2008

Integrating exploration dataset in GIS using fuzzy inference modeling

Basab Mukhopadhyay

Niladri Hazra

M K Mukhopadhyay

Geodata and Database Division
Geological Survey of India, CHQ, Kolkata
gsi_chq@vsnl.com

The Singhbhum Copper Belt, located in Jharkhand state in Eastern India, forms an arcuate linear zone (Fig.1) in the Precambrian Singhbhum Crustal Province (PSCB), houses over 250 million tonnes of copper ore of variable tenor and considered one of the most potential copper sulphide bearing stretch of the country. It is found that only 15% of the total 128 Km stretch of the copper belt shear zone between Bhatin and Badia yield maximum number of economic copper deposits. Five decades of exploration by GSI has generated huge inventory of spatial and related attribute data which need to be relooked again to find out new locales for further exploration, as ore reserves remained stagnant in this belt over a decade. Geological knowledge of an area may play the most important role, if not the only one, in finding out the mineral potential. But unfortunately, in most of the cases, this is a qualitative classification which cannot be transmitted in the modeling environment of GIS. A qualitative spatial representation between geological features in terms of predictive mineral potential model (taking into consideration the nature of known mineralisation), is by far the most vital part in any analysis.

The quantified spatial association between different themes based on exploration model and copper occurrences in PSCB, has already been quantified in an earlier publication (Mukhopadhyay et. al., 2002) by an intuitive knowledge driven approach. Same data layers and weight scheme have been used in this analysis to calculate values for fuzzy membership function and combined by fuzzy logic as inference engine.

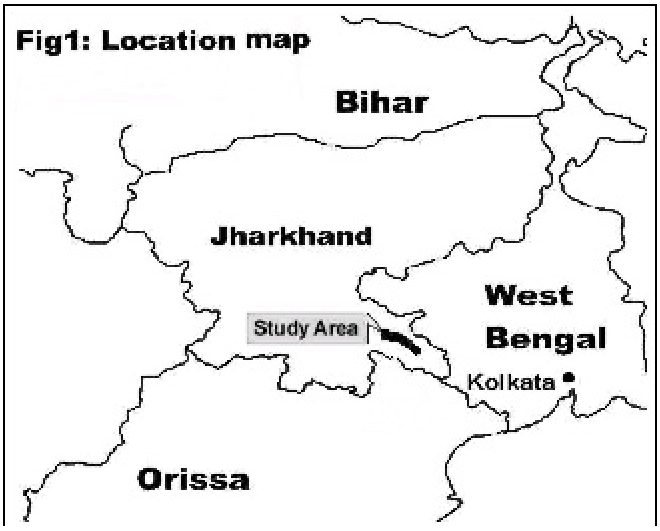

Fig1: Location map

GIS Modeling

In the classical GIS modeling, the process converts the multiclass maps into binary predictor pattern. The pattern assumes a boundary between favourable and unfavourable ground (Carranza and Hale, 2000). However, the boundary between these two classes, is imprecise and thus fuzzy (Carranza and Hale, 2001). Hence, classifying predictor maps on the basis of their mineral favourability needs a concept which takes care of the favourability zones on a gradational basis rather than simply classifying them into classes of membership or non membership. As fuzzy set is expressed on a continuous scale from 1 (full membership) to 0 (full non membership) (Bonham-Carter, 1994), the inference engine generates map on a gradational pattern depending on the fuzzy membership value, which also takes into consideration the probability and possibility of finding mineral potential in actual ground. In the fuzzy system, the extraction and combination of different evidences, is carried out by operators. An.p., et. al. (1991) discussed five operators, which are found useful for combining the exploration dataset. These are fuzzy and, fuzzy or, fuzzy algebric product, fuzzy algebric sum and fuzzy gamma operators. Out of these five operators: the last four operators have been used which deserve elaboration. (Bonham –Carter, 1994).

- *Fuzzy or* is like Boolean or operator (logical union). The output membership values are controlled by the maximum value of input map. The function is defined as
  $m_{Combination} = Max (m_A, m_B, m_C, \ldots\ldots)$

- Fuzzy algebric product is defined as
  $m_{Combination} = {}^{i=1}P^{n} (m_i)$; Where m_i is the fuzzy membership values of i^{th} map and i= 1,2,3,..n
  The combined fuzzy membership values tend to be very small due to multiplying effect of several numbers less than 1, i.e. the effect is decreasing.

- Fuzzy algebric sum is complementary to algebric product and defined as:
  $m_{Combination} = 1 - {}_{i=1}P^{n} (1 - m_i)$; Where m_i is the fuzzy membership values of i^{th} map and i= 1,2,3,..n. The result of this operation is always larger than or equal to largest contributing fuzzy membership value i.e. the effect is increasing.

- Fuzzy gamma operator is defined as:
  $m_{Combination} = (\text{fuzzy algebric sum})^{g} * (\text{Fuzzy algebric product})^{(1-g)}$
  The g value is arbitrary and ranges from 0 to 1. When g is equal to 0 then the combination is fuzzy algebric product. As g is equal to 1 then combination is fuzzy algebric sum.

Application of fuzzy operators on exploration dataset

Brief Geology and Mineralisation

The Singhbhum Shear Zone is developed along the southern fringe of the Proterozoic Fold Belt of North Singhbhum. This fold belt is sandwiched between the Early Archean Cratonic Nucleous represented by Singhbhum and Bonai Granite in the south and Proterozoic Chottanagpur Granite Complex to the north. The intervening gap area between the Singhbhum and Chottanagpur crustal province, is occupied by a curvilinear belt of metasedimentaries belonging to Dhanjori and Singhbhum Group of Proteropzoic age. The Singhbhum shear zone which has developed in this Proterozoic belt, is a northery dipping arcuate ductile shear zone (Ghosh and Sengupta, 1987) marked by lenticular mylonite zone. The width and trend of the shear zone is 10 km and SW-NE in the western part , gradually narrows down to 1 km and E-W in the central part and again widens to more than 5 km and NW-SE in southeastern part. In the southeastern part the shear zone splits into a number of N-S trending narrow shear zones (Banerji,1981). In the western part the shear zone branches out and follows the northern and southern boundary of Chakradharpur Granite Gneiss. The rocks within the Singhbhum shear zone form a tectonic mélange comprising of granite mylonite, quartz-mica phyllonite, quart-tourmaline rock and deformed volcanic and volcanoclastic rocks (Mukhopadhyay and Deb, 1995). The shear sense indicator suggests a thrust type of deformation (Mukhopadhyay and Deb, 1995). The copper mineralised zone runs parallel to Singhbhum Shear Zone.

The principal ore in this belt consists of chalcopyrite, pyrite and pyrrhotite. The ore zones form a number of parallel to sub-parallel discontinuous lodes aligned along the major tectonic grains of the area. Mode of occurrence varies from massive to braided veins, stringers, dissemination and discordant to sheet like bodies. Volcanic origin of the orebody has been suggested by several workers on the basis of d34 S data. Existence of both structural and stratigraphic control on ore localisation is apparent. The general trend of the orebody is controlled by the local trend of shear bands, these bands also act as a channel for remobilisation (Anon, GSI, 1991). Chloritisation, sericitisation, biotitisation, tourmalinisation and albitisation are common wall rock alteration products (Anon, GSI, 1991).

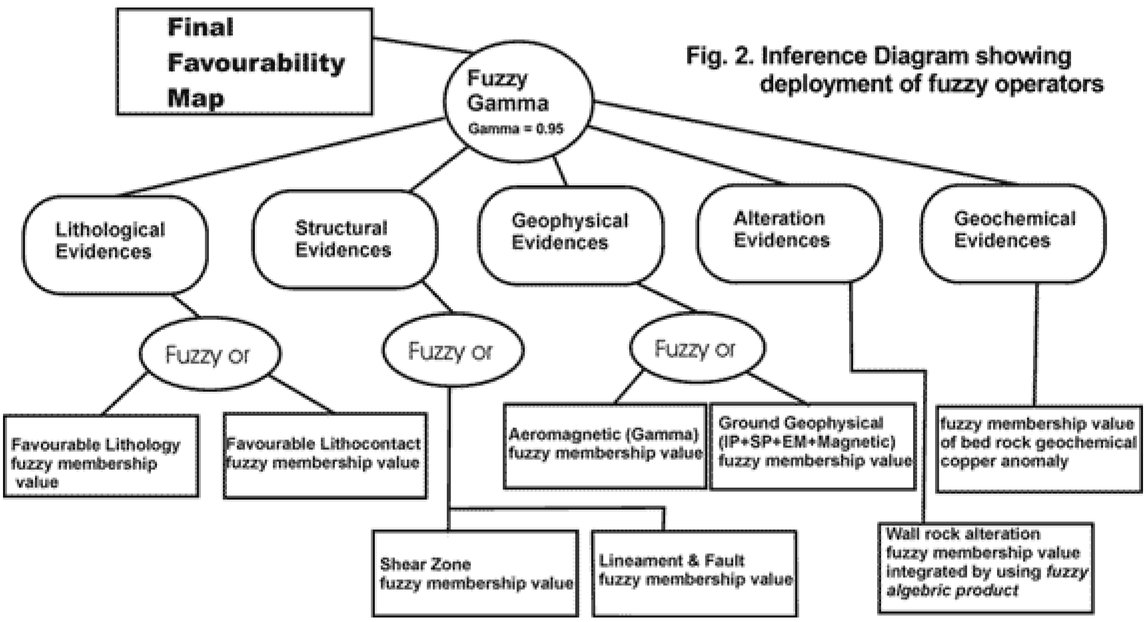

Fig. 2. Inference Diagram showing deployment of fuzzy operators

Exploration model

- Surface and subsurface investigations suggest that chlorite schist, quartz-chlorite schist, sericite-quartz chlorite schist, chlorite-quartz schist and its variants, altered basic rocks in most of the cases and soda-granite in Mosabani - Badia area belonging to Singhbhum and Dhanjori Groups act as host rocks for copper mineralisation.

- Lithocontacts of above mentioned metasediments and basic volcanic rocks serve as easy channel for ore mobilisation during shearing.

- Structural fabric generated during folding episodes and shearing are the fundamental planes for ore localisation. Shear zone itself and lineaments parallel and close to it also serves as general conduit for ore mobilisation.

- High aeromagnetic and ground geophysical anomalies are important signature for subsurface mineralisation.

- Wall rock alteration in the form of chloritisation, sericitisation, biotitisation and tourmalinisation are imprint caused by ore fluid and host rock interation.

- Presence of bed rock geochemical anomaly is indicator of subsurface mineralisation.

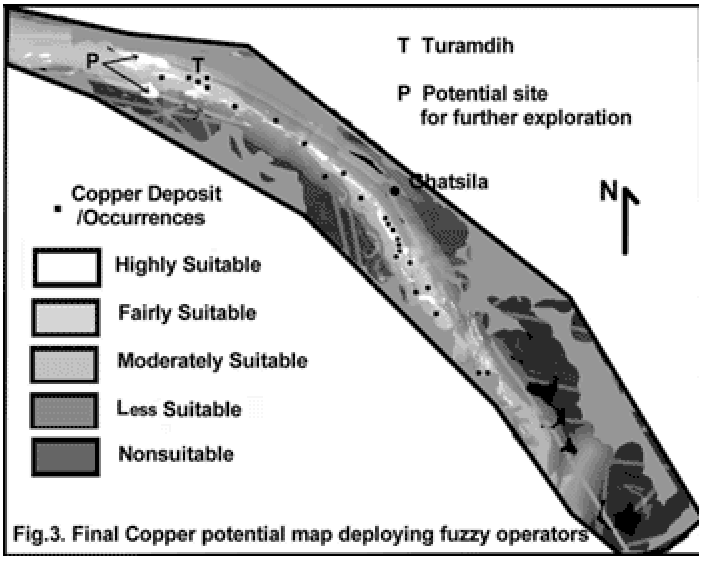

Fig.3. Final Copper potential map deploying fuzzy operators

GIS data set

The GIS data set comprises of following layers

Lithology and favourable contacts: Existing field geological map, compiled in 1:50000 scale was digitised. After creating the polygon topology, lithological attributes are updated. Similarly the favourable lithological contacts were also digitised from the same map.

Lineament, fault and shear zone: The lineament map interpreted from satellite imagery (courtesy Mr. D.P. Das, Geologist (Sr.), GSI) were digitised. The shear zone and faults were digitised from compiled degree sheet of 73J in 1:2,50,000 scale and 1:50,000 scale compiled geological map respectively.

Alteration: The main lithounits underwent alteration mentioned above were digitised from the compiled map. Geophysical: The contours of aeromagnetic map were digitised and converted into polygon topology. The polygon attribute values are updated from contour value. The ground linear anomaly axis of IP,SP,EM and magnetic were digitised from exiting ground geophysical map.

Geochemical: Interpreted geochemical anomalies (generated from analytical value of bed rock samples) in the form of available contour maps were digitised into polygon coverage.

Generation of fuzzyset

The exploration model outlined earlier suggests the importance of each GIS dataset in analysis.The pricipal approaches taken for calculating fuzzy membership values are illustrated below.

- Reclassification of complex geological, aero magnetic and geochemical map into smaller numbers of simplified units.

- Generation of proximity map by buffering operation showing classes of distance to linear features (such as favourable litho contact, lineaments, shear zone, ground geophysical anomaly axis etc.).

- Assignment of fuzzy membership values to each element (class) of a map by intuitive subjective judgment in case of qualitative/discrete data or by defining a simple mathe-matical function in case of quantified/continuous data.

The procedure adopted on different GIS layers is summarised below.

Analysis of host lithology: The sulphide mineralisation is considered to be associated mainly with volcanics and metatuffs of Singhbhum and Dhanjori Groups. The geological map, originally containing 28 lithounits, was reclassified into four groups as per exploration model and assigned a fuzzy membership value of 0.9,0.8,0.6 & 0.2 respectively (Table 1).

Analysis of favourable contact: Detailed exploration reveals that contact between metasediments and metavolcanics are generally mineralised to a varied extent. The favourable contacts are buffered at an interval of 250m. The buffered polygons are reclassified into four broad classes according to its significance towards copper mineralisation and assign a fuzzy membership value of 0.9,0.8,0.6 and 0.2 respectively (Table 1).

Analysis of aeromagnetic data: The aeromagnetic polygon anomaly data represents a range from 700 to 4500 gamma. The fuzzy membership value of each polygon is obtained by dividing the gamma value of that polygon by 4500 (the highest value), thus, represents a range between 0 and 1.

Analysis of shear zone: The shear zone is represented as a line on the map. This line was differentially buffered at an interval of 500m and classified into six groups. The groups are assigned a fuzzy membership value from 0.9 to 0.4 depending upon its distance from shear zone (Table 1).

Analysis of lineaments and faults: Lineaments interpreted from Landsat imagery and faults marked on regional mapping were buffered using a distance of 100m. The polygons were reclassified into three categories according to its orientation and relation with the shear zone. The fuzzy membership values are assigned to those groups as 0.5,0.3 and 0.1 respectively (Table 1).

Analysis of ground geophysical anomaly: The groung geophysical anomaly axis of IP, SP, EM and magnetic were buffered with a distance of 250m. The buffered polygons are subdivided into two classes and assigned a fuzzy membership value of 0.9 and 0.2 respectively (Table 1).

Analysis of wall rock alteration: Four types of wall rock alteration described earlier are prevalent in the area. In a particular polygon which represents simultaneous occurrence of two or more alteration type, is assigned a fuzzy membership value of 0.5, whereas for the presence of one alteration type fetches value as 0.3 and rest is assigned a value of 0.01 (Table 1).

Analysis of bed rock geochemical data: Geochemical evaluation of an area leads to identification of host rock and possible source of mineralisation. In this process both primary and secondary dispersion pattern of element are evaluated and a relationship between them are established. A definitative relationship between soil and bed rock geochemical pattern is apparently not established in this area. Therefore, geochemical data of bed rock alone was used to generate primary anomaly polygons. The copper value ranges from 100 to 4000ppm. The fuzzy membership value of each polygon is obtained by dividing the copper value of that polygon by 4000.

Map combination using fuzzy operators

Map combination is an intuitive method where different primary and derived evidences are combined by a set of principles. For example, in this case, the evidence maps generated in earlier section can be combined in raster mode by a single or combination of fuzzy operators. A detailed inference diagram (fig. 2) is attempted to show how the different layers are combined and finally integrated by fuzzy operators. Here, the geological, geophysical and structural evidences are combined by fuzzy or operator to extract the maximum evidence from each layer. It also suggests that high value of any layer can be a useful evidence for copper mineralisation. Fuzzy algebric product operator is used in wall rock alteration layer to extract evidences for one or more alteration evidences. Finally all the evidence maps are combined by fuzzy gamma operator with gamma value as 0.95 to generate the final predictive map. Choosing of gamma value is subjective. As opined by Bonham-Carter (1994): to generate increasing effect of fuzzy membership values in the final map, gamma value need to be higher than 0.8. In this particular case, increasing gamma value higher than 0.95 bears very little effect on the final map (i.e. final GIS model). The final map grades the region into five subclasses in terms of suitability of finding copper occurrences i.e. highly suitable, fairly suitable, moderately suitable, less suitable and nonsuitable (Fig. 3).

Table 1: Fuzzy memebership value assigned to geological features of Singhbhum Copper Belt.

Lithology		Favourable Contact		Shear Zone		Lineament and Fault		Wall Rock Alteration		Ground Geophysical (IP+SP+EM+Magnetic)	
Lithological Unit	Fuzzy Mem. Value	Contact between	Fuzzy Mem. Value	Distance class in meters	Fuzzy Mem. Value	Relationship with shear zone	Fuzzy Mem. Value	Criteria	Fuzzy Mem. Value	Characte-ristics	Fuzzy Mem. Value
(I) Chlorite schist/ quartz chlorite schist/ sericite quartz chlorite schist/ chlorite quartz schist/ Talc chlorite schist / soda granite	0.9	(i) Units of Group (I) of column 1	0.9	<= 500	0.9	(i) Within 250m and parallel to sub-parallel to shear zone	0.5	(i) Two or more alteration type present	0.5	(i) Strong ground anomaly	0.9
(II) Hornblende schist and Epidiorite	0.8	(ii) Units of Group (II) and between Group (I) & (II)	0.8	>500 - <=1000	0.8	(ii) Within 250m and not parallel to shear zone	0.3	(ii) Only one alteration type present	0.3	(ii) Weak ground anomaly	0.2
(III) Ultrabasics and mica schist	0.6	(iii) Units of Group (III) and between Group (II) & (III)	0.6	>1000 - <=1500	0.7	(iii) Outside 250m of shear zone	0.1	(iii) No alteration present	0.01		
(IV) Other rock types	0.2	(iv) Other rock types	0.2	>1500 – <= 2000	0.6						
				>2000 – <= 2500	0.5						
				>2500 – 3000	0.4						

Inference and conclusion

The final potential map or GIS model generated by deploying fuzzy inference engine are cross-validated by two different methods. Firstly, the known major copper occurrences / deposits are plotted on the final model i.e. potential map (Fig. 3). It is found that 60% of the deposits are lying on the high suitability zone. Secondly, it is also found that high suitability zone coincide well with the high bed-rock geochemical anomaly. Thus, it can be stated that the criteria and combination method chosen for this modeling fitted well with the existing ground reality. From the final predictive map it is inferred that the two clusters (marked as P) located west of Turamdih area are considered highly as the potential sites for further detailed exploration. It is worthwhile to mention that the areas west of Turamdih as potential areas for further exploration were also delineated by Mukhopadhyay et. al., 2002 by index overlay method. It is also to be noted that surfacial expression of mineralisation in these areas is less prominent. Hence, deeper probing by drilling or geophysical survey may be a good alternative.

Acknowledgement

The authors express their gratitude to all the officers who worked on Project Singhbhum and Project geoinformatics – Singhbhum Precambrian on 73J. They also remain grateful to DG, GSI for giving permission to publish this paper.

References

- An,P., Moon, W.M. and Rencz, A., 1991. Application of fuzzy set theory for integration of geological, geophysical and remote sensing data, Canadian Journal of Exploration Geophysics, V 27 : 1-11
- Anon, GSI, ER, 1991. Unpublished GSI report on Project Singhbhum – Synthesis of data of Singhbhum Copper Belt, Singhbhum District, Bihar: Part I & II., unpublished
- Bonham-Carter, G. F.,1994, Geographic Information System for Geoscientists: Modelling with GIS: Pergamon.
- Banerji, A.K.,1981. Ore genesis and its relationship to volcanism, tectonism, granite activity and metamorphism along the Singhbhum Shear Zone, Eastern India, Economic Geology, V 76: 905-912
- Carranza ,E.J.M.. and Hale, M., 2000, Geologically-contrained probabilistic mapping of gold potential, Baguio district, Phillipines, Natural Resource Research, V9, no 3: 237-253.
- Carranza ,E.J.M.. and Hale, M., 2001, Geologically-contrained fuzzy mapping of gold mineralisation potential, Baguio district, Phillipines, Natural Resource Research, V10, no 2 : 125-136.
- Ghosh, S. K. & Sengupta, S., 1987, Progressive development of structures in a ductile shear zone: Journal of Structural Geology. V 9 : 277-287.
- Mukhopadhyay, Basab., Hazra, Niladri.,Das, Swapan Kumar.,and Sengupta, Sujit Ranjan., 2002, Mineral potential map by a knowledge driven GIS modeling : an example from Singhbhum copper belt, Jharkhand, Proceedings of 5th annual international conference Map India 2002, New Delhi : 405-411.
- Mukhopadhyay, D. and Deb, G.K., 1995, Structural and textural development in Singhbhum Shear Zone, Eastern India, Proc.Indian.Acad.Sci, V104, no3: 385-408.