A GIS-based Fuzzy Logic Method for Mineral Potential Mapping: An Experiment with a Geological Map of the Parry Islands, NWT, Canada.

Thesis submitted in partial fulfillment
of the requirements
for the degree

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"...How then am I so different
From the first men through this way
Like them I left a settled life
I threw it all away
To seek a Northwest Passage
At the call of many men
To find there but the road back home again.

Ah, for just one time
I would take the Northwest Passage
to find the hand of Franklin reaching
for the Beaufort Sea
Tracing one warm line
Through a land so wide and savage
And make a Northwest Passage to the sea."

Stan Rogers (1949-1983).
From "Northwest Passage".

ABSTRACT

The application of fuzzy logic in a GIS framework is a valuable method to assist in mineral resource assessments (MRA) in areas where data are sparse. This study uses a digital geological map, backed by a digital geological data model, derived from published legends and reports. Together they function as a 'spatial-attribute relational data model' that provides evidence, in the form of derivative maps, to support mineral potential according to deposit model criteria. A knowledge-base is created with fuzzy membership functions linked to the classes of each derivative map that indicate favourability between geological features present in the database with those required by model criteria. A fuzzy-logic-based 'inference net', as implemented in the GIS modelling language, is used to combine spatial evidence to determine mineral resource potential for three mineral deposit sub-types: 1) MVT Pb-Zn, 2) Sedimentary Cu and 3) Sediment-Hosted Sulphides. This method is shown to be valuable for providing an 'audit trial' for the complex decision-making process associated with resource assessment; it provides a means for experimenting and testing various hypotheses and viewpoints associated with mineral deposit models, and mimics some aspect of how geologists determine mineral potential for a region using information provided in geological maps and mineral deposit model literature.

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1. CHAPTER 1 - INTRODUCTION

1.1. Introduction

A mineral deposit model is defined as "systematically arranged information describing the (some or all of the) essential attributes (properties) of a class of mineral deposits" that may be empirical (descriptive) or theoretical (genetic) (Cox et. al. 1986). As a sub-discipline of geology, mineral deposit modelling is still in its early stage of development, however, deposit models developed over the past several decades have been very useful for mineral resource assessment and mineral exploration. The practice of 'mineral potential mapping' allows a typical mineral resource assessment to portray the potential of a region according to the relative potential of a various mineral deposit model types.

Whereas most current practices of mineral resource assessment are subjective and qualitative, this thesis presents one approach towards more objective and quantitative mineral resource assessment using geographical information system (GIS) techology. The power of GIS combined with knowledge-based systems design provides a potentially useful tool for applying todays' deposit models for exploration and resource assessment, and further enhances the ability to continue to test, refine, or modify existing models, and develop new ones.

The objective of this study is to research and develop a 'prototype' method that combines GIS and 'fuzzy logic' methodology for mineral potential mapping. For demonstration purposes, the method is applied with three example mineral deposit sub-types for the Parry Islands, Northwest Territories. The results provide the relative mineral potential for MVT Pb-Zn, Sedimentary Cu, and Sediment-Hosted Sulphide deposits on the Parry Islands, according to deposit sub-type criteria provided in Eckstrand (1984). The prototype design provides one foundation for the development and implementation of a full mineral deposit modelling system.

1.2. Background

Geologists are accustomed to working with geological maps as an aid to solve many types of geological problems. Geological decision-making frequently invloves either one, or a group, of geologists reading a geological map and making inferences and drawing conclusions about geological processes. This is common practice during the early stages of mineral resource assessments. When geologists are asked to determine the relative mineral potential for an area, they examine geological maps, and associated data and reports, and produce a new map of mineral potential for various commodities or mineral deposit types. Their results are products of their knowledge combined with the information derived from the geological map and associated reports. In this process, there are three basic components at work: geological data, mineral potential criteria (derived from mineral deposit models), and deduction of how well the criteria apply to the geological map. The mineral potential analysis involves a reasoning process that incorporates numerous pieces of data, information and knowledge derived from experience.

When this process is applied using hard copy geological maps by manually tracing the mineral potential on to a transparent overlay, there are several constraints that limit the results. First, the manual process of tracing information on to separate overlays is laborious and time consuming. Geologists involved in mineral resource assessment usually work with time and budget constraints, so any method that may automate and speed up this process is worth investigating. Second, the knowledge and decisions made during the process are difficult to document thoroughly. The lack of an 'audit trail' makes it difficult to repeat the process, either to duplicate the results given the same data, or to experiment with different assumptions during the mineral potential mapping process. In order to overcome some of these limitations, geologists have been researching the application of Geographical Information Systems (GIS) technology.

Geological research has benefited in a number of areas from the use of Geographic Information Systems (GIS) and related digital mapping technologies in recent years. Since the late 1980s, GIS technology has become more accessible to geologists through PC and workstation-based software, which in turn has catalyzed development of a large number of digital geoscience databases. Research in mineral potential mapping methods has also been catalyzed by GIS technology. Some of the recently developed methods include: weights of evidence (Bonham-Carter et al. 1990), Dempster-Shafer belief theory (An et al. 1993, 1994; Chung and Fabbri, 1993), area-weighted logistic regression (Reddy et al., 1992), fractal and multi-fractal techniques (Cheng, 1994), prospector-style inference networks (Reddy et al. 1992; Bonham-Carter, et al. 1994), decision trees (Reddy and Bonham-Carter, 1991), and fuzzy logic (An et al. 1991; Bonham-Carter 1994; Eddy et al. 1993; Wright and Bonham-Carter, 1994). Different methods may be applied in different areas depending primarily on factors such as the type, quality and scale of available data, and the context in which mineral potential must be portrayed.

Whereas most of these methods are readily available for any type of mineral resource assessment, they were developed for situations involving 'multi-layered' geoscience datasets. Multi-layered geoscience datasets comprise not only geological maps, but also various types of geochemical and geophysical layers, and sometimes evidence of mineralization in the form of locations of mineral deposits and occurrences, or alteration zones. The application described here is unusual in that it uses a 'single-layered' geoscience dataset comprised solely of a geological map, although a 'multi-layered' dataset is preferable where the data are available. Whereas statistical methods of quantitative mineral potential mapping assist in identifying relationships between various types of geological patterns among the multiple layers, the present application provides a method that simulates some aspects of how geologists determine the mineral potential of an area based solely on their knowledge of the geology, and mineral deposit model criteria. The objective of this study is to develop a prototype 'expert system' application that uses fuzzy logic as the means for representing knowledge and inferring mineral potential.

Although this application is designed specifically for mineral potential mapping of three specific mineral deposit sub-types, the general design may be used as a foundation for modelling the potential for other mineral deposit types; or it may also be used for other application areas such as environmental sensitivity and resource management decision making. The fuzzy logic method is applied to the Parry Islands, NWT, (Location Map, Enclosure 1B), for Mississippi Valley Type Pb-Zn, Sedimentary Cu and Sediment-Hosted Sulphide potential.

The Parry Islands represents a suitable test area because the geological data available for this area are limited to a 1:1,000,000 geological map (Okulitch, in prep.) and associated reports (Harrison, 1991, Harrison, 1994, Kerr, 1974). The scale of available geological maps and regional geological reports of these types is typical of most large regions in the NWT where resource assessment is applied. The 1:1,000,000 scale geological map is used as a means to express various abstractions of the regional geological setting of the Parry Islands, and its inferred mineral potential. Limitations of the results of this experiment are in some ways attributed to the nature and quality of the available data, however, the fuzzy logic method is capable of yielding higher quality results when more detailed information is used.

1.3. Thesis Format

This thesis represents an integration of three discipline areas: 1) Mineral Resource Assessment and Mineral Potential Mapping, 2) GIS technology, and 3) Expert Systems and Fuzzy Logic (Figure 1.1). The discussion in this thesis deals with a mixture of these subjects. Developing a new method for mineral potential mapping for use in mineral resource assessment is the ultimate objective of the thesis. The method applies concepts from expert systems using fuzzy logic and implemented with GIS technology to meet this objective.

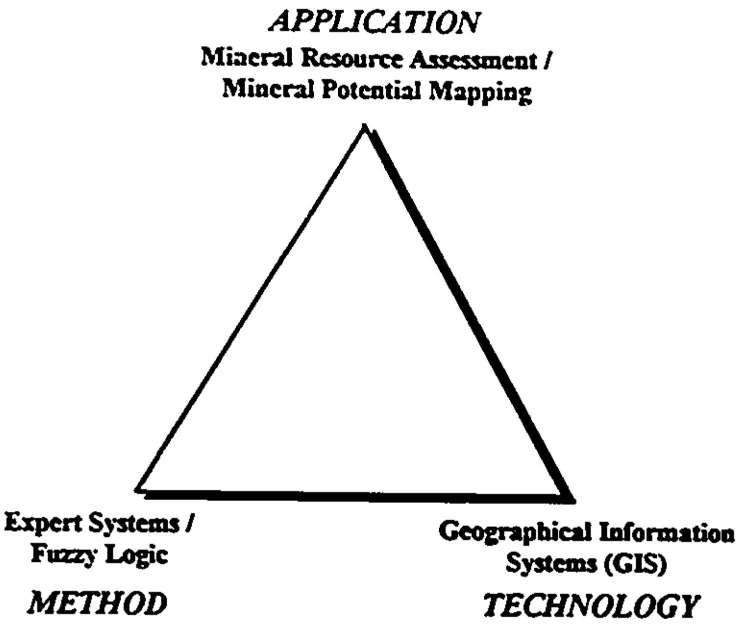

FIGURE 1.1. THREE DISCIPLINE AREAS INTEGRATED IN THIS THESIS.

Chapter 1 - Introduction - provides an overview and scope of the thesis in terms of the objective, background, and research requirements. In **Chapter 2 - Expert Systems and Fuzzy Logic** - a general introduction to expert systems is presented that focuses on the use of fuzzy logic as a method for knowledge representation and reasoning in decision making. This discussion establishes the context for the application of fuzzy logic to mineral potential mapping.

Chapter 3 presents a structured approach for designing the application. This design method involves progressing from a 'conceptual model' to a 'logical model' to an 'implementation model' for the prototype application. The conceptual model identifies the key components and processes that operate in the system, and identifies the role of fuzzy logic in the mineral potential mapping process. In the logical model, the conceptual model is enhanced to consider how the components and processes operate in a GIS.

This model is used to guide the process for implementing the application, which is introduced in **Chapter 4 - Database Development**. The database development process requires careful consideration of the limitations in existing data, knowledge about the data and mineralization processes, and the ultimate objective of determining the relative mineral potential for several mineral deposit types. This process results in the design of the 'implementation model' for the system.

Chapter 5 - Mineral Potential Mapping - illustrates how the application is used for mineral potential mapping. This is achieved by incorporating 'knowledge' in a computerized database, and how the 'knowledge-base' is used for determining mineral potential. Each of three deposit models are iterated twice to demonstrate the flexibility of the GIS-based fuzzy logic method and illustrate how changes in model assumptions affect the results. A brief discussion on the significance of the results, limitations of the method, and key conclusions are presented in **Chapter 6 - Discussion.**

1.4. Acknowledgements

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2. CHAPTER 2 - EXPERT SYSTEMS and FUZZY LOGIC

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2.1. Fundamentals of Expert Systems

An 'expert system' is a computerized system which utilizes data and knowledge to make decisions (Biondo, 1991). Most literature on expert systems technology approach the subject from the standpoint of a particular application, which has resulted in a diversity of concepts and architectures. However, there are some common features of expert systems which are used as models to guide an expert system design process. Biondo (1991) provides a useful overview of some fundamental concepts of expert systems that is consistent with the research and development of expert systems for mineral potential mapping. This section provides a brief overview of the principles of expert systems to allow clarification of the relationship between 'fuzzy logic' and knowledge-based mineral potential mapping with GIS.

Expert systems are designed to assist or mimic conventional decision-making, and are applied in situations where a computerized method is considered more efficient and reliable than non-computerized methods. Decision-making uses data and knowledge combined with information processing and reasoning. There are four components involved in this concept: 1) Data, 2) Information, 3) Knowledge and 4) the Decision.

"Data" are considered to be a collection of numbers, facts or symbols. The transformation of data into "information" is done by some decoding mechanism. The information is then used in conjunction with "knowledge" to make a "decision". For example, consider a man in a clothing store making a decision on whether or not to purchase a certain winter coat. The price marked on the coat is $ 59.95, and the salesperson mentions that there is also a 10 % off sale. The retail price of $ 59.95 is a datum, the sale price (including tax) of $ 62.09 is information, "This coat is poor quality" is knowledge, and "I will not purchase this coat" is the decision. In this case, knowledge conveys a relationship between the cost of the coat and a subjective judgment of its quality. The decision to not purchase the coat utilized the original data, transformed it into information by the equation $((59.95 - 5.99)+(.15*(59.95-5.99))= 62.09$, and recognized subjectively that the quality was not worth the monetary value. This analogy is developed in greater detail with fuzzy logic in section 2.3.

Biondo (1990) presented three basic elements for an architecture of an expert system that interact in such a way to mimic this type of decision-making: 1) A knowledge source, 2) a Knowledge Base, and 3) an Inference Engine (Figure 2.1). The three spheres in Figure 2.1 represent the system components in which knowledge is represented in different forms. The data / information component represents 'objective' factual knowledge stored as data and extracted information elements. The knowledge base stores 'subjective' information about the data that is context sensitive to a given proposition. The inference engine drives the reasoning process by which various data and information elements and their associated knowledge-base elements are combined as evidence to produce a decision. The knowledge source may be treated as all sources of knowledge pertaining to the data, the knowledge-base, and the reasoning process. In this sense it is the larger 'knowledge source' from which all three components are derived.

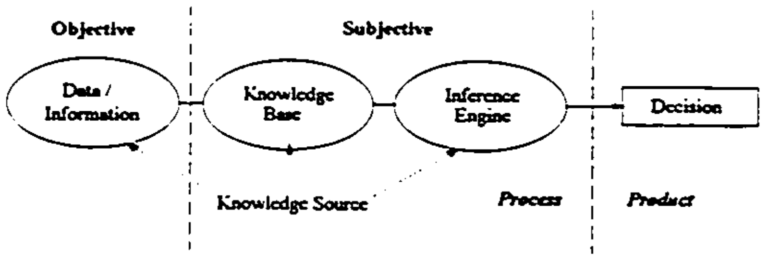


FIGURE 2.1. SCHEMATIC DIAGRAM SHOWING BASIC COMPONENTS OF EXPERT SYSTEMS.

The architecture of an expert system may vary depending upon the type of application. An important element of their design is how these three components interact to mimic decision-making in a given situation. An ideal setting would comprise a complete database from which any type of information could be derived. However, decision-making in the real world is non-ideal due to limitations in the availability of data, and knowledge about the data and subject of the issue being addressed.

The choice of which reasoning technique to use depends on the nature of the uncertainties in the process with respect to data and knowledge. Strict logical reasoning, based on classical Boolean rules using incomplete data and knowledge, is not possible (Biondo, 1991). Real decision making is usually not based on such clear certainty of evidence; therefore, a means of logical deduction is required that is capable of dealing with uncertainties in data and knowledge. Biondo (1991) identified five principal mathematical methods used in inference engines that are capable of dealing with uncertainty. The methods are classified into numeric and non-numeric approaches (Figure 2.2).

Approach	Methods
Numeric (Quantitative)	Bayesian probability Certainty Factors Dempster-Shafer belief Fuzzy Logic
Non-numeric (Qualitative)	Non-monotonic

FIGURE 2.2. METHODS FOR DEALING WITH UNCERTAINTY IN AN EXPERT SYSTEM. (SIMPLIFIED FROM BIONDO, 1991).

A numeric method represents a quantitative approach, wheras a non-numeric method represents a qualitative approach. Each method contains its own forms of knowledge representation and reasoning techniques, or combination rules. The combination rules refer to the reasoning mechanisms used for combining evidence in an inference network. For example, classical logical reasoning uses Boolean logic. For knowledge representation, each piece of evidence used to support a proposition takes on a value of either "1 ", representing true, or "0", representing false. Evidence is combined with "AND/OR/XOR" rules to reach a conclusion (Copi, 1982).

The numeric methods in Figure 2.2 depart from the classical Boolean logic method in that they allow for uncertainty in the evidence variables. These methods can provide the foundation for a quantitative approach to GIS-based mineral potential mapping. The following section summarizes some of their applications, and establishes the conditions by which fuzzy logic is used in this study.

2.2. Expert System Applications in Mineral Potential Mapping

The methods discussed by Biondo (1991) for use in expert systems are fundamentally similar to some methods applied in mineral potential mapping. Because of the spatial context of geoscience data and knowledge, these methods have been modified for application to mineral potential mapping (Chung and Fabbri, 1993). One distinction among GIS-based mineral potential mapping methods lies in the data and information used to drive the process. Quantitative methods used in GIS-based mineral potential mapping may be categorized as either "data-driven" or "knowledge-driven". Data-driven methods determine mineral potential on the basis of evidence statistically associated with known mineralization, whereas knowledge-driven methods use expert knowledge of mineralization processes, and combine geoscientific evidence to determine favourability subjectively (Bonham-Carter, 1994).

Some of the data-driven methods that have been applied successfully include: weights of evidence (Bonham-Carter et al. 1990), area-weighted logistic regression (Reddy et al., 1992; Agterberg et al. 1993), fractal and multi-fractal techniques (Cheng, 1994), decision trees (Reddy and Bonham-Carter, 1991) and neural-networks (An et al. 1993). The principal requirement for the application of data-driven methods are training sites, or analogues. Data-driven mineral potential mapping requires sufficient known mineral occurrences in the study area to adequately compare the conditions for mineralization with geological factors represented in a geoscience dataset. Mineral favourability is determined quantitatively by analysing the association between evidence layers and mineral occurrence locations; the statistical associations are then used to calculate mineral potential throughout the study region.

Knowledge-driven methods include: Dempster-Shafer belief theory (An et al.1994; Chung and Fabbri, 1993), certainty factors (Chung and Fabbri, 1993) prospector-style inference networks (Campbell et al. 1982; Reddy et al. 1992) and fuzzy logic (An et al. 1991; Bonham-Carter 1994, Eddy et al. 1993, Wright and Bonham-Carter, 1994). Knowledge-driven methods are applied to areas where there is a paucity of known mineralization, or where quantitative relationships among geological patterns are not clearly defined. It is also possible for a hybrid of data-driven and knowledge-driven methods to be used in an expert system as long as a 'knowledge-base' is used. For the purpose of this study, only knowledge-driven methods are reviewed, which are summarized in Table 2.1.

TABLE 2.1. SUMMARY OF KNOWLEDGE DRIVEN METHODS USED IN MINERAL POTENTIAL MAPPING DISTINGUISHED ON THE BASIS OF KNOWLEDGE REPRESENTATION AND RULES OF INFERENCE.

Method	Applications	Knowledge Representation	Inference Rules
1. Dempster-Shafer Belief	An et al. 1994; Chung and Fabbri, 1993.	Belief Function (x_1) and Plausible Function (x_2) on [0,1] interval, where x_1 = degree of belief, ($1-x_2$ = degree of disbelief, and (x_1-x_2)=degree of uncertainty.	Uses Dempsters' combination rule that treat belief and plausible functions in a probabilistic manner.
2. Certainty Factor	Chung and Fabbri, 1993.	Certainty in evidence is represented on [-1,1] interval where (-1,0) values represent decreasing certainty, (0,1) values represent increasing certainty.	Uses AND/OR combination rules and treats factors by updating prior probabilities with certainty factors associated with evidence.
3. Prospector Inference Net	Campbell et al. 1982; Reddy et al. 1992.	Prior probabilities assigned to evidence and hypotheses, and likelihood ratios as strength of inference between individual evidence-hypothesis chains.	Uses Fuzzy Logic and BAYES probability updating with AND, OR, and BAYES combination rules.
4. Fuzzy Logic	An et al. 1991, Bonham-Carter, 1994; Chung and Fabbri, 1993; Eddy et al. 1993; Wright and Bonham-Carter, 1994.	Fuzzy membership values in the range of [0,1] are assigned to evidence in support of a proposition.	Fuzzy combination rules AND, OR, SUM, PRODUCT, and GAMMA.

Each of these methods is suitable for different applications depending upon the type and quality of geoscience data available, the type of mineral potential being modelled, and knowledge availability. Each method employs 'favourability functions' that allow the expert to express subjectively the degree of support on favourability of various pieces of evidence. The proposition (or hypothesis) is that a location on the map is favourable for mineral deposits of a particular type. Favourability functions associated with different exploration datasets (each one considered to be a piece of evidence) are combined together with rules. The rules define how conflicting or mutually supportive evidence are merged to give a combined favourability value. Combined favourabilities are calculated for each location on a map and the result is a favourability map that represents the potential for mineral deposits of that particular type. The four methods in Table 2.1 are similar in that they all use favourability functions and combination rules. They differ in the nature of the favourability functions and the form of the rules. For this study, it is important to establish the distinction between fuzzy logic and the other knowledge-driven methods.

The fuzzy logic method is different from the first three methods in three ways. First, the fuzzy logic favourability functions are expressed in terms of 'possibilities' as opposed to 'probabilities', thereby avoiding the need to deal with probability distributions (An et al. 1991) or to assume conditional independence (Biondo, 1990). This is important since it is often difficult to determine a probabilistic relationship between geological features and mineralization. The possiblity scale, like the probability scale, is defined over the range [0,1], but possibilities need not satisfy probability rules. Thus the possibility of an event occurring need not equal 1 - possibility of the event not occurring, as is the case for probability.

Second, the fuzzy logic favourability functions (also called fuzzy membership functions) express a single favourability for each value of a mapped variable being used as evidence. This is in contrast to the Dempster-Shafer method which uses a pair of favourability functions (or belief functions) for each variable: a lower belief function and an upper belief (or plausibility) function. Thus in the Dempster-Shafer method, each value of a variable used as evidence is associated with two favourabilities: a lower belief and an upper belief. This is known as the evidential interval.

Thirdly, a wide variety of combination rules have been proposed for combining fuzzy membership functions. These rules can express a range of decision-making behaviour, whereas the Dempster-Shafer, certainty factor, and Bayesian updating rules for probabilities are less flexible. The following section describes the favourability functions and combination rules of the fuzzy logic method as used in this thesis.

2.3. Elements of Fuzzy Logic

Fuzzy logic represents knowledge in the form of 'fuzzy membership functions' that are assigned to evidence variables according to a given proposition. Algebraically, a fuzzy membership finction is a set of ordered pairs:

$$\{[x, \mu_x] \mid x \in X \qquad (1)$$

where X is variable used as evidence, x is the value of X, and μ_x is a fuzzy membership value assigned by an expert to x that reflects its level of favourability for a proposition.

As a variation on the above example that involved the decision to purchase a coat, suppose the customer would like to select from a variety of coats that have different costs and qualities. If the first proposition is to determine whether the coat is good value, the proposition in this case may be stated: "*The coat is expensive.*" A fuzzy membership set would comprise an assigned favourability value for each price (Table 2.2).

TABLE 2.2. A FUZZY MEMBERSHIP FUNCTION FOR THE PROPOSITION: "*The coat is expensive.*"

COST (x)	$(\mu_X(x))$
$ 32.65	0.25
$ 45.53	0.35
$ 52.97	0.60
$ 62.09	0.75
$ 75.88	1.00

This fuzzy set is a numerical representation of the knowledge of the relationship cost and favourability. However, this is not the only factor the customer wishes to use for his decision. He will consider the cost factor combined with a quality factor. To do this, the customer must apply a subjective judgment on the quality of each coat by assigning a fuzzy membership value to the relative quality values. Table 2.3 shows the values of two fuzzy membership functions that correspond to the cost factor and the quality factor, for a particular selection of five coats. The final decision requires a reasoning process that combines the cost factor and the quality factor. In this case, the choice of combination rule will vary according to the customers' preference.

TABLE 2.2. EXAMPLE FUZZY MEMBERSHIP VALUES (μ_{x1} AND μ_{x2}) FOR FIVE WINTER COATS FOR TWO FACTORS: COST (x_1) AND QUALITY (x_2). THE FUZZY COMBINATION RULES, AND, OR, ALGEBRAIC PRODUCT, ALGEBRAIC SUM AND GAMMA PRODUCE COMBINED FAVOURABILITY FOR EACH COAT DEPENDING ON DIFFERENT.

Coat #	COST (x_1)	Quality (x_2)	μ_{x1}	μ_{x2}	Fuzzy AND	Fuzzy OR	Fuzzy Product	Fuzzy Sum	Fuzzy Gamma ($\gamma = 0.85$)	Fuzzy Gamma ($\gamma = 0.15$)
1	$ 32.65	Fair	0.95	0.20	0.20 (4)	0.95 (1)	0.19 (4)	0.96 (1)	0.75 (3)	0.24 (4)
2	$ 45.53	Good	0.85	0.60	0.60 (1)	0.85 (2)	0.51 (1)	0.94 (2)	0.86 (1)	0.56 (1)
3	$ 52.97	Very Good	0.60	0.80	0.60 (1)	0.80 (3)	0.48 (2)	0.92 (4)	0.83 (2)	0.52 (2)
4	$ 62.09	Good	0.35	0.60	0.35 (3)	0.60 (5)	0.21 (3)	0.74 (5)	0.61 (5)	0.25 (3)
5	$ 75.88	Very Good	0.20	0.80	0.20 (4)	0.80 (3)	0.16 (5)	0.84 (3)	0.65 (4)	0.21 (5)

For demonstration purposes, five fuzzy operators used as combination rules for mineral potential mapping applications (An et al. 1991) are employed to demonstrate which coat is most favourable according to different reasoning techniques. They are the fuzzy AND, OR, algebraic PRODUCT, algebraic SUM and GAMMA combination rules. In each case, the combined fuzzy membership value, μ_c, is a function of the individual fuzzy membership values μ_{x1} and μ_{x2}:

$$\mu_c = f_{comb}(\mu_{x1}, \mu_{x2}) \qquad (2).$$

Suppose the customer wants to evaluate each coat on the basis of its least favourable feature. In some cases, the quality may be poor, or the price may be expensive. The coat with the minimum fuzzy membership value determines the favourable of the combination. The fuzzy AND combination rule is used to select the minimum fuzzy membership value with respect to cost and quality. Mathematically, the fuzzy AND combination rule is simply:

$$\mu_c = \min(\mu_{x1}, \mu_{x2}) \qquad (3).$$

Applying this equation to each item results in coat numbers 2 and 3 being equally more favourable than the other three (Table 2.2). The minimum operator effectively screened out the coats that were considered too expensive or poor in quality. It is a conservative rule, where least favourable evidence determines the outcome.

Alternatively, suppose the customer wants to evaluate the combined favourability on the basis of most favourable evidence. The fuzzy OR operator achieves this by taking the maximum value of the fuzzy membership values. The fuzzy OR operator is expressed mathematically as:

$$\mu_c = \max(\mu_{x1}, \mu_{x2}) \qquad (4).$$

In this case, coat number 1 is most favourable, as it received a high membership value because of its low cost. It is easy to identify with the dilemma now facing the customer. Which reasoning process will he use to decide which coat is better ? Most people experience this type of conflict when they are shopping. Perhaps the customer will reconcile the cost and quality factors in a different way.

Recall that the customer first wanted to determine the best buy on the basis of the worst feature of each coat. There was a tie between coat numbers 2 and 3. Although their final ranking rated them equally, coat number 2 was assigned a slightly better value on price than the quality value of coat number 3. The fuzzy algebraic PRODUCT operator could be used to make this distinction. The fuzzy algebraic PRODUCT is simply the mathematical product of the fuzzy membership values in the set; expressed as:

$$\mu_c = \mu_{x1} * \mu_{x2} \qquad (6).$$

As shown in Table 2.2, the fuzzy algebraic PRODUCT produces lower values than either fuzzy AND or fuzzy OR, but the values of all membership functions used as evidence influence the result, that we see that coat number 2 is determined to be slightly more favourable than coat number 3. The fuzzy algebraic PRODUCT results in a value of favourability which is less than or equal to fuzzy membership evidence value, but the relative rankings of the combined favourability differ from both fuzzy AND and fuzzy OR. As noted above, the cost value of coat number 2 is slightly higher than the quality value of coat number 3, which results in a slightly higher ranking.

Another way of deciding which coat is best is to consider that the better features a coat may have, the better it should be ranked. In this case, the fuzzy algebraic SUM would apply. The fuzzy algebraic SUM results in a combined value greater than or equal to any one component value. As with the fuzzy algebraic PRODUCT, the output value depends on the range of values being combined. The fuzzy algebraic SUM is expressed mathematically as:

$$\mu_c = 1 - ((1 - \mu_{x1}) * (1 - \mu_{x2})) \qquad (5).$$

For this rule, coat number 1 ranks the highest in favourability, second is coat number 2, similar to fuzzy OR. However, coats 3 and 5 are ranked equally by fuzzy OR, whereas coat 3 is ranked more favourably than 5 using the fuzzy algebraic sum. Using the fuzzy algebraic SUM shows that for the mutually dependent favourability of cost and quality, coat number 4 is significantly better, and ranked very closely behind coats 1 and 2.

Another alternative is to allow the conditions of the decision to vary in a range between the fuzzy algebraic SUM and the fuzzy algebraic PRODUCT. A favourability ranking may be calculated this way by using the fuzzy GAMMA operator, which is the product of the fuzzy albebraic SUM operator raised to the power of γ and the PRODUCT operator raised to the power of 1- γ, where γ A is a parameter in the [0,1] range. The fuzzy GAMMA operator is expressed mathematically as:

$$\mu_c = [1-(1-\mu_{x1})*(1-\mu_{x2})]^{\gamma} * [\mu_{x1}*\mu_{x2}]^{1-\gamma} \qquad (7).$$

Table 2.2 shows favourability rankings for γ values of 0.85 and 0.15. Lower γ values generally tend toward a 'decreasive' effect, wheras higher γ values tend toward an 'increasive' effect. This effect of the γ value on the favourability ranking is illustrated in relation to the other four fuzzy operators (Figure 2.3). For coat number 3, the ranking is 0.83 and 0.52 respectively.

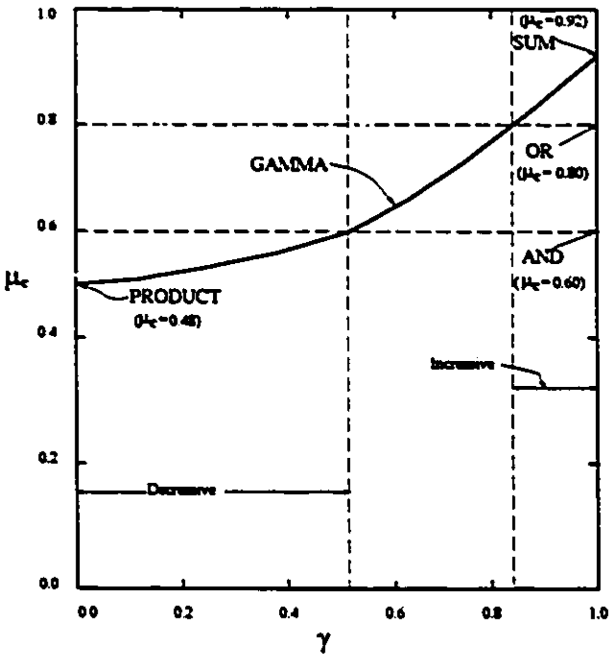


FIGURE 2.3. EFFECT OF γ VALUES ON COMBINED FUZZYMEMBERSHIP VALUE, μ_c, USING FUZZY MEMBERSHIP VALUES 0.60 AND 0.80, ASSIGNED TO COAT NUMBER 3 IN THE ABOVE EXAMPLE. (MODIFIED FROM BONHAM-CARTER, 1994). TERMS ARE EXPLAINED IN TEXT.

The purpose of the above example is to demonstrate how fuzzy logic may be applied in a typical decision-making process. Fuzzy logic provides a means of representing favourability of evidence, and combining disparate information sources. The outcome produces ranked values of favourability that should be used in a relative sense. In mineral potential mapping, different operators are used for different combination reasoning applied with mineral deposit model criteria.

The above example considers different coats as objects for which a favourability ranking must be obtained. The favourability ranking of each coat is determined on the basis of cost and quality factors associated with each coat. As real objects, coats obviously differ from geological phenomena. Geological phenomena, the objects on which mineral favourability is determined, are spatial objects. Therefore favourability ranking in mineral potential mapping is applied to point, line and polygonal objects in geographic space, and geological variables are considered attributes of these objects. Mineral potential favourability is determined for each location of a study area on the basis of a variety of variables such as [illegible] nes, structural features, alteration zones, geochemical signatures, and other factors.

[illegible] method allows the modeller to develop an inference network, in which a variety of fuzzy lo [illegible] an be employed together. The following chapter provides an overview on how fuzzy logic [illegible] nented in a GIS for mineral potential mapping.

3. CHAPTER 3 - APPLICATION DESIGN

3

3.1. Introduction

The implementation of fuzzy logic for mineral potential mapping requires various types of data, information and knowledge to be represented digitally in a GIS in various file types. The process for implementing most computer applications generally follows three stages of development. The first stage determines the 'conceptual model' of the system, the second stage determines the 'logical model', and the third stage determines the 'implementation model'. The purpose of the conceptual model is to focus on the processes that will operate in the system, the logical model advances the conceptual model to the application of a suitable technology, and the implementation model determines the actual design as implemented with a certain selection of hardware and software. This chapter provides a detailed account of how the application was developed using this approach.

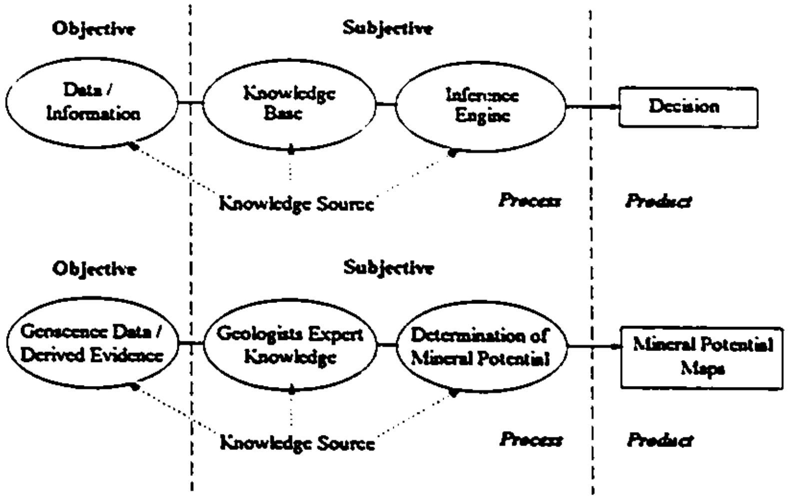
3.2. Conceptual Model

The basic principle underlying the conceptual model is the application of an expert-systems approach for mineral potential mapping using fuzzy logic. Chapter 2 discussed expert systems and fuzzy logic in a general form using an example of a customer in a clothing store trying to make a decision on which coat to purchase. The design of the conceptual model for mineral potential mapping is more complex; its purpose is to identify in detail the various systems components and processes.

Figure 3.1 shows the extension of the conceptual expert systems model as applied in mineral potential mapping. In this model, the 'data/information' component is represented by the source data for a study area, and any derived information that may be used as evidence of potential mineralization. The knowledge base is represented by an expert geologist who is qualified to pass appropriate judgement on the potential evidence with respect to selected deposit models (i.e. define the fuzzy membership functions). The inference engine is represented by the actual mineral potential mapping process where the geologist uses a variety of logical inference techniques to combine evidence and determine the most suitable representation of mineral potential.

In contrast to the example in the Chapter 2, a significant difference in the applicaiton of fuzzy logic to mineral potential mapping is that the whole process must work on spatial data. Therefore, the process must focus on weighting evidence for potential mineralization in map form. The next stage in the process is to detail the 'logical model' that will provide more detail into the relationships among the various sub-components of the system.

FIGURE 3.1. 'CONCEPTUAL MODEL' OF EXPERT SYSTEM FOR MINERAL POTENTIAL MAPPING APPLICATION. CONCEPTUAL MODEL SHOWS ORGANIZATION OF GEOSCIENCE DATA, GEOLOGISTS' KNOWLEDGE, AND MINERAL POTENTIAL MAPPING PROCESS AS PRINICPAL COMPONENTS.



3.3. Logical Model

The purpose of the logical model is to extend the design of the conceptual model so that the three main system components are represented by the various resources that will be used for processing (Figure 3.2). In this case, the logical model considers an implementation with GIS. The 'data/information' component is represented by analogue and digital data. The analogue data are comprised of maps and reports that require digital conversion into a GIS database. The digital GIS database is comprised of a 'spatial' component and an 'attribute' component. Together, they form a 'spatial-attribute relational data model'. The spatial component stores all point, line and area features collected from source maps, while the attribute component stores all of the attributes of these features. The content of the attribute component determines the level of information that can be derived from the primary source maps. The 'derivative maps' represent 'information' that is processed from the source data. Their purpose is to separate the information stored in a conventional geological map into various geological themes that are relevant as evidence of mineral potential.

The classes of the derivative maps are used as keys on which to build the 'knowledge-base'. The knowledge base is comprised of a set of tables where the rows (records) are linked to the class value of an associated derivative map, and the columns (fields) represent the different fuzzy membership values that are assigned to the map classes on the basis of favourability for a mineral deposit model criteria. The derivative map set, along with the knowledge-base, are combined in various ways in the inference engine to determine mineral potential. The inference engine is represented by GIS modelling equations.
Finally, the output of the system is the mineral potential map. The digital conversion and preparation of the digital geological database and associated derivative maps is considered an 'objective' process since no new knowledge is introduced by the process. While the source knowledge may be considered 'subjective' knowledge, all of the information produced in the compilation of the database is driven strictly by the data and knowledge provided in the source documents, and therefore this is considered an 'objective process'. The 'subjective process' occurs when an expert assigns fuzzy membership functions to the derivative map during the modelling process. This process depends on the expert, and is therefore considered to be 'subjective'. The mineral potential map is based on a combination of 'objective' and 'subjective' processing of data, information and knowledge.

The logical model is a schematic of how the components are organized with a GIS. The implementation model defines how the model actually works. The implementation process requires a number of project planning tasks such as the selection and evaluation of geoscience data and mineral deposit models, database development, and mineral potential modelling. These tasks are represented by the numbered circles in the logical model in Figure 3.2 and are summarized in Table 3.1.

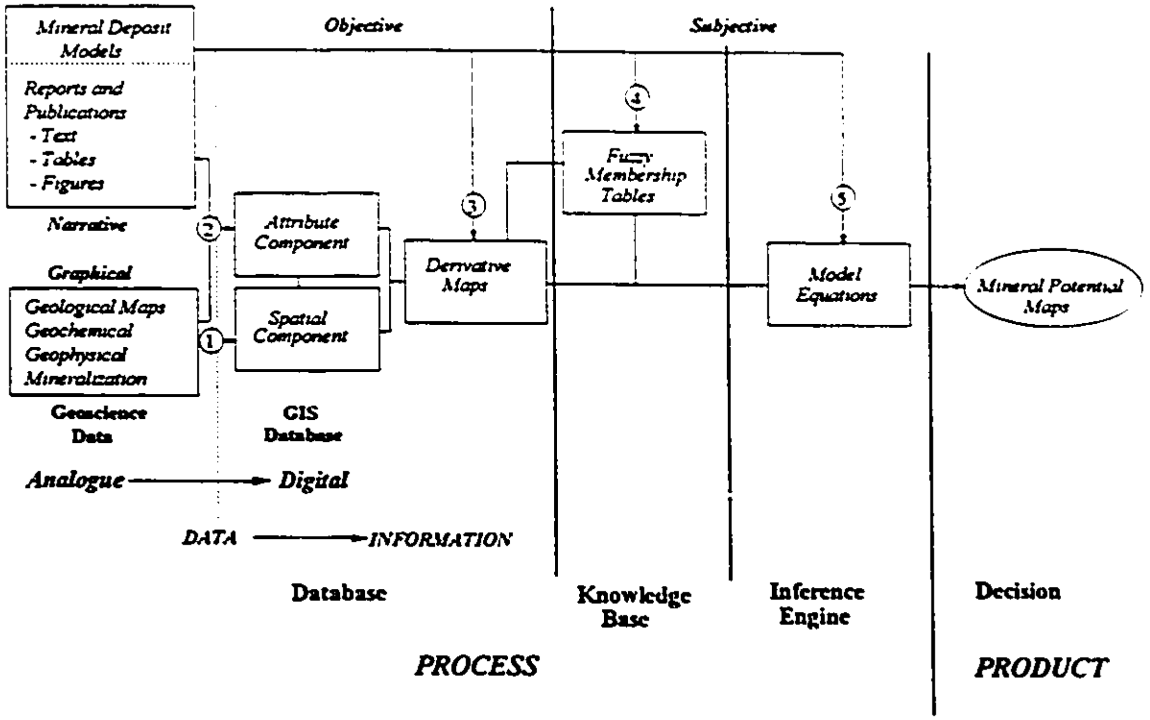


Figure 3.2. Logical model of expert system for mineral potential mapping using fuzzy logic. Three main components, Database, Knowledge Base and Inference Engine are shown in relation to various GIS system files, source material and project activity (indicated by numbered circles).

TABLE 3.1 SUMMARY OF FIVE MAJOR PROJECT TASKS PERFORMED IN CONSTRUCTION OF THE PARRY ISLANDS MINERAL POTENTIAL MAPPING APPLICATION. THE LOCATIONS OF PROJECT TASKS IN RELATION TO SYSTEM COMPONENTS ARE SHOWN IN FIGURE 3.2.

Task No.	System Component	Application File(s)	Tasks
1	**Database / Information**	Spatial Component	Review, compile, and digitize all relevant spatial data. Requires review of all available geological maps, geochemical and geophysical data, and mineral occurences. Some data may already be in digital format, and some geological map compilation may be required.
2	**Database / Information**	Attribute Component	Build attribute tables for all maps entered in Task 1. This process pertains to the development of a 'spatial-attribute relational data model' that stores more detailed data about geological units and structural features in the geological map.
3	**Database / Information**	Derivative Maps	From selected mineral deposit model criteria, derive evidence maps from the spatial-attribute data model. The evidence maps serve as the 'information' component of the system. This usually involves a variety of reclassification operations on the geological map, geochemical and geophysical anomalies, or buffering significant linear features such as faults and contacts.
4	**Knowledge Base**	Fuzzy Membership Tables	Restate deposit model criteria in the form of logical expressions using the evidence maps created in Task 3. Build Fuzzy Assignment Tables for each evidence map. From the mineral deposit model criteria, assign a fuzzy membership value to each class of the map(s) which indicates the favourability of evidence for the stated proposition.
5	**Inference Engine**	Modelling Equations	Identify mineral deposit types that are reasonably possible for the study area. Select established criteria for each selected deposit model. Extract key factors from each deposit model type for consideration during database construction and derivative mapping processing. Write a model equation for each mineral deposit model which combines the evidence maps with associated fuzzy membership values following the logical inference of the deposit model as a whole.

3.4. How the Model Works

Mineral potential mapping involves the calculation of relative favourability values for spatial entities based on their geological attributes. In this approach, relative favourability refers to ranking mineral potential of one area as relatively higher or lower than other areas, but is limited in application to the immediate study area. Therefore, a value of 0. 75 in the Parry Islands would not necessarily be equal to a 0.75 value in another study area. The two values are numerically equal, but they were derived from different considerations associated with data and knowledge specific to each study area.

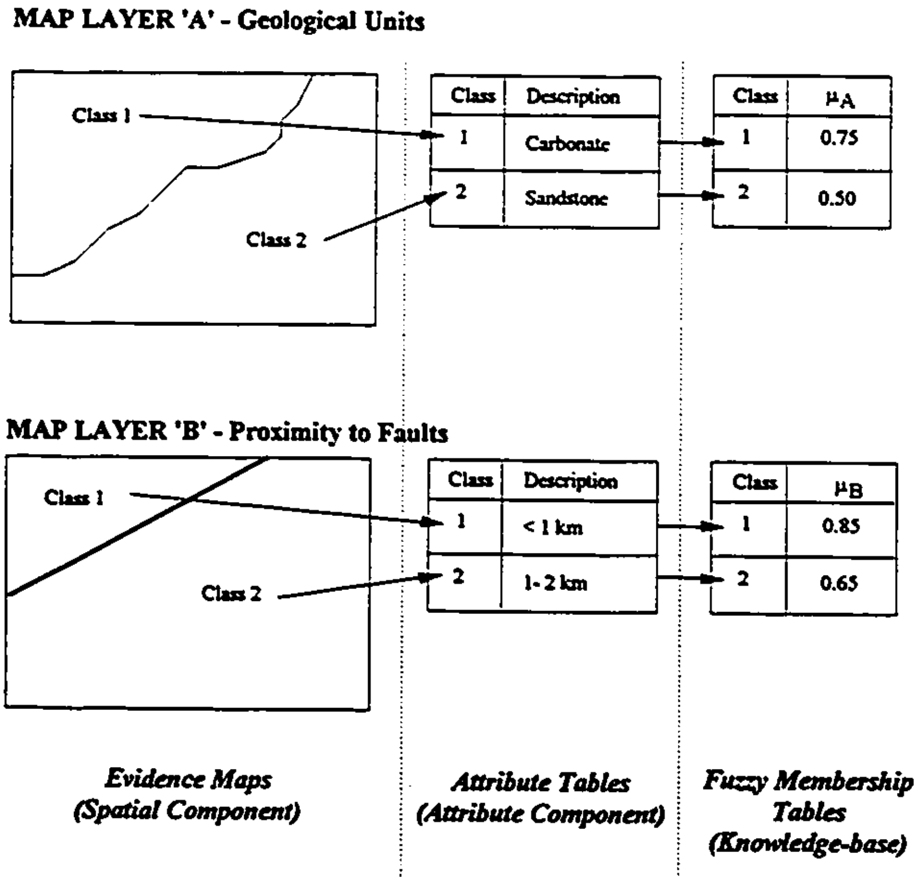
A spatial database in a GIS stores multiple attributes (e.g. lithology, structure, age) by separating spatial phenomena into 'layers'. This is a key requirement for mineral potential mapping because evidence of mineralization consists of information from a variety of sources. A geological map is a model of the spatial distribution of geological features for an area on the surface of the earth. Geological maps depict the patterns of map units that are defined on the basis of rock type and age relationships, plus many other features such as stratigraphic contacts, faults, folds, and other structural elements. The formation or deposition of geological units, and subsequent deformation events that lead to faulting and folding of rock units may be considered separate events, yet the geological units and deformational elements occupy the same space. In a GIS database, geological units and structural features are usually represented as separate map layers. Many physical and temporal attributes are modelled or analysed in multiple layers using map combination routines (Bonham-Carter, 1994).

Suppose a favourability map was required for a region based on criteria for a deposit type such as: *"Mineralization occurs as a result of migration of Pb-Zn bearing fluids along faults. Deposits form most commonly in carbonate rocks, and less commonly in sandstone rocks"*. The proposition is "*This location is favourable for deposits of this type*". Favourability is determined by combining two map layers, **A** and **B** as evidence, where layer **A** represents lithologic units and layer **B** represents proximity to a fault (Figure 3.3).

Each map contains a set of polygons that represent *n* classes. Each polygon has a unique polygon identifier and a class identifier. The class identifier provides a link to an 'attribute table' that contains data associated with each class. The 'fuzzy membership functions' are held as fields in fuzzy membership tables, and each class is associated with a fuzzy membership value. Fuzzy membership tables are stored separately from the map attribute tables in order to maintain the distinction between the 'data/information' component and the 'knowledge-base' component. The favourability of each location on the map is evaluated by combining the fuzzy membership functions from the maps. In this case, equation (2) may be expressed as:

$$\mu_c = f_{comb}(\mu_A, \mu_B) \qquad (7).$$

where μ_c represents the combined fuzzy membership, μ_A is the fuzzy membership value for map A, and μ_B is the fuzzy membership value of for map B.



Class	Description
1	Carbonate
2	Sandstone

Class	μ_A
1	0.75
2	0.50

Class	Description
1	< 1 km
2	1- 2 km

Class	μ_B
1	0.85
2	0.65

FIGURE 3.3. EXAMPLE ILLUSTRATION OF THE RELATIONSHIP AMONG EVIDENCE MAPS, ATTRIBUTE TABLES AND FUZZY MEMBERSHIP TABLES. IN THIS CASE, EACH MAP CONTAINS ONLY TWO CLASSES, BUT IN REALITY EVIDENCE MAPS CONTAIN MANY CLASSES.

A favourability map is produced by combining these maps according to the logic implied in the statement of criteria. An intermediate step is required that restates the criteria in the context of the maps used as evidence; for example: *"(Close to Faults) AND(rock types = Carbonate or Sandstone)"*. Some degree of uncertainty is indicated in the proposition by the use of the words "*most commonly*", and " *less commonly*". The fuzzy membership values assigned to each class of map A reflect these uncertainties. In this case, the value of 0.75 is assigned to the 'carbonate' rock type to reflect the knowledge that

"*Deposits form most commonly in carbonate rocks*", and the value of 0.50 assigned to the 'sandstone' rock type reflects the knowledge that "(*Deposits form*)... *less commonly in sandstone rocks*". The relative favourability of proximity classes is reflected in the fuzzy membership values assigned to the classes of map B.

The three components of the expert system environment are used as a model to organize data, knowledge and inference. In Figure 2.4, the data/information component is represented by the evidence maps and associated attribute tables, and the knowledge base is represented by the fuzzy membership assignment table. To calculate the favourability for each location in the area, a 'model equation' is used to combine the maps to reflect the complete statement. Using the criteria stated above, a model equation may be written as follows:

```
E ZNFAVOR Calculate Zn Favourability using Rock Types and Faults
:Access maps and Fuzzy membership tables
x1=table('fuzzyA',class(MAPA),'member');
x2=table('fuzzyB',class(MAPB),'member');
:Combine evidence maps to map favourability using the AND operator
fmap=min(x1,x2);
:Execute the statement
fmap
```

This configuration of a geological map, derivative maps used as evidence maps, attribute tables, fuzzy membership tables and modelling equations form the basic components of the implementation model. For this project, the Tydac SPANS GIS system was used on an IBM 486 PC with the OS/2 operating system. Ths modelling equation uses the convention of the map modelling language used in the SPANS GIS software.

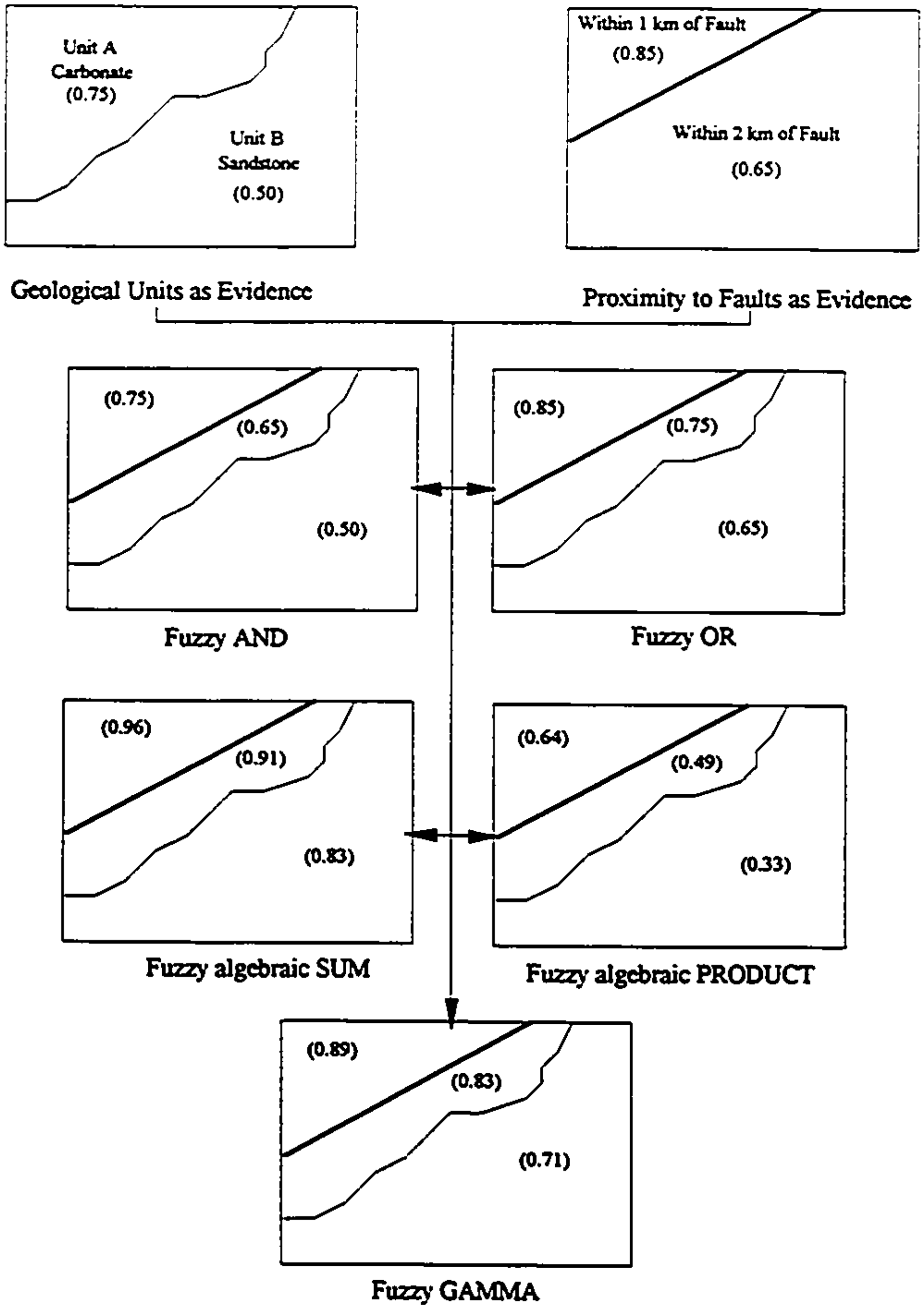


Figure 3.4. Illustration of effect of combining two maps, lithological units and proximity to faults, with associated fuzzy memberhsip values that reflect favourability for Zn Deposit Type potential according to the criteria "*Mineralization occurs as a result of migration of Pb-Zn bearing fluids along faults. Deposits form most commonly in carbonate rocks, and less commonly in sandstone rocks*". Example combinations are shown for the fuzzy combination operators AND, OR, algebraic SUM, algebraic PRODUCT and GAMMA.

4

4. CHAPTER 4 - DATABASE DEVELOPMENT

4.1. Review of Available Data

Four types of geoscience data are typically used in mineral potential mapping projects: 1) geological, 2) geophysical, 3) geochemical and 4) mineral occurrences. This section provides a review of the availability of these types of data for the Parry Islands and considers their potential use in terms of data quality, coverage, scale and applicability to this study. In some cases, the decision to include or exclude a particular dataset hinged upon its application to a particular mineral deposit type.

4.1.1. Geological Maps

Because this application is focused on mineral potential mapping using GIS, the most critical data required are provided by a geological map of the Parry Islands. Several criteria were used to evaluate the suitability of available maps including: 1) scale, 2) coverage, 3) date of coverage, 4) detail of geological information and 5) physical quality. Four maps were considered for potential use (Table 4.1). Given that the study area includes Bathurst, Melville and surrounding islands, the maps must provide coverage of the entire region, either individually or in combination.

Okulitch's (1991) geological map of the entire High Arctic was considered inappropriate due to the small map scale and regional context. Two other available published maps are Harrison (1991) for Melville Island, and Kerr (1974) for Bathurst Island. Although both maps are at the same 1:250,000 scale, there is a noticable contrast in the amount of geological detail. Harrison (1991) shows greater detail of geological units, and significantly more structural detail than that of Kerr (1974). Also, Harrison (1991) presents the geology of Melville Island in light of newer stratigraphic and structural models, which are based on detailed (1:100,000) maps, numerous oil well logs and seismic data. Kerr (1974) based his compilation work primarily on reconnaissance field mapping, and his structural and stratigraphic models were developed without the benefit of more recent geological interpretation of the Arctic Islands, or the 3-dimensional data available to Harrison (1991) for Melville Island.

Although these maps provide complete coverage of the study area, the disparity of geological representation between these two maps is problematic. If these maps were to be used, it would be necessary to recompile both into one, which would require synthesizing older data with newer data. An interim synthesis of these maps was prepared by Okulitch (in prep.) as part of a more detailed compilation of the Canadian High Arctic. Although the map is not as detailed as the maps produced by either Harrison (1991) or Kerr (1974), the detail is sufficient to serve the purposes of this project. It was decided that the geological map compiled by Okulitch (in prep.) would be used in conjunction with the legends and reports provided by Harrison (1991) and Kerr (1974) as the principal sources for a digital geological map and associated attribute data.

4.1.2. Geophysical Data

Many mineral potential mapping projects have used geophysical data as an important element for analysis (An et al. 1991, Atgerberg et al. 1993, Bonham-Carter, 1994, Bonham-Carter et al. 1990, Chung and Fabbri, 1993). Geophysical data are used for mineral potential analysis if there is a known or possible relationship between geophysical signatures and a certain type of mineralization. Usually, these projects are site-specific based on map scales in the range of 1:100,000 to 1:10,000. The geophysical data applied in such studies are gathered at resolutions and coverages compatible with the scope of the application. However, due to the large geographic extent of the Parry Islands, the only compatible geophysical data available are in the National Aeromagnetic and National Gravity databases available from the Geophysics Division of the GSC. On the basis of criteria stated for the three deposit models selected for this study (see **Chapter 5**), there was no direct requirement for these data. Therefore, the available geophysical data were not considered for use in this study.

4.1.3. Geochemical Data

Geochemical data can be valuable for mineral potential studies because they frequently provide a direct indication of mineralization in a region. However, there have been very few, if any, systematic geochemical surveys conducted on the Parry Islands. Only several local surveys have been carried out by the mineral exploration industry, and their data were held under proprietary status at the time of database review. The National Geochemical Reconnaissance Program has the Parry Islands on its agenda, but additional funding is required to fulfill this work (P. Friske, pers. comm. 1993). Therefore, no geochemical data were available for use in this study.

4.1.4. Mineral Deposits and Occurrences

Only one known mineral deposit occurs in the study area. That deposit is the Mississippi Valley Type (MVT) Pb-Zn Polaris Mine on Little Cornwallis Island (Enclosure 1A and 1b). Twenty known mineral occurrences have been recorded, and nine of these are coal. The remaining sparse mineral occurrences were mostly discovered by Harrison (1991), on Melville Island. Several other occurrences are noted on the Land Use Information Series (LUIS) Maps compiled by Environment Canada and the Department of Indian and Northern Affairs in 1981 (NRCan, 1981).

Whereas the Polaris Pb-Zn deposit is relatively well documented, the mineral occurrences located on Bathurst Island are poorly defined and are classified only by element. The locations of two Pb/Zn occurrences on the eastern portion of the island were obtained from the LUIS maps (NRCan, 1981). This map series also provided locations for nine coal occurrences on Melville and Bathurst islands. Locations and full descriptions for the remaining nine occurrences are provided in Harrison (1991). Five of these are base metal (Pb, Zn, and Cu) occurrences, some of the remaining are indirect indicators (S, F, and Ba) of base metal mineralization (Harrison,1991).

The paucity of mineral occurrence data is the main reason that a knowledge-driven method is required for this study area, with respect to the selection of an appropriate mineral potential mapping method as discussed in Chapter 2. This deficiency of known mineral occurrences precludes the application of any data-driven methodology. However, the available occurrences provide some direct evidence that geological processes typically associated with MVT Pb/Zn or Sedimentary Exhalative type mineralization have taken place (Harrison, 1991). This information influences the selection of three mineral deposit sub-types (Chapter 5).

4.1.5. Summary of Data Review

It is clear that geoscience data available for the Parry Islands are sparse relative to the quantity, quality and variety of data available to mineral potential mapping of other areas. In summary, the raw data feeding this application simply comprise a 1:1,000,000 geological compilation supplemented by locations of one known mineral deposit, and 20 mineral occurrences. Given these circumstances, the applied method must rely heavily on the background knowledge of the geology and mineral potential for the area. To apply the fuzzy logic approach, much of this knowledge must be integrated with the available geological map to allow the extraction of information required to create a functional knowledge base. In view of this problem, the following section provides a more detailed discussion on the database requirements for mineral potential mapping using only mineral deposit models and a geological map.

TABLE 4.1 REGIONAL GEOLOGICAL MAPS AVAILABLE FOR THE PARRY ISLANDS.

Title	Reference	Scale	Coverage	Pub. Date	Physical Quality	Comments
1. **Geology of the Canadian Arctic Archipelago, Northwest Territories and North Greenland.**	Okulitch, 1991	1:2,000,000	All of High Arctic including complete coverage of Melville and Bathurst Islands.	1988	Very Good	Provides the geology on Parry Islands in context of entire High Arctic. Limited structural features.
2. **Map 1350A - Bathurst Island and Byam Martin Island, Arctic Canada.**	Kerr, 1974	1:250,000	Bathurst and Byam Martin Islands.	1974	Very Good	Synthesis of geology on Bathurst Island, stratigraphic and structural framework is undergoing significant revision (Harrison, pers. comm.).
3. **Geology of Melville Island.**	Harrison, 1991	1:250,000	Melville Island	1991	Very Good	Synthesis of geology on Melville Island. Structure and stratigraphy is in context of recent models.
4. **Geology of Canadian High Arctic.**	Okulitch, in prep.	1:1,000,000	Melville, Bathurst and adjacent Islands.	in prep.	Adequate	Synthesis of Melville and Bathurst Islands. Map unit boundaries are based on Harrison (1991) and Kerr (1974) with some modifications; structure is much more generalized.

4.2. Database Requirements

Identifying database requirements is the first important step in creating a functional GIS database. The application of GIS to mineral potential mapping using simply a geological map presents a challenge of how to adapt to minimal data. The digitization process involved in entering a geological map is usually limited to the application of conventional digitizing and mapping software. However, this study demands more digital representation of information from the geological map. This information, such as lithology, age, structure and stratigraphic relationships, must be captured in a way that it can be applied as evidence for mineral deposits. Therefore, it is important to establish a framework for how the database will operate in the application.

In order to extract as much information from the geological map as possible for the creation of a functional knowledge base, it is necessary to incorporate not only line and polygon objects representing geological map patterns, but also specific knowledge about those patterns that will allow the geological map to be subdivided into different layers according to the information content. A 'spatial-attribute relational data model' will capture information from the legend and allow various map modelling operations to be performed as required by criteria for mineral deposit models.

The following example is used to illustrate application of a geological data model. Suppose a mineral deposit model criterion states: "*Deposits commonly form along facies boundaries in carbonate shelf and deep marine sediments of Devonian age*". This statement requires the extraction of 'facies boundaries' and units with 'carbonate and deep marine sediments that are of Devonian age' from the digital geological map via the geological data model. To extract this information automatically from a digital geological map, there needs to be some means of determining which geological units on the map contain carbonate shelf or deep marine sedimentary rocks that are of Devonian age, and which contacts between these units are actual facies boundaries as opposed to conformable boundaries, or other types of contacts.

Mineral potential mapping in a GIS requires storing as much data as possible about the geological units and their contact and stratigraphic relationships in a structured digital format that will faciliate this type of information extraction. On the basis of this requirement, the database has been created to allow the following information extraction operations:

1. **Reclassify geological units on the basis of age, rock type, depositional setting, and syn-depositional tectonic setting attributes.**
2. **Extract specific contacts such as unconformities and facies boundaries.**
3. **Extract structural features such as faults or folds.**

Current protocols for creating digital geological maps make these operations difficult. One reason for this is that during the rapid increase in the application of GIS in geoscience over the past decade, geological maps have been digitized and entered into geoscience databases as stand-alone products. To date their most frequent use has been simply for more rapid, and state-of-the-art computerized mapping, publication and data archiving. As a result, most computerized geological maps are digitally structured as static representations of their parent hard copies. Most of the digital structuring and coding of geological features is suited for cartographic requirements and not for extracting geological information or geological data modelling.

Other reasons for not structuring map legends with digital geological data models are: (1) the rather weak relational database capability of many commercial GIS, and (2) the high cost of data modelling and capture. Very little research has been done on this subject in geology, mainly because GIS is still in its infancy and applications that demand structured map data have to date been few. The database requirements for this application suggest that a new approach must be developed for entering, storing and managing a digital geological map database. This requirement must be fulfilled using the tools provided in GIS technology, and built on established technical protocols. The following section outlines a set of database design protocols for a digital geological map using conventional GIS and RDBMS concepts.

4.3. Database Design Protocols

Geological maps are typically entered into a GIS database as a mosaic of polygons, and each polygon has an identifier, and a map unit or class identifier (Figure 4.1). The unit identifiers are related to a digital legend that provides the unit name, and in some cases, the relative age of the unit, a descriptive list of rock types, and possibly other characteristics. In this format, the polygons represent the '*spatial component*', the legend data represents the '*attribute component*', and the unit identifier is the key that links the two components.

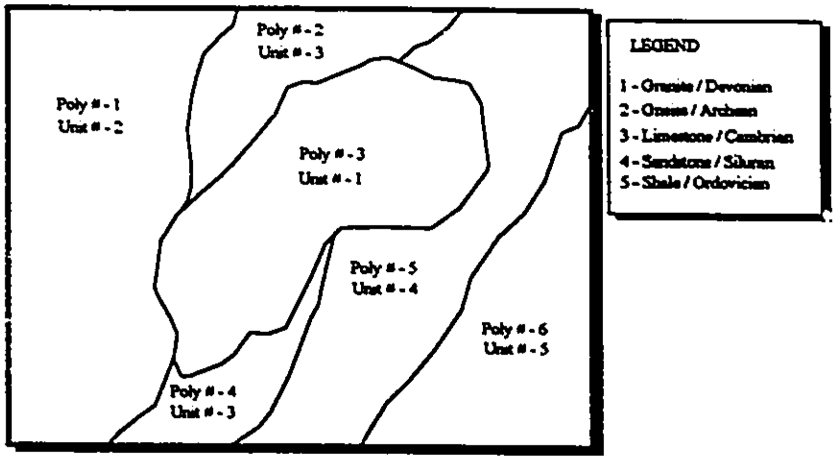


FIGURE 4.1. SIMPLE GEOLOGICAL MAP SHOWING THE RELATIONSHIPS BETWEEN POLYGONS AND GEOLOGICAL UNITS LISTED IN LEGEND.

As an example, suppose there is a requirement to reclassify the map shown in Figure 3.1 according to three primary rock types: 1) igneous, 2) sedimentary and 3) metamorphic. The operation is usually performed on the map with the assistance of a 'reclassification' routine. At this stage, a geologist would assign to each unit on the map a value of 1, 2 or 3, representing igneous, sedimentary or metamorphic rock types respectively. The new map would appear as in Figure 4.2. Although this is a small task for simple maps such as the one shown in Figure 4.1, complex geological maps would involve exhaustive and often redundant data processing, with continual reference to hard copy material such as legends, cross-sections or text.

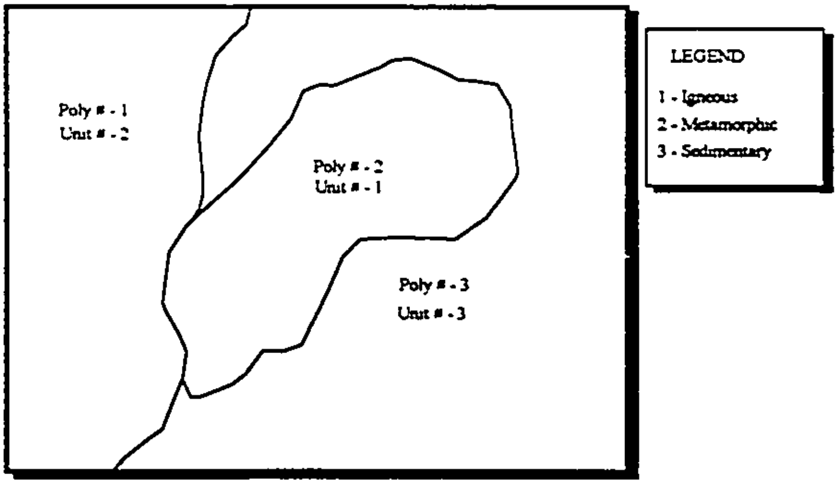


FIGURE 4.2. SIMPLE GEOLOGICAL MAP RECLASSIFIED ACCORDING TO PRIMARY ROCK TYPES.

The reclassification example shown in Figure 4.2 is straight forward. But suppose there is a requirement to map all units that contain carbonate rocks, which were deposited in an unstable shelf margin environment, and are bound by either facies boundaries or unconformities. Not only would the geological map require the digital storage of information on rock types and tectono-stratigraphic environments, but it would also require the storage of information on unit boundaries. In essence, the geological map would have to contain data that provides much more digital information than just the unit name and text description.

A 'digital geological data model' involves the integration of a digital geological map with a digital attribute database that provides more detailed data for geological units and their stratigraphic relationships. In RDBMS technology, the concept of a 'data model' is used as a schema for organizing data in the most efficient possible way to suit a particular application (ESRI, 1993). The integration of a geological map with this type of database requires the development of a two-component 'spatial-attribute relational data model', which some refer to as a 'geo-relational data model' (ESRI, 1993).

In a 'spatial-attribute relational data model', the digital geological map represents the spatial component, and the digital geological data model represents the attribute (non-spatial) component. In terms of a product specification, the spatial component represents a digital description of the distribution of geological units and structural features in space, and the attribute component represents a digital description of the attributes of the geological units, including their stratigraphic and structural relationships.

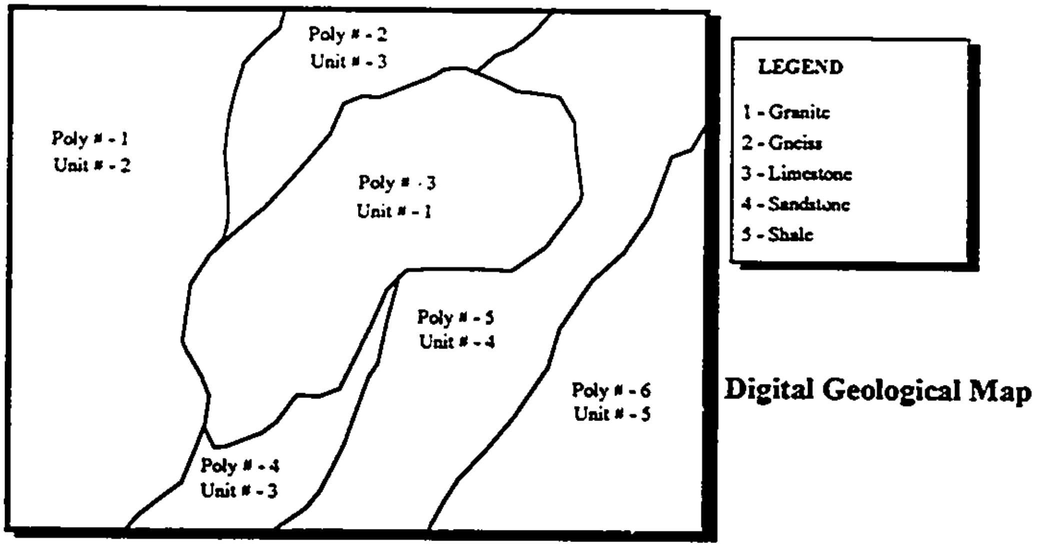
As a simple example, the digital file organization for the map in Figure 4.1 is presented in Figure 4.3, to illustrate three basic levels in the architecture of GIS data. At the top level, the digital map is composed of a mosaic of polygons that contain data associated with the polygon number and a unit identifier. The next level illustrates the table organization of the polygon data and unit attributes. Underlying these two levels is the conceptual data model. The data model serves as a database design protocol that determines the type of information that is obtainable from the database.

In RDBMS terms, the poly_id table contains the relationship between the unit identifier (unit_id) and the polygon identifier (poly_id). In this table, the poly_id serves as the key field. The key field represents an index field in the database where every entry corresponds to an individual polygon. The unit_id field in the poly_id table represents the 'parent field' that provides the relational ability to link the legend table to the poly_id table through the unit_id field (child field) in the legend table. The unit_id field in the legend table is the key field that has the same field format as the unit_id field in the poly_id table. The difference between the two locations is that a value can be entered more than once in the poly_id table, whereas a value can only be entered once in the legend field because it is the key field in this table.

The use of a data model is a common approach adapted in RDBMS to minimize duplication of data entry, simplify editing and provide a clean and unambiguous description of data relationships. In the above example, the legend table contains information on rock type only. SPANS GIS will allow any description of units to be entered a legend, although the space allowed is usually limited to only one 'Description' field, containing not more than 40 characters in width. In some software, an associated field for supplementary narrative information is available. This configuration limits the ability to model the geological map from various viewpoints. There is no capacity in this configuration to enter other attributes of the units in a structured database environment that would allow easy extraction of more detailed information associated with specific geological elements.

To enhance the data associated with each unit, suppose the data model is modified so that more fields are added to the legend table to allow the entry of more detailed information associated with each entity. Such fields could include depositional age, rock types, depositional environment, etc. The data model shown above might then take on the form as shown in Figure 4.4.

The fields that are added depend on evaluating the information requirements of the application, and the data available. The following section provides a detailed discussion of how the spatial-attribute relational data model concept is applied through the integration of the geological map (Okulitch (in prep.)) with additional legend and report data of Harrison (1991,1994) and Kerr (1974).



Poly_id Table

Poly_id	Unit_id
1	2
2	3
3	1
4	3
5	4
6	5

Key Field Parent Field

Legend Table

Unit_id	Description
1	Granite
2	Gneiss
3	Limestone
4	Sandstone
5	Shale

Child Field

Table Organization

Poly_id Table

Field 1 - Poly_id - Key Field
Field 2 - Unit_id - Parent Field

Legend Table

Field 1 - Unit_id - Key Field
Field 2 - Description - Data Field

Data Model

FIGURE 4.3 EXAMPLE DIGITAL GEOLOGICAL MAP SHOWN WITH ITS TABLE ORGANIZATION AND DATA MODEL. THIS CONFIGURATION IS FOR ILLUSTRATION ONLY. TRUE CONFIGURATIONS VARY AMONG GIS AND RDBMS SOFTWARE DEPENDING ON APPLIED SPATIAL MODEL, PROGRAMMING LANGUAGE, OPERATING PLATFORM AND DATABASE PROTOCOL. THE ARROWS INDICATE 'LINKED' FIELDS.

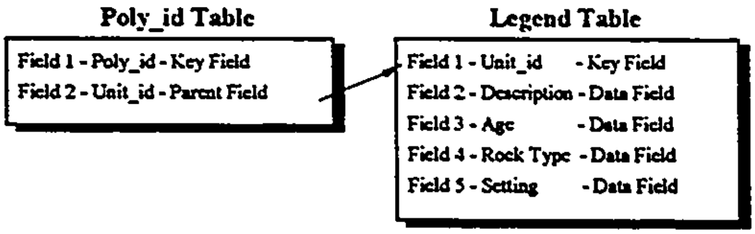
Poly_id Table

Poly_id	Unit_id
1	2
2	3
3	1
4	3
5	4
6	5

Legend Table

Unit_id	Description	Age	Rock Type	Setting
1	Granite	Devonian	Igneous	S-type
2	Gneiss	Sil. - Dev.	Metamorphic	Amphibolite
3	Limestone	Carboniferous	Sedimentary	Reef
4	Sandstone	Ord.	Sedimentary	Shelf
5	Shale	Ord.	Sedimentary	Basin

Table Organization



Data Model

FIGURE 4.4. EXAMPLE DATA MODEL ASSOCIATED WITH DIGITAL MAP SHOWN IN FIGURE 3.3 MODIFIED TO INCLUDE MORE DETAILED DATA ASSOCIATED WITH EACH UNIT. ARROWS INDICATE 'LINKED' FIELDS.

4.4. Data Model for the 'Data / Information' Component

The data model for the 'data/information' system component comprises three physical components: 1) the spatial component, 2) the attribute component and 3) the source reference component. Together they function as a spatial-attribute relational data model that is used to extract information from the geological map while preserving the lineage of the information processing. The information extraction process generates a set of derivative maps that function as the building blocks for the creation of the knowledge base and evidence for mineral potential. This model is created on the basis of the protocols established in the previous section. The three components are presented in Enclosure sets 1(a and b) and 2(a and b), and their inter-relationships are illustrated in Figure 4.5.

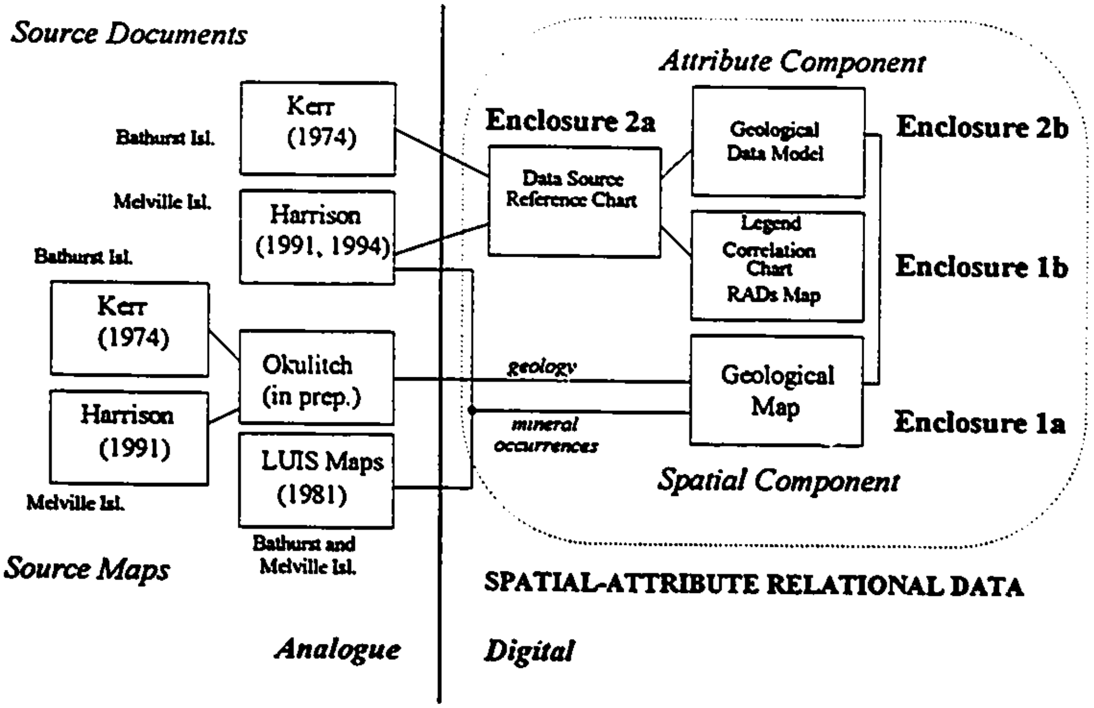


Figure 4.5 Relationships among source maps and documents used during GIS database construction. Process involves an analogue to digital transformation of maps and text into structured digital GIS database. GIS database allows rapid, semi-automated extraction of information from digital geological map based on stratigraphic models provided in Harrison (1991,1994) and Kerr (1974).

The database building process involves an analogue to digital conversion of source maps and documents into a structured GIS database. Textual data from Harrison (1991,1994) and Kerr (1974) were synthesized in the tables shown in Enclosure 2A. The data shown in these tables form the basis for coding attribute variables that were entered in the geological data model (Enclosure 2B). The digital geological map (Enclosure 1A) and the geological data model (Enclosure 2B) form the spatial and attribute components of the database respectively. The data source reference chart (Enclosure 2A) presents a means for tracking and verifying attribute data with their source documents. The legend, location map, correlation chart, and map of resource assessment domains (Enclosure 1B) complement the geological map and the geological data model as a graphical representation of stratigraphic relationships stored in these components.

Tables 4.2A and 4.2B summarize the GIS-database files that constitute the spatial and attribute components of the database. The spatial component comprises a digital geological map (Enclosure 1A) which is separated into four layers: 1) geological units, 2) faults, 3) folds and 3) mineral occurrences. The geological units layer is stored as an 'area' spatial data type (quadtree raster structure in SPANS GIS). The faults and folds are stored as vector files, and the mineral occurrences are stored as a point-attribute file.

There are two primary types of tables in the attribute component: 1) Data tables and 2) Look-up Tables. Each of the fields in the data tables contain variables represented in numeric form. Each field has an associated look-up table that contains descriptions for the numerically coded variables. The arrows pointing from the fields in the data tables to the look-up tables indicate the parent-child relations between tables.

The attribute component is a set of relational tables that are keyed on the geological unit class values of the geological map. This set of tables stores data that describe the 'unit attributes' and 'boundary relationships' associated with geological units. The synthesis of stratigraphic data provided in Harrison (1991,1994) and Kerr (1974) allowed the entry of the following 'unit' and 'boundary' attributes in the geological data model. The unit area attributes include 1) age, 2) rock types, 3) depositional setting, and 4) syn-depositional tectonic setting. Two additional fields record simplified age and lithology classifications; 'ageclass' and 'litclass'. The age class codes were derived directly from the age range of each unit. The lithology class codes were created to group the major classes of rock types that occur in the sequence. The boundary attributes contain information on where facies boundaries and unconformities occur.

The 'element relations diagram' in the lower right corner of Enclosure 2B maps the database file structures and their relationships. Each file is presented according to its respective file structure and described in terms of a short field name, long field name, field type and width. The first field in each table represents the key field for which a relation is set to another data table, or an associated look-up table.

TABLES 4.2A AND 4.2B. SUMMARY TABLES OF DATABASE FILES THAT CONSTITUTE DATABASE COMPONENT OF THE APPLICATION. TABLE 3.2A SUMMARIZES 'SPATIAL COMPONENT' AND TABLE 3.2B SUMMARIZES ATTRIBUTE COMPONENT. THE 'FILE TYPE' CODES REFER TO: Q - QUADTREE MAP FILE, VA - VECTOR AREA FILE, VL - VECTOR LINE FILE, PT - POINT - DATA TABLE, AND LT - LOOK-UP TABLE.

Table 4.2a - *SPATIAL COMPONENT*

Title	File	File type	Description
Geological Units	BEDROCK.MAP	Q	Area coverage of 36 geological units in quadtree map format. This file is used for all analytical and modelling operations done for geological units.
Geological Units	BEDROCK.TOP/VTX.	VA	Same as BEDROCK.MAP, except in the vector area format. This file is used for high quality cartographic output (Enclosure 1A)
Faults	SFAULTS.TOP/VTX	VL	Contains the location and geometry of all faults (unclassified) from Okulitch (in prep.). This file is used for display and to generate buffer maps which indicate the proximity to faults.
Anticlines	SANTI.TOP/VTX	VL	Contains the location and geometry of all anticlines. Used for the same purposes as SFAULTS.TOP/VTX.
Synclines	SSYNC.TOP/VTX	VL	Contains the location and geometry of all synclines. Used for the same purposes as SFAULTS.TOP/VTX and SANTI.TOP / VTX.
Mineral Occurrences (1)	MOC.TBA/TBB	PT	Contains the locations and descriptions of all known mineral deposits and occurrences. Used for display and associating known occurrences with geological units.

(1) The mineral occurrences file is a mixture of spatial and attribute components. This is a common protocol for point data in a GIS database. Although it is possible to store the spatial and attribute components separately, keeping them in one file is better practice. In this file, the spatial component is stored as Morton numbers, and latitude and longitude coordinates in the fields 'Morton', and 'lat', 'long' respectively. The remaining fields contain descriptions of each occurrence.

Table 4.2b - *ATTRIBUTE COMPONENT*

Title	File	File type	Description
Master Data Table	MDT.TBA / TBB	DT	Contains coded descriptions for all geological units including: map class, unit abbreviation, unit name, upper and lower ages, rock types, depositional setting, syn-depositional tectonic setting, and simplified rock type and age range classifications. This file functions as the master table in the geological data model. It is keyed on the field 'map class', which links the spatial component of the database to the attribute component in the classes of BEDROCK.MAP. Its related look-up tables include: LUTIM, LULIT, LUDEP, LUTEC, and LULIC (.TBA/.TBB).
Sequence Relations Table	SRT.TBA / TBB	DT	This table is a 36 x 9 array which identifies which units constitute each resource assessment domain at surface, and the locations of unconformities. The value '0' means the unit is not present, '1' means it is contained in the first sequence, '2' second sequence, etc. A change in values > 1 represents an unconformity between consecutive units.

Table 4.2b - *ATTRIBUTE COMPONENT (cont'd)*

Title	File	File type	Description
Facies Relations Table	FRT.TBA / TBB	DT	This table is similar to SRT.TBA / TBB, except that the values indicate where facies boundaries occur between consecutive units. A value of '0' means the unit is not present, '1' represents the first facies, '2' the second facies, etc. A change in values > 1 indicates the location of a facies boundary.
Geologic Time Table	LUTIM.TBA / TBB	LT	The look-up table for the codes entered in the fields 'upperage' and 'lowerage' in the master data table. The 'upperage' and 'lowerage' fields in MDT.TBA/TBB are the parent fields, and the field 'class' in this table is the child field. The corresponding geological time description is entered in the field 'legend'.
Rock Types Table	LULIT.TBA / TBB	LT	The look-up table for the rock type field ('litho1','litho2','litho3'....'litho9') codes entered in the master data table. The rock-type fields are the parent fields and the field 'class' in this table is the child field. The corresponding rock type description is entered in the field 'legend'.
Depositional Settings Table	LUDEP.TBA / TBB	LT	The look-up table for the codes entered in the 'deposet' field in the master data table. The 'deposet' field in MDT.TBA/TBB is the parent field and the field 'class' in this table is the child field. The corresponding depositional setting description is entered in the field 'legend'.
Syn-depositional Tectonic Settings Table	LUTEC.TBA / TBB	LT	The look-up table for the codes entered in the 'tectposet' field in the master data table. The 'tectoset' field in MDT.TBA/TBB is the parent field and the field 'class' in this table is the child field. The corresponding tectonic setting description is entered in the field 'legend'.
Simplified Rock Type Classification Table	LULIC.TBA / TBB	LT	The look-up table for the codes entered in the 'litclass' field of the master data table. The 'litclass' field in MDT.TBA/TBB is the parent field, and the field 'class' is the child field. The corresponding lithology class description is entered in the field 'legend'.
Age Range Classification Table	LUARC.TBA / TBB	LT	The look-up table for the codes entered in the 'ageclass' field of the master data table. The 'ageclass' field in MDT.TBA/TBB is the parent field, and the field 'class' is the child field. The corresponding age-range class description is entered in the field 'legend'.
Age Relationship Types Table	LUART.TBA /TBB	LT	The look-up table for the codes entered in the age relation table array. All 36 fields in ART.TBA/TBB are the parent fields, and the field 'class' is the child field. The corresponding age relationship descriptions are entered in the field 'legend'.
Mineral Occurrence Types	LUMOT.TBA / TBB	LT	The look-up table for the codes entered in the 'mintype' field in the mineral occurrence table. The 'mintype' field in the mineral occurrence table is the parent field, and the field 'class' is the child field. Each numeric code has a corresponding mineral occurrence type description in the field 'legend'.
Mineral Occurrence Source Reference	LUMOS.TBA /TBB	LT	The look-up table for the codes entered in the 'minsrce' field in the mineral occurrence table. The 'minsrce' field is the parent field, and the field 'class' is the child field. Each numeric code has a corresponding source reference description in the field 'legend'.

The data source reference chart (Enclosure 2A) documents all data elements entered in these tables as provided in each stratigraphic model proposed in Harrison (1991,1994) and Kerr (1974). This chart demonstrates the migration of data elements from their source documents to the various tables through the key 'mapclass' field which represents the units in the geological map legend. The upper left box contains data provided in stratigraphic models for Melville Island as interpreted by Harrison (1991,1994). The lower left box contains data provided in stratigraphic models for Bathurst Island as interpreted by Kerr (1974). The larger right box contains the list of units provided by Okulitch (in prep.) as part of the regional geological compilation. The lower right box contains the units as shown in the geological map of the Parry Islands study area, as digitized for this project.

Harrison (1991) provides a detailed legend and correlation chart associated with the map of the Geology of Melville Island. These data are supplemented by a simplified model in a more recent publication (Harrison, 1994). Kerr (1974) presented a stratigraphic model as a 'Table of Formations' which shows the chrono-stratigraphic positions of geological units and their boundary relationships in terms of locations of unconformities and facies boundaries. This table is supplemented by the legend of Map 1350, which provides more detailed data on rock types.

The unit attributes extracted from these data sources include the unit abbreviation, name, rock types, age ranges, depositional and syndepositional tectonic settings. These attributes are assigned to the geological units on the geological map in one of three possible modes as indicated on the legend in Enclosure 2A. The first mode is a 'direct assignment' for units where there is consistent agreement among the stratigraphic models of Harrison (1991/1994) and/or Kerr (1974), with the location, identification and geometry of the unit boundaries on the geological map compiled by Okulitch (in prep.).

The second mode is 'assigned by group'. In some cases, Okulitch (in prep.) simplified the unit boundaries on the map by grouping units or sub-units, or some units were grouped during digital structuring in this project to conform to data presented in the synthesized stratigraphic model (Enclosure 1B). In these cases, the attributes represent a combination of the source unit attributes. For example, Okulitch (in prep.) compiled the Parry Islands Fm. as one unit, whereas Harrison (1991) showed the Parry Islands Fm. as a group of sub-units that contain their own specific rock types. All of the rock types listed by Harrison (1991) for the sub-units of the Parry Islands Fm. were entered as the rock types for the Parry Islands Fm. as compiled by Okulitch (in prep.).

The third mode of assignment is 'non-assignment'. Some units from the Okulitch legend were not assigned because they occur outside of the Parry Islands study area (the legend applies to the greater western High Arctic, not just the Parry Islands). Some units in the Harrison tables were not assigned because they were too small to depict on the Okulitch compilation, or they were only observed in sub-surface data. Some units in the Kerr tables were left unassigned due to updating of mapped units from more recent mapping activities on Bathurst Island (Okulitch, pers. comm. 1993).

This approach to database design of a digital geological map and geological data model allows various information extraction routines to be performed. In a GIS, the process of spatial information extraction is commonly referred to as 'derivative mapping'. The following section presents the GIS operations performed to extract a set of eight 'derivative maps' that are used as the building blocks on which the knowledge base is created.

4.5. Derivative Mapping Process

Mapping mineral potential with mineral deposit models requires the extraction of geological features from the database to be used as evidence for mineral potential. Many mineral deposit models have criteria that are based on geological features such as the age and type of host rock, the presence of faults or other tectonic activity, stratigraphic relationships, etc. This section details the process of extracting a set of eight derivative maps. These maps will be used as evidence to map the favourability of mineralization according to stated criteria for three mineral deposit models.

Three basic types of GIS transformations were used to generate the eight derivative maps: (1) reclassification of geological units, (2) buffering specific geological contacts, and (3) buffering faults. These transformation processes are used to create two types of derivative maps. The first type considers multiple attributes associated with each geological unit as 'areas features'. The second type considers a proximity factor to 'linear features' such as geological contacts and faults. Tables 4.3A, 4.3B and Enclosure 3 summarize the transformation processes involved in the derivation of each map. Table 4.3A summarizes the area-feature transformation processing. Table 4.3B summarizes the linear-feature transformation processing.

In essence, the area-feature transformation involves recasting the geological unit areas in different displays according to the attributes of each unit. This allows derivative maps to be created that re-cast the geological setting of the study area in terms principal rock types, depositional age, depositional setting, and syn-depositional tectonic setting.

The process involved reclassifying the geological units using the attributes of the geological units stored in the attribute component of the database. The look-up tables for the various attribute fields are used as legends for each map. As shown in Enclosure 3, different patterns emerge as the geological units are portrayed according to their various attributes.

The linear-feature transformation process involves buffering linear features such as specific geological contacts and faults. These derivative maps allow proximity to linear features to be a factor for mineral potential evaluation. In this study, proximity maps were generated for facies boundaries, unconformities and faults. The proximity-to-faults map was produced simply by transforming its vector format file into an area format file with a buffering routine. The proximity-to-facies-boundaries and unconformities maps required preprocessing for the extraction of these contact types from the geological map. The facies relations table and the sequence-relations table were used for this preprocessing.

The derivative maps produced for this study represent only a portion of the types of maps that are extractable from the database. This set of derivative maps were produced in response to mineral deposit model criteria of the selected deposit models. The relationship of the derivative maps to the spatial-attribute relational data model is illustrated in Figure 4.6 along with the remaining application files and system components. The derivative maps represent the 'information' portion of the 'data/information' component of the system. The next task involves creating the 'knowledge-base' and 'inference engine' components of the system. **Chapter 5 - Mineral Potential Mapping**, discusses how three mineral deposit models were selected and used as the knowledge source for these two components.

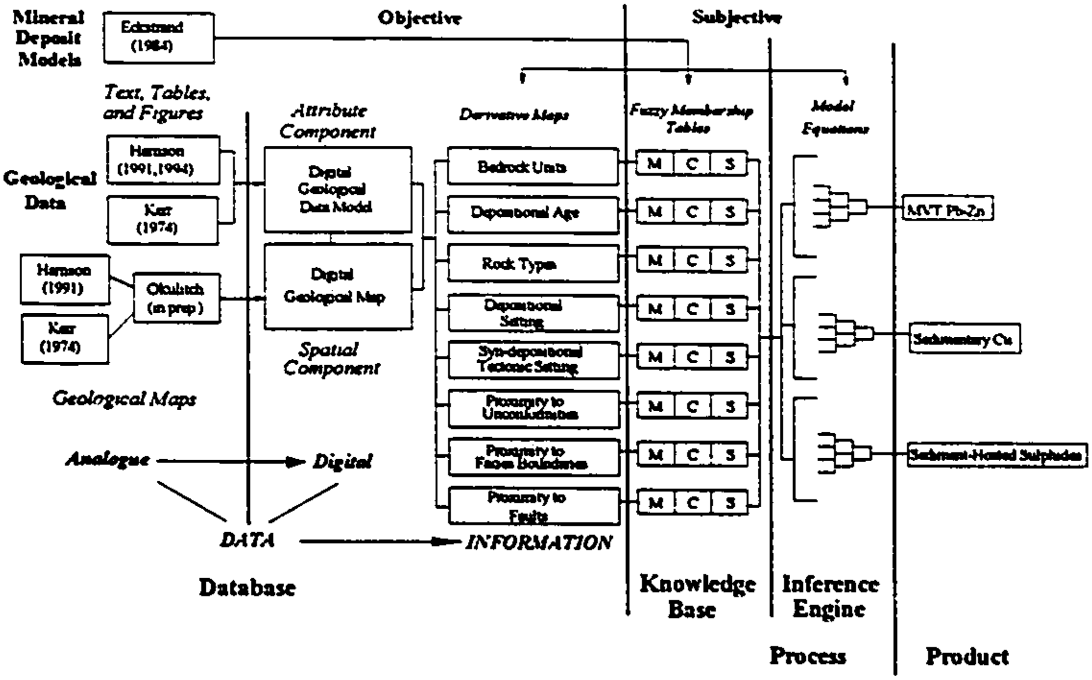


FIGURE 4.6. 'IMPLEMENTATION MODEL' ILLUSTRATING THE RELATIONSHIP AMONG THE VARIOUS GIS SYSTEM FILES WITH RESPECT TO EXPERT SYSTEM COMPONENTS, DATA PROCESSING AND MINERAL POTENTIAL MAPPING PROCESS.

TABLE 4.3.A. SUMMARY TABLE OF DERIVATIVE MAPPING PROCESS USED TO MAP 'AREA FEATURE' ATTRIBUTES ASSOCIATED WITH GEOLOGICAL UNITS.

Derivative Map Title and Filename	Criteria for Extraction	Data Files Used	Transformation Process
Geological Units - BEDROCK.MAP	To allow individual geological units to be treated as potential evidence either by known mineralization, or unique combination of rock types or stratigraphic characteristics.	BEDROCK.MAP	No transformation was required. The BEDROCK.MAP file is used directly as a derivative of itself. (Note: this map is not shown as a derivative map in Enclosure 3 because no transformation was required).
Depositional Age - AGECLASS.MAP	To allow the depositional age of geological units to be a factor for evidence of mineralization.	BEDROCK.MAP MDT.TBB/TBA LUTIM.TBB/TBA	Reclassify BEDROCK.MAP according to the field 'AGECLASS' in the file MDT.TBB, using the look-up table LUTIM.TBB/TBA as the legend for the map.
Rock Types - LITCLASS.MAP	To allow general rock type to be a factor for mineralization in response to mineral deposit model criteria that specify general rock type associations such as 'evaporites' rather than 'salt', 'gypsum', etc.	BEDROCK.MAP MDT.TBB/TBA LULIC.TBB/TBA	Reclassify BEDROCK.MAP according to the field 'LITCLASS' in the file MDT.TBB, using the look-up table LULIC.TBB/TBA as the legend for the map.
Depositional Setting - DEPOSET.MAP	To allow depositional setting to be a factor for mineralization for model criteria that specify environments such as 'carbonate shelf', 'starved basin', etc.	BEDROCK.MAP MDT.TBB/TBA LUDEP.TBB/TBA	Reclassify BEDROCK.MAP according to the field 'DEPOSET' in the file MDT.TBB, using the look-up table LUDEP.TBB/TBA as the legend for the map.
Syn-depositional Tectonic Setting - TECTOSET.MAP	To allow the tectonic setting associated with the depositional environment to be a factor for model criteria which specify settings such as 'rift-related', 'subsidence', 'basement uplift', etc.	BEDROCK.MAP MDT.TBB/TBA LUTEC.TBB/TBA	Reclassify BEDROCK.MAP according to the field 'TECTOSET' in the file MDT.TBB, using the look-up table LUTEC.TBB/TBA as the legend for the map.

TABLE 4.3A. SUMMARY TABLE OF DERIVATIVE MAPPING PROCESS USED TO BUFFER 'LINEAR FEATURE' ATTRIBUTES ASSOCIATED WITH GEOLOGICAL CONTACTS AND FAULTS.

Derivative Map Title and Filename	Criteria for Extraction	Data Files Used	Transformation Process
Proximity to Facies Boundaries PROXFACI.MAP	To allow proximity to facies boundaries to be used as a factor for mineralization. Lacking a quantified spatial relationship between distance to facies boundaries and mineralization, the buffer interval of 0.5 km was chosen arbitrarily.	BEDROCK.MAP RADMAP.MAP FRT.TBA FRT.MAP FRT.TOP/VTX PROXFACI.TOP/VTX	Reclassify BEDROCK.MAP according to the values in 'Facies Relations Table', FRT.TBA. The reclassified map would take on the value assigned to a given resource assessment domain field for each domain in the map RADMAP.MAP. The result is a map that shows the facies boundaries that occur in each domain. This map was then converted to a vector format (FRT.TOP/VTX). This file was transformed back to a map format file by buffering the contacts at 0.5 km intervals to a 5 km threshold.
Proximity to Unconformities PROXUNCO.MAP	To allow a factor of proximity to unconformities as an indication of erosion and diagenetic processes as required by some deposit model criteria. A buffer interval of 0.5 km was chosen arbitrarily for the same reasons stated for proximity to facies boundaries.	BEDROCK.MAP RADMAP.MAP SRT.TBA SRT.MAP SRT.TOP/VTX PROXUNCO.TOP/VTX	Reclassify BEDROCK.MAP according to the values in 'Sequence Relations Table', SRT.TBA. The reclassified map takes on the value assigned to a given resource assessment domain field for each domain in the map RADMAP.MAP. The result is a map of unconfomable contacts in each domain. This map has been converted to a vector format (SRT.TOP/VTX). This file has been transformed back to a map format file by buffering the contacts at 0.5 km intervals to a 5 km threshold.
Proximity to Faults PROXFALT.MAP	To allow a proximity to faults as a factor of tectonic instability or channels for fluid migration and mineralization as suggested in some deposit model criteria. In this study it is assumed that some late deformational faults are close to, and/or originate from faults that were active during sedimentation.	FAULTS.TOP / VTX	This file was transformed to a map format file by buffering the fault lines at 0.5 km intervals to a 5 km threshold.

5. CHAPTER 5 - MINERAL POTENTIAL MAPPING

5

5.1. Introduction

Chapter 4 discussed the development of the 'data/information' component for the Parry Islands application and the derivation of a subset of maps that portray elements of the geology on the basis of lithology, depositional age, depositional setting, syn-depositional tectonic setting, and proximity to faults, unconformities, and facies boundaries. This chapter discusses how the GIS database is applied for mineral potential mapping with fuzzy logic through the creation of the knowledge-base and inference engine components.

The knowledge-base represents an expert judgement on how favourable the geological features represented by the classes in each derivative map comply with mineral deposit model criteria. The set of derivative maps combined with the knowledge-base represent a collection of individual layers of evidence for mineral potential. The evidence is processed through an inference engine that combines the various maps in response to various combination rules inferred from mineral deposit models. Because the selection and implementation of combination rules is a subjective reasoning process, each model is iterated twice to demonstrate the flexibility of the system to reprocess the data in response to an alternative viewpoint or interpretation of how the evidence should be combined. In order to gain a full appreciation of how the process works, it is important at this stage to review the geology of the Parry Islands and reasons for selecting the three deposit models: MVT Pb-Zn, Sedimentary Cu, and Sediment Hosted Sulphide deposits.

5.2. General Geology

This discussion of the general geology of the Parry Islands is derived from syntheses provided by Harrison (1991,1994) and Kerr (1974), supplemented by the regional compilation work of Okulitch (in prep.). This combination of data provides a comprehensive view of the geology of the Parry Islands in a regional context, which is of principal concern in this study. Considering that the contents of the digital GIS database are derived from these sources, this discussion focuses on regional aspects of the geology of the Parry Islands as represented in the GIS database.

For mineral potential mapping purposes, the study area is partioned into nine Resource Assessment Domains (RADs) (Enclosures 1a-b). At surface, each domain exhibits contrasting stratigraphic and structural features that are taken into account during mineral resource assessment. For example, the Cornwallis Fold Belt (RAD 5) exhibits angular unconformities between formations that have conformable contacts in the West-central Bathurst Island (RAD 4), and Southeastern Melville Island (RAD 3). This stratigraphic feature is illustrated in the cross-correlation chart (Enclosure 1B), however, the unit boundaries were not symbolized on the geological map prepared by Okulitch (in prep.). Therefore, the RADs allow 'logical' stratigraphic and contact relationships to be considered during the modelling process. It is also important to distinguish structural and stratigraphic features of each domain to avoid, or at least minimize, misrepresenting areas that may contain distinct features. This is reflected in the organization of the correlation chart presented in Enclosure 1B, and also permits reference to these domains for discussion on relevant geological events.

The Parry Islands are underlain almost exclusively by sedimentary rocks of the Franklinian and Sverdrup successions (Enclosure 1A). The Franklinian succession comprises a thick marine sequence (~ 7 km) of intercalated carbonate and clastic sedimentary rocks deposited on a tectonically unstable continental shelf-margin. The younger Sverdrup Succession comprises in part an equally thick sequence of sedimentary rocks deposited in a clastic/carbonate shelf, and in part by rocks deposited in a pelitic shelf and a fluvial-deltaic environment. The two successions are separated by a regional angular unconformity, which developed during the Ellesmerian Orogeny. The unconformity approximates the boundary between the southern Parry Islands Fold Belt and the northern Sverdrup Basin. A third minor succession of recent clastics includes the Beaufort Fm, a portion of which remains on southeastern Melville Island.

The only known non-sedimentary rocks found on the Parry Islands are late-Cretaceous igneous dykes and sills discovered in the salt dome areas of the northern part of Sabine Peninsula on Melville Island, and as an irregular blocky patch of intrusions on the southeastern portion of Bathurst Island. Although the intrusions are approximately the same age on both islands, their significance to the regional geological setting is not clear.

The Franklinian Succession comprises the Thumb Mountain and Irene Bay Formations of Ordovician age through to the Late Devonian Griper Bay Group. The Thumb Mountain and Irene Bay formations contain limestone and dolomite with lesser shale and anhydrite deposited on a stable carbonate shelf. They are succeeded by the starved-basin-type rocks of the Cape Phillips Formation, which includes siltstone and shale interlayered with dolomite, limestone and chert deposited during Late Ordovician to Late Silurian time. These units intercalate with the Canrobert and Ibbet Bay formations, which contain sediments deposited in a deeper offshore carbonate shelf and slope and starved basin environment.

The remaining portion of the Franklinian Succession was deposited when several significant tectonic events caused multiple folding and thrust patterns throughout the region. The Cornwallis Fold Belt (approximately the area of RAD 5) developed in response to the Boothia Uplift, which affected the rocks on eastern Bathurst Island. The uplift occured in multiple phases, which resulted in erosion in the near and onshore areas, and deposition further offshore. This is reflected in the angular unconformable contacts between the Bathurst Island and Stuart Bay formations, and between the Stuart Bay and Disappointment Bay formations in the Cornwallis Fold Belt. The rapid facies changes between the Bathurst Island and Stuart Bay, and among the Disappointment Bay, EIDS and Blue Fiord formations, are also indicative of the tectonic instability of this region during Early to Mid-Devonian time.

Numerous N-S striking vertical faults developed throughout the Cornwallis Fold Belt, and are cross-cut by E-W oriented thrust faults developed as part of the Parry Islands Fold Belt to the west. On Enclosures 1a and 1b, the ages of these faults are not differentiated because of generalization during the compilation process. This is unfortunate because the relative ages of faults to host rocks is an important element to consider for modelling the Sediment-Hosted Sulphide deposit type potential. The impact of this on the quality of the results is discussed further in Chapter 6.

A significant spatial-temporal overlap occurs between the development of the two fold belts that resulted in the complex folding and fault patterns that contrast eastern Bathurst Island with West-central Bathurst Island (RAD 4). The influence of the Boothia Uplift dampened toward the west, which permitted development of the E-W oriented, southerly verging fold thrust pattern that characterizes West-central Bathurst Island (RAD 4) and Southeastern Melville Island (RAD 3). This fold belt is less prominent in Southwestern Melville Island (RAD 2) where numerous normal faults prevail. A rifting event of the Sverdrup Basin occured during later Carboniferous and Early Permian time that resulted in the development of the Canrobert Hills Fold Belt (RAD 1). In this area, numerous tight east-west trending folds are cross-cut by normal faults, and the Canrobert, Ibbet Bay, Blackely and Cape de Bray formations are exposed.

The Sverdrup Succession comprises the Otto Fiord Fm through to the Eureka Sound Fm and Cretaceous igneous intrusions. Several periods of tectonic instability related to rifting of the Sverdrup Basin resulted in several angular unconformities within the sequence, and occasional normal and thrust faults in the Sproule and Sabine peninsulas (RADS 6 and 8), and Cameron Island (RAD 9). The St. Arnaud Hills (RAD 7) are characterized by the presence of the Canyon Fiord Fm and the Belcher Channel and Sabine Bay formations (undifferentiated on Enclosure 1A). This represents a significant angular unconformable boundary with the Franklinian rocks in Southwestern Melville Island (RAD 3). A notable feature of the

Sverdrup Succession are the circular evaporite intrusions on the northern tip of Sabine Peninsula. These rocks occur along with the Cretaceous igneous rocks that have intruded along diapiric fault planes.

5.3. Mineral Deposit Model Selection

The selection of mineral deposit models, and their respective criteria, may involve using published empirical and genetic models for various commodities and deposit sub-types, supplemented with expert knowledge of the geological favourability of a given study area (Eckstrand, 1984; IAMG, 1994; Jefferson, 1994; Scoates et al., 1986; Singer 1981,1993). The scope of this project is to demonstrate how various deposit model criteria are applied to a geoscience dataset with fuzzy logic to determine the relative favourability for mineral potential. Therefore, for demonstration purposes, the selection of mineral deposit models and model criteria is limited to those provided in Eckstrand (1984).

Given that the geology on the Parry Islands is predominantly sedimentary, the review and selection of deposit models is limited to sedimentary deposit types. There are several deposit types, and associated 'sub-types', listed in Eckstrand (1984) whose criteria contain reference to geological features that match reasonably well with geological features on the Parry Islands (Table 5.1). To demonstrate the flexibility in applying different models with fuzzy logic, three deposit sub-types were selected: 1) MVT Pb-Zn, 2) Sedimentary Cu, and 3) Sediment-Hosted Sulphide. These three deposit sub-types were selected because their geological characteristics match well with the geology on the Parry Islands. Most of the geological features mentioned in the three sub-types are extractable from the database as derivative maps to build evidence for mineral potential. The criteria for each deposit sub-type is presented in more detail in the next section.

It is important to note that the criteria provided in Eckstrand (1984) for the three selected deposit sub-types are treated as deposit 'types' as opposed to deposit 'models'. Generally, deposit types represent a collection of descriptive information about a group of known mineral deposits that share similar characteristics enough to be classified in the same group. A deposit model is a collection of information that extends the descriptive information to a level where at least one possible process of formation is described. In short, a deposit type is descriptive in its information content, and a deposit model is more genetic and carries more of a predictive context. In this thesis, the criteria from deposit sub-types provided in Eckstrand (1984) are used as the basis for the deposit modelling aspect of the predictive mineral potential mapping process. Two iterations of each deposit sub-type is applied to demonstrate the impact of changing assumptions about how the various descriptive factors should be combined to construct a deposit model.

TABLE 5.1 TABLE OF 'SEDIMENTARY' DEPOSIT TYPES FROM ECKSTRAND (1984) CONSIDERED DURING MODEL SELECTION, SHOWING DEPOSIT TYPE, DEPOSIT SUB-TYPE, AND COMMODITIES (ASSOCIATED MINERALS ARE IN BRACKETS). THE THREE SELECTED DEPOSIT MODELS ARE SHOWN IN BOLD.

Deposit Type	Sub-type / Secondary Sub-type	Commodities
1. Evaporites and Brines	1.a Marine	NaCl, Kcl, gypsum
2. Stratiform Phosphate (Phosphorite)	4.a Miogeosynclinal	P (U,F,V)
	4.b Platformal	P (U,F,V)
5. Placer Uranium, Gold	5.1 Pyritic Paleoplacer Uranium, Gold	U, Au
	5.2 Placer Gold	Au
6. Stratabound Sediment-Hosted Lead, Zinc, Copper, Uranium	**6.1 Mississippi Valley Type Lead-Zinc**	Pb, Zn (Ag,Cd)
	6.2 Sandstone Lead	Pb (Zn, Ag, Cu, As, Ni, co)
	6.3 Sedimentary Copper	Cu (Ag, Co)
7. Chemical-Sediment-Hosted Gold	7.c Stratiform Pyrite	Au (Ag, Cu)
	7.d Chert-Sulphide	Au (Ag, Cu)
8. Clastic-Sediment-Hosted Gold	8.1 Carbonaceous Shale / Carbonate-Hosted Gold	Au (As, Hg, Ag, Sb, Ti)
9. Stratiform Sulphide, Barite	**9.2 Sediment-Hosted Sulphide**	Zn,Pb,Ag,barite (Cd, Cu, Sn)
	9.3 Sediment-Hosted Barite	Ba

5.4. Knowledge-base Preparation

Representing the knowledge of the mineral potential involves combining the knowledge of the geology of the study area with knowledge of mineral potential as presented by criteria in the mineral deposit models. This process requires that fuzzy membership values [0,1] be assigned to the classes of each derivative map to indicate the favourability each geological feature has with criteria statements. There are four steps in this process:

1. **The selection of key statements from deposit sub-type criteria,**
2. **Translation of the key statements into 'logical statements',**
3. **Determination of which derivative maps will be used as evidence to support the statement, or sub-statement, and**
4. **Assignment of fuzzy membership values to derivative map classes in fuzzy assignment tables.**

Tables 5.2A-Cc show the three selected deposit models as presented in Eckstrand (1984). They represent the knowledge source on which the knowledge base is created. The author of each deposit model present their criteria in a systematic categorical format that describes common properties among many of the 'sub-type' deposits that comprise each model (Tables 5.2A-C). Some of the categories provide information that do not have direct significance to the modelling process in this study (e.g. Examples, Importance, Form of Deposit). The only categories that were considered for the extraction of key statements for the creation of the knowledge-base were those that contained reference to mappable geological features.

The key statements extracted from each model description (shown in **bold** in Tables 5.2A-C) were used as the knowledge source on which to build fuzzy membership tables linked to the set of derivative maps. The process involved in building the knowledge base is illustrated in Figure 5.1. The key statements (column 1, Figure 5.1) were translated into 'logical statement' (column 2, Figure 5.1). The logical statement syntax refers to the derivative map containing a feature class that best described the geological feature mentioned in the narrative statement. Depending on the structure and complexity of the statement, each logical statement was deciphered to determine which derivative maps would be required (column 3) , and identify the fuzzy membership sets that were required to represent a portion of the statment (column 4).

Fuzzy membership values in the range of [0,1] were then assigned to each class for each derivative map on the basis of how well the geological feature described what the statement implied. These values were entered in a series of data tables that are keyed on the class values of related derivative maps. The example in Figure 5.1 shows only one column of fuzzy membership values, however, as implemented in the application, each table contains many columns of fuzzy membership values that correspond to the fuzzy set identifiers in column 4 of the model tables (Enclosure 3b).

In the case that a statement makes reference to a geological feature that is not contained in the database, it is given a 'null' fuzzy set to indicate missing data, and therefore cannot be used as a favourability factor during the modelling process. Testing this method identified other problems associated with geoscience data, in that not all geological features mentioned in model criteria may have been observed in the study area, or have been represented completely in the database. Furthermore, there are frequent 'adjective' gaps between terms mentioned in narrative criteria that cannot be incorporated in the logical statements (e.g. 'brecciated dolomite') because many legend descriptions lack a systematic scheme for attaching adjectives to rock type descriptions. This must be considered when assigning the fuzzy membership value to a given unit. The assigned value should reflect the possibilities that a given map class corresponds to the adjective. In most cases, this is not possible because of inconsistencies in legend descriptions and textual interpretations. Therefore, the assigned fuzzy membership values reflect this adjective gap. For example, if a legend description for a geological unit explicitly and consistently stated that the unit contained 'exclusively' brecciated dolomite, then that unit would be assigned a high membership value (e.g. 0.99). If, however, the legend did not meet such strict requirements, the report text would be searched to see if the author noted breccia to occur anywhere in the unit in question. Depending on the nature and extent of the breccia, as described by the author, a membership value commensurate with the breccia description would be assigned to this unit. If, however, the report text makes no mention of breccia in this unit, then a lower membership value would be assigned (e.g. 0.65).

A good example of how fuzzy combination rules work is in the application of statements that make reference to stratigraphic position of host rocks relative to certain boundary types. For example, a MVT Pb-Zn narrative criteria such as *"Unconformities within carbonate sequence (ore horizon will be below unconformities"*, may be translated to a logical statement such as : 'Rock types' = Carbonates .AND. 'Unconformities'=close. The unconformities map in this experiment shows proximity to unconformities as buffers at 1 km intervals, where the fuzzy assignment values of the intervals range from 0.95 (within 1 km) to 0.05 (more than 10 km). The fuzzy 'AND' operator will take the lowest of the two values assigned for the 'Rock Types' map, and the 'Proximity to Unconformities' map. Therefore, when the two are combined, a sandstone unit that lies stratigraphically above a carbonate unit will receive a low assignment value (e.g. 0.05), and the carbonate unit may receive a high value (e.g. 0.95). Even though some of the sandstone unit is just as close to the unconformity as some of the carbonate unit, the region occupied by the sandstone unit will receive the lowest value of the combination (0.05) while region occupied by the carbonate unit will be high (0.95) when it is close to the unconformity, but will decrease as a function of distance from the unconformity (to 0.05).

This process was applied for the three deposit models as shown in Tables 5.3A-C. The fuzzy membership tables that contain the fuzzy membership sets (i.e. the knowledge-base) are shown in Enclosure 3b.

TABLE 5.2A MINERAL DEPOSIT MODEL CRITERIA FOR MISSISSIPPI VALLEY LEAD-ZINC TYPE DEPOSITS FROM ECKSTRAND (1984). KEY STATEMENTS USED FOR THE CREATION OF THE KNOWLEDGE-BASE ARE SHOWN IN BOLD TYPEFACE.

6. STRATABOUND SEDIMENT-HOSTED LEAD, ZINC, COPPER, URANIUM

6.1 MISSISSIPPI VALLEY LEAD-ZINC

COMMODITIES	Pb, Zn (Ag, Cd)
EXAMPLES: Canadian - *Foreign*	Pine Point and Polaris, N.W.T.; Newfoundland Zinc, Nfld.; - *Viburnum Trend and Old Lead Belt Districts, Missouri; East Tennessee District, Tennessee; Silesian District, Poland*
IMPORTANCE	Canada: abount 30% of lead-zinc production. World: major source of lead and zinc in U.S.A., Poland and Austria.
TYPICAL GRADE, TONNAGE	Data for individual deposits are difficult to obtain because of lack of production records and the fact that, in many disticts, deposits tend to be interconnected. Best estimate for most deposits: 5 to 10% combined Pb-Zn, 1 to 10 million tonnes.
GEOLOGICAL SETTING	**In platform carbonate successions.** Commonly, but not always, **located between a zone of tectonic instability characterized by vertical movement** (commonly called a **"hinge line"** and **marked by rapid lithological facies changes such as at a reef front, or edge of a sedimentary basin), and the tectonically stable platform.**
HOST ROCKS OR MINERALIZED ROCKS	**Carbonate rocks**, generally **highly brecciated dolomite.**
ASSOCIATED ROCKS	**Most commonly limestone; less commonly shale, sandstone and evaporites.**
FORM OF DEPOSIT, DISTRIBUTION OF ORE MINERALS	Form: highly irregular in shape, usually discordant on deposit-scale but stratabound on a district-scale. Distribution of ore minerals: mostly as open-space filling in highly brecciated dolomite in which sphalerite, especially, shows colloform texture. Also, commonly disseminated with secondary carbonate gangue; occasionally massive, coarsely crystalline aggregates.
MINERALS: Principal ore minerals - *Associated Minerals*	**Sphalerite, galena.** - ***Pyrite, marcasite, dolomite, calcite,*** *lesser amounts of* ***quartz, barite, flourite, chalcopyrite.***
AGE, HOST ROCKS	Canada: **Helikian to Carboniferous; most abundant in early to mid-Paleozoic.** Foreign: **mainly Cambrian to Triassic.**
AGE, ORE	Not known with any certainty.
GENETICAL MODEL	Although "...no general consensus has been reached...geologists do not know the physiochemical reasons why Mississippi Valley deposits are where they are..." (Ohle, 1980, p. 163), **fluid inclusion studies suggest ores were precipitated from low temperature** (commonly 80° - 150° C) **brines.** A commonly cited model is based on the Beales and Jackson (1966) interpretation whereby the brines **originated from shale basins adjacent to the platform carbonates, and the ore minerals precipitated on some cases during early diagenesis, and in other cases long after lithification of host rocks.**
ORE CONTROLS, GUIDES TO EXPORATION	No consensus on genetic models hence no consensus on ore controls, or guides. However, one or more of the following features are commonly associated with these deposits: 1. **Secondary breccia in dolomite, cemented by white sparry dolomite.** 2. **Unconformities within carbonate sequence (ore horizon will be below unconformities).** 3. **Reefs.** 4. **Carbonate-shale and limestone-dolomite facies changes.** 5. **Basement high(s).** 6. **Open spaces of any type within carbonate sequences, especially those formed by karstification as evidenced by brecciation, thinning of carbonate strata, local increase in concentration of insoluble residue material.**
AUTHOR	D.F. Sangster

TABLE 5.22 MINERAL DEPOSIT MODEL CRITERIA FOR SEDIMENTARY COPPER TYPE DEPOSITS FROM ECKSTRAND (1984). KEY STATEMENTS USED FOR THE CREATION OF THE KNOWLEDGE-BASE ARE SHOWN
IN BOLD TYPEFACE.

6. STRATABOUND SEDIMENT-HOSTED LEAD, ZINC, COPPER, URANIUM

6.3 SEDIMENTARY COPPER

6.3.a Paralic marine (Kupferschiefer-type)

6.3.b Continental (Red bed-type)

COMMODITIES	Cu (Ag, Co)
EXAMPLES: Canadian - *Foreign*	(6.3.a) Redstone, N.W.T. - *Kupferschiefer, Poland-Germany; Zambin and Zairean Copperbelts; Udokan, U.S.S.R.; White Pine, Michigan; Spar Lake, Montana; Creta, Oklahoma.* (6.3.b) Dorchester, N.B. - *Dzhezkazgan, U.S.S.R.; Nacimiento, New Mexico.*
IMPORTANCE	Canada: No economic deposits in Canada but large deposits in United States near Canadian border. World: 15% to 20% of world copper production and reserves; primarily from a few large districts such as Zambian and Zairean Copperbelts; Lubin, Polan; and Dzheskazgan, U.S.S.R.
TYPICAL GRADE, TONNAGE	(6.3.a) Highly variable. 1.0 to 5.0% Cu and 1 to 30 g Ag/tonne; 5 to 500 million tonnes. Cobalt is an important byproduct in Zambian and Zairean Copperbelts. (6.3.b) 1 to 2% Cu and 1 to 30 g Ag/tonne, 1 to 10 million tonnes.
GEOLOGICAL SETTING	**Contintental or shallow marine sedimentary rocks deposited in low latitude, arid and semi-arid environments. Evaporites occur in the section.** **(6.3.a) Anoxic marine rocks overlie or are interlayered with redbeds.** **(6.3.b) Anoxic fluvial and lacustrine rocks overlie or are interlayered with redbeds.**
HOST ROCKS OR MINERALIZED ROCKS	**(6.3.a) Carbonaceous claystone, siltstone, sandstone, marl, limestone and dolomite.** (6.3.a) Carbonaceous sandstone, conglomerate, claystone and siltstone.
ASSOCIATED ROCKS	**Redbeds, evaporites.**
FORM OF DEPOSIT, DISTRIBUTION OF ORE MINERALS	Concordant or peneconcordant zones of disseminated sulphides, mainly tabular or blanket-shaped, but also channel-like or linear. Typical lateral extent of mineralized beds is of the order of kilometres; typical thickness, 0.5 to 30 m. Sulphides are commonly zoned both vertically and laterally, showing part or all of the following sequence (upward and outward from the base of the orebody): native copper, chalcocite, bornite, chalcopyrite, galena, shpalerite, pyrite.
MINERALS: Principal ore minerals *- Associated Minerals*	**Chalcopyrite, bornite, chalcocite, native copper, carrollite.** *- Pyrite, other sulphides, ordinary rock forming minerals of sedimentary rocks such as quartz, feldspar, carbonates, clays*
AGE, HOST ROCKS	**Early Proterozoic (about 2.25 Ga) to Tertiary.** Only after the formation of undisputed redbeds.
AGE, ORE	The same as, or slightly younger than, host rocks.
GENETICAL MODEL	**Diagenetic subsurface brines (probably derived from evaporites) extracted copper from available basement rocks or sediments, transported it through oxidized beds, and precipitated it by reduction in anoxic sediments. Early diagenetic pyrite was a common reductant.**
ORE CONTROLS, GUIDES TO EXPORATION	1. **Low latitude, arid, continental and shallow marine sedimentary sequences.** 2. **Source of copper such as copper-bearing basement and/or sediments.** 3. **Extensive redbed or other oxidized aquifer system and adjacent pyritic, carbonaceous host rocks. The typical sites of ore deposition differ in the two subtypes: (6.3.a) the base of a major marine transgressive unit overlying redbeds; (6.3.b) the permeable lower parts of fining-upwards fluvial cycles.** 4. **Large-scale zoning of sulphides (indicating that the mineralizing systems were large-scale phenomena).**
AUTHOR	R.V. Kirkham

TABLE 5.2C MINERAL DEPOSIT MODEL CRITERIA FOR SEDIMENT-HOSTED SULPHIDE TYPE DEPOSITS FROM ECKSTRAND (1984). KEY STATEMENTS USED FOR THE CREATION OF THE KNOWLEDGE-BASE ARE SHOWN IN BOLD TYPEFACE.

9. STRATAFORM SULPHIDE, BARITE

9.2 SEDIMENT-HOSTED SULPHIDE

COMMODITIES	Zn, Pb, Ag, barite (Cd, Cu, Sn)
EXAMPLES: Canadian - *Foreign*	Sullivan, Cirque, B.C.; Faro, Howards Pass, Tom and Jason, Yukon; Walton, N.S. is probably a deposit of this type, comparable to Silvermines, Ireland. - *Balmat, New York; Broken Hill, Mt. Isa and McArthur River, Australia; Broken Hill and Gamsberg, South Africa; Rammelsberg and Meggan, West Germany; Silvermines and Tynagh, Ireland.*
IMPORTANCE	Canada: in 1977-78, 16% of the zinc, 45% of the lead and 10% of the silver produced in Canada was from this type of deposit. These proportions will probably increase in the future. World: currently, the bulk of the world's known reserves of zinc and lead in deposits of this type occur in Australia, Canada, and South Africa.
TYPICAL GRADE, TONNAGE	Range (and weighted average) of 38 world examples: 4 to 550 (av. 60) million tonnes; 0.6% to 18% (av. 7.3%) Zn; 0.3% to 13% (av. 4.0%) Pb; nil to 1.0% (av. 0.1%) Cu; trace to 180 g/tonne (av. 48 g/tonne) Ag. Some deposits have large reserves of barite associated with the sulphide ores, e.g. Walton, N.S. (now closed) produced about 4 million tonnes $BaSO_4$. Meggen, Germany produced about 7 million tonnes $BaSO_4$. Anvil district deposits (e.g. Faro), Tom and Jason, Yukon and Cirque, B.C. have substantial barite contents.
GEOLOGICAL SETTING	**Within second order, often tectonically (growth fault) controlled sedimentary basins situated in a continental rise, continental shelf, or intracontinental marine basin.**
HOST ROCKS OR MINERALIZED ROCKS	**Deep marine clastic sedimentary rocks (shales, siltstones, fine to coarse grained turbidites), starved basin lithofacies (carbonaceous to siliceous shales, chert), shallow marine lithofacies (calcareous shales, carbonates).**
ASSOCIATED ROCKS	**Sedimentary breccias and conglomerates**, especially in the stratigraphic footwall; talus from synsedimentary fault scarp. Sulphide zone may be overlain by, or pass laterally into, **chemical sediments, particularly chert and baritite.** Minor amounts of volcanic rocks, especially tuffs, recognized in host rocks of some deposits. Discordant feeder zone may be silicified, carbonatized, tourmalinized. Increase in biogenic activity near hydrothermal vents may be indicated by increase in carbon, silica and phosphorous content of associated rocks.
FORM OF DEPOSIT, DISTRIBUTION OF ORE MINERALS	Concordant interbedded layers of sulphide and host rocks form mineralized bodies whose lateral extents are tens to hundreds of times greater than their thicknesses. Ores are typically bedded on a scale varying from a few microns to several centimetres. Individual sulphide beds are often monomineralic. Relatively small "feeder zones" discordant to stratiform mineralization have been identified in many deposits. Pb/Zn, Cu/Zn, Zn/Ba ratios of the stratiform mineralization typically decrease away from the feeder zone.
MINERALS: Principal ore minerals - *Associated Minerals*	**Sphalerite, galena, barite.** - *Quartz, pyrrhotite, pyrite, chalcopyrite, marcasite, arsenopyrite, sulphosalts, cassiterite*
AGE, HOST ROCKS	Canada: Sullivan, 1.43 Ga; Northern B.C.-Yukon, 0.55-0.34 Ga; Australia, South Africa, 2.0-1.7 Ga; Europe, 0.38-0.36 Ga.
AGE, ORE	Same as host rocks.
GENETICAL MODEL	**Deposition in a brine pool in a second order basin.** Discharge temperature of fluids is generally less than that of volcanic-associated deposits (9.1) i.e., probably in the range 150-250 degrees C. **Hydrothermal activity is associated with tectonic activity, manifested by growth faults, slump breccias,** etc. Some deposits may be a product of **low heat flux discharge or seepage of stratafugic water** (e.g., derived by compaction of underlying sedimentary pile) **into a euxinic, starved basin environment.**
ORE CONTROLS, GUIDES TO EXPLORATION	1. **The majority of deposits are spatially associated with intracontinental or continental margin basins - usually thick successions of clastic sedimentary rocks.** 2. **Second order basins are prime exploration targets, and are recognized by local lithological facies that are additional or exotic to the regional lithological succession, and rapid lateral facies change.** 3. **Evidence of syndepositional tectonic activity: growth faults, fault scarp talus, slump and slide breccias. Tectonically active zone may represent reactivation of basement faults.** 4. **Evidence of syndepositional geothermal activity: presence of volcanic rocks in the succession, usually local flows or thin tuff horizons; presence of other chemical sediments of hydrothermal origin (e.g. chert, baritite, sediments enriched in iron and manganese), or of biogenic origin resulting from hydrothermal activity (e.g. sediments enriched in carbon, phosphorous, and silica).**
AUTHOR	J.W. Lydon, D.F. Sangster

Original statement:

In platform carbonate successions. Commonly, but not always, **located between a zone of tectonic instability characterized by vertical movement** (commonly called a **"hinge line"** and **marked by rapid lithological facies changes such as at a reef front, or edge of a sedimentary basin), and the tectonically stable platform.**

Extracted Statement (narrative)	Logical Statement	Derivative Maps Used	Fuzzy Membership
"In platform carbonate successions. ...located between a zone of tectonic instability characterized by vertical movement ('hinge line' marked by rapid lithological facies changes such as at a reef front, or edge of a sedimentary basin), and the tectonically stable platform."	('Depositional Setting' = platform carbonates, .AND. 'Tectonic Setting'= instability,) .AND. (close to 'Faults' .OR. close to 'Facies Boundaries')	- Depositional Setting - Tectonic Setting - Proximity to Facies Boundaries - Proximity to Faults	M14 M15 M17 M18

Map Class	Depositional Setting	$\{M_{14}\}$
1	Alluvial Fan	0.05
2	Fluvial-Deltaic	0.05
3	Carbonate/Clastic Shelf	0.80
4	Pelitic Shelf and Slope	0.05
5	Carbonate Shelf and Slope	0.95
6	Restricted Shelf	0.05
7	Starved Basin	0.05
8	Submarine Fan	0.05
9	Igneous Intrusion	0.05
10	Glacial / Post-Glacial	0.05
11	Fluvial-Deltaic/Carb. Shelf and Slope	0.50
12	Fluvial-Deltaic/Carb-Clastic Shelf	0.30
13	Submarine Fan/Pelitic Shelf	0.05

Map Class	Tectonic Setting	$\{M_{15}\}$
1	Trailing Margin Subsidence	0.40
2	Unstable Shelf Margin	0.65
3	Foreland Subsidence	0.75
4	Ellesmerian Orogeny	0.75
5	Sverdrup Basin Rifting	0.75
6	Melvillian Transpression	0.65
7	Melvillian Transtension	0.65
8	Passive Post-rift Subsidence	0.55
9	Incipient Rifting	0.55
10	Eurekan Orogeny	0.45
11	Stable Platform	0.05
12	Boothia Uplift	0.95
13	Unrelated	0.05

Map Class	Proximity to Facies Boundary	$\{M_{17}\}$
1	0 - 500 metres	0.95
2	500 - 1000 metres	0.85
3	1000 1500 metres	0.75
4	1500 - 2000 metres	0.60
5	2000 - 2500 metres	0.50
6	2500 - 3000 metres	0.40
7	3000 - 3500 metres	0.30
8	3500 - 4000 metres	0.20
9	4000 - 4500 metres	0.10
10	> 4500 metres	0.05

Map Class	Proximity to Faults	$\{M_{18}\}$
1	0 - 500 metres	0.95
2	500 - 1000 metres	0.85
3	1000 - 1500 metres	0.75
4	1500 - 2000 metres	0.60
5	2000 - 2500 metres	0.50
6	2500 - 3000 metres	0.40
7	3000 - 3500 metres	0.30
8	3500 - 4000 metres	0.20
9	4000 - 4500 metres	0.10
10	> 4500 metres	0.05

FIGURE 5.[illegible] GENERAL PROCESS FOR KNOWLEDGE-BASE CREATIONIN INVOLVES 4 STEPS: (1) EXTRACTION OF KEY STATEMENTS FROM DEPOSIT MODEL CRITEREA (NARRATIVE), (2) TRANSLATION OF KEY STATEMENTS INTO 'LOGICAL STATEMENTS', (3) DETERMINATION OF DERIVATIVE MAPS TO BE USED AS EVIDENCE FOR THE STATEMENT, OR SUB-STATEMENT, AND 4) THE ASSIGNMENT OF FUZZY MEMBERSHIP VALUES TO DERIVATIVE MAP CLASSES.

TABLE 5.3A. MISSISSIPPI VALLEY TYPE PB-ZN DEPOSIT MODEL CRITERIA, LOGICAL STATEMENTS, AND FUZZY MEMBERSHIP SETS.

Criteria Category	Extracted Statement (narrative)	Logical Statement	Derivative Maps Used	Fuzzy Set
1. **Geological Setting**	"In platform carbonate successions. ...located between a zone of tectonic instability characterized by vertical movement ('hinge line' marked by rapid lithological facies changes such as at a reef front, or edge of a sedimentary basin), and the tectonically stable platform."	('Depositional Setting' = platform carbonates, .AND. 'Tectonic Setting'= instability,) .AND. ('Faults'=close .OR. 'Facies Boundaries'=close)	- Depositional Setting - Tectonic Setting - Proximity to Facies Boundaries - Proximity to Faults	M14 M15 M17 M18
2. **Host Rocks or Mineralized Rocks**	"Carbonate rocks, ...highly brecciated dolomite."	'Rock Types' = carbonate, dolomite	- Rock Types	M23
3. **Associated Rocks**	"Most commonly limestone; less commonly shale, sandstone evaporites."	'Rock Types' = 'limestone, shale,sandstone, or evaporites	- Rock Types	M33
4. **Principal Ore Minerals**	"Sphalerite, galena."	'Bedrock Units' = sphalerite, or galena mineralization	- Bedrock Units	M41
5. **Associated Minerals**	"Pyrite, marcasite, dolomite, calcite, ... barite, flourite, chalcopyrite."	'Bedrock Units' = pyrite, marcasite, dolomite, calcite, barite, flourite, or chalcopyrite mineralization	- Bedrock Units	M51
6. **Age, Host Rocks**	"(In Canada) Helikian to Carboniferous; most abundant in early to mid-Paleozoic. (Foreign) Cambrian to Triassic."	'Depositional Age' = Helekian to Triassic	- Depositional Age	M62
7. **Genetic Model**	". . fluid inclusion studies suggest ores were precipitated from low temperature brines. ... brines originated from shale basins adjacent to the platform carbonates, and the ore minerals precipitated in some cases during early diagenesis, and in other cases long after lithification of host rocks."	*(NULL)*	- *No data (requires other forms of information from field and laboratory studies).*	*(NULL)*
8. **Ore Controls, Guides to Exploration**	1. "Secondary breccia in dolomite, cemented by white sparry dolomite."	*(NULL)*	- *No data (requires other forms of information from field and laboratory studies).*	*(NULL)*
	2. "Unconformities within carbonate sequence (ore horizon will be below unconformities)."	'Rock Types' = Carbonates .AND. 'Unconformities' =close	- Rock Types - Proximity to Unconformities	M823 M826
	3. "Reefs."	'Rock Types' = Reef lithologies	Rock Types	M832
	4. "Carbonate-shale and limestone-dolomite facies changes."	'Bedrock Units'=carbonate/shale, limestone/dolomite	- Bedrock Units	M841
	5. "Basement high(s)."	*(NULL)*	- *No data. (Requires other forms of information from geophysical studies).*	*(NULL)*
	6. "Open spaces of any type within the carbonate sequences, especially those formed by karstification as evidenced by brecciation, thinning of carbonate strata, local increase in concentration of insoluble residue material."	'Faults' =close	- Proximity to Faults	M868

TABLE 5.3B. SEDIMENTARY CU DEPOSIT MODEL CRITERIA, LOGICAL STATEMENTS, AND FUZZY MEMBERSHIP SETS.

Criteria Category	Extracted Statement (narrative)	Logical Statement	Derivative Maps Used	Fuzzy Set
1. **Geological Setting**	"Continental or shallow marine sedimentary rocks deposited in low latitude, arid and semi-arid environments. Evaporites occur in the section. (Paralic Marine) - Anoxic marine rocks overlie or are interlayered with redbeds. (Continental (redbeds)) - Anoxic fluvial and lacustrine rocks overlie or are intelayered with redbeds."	'Bedrock Units' .OR. 'Rock Types' = evaporites, redbeds, 'Depositional Setting' = continental / shallow marine sediments.	- Bedrock Units - Rock Types - Depositional Setting	C_{11} C_{13} C_{14}
2. **Host Rocks or Mineralized Rocks**	"Cabonaceous claystone, siltstone, sandstone, marl, limestone, dolomite, conglomerate."	'Bedrock Units ' = claystone,siltstone, sandstone, marl, limestone, dolomite, conglomerate	- Bedrock Units	C_{21}
3. **Associated Rocks**	"Redbeds, evaporites."	'Bedrock Units' = Redbeds, evaporites	- Bedrock Units	C_{31}
4. **Principal Minerals**	"Chalcopyrite, bornite, chalcocite, native copper, carrollite."	'Bedrock Units' = Chalcopyrite, bornite, chalcocite, native copper, carrollite mineralization	- Bedrock Units	C_{41}
5. **Associated Minerals**	"Pyrite, other sulphides,	'Bedrock Units' = Pyrite, sulphide mineralization	- Bedrock Units	C_{51}
6. **Age, Host Rocks**	Early Proterozoic (about 2.25 Ga) to Tertiary.	'Depositional Age' = Early Proterozoic to Tertiary	- Depositional Age	C_{62}
7. **Genetic Model**	"Diagenetic subsurface brines (probably derived from evaporites) extracted copper from available basement rocks or sediments, transported it through oxidized beds, and precipitated it by reduction in anoxic sediments. Early diagenetic pyrite was a common reductant."	*(NULL)*	- *No data (requires other forms of information from field and laboratory studies).*	*(NULL)*
8. **Ore Controls, Guides to Exploration**	1. "Low latitude, arid, continental and shallow marine sedimentary sequences."	'Depositional Setting' = continental, shallow sedimentary sequences	- Depositional Setting	C_{814}
	2. "Sources of copper such as copper-bearing basement and/or sediments."	*(NULL)*	- *No data (requires other forms of information from field and laboratory studies).*	*(NULL)*
	3. "Extensive redbed or other oxidized aquifer system and adjacent pyritic, carbonaceous host rocks. .... typical sites differ by subtype... (Paralic Marine) - base of major transgression overlying redbeds. (Continental (redbeds)) - the permeable lower parts of fining-upwards fluvial cycles."	'Bedrock Units' = redbeds, base of major transgression, permeable parts of fluvial cycles	- Bedrock Units	C_{831}
	4. "Large-scale zoning of sulphides (indicating that the mineralizing systems were large-scale phenomena)."	*(NULL)*	- *No data (requires other forms of information from field and laboratory studies).*	*(NULL)*

TABLE 5.3C. SEDIMENT-HOSTED SULPHIDE DEPOSIT MODEL CRITERIA, LOGICAL STATEMENTS, AND FUZZY MEMBERSHIP SETS.

Criteria Category	Extracted Statement (narrative)	Logical Statement	Derivative Maps Used	Fuzzy Set
1. Geological Setting	"Within second order, often tectonically (growth fault) controlled sedimentary basins situated in a continental rise, continental shelf or intracontinental marine basin."	('Depositional Setting' = continental rise, shelf, marine basin,) .AND. ('Tectonic Setting' = active .OR. 'Faults'=close)	- Depositional Setting - Tectonic Setting - Proximity to Faults	S_{14} S_{15} S_{18}
2. Host Rocks or Mineralized Rocks	"Deep marine clastics (shales, siltstones, ... turbidites), starved basin lithofacies (carbonaceous to siliceous shales, chert), shallow marine lithofacies (calcareous shales, carbonates)."	('Rock Types' = shales, siltstones, turbidites, chert, carbonates) .OR. ('Depositional Setting' = deep marine clastics, starved basin, shallow marine)	- Rock Types - Depositional Setting	S_{23} S_{24}
3. Associated Rocks	"...breccias and conglomerates, ... talus, ... chemical sediments, particularly chert and baritite."	'Bedrock Units' = breccias, conglomerates, talus, chemical sediments, chert and baritite	- Bedrock Units	S_{31}
4. Principal Ore Minerals	"Sphalerite, galena, barite."	'Bedrock Units' = sphalerite, galena, barite mineralization	- Bedrock Units	S_{41}
5. Associated Minerals	"Pyrrhotite, pyrite, chalcopyrite, marcasite, arsenopyrite, sulphosalts, cassiterite."	'Bedrock Units' = pyrrhotite, pyrite, chalcopyrite, marcasite, arsenopyrite, sulphosalts, cassiterite mineralization	- Bedrock Units	S_{51}
6. Age, Host Rocks	"... 2000 Ga to ... 360 Ga."	'Depositional Age' = 2000 Ga - 360 Ga	- Depositional Age	S_{63}
7. Genetic Model	"Deposition in a brine pool in a second order basin. ....Hydrothermal activity is associated with tectonic activity, manifested by growth faults, slump breccias. .... flux discharge or seepage of stratafugic water into a euxinic, starved basin environment."	('Depositional Setting' = starved basin) .AND. ('Faults'=close)	- Depositional Setting - Proximity to Faults	S_{74} S_{78}
8. Ore Controls, Guides to Exploration	1. "The majority of deposits are spatially associated with intracontinental or continental margin basins - usually thick successions of clastic sedimentary rocks."	('Depositional Setting' = intracontinental basins, continental margin basins) .AND. ('Rock Types = clastics)	- Rock Types - Depositional Setting	S_{813} S_{814}
	2. "Second order basins are prime exploration targets, and are recognized by local lithological facies that are additional or exotic to the regional lithological succession, and rapid lateral facies change."	'Facies Boundaries'=close	- Proximity to Facies Boundaries	S_{827}
	3. "Evidence of syndepositional tectonic activity: growth faults, fault scarp talus, slump and slide breccias. Tectonically active zone may represent reactivation of basement faults."	'Tectonic Setting' = active .OR. 'Faults'=close	- Tectonic Setting - Proximity to Faults	S_{835} S_{838}
	4. "Evidence of syndepositional geothermal activity: presence of volcanic rocks in the succession, usually local flows or thin tuff horizons; presence of other chemical sediments of hydrothermal origin (e.g. chert, baritite, sediments enriched in iron and manganese), or of biogenic origin resulting from hydrothermal activity (e.g. ... enriched in carbon, phosphorous, and silica)."	'Rock Types' = chemical sediments	- Rock Types	S_{843}

5.5. Mineral Potential Mapping

Mineral potential mapping is the final stage in the process that involves building the inference engine to determine mineral potential for the three selected deposit models. The inference engine is created using the GIS modelling language that combines derivative maps (linked to fuzzy membership tables) to map the mineral potential for each of the three deposit sub-types. Figures 5.5a - 5.7b, and Enclosures 2a - 4b, represent two iterations for each of the three deposit models. The figures are provided for discussion purposes, while the enclosures provide interim views of the results at each node of the inference nets.

In the figures below, the GIS modelling language code for the inference net is shown in the box on the left with a graphical presentation of the inference net on the right. Each deposit model was iterated twice to demonstrate the flexibility for mapping mineral potential using different assumptions. The difference in assumptions are reflected in the different combination rules applied in each iteration without altering the contents of the knowledge-base (fuzzy membership tables) or the database (derivative maps). It is important to recognize that the experimentation performed in these models is limited to changing assumptions in the inference net only. It is possible to experiment further by changing the contents of the knowledge base (by assigning new fuzzy membership values), or the contents of the database (such as using a different geological map).

Each model is created on the basis of combining various factors for potential mineralization. The model factors were derived primarily from the categories provided in Eckstrand (1984), and were supplemented for models that have known deposits in the study area. These criteria have been grouped into the following categories:

- **Associated with Known Deposits**
- **Geological Setting**
- **Host Rocks and Associated Rocks**
- **Ore Minerals and Associated Minerals**
- **Age of Host Rocks**
- **Genetic Model**
- **Guides to Exploration.**

The decisions regarding the selection of combination rules for combining evidence for each model are first based on using any combination rule suggested by logical statements. This applies mostly to the combination of various fuzzy sets to produce evidence associated with individual factors. However, the rules applied to combine all factors in the final result are usually not spelled out in the deposit models, but may be implicit in the model description. The choice of combination rule is often quite arbitrary, and is usually a balance between the fuzzy AND and the fuzzy OR rules. Generally, mineral potential mapping and mineral exploration lean toward the use of OR rules (the presence of any positive evidence is enough to trigger interest), but sometimes the co-occurrence of evidence is essential, requiring the use of the fuzzy AND rule. With fuzzy logic, the GAMMA operator is particularly useful because the choice of value of the γ parameter allows the modeller to choose from a spectrum of outcomes that range from the fuzzy algebraic PRODUCT thruough fuzzy AND to fuzzy OR and the fuzzy algebraic SUM at the other extreme. The following sections discuss how the inference nets for each iteration of each deposit model were created. In some cases, a radical change in assumptions did not affect the results greatly, and in other cases, a slight change in the sequence of combinations changed the results dramatically.

5.5.1. MVT Pb-Zn - First Iteration

The key statements extracted from Eckstrand (1984) for the MVT Pb-Zn model combined with available data allowed six factors to be considered. Each factor represents knowledge of significant geological features of MVT Pb-Zn deposits. In the case of the MVT Pb-Zn model, Factors 2 - 6 were provided by Eckstrand (1984), and Factor 1 is an overriding factor that considers the influence of geological units associated with one known MVT Pb-Zn deposit in the study area. The Polaris mine on Little Cornwallis Island is hosted by the Thumb Mountain and Irene Bay formations, and is associated with the Cape Phillips Fm. Therefore, Factor 1 is included to elevate the potential of all areas where these units occur, overriding the favourability based on deposit model criteria alone. The following discussion describes the logic and results of the model, and should be read with Enclosures 4 A,B, Figures 5.5A,B, and Enclosure 3B (fuzzy membership tables) open for reference. Note that the actual GIS modelling statements are shown in Figures 5.5A,B.

In Factor 2, the geological setting, evidence was combined strictly according to the rules explicit in the logical statement. Node 1 represents the combination of {M_{14}} and {M_{15}} with the fuzzy AND operator to reflect the sub-statement: "*Depositional Setting=platform carbonates, .AND. Tectonic Setting=instability*". The combination of {M_{17}} and {M_{18}} (node 2) used the fuzzy OR combination to reflect the sub-statement: "*close to Faults .OR. close to Facies Boundaries*". Enclosure 2A shows the results of these two nodes. In essence, the map shown at Node 1 indicates the relative favourability of areas where the depositional setting characteristics of the rocks in the area involved the deposition of platform carbonates in a tectonically unstable area. High ranking values resulted for Eastern Bathurst Island because this area contains carbonate units affected by the Boothia Uplift in the Cornwallis Fold Belt. The map shown at node 2 indicates the relative favourability for being close to either a fault or a facies boundary. Again, eastern Bathurst Island ranks very high due to the influence of the Cornwallis Fold Belt.

The calculation of node 3 involves using the fuzzy AND operator to combine the results of nodes 1 and 2. Recall from Chapter 2 that the fuzzy AND function maps the minimum of a set of values. This is demonstrated well in the map at node 3 because it shows eastern Bathurst Island remains highly favourable, where as most of Melville Island received a lower favourability ranking since the logic of the model statement dictates that the presence of faults or facies boundaries are only favourable if they exist in combination with carbonate rocks affected tectonically unstable area. Therefore, most of the higher favouability ranking on Melville Island at node 2 is subdued at node 3 due to the lack of favourable rock types. And vise versa, the Griper Bay Group rocks that receive a moderate favourability ranking in the map at node 1 have received a lower ranking in areas where faults and unconformities are not present.

Factor 3 considered the host rock types and associated rock types of MVT Pb-Zn deposits. In this factor, rock types are considered in a different context than in Factor 1. The model criterion provides a list of rock types that are hosted by, or are associated with, MVT Pb-Zn deposits. Whereas Factor 2 considered 'platform carbonates' in the context of depositional setting, Factor 3 lists the specific rock types 'carbonates' and 'dolomites' as host rocks, and 'limestone, shale, sandstone or evaporites' as associated rock types. Evidence for the occurrence of these rock types is found in the 'rock types' derivative map. In this case, the two fuzzy membership sets linked with the 'rock types' derivative map, $\{M_{33}\}$ and $\{M_{34}\}$, were combined with the fuzzy SUM operator to increase the net favourablity on the basis of favourable host rocks and associated rocks coexisting in the same location. The result of this combination is shown in the map at node 4. Most of the area received high favourability because of the broad range of favourable rock types common in the study area. (Note: Iteration 2 considers this factor in a different manner).

The next factor considered the presence of ore minerals and associated minerals. The fuzzy membership sets $\{M_{41}\}$ and $\{M_{51}\}$ indicate evidence for all geological units that contain known occurrences of ore minerals and associated minerals respectively. As with Factor 3, the fuzzy SUM operator was used to combine these fuzzy sets to increase the net favourability of locations where both ore minerals and associated minerals were observed.

Nodes 6 and 7 present the calculations of favourability according to Factor 6, which considers 'guides to exploration'. Fuzzy sets $\{M_{63}\}$ and $\{M_{64}\}$ are combined with the fuzzy AND operator to map the favourability of the logical statement: "*Rocktypes=carbonates .AND. close to unconformities*". This reflects the explicitness of the 'union' relationship between rock types and unconformities in the original statement: "*Unconformities within carbonate sequence*". The map at node 6 shows the relative favourability for locations where carbonates occur with, or are close to, unconformities.

The other fuzzy sets in Factor 6 refer to evidence for other guides to exploration (Table 4.3A). Node 7 is a calculation of the net favourability of all evidence associated with the geological features that are suggested as guides to exploration. These fuzzy sets were combined using the fuzzy SUM operator under the assumption that wherever any of the geological features coexist, the favourability ranking will be higher. In effect, the result is that most of the Parry Islands receives high favourability (node 7) for this factor since the guides to exploration represent a range of rock types and features that are common throughout the study area. (As with Factor 3, this Factor is treated in a different manner in the second iteration).

The next node (node 8) in the inference net combines all factors, which now includes the age of the host rocks as a factor (Factor 5), but excludes the overriding factor of units with known deposits. At this level in the net, the decisions for applying certain combination rules become more subjective since the combination rules are not as explicit in the deposit model as a whole as it is within individual statements and sub-statements provided in model criterion. For experimentation purposes, the fuzzy GAMMA operator was used to combine all deposit model factors. The γ value was set to 0.85, which tends towards an 'increasive'effect of all factors, but not as extreme as the fuzzy SUM. In this case, the assumption is that the favourability ranking of areas will increase if the inputs are all favourable. In essence, the function is not quite a direct average of all factors, nor does it simply take the best value available to an area. The GAMMA operator creates an output favourability that is a compromise of the input favourabilities; but if γ is large, say 0.85 or greater, the output can be greater than any on input, if several inputs are large and reinforcive.

Factor 1 is finally combined with the output of node 8 (at node 9) using an overriding fuzzy OR. As stated above, Factor 1considers all areas where the Thumb Mountain and Irene Bay, and Cape Phillips formations exist and is used to override the other factors based on deposit model criteria. The significance of this result is discussed below in comparison with the result of the second iteration of the MVT Pb-Zn model.

5.5.2. MVT Pb-Zn - Second Iteration

The approach taken in the second iteration was to return to the first iteration and examine locations in the inference net where some alternative combination rules might be considered. For example, the combination rules for the logical statements associated with nodes 1,2,3, 5 and 6 are reasonably explicit in the model criteria. However, nodes 4, 7, and 8 used combination rules that were more arbitrary. Therefore, the inference net was altered for the second iteration at nodes 4,7, and 8 as shown in Figure 5.5B and Enclosure 2B.

For node 4 (both iterations), the first iteration applied the fuzzy SUM operator to assign a favourability if either favourable host rocks or associated rocks occur, which elevates the favourability for areas where both favourable host rocks and favourable associated rocks occur. As an alternative assumption , in the second iteration the fuzzy AND was applied so that both host rocks and associated rocks need to be favourable to receive a combined favourability ranking. The result is shown in the map at node 4. While the relative favourability for both host rocks and associated rocks remains moderately high for most of the study area, because the net favourability of these 2 maps tends to be correlated, the net favourability ranking is more subdued in the second iteration than the result at node 4 in the first iteration.

Another modification applied for combining evidence associated with guides to exploration (Factor 6, node 7 - first iteration, node 8 - second iteration). In the first iteration, the fuzzy SUM was used under the assumption that an area will receive a favourable ranking if there is any evidence of geological features suggested as guides to exploration, and the net favourability ranking would increase at locations where there is compound evidence. The fuzzy GAMMA operator was applied, with $\gamma = 0.75$. If effect, this causes the favourability ranking to be suppressed in areas where there is conflicting evidence, and greatly reduces the overall favourability of the guides to exploration factor.

The next change in the design of the inference net involved considering geological setting (Factor 2) and favourable rock types (Factor 3) in isolation from the rest of the model factors (node 5 - second iteration). With this assumption, geological favourability may be considered separately from areas with known mineralization. The fuzzy SUM operator was used to combine evidence of favourable geological setting with evidence of favourable rock types under the assumption that if either favourable geological setting or favourable rock types occur, the favourability ranking would be high, and the net ranking would be higher in areas where both factors were favourable simultaneously. The result is shown in the map at node 5. This map is used in combination with Factor 5, age of host rocks, and the map at node 8 (guides to exploration) to produce a net geological favourability map (node 10). These maps were then combined in turn with the fuzzy GAMMA operator (γ=0.75). The resulting map considers geological favourability in the context of mutually supportive evidence as suggested by the maps at nodes 5, 8 and Factor 5 (age of the host rocks), and areas with conflicting evidence are taken into account.

Finally, units with known ore (e.g. galena) and associated minerals (e.g. pyrite) (Factor 4) were combined with units with known deposits (e.g. Polaris) as the final overriding factor. This was done by applying the fuzzy OR function to the combination of Factor 1, bedrock units associated with known MVT Pb-Zn deposits, with the map at Node 6, bedrock units with known mineral occurrences. The resulting map shown at node 9 shows the distribution of bedrock units with either known deposits or ore minerals. This map, which is considerably different from Factor 1 on its own, is combined with favourable geological setting (node 10) to produce the final map at node 11. The fuzzy OR operator was used in the same way as the first iteration give precedence to the units with deposits or ore minerals over the factors derived from deposit model criteria.

5.5.3. Sedimentary Cu - First Iteration

The key statements provided by Eckstrand (1984) for the Sedimentary Cu deposit sub-type combined with available data allowed five factors to be considered for modelling Sedimentary Cu potential. There are no known Sedimentary Cu type deposits in the study area, therefore, there is no overriding factor as in Factor 1 of the MVT Pb-Zn models. The inference net is designed strictly on the basis of the criteria provided in the Sedimentary Cu model within the constraints of the information provided by the database.

The map shown at node 1 shows the favourability with respect to specific rock types (redbeds) associated with favourable geological setting. In this case, the fuzzy sets $\{C_{11}\}$ and $\{C_{11}\}$were assigned to derive the most evidence possible from the database through linkage with the 'bedrock units' and 'rock types' derivative maps. The reason for this is that although redbeds are accounted for in the 'bedrock units' map through the 'rock types' fields in the geological data model, they are not accounted for in the general 'rock types' derivative map legend. The fuzzy OR operator was used to combine evidence, yielding favourable zones where either condition occurs.

Factor 2 considers evidence for favourable host rocks and associated rocks, as shown in the map at node 2. In this case the fuzzy AND operator was used to combine evidence, so that areas are favourable only where host rocks and associated rocks are both favourable. For Factor 3, (presence of ore minerals or associated minerals) the fuzzy SUM operator was applied to allow the presence of either class of minerals to be considered favourable. The main reason for this choice is to emphasise the importance of the reference to "*other sulphides*" in the extracted statement under the 'Associated minerals' category (Figure 5.4A). Also, since there are no known Sedimentary Cu deposits in the study area, the known presesnce of ore minerals represents the closest factor for evidence of potential Sedimentary Cu mineralization. The result is shown in the map at node 3.

The next set of nodes in the network (nodes 4 and 5) were derived under the assumption that any criteria that made direct reference to 'redbeds' would be considered separately from other factors. Here, the fuzzy SUM operator was used to combine the evidence of nodes 1, 2 and fuzzy set $\{C_{u1}\}$ (Tables 5.3B, 5.4A). The map shown at node 4 provides evidence of redbeds, along with evidence of presence of favourable host rocks (node 2), and favourable stratigraphic position (fuzzy set $\{C_{u1}\}$, Factor 5). The favourable host rocks include claystone, siltstone, sandstone, marl, limestone, dolomite and conglomerate. The main assumption is that if there is evidence of redbeds, the net favourability is increased in the presence of favourable host rocks, but the occurrence of favourable host rocks is also considered moderately favourable.

The map shown at node 5 provides evidence for factors associated with depositional setting and the age of the host rocks. In this case, the fuzzy sets $\{C_{14}\}$and $\{C_{u14}\}$consider depositional setting in two contexts. In the first context, the geological setting category considers "*Continental or shallow marine sedimentary rocks*", whereas the second context considers "*...continental and shallow marine sedimentary sequences*". There is an apparent contradiction in the deposit model concerning the mutual relationship between 'continental' sedimentary rocks and 'shallow marine' sedimentary rocks. Therefore, the fuzzy sets $\{C_{14}\}$ and $\{C_{u14}\}$ reflect the uncertainty in the fuzzy membership values assigned to the depositional settings map classes. Another factor in this deposit model is the favourable age of the host rocks. The specified age range is early Proterozoic to Tertiary. This range covers more than half of geological time, and most of the time of the development of the rocks in the Parry Islands. Therefore, because these factors are not particularly relevent in this context, they were combined with the fuzzy PRODUCT operator to decrease the influence on the final result.

The final map shown at node 6 is a fuzzy OR combination of the results at nodes 4 and 5. In this case, the net relative favourability considers the higher ranked results associated with evidence of redbeds and associated rock types, and in absence of this, favourability on the basis of the less influential factors associated with continental and shallow marine sequences, and the age of the host rocks. Note that tectonic setting, proximity to faults, unconformities and facies boundaries are not considered for this model.

5.5.4. Sedimentary Cu - Second Iteration

The design of the second iteration of the Sedimentary Cu model considers the effects of assumptions regarding the relationship between redbeds and favourable host rocks in the first iteration. In the first iteration (Enclosure 3A), the maps shown at nodes 1, 4 and 6 (result) are very similar. Therefore, it is clear that the rule used for combining evidence for node 1 weighs heavily in the final result. In the first iteration, the fuzzy sets $\{C_{11}\}$ and $\{C_{13}\}$ were used to provide evidence for the occurrence of redbeds or evaporites, but they are linked to two different spatial representations in the 'bedrock units' and 'rock types' derivative maps. The fuzzy set $\{C_{11}\}$ linked to the 'bedrock units' map provides evidence for bedrock units that contain only redbeds or evaporites. However, the fuzzy set $\{C_{13}\}$ linked to the 'rock types' map provides the same evidence, but on the basis of any group of bedrock units that may contain redbeds or evaporites. Therefore, for the second iteration, the two evidence maps are considered separately.

The maps shown at nodes 1 and 2 (second iteration) are the same maps shown at nodes 2 and 3 in the first iteration. The map shown at node 3 is a fuzzy SUM combination of the fuzzy sets $\{C_{11}\}$ and $\{C_{a1}\}$ and the map at node 1. This map provides evidence for redbed association more directly than the map at node 1 in the first iteration. The map at node 4 is similar to the map at node 5 in the first iteration with the addition of the fuzzy set $\{C_{13}\}$. In this case, the vague association of redbeds and evaporites in the broad classes of the 'rock types' map legend is considered in the same context as the depositional setting and age of host rocks factors and is given less weight. Again, the fuzzy PRODUCT is used as the combination operator to decrease the effect of these less influential factors in the final result. The final result map is shown at node 5. It is obvious that a change in the first assumption in the first iteration causes a dramatic change in the net result map.

5.5.5. Sediment-Hosted Sulphides - First Iteration

Six factors were considered in determining the potential for Sediment-Hosted Sulphide deposits. As with the Sedimentary Cu model, there are no known Sediment-Hosted Sulphide deposits in the study area, therefore, the criteria used in the six factors are restricted to the key statements extracted from Eckstrand (1984) as applied to the database.

The combination rules applied to produce the maps shown at nodes 1 and 2 (Figure 5.7A, Enclosure 4A) were provided explicitly by the logical statement derived in the geological setting category (Table 5.3C). The map at node 1 is a fuzzy OR combination of the fuzzy sets $\{S_{13}\}$ and $\{S_{18}\}$, to reflect the sub-statement: "*tectonic setting=active .OR. close to faults*". The result of this combination is combined with fuzzy set $\{S_{14}\}$ with the fuzzy AND operator to produce the map shown at node 2, which represents the evidence for Factor 1. In effect, this map shows the relative favourability for the complete logical statement: "*(Depositional setting = continental rise, shelf, marine basin) .AND. (tectonic setting = active .OR. close to faults)*".

It is important to note, as mentioned above in Section 5.2, that it is unfortunate that the ages of faults are not indicated on the geological map, therefore, they were not differentiated in terms of their timing of development with respect to the deposition of the host rocks. In absence of this information, the only way to treat this statement is to consider the 'possibilities' that some of the faults on the map are growth faults that developed syn-tectonically with the host rocks. The map at node 1 reflects this broad uncertainty about which areas were actually affected by growth faults. However, the original statement requires such faults to co-exist with continental rise, shelf, or marine basin depositional setting. By combining the set $\{S_{14}\}$, which refers for favourable depositional setting, with the map at node 1, the resulting favourability is considerably adjusted as shown in the map at node 2.

The map shown at node 3 is the result of combining fuzzy sets $\{S_{23}\}$ and $\{S_{24}\}$ with the fuzzy AND operator to reflect the logical statement: "*Rock types = shales, siltstones, turbidites, chert, carbonates, .AND. Depositional setting = marine clastics, starved basin, shallow marine*". The evidence for Factor 2 is provided by combining the result at node 3 with the fuzzy set $\{S_{31}\}$ with the fuzzy SUM function. Because this combination rule is not explicit in the model criteria, the fuzzy SUM function was applied under the assumption that while either host rocks or associated rocks are considered favourable, the net favourability ranking should increase in areas where both conditions occur. The map shown at node 4 provides evidence for favourable host rocks and associated rocks.

The map shown at node 5 provides evidence for Factor 3, the location of bedrock units with known ore minerals and associated minerals. This map was calculated by combining fuzzy sets $\{S_{41}\}$ and $\{S_{51}\}$ with the fuzzy SUM operator. The assumption is similar to the one used to produce the map at node 4. The presence of both ore minerals and associated minerals at the same location is considered more favourable than either occurrence type alone.

Factor 6 considers geological features discussed in a genetic model. The genetic models provided in the MVT Pb-Zn and Sedimentary Cu deposit models refer to geological features and processes that do not correspond directly to geological features represented in the database. They are local features that require detailed field investigation and laboratory research to provide evidence for mineral potential. The genetic model provided in the Sediment-Hosted Sulphide deposit model, however, makes reference to some regional geological features that are extractable from the geological map. The map shown at node 6 provides evidence of favourability for starved basins and proximity to faults. The fuzzy SUM operator was used to represent the favourability of locations where either condition is true, and increase the net favourability in areas where both conditions are true.

Factor 7 is a complex combination of fuzzy sets {S[illegible]}, {S[illegible]}, {S[illegible]}, {S[illegible]}, {S[illegible]}, and {S[illegible]}. The fuzzy OR operator was used to calculate the map shown at node 7, which provides evidence for the first guide to exploration. The fuzzy OR operator was used since the relationship between the depositional setting and the reference to clastic sedimentary rocks is not explicit, therefore, evidence of either feature is considered favourable. The map shown at node 8 was also calculated using the fuzzy OR operator to allow either units with tectonically active depositional settings or the presence of faults to represent areas that were tectonically active. The maps at nodes 7 and 8 were combined with fuzzy sets {S[illegible]} and {S[illegible]} with the fuzzy SUM operator to produce the map shown at node 9. The fuzzy SUM operator was used as a means to provide a favourable ranking for evidence where either of the guides to exploration occur, and to increase the net favourability ranking in areas where favourable evidence co-exists. The result map shown at node 9 provides a high favourability ranking for most of the study area because the criteria used in Factor 7 refer to geological features that are common throughout the area, and their favourability rankings are compounded with the fuzzy SUM operator.

The next stage in the design of this inference net is to combine the evidence from the various factors to produce a final result. The rules for the combination of all factors are not explicitly stated in the deposit model, therefore, the assumption used is to allow evidence for all factors to weight equally, except for evidence of known mineralization (Factor 3). The fuzzy GAMMA function was used to combine factors 1, 2, 4, 5, and 6, using a γ value of 0.85. The GAMMA function was used to compensate for areas where the evidence of the various factors are conflicting. This map (node 10) was combined with the map shown at node 5 with the fuzzy OR function to allow the occurrence of bedrock units with known mineralization to take precedence over the remaining factors.

5.5.6. Sediment-Hosted Sulphides - Second Iteration

From a review of the result of the first iteration, combination rules at some nodes in the inference net were changed. Most of the initial factor calculations remain unchanged, except for Factor 7 where the fuzzy OR operator is used in place of the fuzzy SUM operator to combine all evidence for geological features considered as guides to exploration (map shown at node 9). The fuzzy OR operator was considered the only alternative since the individual guides to exploration criteria refer to geological features that are diverse, and the presence of favourable evidence from any source was considered important. This combination still results in a relatively high favourability ranking for the entire study area, as is the case for the result shown at node 9 in the first iteration.

However, an alternative assumption in the combination of all factors with regard to the influence of the genetic model factor may produce dramatically different results. In this iteration, the fuzzy GAMMA function was used to combine all factors except for factors 3 and 6. A γ value of 0.35 was used to produce the map shown at node 10, thereby depressing the overall favourability levels. This map was then combined with Factors 3 and 6, also with the fuzzy GAMMA operator, with $\gamma = 0.85$. In effect, this sequence of GAMMA combinations strengthened the influence of Factors 3 and 6 over other factors, and allowed a moderately 'increasive' favourability where favourable evidence co-exists. This was done under the assumption that bedrock units with known mineralization, starved basin environments, and the presence of faults should take precedence in influencing the results, without completely excluding other factors for mineralization.

```
E MVTNET1 MVT Model - First Iteration
;-----------------------------------------------------------
;FACTOR 1 -> Overriding Factor -
;        Bedrock Units with Known Mineral Deposits
;-----------------------------------------------------------
of1=(0.95 if class(BEDROCK)==36);
of2=(0.95 if class(BEDROCK)==35);
;-----------------------------------------------------------
;FACTOR 2 -> Nodes 1,2,3 - Geological Setting
;-----------------------------------------------------------
m14=table('fatdepo',class(DEPOSET),'m1'),
m15=table('fattect',class(TECTOSET),'m1'),
m17=table('fatfact',class(PROXFACT),'m1'),
m18=table('fatfalt',class(PROXFALT),'m1'),
mn1=min(m14,m15),
mn2=max(m17,m18),
mn3=min(mn1,mn2),
;-----------------------------------------------------------
;FACTOR 3 -> Node 4 - Host Rocks and Associated Rocks
;-----------------------------------------------------------
m22=table('fatlith',class(LITCLASS),'m2'),
m33=table('fatlith',class(LITCLASS),'m3'),
mn4=1-((1-m22)*(1-m33)),
;-----------------------------------------------------------
;FACTOR 4 -> Node 5 - Units with Known Mineralization
;-----------------------------------------------------------
m41=table('fatbed',class(BEDROCK),'m4'),
m51=table('fatbed',class(BEDROCK),'m5'),
mn5=1-((1-m41)*(1-m51)),
;-----------------------------------------------------------
;FACTOR 5 -> Age of Host Rocks
;-----------------------------------------------------------
m62=table('fatage',class(AGECLASS),'m6'),
;-----------------------------------------------------------
;FACTOR 6 -> Nodes 6,7 - Guides to Exploration
;-----------------------------------------------------------
m823=table('fatlith',class(LITCLASS),'m82'),
m826=table('fatunco',class(PROXUNCO),'m82'),
m833=table('fatlith',class(LITCLASS),'m83'),
m841=table('fatbed',class(BEDROCK),'m84'),
m868=table('fatfalt',class(PROXFALT),'m86'),
mn6=min(m823,m826),
mn7=1-((1-mn6)*(1-m833)*(1-m841)*(1-m868)),
;-----------------------------------------------------------
;RESULT - Node 8 - MVT Potential
;-----------------------------------------------------------
mygamma=.85,
mnfsum=1-((1-mn3)*(1-mn4)*(1-mn5)*(1-m62)*(1-mn7)),
mnfprod=mn3*mn4*mn5*m62*mn7,
mn8=pow(mnfsum,mygamma)*pow(mnfprod,1-mygamma),
mn9=max(of1,of2,mn8),
mn9
```

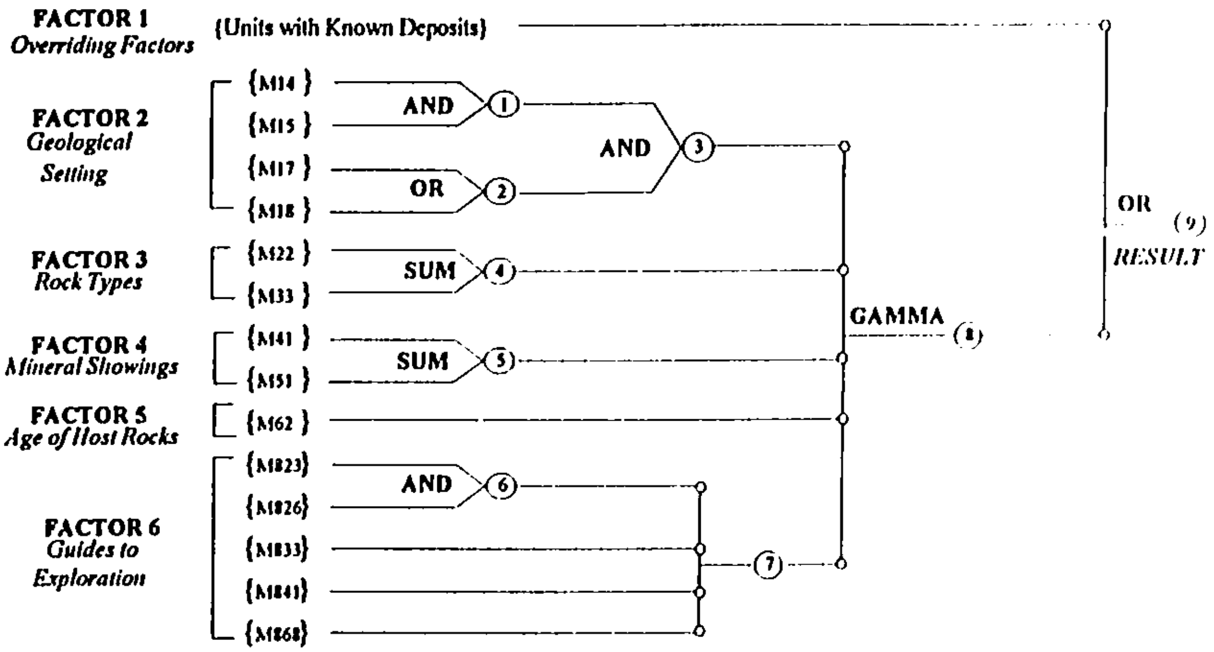


FIGURE 5.5A. MISSISSIPPI VALLEY TYPE PB-ZN MODEL - FIRST ITERATION, GIS MODELLING EQUATION AND INFERENCE NET.

```
E MVTNET2 MVT Model - Second Iteration
;----------------------------------------------------------------
;FACTOR 1 -> Overriding Factor -
;        Bedrock Units with Known Mineral Deposits
;----------------------------------------------------------------
of1=(0.95 if class(BEDROCK)==36);
of2=(0.95 if class(BEDROCK)==35);
;----------------------------------------------------------------
;FACTOR 2 -> Nodes 1,2,3 - Geological Setting
;----------------------------------------------------------------
m14=table('fatdepo',class(DEPOSET),'m1');
m15=table('fatect',class(TECTOSET),'m1');
m17=table('fatfact',class(PROXFACT),'m1');
m18=table('fatfalt',class(PROXFALT),'m1');
mn1=min(m14,m15);
mn2=max(m17,m18);
mn3=min(mn1,mn2);
;----------------------------------------------------------------
;FACTOR 3 -> Node 4 - Host Rocks and Associated Rocks
;----------------------------------------------------------------
m22=table('fatlidt',class(LITCLASS),'m2');
m33=table('fatlidt',class(LITCLASS),'m3');
mn4=min(m22,m33);
;----------------------------------------------------------------
;FACTOR 4 -> Node 6 - Units with Known Mineralization
;----------------------------------------------------------------
m41=table('fatbed',class(BEDROCK),'m4');
m51=table('fatbed',class(BEDROCK),'m5');
mn6=1-((1-m41)*(1-m51));
;----------------------------------------------------------------
;FACTOR 5 -> Age of Host Rocks
;----------------------------------------------------------------
m62=table('fatage',class(AGECLASS),'m6');
;----------------------------------------------------------------
;FACTOR 6 -> Nodes 7,8 - Guides to Exploration
;----------------------------------------------------------------
m823=table('fatlidt',class(LITCLASS),'m82');
m826=table('fatunco',class(PROXUNCO),'m82');
m833=table('fatlidt',class(LITCLASS),'m83');
m841=table('fatbed',class(BEDROCK),'m84');
m868=table('fatfalt',class(PROXFALT),'m86');
mn7=min(m823,m826);
mn8sum=1-((1-mn7)*(1-m833)*(1-m841)*(1-m868));
mn8prod=mn7*m833*m841*m868;
mn8gam=0.75;
mn8=pow(mn8sum,mn8gam)*pow(mn8prod,1-mn8gam);
;----------------------------------------------------------------
;RESULT - Nodes 5,9,10,11 - MVT Potential
;----------------------------------------------------------------
mn5=1-((1-mn3)*(1-mn4));
mn9=max(of1,of2,mn6);
mn10gam=0.75;
mn10sum=1-((1-mn5)*(1-m62)*(1-mn8));
mn10prod=mn5*m62*mn8;
mn10=pow(mn10sum,mn10gam)*pow(mn10prod,1-mn10gam);
mn11=max(mn9,mn10);
mn11
```

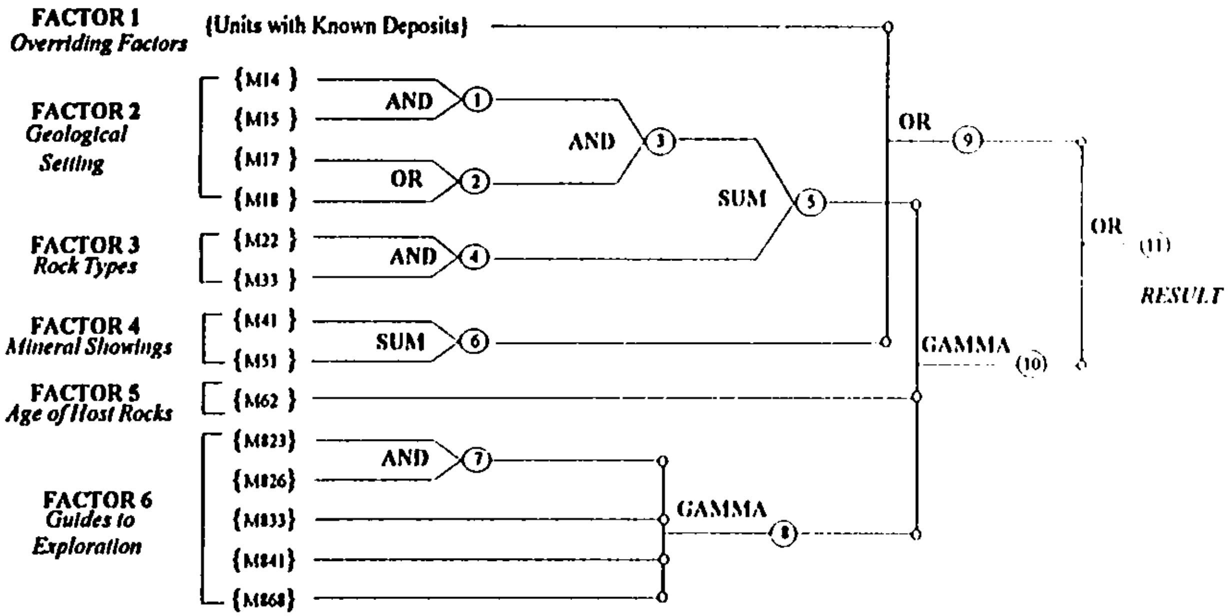
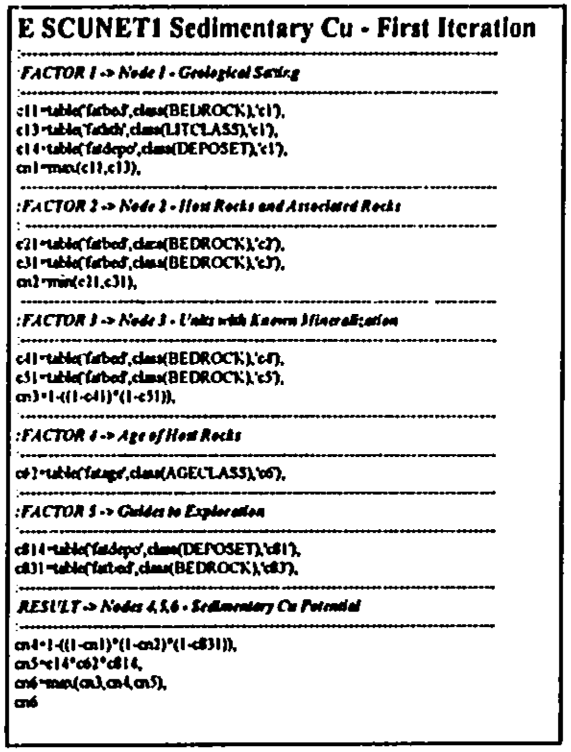


FIGURE 5.5B. MISSISSIPPI VALLEY TYPE PB-ZN MODEL - SECOND ITERATION, GIS MODELLING EQUATION AND INFERENCE NET.



```
E SCUNET1 Sedimentary Cu - First Iteration
;------------------------------------------------------------
;FACTOR 1 -> Node 1 - Geological Setting
;------------------------------------------------------------
c11=table('fatbed',class(BEDROCK),'c1'),
c13=table('fatlit',class(LITCLASS),'c1'),
c14=table('fatdepo',class(DEPOSET),'c1'),
cn1=max(c11,c13),
;------------------------------------------------------------
;FACTOR 2 -> Node 2 - Host Rocks and Associated Rocks
;------------------------------------------------------------
c21=table('fatbed',class(BEDROCK),'c2'),
c31=table('fatbed',class(BEDROCK),'c3'),
cn2=min(c21,c31),
;------------------------------------------------------------
;FACTOR 3 -> Node 3 - Units with Known Mineralization
;------------------------------------------------------------
c41=table('fatbed',class(BEDROCK),'c4'),
c51=table('fatbed',class(BEDROCK),'c5'),
cn3=1-((1-c41)*(1-c51)),
;------------------------------------------------------------
;FACTOR 4 -> Age of Host Rocks
;------------------------------------------------------------
c62=table('fatage',class(AGECLASS),'c6'),
;------------------------------------------------------------
;FACTOR 5 -> Guides to Exploration
;------------------------------------------------------------
c814=table('fatdepo',class(DEPOSET),'c81'),
c831=table('fatbed',class(BEDROCK),'c83'),
;------------------------------------------------------------
;RESULT -> Nodes 4,5,6 - Sedimentary Cu Potential
;------------------------------------------------------------
cn4=1-((1-cn1)*(1-cn2)*(1-c831)),
cn5=c14*c62*c814,
cn6=max(cn3,cn4,cn5),
cn6
```

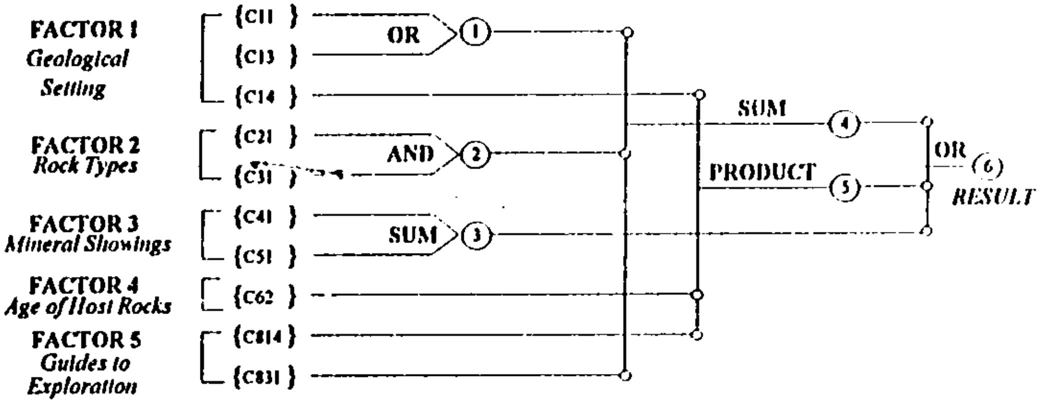


FIGURE 5.6A. SEDIMENTARY CU POTENTIAL MODEL - FIRST ITERATION, GIS MODELLING EQUATION AND INFERENCE NET.

```
E SCUNET2 Sedimentary Cu - Second Iteration
;-----------------------------------------------------------
:FACTOR 1 -> Geological Setting
;-----------------------------------------------------------
c11=table('fatbed',class(BEDROCK),'c1'),
c13=table('fatlit',class(LITCLASS),'c1'),
c14=table('fatdepo',class(DEPOSET),'c1'),
;-----------------------------------------------------------
 FACTOR 2 -> Node 1 - Host Rocks and Associated Rocks
;-----------------------------------------------------------
c21=table('fatbed',class(BEDROCK),'c2'),
c31=table('fatbed',class(BEDROCK),'c3'),
cn1=min(c21,c31),
;-----------------------------------------------------------
 FACTOR 3 -> Node 2 - Units with Known Mineralization
;-----------------------------------------------------------
c41=table('fatbed',class(BEDROCK),'c4'),
c51=table('fatbed',class(BEDROCK),'c5'),
cn2=1-((1-c41)*(1-c51)),
;-----------------------------------------------------------
 FACTOR 4 -> Age of Host Rocks
;-----------------------------------------------------------
c62=table('fatage',class(AGECLASS),'c6'),
;-----------------------------------------------------------
 FACTOR 5 -> Guides to Exploration
;-----------------------------------------------------------
c814=table('fatdepo',class(DEPOSET),'c81'),
c831=table('fatbed',class(BEDROCK),'c83'),
;-----------------------------------------------------------
RESULT -> Nodes 3,4,5 - Sedimentary Cu Potential
;-----------------------------------------------------------
cn3=1-((1-c11)*(1-cn1)*(1-c831)),
cn4=c13*c14*c62*c814,
cn5=max(cn2,cn3,cn4);
cn5
```

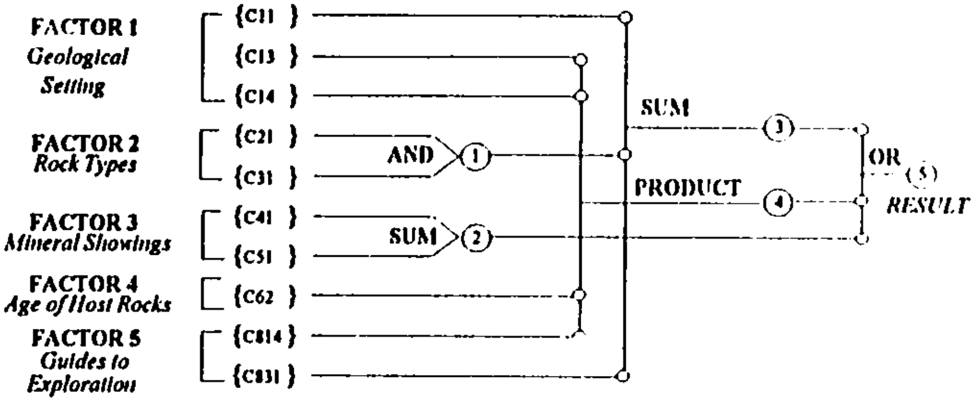


FIGURE 5.6B. SEDIMENTARY CU POTENTIAL MODEL - SECOND ITERATION, GIS MODELLING EQUATION AND INFERENCE NET.

E SHSNET1 Sediment Hosted Sulphide - First Iteration

```
;--------------------------------------------------------------
--------
FACTOR 1 -> Nodes 1,2 - Geological Setting Nodes
;--------------------------------------------------------------
--------
s14=table('fatdepo',class(DEPOSET),'s1').
s15=table('fattect',class(TECTOSET),'s1').
s18=table('fatfalt',class(PROXFALT),'s1').
sn1=max(s15,s18).
sn2=min(sn1,s14).
;--------------------------------------------------------------
--------
FACTOR 2 -> Nodes 3,4 - Host Rocks and Associated Rocks
;--------------------------------------------------------------
--------
s23=table('fatlitd',class(LITCLASS),'s2').
s24=table('fatdepo',class(DEPOSET),'s2').
s31=table('fatbed',class(BEDROCK),'s3').
sn3=min(s23,s24).
sn4=1-((1-sn3)*(1-s31)).
;--------------------------------------------------------------
--------
FACTOR 3 -> Node 5 - Units with Known Mineralization
;--------------------------------------------------------------
--------
s41=table('fatbed',class(BEDROCK),'s4').
s51=table('fatbed',class(BEDROCK),'s5').
sn5=1-((1-s41)*(1-s51)).
;--------------------------------------------------------------
--------
FACTOR 4 -> Age of Host Rocks
;--------------------------------------------------------------
--------
s62=table('fatage',class(AGECLASS),'s6').
;--------------------------------------------------------------
--------
FACTOR 5 -> Node 6 - Genetic Model
;--------------------------------------------------------------
--------
s74=table('fatdepo',class(DEPOSET),'s7').
s78=table('fatfalt',class(PROXFALT),'s7').
sn6=1-((1-s74)*(1-s78)).
;--------------------------------------------------------------
--------
FACTOR 6 -> Nodes 7,8,9 - Guides to Exploration
;--------------------------------------------------------------
--------
s813=table('fatlitd',class(LITCLASS),'s81').
s814=table('fatdepo',class(DEPOSET),'s81').
sn7=max(s813,s814).
s827=table('fatfact',class(PROXFACT),'s82').
s835=table('fattect',class(TECTOSET),'s83').
s838=table('fatfalt',class(PROXFALT),'s83').
sn8=max(s835,s838).
s843=table('fatlitd',class(LITCLASS),'s84').
sn9=1-((1-sn7)*(1-s827)*(1-sn8)*(1-s843)). .
;--------------------------------------------------------------
--------
RESULT- Nodes 12,13 - SHS Potential
;--------------------------------------------------------------
--------
sgamma=0.85.
sn10sum=1-((1-sn2)*(1-sn4)*(1-s62)*(1-sn6)*(1-sn9)).
sn10prod=sn2*sn4*s62*sn6*sn9.
sn10=pow(sn10sum,sgamma)*pow(sn10prod,1-sgamma).
sn11=max(sn5,sn10).
```

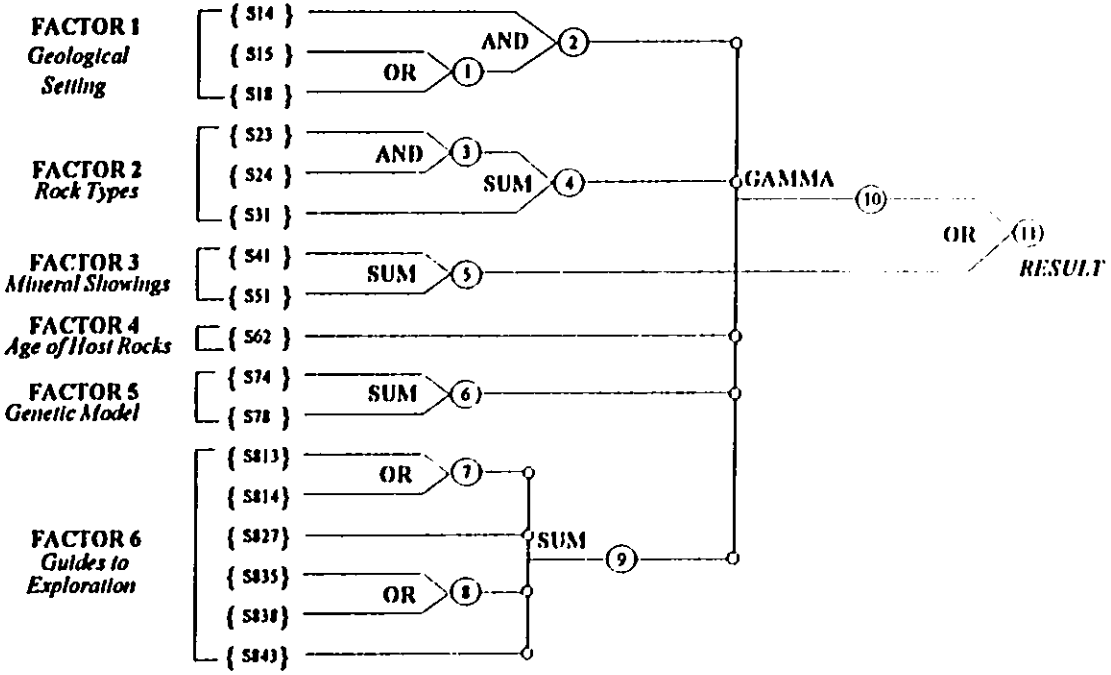


FIGURE 5.7A. SEDIMENT-HOSTED SULPHIDE MODEL - FIRST ITERATION, GIS MODELLING EQUATION AND INFERENCE NET.

E SHSNET2 Sediment Hosted Sulphide - Second Iteration

FACTOR 1 -> Nodes 1,2 - Geological Setting Nodes

```
s14=table('fatdepo',class(DEPOSET),'s1'),
s15=table('fattect',class(TECTOSET),'s1'),
s18=table('fatfalt',class(PROXFALT),'s1'),
sm1=max(s15,s18),
sm2=min(sm1,s14),
```

FACTOR 2 -> Nodes 3,4 - Host Rocks and Associated Rocks

```
s23=table('fatlit',class(LITCLASS),'s2'),
s24=table('fatdepo',class(DEPOSET),'s2'),
s31=table('fatbed',class(BEDROCK),'s3'),
sm3=min(s23,s24),
sm4=1-((1-sm3)*(1-s31)),
```

FACTOR 3 -> Node 5 - Units with Known Mineralization

```
s41=table('fatbed',class(BEDROCK),'s4'),
s51=table('fatbed',class(BEDROCK),'s5'),
sm5=1-((1-s41)*(1-s51)),
```

FACTOR 4 -> Depositional Age

```
s62=table('fatage',class(AGECLASS),'s6'),
```

FACTOR 5 -> Node 6 - Genetic Model

```
s74=table('fatdepo',class(DEPOSET),'s7'),
s78=table('fatfalt',class(PROXFALT),'s7'),
sm6=1-((1-s74)*(1-s78)),
```

FACTOR 6 -> Nodes 7,8,9 - Guides to Exploration

```
s813=table('fatlit',class(LITCLASS),'s81'),
s814=table('fatdepo',class(DEPOSET),'s81'),
sm7=max(s813,s814),
s827=table('fatfact',class(PROXFACT),'s82'),
s835=table('fattect',class(TECTOSET),'s83'),
s838=table('fatfalt',class(PROXFALT),'s83'),
sm8=max(s835,s838),
s843=table('fatlit',class(LITCLASS),'s84'),
sm9=max(sm7,s827,sm8,s843)),
```

RESULT- Nodes 10,11 - SHS Potential

```
s10gam=0.35,
sm10sum=1-((1-sm2)*(1-sm4)*(1-s62)*(1-sm9)),
sm10prod=sm2*sm4*s62*sm9,
sm10=pow(sm10sum,s10gam)*pow(sm10prod,1-s10gam),
s11gam=0.85,
s11sum=1-((1-sm5)*(1-sm6)*(1-sm10)),
s11prod=sm5*sm6*sm10,
sm11=pow(s11sum,s11gam)*pow(s11prod,1-s11gam),
sm11
```

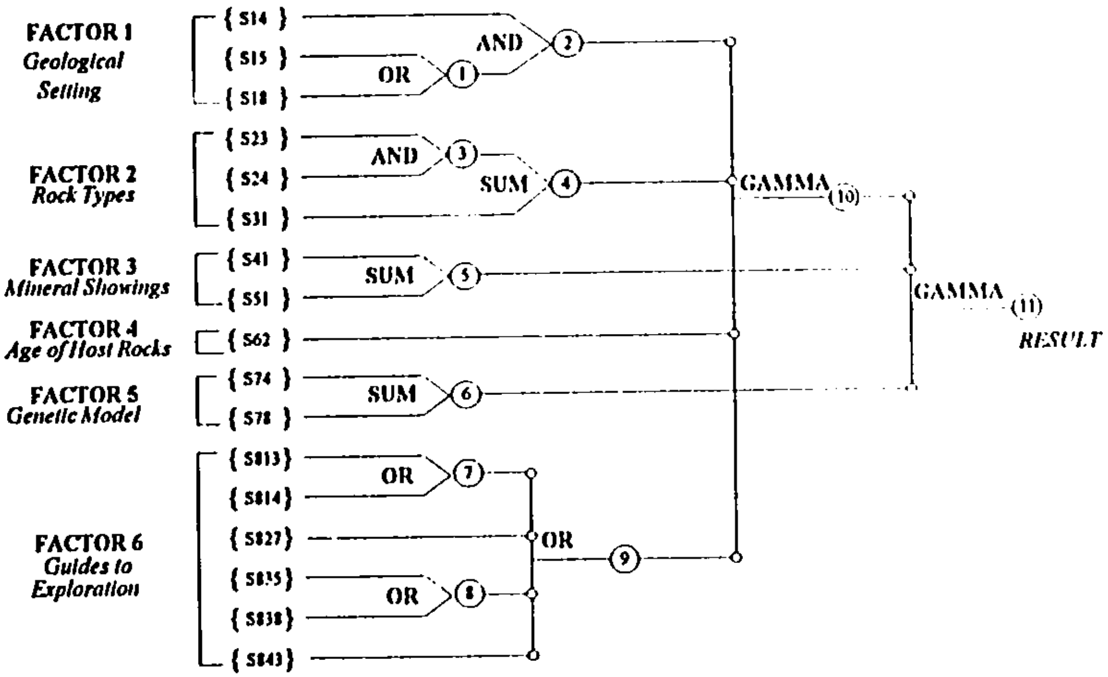


FIGURE 5.7B. SEDIMENT-HOSTED SULPHIDE MODEL - SECOND ITERATION, GIS MODELLING EQUATION AND INFERENCE NET.

6. CHAPTER 6 - DISCUSSION

6

6.1. Significance of Results

This thesis demonstrates one method for using GIS in mineral potential mapping projects. The expert systems approach using fuzzy logic implemented in a GIS mimics some aspects of how geologists conventionally determine the mineral potential of an area on the basis of comparing favourable geological setting according to mineral deposit model criteria. Each iteration of the three deposit models are different approximations or estimations of the relative mineral potential of the Parry Islands, and it is important that the results are used in context of the various constraints applying to this type of study.

The mineral potential maps produced with this method are 'relative' estimations of favourability, which means that the favourability at each location in the study area is rated relative to the favourability of other areas. Although this method is considered a 'quantitative' approach to mineral potential mapping, the results are not estimations of mineral potential in absolute quantities such as tonnage or volume. With respect to the approach used by the Geological Survey of Canada (GSC), the type of mineral potential maps produced by the fuzzy logic method are similar to those of Phase 1 Mineral and Energy Resource Assessments (MERA) (Scoates, et. al. 1986).

The great advantage of this approach lies in the ability to produce an 'audit trail', so that given the same assumptions and parameter settings, exactly the same results can be produced from repeated trials. It also provides a framework for experimentation, examining the effects of making changes to the inference network and to the weighting functions (fuzzy membership tables). This greatly aids in describing how a particular favourability rating is achieved, and puts a complex decision-making process on to a more 'accountable' footing.

6.2. Analytical Constraints

The limitations of results of this experiment lie mostly in the source data that was used, not necessarily in the method. There are inherent limitations in all types of geological data, and caution should be used when applying the fuzzy logic method, or any other method. It is important to treat various geological data in context with the method and objective of any application of the data. For the fuzzy logic method, as applied with the geological map used in this thesis, these inherent characteristics of a 1:1,000,000 geological map impose several constraints on the quality of the results.

For example, some deposit model criteria that make reference to local or fine scale geological features could not be treated due to the limits of the scale of the geological map and shortcomings of the GIS database. This is an inherent limitation associated with cartographic techniques used in geological compilation. The geological map used in this study was compiled at 1:1,000,000. If one assumes that the smallest feature detectable by a human eye is 0.2 mm, then at this scale, the smallest feature that may be represented accurately would be no smaller than 20 metres, which represents the maximum precision of mappable features. The software used in this analysis would allow a maximum resolution of 47 metres, which translates to 0.47 mm at 1:1,000,000.

The limitation of scale is not the measure of the geo-positional accuracy or the accuracy of the attributes of the geological features. It is common practice in the cartographic design of geological maps to generalize many types of geological features. Therefore, the accuracy of the database varies according to the type of feature. As discussed in **Chapter 4**, it is determined that the boundaries of the geological units are more accurate than the locations and geometries of linear features such as faults and folds. Grouping all fault types in to one category, and transforming their representation from lines to buffers compensates for this discrepancy. As a result, the positions and attributes of all geological features represented in the database are considered equally accurate, at the expense of generalizing primary observations made by Harrison (1991,1994) and Kerr (1974). One reason for the output favourability maps having large areas showing relatively high to very high favourability is because the geological features represented in the database are geographically large.

Another constraint is the variability of the types and scales of geological features mentioned in mineral deposit model criteria, which means that not all mineral deposit models could be applied equally. It is important to consider the compatibility of the representation of geological features in the database in context with the types of features mentioned in deposit model criteria. Mineral deposit models that have criteria defined on the basis of local deposit scale geological features could not be applied with the database created for this application. This would require database updating and integration with finer scale geological data, and would not be practical for regional resource assessments.

The results of this study have provided guidance for future geological and geochemical surveys of the Parry Islands (Anglin, pers. comm., 1995). The task of updating the geological map and geological data model with new data, or the addition of new layers to the database such as geochemical data would not be complicated. Further, updates to the existing knowledge base and inference engine could also be made to model new results in light of new evidence for mineral potential. The inclusion of data that provide evidence for some of the fine scale features, such as geochemical data, would certainly help delineate the mineral potential to smaller areas. Further, identification of more accurate positions, geometry and age relationships of faults would certainly increase the quality of the results.

6.3. Other Applications

In essence, the design of this application provides a foundation for any application that requires qualitative decision making based on weighting spatial criteria. Other applications could be applied in environmental sensitivity, land use, site selection, cost/distance analysis, or even the management of field projects.

One application of this method would be to use the existing database for land use and resource management decision making. The results of this application will be used as one factor for deciding the best location for a National Park for the Parry Islands (Jefferson, pers. comm.). Finding the best location for a National Park involves weighting various biological, geological, and cultural criteria. These criteria could be entered into the database as separate layers in a similar way that the derivative maps operate in this application. A separate knowledge-base and inference engine could be created to decide the best location of a park.

Environmental sensitivity mapping projects could also take advantage of this method. Given that the environment has different sensitivities to different types of development activities, it is logical that environmental factors would be weighted differently for different potential impacts. This would futher provide a basis for conducting environmental impact assessments (EIA). In an EIA, a variety of environmental factors are evaluated according to a particular development activity, where the value of various environmental phenomenon is weighted relative to the potential impact. For example, the impact on a Caribou migration route would be different for acitivities associated with developing a National Park than they would for the development of a major highway. In most cases, the impact rating would involve weighting spatial phenomenon and analysing potential impacts by combining various factors according to a model.

6.4. Considerations for Future Research

This application provides a foundation for a variety of future research activities. First, on the technical level, this application was designed and implemented in the SPANS GIS system. In this sense, the application represents a prototype expert system. A more sophisticated expert system would require the development of customizable software that could be tailored for different applications. This could be provided by GIS software vendors as a module to an existing GIS, or it could be developed independently.

One limitation of this application is that the results are based on the views of one expert. It would be worthwhile investigating the requirements for using different subjective views from a panel of experts. This approach would be advantageous because the integrity of the knowledge-base would be enhanced by diverse viewpoints and experience. The problem of determining how various viewpoints would be pooled in the modelling process presents an interesting opportunity for further research. Monte-Carlo Simulation and Influence Allocation Processing techniques (Stanley, et. al. 1994) could provide a framework for developing a new approach using fuzzy logic as the means of knowledge representation and inference.

6.5. Conclusions

This study demonstrates one method for determining mineral resource potential of an area by using fuzzy logic to integrate geological data with mineral deposit modelling in a GIS. This method could be implemented formally in the mineral resource assessment toolbox, and/or applied to other application areas such as environmental sensitivity and land-use decision making. The following conclusions highlight the key benefits and limitations of the fuzzy logic method as applied to mineral potential mapping:

Benefits

1. It provides an 'audit trail' for complex decision-making. This provides better quality control and accountability in the decision-making process.
2. It provides a powerful means of constructing model outputs with great efficiency to test alternative viewpoints and hypotheses.
3. The 'spatial-attribute relational data model' provides an efficient means for deriving information from the spatial database. Therefore, the same database could be used directly to investigate other geological problems.
4. The combination rules provided by fuzzy logic are designed to reflect human thought patterns typical of qualitative decision-making, and provide more flexibility for combining evidence according to complex relationships among evidence variables.

Limitations

1. As with many other methods used in mineral potential mapping, good quality results are attainable on the condition that the data used is suitable for the deposit type criteria and the deposit modelling process.
2. Additional processing of geological data is required to create a digital geological data model that is suitable for the mineral deposit types being considered.
3. The relative favourability ranking scheme applies within the study area only, which means that results of one study area cannot be compared directly with results of other areas that used the same method.

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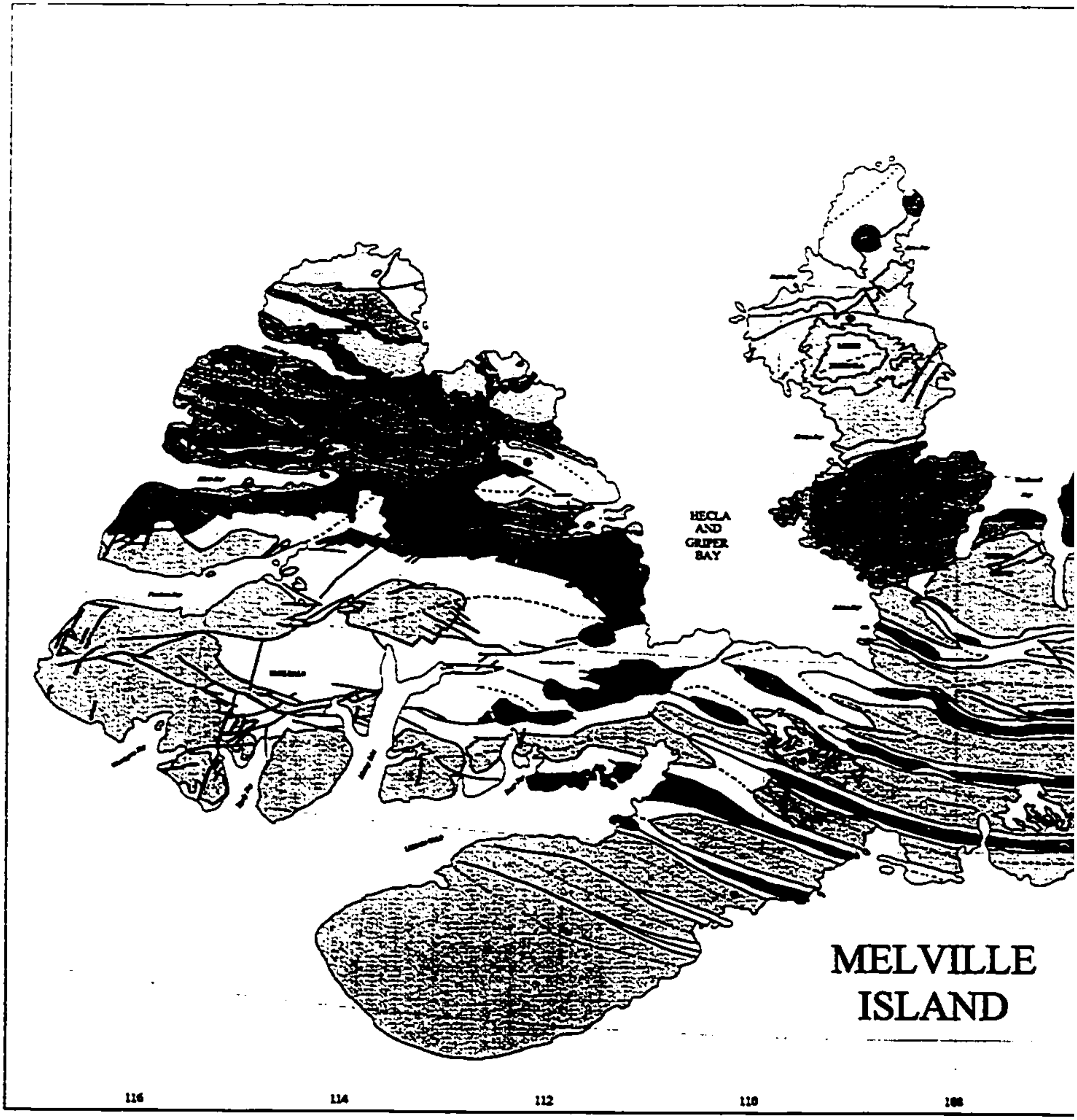
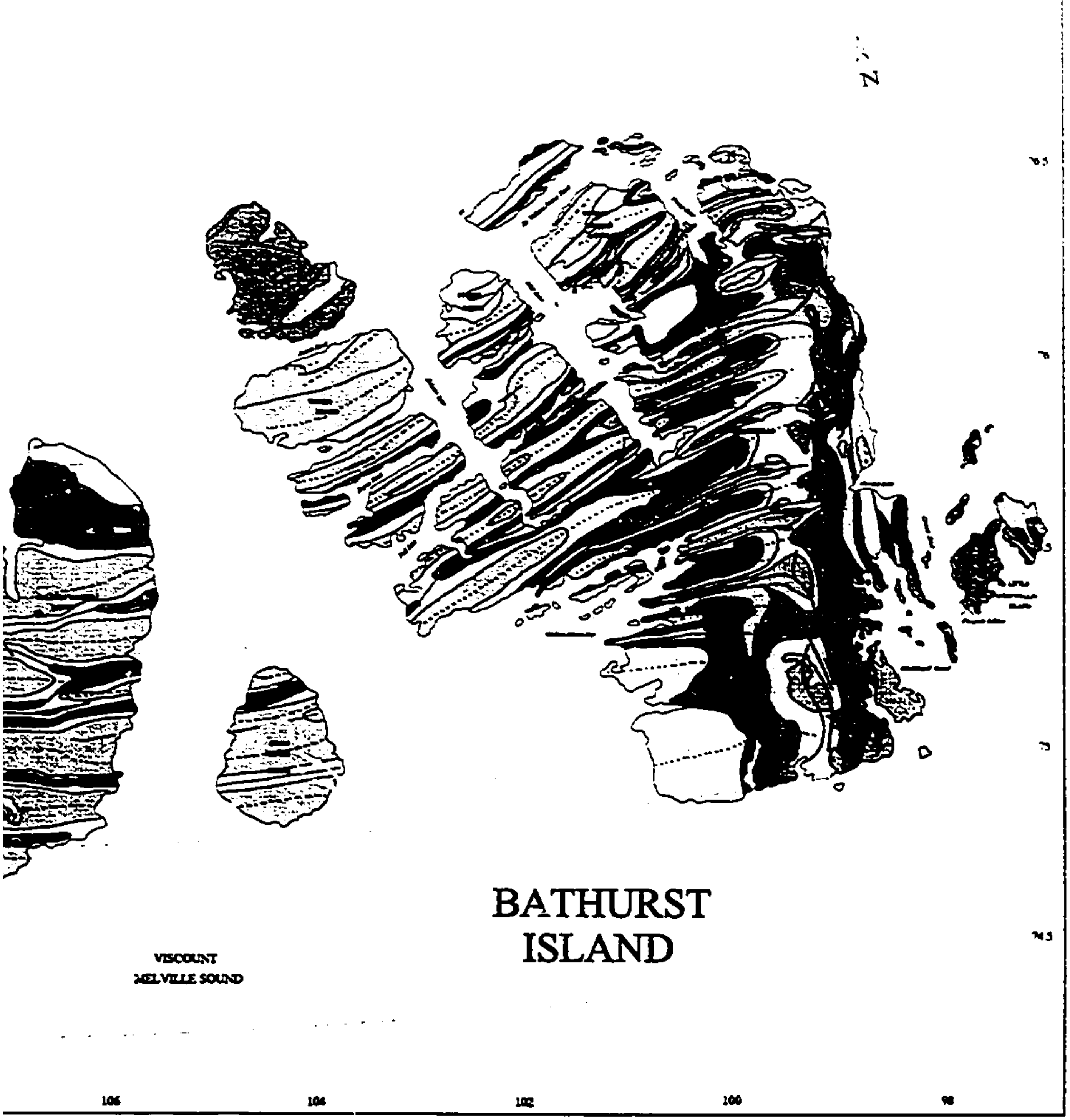


Note: Geologic unit boundaries digitized from O'Kelliah (in prep.).
The legend and associated correlation chart were compiled by Eddy (1996).

Geology and Mi
of the Parry Isl

-25 0



ineral Showings
slands, NWT.

25 km

Projection: Lambert Conformal
Parameters: SP - 74.[illegible],77.[illegible]
CM - [illegible], CL - 75.5
Spheroid: Clarke, 1866

ENCLOSURE 1A.

Legend

Sverdrup Succession

- TNB Beaufort Fm
- ■ Kb Igneous Intrusions
- KTES Eureka Sound Fm
- KK Kanguk Fm
- KH Hassel Fm
- KC Christopher Fm
- KI Isachsen Fm
- ▨ JKDB Deer Bay Fm
- ░ JA Awingak Fm
- ■ JR Ringnes Fm
- ░ JHC Hiccles Cove Fm
- ░ JMI McConnell Island Fm
- ■ JJS Jameson Bay and Sandy Point Fms
- ▨ TrH Heiberg Fm
- ▨ TrB Bjorne Fm
- ▨ TrBF Blind Fiord Fm
- ▨ PAT Assistance and Trold Fiord Fms
- ■ PBS Belcher Channel and Sabine Bay Fms
- ■ CPCF Canyon Fiord Fm
- ■ COF Otto Fiord Fm

Franklinian Succession

- DGB Griper Bay Group
- DHB Hecla Bay Fm
- ▨ DW Weatherall Fm
- ■ DBF Bird Fiord Fm
- ░ DCB Cape de Bray Fm
- ■ DBY Blackley Fm
- ■ ODI Ibbett Bay Fm
- ░ OC Canrobert Fm
- ■ DBL Blue Fiord Fm
- DE EIDS Fm
- ░ DDB Disappointment Bay Fm
- DSB Stuart Bay and Bathurst Island Fms
- DS Stuart Bay Fm
- ░ DB Bathurst Island Fm
- ■ OSCP Cape Phillips Fm
- ░ ODTI Thumb Mountain and Irene Bay Fms

——— Faults
——— Anticlines
------------- Synclines

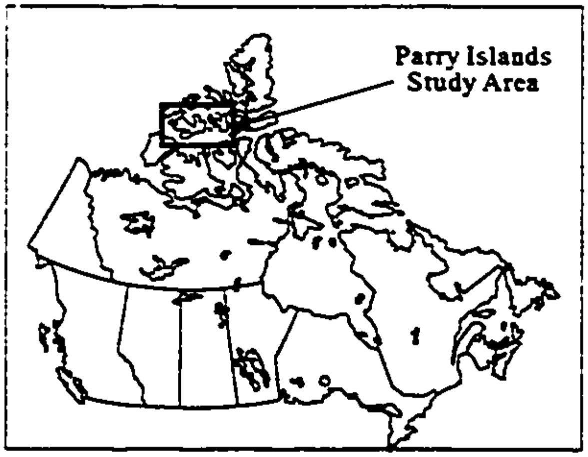
Mineral Showings

- ⚒ Pb / Zn Deposit
- ● Pb / Zn
- ● Pb
- ● Cu
- S
- Ba
- ● F
- ● Coal

Unit boundary types (correlation chart only)

——— Conformity
━━━ Unconformity
～— Facies Boundary

Location Map

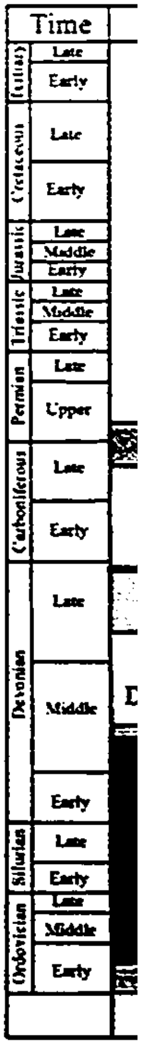


Notes:

1. Geological unit boundaries were digitized from Okulitch (in prep.).
2. The correlation chart was constructed by synthesizing legend and correlation chart information provided in Harrison (1991,1994) for Melville Island, and Kerr (1974) for Bathurst Island.

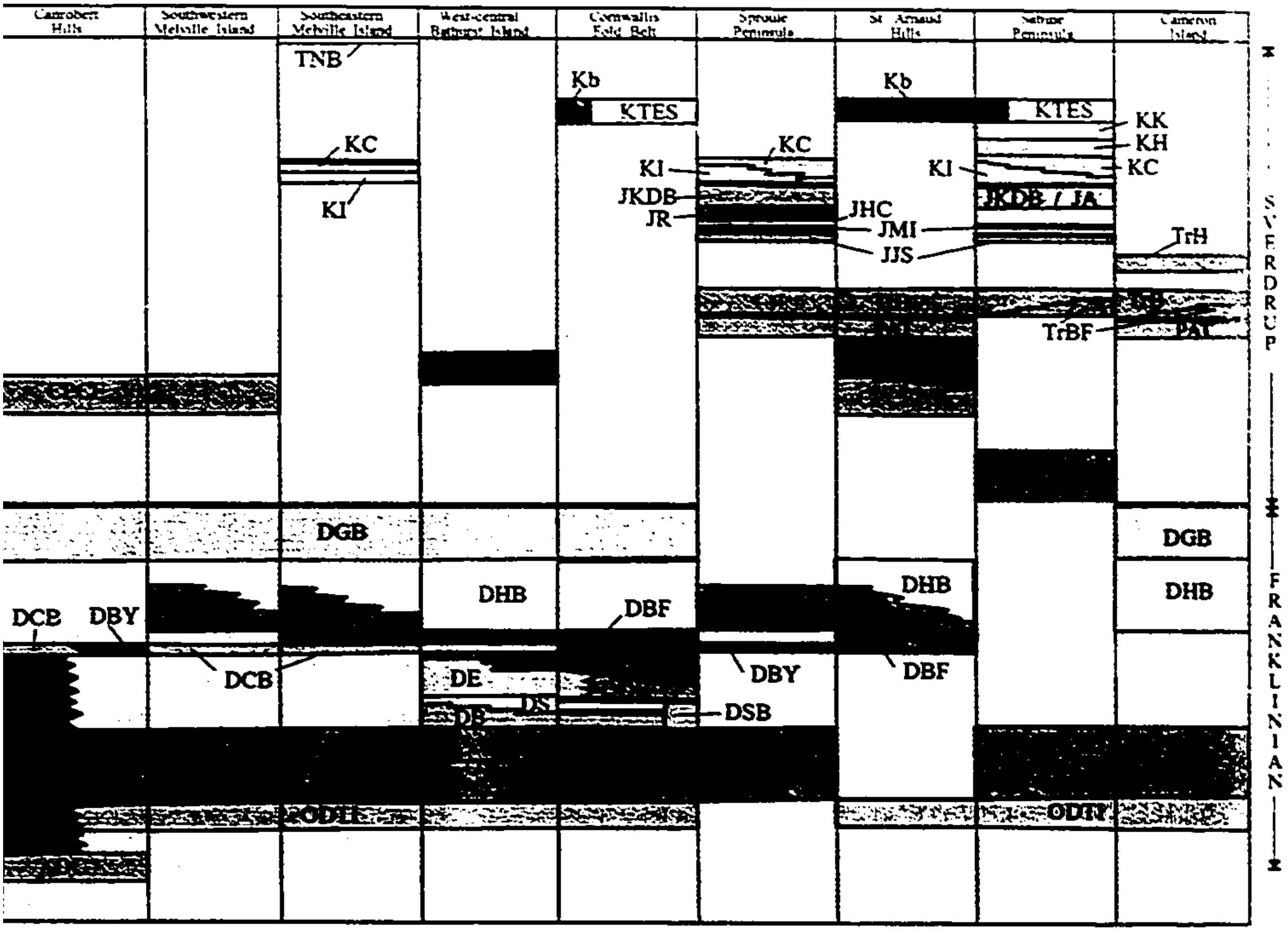
   The chart is partitioned by Resource Assessment Domain (see note 5) and shows occurrence of units mapped at surface, and at subsurface as observed in cross-sections.

   (Refer to Enclosure 2a - Data Source Reference Chart for tracking and derivation of mapped units.)
3. Detailed age, lithology, depositional, and tectonic setting information is provided in the Geologic Data Model.
4. Locations for mineral showings were provided by Harrison (1991) and the Land Use Information Series (NRCan, 1981).
5. Resource Assessment Domains were derived on the basis of contrasting structural and stratigraphic features. They are used for Mineral Resource Assessment purposes and may, but do not necessarily represent distinctive geological zones or domains.

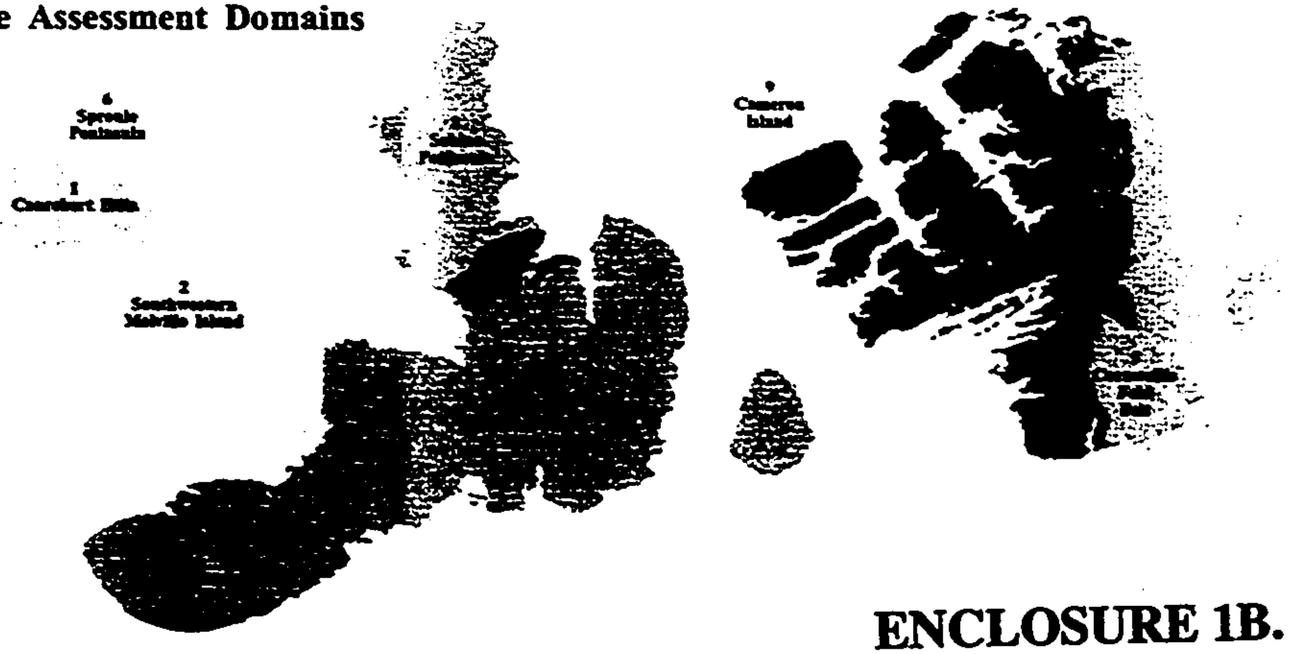


Res

Correlation Chart



esource Assessment Domains



ENCLOSURE 1B.

Data Source Ref

Source Data 1

INDEX	UNIT	NAME	LITHOLOGIES	U.AGE	L.AGE	DEPOSITIONAL SETTING
[illegible]	Q		[illegible] sedm	Q	Q	[illegible] deltaic marine
[illegible]	TQG		[illegible]	Q	T	fluvial, glacial, marine
[illegible]	KTE	EUREKA SOUND FM		T	K	
104	KTE2	upper part	sh,slt			prodeltaic
105	KTE1	lower part	ss,slt			deltaic
106	KK	KANGUK FM	sh	uK	uK	offshore marine
107	KH	HASSEL FM	ss,slt,sh	uK	lK	marginal marine
108	KC	CHRISTOPHER FM		lK	lK	
109	KMP	Macdougall Point Member	sh,slt,ms			marine
110	KIP	Invincible Point Member	sh,slt,ss			marine
[illegible]	KI	ISACHSEN FM		K	K	
112	KWI	Walker Island Member	ss,co,			deltaic nearshore marine
113	KR	Rondon Member	sh,slt,ss			prodeltaic
114	KPI	Paterson Island Member	ss,co			fluvial
115	KG	Gabbro, gabbro dykes and sills		[illegible]		Magmatic intrusions
116	JK	RINGNES, AWINGAK and DEER BAY FMS				
117	JD JKD	DEER BAY FM	slt,sh,ss	lK	uJ	offshore marine
118	JA	AWINGAK FM	ss,slt,cg	uJ	uJ	nearshore marine
119	JR	RINGNES FM	sh,slt,ss	uJ	uJ	offshore marine
120		WILKIE POINT GROUP				
121	JHC	HIGGLES COVE FM	ss,tr,slt,co	mJ	mJ	nearshore marine
122	JMI	McCONNELL ISLAND FM	sh,slt,ss,tr,cg	mJ	mJ	marine
123	JJS	JAMESON BAY and SANDY POINT FMS	ss,sh,slt,cg	mJ	lJ	marine
124	JG	GROSVENOR ISLAND FM	sh,slt,ss,tr	lJ	lJ	nearshore marine
125	JGM	GROS. ISL. and MACLEAN STRAIT FMS	ss,slt,sh			
126	TrS	SCHEI POINT GROUP	ss,slt,lmst,sh	uTr	mTr	
127	TrB	BJORNE FM	ss,cg,sh	lTr	lTr	alluvial deltaic
128	TrBF	BLIND FIORD FM	slt,sh,ss	lTr	lTr	basin slope and rise
129	PAT	ASSISTANCE and TROLD FIORD FM	ss,slt,sh,lmst,cg			
130	PTF	TROLD FIORD FM	ss,lmst,ch	uP	uP	marine
131	PD	DEGERBOLS FM	lmst	uP	uP	unrestricted shallow marine
132	PVH	VAN HAUEN FM	ch,sh,slt	uP	lP	starved basin
133	PA	ASSISTANCE FM	ss,slt,tr	lP	lP	transgressive marine
134	PSB	SABINE BAY FM	ss,sh,cg,slt	lP	lP	alluvial marginal marine
135	PR	RAANES FM	lmst,ss	lP	lP	unrestricted shallow marine
136	PBC	BELCHER CHANNEL FM	lmst,ss,slt	lP	lP	unrestricted shallow marine
137	CPHO	HARE FIORD and TRAPPERS COVE FMS	ss,lmst,sh,ch	lP	uC	starved basin
138	CPC CCC	CANYON FIORD FM	ss,sh,cg,bc,lmst	lP	uC	alluvial and shallow marine
139	COF SCGF	OTTO FIORD FM	ev,ss,lmst,dol,sh,ss	uC	uC	restricted marine
140	DPI	PARRY ISLANDS FM		uD	uD	
141	DPI5	Ross Cove Member	ss,co			deltaic
142	DPI4	Byam River Member	sh,sid nodu,			prodeltaic or lacustrine
143	DPI3	Consett Head Member	ss			deltaic
144	DPI2	Cape Fortune Member	slt,ss,sh			shallow marine
145	DPI1	Burnett Point Member	ss,slt,sh, co			deltaic
146	DBI	BEVERLEY INLET FM	ss,slt,sh,co	uD	uD	fluvial and marginal marine
147	DHB DHBC	HECLA BAY FM	ss,slt,sh,co	mD	mD	deltaic and marginal marine
148	DW	WEATHERALL FM	slt,ss,sh,	mD	mD	deltaic front sea marginal
149	DCB	CAPE DE BRAY FM	sh,ss,slt	mD	mD	marine
150	DB	[illegible]	ss,slt,sh	mD	mD	basin slope and rise
151	DK	[illegible]	sh,lmst	mD	lD	flysch
152	DBL	BLUE FIORD FM	lmst,dol	mD	lD	offshore marine and starved
153	SDCP	CAPE PHILLIPS FM		lS	lD	subtidal intertidal
154	OSDCP	CAPE PHILLIPS FM	sh,lmst,dol,ch	mD	uO	
155	OSDI	IBBETT BAY FM				starved basin
156	OSDI5	Upper Shale Member	sh,dol,ch	mD	uS	
157	OSDI4	Brown Siltstone Member	slt,dol,sh	uS	uS	starved basin
158	OSDI3	Lower Shale Member	sh,ch,dol,	uS	uO	basin
159	OSDI2	Dolostone Member	dol,sh,	uO	mO	starved basin
160	OSDI1	Chert Member	ch,sh,dol	mO	lO	basin slope
161	SBI	BARLOW INLET FM	lmst,dol,	uS	uS	starved basin
162	SD	DOURO FM	lmst,dol,	uS	uS	shallow subtidal / intertidal
163	SCS	CAPE STORM FM	lmst,	uS	uS	shallow subtidal / intertidal
164	OSA	ALLEN BAY FM	dol,lmst,br	uS	uO	subtidal
165	OSC	ALLEN BAY,CAPE STORM, BAR. IN. FMS		uS	uO	intertidal
166	OIB	IRENE BAY FM	lmst,	uO	uO	
167	OTM	THUMB MOUNTAIN FM	dol,ss,lmst	uO	mO	transgressive marine
168	OBF	BAY FIORD FM	dol,ch,br,ss,lmst			intertidal
169	OBF2	Upper Part	dol,sh,br	mO	mO	intertidal
170	OBF1	Lower Part	ss,dol,ss,sh	mO	mO	restricted marine
171	OCR	CANROBERT FM	dol,br,cg,ss,	lO	lO	restricted marine
172	OE	ELEANOR RIVER FM	dol,lmst	lO	lO	basin slope

Source Data 1 data elements extracted from the legend for Melville Island and Adjacent Small Islands.

In. Melville Island's Salt Based Fold Belt. Unpublished PhD Thesis, Rice University, Houston, Texas, 1991.

Source Data 2

INDEX	UNIT	NAME	LITHOLOGIES	U.AGE	L.AGE	DEPOS
201	KTE	Eureka Sound Fm	ss,co	T	K	Fluvial-
202	KK	Kanguk Fm	sh,slt	uK	uK	Pelitic
203	KH	Hassel Fm	ss,co	uK	lK	Fluvial-
204	KC	Christopher Fm.	sh,slt	lK	lK	Pelitic
205	KI	Isachsen Fm	ss,co	lK	lK	Fluvial-
206	JKA	Awingak Fm	ss,co	lK	uJ	Fluvial-
207	JKA	Deer Bay Fm	ss,lmst,slt	lK	uJ	Clastic
208	JR	Ringnes Fm	sh,slt	mJ	mJ	Pelitic
209	JW	Wilkie Point Group	ss,lmst,slt	mJ	mJ	Clastic
210	JHC	Hiccles Cove Fm	ss,co	mJ	mJ	Fluvial-
211	JMI	McConnell Island Fm	ss,slt	mJ	mJ	Pelitic
212	JSP	Sandy Point Fm	ss,lmst,slt	lJ	lJ	Clastic
213	JJB	Jameson Bay Fm	sh,slt	lJ	lJ	Pelitic
214	JGI	Grosvenor Island Fm	sh,slt	lJ	lJ	Pelitic
215	TrS	Schei Point Group	sh,slt ss,lmst,slt	uTr	mTr	[illegible]
216	TrB	Bjorne Fm	ss,co	mTr	lTr	Fluvial-
217	TrBF	Blind Fiord Fm	sh,slt	lTr	uP	Pelitic
218	PT	Trold Fiord Fm	ss,lmst,slt	uP	lP	Clastic
219	PD	Degerbols Fm	lmst,dol	uP	lP	Carbona
220	PA	Assistance Fm	lmst,dol sh,slt	lP	lP	Carb sh
221	PSB	Sabine Bay Fm	ss,co	lP	lP	Fluvial-
222	PVH	Van Hauen	sh,ch,bc	lP	lP	Starved
223	PBC	Belcher Channel Fm	lmst,dol	lP	lP	Carbona
224	CPHO	Hare Fiord Fm	sh,ch,bc	uC	lP	Starved
225	CPC	Canyon Fiord Fm	rb,cg	uC	lC	Alluvia
226	COF	Otto Fiord Fm	ev	uC	lC	Restrict
227	DPI	Parry Islands Fm	ss,co ss,lmst,slt	uD	uD	Fluv.-de
228	DBI	Beverly Inlet Fm	ss,lmst,slt	uD	uD	Clastic
229	DHB	Hecla Bay Fm	ss,lmst,slt	mD	mD	Clastic
230	DW	Weatherall Fm	ss,co	mD	mD	Fluvial-
231	DCB	Cape de Bray Fm	sh,slt	mD	mD	Pelitic
232	DBL	Blue Fiord Fm	lmst,dol	lD	lD	Carbona
233	DK	Kitson Fm	sh,ch,bc	lD	lD	Starved
234	DBl	Blackley Fm	ss,sh,tb	mD	lD	Submar
235	OSDC	Cape Phillips Fm	sh,ch,bc	lD	uO	Starved
236	OSDI	Ibbett Bay Fm	sh,ch,bc	lD	lO	Starved
237	OCR	Canrobert Fm	lmst,dol	lO	lO	Carbona
[illegible]	OIB	Irene Bay Fm				
238	OTM	Thumb Mountain Fm	lmst,dol	uO	mO	Carbona
239	OBF	Bay Fiord Fm	ev	lO	lO	Restrict
240	OE	Eleanor River Fm	lmst,dol	lO	lO	Carbona

Source Data 2 data ele
Chart for the Franklini
Melville Island, Eglinto
Platform of Melville a

In. A Summary of t
Canadian Arctic Archi
Arctic Canada. GSC B

Mel

J.C.H

Source Data 3

INDEX	UNIT	NAME	LITHOLOGIES	U.AGE	L.AGE
301	Q		stream, deltaic sedm	Q	Q
302	KTi	IGNEOUS ROCKS		T	K
303	KTe	EUREKA SOUND FM	ss,sh,co	T	K
304	Jj	JAEGER FM	ss	J	J
305	Trh	HEIBERG FM	ss,co	Tr	Tr
306	Trs	SCHEI POINT FM	ss,lmst	Tr	Tr
307	Trb	BJORNE FM	ss	Tr	Tr
308	Ptf	TROLD FIORD FM	ss,ch	P	P
309	Pbc	BELCHER CHANNEL FM	lmst,dol,ch	P	P
310	Dmg	GRIPER BAY FM	ss,slt,sh	uD	mD
311	Dmh	HECLA BAY FM	ss	mD	mD
312	Dbi	BIRD FIORD FM	lmst,ss,slt	mD	mD
313	Dbl	BLUE FIORD FM	lmst	mD	lD
314	De	EIDS Fm	lmst,slt,sh	mD	lD
315	Ddb	DISAPPOINTMENT BAY FM	dol	mD	lD
316	D	BATHURST ISL. STUART BAY FMS			
317	Dst	Stuart Bay Fm	slt,sh,cg,lmst	lD	lD
318	Dba	Bathurst Island Fm	slt,ss,dol,lmst	lD	lD
319	O-Dcp	CAPE PHILLIPS FM	slt,sh,lmst,dol	lD	uO
320	Oct	IRENE BAY FM THUMB MTN. FMS	lmst,sh,dol	uO	mO
321	Obf	BAY FIORD FM	ss,sh,lmst,dol	uO	mO

Source Data 3 data elements extracted from the legend of Map 1350A.

In. Geology of Bathurst Island Group and Byam Martin Island, Arctic Canada. (Operation Bathurst Island). GSC Memoir 378, EMR, 1974.

Source Data 4

INDEX	UNIT	NAME	LITHOLOGIES	U.AGE	L.AGE	DEPOSIT
401	Q	UNNAMED	sl,ss,gr,cy,md	Q	Q	
402	KTe	EUREKA SOUND FM	ss,slt,co	T	K	
403	Jj	JAEGER FM	ss	mJ	mJ	
404	Trh	HEIBERG FM	ss,co	uTr	uTr	
405	Trs	SCHEI POINT FM	ss,lmst	mTr	mTr	
406	Trb	BJORNE FM	ss	lTr	lTr	
407	Ptf	TROLD FIORD FM	ss,ch	uP	uP	
408	Pbc	BELCHER CHANNEL FM	lmst,ch	lP	lP	
409	Dmg	GRIPER BAY FM	ss,slt,sh	uD	uD	molasse
410	Dmh	HECLA BAY FM	ss	uD	mD	molasse
411	Dbi	BIRD FIORD FM	lmst,ss,slt	mD	mD	molasse
412	De	EIDS FM	lmst,slt,sh	mD	lD	flysch
413	Dbl	BLUE FIORD FM	lmst	mD	lD	flysch
414	Ddb	DISAPPOINTMENT BAY FM	dol	mD	lD	flysch
415	Dst	STUART BAY FM	slt,sh,cg,lmst,dol,cg	lD	lD	flysch
416	Dba	BATHURST ISLAND FM	slt,ss,dol,lmst	lD	lD	flysch
417	O-Dcp	CAPE PHILLIPS FM	ss,sh,lmst,dol	S	uO	starved b
418	Oct	IRENE BAY FM	lmst,sh	uO	uO	platform
419	Oct	THUMB MOUNTAIN FM	lmst,dol	uO	mO	platform
420	Obf	BAY FIORD FM	ss,sh,lmst,dol	mO	mO	platform

Source Data 4 data elements extracted from Table 1 - Table of Formations, p. 12, supplemented by discussion on depositional and tectonic settings in text.

In. Geology of Bathurst Island Group and Byam Martin Island, Arctic Canada. (Operation Bathurst Island). GSC Memoir 378.

B

Byam

eference Chart

POSITIONAL SETTING	TECTONIC SETTING
vial-deltaic	Passive-post rift subsidence
atic shelf and slope	Passive-post rift subsidence
vial-deltaic	Passive-post rift subsidence
itic shelf and slope	Passive-post rift subsidence
vial-deltaic	Passive-post rift subsidence
vial-deltaic	Incipient Rifting
atic carbonate Shelf	Incipient Rifting
atic shelf and slope	Incipient Rifting
atic carbonate Shelf	Incipient Rifting
vial-deltaic	Passive-post rift subsidence
atic shelf and slope	Passive-post rift subsidence
atic carbonate Shelf	Passive-post rift subsidence
atic shelf and slope	Passive-post rift subsidence
atic shelf and slope	Passive-post rift subsidence
slope, Clast.-carb. shelf	Passive-post rift subsidence
vial-deltaic	Passive-post rift subsidence
atic shelf and slope	Passive-post rift subsidence
atic carbonate shelf	Melvillian Transgression
rbonate shelf and slope	Melvillian Transgression
b shelf Pelitic slope	Melvillian Transgression
vial-deltaic	Melvillian Transgression
rved basin	Melvillian Transgression
rbonate shelf and slope	Sverdrup Basin Rifting
rved basin	Sverdrup Basin Rifting
uvial fans	Sverdrup Basin Rifting
stricted Shelf	Sverdrup Basin Rifting
v.-delt. Clast.-carb. shelf	Foreland Subsidence
atic carbonate shelf	Foreland Subsidence
atic carbonate shelf	Foreland Subsidence
vial-deltaic	Foreland Subsidence
atic shelf and slope	Foreland Subsidence
rbonate shelf and slope	Unstable shelf margin
rved basin	Unstable shelf margin
bmarine fans	Unstable shelf margin
rved basin	Unstable shelf margin
rved basin	Trailing margin subsidence
rbonate shelf and slope	Trailing margin subsidence
	Trailing margin subsidence
rbonate shelf and slope	Trailing margin subsidence
stricted Shelf	Trailing margin subsidence
rbonate shelf and slope	Trailing margin subsidence

n elements extracted from Figure 2 - Correlation
llinian Mobile Belt and Sverdrup Basin of
glinton Graben of Eglinton Island, and the Arctic
le and Victoria islands.

of the Structural Geology of Melville Island,
rchipelago. In The Geology of Melville Island,
C Bulletin 450, Natural Resources Canada, 1994.

elville Island

1:250,000

. Harrison (1991,1994)

OSITIONAL SETTING	TECTONIC SETTING
ase	Ellesmerian Orogeny
ase	Ellesmerian Orogeny
ase	Ellesmerian Orogeny
h	Boothia Uplift
h	Boothia Uplift
h	Boothia Uplift
h	Boothia Uplift
h	Boothia Uplift
ed basin	Tectonic Stability
orm facies	Tectonic Stability
orm facies	Tectonic Stability
orm facies	Tectonic Stability

Bathurst and
m Martin islands

1:250,000

J.Wm. Kerr, (1974)

Source Data 5

INDEX	UNIT	NAME
501	ZQS	BEAUFORT FM and quaternary sediments
502	TNB	BEAUFORT FM
503	[illegible]	EUREKA SOUND GROUP
504	KTES	EUREKA SOUND GROUP
505	KS	gabbro dykes and sills
506	KK	KANGUK FM
507	[illegible]	HASSEL AND KANGUK FMS
508	KH	HASSEL FM
509	KC	CHRISTOPHER FM
510	JKS	ISACHSEN and CHRISTOPHER FMS
511	KI	ISACHSEN FM
513	JKS	SAVIK GROUP (Awingak and Deer Bay Fms)
514	JKDB	DEER BAY FM
515	JKMK	MACKENZIE KING FM
516	JSA	SAVIK GROUP and Awingak Fm
517	JA	AWINGAK FM
518	JR	RINGNES FM
519	JWP	WILKIE POINT GROUP
520	JHC	HIECCLES COVE FM
521	JMI	McCONNELL ISLAND FM
522	JSMH	SANDY POINT, McCONNELL ISLAND, HIECCLES COVE FMS
523	JSP	SANDY POINT FM
524	JJB	JAMESON BAY FM
525	JJBS	Snowpatch Member
526	JJBC	Cape Canning Member
527	JJBI	INTREPID INLET MEMBER
528	JKC	KING CHRISTIAN FM
529	JLI	LOUGHEED ISLAND FM
530	JMS	MACLEAN STRAIT FM
531	JGI	GROSVENOR ISLAND FM
532	TrJHS	HEIBERG FM and SAVIK GROUP
533	TrJH	HEIBERG FM
534	NTrS	SKYBATTLE FM
535	aTrB	BARROW FM
536	TrBM	BLAA MOUNTAIN GROUP
537		SCHEI POINT GROUP
538	TrPB	PAT BAY FM
539	TrRP	ROCHE POINT FM
540	TrHB	HOYLE BAY FM
541	TrMH	MURRAY HARBOUR FM
542	lTrB	BJORNE FM
543	TrBF	BLIND FIORD FM
544	PTT	TROLD FIORD FM
545	PD	DEGERBOLS FM
546	PAT	ASSISTANCE AND TROLD FIORD FMS
547	PA	ASSISTANCE FM
548	PBC	BELCHER CHANNEL FM
549	CPCB	CANYON FIORD and BELCHER CHANNEL FMS
550	CPC	carbonate
551	CPEC	evaporite and carbonate
552	CCF	CANYON FIORD FM
553	COF	OTTO FIORD FM
554	CEF	EMMA FIORD FM
555	DOB	OKSE BAY GROUP
556		GRIPER BAY SUBGROUP
557	DPI	PARRY ISLANDS FM
558	DNP	NORDSTRAND POINT FM
559	mDBI	BEVERLEY INLET FM
560	DHG	HELL GATE FM
561	DF	FRAM FM
562	DHB	HECLA BAY FM
563	DSF	STRATHCONA FIORD FM
564	DW	WEATHERALL FM
565	mDBF	BIRD FIORD FM
566	DC	carbonate
567	DBF	BLUE FIORD and BIRD FIORD FMS
568	lmDBF	BLUE FIORD FM
569	DDB	DISAPPOINTMENT BAY FM
570	Dp	shale (See Note 4)
571	lDBF	BLUE FIORD FM
572	lDS	BATHURST ISLAND and STUART BAY FMS
573	DSB	STUART BAY FM
574	DPA	PRINCE ALFRED FM
575	lDBI	BATHURST ISLAND FM
576	DGF	GOOSE FIORD FM
577	DSR	SUTHERLAND RIVER FM
578	DSL	SOPHIA LAKE FM
579	lDSB	SNOWBLIND BAY FM
580	SDS	DEVON ISLAND, GOOSE FIORD and PRINCE ALFRED FMS
581	SDDG	DEVON ISLAND and GOOSE FIORD FMS
582	SDDI	DEVON ISLAND FM
583	SD	DOUCRO FM
584	SCD	CAPE STORM and DOUCRO FMS
585	SCS	CAPE STORM FM
586	OSCP	CAPE PHILLIPS FM
587	OSAB	ALLAN BAY FM
588	OSCA	CORNWALLIS GROUP and ALLAN BAY FMS
589	OC	CORNWALLIS GROUP (undivided)
590	OTI	THUMB MOUNTAIN and IRENE BAY FMS
591	mOBF	BAY FIORD FM
592	OER	ELEANOR RIVER FM
593	OBB	BLANLEY BAY FM
594	lOBF	BAUMANN FIORD FM
595	OCR	CHRISTIAN RIV FM
596	OCC	CAPE CLAY FM
597	E-OCC	CASS FIORD and CAPE CLAY FMS (See Note 4)
598	E-OCF	CASS FIORD FM

(Arctic Islands)

1:1,000,000

A. Okulitch, (in prep)

Source Data 5 was extracted from a preliminary legend for a regional compilation of the geology of the Arctic Islands. This source does not provide any attributes of geological units other than depositional age implied in the unit annotation.

Legend for the Assignment of Unit Attributes

Assigned Directly

Information from legend items assigned directly include those which correspond directly to labelled boundaries either by abbreviation or unit name

Assigned by Group

Information from legend items assigned by group include those which boundaries have been mapped by group, or those which have been grouped in the data model to maximize agreement of unit attributes among data sources.

Not Assigned

Information from legend items not assigned include those which were not shown on the O'Kulitch (1994) compilation. These units were omitted due to either they are too small to be mappable at 1:1,000,000, they are observed only in subsurface, or they apply to areas outside the study area

NOTES

1 - All age ranges are rounded to the nearest period

2 - Unit abbreviations vary considerably among all source legends, and therefore were reassigned for this application

3 - Units DC and E-OCC were relabeled to Blue Fiord Fm (DBL) and Canrobert Fm (OC) respectively

4 - Due to font limitations in the software used, unit abbreviations with Tr = Triassic and E = Cambrian

Map Legend

INDEX	UNIT	NAME
1	TNB	Beaufort Fm
2	Ks	Igneous Intrusions
3	KTES	Eureka Sound Fm
4	KK	Kanguk Fm
5	KH	Hassel Fm
6	KC	Christopher Fm
7	KI	Isachsen Fm
8	JKDB	Deer Bay Fm
9	JA	Awingak Fm
10	JR	Ringnes Fm
11	JHC	Hiccles Cove Fm
12	JMI	McConnell Island Fm
13	JJS	Jameson Bay and Sandy Point Fm
14	TrH	Heiberg Fm
15	TrB	Bjorne Fm
16	TrBF	Blind Fiord Fm
17	PAT	Assistance - Trold Fiord Fms
18	PBS	Belcher Channel - Sabine Bay Fms
19	CPCF	Canyon Fiord Fm
20	COF	Otto Fiord Fm
21	DGB	Griper Bay Subgroup
22	DHB	Hecla Bay Fm
23	DW	Weatherall Fm
24	DBF	Bird Fiord Fm
25	DCB	Cape de Bray Fm
26	DBY	Blackley
27	ODI	Ibbet Bay Fm
28	OC	Canrobert Fm
29	DBL	Blue Fiord Fm
30	DE	EIDS Fm
31	DDB	Disappointment Bay Fm
32	DSB	Stuart Bay - Bathurst Island Fms
33	DS	Stuart Bay Fm
34	DB	Bathurst Island Fm
35	OSCP	Cape Phillips Fm
36	OTI	Thumb Mtn Irene Bay Fm

Parry Islands

Digital Geological Map and Geological Data Model

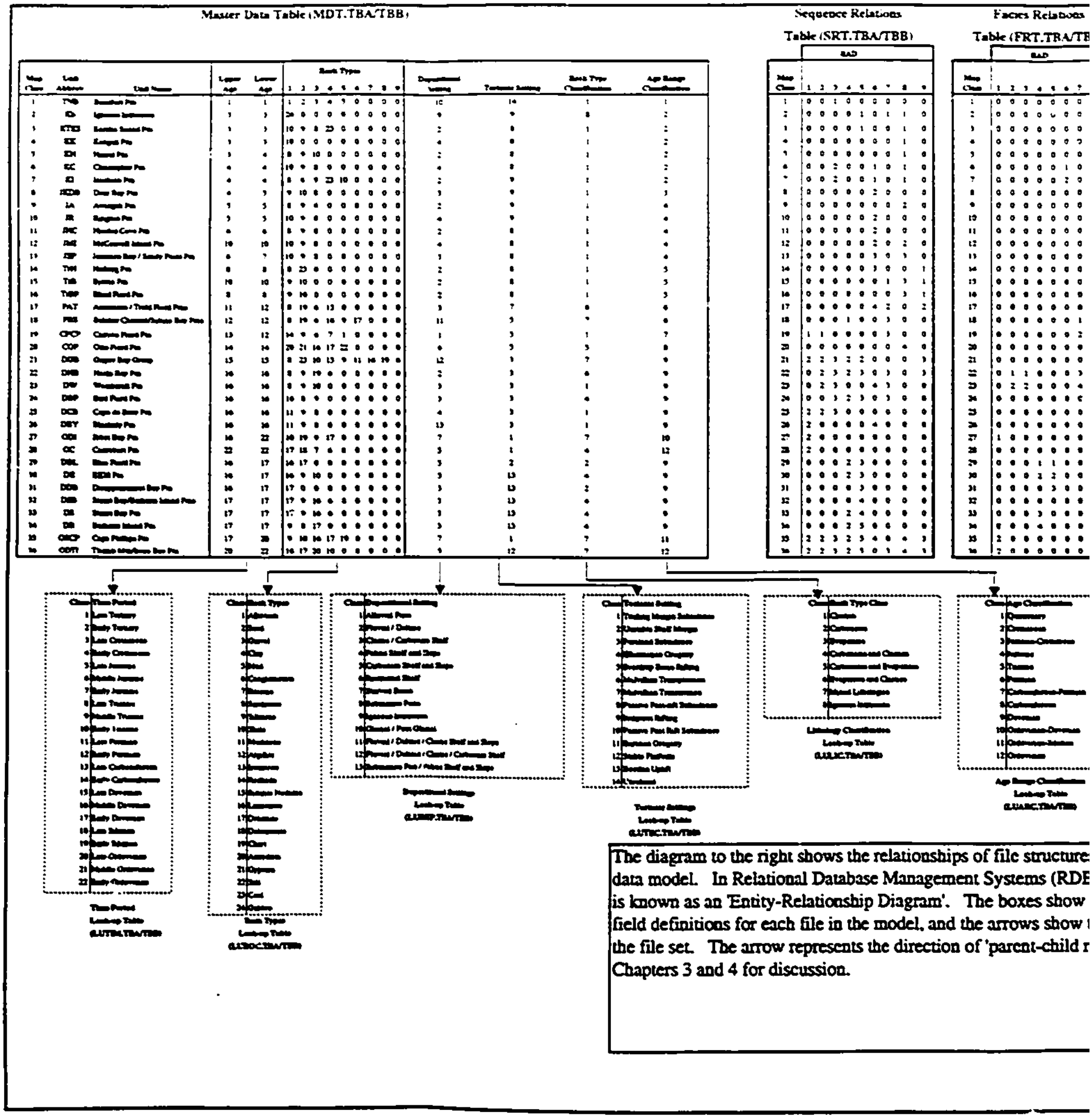
1:1,000,000

B.G. Eddy (this thesis)

This legend represents the key fields on which the Digital Data Model was constructed. All data elements contained in the model can be traced to at least one of the five data sources

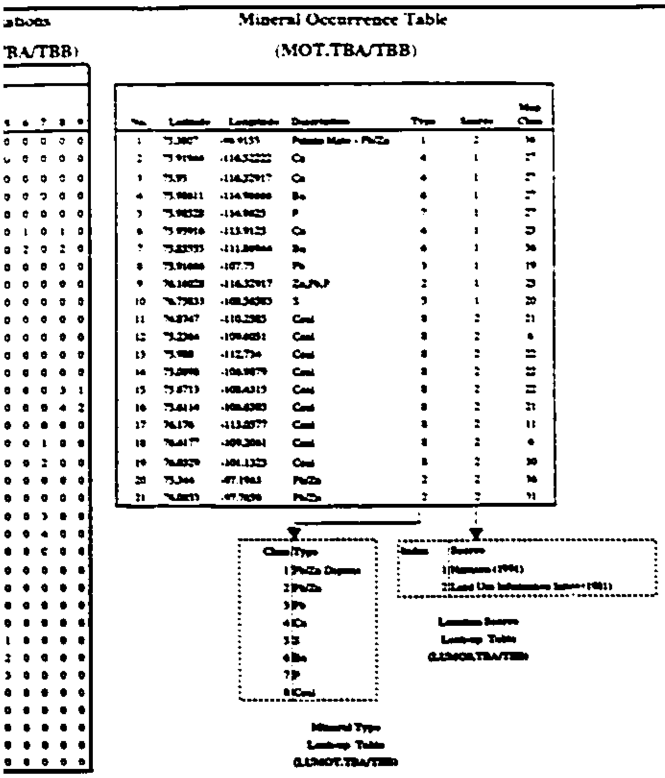
ENCLOSURE 2A.

DIGITAL GEOLOGIC



The diagram to the right shows the relationships of file structure
data model. In Relational Database Management Systems (RDE
is known as an 'Entity-Relationship Diagram'. The boxes show
field definitions for each file in the model, and the arrows show t
the file set. The arrow represents the direction of 'parent-child r
Chapters 3 and 4 for discussion.

[CAL DATA MODEL



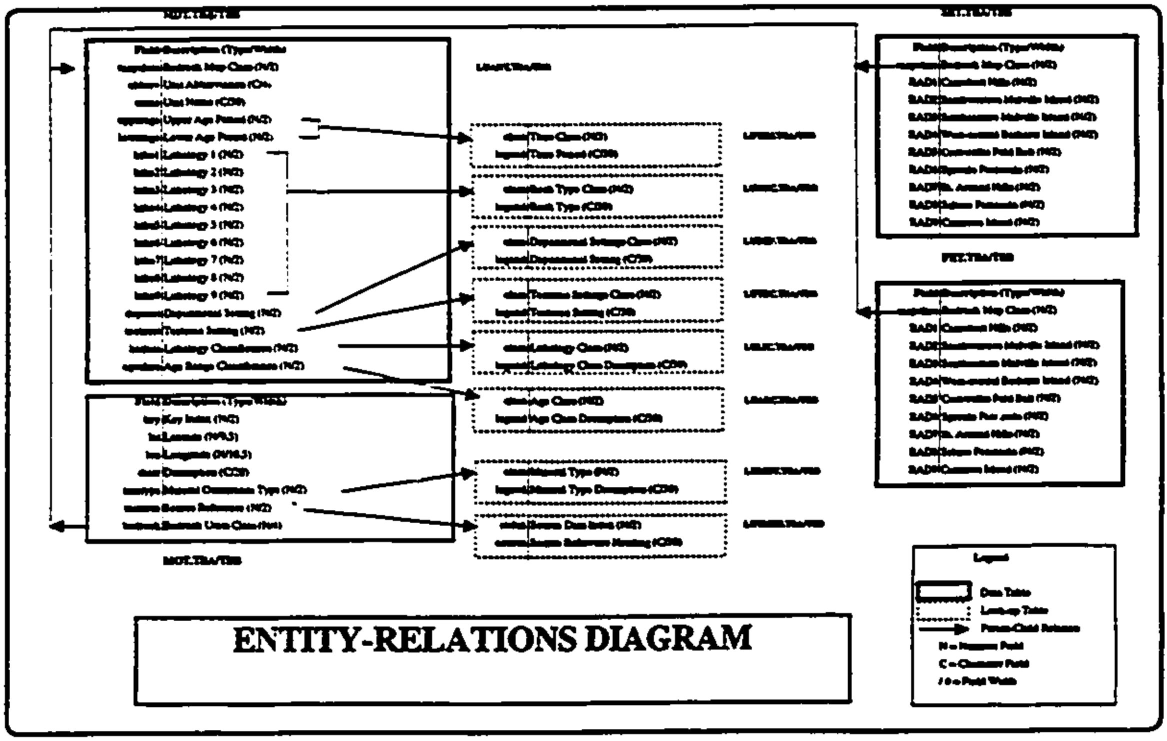
Notes:

1. The Digtial Data Model is designed according to the database management specifications of SPANS GIS software, although file structures and relations are compatible with many commercial relational database management systems (RDBMS).

2. All data elements are assigned from at least one of the five data sources shown in the Data Source Reference Chart (Enclosure 2a).

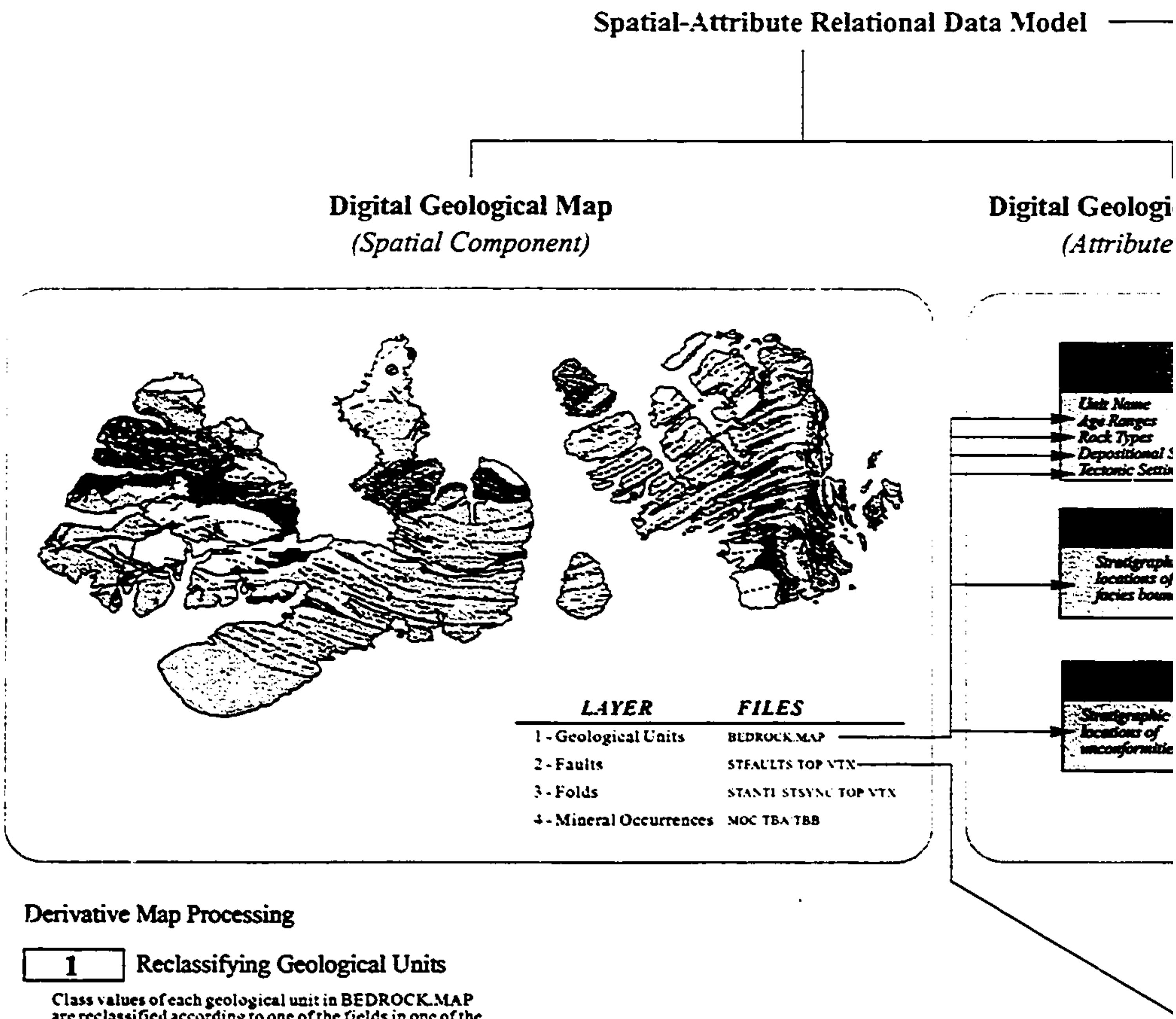
3. The term 'RAD' refers to Resource Assessment Domain. The map of the Parry Islands is partitioned into 9 RADs, which are described in detail in Chapter 5.

ctures in the geological
(RDBMS) terminology, it
show the structure and
how the relations among
hild relation'. Refer to



ENTITY-RELATIONS DIAGRAM

ENCLOSURE 2B.



Spatial-Attribute Relational Data Model

Digital Geological Map
(Spatial Component)

Digital Geologi
(Attribute

LAYER	*FILES*
1 - Geological Units	BEDROCK.MAP
2 - Faults	STFAULTS TOP VTX
3 - Folds	STANTI STSYNC TOP VTX
4 - Mineral Occurrences	MOC TBA TBB

Derivative Map Processing

1 Reclassifying Geological Units

Class values of each geological unit in BEDROCK.MAP are reclassified according to one of the fields in one of the 'data tables' in the geological data model.

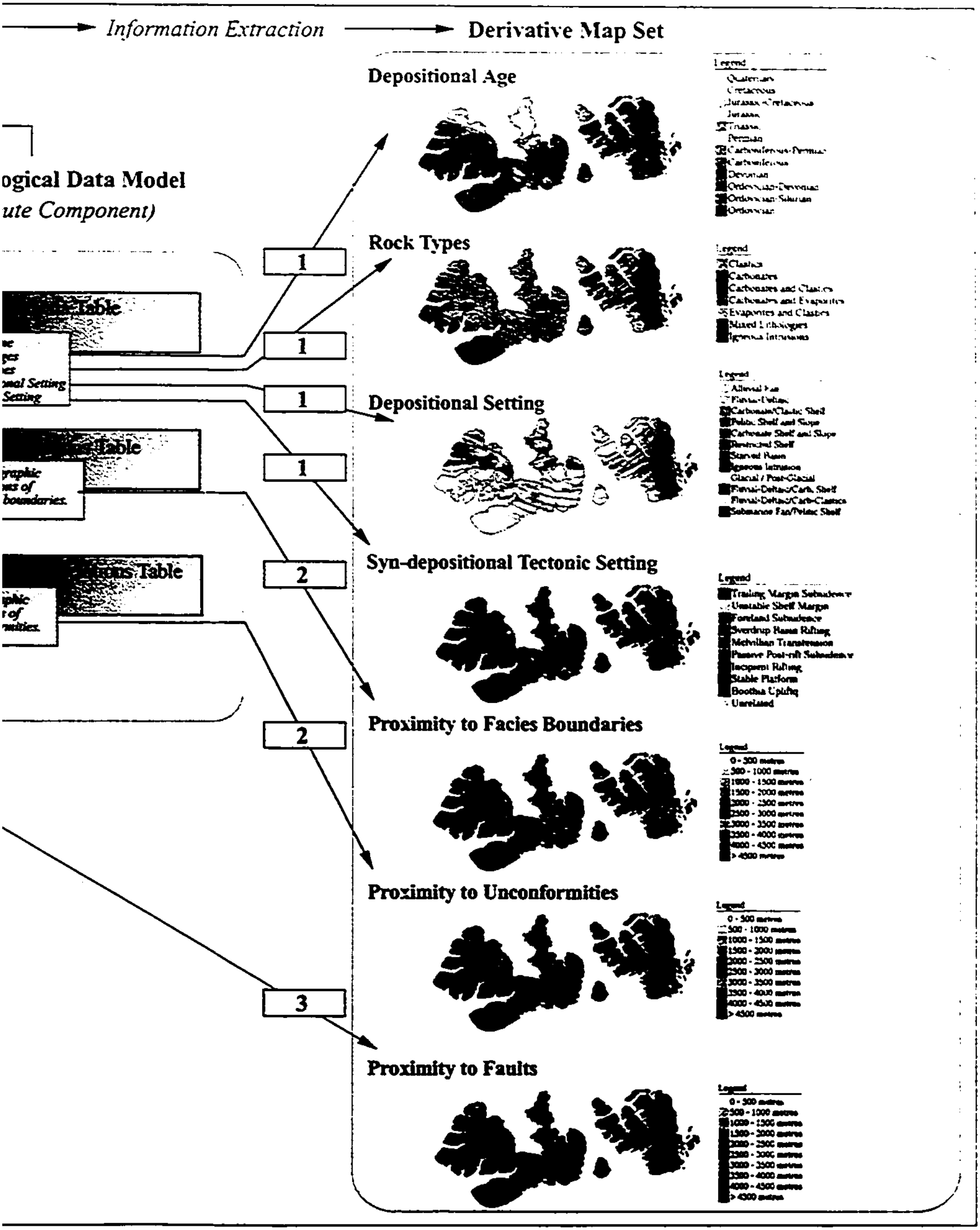
2 Buffering FaciesBoundaries and Unconformities

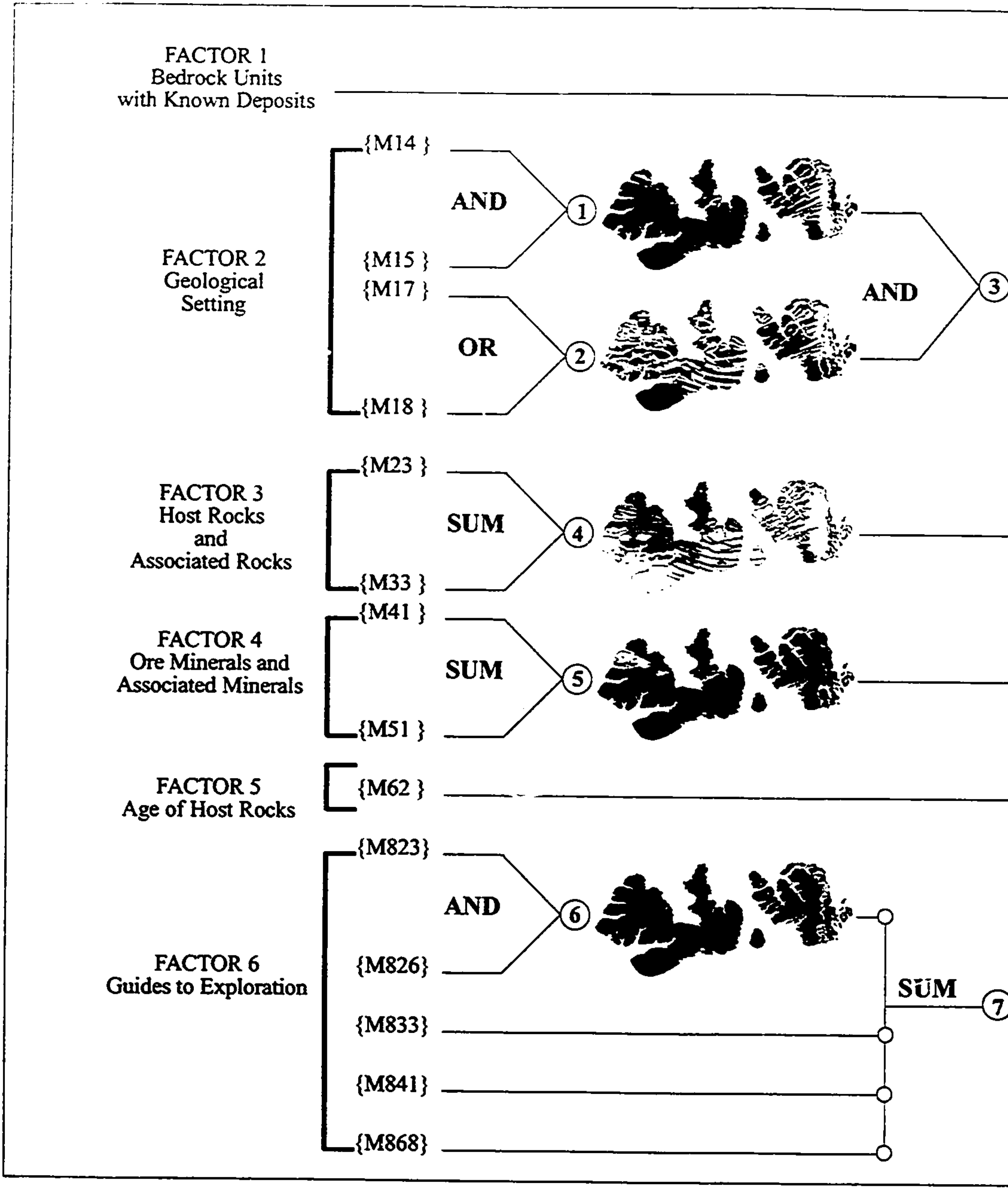
Specific contact types are extracted by first reclassifying BEDROCK.MAP with values assigned for facies relationships or sequence relationships. The boundaries of the areas of these maps are then extracted by transforming the raster area file to its vector area file equivalent. The vectors are buffered at 0.5 km intervals to a 5 km threshold.

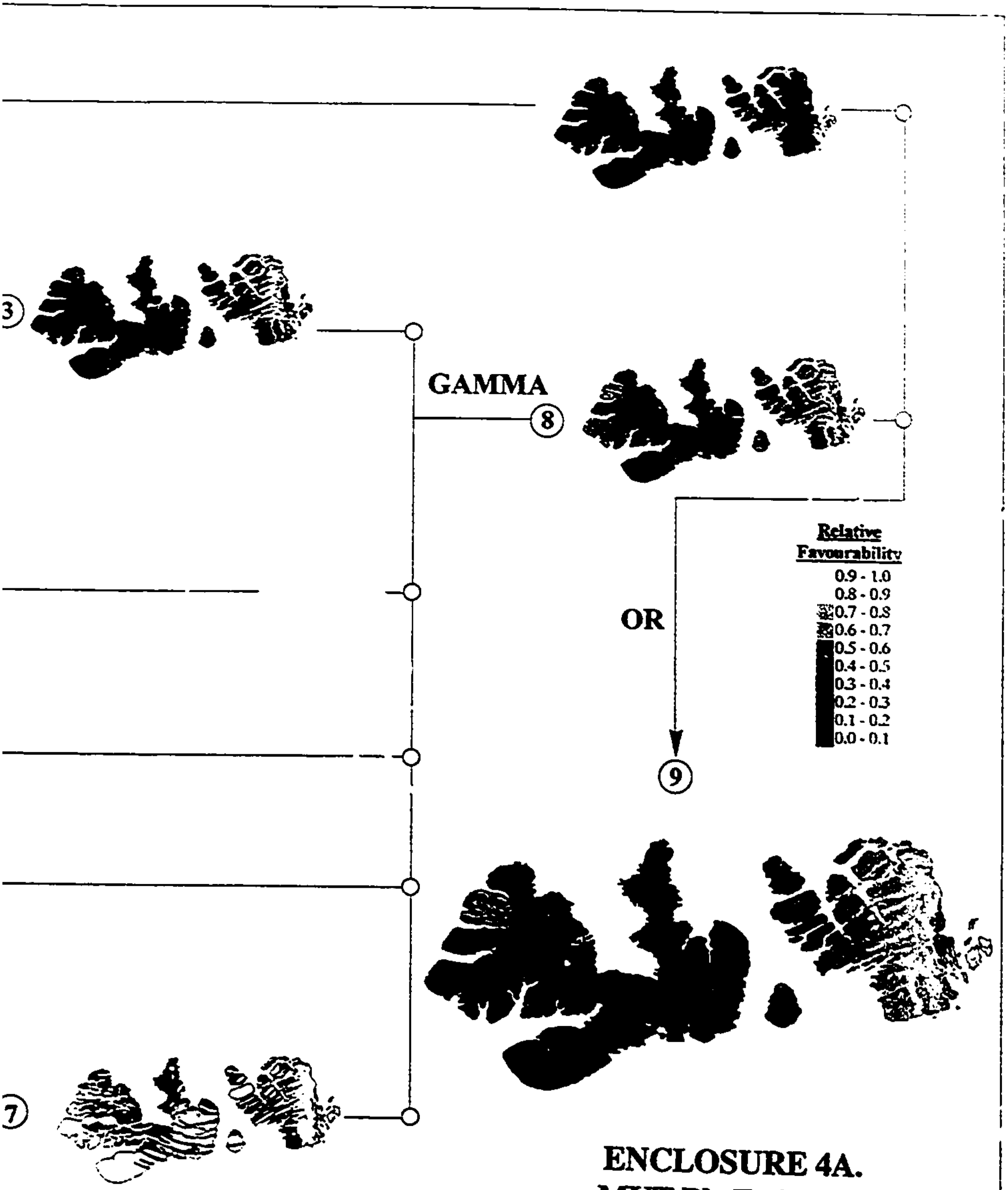
3 Buffering Faults

The faults vector file is buffered at 0.5 km intervals to a 5 km threshold.

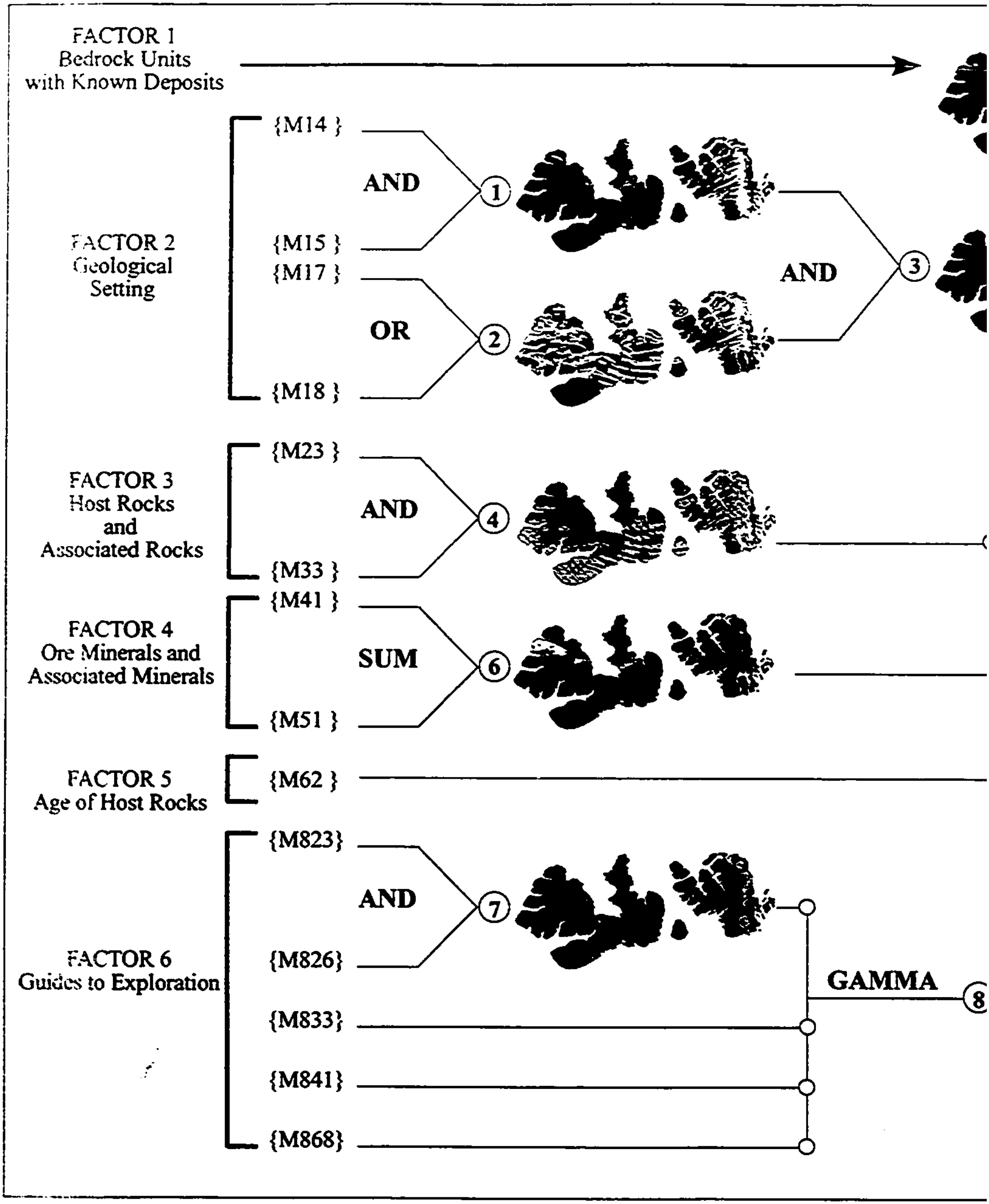
ENCLOSURE 3A. Derivative Mapping Process.


Information Extraction
Derivative Map Set
ogical Data Model
ute Component)
table
Table
Table
ne
ges
es
onal Setting
Setting
graphic
ns of
boundaries.
phic
r of
mities.
1
1
1
1
2
2
3
Depositional Age
Legend
Quaternary
Cretaceous
Jurassic-Cretaceous
Jurassic
Triassic
Permian
Carboniferous-Permian
Carboniferous
Devonian
Ordovician-Devonian
Ordovician-Silurian
Ordovician
Rock Types
Legend
Clastics
Carbonates
Carbonates and Clastics
Carbonates and Evaporites
Evaporites and Clastics
Mixed Lithologies
Igneous Intrusions
Depositional Setting
Legend
Alluvial Fan
Fluvio-Deltaic
Carbonate/Clastic Shelf
Pelagic Shelf and Slope
Carbonate Shelf and Slope
Restricted Shelf
Starved Basin
Igneous Intrusion
Glacial / Post-Glacial
Fluvial-Deltaic/Carb. Shelf
Fluvial-Deltaic/Carb-Clastics
Submarine Fan/Pelagic Shelf
Syn-depositional Tectonic Setting
Legend
Trailing Margin Subsidence
Unstable Shelf Margin
Foreland Subsidence
Sverdrup Basin Rifting
Melvillian Transtension
Passive Post-rift Subsidence
Incipient Rifting
Stable Platform
Boothia Uplift
Unrelated
Proximity to Facies Boundaries
Legend
0 - 500 metres
500 - 1000 metres
1000 - 1500 metres
1500 - 2000 metres
2000 - 2500 metres
2500 - 3000 metres
3000 - 3500 metres
3500 - 4000 metres
4000 - 4500 metres
> 4500 metres
Proximity to Unconformities
Legend
0 - 500 metres
500 - 1000 metres
1000 - 1500 metres
1500 - 2000 metres
2000 - 2500 metres
2500 - 3000 metres
3000 - 3500 metres
3500 - 4000 metres
4000 - 4500 metres
> 4500 metres
Proximity to Faults
Legend
0 - 500 metres
500 - 1000 metres
1000 - 1500 metres
1500 - 2000 metres
2000 - 2500 metres
2500 - 3000 metres
3000 - 3500 metres
3500 - 4000 metres
4000 - 4500 metres
> 4500 metres

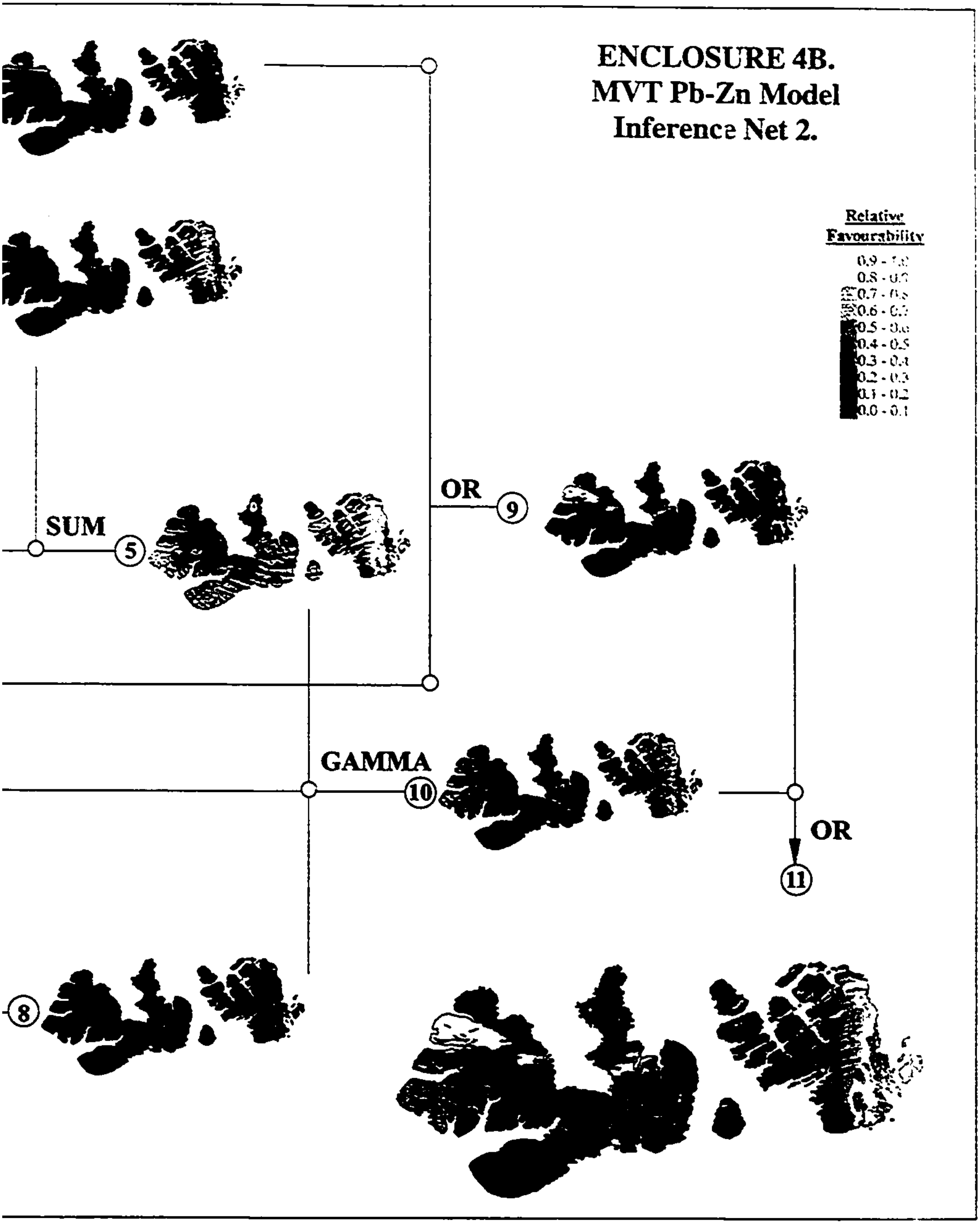

FACTOR 1
Bedrock Units
with Known Deposits
FACTOR 2
Geological
Setting
{M14 }
{M15 }
AND
1
{M17 }
{M18 }
OR
2
AND
3
FACTOR 3
Host Rocks
and
Associated Rocks
{M23 }
{M33 }
SUM
4
FACTOR 4
Ore Minerals and
Associated Minerals
{M41 }
{M51 }
SUM
5
FACTOR 5
Age of Host Rocks
{M62 }
FACTOR 6
Guides to Exploration
{M823}
{M826}
AND
6
{M833}
{M841}
{M868}
SUM
7



ENCLOSURE 4A.
MVT Pb-Zn Model
Inference Net 1.


FACTOR 1
Bedrock Units
with Known Deposits
FACTOR 2
Geological
Setting
{M14 }
{M15 }
AND
1
{M17 }
{M18 }
OR
2
AND
3
FACTOR 3
Host Rocks
and
Associated Rocks
{M23 }
{M33 }
AND
4
FACTOR 4
Ore Minerals and
Associated Minerals
{M41 }
{M51 }
SUM
6
FACTOR 5
Age of Host Rocks
{M62 }
FACTOR 6
Guides to Exploration
{M823}
{M826}
AND
7
{M833}
{M841}
{M868}
GAMMA
8

ENCLOSURE 4B.
MVT Pb-Zn Model
Inference Net 2.



FUZZY MEMBERSHIP TABLES

Map Number	Map Name	Map Class	Legend Description	Mississippi Valley Type Pb-Zn Criteria													Sedimentary Cu Criteria									
				1	2	3	4	5	6	7	8.1	8.2	8.3	8.4	8.5	8.6	1	2	3	4	5	6	7	8.1	8.2	8.3
1	bedrock		Bedrock Units				M41	M51						M841			C11	C21	C31	C41	C51					C831
		1	TNB Beaufort Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.20	0.05	0.05	0.05	-	-	-	-	0.05
		2	Kb Igneous Intrusions	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.05	0.05	0.05	0.05	-	-	-	-	0.05
		3	KTES Eureka Sound Gp	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		4	KK Kanguk Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.05	0.05	0.05	0.05	-	-	-	-	0.05
		5	KH Hassel Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		6	KC Christopher Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		7	KI Isachsen Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.05
		8	JKDB Deer Bay Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		9	JA Awingak Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.70	0.05	0.05	0.05	-	-	-	-	0.05
		10	JR Ringnes Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		11	JHC Hiccles Cove Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		12	JMI McConnell Island Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.25	0.05	0.05	-	-	-	-	0.05
		13	JJS Jameson Bay/Sandy Pt. Fms	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		14	TrH Heiberg Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.30	0.05	0.05	0.05	-	-	-	-	0.05
		15	TrB Bjorne Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.50	0.05	0.05	0.05	-	-	-	-	0.30
		16	TrBF Blind Fiord Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.50	0.05	0.05	0.05	-	-	-	-	0.40
		17	PAT Assistance/Trold Fiord Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.50
		18	PBS Belcher Ch./Sabine Bay Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-	0.05	0.85	0.05	0.05	0.05	-	-	-	-	0.60
		19	CPCF Canyon Fiord Fm	-	-	-	0.95	0.05	-	-	-	-	-	0.05	-	-	0.95	0.30	0.90	0.05	0.05	-	-	-	-	0.95
		20	COF Otto Fiord Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-	0.05	0.65	0.95	0.05	0.75	-	-	-	-	0.95
		21	DGB Griper Bay Group	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-	0.05	0.80	0.05	0.05	0.05	-	-	-	-	0.05
		22	DHB Hecla Bay Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.05
		23	DW Weatherall Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		24	DBF Bird Fiord Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		25	DCB Cape De Bray Fm	-	-	-	0.95	0.95	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.95	0.95	-	-	-	-	0.05
		26	DBY Blackley Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		27	ODI Ibbett Bay Fm	-	-	-	0.05	0.95	-	-	-	-	-	0.80	-	-	0.05	0.65	0.05	0.95	0.95	-	-	-	-	0.90
		28	OC Canrobert Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.75	0.05	0.05	0.05	-	-	-	-	0.05
		29	DBL Blue Fiord Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.05
		30	DE EIDS Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.05
		31	DDB Disappointment Bay Fm	-	-	-	0.95	0.05	-	-	-	-	-	0.05	-	-	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05
		32	DSB Stuart Bay/Bath. Isl. Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-	0.05	0.95	0.05	0.05	0.05	-	-	-	-	0.05
		33	DS Stuart Bay Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-	0.05	0.90	0.05	0.05	0.05	-	-	-	-	0.05
		34	DB Bathurst Island Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.05
		35	OSCP Cape Phillips Fm	-	-	-	0.05	0.05	-	-	-	-	-	0.95	-	-	0.95	0.70	0.05	0.05	0.05	-	-	-	-	0.05
		36	ODTI Thumb Mtn./Irene Bay Fm	-	-	-	0.95	0.95	-	-	-	-	-	0.95	-	-	0.95	0.60	0.90	0.05	0.05	-	-	-	-	0.05
2	[illegible]		Depositional Age						M62													C62				
		1	Quaternary	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-
		2	Cretaceous	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
		3	Jurassic-Cretaceous	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
		4	Jurassic	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
		5	Triassic	-	-	-	-	-	0.50	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
		6	Permian	-	-	-	-	-	0.60	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
		7	Carboniferous-Permian	-	-		-	-	0.75	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
		8	Carboniferous	-	-	-	-	-	0.85	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
		9	Devonian	-	-	-	-	-	0.90	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
		10	Ordovician-Devonian	-	-	-	-	-	0.90	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
		11	Ordovician-Silurian	-	-	-	-	-	0.90	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
		12	Ordovician	-	-	-	-	-	0.90	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-
3	[illegible]		Rock Types		M23	M33						M823	M833				C13									
		1	Clastics	-	0.05	0.25	-	-	-	-	-	0.05	0.05	-	-	-	0.05	-	-	-	-	-	-	-	-	-
		2	Carbonates	-	0.95	0.95	-	-	-	-	-	0.95	0.95	-	-	-	0.05	-	-	-	-	-	-	-	-	-
		3	Evaporites	-	0.05	0.35	-	-	-	-	-	0.05	0.05	-	-	-	0.95	-	-	-	-	-	-	-	-	-
		4	Carbonates and Clastics	-	0.65	0.85	-	-	-	-	-	0.75	0.65	-	-	-	0.05	-	-	-	-	-	-	-	-	-
		5	Carbonates and Evaporites	-	0.75	0.75	-	-	-	-	-	0.75	0.65	-	-	-	0.65	-	-	-	-	-	-	-	-	-
		6	Evaporites and Clastics	-	0.05	0.50	-	-	-	-	-	0.05	0.05	-	-	-	0.70	-	-	-	-	-	-	-	-	-
		7	Mixed Lithologies	-	0.60	0.65	-	-	-	-	-	0.55	0.55	-	-	-	0.55	-	-	-	-	-	-	-	-	-
		8	Igneous Intrusions	-	0.05	0.05	-	-	-	-	-	0.05	0.05	-	-	-	0.05	-	-	-	-	-	-	-	-	-
4	deposet		Depositional Setting	M14													C14							C814		
		1	Alluvial Fan	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.65	-	-	-	-	-	-	0.85	-	-
		2	Fluvial-Deltaic	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.85	-	-	-	-	-	-	0.90	-	-
		3	Carbonate/Clastic Shelf	0.80	-	-	-	-	-	-	-	-	-	-	-	-	0.35	-	-	-	-	-	-	0.55	-	-
		4	Pelitic Shelf and Slope	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-	-	0.60	-	-
		5	Carbonate Shelf and Slope	0.95	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	0.25	-	-
		6	Restricted Shelf	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	0.05	-	-
		7	Starved Basin	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	0.05	-	-
		8	Submarine Fan	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	0.05	-	-
		9	Igneous Intrusions	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	0.05	-	-
		10	Glacial / Post-Glacial	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	0.05	-	-
		11	Fluvial-Deltaic/Carb. Shelf and Slope	0.50	-	-	-	-	-	-	-	-	-	-	-	-	0.55	-	-	-	-	-	-	0.55	-	-
		12	Fluvial-Deltaic/Carb-Clastic Shelf	0.30	-	-	-	-	-	-	-	-	-	-	-	-	0.65	-	-	-	-	-	-	0.55	-	-
		13	Submarine Fan/Pelitic Shelf	0.05	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	0.55	-	-
5	tectset		Tectonic Setting	M15																						
		1	Trailing Margin Subsidence	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	Unstable Shelf Margin	0.65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		3	Foreland Subsidence	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		4	Ellesmerian Orogeny	0.95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5	Sverdrup Basin Rifting	0.95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	Melvillian Transpression	0.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7	Melvillian Transtension	0.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

FUZZY MEMBERSHIP TABLES

	Mississippi Valley Type Pb-Zn Criteria												
	1	2	3	4	5	6	7	8.1	8.2	8.3	8.4	8.5	8.6
				M41	M51						M841		
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
n	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
n	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
m	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-
	-	-	-	0.95	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.95	0.95	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.95	-	-	-	-	-	0.80	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-
	-	-	-	0.95	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.80	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.05	-	-
	-	-	-	0.05	0.05	-	-	-	-	-	0.95	-	-
Fm	-	-	-	0.95	0.95	-	-	-	-	-	0.95	-	-
						M62							
	-	-	-	-	-	0.05	-	-	-	-	-	-	-
	-	-	-	-	-	0.05	-	-	-	-	-	-	-
	-	-	-	-	-	0.05	-	-	-	-	-	-	-
	-	-	-	-	-	0.05	-	-	-	-	-	-	-
	-	-	-	-	-	0.50	-	-	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-	-	-
	-	-	-	-	-	0.75	-	-	-	-	-	-	-
	-	-	-	-	-	0.85	-	-	-	-	-	-	-
	-	-	-	-	-	0.90	-	-	-	-	-	-	-
	-	-	-	-	-	0.90	-	-	-	-	-	-	-
	-	-	-	-	-	0.90	-	-	-	-	-	-	-
	-	-	-	-	-	0.90	-	-	-	-	-	-	-
		M23	M33						M823	M833			
	-	0.05	0.25	-	-	-	-	-	0.05	0.05	-	-	-
	-	0.95	0.95	-	-	-	-	-	0.95	0.95	-	-	-
	-	0.05	0.35	-	-	-	-	-	0.05	0.05	-	-	-
	-	0.65	0.85	-	-	-	-	-	0.75	0.65	-	-	-
	-	0.75	0.75	-	-	-	-	-	0.75	0.65	-	-	-
	-	0.05	0.50	-	-	-	-	-	0.05	0.05	-	-	-
	-	0.60	0.65	-	-	-	-	-	0.55	0.55	-	-	-
	-	0.05	0.05	-	-	-	-	-	0.05	0.05	-	-	-
	M14												
	0.05	-	-	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-	-	-
	0.80	-	-	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-	-	-
	0.95	-	-	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-	-	-
d Slope	0.50	-	-	-	-	-	-	-	-	-	-	-	-
helf	0.30	-	-	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-	-	-
	M15												
	0.40	-	-	-	-	-	-	-	-	-	-	-	-
	0.65	-	-	-	-	-	-	-	-	-	-	-	-
	0.40	-	-	-	-	-	-	-	-	-	-	-	-
	0.95	-	-	-	-	-	-	-	-	-	-	-	-
	0.95	-	-	-	-	-	-	-	-	-	-	-	-
	0.75	-	-	-	-	-	-	-	-	-	-	-	-
	0.75	-	-	-	-	-	-	-	-	-	-	-	-

	Sedimentary Cu Criteria										
	1	2	3	4	5	6	7	8.1	8.2	8.3	8.4
	C11	C21	C31	C41	C51					C831	
	0.05	0.20	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.05	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.05	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.70	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.25	0.05	0.05	-	-	-	-	0.05	-
n	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.30	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.50	0.05	0.05	0.05	-	-	-	-	0.30	-
	0.05	0.50	0.05	0.05	0.05	-	-	-	-	0.40	-
n	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.50	-
m	0.05	0.85	0.05	0.05	0.05	-	-	-	-	0.60	-
	0.95	0.30	0.90	0.05	0.05	-	-	-	-	0.95	-
	0.05	0.65	0.95	0.05	0.75	-	-	-	-	0.95	-
	0.05	0.80	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.95	0.95	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.65	0.05	0.95	0.95	-	-	-	-	0.90	-
	0.05	0.75	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.60	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.95	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.90	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.05	0.65	0.05	0.05	0.05	-	-	-	-	0.05	-
	0.95	0.70	0.05	0.05	0.05	-	-	-	-	0.05	-
Fm	0.95	0.60	0.90	0.05	0.05	-	-	-	-	0.05	-
						C62					
	-	-	-	-	-	0.05	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	-	-	-	-	-	0.60	-	-	-	-	-
	C13										
	0.05	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-
	0.95	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-
	0.65	-	-	-	-	-	-	-	-	-	-
	0.70	-	-	-	-	-	-	-	-	-	-
	0.55	-	-	-	-	-	-	-	-	-	-
	0.05	-	-	-	-	-	-	-	-	-	-
	C14							C814			
	0.65	-	-	-	-	-	-	0.85	-	-	-
	0.85	-	-	-	-	-	-	0.90	-	-	-
	0.35	-	-	-	-	-	-	0.55	-	-	-
	0.25	-	-	-	-	-	-	0.60	-	-	-
	0.05	-	-	-	-	-	-	0.25	-	-	-
	0.05	-	-	-	-	-	-	0.05	-	-	-
	0.05	-	-	-	-	-	-	0.05	-	-	-
	0.05	-	-	-	-	-	-	0.05	-	-	-
	0.05	-	-	-	-	-	-	0.05	-	-	-
	0.05	-	-	-	-	-	-	0.05	-	-	-
d Slope	0.55	-	-	-	-	-	-	0.55	-	-	-
helf	0.65	-	-	-	-	-	-	0.55	-	-	-
	0.05	-	-	-	-	-	-	0.55	-	-	-
	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-

	Sediment-Hosted Sulphide Criteria										
	1	2	3	4	5	6	7	8.1	8.2	8.3	8.4
			S31	S41	S51						
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.40	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
n	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
n	-	-	0.40	0.05	0.05	-	-	-	-	-	-
m	-	-	0.40	0.05	0.05	-	-	-	-	-	-
	-	-	0.60	0.65	0.05	-	-	-	-	-	-
	-	-	0.90	0.65	0.05	-	-	-	-	-	-
	-	-	0.65	0.05	0.05	-	-	-	-	-	-
	-	-	0.40	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.90	0.85	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.75	0.85	-	-	-	-	-	-
	-	-	0.60	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.75	0.05	-	-	-	-	-	-
	-	-	0.40	0.05	0.05	-	-	-	-	-	-
	-	-	0.40	0.05	0.05	-	-	-	-	-	-
	-	-	0.05	0.05	0.05	-	-	-	-	-	-
	-	-	0.40	0.05	0.05	-	-	-	-	-	-
Fm	-	-	0.40	0.75	0.85	-	-	-	-	-	-
						S62					
	-	-	-	-	-	0.05	-	-	-	-	-
	-	-	-	-	-	0.05	-	-	-	-	-
	-	-	-	-	-	0.05	-	-	-	-	-
	-	-	-	-	-	0.05	-	-	-	-	-
	-	-	-	-	-	0.05	-	-	-	-	-
	-	-	-	-	-	0.05	-	-	-	-	-
	-	-	-	-	-	0.05	-	-	-	-	-
	-	-	-	-	-	0.05	-	-	-	-	-
	-	-	-	-	-	0.90	-	-	-	-	-
	-	-	-	-	-	0.90	-	-	-	-	-
	-	-	-	-	-	0.90	-	-	-	-	-
	-	-	-	-	-	0.90	-	-	-	-	-
		S23						S813	S823		S843
	-	0.25	-	-	-	-	-	0.95	0.05	-	0.05
	-	0.65	-	-	-	-	-	0.05	0.05	-	0.05
	-	0.85	-	-	-	-	-	0.05	0.05	-	0.85
	-	0.35	-	-	-	-	-	0.75	0.75	-	0.05
	-	0.95	-	-	-	-	-	0.05	0.75	-	0.70
	-	0.60	-	-	-	-	-	0.75	0.75	-	0.70
	-	0.50	-	-	-	-	-	0.05	0.85	-	0.55
	-	0.05	-	-	-	-	-	0.05	0.05	-	0.05
	S14	S24					S74	S814	S824		
	0.50	0.05	-	-	-	-	0.05	0.05	0.05	-	-
	0.15	0.05	-	-	-	-	0.05	0.05	0.05	-	-
	0.55	0.15	-	-	-	-	0.05	0.25	0.65	-	-
	0.55	0.55	-	-	-	-	0.05	0.65	0.05	-	-
	0.55	0.15	-	-	-	-	0.05	0.15	0.30	-	-
	0.85	0.75	-	-	-	-	0.05	0.75	0.05	-	-
	0.85	0.95	-	-	-	-	0.95	0.95	0.05	-	-
	0.25	0.25	-	-	-	-	0.05	0.15	0.05	-	-
	0.05	0.05	-	-	-	-	0.05	0.05	0.05	-	-
	0.05	0.05	-	-	-	-	0.05	0.05	0.05		
d Slope	0.35	0.15	-	-	-	-	0.05	0.35	0.55		
helf	0.35	0.15	-	-	-	-	0.05	0.15	0.60		-
	0.25	0.35	-	-	-	-	0.05	0.45	0.65	-	-
	S15									S835	
	0.40	-	-	-	-	-	-	-	-	0.40	-
	0.65	-	-	-	-	-	-	-	-	0.65	-
	0.40	-	-	-	-	-	-	-	-	0.40	-
	0.95	-	-	-	-	-	-	-	-	0.95	-
	0.95	-	-	-	-	-	-	-	-	0.95	-
	0.75									0.75	
	0.75	-	-	-	-	-	-	-	-	0.75	

			[illegible]										
		2	Cretaceous				[illegible]					[illegible]	
		3	Jurassic Cretaceous				[illegible]					[illegible]	
		4	Jurassic				[illegible]					[illegible]	
		5	Triassic				0.50					[illegible]	
		6	Permian				0.60					[illegible]	
		7	Carboniferous Permian				[illegible]					0.60	
		8	Carboniferous				0.85					0.60	
		9	Devonian				0.90					0.60	
		10	Ordovician Devonian				0.90					0.60	
		11	Ordovician Silurian				0.90					0.60	
		12	Ordovician				0.90					0.60	
3	**lithfam**		**Rock Types**		M23	M33		MR23	MR33		C13		
		1	Clastics		0.05	0.25		0.05	0.05		0.05		
		2	Carbonates		0.95	0.95		0.95	0.95		0.05		
		3	Evaporites		0.05	0.35		0.05	0.05		0.95		
		4	Carbonates and Clastics		0.65	0.85		0.75	0.65		0.05		
		5	Carbonates and Evaporites		0.75	0.75		0.75	0.65		0.65		
		6	Evaporites and Clastics		0.05	0.50		0.05	0.05		0.70		
		7	Mixed Lithologies		0.60	0.65		0.55	0.55		0.55		
		8	Igneous Intrusions		0.05	0.05		0.05	0.05		0.05		
4	**depsett**		**Depositional Setting**	M14							C14		CR14
		1	Alluvial Fan	0.05							0.65		0.85
		2	Fluvial-Deltaic	0.05							0.85		0.90
		3	Carbonate/Clastic Shelf	0.80							0.35		0.55
		4	Pelitic Shelf and Slope	0.05							0.25		0.60
		5	Carbonate Shelf and Slope	0.95							0.05		0.25
		6	Restricted Shelf	0.05							0.05		0.05
		7	Starved Basin	0.05							0.05		0.05
		8	Submarine Fan	0.05							0.05		0.05
		9	Igneous Intrusion	0.05							0.05		0.05
		10	Glacial / Post-Glacial	0.05							0.05		0.05
		11	Fluvial-Deltaic/Carb. Shelf and Slope	0.50							0.55		0.55
		12	Fluvial-Deltaic/Carb-Clastic Shelf	0.30							0.65		0.55
		13	Submarine Fan/Pelitic Shelf	0.05							0.05		0.55
5	**tectsett**		**Tectonic Setting**	M15									
		1	Trailing Margin Subsidence	0.40									
		2	Unstable Shelf Margin	0.65									
		3	Foreland Subsidence	0.40									
		4	Ellesmerian Orogeny	0.95									
		5	Sverdrup Basin Rifting	0.95									
		6	Melvillian Transpression	0.75									
		7	Melvillian Transtension	0.75									
		8	Passive Post-rift Subsidence	0.65									
		9	Incipient Rifting	0.70									
		10	Eurekan Orogeny	0.45									
		11	Stable Platform	0.05									
		12	Boothia Uplift	0.95									
		13	Unrelated	0.05									
6	**proxunco**		**Proximity to Unconformities**					MR26					
		1	0 - 500 metres					0.95					
		2	500 - 1000 metres					0.85					
		3	1000 - 1500 metres					0.75					
		4	1500 - 2000 metres					0.65					
		5	2000 - 2500 metres					0.50					
		6	2500 - 3000 metres					0.40					
		7	3000 - 3500 metres					0.30					
		8	3500 - 4000 metres					0.20					
		9	4000 - 4500 metres					0.10					
		10	>4500 metres					0.05					
7	**proxfaci**		**Proximity to Facies Boundaries**	M17					MR47				
		1	0 - 500 metres	0.95					0.95				
		2	500 - 1000 metres	0.85					0.85				
		3	1000 - 1500 metres	0.75					0.75				
		4	1500 - 2000 metres	0.60					0.65				
		5	2000 - 2500 metres	0.50					0.50				
		6	2500 - 3000 metres	0.40					0.40				
		7	3000 - 3500 metres	0.30					0.30				
		8	3500 - 4000 metres	0.20					0.20				
		9	4000 - 4500 metres	0.10					0.10				
		10	>4500 metres	0.05					0.05				
8	**proxfalt**		**Proximity to Faults**	M18						MR48			
		1	0 - 500 metres	0.95						0.95			
		2	500 - 1000 metres	0.85						0.85			
		3	1000 - 1500 metres	0.75						0.75			
		4	1500 - 2000 metres	0.60						0.65			
		5	2000 - 2500 metres	0.50						0.50			
		6	2500 - 3000 metres	0.40						0.40			
		7	3000 - 3500 metres	0.30						0.30			
		8	3500 - 4000 metres	0.20						0.20			
		9	4000 - 4500 metres	0.10						0.10			
		10	>4500 metres	0.05						0.05			

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
0.50	[illegible]	[illegible]
0.60	[illegible]	[illegible]
0.75	0.60	[illegible]
0.85	0.60	[illegible]
0.90	0.60	[illegible]
0.90	0.60	0.90
0.90	0.60	0.90
0.90	0.60	0.90

	M23	M33	MR23	MR33	C13	S23	SR13	SR23	SR43
	0.05	0.25	0.05	0.05	0.05	0.25	0.05	0.05	0.05
	0.95	0.95	0.95	0.95	0.05	0.65	0.05	0.05	0.05
	0.05	0.35	0.05	0.05	0.95	0.85	0.05	0.05	0.85
	0.65	0.85	0.75	0.65	0.05	0.35	0.25	0.25	0.05
sica	0.75	0.75	0.75	0.65	0.65	0.95	0.05	0.25	0.20
	0.05	0.50	0.05	0.05	0.70	0.60	0.25	0.25	0.20
	0.60	0.65	0.55	0.55	0.55	0.50	0.05	0.85	0.55
	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

	M14	C14	CR14	S14	S24	S74	SR14	SR24
	0.05	0.65	0.85	0.50	0.05	0.05	0.05	0.05
	0.05	0.85	0.90	0.15	0.05	0.05	0.05	0.05
r	0.80	0.35	0.55	0.55	0.15	0.05	0.25	0.65
	0.05	0.25	0.60	0.55	0.55	0.05	0.65	0.05
ope	0.95	0.05	0.25	0.55	0.15	0.05	0.15	0.30
	0.05	0.05	0.05	0.85	0.75	0.05	0.75	0.05
	0.05	0.05	0.05	0.85	0.95	0.95	0.95	0.05
	0.05	0.05	0.05	0.25	0.25	0.05	0.15	0.05
	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
helf and Slope	0.50	0.55	0.55	0.35	0.15	0.05	0.35	0.55
lastic Shelf	0.30	0.65	0.55	0.35	0.15	0.05	0.15	0.60
Shelf	0.05	0.05	0.55	0.25	0.35	0.05	0.45	0.65

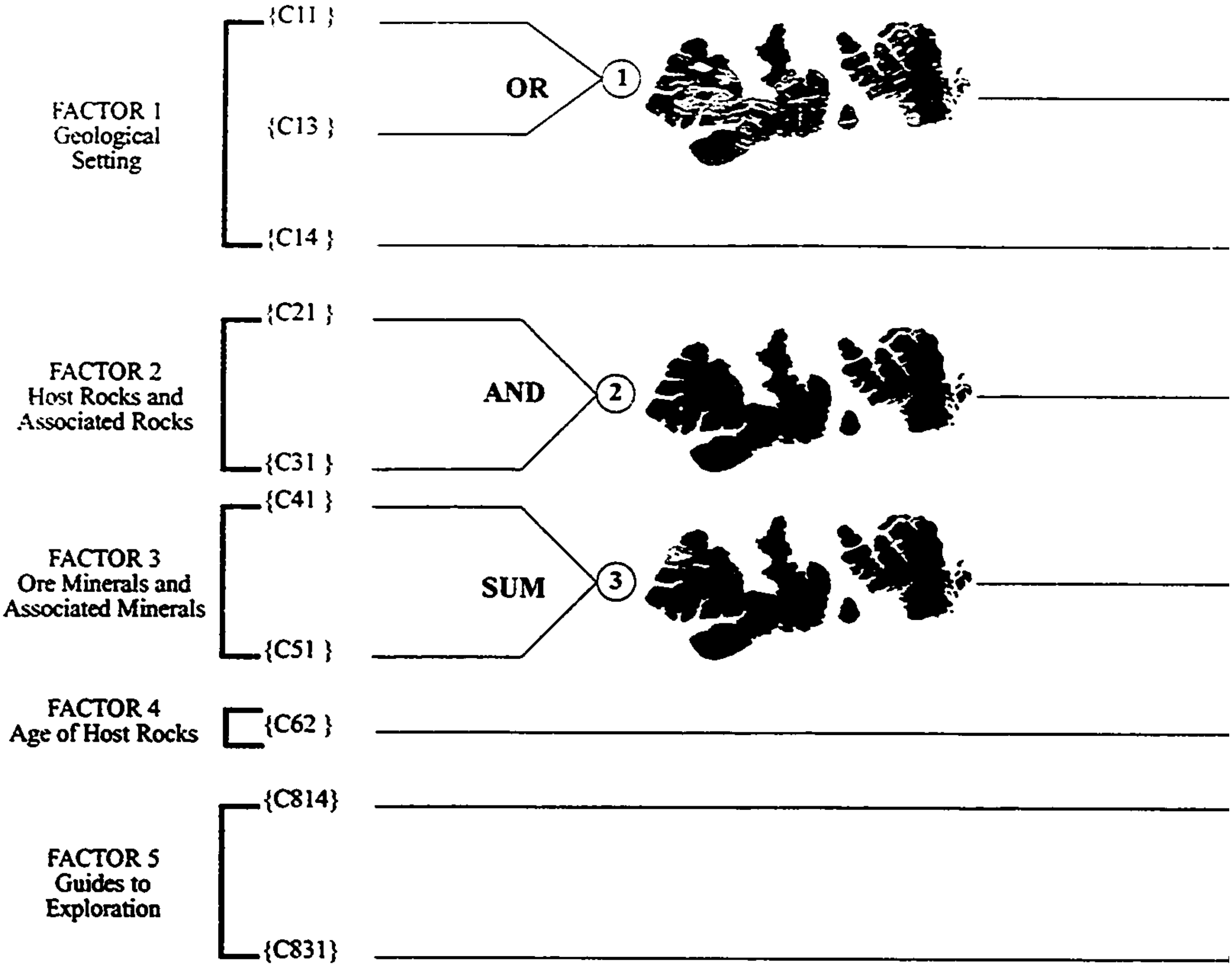
	M15	S15	SR35
ence	0.40	0.40	0.40
	0.65	0.65	0.65
	0.40	0.40	0.40
	0.95	0.95	0.95
	0.95	0.95	0.95
n	0.75	0.75	0.75
n	0.75	0.75	0.75
lence	0.65	0.65	0.65
	0.70	0.70	0.70
	0.45	0.45	0.45
	0.05	0.05	0.05
	0.95	0.95	0.95
	0.05	0.05	0.05

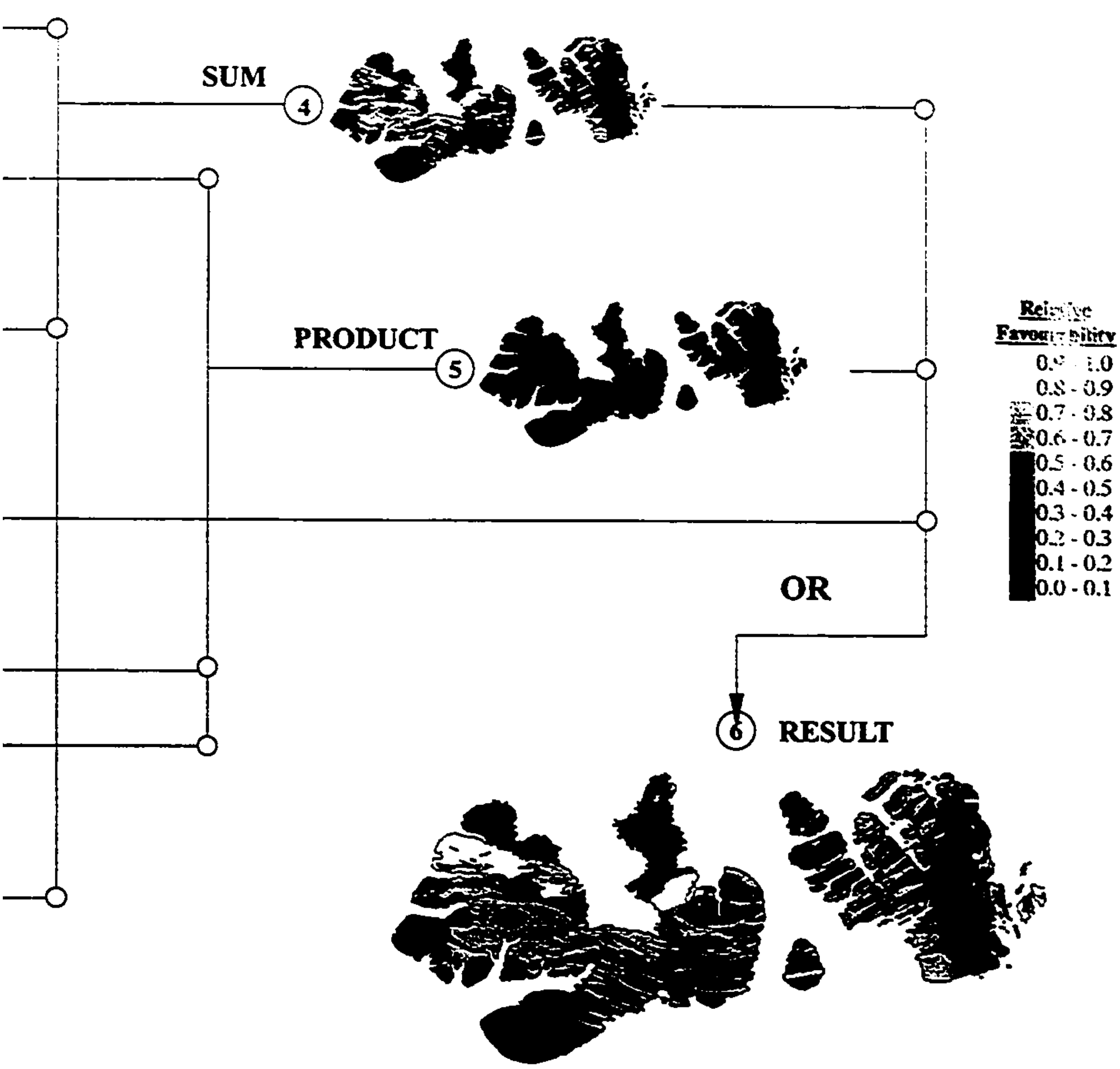
oundities	MR26
	0.95
	0.85
	0.75
	0.65
	0.50
	0.40
	0.30
	0.20
	0.10
	0.05

oundaries	M17	MR47	SR27
	0.95	0.95	0.95
	0.85	0.85	0.85
	0.75	0.75	0.75
	0.60	0.65	0.65
	0.50	0.50	0.50
	0.40	0.40	0.40
	0.30	0.30	0.30
	0.20	0.20	0.20
	0.10	0.10	0.10
	0.05	0.05	0.05

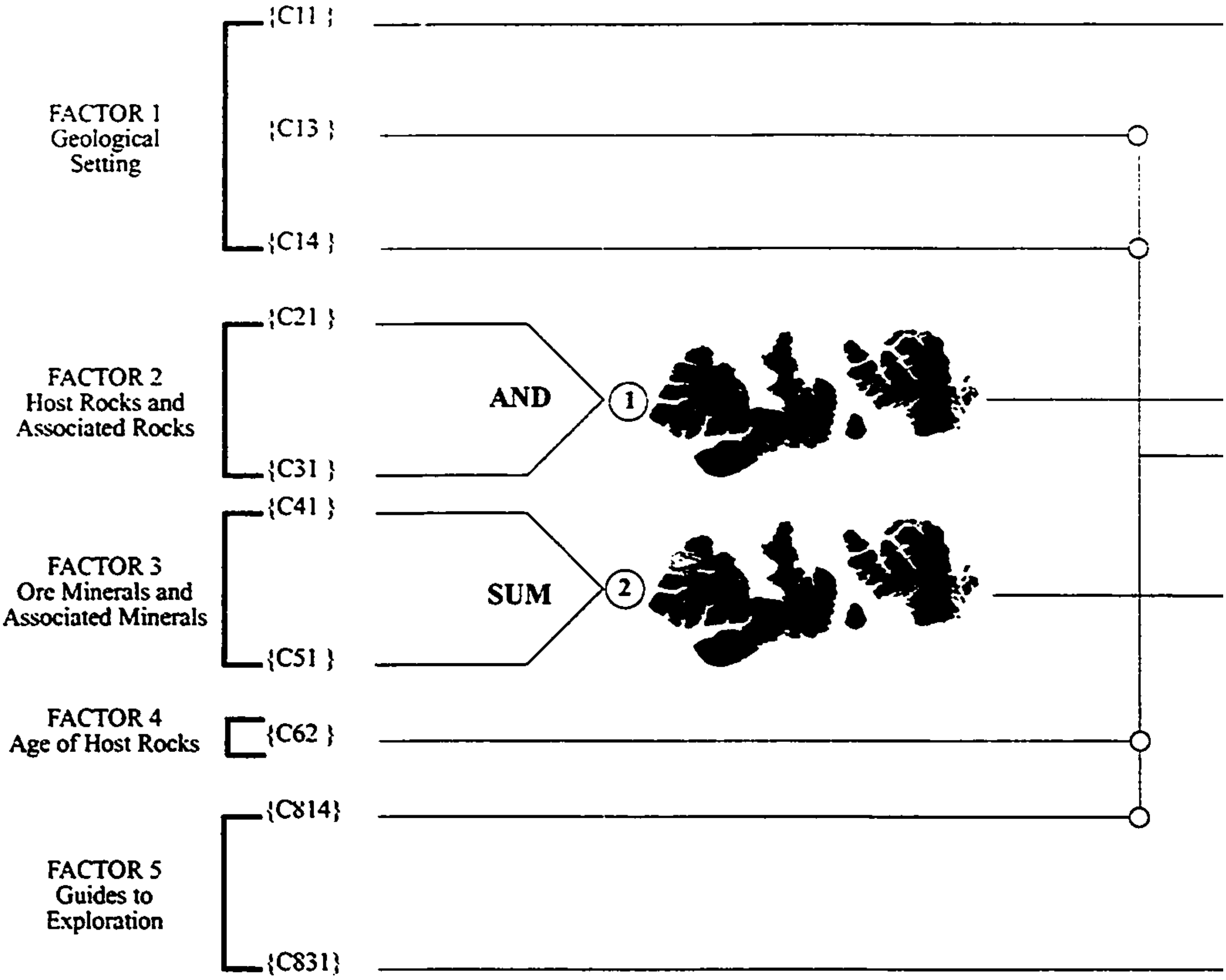
	M18	MR48	S18	S78	SR38
	0.95	0.95	0.95	0.95	0.95
	0.85	0.85	0.85	0.85	0.85
	0.75	0.75	0.75	0.75	0.75
	0.60	0.65	0.65	0.65	0.65
	0.50	0.50	0.50	0.50	0.50
	0.40	0.40	0.40	0.40	0.40
	0.30	0.30	0.30	0.30	0.30
	0.20	0.20	0.20	0.20	0.20
	0.10	0.10	0.10	0.10	0.10
	0.05	0.05	0.05	0.05	0.05

ENCLOSURE 3B.


FACTOR 1
Geological
Setting
{C11}
{C13}
{C14}
OR
1
FACTOR 2
Host Rocks and
Associated Rocks
{C21}
{C31}
AND
2
FACTOR 3
Ore Minerals and
Associated Minerals
{C41}
{C51}
SUM
3
FACTOR 4
Age of Host Rocks
{C62}
FACTOR 5
Guides to
Exploration
{C814}
{C831}



ENCLOSURE 5A.
Sedimentary Cu Model
Inference Net 1.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FACTOR 1
Geological
Setting
{C13}
{C14}
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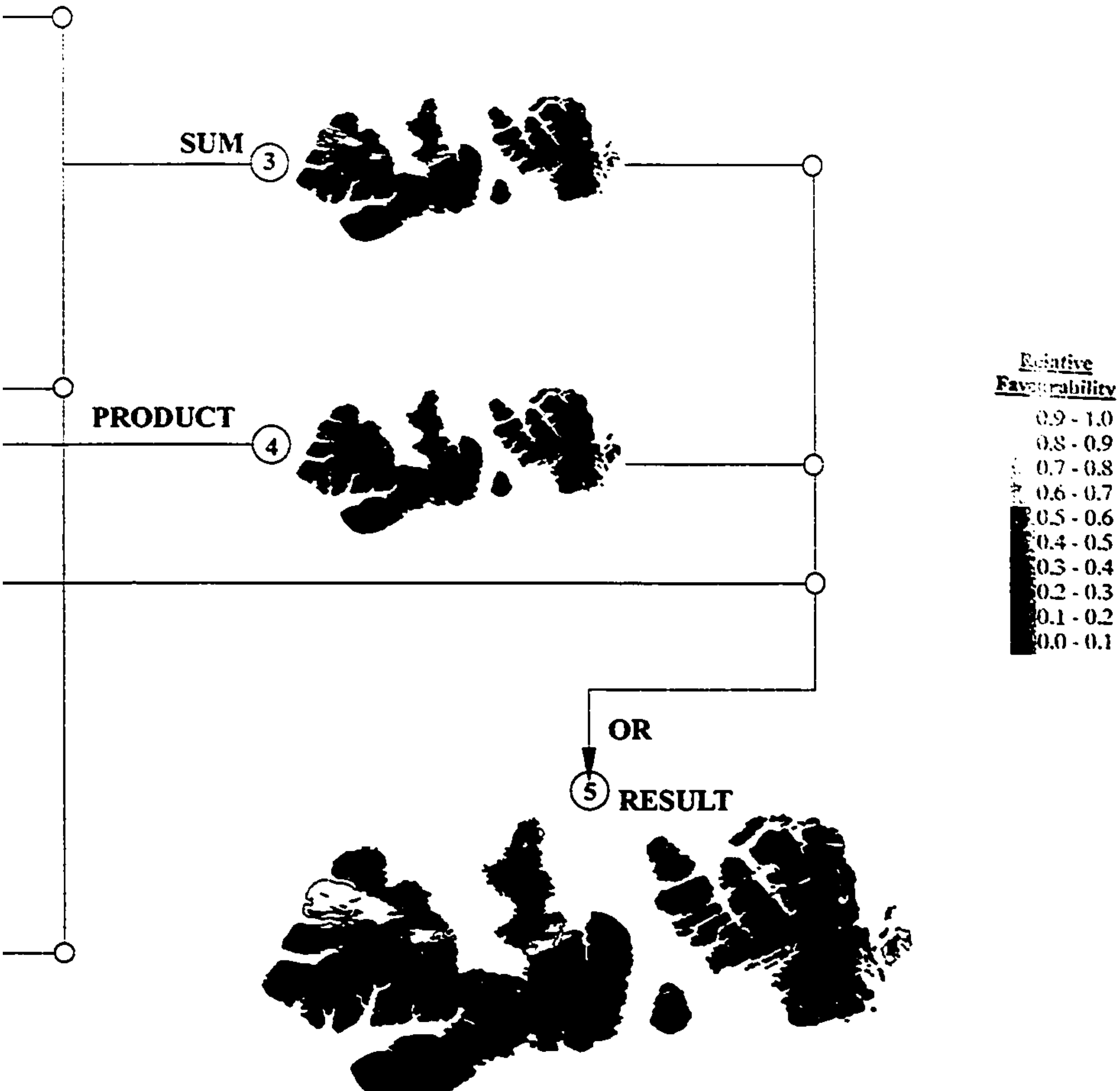
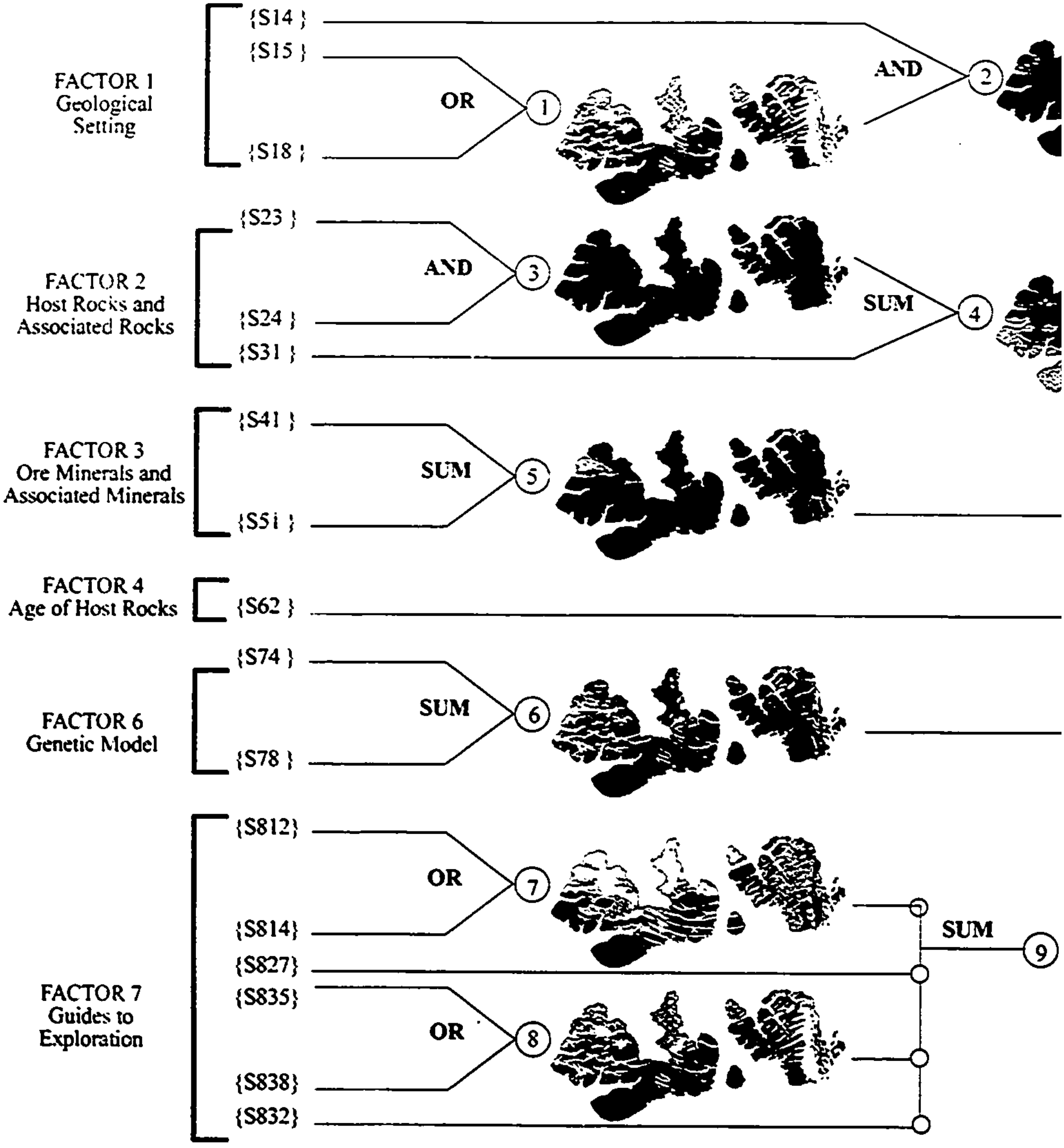
FACTOR 2
Host Rocks and
Associated Rocks
AND
①
{C31}
{C41}
FACTOR 3
Ore Minerals and
Associated Minerals
SUM
②
{C51}
FACTOR 4
Age of Host Rocks
{C62}
{C814}
FACTOR 5
Guides to
Exploration
{C831}



ENCLOSURE 5B.
Sedimentary Cu Model
Inference Net 2.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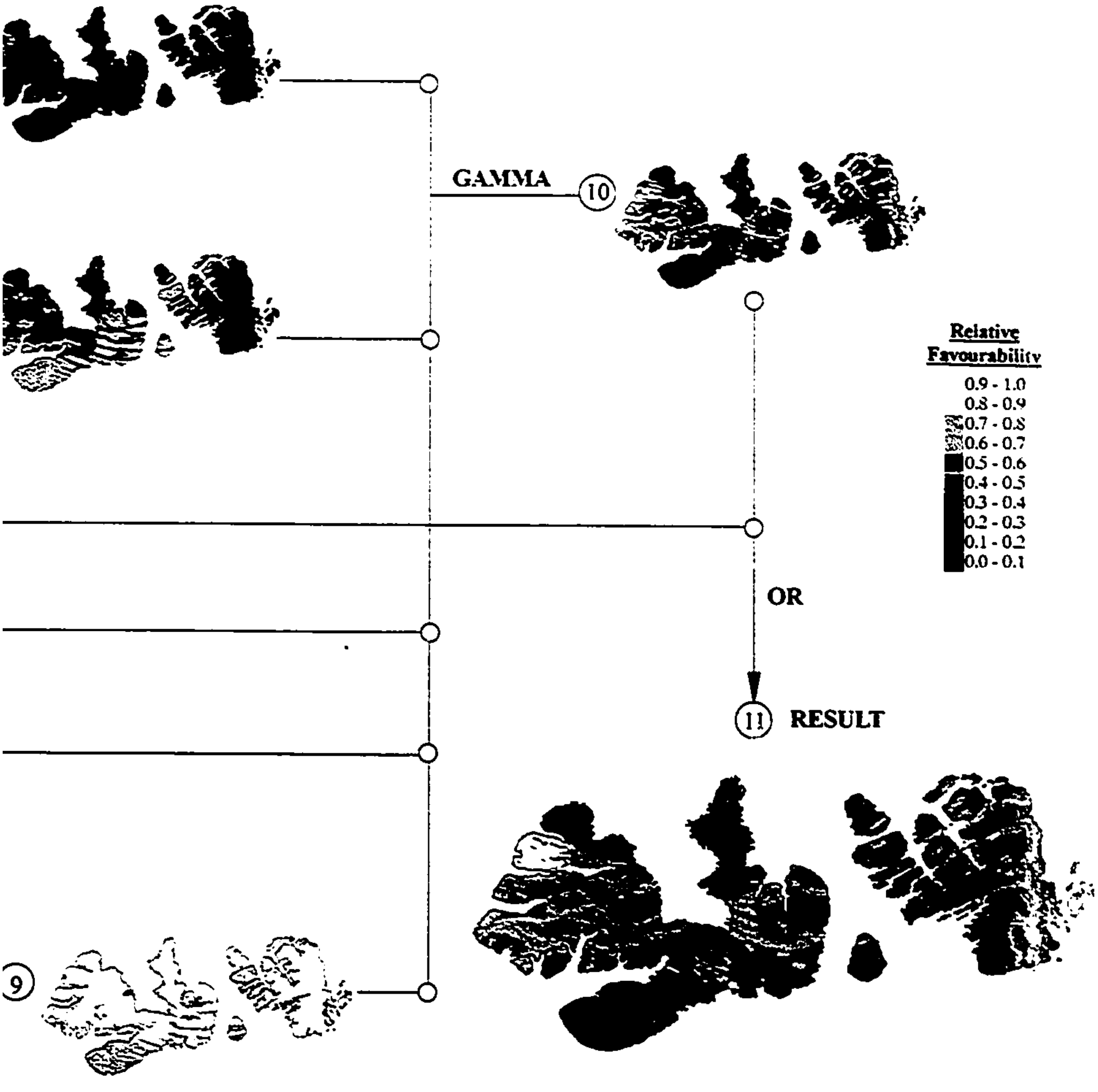
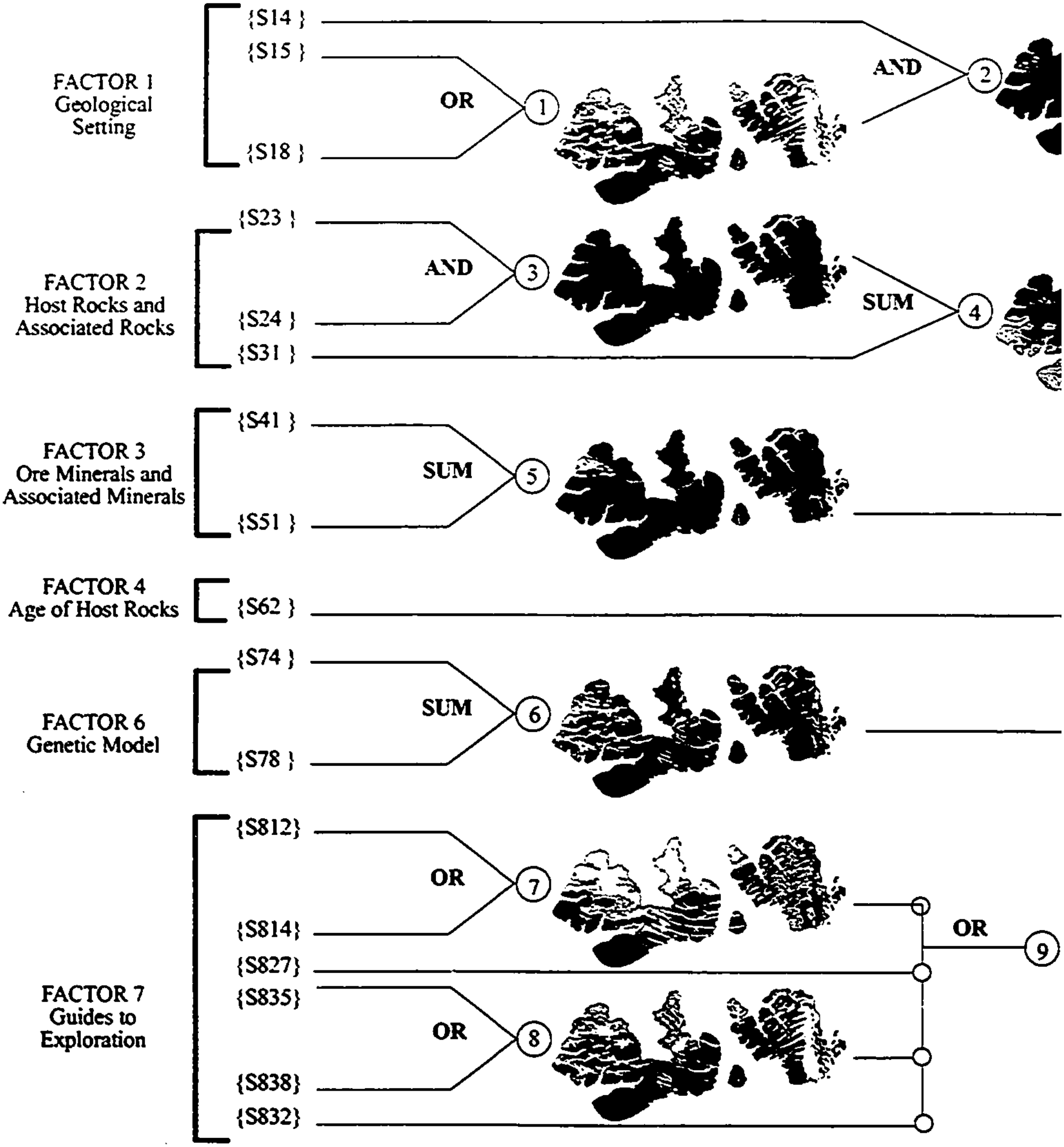
{S14}
{S15}
{S18}
OR
1
AND
2
FACTOR 2
Host Rocks and Associated Rocks
{S23}
{S24}
{S31}
AND
3
SUM
4
FACTOR 3
Ore Minerals and Associated Minerals
{S41}
{S51}
SUM
5
FACTOR 4
Age of Host Rocks
{S62}
FACTOR 6
Genetic Model
{S74}
{S78}
SUM
6
FACTOR 7
Guides to Exploration
{S812}
{S814}
{S827}
{S835}
{S838}
{S832}
OR
7
OR
8
SUM
9



ENCLOSURE 6A.
Sediment-Hosted Sulphides Model
Inference Net 1.


FACTOR 1
Geological Setting
{S14 }
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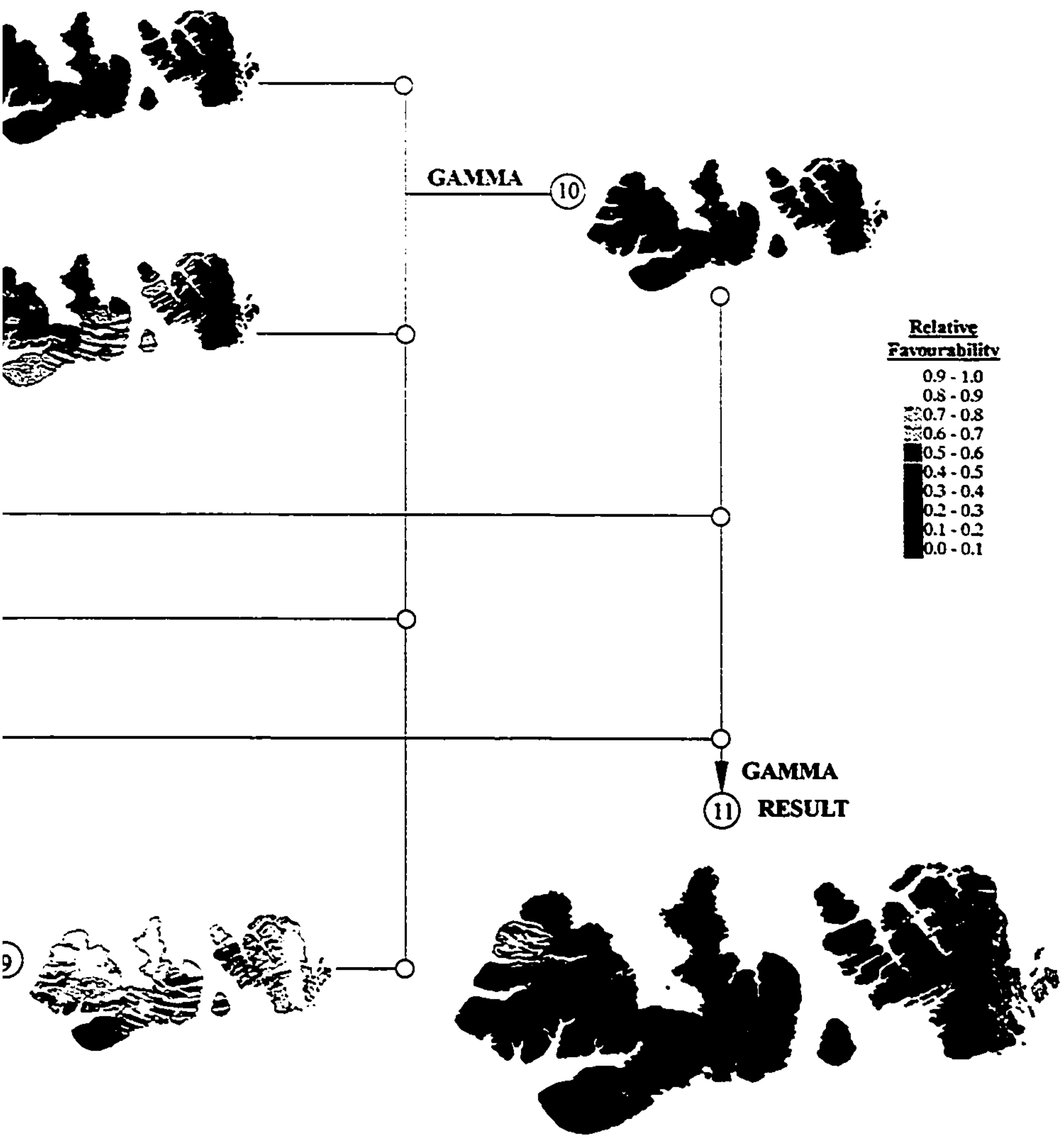
OR
1
AND
2
FACTOR 2
Host Rocks and Associated Rocks
{S23 }
{S24 }
{S31 }
AND
3
SUM
4
FACTOR 3
Ore Minerals and Associated Minerals
{S41 }
{S51 }
SUM
5
FACTOR 4
Age of Host Rocks
{S62 }
FACTOR 6
Genetic Model
{S74 }
{S78 }
SUM
6
FACTOR 7
Guides to Exploration
{S812}
{S814}
{S827}
{S835}
{S838}
{S832}
OR
7
OR
8
OR
9



ENCLOSURE 6B.
Sediment-Hosted Sulphides Model
Inference Net 2.