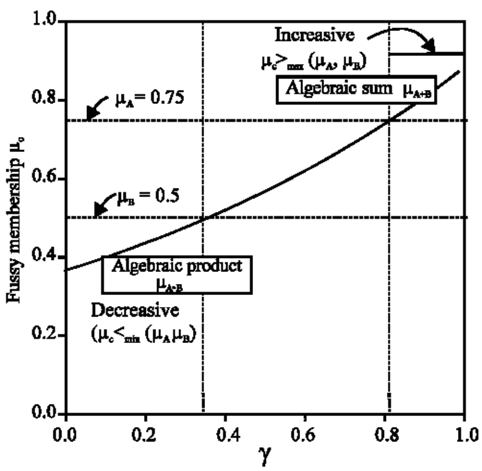

Fig. 1: A graph of fussy membership μ_c obtained combing two fussy membership μ_A and μ_B[6]

Table 1: Fussy membership scores for the various factors

		Copper		Gold	
Lithology	Fussy score	Classes	Score	Classes	Score
T↑3↓BS⊥	0.90	15.68	0.20	0.91	0.01
C-P	0.20	23.59	0.30	1.28	0.10
D2-3	0.19	27.59	0.30	2.19	0.20
E1-2	0.80	33.50	0.50	4.19	0.40
Eγπ	0.40	51.18	0.55	10.26	0.50
J1-2	0.55	82.23	0.60	24.75	0.70
JKγ	0.40	143.73	0.70	61.41	0.80
K1	0.85	265.51	0.80	152.56	0.90
K2ηγ	0.40	506.71	0.90		
P1	0.40				
P2-3	0.49				
Pt	0.15				
Pt3	0.49				
Pz1	0.12				
Qhall	0.70				
T1-2BS	0.65				
T1-2MS	0.45				
T2ESF	0.15				
T3MS	0.15				
Tδoπ	0.13				
∊2-3	0.15				
Silver		Lead		Lineament	
Classes	Score	Classes	Score	Classes	Score
57.50	0.10	19.56	0.01	549.31	0.00
81.09	0.20	28.34	0.10	1288.66	0.01
138.59	0.30	47.90	0.20	2283.80	0.01
278.81	0.60	91.53	0.40	3623.22	0.10
620.71	0.75	188.86	0.65	5426.02	0.20
1454.38	0.85	405.94	0.70	7852.52	0.40
3487.17	0.90	890.11	0.80	11118.50	0.60
		1970.02	0.90	15514.38	0.90

Fussy geo-variables for predicting hydrothermal mineral occurrences: The following are the geological criteria considered for the study;

Lineament: Extracted from Lansat images of the area.

Lithology: Reclassified based on the geological time scale (Fig. 2).

Geochemical data: Stream sediment sample result of Cu, Au, Ag, Pb-Zn.

Fussy membership scores

Lithology: The membership scores for lithologies were determined subjectively based on their relationship to the mineralization. The highest score was given to the Triassic Gaocheng series and the rest of the scores assigned to others shown on Table 1.

Lineament: The lineament map consists of both ring structures and linear features. The linea-density was

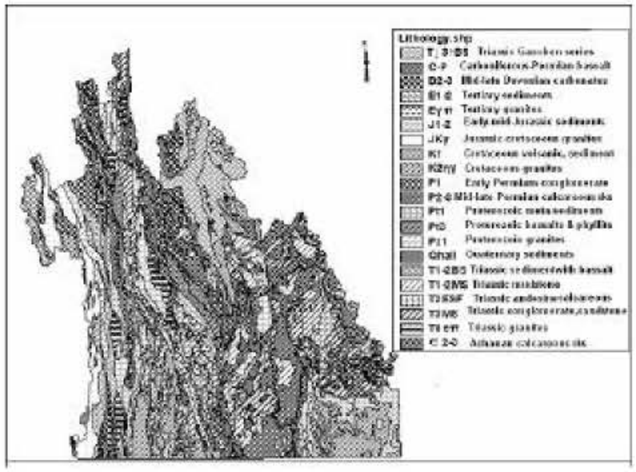

Fig. 2: Reclassified lithology map of NW Yunnan. The symbols adopted by Yunnan Geological Bureau. The classification for prediction purposes only

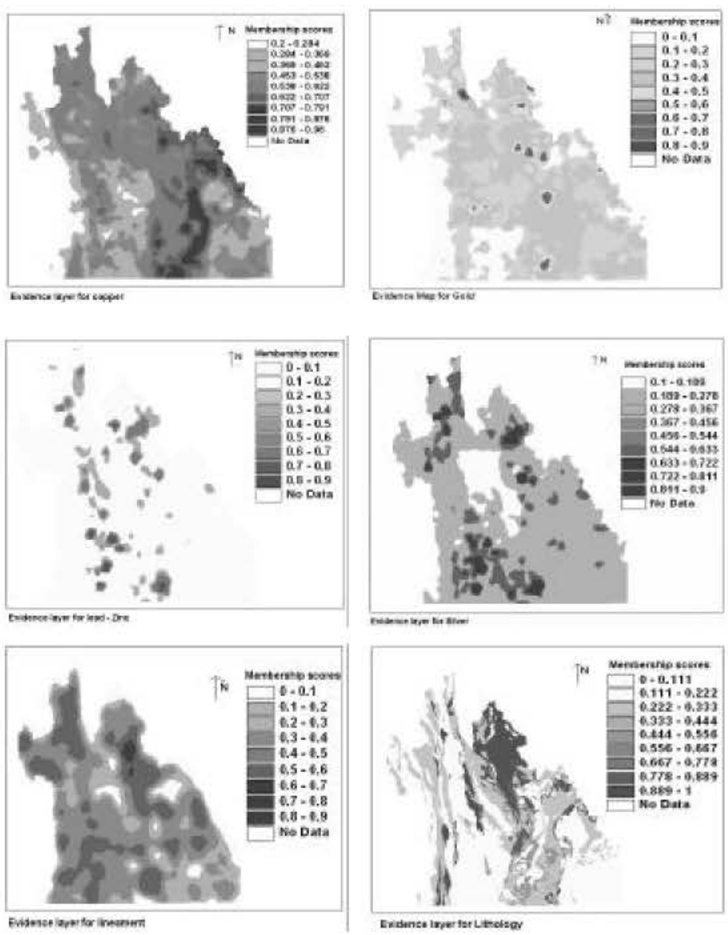

Fig. 3: The evidence map for the various factors

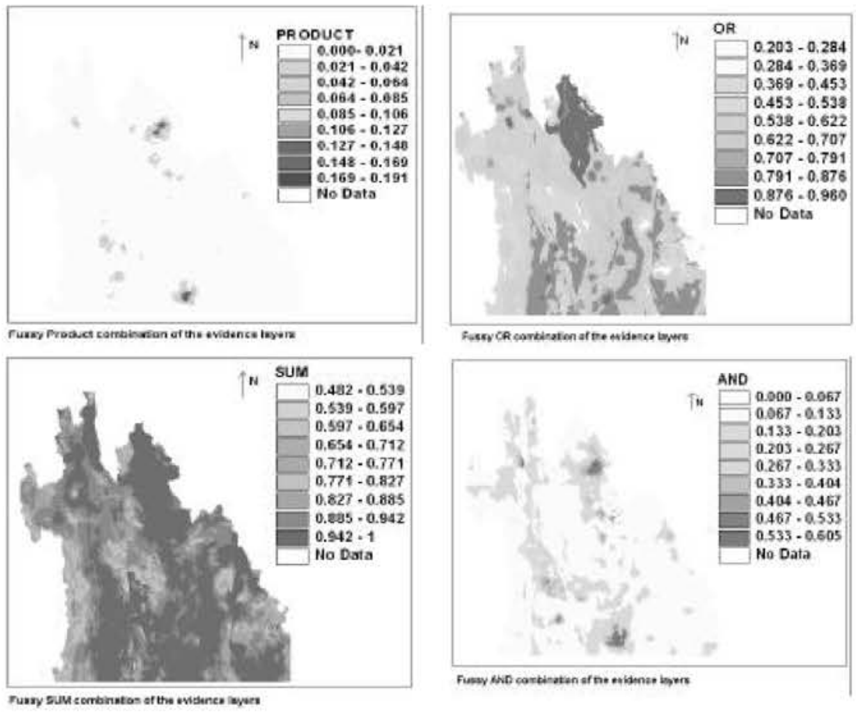

Fig. 4: The map for the various operations adopted by An *et al.*[1]

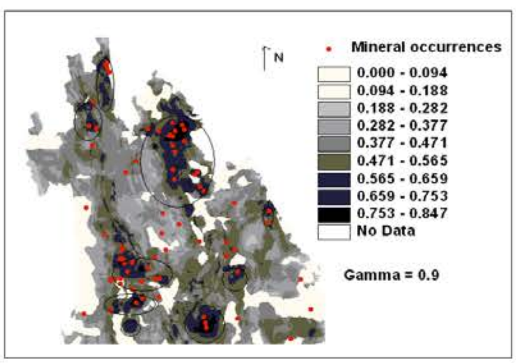

Fig. 5: Fussy favorability map for the occurrence of Au, Ag, Cu, Pb-Zn overlaid with known mineral occurrence

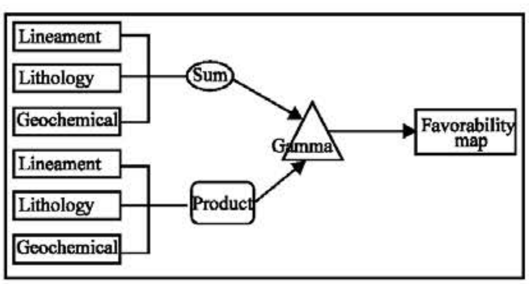

Fig. 6: Inference network for producing hydrothermal Au, Ag, Cu, Pb-Zn, in northwestern Yunnan

calculated using MapGIS software developed by CUG and after, exported to Arc GIS and contoured using universal Kriging. The various scores were assigned to them based on their relationship to the known mineralization shown on Table 1.

Geochemical: The geochemical data of the various elements were also contoured using the same universal Kriging function and the contour values depict their assay values from stream sediment analysis. The membership values were assigned with respect to these values where the highest membership scores were assigned to the highest assay values also shown Table 1. Fussy evidence maps: The evidence maps for the various factors were extracted shown in Fig. 3.

Integration of fussy sets: With the various scores assigned to the fussy sets, the various operators were used to integrate them representing intermediate stages. The Fig. 4 shows the various combinations.

Fussy favorability map for hydrothermal Cu, Au, Ag Pb-Zn: The Fig. 5 below shows the inference network for producing the favorability map for the occurrences of the above mineralization. Two of the intermediate stages Sum and PRD were combined with a gamma value of 0.9 and this resulted in producing favorable areas of the above mineralization. Combination of the OR and AND also produced the same result with the same gamma value but not shown due to lack of space.

The overlay of the known occurrences with the predicted result has demonstrated a successful implementation of fussy logic in northwestern Yunnan for producing favorable location of hydrothermal mineralization of Cu, Au, Ag and Pb-Zn (Fig. 6). The result covers more than 70% of the known mineral occurrences and has also predicted new area for follow up.

REFERENCES

1. An, P., W.P. Moon and A. Renc, 1991. Application of fuzzy set theory to integrate mineral exploration. Can. J. I Exploration Geophys., 27: 1-11.
2. Chung, C.F. and F.P. Agterberg, 1998. Poisson Regression Analysis and its Application. In: Chung, C.F. A.G. Fabri and R. Sinding-Larsen, (Eds.), Quantitative Analysis of Mineral and Energy Resources. D. Reidel Publishing Company, Dordrecht, pp: 29-36.
3. Zadeh, L.A., 1965. Fussy sets. Institute of Electrical and Electronic Engineering Information Control, 8: 338-353
4. Zimmerman, H., 1991. Fussy Set Theory and its Applications. 3rd Ed., Kluver Academic, Dordrencht.
5. Zadeh, L.A., 1973. Outline of a new approach to the analysis of complex systems and decision processes. Institute of Electrical and Electronic Engineering, Transactions on Systems, Man and Cyberntics, 3: 28-44.
6. Bonham-Cater, G.F., 1994. Geographic Information Systems for Geoscientists, Modeling with GIS Pergamon Ontario.
7. Qingtong, H. Yunzhong and Y. Yuenqing *et al*., 1992. Regional geochemical background and gold, silver and lead-zinc mineralization in the Nujiang-Lancangjiang-Jinshajiang area. Geol. Memoirs, Series 4, No. 25, Geological Publishing House, People's Republic of China, pp: 274-279.
8. Nang, Li. and J.R. Kyle, 1997, Geologic controls sandstone-hosted Zn-Pb-(Sr) mineralization, Jingding deposit. Yunnan province, China-A new environment for sedimenthosted Zn-Pb deposits. Proc., 30th Intl. Geol. Congr., 9: 67-82.
9. Kyle, J.R. and Li. Ning, 2002, Jingding: A giant Tertiary sandstone-hosted Zn-Pb deposit, Yunnan, China. SEG Newsletter, No. 50: 1-15.
8. Guihua, Q.S., 1991. Lead-Zinc Deposit in Nujiang. Lanangjiang-Jinshajiang, pp: 148-158.
10. Zadeh, L.A., 1983. the role of fussy logic in the management of uncertainty. Fussy Sets and Systems, 11: 199-227.