

Investigation into Development and Implementation of Natural
Resources Geographical Information Systems (GIS): Case Study
Geological Survey of British Columbia

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Patrick M. Bartier
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We accept this thesis as conforming
to the required standard

Dr. C.P. Keller, Supervisor (Department of Geography)

Dr. E. Van der Flier-Keller, Departmental Member (Department
of Geography, Centre for Earth and Ocean Research)

Dr. J. Littlepage, Outside Member (Department of Biology)

Dr. W.R. Smyth, Additional Member (Chief Geologist,
Geological Survey Branch, British Columbia)

Dr. J.R. Moehr, External Examiner (Health Information
Sciences)

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University of Victoria

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Supervisor: Dr. C. Peter Keller

ABSTRACT

Traditional methods for managing resource information increasingly are proving inadequate for the quantity, diversity, and complexity of tasks which must be performed upon the data. Geographical information systems (GIS), have emerged as a promising means for resolving spatial data management difficulties.

This thesis examines the problem of developing and implementing GIS within natural resource organisations. The problem is defined as follows. Natural resource agencies typically collect, manage and perform various tasks upon resource data according to a mandate. Characteristically, the mandate is long-term, data collection is costly and time-consuming, and tasks and expectations change through time. Developing and implementing GIS has proven to involve considerable costs and commitment. An agency therefore will require stability and flexibility from GIS in order to justify the efforts and resources invested. Current implementation strategies stress development based upon commercial software products. However, commercial products tend to be volatile and inflexible as they are subject to rapid changes in technology, and they often employ vendor unique data structures and patent protected code.

Existing implementation strategies are criticised for basing costly GIS development and implementation upon volatile and inflexible products. An alternate strategy is put forth emphasising a linkage between spatial data models based upon established concepts and principles, and the organisational mandate. It is argued that GIS developed in this manner will deliver the flexibility, security and long-term stability required.

The Geological Survey of British Columbia is used as a case study. GIS requirements for this organisation are assessed through an examination of its mandate, tasks, data management practices, and spatial characteristics of data sets under its stewardship.

Examiners:

[REDACTED]

Dr. C.P. Keller, Supervisor (Department of Geography)

[REDACTED]

Dr. E. Van der Flier-Keller, Departmental Member (Department of Geography, Centre for Earth and Ocean Research)

[REDACTED]

Dr. J. Littlepage, Outside Member (Department of Biology)

[REDACTED]

Dr. W.R. Smyth, Additional Member (Chief Geologist, Geological Survey Branch, British Columbia)

[REDACTED]

Dr. J.R. Moehr, External Examiner (Health Information Sciences)

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CHAPTER ONE

INTRODUCTION

In 1969 the Chief of the Mineralogical Branch, British Columbia Department of Mines and Petroleum Resources,¹ expressed that within this organisation "Data proliferation is a major problem of the day." (Hedley, 1969:2). This is even more true today, given that in the last two decades the B.C. Geological Survey has experienced continued significant growth in existing data sets, and the creation of entirely new ones. The Quebec and Ontario geological surveys appear to have encountered similar problems of data proliferation, noting that expanding and poorly managed data volumes have rendered geoscience information sets ineffective for the purposes they were created (Chauvin, 1989; Currie and Ady, 1989).

Inefficient data management can impair an organisation's ability to access and cross-reference data, to perform research and analysis, and to distribute information to its clients. Organisations therefore face the challenge of implementing efficient and effective data management techniques to allow for integration of diverse data, and to ensure the data can be accessed readily for simple and complex analysis within the organisation in order to meet mandates.

¹ This is the predecessor of the existing Geological Survey Branch, British Columbia Ministry of Energy, Mines and Petroleum Resources.

Geographical Information Systems (GIS), broadly defined as automated systems for input, output, storage, and analysis of geo-referenced information, have emerged as a means for resolving spatial data management problems, providing a platform for enhanced analysis and research capabilities, and for automating cartographical drafting.

The decision to implement GIS, including the conversion of information from analog to digital formats, requires commitment of considerable human effort and financial resources. Commercial GIS are subject to rapidly evolving technology and a risk exists that digital information can quickly become obsolete if improperly formatted and managed. It is therefore important that information is organised upon principles which transcend technological change, yet allow the agency to grow with and to take advantage of such changes.

This study will examine the problem of implementing geographical information systems within a geological survey setting. To this end, the B.C. Geological Survey is used as a case study. Various aspects of this organisation, including its tasks, information management practices, products, and client services, will be investigated in order to determine an appropriate strategy for implementing GIS to improve that organisation's efficiency and effectiveness in handling spatial data.

Chapter Two is a literature review which focuses upon theoretical concepts underlying GIS development, and strategies for implementing GIS in an organisational setting. It is concluded that present implementation strategies stress short term goals and technology over theoretical concepts and organisational mandates. Accordingly, an alternate implementation strategy is proposed. This strategy forms the framework for the following case study of GIS implementation in the B.C. Geological Survey.

An unbiased enumeration of GIS functionality is critical to the implementation process. Chapter Three therefore is devoted to identifying GIS functionality at a level which aims to transcend technological trends and commercial products.

Chapter four describes the B.C. Geological Survey with emphasis upon its mandates and supporting activities, current data management practices, the organisation's products and services, and the utilisation of this output.

GIS functional requirements for the B.C. Geological Survey are summarised in Chapter Five according to terminology introduced in Chapter Three. The ability of data models to fulfil the identified requirements are assessed and an argument is put forth for the support of a specific data model taking into account the organisation's mandates, information requirements, and functional needs. This chapter

concludes with a discussion of a scenario for actual GIS implementation.

Two contexts of GIS are described in Chapter Six. There exists a commercial view of GIS with emphases upon technology and functionality. Conversely there exists the corporate view of GIS with emphases upon integrity and long-term flexibility, ie. technology-independence of spatial data sets. It is argued that development of GIS in a geological survey must occur in the latter context.

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CHAPTER TWO

GENERAL LITERATURE REVIEW

2.0 INTRODUCTION

This chapter is organised into several sections. Section 2.1 defines GIS, briefly reviews its history, and discusses the conditions responsible for its emergence. The following section reviews conceptual advances in GIS with emphasis upon principles underpinning current development. Various factors motivating geological surveys to acquire GIS technology are examined in section 2.3. Section 2.4 looks at strategies currently employed to acquire and implement GIS. Based upon criticism of current implementation practices, an alternate approach is proposed in section 2.5.

2.1 BACKGROUND INFORMATION

A Geographic Information System is often defined as an automated system for input, output, storage and analysis of geographical information (Burrough, 1987; De Man, 1988; Goodchild, 1987a; Marble, 1984). GIS can be distinguished from other automated systems such as computer assisted drafting or mapping (CAD/CAM) by its ability to analyze spatial information (Cowen, 1988; Dueker, 1985; Lai, 1990). It can be distinguished from database management systems (DBMS) by its ability to analyze and query spatial data (Herring, 1989). Lai (1990) also notes that GIS is the only

system capable of rapidly accessing and updating integrated spatial data.

Topological relationships are implicitly maintained on paper maps. Thus, if the analog is to be replaced by digital databases, topological relationships must be defined in an explicit manner (Chrisman, 1987b; Currie, 1986; Nyerges, 1980). Most spatial analysis assumes topological knowledge, a non-topological database therefore has limitations for performing such analysis. GIS is recognized as the only system capable of handling such relationships (Dueker, 1987; Parker, 1988).

Current GIS, however, have their limitations. There are problems handling data and applications in three dimensions (see, for example, Jones, 1989; White, 1984a). Similarly, it is noted that current developments in GIS do not adequately address spatio-temporal information and applications (see, for example, Langran, 1989; Vrana, 1989). Loudon (1986) points out that GIS lacks geological mapping capabilities, including graphic manipulation and the representation of geological surfaces such as folds or faults. GIS is often promoted for its ability to integrate spatial data of all types. However there is a considerable body of literature devoted to the problem of integrating GIS with remotely sensed data (see, for example, Barker, 1988; Ehlers et al. 1989; Fisher and Lindenbergh, 1989; Maffini, 1987).

Early GIS development was slow, initially being limited to large government organizations involved with forestry, utilities and municipal planning (Tomlinson, 1987). Some pioneering systems include the Canadian Geographic Information System (CGIS) in 1964, the New York Landuse and Natural Resources Information System in 1967, and the Minnesota Land Management System in 1969 (Smith et al. 1987). The initial slow expansion of GIS usage can be explained by a number of factors. Tomlinson (1987) cites a lack of digital base map material, high digitising costs, poor awareness, and expensive hardware and software as contributing factors. Smith et al. (1987) also note that a lack of academic research has contributed. These impediments have largely been overcome now and, as the following paragraphs will explain, GIS has become 'institutionalised', with established university curricula, professional journals, and formal government agencies devoted to the discipline.

There have been complaints that much literature dealing with GIS is fugitive, largely found in conference proceedings, private reports and government agency reports (Goodchild, 1985; Tomlinson, 1987). Although much literature is still obtained from these sources, there now is at least one refereed professional journal dedicated to the subject (International Journal of Geographic Information Systems, est. 1987) and several journals dealing with cartography and

remote sensing commonly dedicate significant portions of their issues towards the topic.¹

Tomlinson (1984; 1989) explains that GIS development has taken place not in response to academic curiosity, but as a reaction to the need for improved data handling needs within government. The need for more efficient data handling methods is an important factor directing GIS development; however academic influences are playing an increasingly important role. Morgan (1987) reports that, as of 1987, at least 125 geography departments in the United States and Canada are offering instruction in GIS. A formal framework for GIS education and research in universities is presented by Keller (1990a), Nyerges and Chrisman (1989), and Unwin et al. (1990). GIS curricula usually involve components of technology such as computer graphics and hardware devices, but much emphasis is also placed upon data models and structures, cartography, spatial statistics, and spatial analysis (see, for example, Goodchild, 1985; Keller, 1990a; Nyerges and Chrisman, 1989).

With an increasing quantity of public information being maintained in digital formats, governments at the federal and provincial levels are taking a more active role in GIS development. The British Columbia Ministry of Crown Lands,

¹ The title of the journal 'The American Cartographer' also has been changed to 'Geographic Information Systems and Cartography' as of beginning, 1990.

for example, now contains a unit devoted to geomatics.² According to Sawayama (1989) the primary issue for British Columbia is the sharing of data across the public and private sectors. Three approaches are being applied to address this problem; (1) topographic data standards consistent with those at the federal level have been developed, (2) a program of digital topographical mapping, upon which provincial resource inventories can be referenced, has been initiated,³ and (3) there exists a move towards:

...a government-wide strategy to ensure that future GIS development in individual government departments conform to an overall architecture that raises the concept of standardized data onto its own pedestal and relegates ever-changing technology to a more appropriate role. (Sawayama, 1989:276)

Other Canadian provinces, notably Ontario, Alberta, and Quebec, have established units similar to the geomatics unit in the B.C. Ministry of Crown Lands. At the Federal level, an inter-agency committee on geomatics has been established to coordinate geomatics activities within the federal government. With respect to GIS development in Canada, O'Donnell (1989) lists standards to facilitate the exchange

² Geomatics is a term often used by Government and Universities in Canada. It refers to "...methods, procedures and technologies associated with systems for the collection, manipulation, display and dissemination of geographically-referenced digital data." (Federal Geomatics Bulletin, p.2).

³ The program, formally known as TRIM (for Terrain Resources Information Management), is a three dimensional model of standardized topographic data (Sawayama, 1989).

of data and digital database development as among the most important tasks for the federal government to perform.

O'Donnell (1989) characterises GIS development as a marriage between technology and a demand for geo-referenced information. Technological factors, such as advances in computers, cartography, remote sensing, and earthbound surveys have played an important role in GIS development (Burrough, 1987; Smith et al., 1987). Early systems tended, therefore, to be hardware dependent and application specific. However, with GIS becoming available to an increasing number and variety of users, there is increasing emphasis for data to be independent of technological change and in a generic format such that it can be used by anyone for any purpose. In effect, there is a need for GIS to be based upon more abstract principles. With GIS established in universities, and government policies being established for the orderly development and transfer of digital information, there is a growing emphasis upon spatial theory, data models and efficient data structures. The editors of the International Journal of Geographic Information Systems, in its premier edition, for example, emphasize to potential contributing authors the importance of articles focusing upon data structures (and therefore data models) (Coppock and Anderson, 1987). Considerable research is now undertaken studying standards for query languages, graphics, and for the transfer of digital information between various agencies

and organizations. Principles and theoretical concepts underlying current GIS development are reviewed in the following section.

2.2 THEORETICAL DEVELOPMENTS IN GIS

A tradition of development based upon specific applications and technological advances imparts a perception that GIS is a field lacking in theory. For example Jordan (1988) reports that GIS is nonintellectual,⁴ and Goodchild (1987b:27) observes that, to those not familiar with the field, "...GIS research appears as a mass of relatively uncoordinated material with no core of theory or organizing principles." This perception may change as GIS is now established as a field of study and research in universities, and with the organisation of government agencies devoted to managing and coordinating a growing diversity of spatial information in digital formats. Simpson (J.W., 1989) asserts that analysis using GIS has a conceptual background based upon environmental complexity, determinism, environmental stewardship, and spatial patterns. Muller (1985) feels that a distinct school of

⁴ Jordan's comments prompted several replies. Abler (1988) states that "If GIS is nonintellectual, geography is nonintellectual.". Nicholson (1988) comments that if geography does not keep pace university geography departments may be eliminated and geographers may lose job opportunities. Dobson (1988), Gilmartin et al. (1988) and Hammen (1988) also published comments supporting GIS as an area of research in geography.

thought has emerged in GIS as an operational ground for solving practical environmental issues, and as a philosophy for the integration of spatial data from various sources and formats. There is some discussion of selected universities opening new Departments to be called "Department of Geographic Information Sciences" (Keller, 1990c). Abler (1987:515) goes as far to assert that GIS:

...is to geographic description and analysis what the microscope, the telescope, and computers have been to other sciences.

The primary focus of current GIS research includes investigations into conceptual models and digital structures for organising geographical data. Muller (1985) stresses the importance of such research, warning that without it, GIS will remain a discipline emphasising the case study as opposed to the theory of spatial information. Frank (1987:215) agrees by noting that "The absence of a coherent spatial theory hinders development of GIS." However he goes on to note that "Building a comprehensive, coherent spatial theory will not be simple." (p. 215).

Development of GIS based upon conceptual principles, as opposed to technological factors, has important implications for resource agencies considering GIS development. Resource data is gathered by government agencies at considerable cost and according to a long term mandate. Converting this data to digital formats requires considerable additional costs and resources. Therefore it is important to ensure that the

information adheres to more established standards and principles as opposed to vendor-specific technology which may soon be obsolete. Basic concepts and principles underlying current GIS research and development are reviewed below.

2.2.1 The Data Abstraction Continuum

Fundamental to a spatial model is a professional's perception and interpretation of the world. In turn, this interpretation is influenced by the education and working paradigms of the professional. Based upon this understanding of reality, an abstract model is formulated. Loudon (1986:61) explains that:

Underlying the geological map is the geologist's conceptual spatial model, that is, his opinions on the location, form, composition of the rock units and their origin of evolution. [And] If the model itself can be represented digitally, then the full detail of the conceptual model can be captured and communicated.

Analog maps are the traditional model for portraying perceptions of reality. With the advent of computer technology, the map has been further abstracted into models which explicitly identify physical and intuitive geographical properties of the map. These properties are organised into a logical framework, or data structure, which subsequently forms the basis for digital encoding.

Abstraction levels are explained in Table 2.1. Various levels of abstraction are recognized in the literature (see, for example, Guptill, 1989b; Nyerges, 1980; Peuquet, 1984;

ABSTRACTION LEVEL	EXPLANATION
REALITY	Geology as it exists in nature including all those phenomena and relationships not recognized nor perceived.
DATA REALITY	An interpretation of reality according to educational background and working paradigms of the geologist.
DATA ABSTRACTION	Geology as it appears in maps, cross-sections, in files and reports.
DATA MODEL	A representation of the data abstraction incorporating only those concepts and relationships thought to be relevant.
DATA STRUCTURE	The data model represented by logical organization using flow diagrams and pointers.
FILE STRUCTURE	The data structure implemented as computer code.

Figure 2.1: Levels in the data abstraction continuum.

Tompa, 1977) and do not necessarily conform to, or agree with, the scheme presented in Table 2.1. There are also inconsistencies in the literature with usage of the terms 'data model' and 'data structure'.

In the context of this discussion, there is an increase in abstraction and decreasing definition towards the reality end of the continuum. However, to a field geologist

concerned with mapping and interpreting reality, the abstraction may appear to be in reverse order. The potential for loss of information increases towards the file structure end of the continuum.

Critical to this process is the identification and understanding of spatial phenomena towards the reality end of the continuum. It will be easier to incorporate spatial characteristics into a model if they are identified and placed into the framework of a model before digital encoding takes place.

2.2.2 Spatial Characteristics of Geological Data

The search for order and understanding in spatial models is based upon some abstraction of reality, but with the ultimate goal of attaining reality. For information to be accessed for query and analysis in a digital system, its characteristics must be encoded in an explicit manner. It therefore follows that the spatial characteristics of geological information must first be identified.

At a fundamental level, geological phenomena can occur in one of four dimensions; as points, lines, areas, or volumes. Some phenomena are spatially discrete, for example faults and intrusive bodies, with changes occurring abruptly along well-defined boundaries; other phenomena exhibit continuous spatial variation, for example geochemical distributions and topographical variables, and do not have well-defined

boundaries. However, both discrete and continuous data types occupy a position in three dimensional space. To describe these positions in relative and absolute terms, information is referenced according to the specifications of a coordinate system. Coordinates describing the position of locational information are termed metric data.

All spatial information types can have associated locational and non-locational attributes. Locational attributes can describe relationships of a topological or proximal nature. In the case of topology, relationships can be described in terms of physical linkages, for example by connectivity, adjacency, or inclusion. Relationships involving proximity often are semantically implied according to the interpretation of a geoscientist. Non-locational attributes include descriptive text, numerical descriptions, and even relationships with other attributes. It is also possible for attributes and positions of spatial phenomena to change or vary through time. Thus a temporal component exists.

At a more general level spatial information is often organised into thematic classes. Examples of geological thematic data include stratigraphic polygons, faults, and geochemical sample points. It is also possible to have one or more subclasses associated with thematic data and, according to an individual's interpretation, subclasses may

be regarded as themes unto themselves. Stratigraphic hierarchies constitute such an example in geology.

In collecting and describing geoscience information it is often necessary to impose classification schemes, to generalise, and to restrict or define accuracy. Thus, in a digital environment an additional component exists, metadata, which describes the nature of information (Nyerges, 1987). Metadata may consist of attribute schema; it can describe geographical extent (geological data is often collected according to 1:50,000 or 1:250,000 scale NTS blocks); and it can characterise data quality in terms of positional and temporal accuracy, logical consistency, completeness, lineage, technical and administrative details. Although metadata is not a natural physical component of spatial information, it is important to those who use the data because it reflects the conditions imposed for collection and recording.

The spatial characteristics of geological data can thus be enumerated as follows:

1. Spatial phenomena can exist as zero (point), one (line), two (polygon), or three (volumes) dimensional entities.
2. Phenomena may be spatially continuous or spatially discrete.
3. All geographical information occupies a position in space and can be described according to some referencing system. The coordinate data describing the position of spatial entities in such a system is termed metric information.

4. Attributes of spatial elements can exist to describe topological and proximal relationships, or describe associated non-locational characteristics.
5. There is a temporal component. It is possible for spatial phenomena to vary through time.
6. Data can be separated according to theme or class; there may be several subclasses associated with each class as may be the case with stratigraphic hierarchies.
7. The concept of metadata can be applied to describe the nature of data sets.

Ideally, a data model should be able to accommodate all these characteristics. In the following section, the ability of various data models and associated structures to portray properties of spatial information are examined.

2.2.3 Data Models and Structures

With respect to research on spatial data models, Frank (1987) describes three approaches currently under investigation:

1. Defining algebras with finite representation that can model euclidian geometry.
2. Using combinatorial topology to represent geometry with simplices.
3. Applying models based upon finite resolution rasters.

These approaches correspond to CAD, topological, and raster structures respectively. Furthermore, these are recognized as the dominant structures used in GIS (see, for example, Chrisman, 1987b; Fisher and Lindenber, 1989). They form the basis for development of commercial systems.

The CAD and topological approaches belong to the vector model, raster structures belong to the raster model. Two concepts are fundamental to both models. Data are separated according to theme, or class, thus giving GIS databases a 'layered' format. Secondly, metric information describing the spatial position of geographical phenomena is maintained separate from non-locational attribute data. Harvey (1969) acknowledges that lack of conceptual clarification to differentiate between space-time coordinates and their associated attributes has been a source of considerable confusion for explanation and methodology in geography. Tomlinson (1984) notes that the 'dictionary' concept, that is the practice of separating coordinate data from attribute data and maintaining a link by pointers, has been instrumental to GIS development. Such a separation allows for efficient data processing and retrieval of locational information. To illustrate this issue consider, for example, geochemical point data. Points require only a single coordinate pair to describe their spatial address. They therefore can be easily managed with associated attribute data in existing database management systems. However, for data greater than zero dimensions, for example faults and geological polygons, potentially several thousand coordinate pairs may be required to describe their position. Consequently, the size of the data file becomes too large to allow efficient access and analysis of the information.

Attribute data therefore needs to be separated from coordinate information.

Both the raster and vector models are capable of representing multi-theme, multi-dimensional spatial data. However Vrana (1989) notes that they are not always adequate for handling spatio-temporal information. The raster and vector models deal only with the spatial component; a complete model must include non-spatial attributes, temporal information, and metadata. The following sections examine specific models used for GIS development.

2.2.3.1 The Vector Model

In the vector model, spatial entities are constructed into discrete objects of zero, one, and two dimensions from individual point locations. Both CAD and topological structures belong to the vector model, but there are important distinctions between them. The dual concepts of separating data according to theme, and dividing locational data from non-locational attributes form the basis of CAD structures. This has proven effective for automating map production and updating map databases, but according to Tomlinson (1988), CAD structures have limitations for explicit applications requiring geographical analysis because they lack topological consistency. More specifically, Chrisman (1987b:1370) notes a serious flaw in CAD structures because:

...the human eye-mind combination is so used to association by contiguity that the uninformed cannot believe that the CAD computer knows nothing about adjacency.

White (1984a) explains that topological relationships traditionally have been understood in an instinctive manner, but not in an explicit, formal way. White (p.1) continues by stating that:

These ideas are especially important in the construction of automated systems because in a machine human intuition is absent.

Topological structures have been developed in response to this weakness. In a topological structure the physical connectivity between zero, one, and two dimensional objects is defined in an explicit manner. This includes connectivity between lines (lines with coincident points, therefore polygon closure), and adjacency between areas (areas with coincident lines, and areas within areas). The elementary framework of a topological structure is illustrated in Table 2.2. Topological integrity is maintained through relational tables and is thus available for retrieval. When the information is further combined with relational attribute tables, a powerful framework exists which can cross-reference and combine spatial elements and their attributes with spatial relationships for query and analytical purposes.

Although topological structures are still an abstraction of the analog map, the incorporation of instinctive relationships make it a closer representation of reality

than a CAD structure. But identifying all possible spatial relationships presents problems, because, as Nyerges (1980) notes, many relationships are implied through semantics and syntactics. In a geological setting Ady and Curry (1989), and

Currie and Ady (1989) have identified several spatial relationships implicit to geology. These include; hosts-hosted by, intrudes-intruded by, and intersects-intersected by. This is not a complete list, especially when it is considered that the interpretation of some relationships may vary according to the perceptions of the geoscientist. McPhee (1982:37) observes that:

...geology is sometimes intuitive even to the point of being subjective, the sort of field experience one happens to acquire may tend to influence one's posture with regard to deep questions in the science.

To be operational, structures are required upon which computer code can be based. Variations in CAD structures are few due to its relative simplicity; those existing can be largely attributed to proprietary differences. There are several topological structures in use including the DLG

OBJECTS	RELATIONS	METRIC
POINTS	INCIDENCE	COORDINATE
LINES	INCIDENCE	SHAPE
AREAS		SHAPE
<div style="border: 1px solid black; width: 100px; margin: 0 auto; height: 10px;"></div> TOPOLOGY		
<div style="border: 1px solid black; width: 200px; margin: 0 auto; height: 10px;"></div> GEOMETRY		

TABLE 2.1: Geometric elements of a map. After White, 1984b.

series (U.S. Geological Survey); the DIME (Dual Independent Map Encoding) format used by the U.S. Bureau of the Census; and the arc-node format used by many commercial systems.

2.2.3.2 The Raster Model

In contrast to the vector model the raster divides geographical space into units of equal and regular areas, otherwise known as grid cells. All positions for an area divided into grid cells are addressable, thus continuously varying phenomena can be represented in this framework (Burrough, 1987; Goodchild, 1987b) with resolution according to cell dimensions. The grid cell provides a common unit for organising all spatial objects, of any dimension. Thus, the raster model is widely employed for applications requiring the transformation and integration of diverse data types (see, for example, Berry, 1987; Tomlin, 1990). Grid cells are often organised according to ordering strategies which effectively reduce storage of two-dimensional locational coordinates into one dimension (Abel, 1990; Goodchild, 1987b). Various ordering strategies exist for grid cells (see, for example, Abel and Mark, 1990; Goodchild and Grandfield, 1983; Mark, 1990), the advantages of one over another involves storage efficiency, algorithmic complexity, and processing performance.

2.2.3.3 Raster and Vector Comparison

There are critical distinctions between raster and vector models of geographical data that have important implications regarding the nature and representation of information, and the applications for which the information can be used. In the vector model, all objects are explicitly recorded in terms of discrete X,Y coordinate space. In the raster model all information is stored using grid cells, and since they can be stored as arrays, spatial position is inferred by the row and column address of individual grid cells (Star and Estes, 1990). And, as previously noted, this has the effect of reducing storage of locational data into a single coordinate. The merits and drawbacks of each model can be discussed in terms of these differences.

It is generally assumed that vector precision is unlimited (Goodchild, 1987b), while precision in the raster model is limited to the dimensions of the grid cell. Vector structures therefore are widely used for storage of data requiring a high degree of positional accuracy, such as cadastral and utilities data. Raster models are widely used for representing data with less precise or interpretive boundaries, as for example natural resources information (Burrough, 1987).

Vector data models are noted for their inability to portray continuous variance (Burrough, 1987; Chrisman, 1987b), because discrete locations only can be referenced.

However in the raster model, all positions for a given area are referenced by grid cells, therefore high spatial variation can be accommodated (Aronoff, 1989; Burrough, 1987). However referencing all space means that raster structures require much greater physical storage space than vector structures.

The grid cell structure also lends itself well to integration with remotely sensed data, while there exists considerable literature on the difficulties of integrating vector data with remotely sensed information (see, for example, Fisher and Lindenber, 1989; Logan and Bryant, 1987; Maffini, 1987).

There exists agreement in the literature that analysis and manipulation of geographical data are easier and more efficient in the raster model (see, for example, Aronoff, 1989; Burrough, 1987; Star and Estes, 1990), as the grid cell provides a common structural unit for combining various information types from all dimensions. Data of different dimensions are structurally different in vector structures which implies considerable difficulty for data integration and analysis.

Although vector structures are more complex, topological encoding offers several advantages including efficient storage, accurate recording of networks, and the ability to accurately represent the quality of hand drawn maps (Aronoff, 1989; Burrough, 1987). Topological encoding of

vector data also allows for easier detection of errors during input (Chrisman, 1987a; Star and Estes, 1990).

Disadvantages of the raster model include lack of precision, large storage requirements and the crudeness in which linear and boundary information are portrayed. Development of raster structures therefore has focused upon compensating for these drawbacks. Run-length encoding, chain encoding, and block encoding are examples of structures that have been developed and successfully implemented to greatly reduce storage requirements. Quadtree encoding, an efficient storage structure based upon hierarchical tessellations of space, is currently receiving much attention by researchers as a raster structure because of its reduced storage requirements (see, for example, Mark and Lauzon, 1984; Mark et al. 1989; Peuquet, 1984; Samet, 1984; 1989). It is felt by some that quadtree structures can approach the accuracy of vector structures for representing linear data (Burrough, 1987; Maffini, 1987).

Given the three dimensional nature of geology, and the complex relationships due to time, erosion, and variations in geological structure, composition, and texture, it is very important that the correct model is chosen or developed. The discussion thus far has focused upon two dimensions. A GIS model for geological purposes will require the means for representing information in three dimensions. There are two basic problems, (1) defining, in an

appropriate framework, phenomena which is three dimensional (volumes), and (2) obtaining locational coordinate data for each of the three dimensions, X,Y and Z. Topological structuring of three dimensional data in the vector model will require precise coordinate data for all three dimensions. This presents problems because geological data tends to be collected and recorded in two dimensions only; information for the third is usually inferred. Furthermore, while it is possible to represent point, line, and areal entities in a vector structure, representation of three dimensional entities (volumes) presents serious mathematical problems (White, 1984a). A triangulated irregular network (TIN's), as described by Peucker et al. (1978), is a topological-vector structure developed for representing three-dimensional surface variation. However TIN's are not suitable for representing irregular polygons in two dimensions, and Jones (1989) notes that it is difficult to represent three dimensional variation with a TIN.

Raster structures may have the greatest potential for three dimensional applications (Jones, 1989; Mark and Cebrian, 1986) as the dividing of two dimensional space into grid-cells lends itself well to the third dimension. Three-dimensional grid cells can be stored as arrays, thus recording of three dimensions is reduced into one. All entities are constructed from identical structural units, thus it can be expected that advantages of raster processing

over vector will be even greater for three dimensional applications. Some three dimensional data types, for example geophysical surveys, are well suited for raster storage as the information is collected as continuous arrays. Commercially, there are systems which can perform volumetric calculations, but capabilities for representing discrete data and for performing analysis in the third dimension are not yet available.

2.2.3.4 Spatio-Temporal Models

Vrana (1989) argues that temporal changes are an important component of geographical information, but are largely neglected for applications requiring historical analysis. For many geological applications, it can be argued that temporal changes are irrelevant since time is a static property that need only be recorded once as an attribute of the spatial entity. However some geoscience investigations, surficial geology for example, and some applications, such as slope stability and geological hazards, rely upon measuring temporal changes in recent stratigraphy. There are also temporal changes related to geological administrative boundaries, such as landuse status and mineral claim records. Langran (1989) notes that it is critical to distinguish between temporal changes that occur in the physical world from those that are recorded in a database. The database may record changes due to conceptual or

managerial changes that do not necessarily reflect an actual physical change. According to Langran and Chrisman (1988:7) a temporally structured database will facilitate the following example queries.

- what was the previous state or version?
- what has changed (during a period or at a place)?
- what is the periodicity of change?
- what trends are evident?

Or, if temporally recorded information were available to geologists, then example queries might include:

- what was the slope before movement occurred?
- what boundary changes have occurred in a mining region?
- what are the exploration trends?

Current GIS developments do not recognise the importance of storing temporal information, nor do they include capabilities for modelling temporal change. A conceptual framework for representing temporal change is presented by Langran and Chrisman (1988); it focuses upon maintaining topological integrity of discrete geometric objects through time. Langran (1989) discusses several barriers to implementing a temporal GIS. She expresses some doubt about incorporating all aspects of the temporal dimension into GIS: "...a single blueprint to satisfy all needs is unlikely." (p.229). Spatial data bases that allow inclusion of the temporal component thus represent one of the biggest challenges confronting the current GIS research agenda.

2.2.3.5 Models for Data Base Management Systems

Raster and vector models are designed for representing spatial data only, but a GIS must be able to integrate spatial data with associated non-spatial attributes. Data base management systems (DBMS) are typically employed for this purpose; the application of DBMS's to GIS are briefly summarised.

Four DBMS models are recognised in the literature, they include the hierarchical, network, relational, and object-oriented models. The hierarchical model takes a top-down approach in which a record can have one or more links to lower records, but only one link to a higher record (Maguire, 1989). Network models are more flexible in that they allow multiple linkages to be established both ways in a hierarchy, as well as within hierarchical levels (Clarke, 1990; Maguire, 1989). Due to numerous problems, namely excessive data redundancy and poor searching capabilities, network and hierarchical models are considered unsuitable for GIS (see, for example, Burrough, 1987; Clarke, 1990; Maguire, 1989). They are not considered further here.

In a relational model, data are stored as records and attributes in two dimensional tables (Burrough, 1987), where attributes can act as pointers to spatial data (lines and polygons) stored elsewhere. Relationships between records are implicit (Stone and Henchtel, 1990) according to the row and column in which attributes are located; thus they can be

extracted according to logical operators. According to Dangermond (1989), relational DBMS's can be extended to include the thematic and topological concepts of GIS, thus the concepts of layering and separation of spatial from non-spatial data can be accommodated. The relational model is currently the most widely used DBMS for GIS applications (Aronoff, 1989).

Despite widespread acceptance usage as a DBMS for GIS, the relational model has many weaknesses. Wright and Stewart (1989) have encountered problems with handling variable geological polygon codes using relation-based DBMS. Egenhofer and Frank (1987, 1989) maintain that relational DBMS are restrictive for many spatial applications including aggregation and the characterisation of complex spatial objects. Aronoff (1989) adds that conventional relational DBMS's cannot manage the sophisticated graphics, complex objects, nor the sophisticated security and updating required for GIS. Aronson (1987) and Clarke (1990) feel that relational DBMS's can be used for query in a GIS; but Aronoff (1989) notes that relational query languages cannot easily accommodate spatial queries involving proximity, containment, overlay, and connectedness.

The object-oriented model is fundamentally different from the relational in that it stores geographical phenomena as objects (Dangermond, 1989; Dueker and Kjerne, 1987), as opposed to layers (themes). An object-oriented data model

includes three basic concepts (Egenhofer and Frank, 1987); namely classification, generalisation, and aggregation. Classification allows similar objects to be grouped into classes or subclasses (thus it can be argued that the layer concept is preserved since a theme represents a collection of objects with common attributes). Generalisation allows objects to be represented in different levels of detail; thus a mineral deposit can represent an area at large scales or, at smaller scales, a point. Associated with generalisation is the concept of inheritance. Through inheritance, primitive objects can belong to several classes but need only be defined once, thereby reducing data redundancy (Chin and Lee, 1989; Egenhofer and Frank, 1987). Thus, a single line segment, or arc, can represent the boundary of (1) a geological terrane at a scale of 1:500,000, (2) a stratigraphic member at 1:50,000, (3) part of an administrative boundary at 1:250,000, or (4) a segment of coastline at 1:2,000,000. Aggregation includes 'part of' and 'consists of' relationships. For example, mineral deposits are part of a mining district, and a mining district consists of mineral deposits. Thus the mineral reserves of a mining district are determined by summing the reserves of the deposits which are 'part of' the mining district.

Proponents of object-orientation promise a more accurate model of real world phenomena and flexible user interfaces

(Pountain, 1990); improved data generalization, modelling of locational behaviour, and development of GIS expert systems (Dueker and Kjerne, 1987); and access to photogrammetric and cartographic applications (Dangermond, 1989). It is also argued that an object-oriented data base model will facilitate operations requiring seamless, scaleless spatial data (Guptill, 1989d).

Object-orientation has its drawbacks. Chin and Lee (1989) explains that an object-oriented model is complicated and defining objects in this environment will require considerable effort. Dangermond (1989) notes that it is awkward to manage in terms of storage and computation, and that updating is difficult, possibly due to its inherent complexity.

According to Duntemann and Marinacci (1990), object-orientation is a paradigmatic shift from structured programming methods (FORTRAN, C, PASCAL, etc.) which have dominated since the 1960's. Since it is possible to translate from structured to object-oriented programming, previous investments may be preserved. As a programming language it is argued that object-orientation is maintainable; programs can be easily adapted to new applications with a minimum of effort (Duntemann and Marinacci, 1990). It is also argued that the property of inheritance, whereby subclasses maintain attributes of higher classes to which they belong, can reduce the code

needed to store relationships (Chin and Lee, 1989). Due to these advantages, the object-oriented DBMS model appears to be more flexible for spatial applications than relational DBMS. According to Chin and Lee (1989), the flexibility of the object-oriented model makes it attractive as a spatial data transfer format. A data transfer model proposed for spatial data managed by the government of British Columbia is based upon object-orientation (Sondheim et al., 1990). The transfer model apparently is designed to accommodate data in a variety of formats in order to facilitate the transfer of information among government agencies. In a preliminary release of the model specifications (British Columbia Ministry of Crown Lands, 1990), the management of metadata is addressed but the handling of spatio-temporal information is not mentioned. Vrana (1989) however does note that the object-oriented paradigm holds promise for integrating the temporal and thematic components of spatial data.

Recent discussions on DBMS for spatial data bases have put the debate of object-oriented versus relational DBMS into a context of objects versus layers (Dangermond, 1989; NCGIA, 1990), where layers represent continuous areal coverage and objects are discrete, individual entities. The object view lends itself well to the utilities management area, the layer view is applied more to areas involving resource management, although there are exceptions (NCGIA,

1990). The ideal DBMS for handling GIS applications clearly has not yet been developed. Aronoff (1989:183) notes:

The urgent need for operational spatial data handling in ... GIS applications has outstripped the ability of the research community to develop the needed spatial data base theory and spatial data base systems. As a result, the design of GIS data base management systems still depends heavily upon ad hoc techniques to bridge the gaps in our theoretical framework.

2.2.4 Section Summary

The development of models for representing spatial characteristics has focused upon two views of geography: discrete objects and continuous variation. These views correspond to the vector and raster models respectively, and, according to Peuquet (1988), have existed implicitly in geography for some time. Both models employ the concepts of separating data according to theme, and maintaining locational information separate from its non-locational attributes. Both are able to represent objects in zero, one, and two dimensions; raster structures can easily be extended to the third dimension, but there is difficulty in doing so with vector structures. The differences between the two models can be summarised in terms of continuous versus discrete phenomena, accuracy and precision, storage requirements, and processing capabilities.

A DBMS is required for integrating the spatial component with non-spatial attributes, including metadata. Current research and development of DBMS focuses upon two models,

the relational and object-oriented models. Most GIS employ a relational DBMS, however the object-orientation model is receiving much attention from researchers as an alternative. Object-oriented GIS's offer potential for handling complex spatial operations, incorporating the time component, and managing metadata.

2.3 GEOLOGY AND GIS

Implementation of GIS into geological surveys has lagged behind other natural resource surveys.⁵ A paper on the developments and applications of GIS in North America by Tomlinson (1987) does not even mention geology as an application, and Wernecke (1988) indicates that few U.S. State geological surveys are involved with GIS. This can be attributed to several factors. The need for quick and efficient updating of maps has been a factor for other resource agencies (eg. forestry, soil surveys) to implement GIS. Due to the static nature of bedrock, map updating is not a high priority activity within geological surveys. Another reason is that spatial relationships in geology exist in a three dimensional framework, a capability which has not yet been developed, neither conceptually nor

⁵ The United States Geological Survey has been a leader in implementing and developing GIS technology. However it should be noted that geology is only a small part of the activities of this organization. Its GIS efforts have been mainly in digital topographic base map development. Projects in geology have lagged behind those in hydrology, hazardous waste and environmental applications.

technologically. Another important factor is that the traditional clients of a geological survey, mainly small to medium size mining and mineral exploration companies, are not equipped to handle information in digital format.⁶ When these factors are combined with those of high data input costs, poor interfacing, and limited analytical capabilities, GIS acquisition has not been practical for geological surveys.

More recently though, geological surveys are showing a strong interest in GIS. A recent survey of GIS usage within U.S. State geological surveys lists three with operational GIS, fourteen with limited or partial capabilities, and another six with approved funding for GIS acquisition (McKay and Leighton, 1988). In Canada, the Ontario Geological Survey embarked on an ambitious program in 1985 to develop an in-house system (see GEOSIS Newsletters 1 to 8). Quebec has completed a feasibility study and a demonstration project as an initial step towards GIS implementation (Chauvin, 1989). Simpson (R.L., 1989) reports that the New Brunswick Geological Survey now has an operational system. The recent interest is partly due to technological advances, lower costs, and an increasing availability of high quality digital base map material. There are also some important

⁶ There are exceptions. Large integrated oil and mining companies are generally well equipped to handle digital data and often develop their own digital data bases and application software.

non-technical reasons for this development. These are discussed below in terms of the situation existing with the B.C. Geological Survey.

2.3.1 GIS and the B.C. Geological Survey

The origins of the B.C. Geological Survey can be traced to the mid-eighteenth century. At this time, an influx of American miners into British Columbia were perceived as a threat to British sovereignty. In order to establish authority, the colonial governor established a policy of assisting the mining industry through road building.⁷ By opening new mines and building roads leading to them, the interior of the province became accessible and a population base established, thus allowing colonial authority to be maintained. Development of resources was perceived as progressive and positive. The commons were spacious and there were few users or user conflicts in the early history of the province.

Today, resource conflicts are commonplace. The mining industry is competing not only with other resource sectors, but with an expanding recreation and tourism industry, and an increasing awareness among the public as to the environmental effects of mineral exploration and development. Trends toward stronger recreation and tourism

⁷ A more detailed historical account of the Geological Survey is presented in chapter four.

based industries are creating fundamental changes in the provincial economy. Mining has long been touted as British Columbia's second industry (after forestry). However, a recent government bulletin indicates that tourism is now the second largest industry (British Columbia, 1989). Another indication of mining's decreasing influence in the provincial economy is illustrated by a recent article in the Victoria Times-Colonist which reports that fishing, bolstered by growth in recreational fishing, is now a larger employer than the mining industry in the province.⁸ With mining decreasing and tourism and recreation increasing in the provincial economy, it is reasonable to assume that pressure to restrict mining activity in the province will increase.

As a result of these changes it is becoming more difficult to develop mines in even the remotest parts of the province. The traditional freedom of mining and mineral exploration is now threatened by annexation from parks, recreational, and environmental interests. The B.C. Geological Survey apparently felt this pressure as early as 1969. An internal memo (Hedley, 1969:3) states that:

In an age of changing values and self-examination the whole large issues of pollution, conservation, reclamation...are being critically examined.

⁸ The Victoria Times-Colonist, Saturday, June, 9, 1990. Victoria, B.C., p.C-10.

The response by geology to proposed land annexations is to define the mineral potential of these areas. If land is to be closed to mining and mineral exploration, then what is the public losing in terms of potential mineral wealth? However mineral potential determinations require a base of geoscience information from which to work with, otherwise much time and effort must be devoted to field investigations and other data collecting activities. Consequently, due to a lack of data and the means with which to process the data, the geological response to proposed land annexations is a reactive one. Thus mining, mineral exploration, and other geological concerns are often not fully considered in landuse decisions. GIS is perceived as a tool with which geologists can become interactive or even proactive; to ensure that minerals interests are considered in the landuse planning process. For this purpose GIS promises improvement in two areas. As a query system for quick access to information for decision making purposes, and as an analytical tool for combining information for defining potential mineral wealth in disputed regions.

The problem of managing growing data volumes within the B.C. Geological Survey was acknowledged in 1969 (Hedley, 1969). As with other resource sectors, geoscience data sets are being created and existing ones are being enlarged and updated. The data sets typically represent large investments of time and resources, but often they cannot be used

effectively for their intended tasks due to unmanageable volumes. For example the Quebec geological survey has amassed 44,000 documents, 800,000 pages of text, nearly 100,000 maps, and more than 75,000 microfiche units over the last fifty years at an estimated cost in excess of three billion dollars; but due to the quantity of this material, the information is being under-utilized (Chauvin, 1989). A similar situation is reported by Currie and Ady (1989b) to exist in Ontario. There, the geological survey is experiencing an overload of information. According to Currie and Ady (1989), the quantity and complexity of this information is such that clients cannot find the information they require. It is in response to these problems that geological surveys have been motivated to automate geoscience databases. Moreover, the promise for more efficient data management and quicker access to information is foremost among those made by commercial vendors. The pressure upon the geological land base from competing interests may increase the demand for mineral potential studies, and thus a demand for expansion of data collection activities. Existing databases will be expanded and perhaps new ones created. Paradoxically, the information might not be fully utilised due to existing data management methods.

Another factor attracting interest in GIS among geological surveys is the promise for enhanced research

capabilities. For example, Tomlinson (1989:298) states that GIS,

...will act as a foundation for geographical methodology and open the way to richer forms of spatial analysis and geographical understanding.

While not referring specifically to geology, it is a geographical theme, and will therefore benefit from richer forms of spatial analysis. Much research in geology can be characterized as a search for order in geological complexity. Geoscience data (eg. geochemistry, geological polygons, alteration, structure) are products of interrelated environmental processes. An aggregate of their spatial patterns and distributions may assist researchers in understanding the geological environments they represent. Metallogeny, as one example, is a branch of geology devoted to examining spatial patterns and temporal relationships among geological phenomena in order to determine ore deposit models and thus gain a better understanding of mineralizing processes. The integration of spatial data is important to this field, but it is primarily carried out using manual overlay techniques and qualitative geographic descriptions in conjunction with non-spatial quantitative analysis. When analysis involves the integration of data from several dimensions (point, line and areal) with variable zones of influence and multiple attributes, it becomes obvious that manual techniques have their limitations.

2.3.2 GIS Applications in Geology

Data management, integration, and analysis, access to locational information, and the automation of cartography, are the basic functional requirements for a geology survey. These functions are required for two very general and somewhat contradictory purposes: to assist with mining and mineral exploration, and to assess an expanding environmental concern over the impacts related to these activities. For analytical purposes, GIS has been employed by the Geological Survey of Canada (Bonham-Carter et al., 1988a, 1988b; Reddy et al., 1990; Watson et al., 1989) and the U.S. Geological Survey (Elliot et al., 1989; Marsh et al., 1989; Green and Pratt, 1987; Trautwein et al., 1988) to quantitatively define mineral resource potential, and it is this task which is singled out by the Quebec Geological Survey as justification for implementing a GIS (Chauvin, 1989). GIS has been employed by Bliss et al. (1987) to assess resource potential in terms of mineral deposit density. GIS has been used in conjunction with remote sensing techniques to explore for minerals (see Bodechtal and Sommer, 1989; Segal et al., 1988). GIS has also been successfully applied in geochemical applications (Dwyer and Nash, 1987; Rogers et al., 1988); geological hazards applications and research (Brabb, 1987; Ellen and Mark, 1988; Keaton and Anderson, 1988; Tarr and Crane, 1988); Coal quality studies (Hohn et al., 1987); and environmental

studies in which geology is a primary component (Krumm et al., 1988; Olimpio and Flynn, 1988; Richardson and Nelms, 1988; Smith et al., 1988).

For management of geological resources, GIS and related technologies have been employed in various ways. Pilot studies using GIS for mineral policy and mineral landuse have been conducted by the U.S. Geological Survey in Alaska, Oregon, and New Mexico (Sturdevant, 1988). The U.S. Bureau of Mines has used GIS to evaluate mineral landuse availability data (Madigan et al., 1988), and Hyndman (1990) describes the use of GIS to assess impact of land restrictions on mining activities.

Although digital cartography is defined as being separate from GIS, development of digital data bases is often carried out with both purposes in mind. The benefits of digital cartography to geological mapping include more flexible products, lower costs, and easier updating (see, for example, Buchanan and Steeples, 1990; Mennim, 1986; Sheath, 1986). Digital cartography can also allow for more flexible display and enhanced visualisation of geoscience data, for example as three dimensional plots (see, for example, Sowerbutts, 1988; Stewart et al. 1988).

2.3.3 Section Summary

It was mentioned above that GIS was late appearing in geological surveys partly as a result of the traditional

client not being equipped to handle information in digital format. The development and availability of quality digital topographic base maps coupled with increasingly powerful hardware at decreasing prices can be expected to change this situation. As well, government agencies increasingly require geological data for policy purposes and landuse related issues. These agencies are generally well equipped to use data in digital formats.

The potential for GIS to assist geological surveys with their activities is recognised. The discussion will now turn to the problem of implementing a GIS.

2.4 THE REQUIREMENTS ANALYSIS

The potential for GIS to assist geological surveys with inventory, management, and analysis of locational information is recognized. The task of choosing a GIS must now be addressed. Prior to 1980, few options were available to organizations wishing to acquire GIS capabilities. Commercial hardware and software were expensive and difficult to use. Agencies perceiving a need for GIS capabilities therefore developed the system(s) internally. This approach tended to be expensive and Tomlinson (1987) notes many forestry agencies developing GIS during this period met with failure.

With an increasing selection of commercial systems available in the 1980's, the problem of acquiring and

implementing a GIS has shifted from internal development to that of choosing the best available commercial system. Initially, few options were available. Some agencies have chosen systems based upon compatibility with existing hardware (Guptill, 1989c), but Tomlinson (1987:211) observes that GIS selection is often characterized by:

...an individual with some background in computing will hear of or see a geographical information system or automatic cartography system in operation and, by attending conferences or workshops, become a promoter within his own agency. With luck he will eventually assemble sufficient resources to acquire a system and can expect to be named manager of it. The rest of the agency will be happy to know that the group is involved in the new technology, but equally happy to know that all obligation to understand it rests with the resident expert.

As a way out of this impasse, a rigorous study of the agency's functional mapping and spatial requirements is widely recommended (see, for example, Guptill, 1988, 1989a; Keller, 1990b; Tomlinson, 1987, 1989). Once completed, these studies, widely known as requirements analysis in the industry, are followed up by system evaluation and selection. Requirements analysis case studies are generally not available in the literature; they are often performed as confidential studies. The interested reader is directed towards Dangermond and Freedman (1983) for one such case study.

A requirements analysis requires that interdependencies and relationships between three variables, an agency's tasks, the information needed to complete the tasks, and the

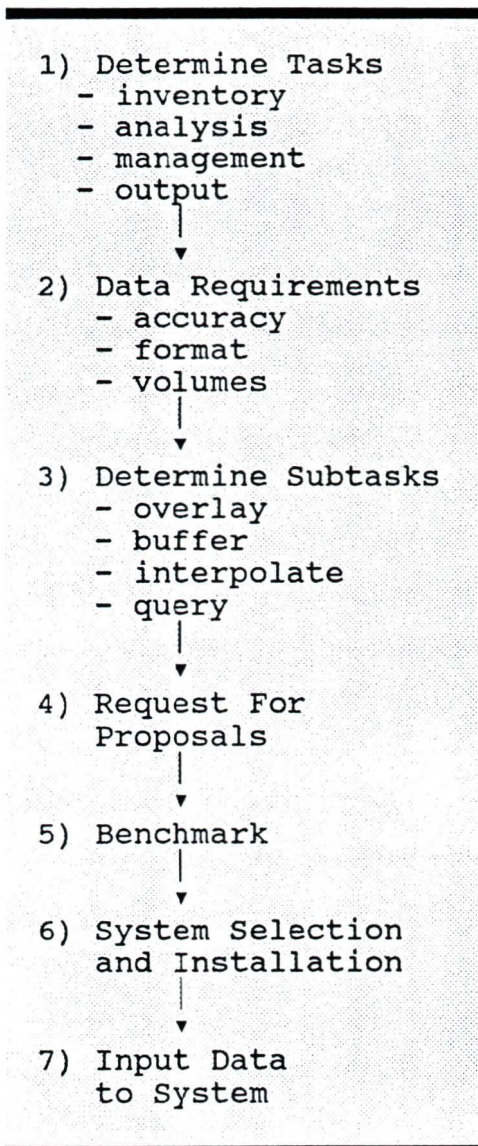


Figure 2.2: Key steps in the requirements analysis.

GIS operations required to support the tasks, be defined. Based upon the results of such an analysis, system specifications can be detailed and subsequently used as a basis for testing, or for benchmarking commercial systems. As a final step, a schedule for system acquisition and data input can be specified according to agency priorities and available funding. Some recommend a cost benefit analysis be included as part of the requirements analysis (Guptill, 1988; Keller, 1990b; Montgomery, 1989). Dickinson and Caulkins (1988) feel it should occur after system selection and digital database creation. The requirements analysis and follow-

up procedures are illustrated in Figure 2.2. Each step is reviewed in more detail.

2.4.1 Defining the Agency's Tasks

A detailed inventory of work performed by various components within an organisation is necessary as a first step towards GIS implementation (Burrough, 1987). Ideally, current, proposed and potential tasks can be specified so the agency will be well positioned to accommodate future needs. Even so, Meckley (1987) notes that future applications are difficult to identify and that current applications usually amount to less than ten percent of the eventual total.

2.4.2 GIS Operations

Following the identification of tasks in step one, it is possible that several GIS functions, or sub-tasks, will be required to complete each task. Goodchild and Rizzo (1987) explain that defining sub-tasks is a critical step, and that these must be defined at a conceptual level in order to eliminate potential biases toward vendors. To emphasize this point, consider, for example, the job of creating a mineral potential map from geological polygons, geochemical sample point data, and fault lines. There will not be a single function to achieve this operation; rather several procedures or sub-tasks such as data input, proximity characterisation, and polygon overlay will be required to complete the task. The correct identification of these

operations at a conceptual level is an important step when considering GIS acquisition.

2.4.3 Data Base Inventory

Various types of data will have to be accessed to support the identified tasks. It is important to determine the spatial characteristics, status, accuracy and format of these data sets in order to minimize loss of information during input. Some data may need to be converted to digital format, other data may already be in a format suitable for GIS usage. Green (1987) notes that entirely new data sets may need to be created. If existing data, such as geological maps, are to be converted to a digital format, it is important to understand how the maps are currently used so that no loss of information occurs when the conversion is made. Selden (1987) asserts that the success of database development (and therefore the GIS) will ultimately depend upon the quality, accuracy, resolution and integration of the data.

2.4.4 Management Considerations

The ability of existing resources and staffing should be evaluated in order to determine the organization's ability to accommodate GIS activities. Green (1987) suggests that adding GIS capabilities to existing systems, as opposed to

using a stand alone GIS workstation, could affect the manpower required to manage the system.

Not only must the types of GIS products to be delivered be identified, but also their frequency (Goodchild and Rizzo, 1987; Tomlinson, 1989). In order to specify the workload, it is necessary to first choose a strategy for implementing the various tasks within a GIS framework. Green (1987) suggests three separate strategies for digital data base creation based upon organisational priorities. One scenario might see a resource agency concentrating on developing, systematically, a digital base for the entire province. A second strategy may see digital data base development piecemeal according to the needs of certain projects. The third approach may see digital database development according to theme, for example bedrock, geochemistry, and surficial geology. To choose an appropriate strategy will require that the tasks be prioritised in terms of relative importance.

2.4.5 Final Requirements Document

When information from the first three steps has been collected, it is recommended that a document be prepared summarizing the results of the analysis (Guptill, 1988; 1989a; Meckley, 1987). This document is a prelude to actual system selection, and may be used as a basis for acquiring proposals from prospective vendors. Meckley (1987) expresses

that the document should allow system choice to be motivated by the requirements, as opposed to the other way around. The document should contain the following information:

1. The tasks to be supported by a GIS.
2. The required GIS operations or subtasks.
3. The program's output and the number of products over time.
4. The required data and data formats and the number of users.

Completion of the final requirements document concludes the requirements analysis. The agency's needs have been defined and it must now determine the system best able to fulfil them. Burrough (1987) recommends supplying a list of requirements to potential vendors for proposal submissions and subsequent short-listing. A benchmark test, in which systems are quantitatively evaluated based upon their functionality and performance of specified tasks is commonly employed to determine which is best among the remaining systems (Burrough, 1987; Guptill, 1988, 1990). Goodchild and Rizzo (1987) describe a model used to predict GIS resource utilization. However, the model is dependent upon data gathered over several years; an unrealistic situation with most installations.

2.4.6 Cost Benefit Analysis

Montgomery (1989) recommends using a proven model for cost benefit analysis of GIS implementation; however,

Montgomery does not suggest a model and there is no consensus in the literature on an accepted model. The basic problem in GIS cost benefit analyses lies in defining benefits. Some benefits, such as time and labour savings, can be easily accounted for. However, many other benefits such as improved decision making and analysis, are intangible and difficult to quantify. One study lists three intangible benefits of acquiring GIS technology as: keeping up with peer groups; leading peer groups and; the discovery of new paradigms, models and theories (Maffini and Saxton, 1987). The authors describe a procedure for determining the relative value of these benefits, but a cost benefit analysis will require a quantitative assessment. Dickenson and Caulkins (1989) describe an approach where the value of 'hard to quantify' or intangible benefits can be estimated. However Wilcox (1990) feels that this approach does not offer a workable structure for a cost benefit analysis. Keller (1990c) notes that, given the complex relationship between tangibles and intangibles, a cost benefit analysis may prove whatever desired. Despite the difficulties involved with performing rigorous cost benefit studies, it is widely accepted that benefits exceed costs; a recent report suggests the ratio is greater than three to one (Joint Nordic Project, 1987).

2.5 CRITIQUE OF THE REQUIREMENTS ANALYSIS

The requirements analysis has several weaknesses. It is noted that the initial step, determining tasks to be supported by a GIS, may identify as few as ten percent of the eventual total. All subsequent steps of the analysis are dependent upon information gathered at this stage, therefore they cannot attain a higher level of accuracy. For the tasks that are recognised, operations necessary to support them must be specified. However it is recognized that a conceptual listing of such operations does not exist. Existing classifications are biased as they are based upon familiarity with commercial products (Goodchild, 1987a). Finally, the process emphasises GIS development based upon the most functional and efficient currently available technology. Given the cost and effort associated with data base development and the rapidly evolving nature of technology in GIS, this may create problems.

If the requirements analysis is so fundamentally flawed, then what is the alternative? Chrisman (1987b) argues that data collection is performed not for technical reasons, but in response to defined mandates. At an elementary level, the work and activities of a natural resource agency are dictated by these mandates. It follows, therefore, that the requirements analysis must begin, not with defining existing tasks, but in understanding the agency's mandate. A clear understanding of the mandate will allow spatial data, tasks,

and operations to be described within the proper context. If tasks are identified that do not have a basis in the agency's mandate, the requirements analysis may only "...automate chaos without understanding or improving it." (Chrisman, 1987b:1368). Not all mandates are explicit policy, an examination of historical and legislative documents is therefore recommended.

Understanding the mandates of an organization may make it possible to identify the basic tasks, but it does not ensure that all spatial relationships and data characteristics will be identified. Many of the spatial tasks employed by geologists may not be apparent. Currie and Ady (1989) note that a professional's use of a tool is conditioned by their educational training. The map is a primary tool to geoscientists; spatial relationships on a map are intuitively recognised and understood by geologists, but must be made explicit if they are to be exploited in a digital environment.

The requirements analysis can be criticised further for not placing any emphasis upon data models as a foundation for GIS design. The mandate may indicate which model(s) will be required. If a mandate includes inventory, publication, and distribution of map data with little or no analysis involved, a CAD structure may be sufficient. However if analysis and query are included, a topological or raster structure may be more appropriate. Adhering to the

specifications of a data model, as opposed to specifications of a commercial system, will allow the agency to be independent of commercial products. Input specifications of commercial systems often adhere to hybrid, vendor-unique data structures which can be equated towards the lower end of the data abstraction continuum. To use such specifications as the basis for a corporate GIS may put an agency in the position of having to reformat, or even re-input information according to the specifications of a new system should the original prove to be ineffective, or should the vendor drop out of the marketplace. Therefore choosing the correct data model and adhering to its specifications at a fundamental level will minimize costs should a system change be required. Achieving independence from commercial products will also allow the organization to take advantage of technical advances. The importance of this cannot be overstated in a field characterised by rapid changes, evolving technologies, and lack of applied theory.

Literature on requirements analysis often stress the importance of obtaining political support for GIS initiatives (Montgomery, 1989; 1990). While this may be the situation with which resource managers must work within, it must not take precedence over the data model and the agency's mandate as a basis for implementing GIS. If a system is acquired according to political motivations only, the agency may obtain a piece of technology for immediate

assistance, but it may only be a short term and potentially expensive solution.

Based upon these criticisms, the objective of the requirements analysis can be restated, and the methodology can be redefined accordingly. The objective is not to match an agency with a commercial product, but to determine a conceptual model which (1) preserves the spatial characteristics of the agency's data, and (2) allows for maximum flexibility in the operations to be performed upon the data. Critical to this process is the identification and understanding of the mandate, for all activities are carried out in response to it. The activities and information can be put into a GIS context; in effect the information can be defined in terms of that which is recognised by GIS models, and activities can be defined in terms of GIS functionality. These specifications will form the basis of a data model which, when implemented, will support both the activities and information of the agency. Ideally the model should never be compromised to accommodate technology. The implementation scheme is depicted in Figure 2.3. The scheme is dependent upon an inventory of GIS functionality defined at a conceptual level. This issue is addressed in Chapter Three.

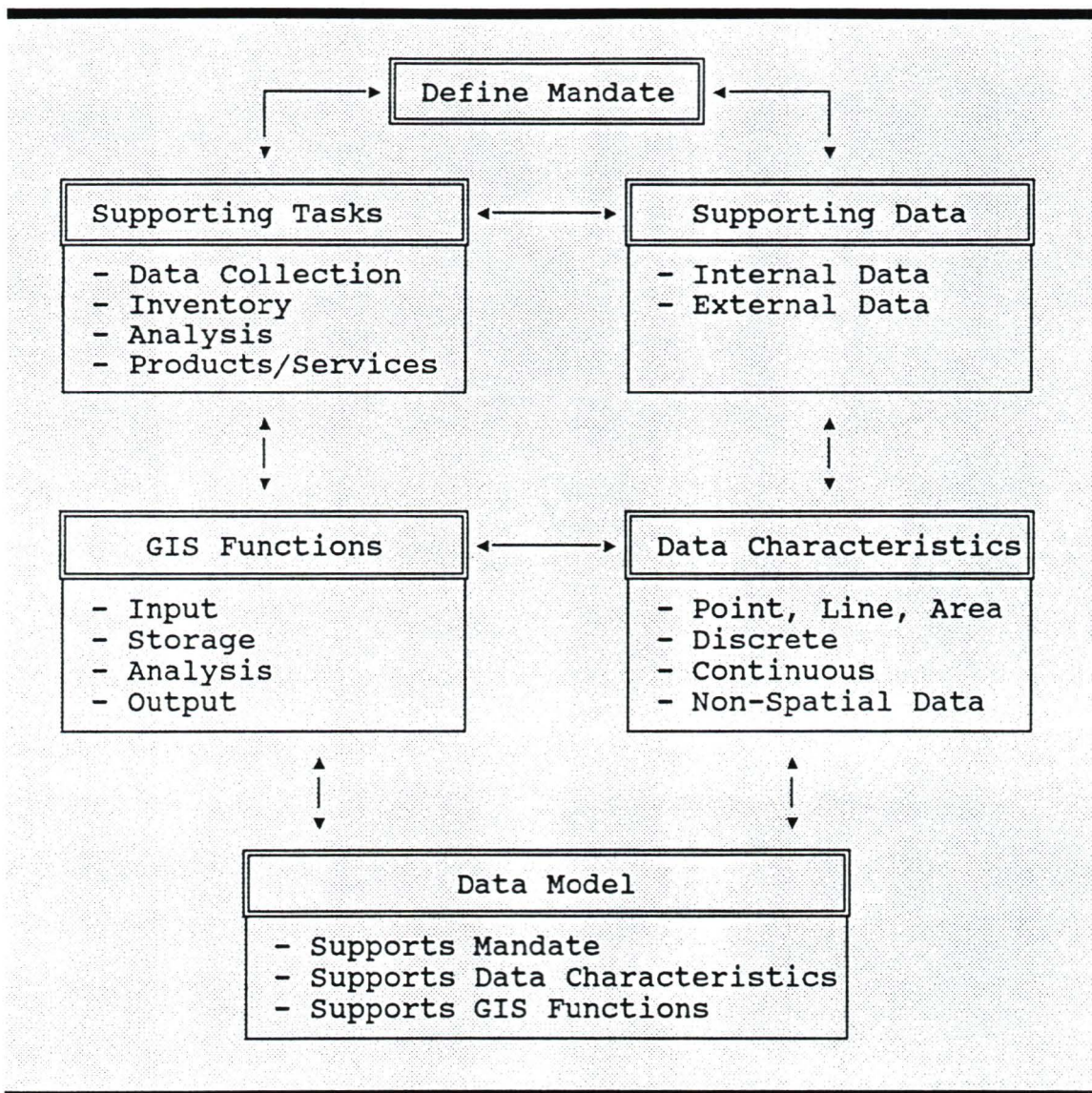


Figure 2.3: Requirements analysis based upon organisational mandate.

2.6 CHAPTER SUMMARY

A geographical information system is defined as an automated system for input, storage, analysis, and output of geographical information. The ability to analyze, integrate, and generally access spatial information distinguishes GIS

from other automated systems. GIS was developed in response to a need for handling geographical information in a more efficient and effective manner. Early development was from a bottom up approach, focusing upon technology and applications. Consequently failures were common and development was perceived to be disorganised. GIS has subsequently become established as a field of study and research in universities, and government agencies have been established to direct development of spatial information in an orderly manner.

Factors motivating geological surveys to obtain GIS capabilities include the need to automate cartographical tasks, enhanced analysis, a need to manage and analyze complex and ever increasing volumes of information, and a desire to become more interactive in landuse issues affecting geology. An agency wishing to acquire these capabilities is faced with a growing number and bewildering variety of commercially available systems. A functional requirements analysis is often carried out in order to determine the commercial product best suited to the agency's needs. It is argued that such a process is flawed in that it does not recognise the mandate as fundamental to understanding how an agency operates, and for not recognising the data model as a basis for organizing spatial information. Accordingly, a modified requirements analysis is proposed for this study, one which addresses these flaws.

It is argued that a GIS based upon a long term mandate and generic spatial models will allow an organisation to be independent of, yet able to take advantage of, technological changes.

The scope for the remainder of the thesis can now be outlined. The requirements analysis format specified in Figure 2.3 will form the basis of this study. Information pertaining to the B.C. Geological Survey, including its mandates, supporting activities and data requirements, services and products, were obtained through personal interviews with Geological Survey staff. Findings are discussed in Chapter Four. GIS functional requirements are defined in Chapter Three and subsequently used as a basis for specifying the requirements of the Geological Survey in Chapter Five. A cost benefit study is not included. GIS is distinguished in section 2.1 from CAD/CAM, DBMS, and remote sensing technologies. Accordingly, this thesis does not cover in detail operations specific to digital cartography, relational data base managers, or image analysis systems. Furthermore, it is recognised that the Geological Survey of British Columbia is situated within a government hierarchy and is subject to several levels of authority and that its activities are integrally related to other government departments. This study will deal in detail with the Geological Survey only.

CHAPTER THREE

GIS FUNCTIONALITY

3.0 INTRODUCTION

GIS functionality described at a conceptual level is identified in Chapter Two as a primary component of the requirements analysis. Such an inventory allows an agency to summarise its functional GIS requirements in a manner which allows for an unbiased comparison of commercial products. However, it is noted that a generic taxonomy of GIS operations does not exist in the current literature. There are many sources listing an extensive and wide range of operations (see, for example, Burrough, 1987; Guptill, 1988; Alberta Research Council, 1988; Parker, 1989; Keller, 1990b); but the functions stated are not standardized. Thus a great deal of variation exists among the lists (Parker, 1989). It has also been noted that these lists are often based upon one's familiarity with commercial products (Goodchild, 1987a). It is clearly unsuitable to use these lists as a basis for unbiased system comparison.

It is the purpose of this chapter to organise GIS functionality such that it covers the spectrum of operations available (or possibly available) from commercial vendors, yet remains free of bias towards any vendor or group of vendors. The rationale upon which the classification is based is outlined below.

3.1 CLASSIFICATION RATIONALE

Input, output, storage, and analysis are the basic functional components of GIS. In addition to these four functions it is necessary to (1) provide a linkage between the locational and non-locational information types, (2) provide an interface which allows the user to interact with the system, including query and modelling languages, and (3) provide security and ensure data quality is maintained. A DBMS is typically employed to provide these capabilities; thus it can be added as a fifth functional component. These five components will be the first criteria for classifying functionality.

In Chapter Two it was established that tasks performed by an agency are critical factors for determining the operations required of an automated system. In turn, the operations require a store of information in digital format from which to work with. A number of data structures are employed for the storage of spatial data, virtually all are based upon vector and raster data models. As Peuquet (1988) notes, the implemented data model will ultimately determine the characteristics of the data to be preserved by a digital system, and will also play an important role in determining the efficiency and usefulness for a given application. Functionality therefore can be characterised according to the raster and vector spatial data models.

GIS operations will be described according to the five functional components of input, output, storage, analysis, and spatial DBMS operations. Within each component reference is made to the strengths and weaknesses of the vector and raster spatial data models for handling the operations falling within the particular category.

3.2 DATA INPUT AND STORAGE

To be utilised in a GIS environment, spatial information must be transferred to the specifications of a data structure or, according to Clarke (1990,42), it must be geocoded, that is; "...the conversion of spatial data into computer readable form.". Clark (1990) defines the goals of geocoding as; (1) minimize data entry costs, (2) detect and eliminate errors, (3) maximize flexibility, and (4) optimize storage efficiency. The geocoding requirements for input and storage are discussed below.

3.2.1 Input

Among the basic functions provided by a GIS, data input is widely regarded as being the slowest and most expensive (Chrisman, 1987a; Tomlinson, 1987). Input of spatial data can be divided into two basic modes; automated and manual. Raster data input tends to be automated as the division of geographical space into cells of equal and regular areas lends itself well to automated scanning techniques. Remote

sensing, analog scanning, rasterisation of vector structures, and video data capture are examples of automated techniques for inputting data to raster structures.

Input to vector structures is achieved largely through manual techniques; mainly digitising, but also keyboard entry of coordinates. Manual techniques tend to be time consuming and subject to operator errors and Goodchild (1987b) notes that technological advances are unlikely to increase efficiency much because complex rules already exist for defining and correcting errors. Scanning techniques can be applied for vector input, but expensive preparation of maps prior to scanning is required (Tomlinson, 1987) as the method is sensitive to line work of conventional maps. Another problem is that considerable manual effort is also required subsequent to scanning to transfer the information from raster into a vector format. This typically involves a series of data reduction techniques, line thinning, error detection and elimination, and interpretation of the resultant information. Digitising remains the most widely employed mode of input to vector based systems, however, it can be expected that automated scanning will become more widely adopted as hardware becomes more reliable and prices decrease, and more complex software is developed to further automate the process.

The volume and complexity of data to be converted to digital format, and the choice of raster versus vector

storage formats will play an important role in the selection of automated versus manual input methods. As coverage of digital geographical databases by Federal and State/Provincial governments (eg. TRIM in B.C.) becomes complete, it can be expected that restructuring and input of these files will become an increasingly important capability.

3.2.2 Vector Storage

In a vector structure, objects of any dimensions are constructed from X-Y coordinate pairs, or point locations.¹ Various object types in each dimension have been specified jointly by the National Committee for Digital Cartographic Data Standards (U.S.), and the Working Group of the Federal Inter-agency Coordinating Committee on Digital Cartography (U.S.). The findings of these committees are presented in a special edition of The American Cartographer (The American Cartographer, 1988) as a proposed exchange standard for digital cartographic data.² They are summarised in Table 3.1. These object types are those defined as part of a proposed Spatial Data Transfer Standard (SDTS) which is undergoing testing and promotion by the U.S. Geological Survey (Rosmeissl, 1989). Other standards exist which define

¹ Volumes and objects in the third dimension will require a third coordinate in the Z direction.

² See Moellering (1988) for an explanation of the conceptual background underlying the proposed standard.

1: ZERO DIMENSIONAL OBJECTS

1.1: Point - a geometric location specified by a set of coordinates.

1.1.1: Entity Point - identifies features (eg. sample points or structural measurements).

1.1.2: Label Point - used for displaying map and chart annotations.

1.1.3: Area Point - a point within an area for linking an area with associated attributes.

1.2: Node - a point specifying a topological junction or end point.

2: ONE DIMENSIONAL OBJECTS

2.1: Line - a one dimensional object.

2.2: Line Segment - a direct line between two points (eg. a simple geometric fault).

2.3: String - a sequence of line segments (eg. a more complex geometric fault).

2.4: Arc - a curve formed by a locus of points and defined by a mathematical function.

2.5: Link - a connection between two nodes.

2.6: Directed Link - a link with one direction specified (eg. a stream with flow direction).

2.7: Chain - a sequence of nonintersecting line segments or arcs with nodes at each end.

2.8: Ring - a sequence of nonintersecting chains, strings, links or arcs representing an enclosed boundary but not the area inside.

3: TWO DIMENSIONAL OBJECTS

3.1: Area - the generic term for a bounded two dimensional object.

3.2: Interior Area - an area not including its boundary.

3.3: Polygon - an area consisting of an interior area, an outer ring and zero or more non-intersecting, non-nested inner rings.

3.4: Pixel - the smallest nondivisible element of an image.

3.5: Grid Cell - an element of a regular or nearly regular tessellation of a surface.

Table 3.1: Cartographic objects defined by the National Committee for Digital Cartographic Data Standards and the Federal Inter-agency Coordinating Committee on Digital Cartography (adapted from *The American Cartographer*, 15(1)).

spatial objects, including the proposed British Columbia Spatial Archive and Interchange Format, or BC-SAIF (British Columbia Ministry of Crown Lands, 1990). However, for the purpose of spatial object definition, the SDTS definitions represents a comprehensive effort. Object definitions

adopted by other standards more or less agree with the SDTS definitions.

To support the object types listed in Table 3.1, digitizing software must allow for the following capabilities.

1. Independent input of zero, one, and two dimensional objects. Input of different object types within each dimension according to Table 3.1 is also required.
2. The identification of connectivity between zero and one dimensional entities, including the closure of polygons, and the identification of connectivity between one and two dimensional entities (left/right adjacency).
3. The identification of inclusion, including islands and lakes.
4. The entry of explicit linkages (area points) to non-spatial attribute tables.

The above capabilities represent minimum requirements for incorporating basic components of a topological-vector structure. If other relationships, such as directed flows (eg. rivers, one way streets) or different types of adjacency and inclusion³ are desired, then additional input options may be required. Digitising software has advanced to the state where it is necessary to input only the various object types and topology can be defined automatically.

³ In geology intrusive and unconformal contacts are examples of adjacency types; intrusive and inlier/outlier examples of inclusion. Wright and Stewart (1989) explain that it might also be necessary to know the direction of digitised lines as some types of structural lineaments have asymmetrical symbology and attributes (eg. thrust faults).

3.2.3 Raster Storage

The simplicity of the raster model clearly gives it an advantage for low input costs; the data need only be scanned. Storage to the raster model is quite simple compared to vector storage since entities of all types and dimensions are constructed from grid cells. It is noted that raster structures require more storage space than their vector counterparts (Peuquet, 1984; Burrough, 1987), therefore storage efficiency is a major consideration. Grid cells may be stored as individual entities, however structures have been devised which take advantage of common attributes in adjacent grid cells to reduce storage space (eg. run-length encoding, quadtree). Some of the more common storage structures are listed in Appendix A, Part 1.

3.2.4 Editing

Editing is an important component of data input and storage, and must therefore be included here. Basic editing functions include the ability to move, rotate, delete, and copy individual objects, or groups of objects according to defined conditions. Other editing functions include edgematching and line generalisation. Editing of objects in a topological structure is difficult because, to permit cartographic changes, relationships must be dismantled and rebuilt in order to preserve topological integrity. Again, it is possible to apply automated techniques to this

process. Line generalisation involves reducing the number of coordinate pairs which define the shape of a line or boundary of a polygon. Ideally, the conditions for generalisation can be defined such that accuracy and geometrical signature characteristics of lines are not compromised. A number of techniques have been developed for line generalisation, the interested reader is directed to Bittenfeld, (1985), McMaster (1987) and White (1985).

Resource data is often collected and recorded on maps according to a geographical partition, for example 1:50,000 or 1:250,000 scale NTS blocks. A data base partitioned according to geographical and thematic criteria is said to be tiled (Goodchild, 1989), where each tile is the equivalent of a map sheet. A digital spatial data base with topological consistency extending across tile boundaries is seamless, that is data can be accessed according to criteria which transcends tile boundaries. Associated with a seamless data base is the concept of scaleless data bases, where a user can move from one level of spatial detail to another (Guptill, 1989d). Thus, a user will be able to select a mining area from a 1:2,000,000 location map and display detailed geology and mineral occurrences at larger scales, say 1:20,000. To create a seamless data base, tile edges must be edited such that topological integrity is maintained across tiles. This can be performed manually. However many software vendors supply edgematching utilities where the

task is performed in an automated manner using object attributes and proximity as matching criteria. Chrisman (1990) provides an informative discussion on the problems associated with partitioned spatial data bases.

Ultimately, editing capabilities are dependent upon the designs of individual software vendors and therefore vary considerably. A list of input and editing functions can be found in Appendix A, Section 1.1.3.

3.2.5 Physical Storage

Formats for data storage discussed in previous sections were noted to be highly dependent upon the chosen data model. In contrast, the physical storage of spatial information is dependent upon advances in hardware technology. Crosswell and Clark (1988) have noted that storage capacity of magnetic media has doubled from 1980 to 1987, and that laser disc technology, with ten to fifty times the storage capacity of magnetic media, may soon be available (Crosswell and Clark, 1988). Paper storage of maps may not necessarily be totally replaced, Goodchild (1987b) notes that advances in scanning technology coupled with new cartographic techniques may make analog storage of maps a safer, more efficient mode of storage than digital mediums. Technology dominated trends have little relevance to data models or the long term mandates of an organization.

Considerations for storage must therefore be of secondary importance system when selecting and implementing GIS.

3.3 DATA ANALYSIS, MANIPULATION, AND INTEGRATION

The operations listed in this section are based upon a model and classification initially put forth by Goodchild (1987a; 1987b). Conditions for the model include:

1. The primitive elements of a map must be defined. These include point, line, and area objects; the grid cell is included as a fourth object for representing continuous surfaces.
2. There may be several classes of objects types. For example points could represent geochemical sample localities or structural measurements. In a similar manner lines may represent faults or air photo lineaments.
3. Object classes may have unlimited attributes. However, each class has a set number of attributes whose meaning is unique to that class.
4. Associated with each object type are a number of reserved fields. These may include, for example, fields for area, length and perimeter. Other fields are reserved for relationships between objects of the same class, and between objects of different classes. Relationships between objects of different classes include topological connections or, in the case of object-pairs, proximity.

Based upon these conditions six elementary categories of spatial operations are listed. They are as follows:

1. Operations which require access to attributes of one class only.
2. Operations requiring access to attributes and locational information for a single class of objects.
3. Operations which create object-pairs from one or more classes of objects.
4. Operations which analyze attributes of object-pairs.

5. Operations requiring access to attributes and locational information for more than one class of objects or object-pairs.
6. Operations which create a new class of objects from an existing class.

A full description of the model's specifications and analytical operations can be found in Goodchild (1987a; 1987b).

The concept of separating data according to theme is present in the model, and it is assumed that the concept of separating locational from non-locational data is also present. Representation of zero, one, and two dimensional objects are recognised in vector format; continuously varying surfaces phenomena are represented by grid cells only. The third dimension is not recognised by the model, nor is the temporal component.

Some modification to the model is required for it to be applied to this study. It must be possible to represent the third dimension, therefore it is added as an additional object type. Secondly, it must be possible to represent both discrete and continuously varying phenomena in either vector or raster format. Continuous variation in vector format can be represented by an array of discrete points in two or three dimensional space. Thus, continuous variation represented by grid cells can be considered the raster equivalent of a vector array of points.

According to Goodchild (1987b:333), the purpose of the model is to allow "...a framework for organizing an

otherwise amorphous mass of spatial analytical techniques." The model is useful for this purpose; but for this study the primitive operations of spatial integration and manipulation must be included, where primitive operations can be combined to form the basis for the construction of more complex operations. Accordingly, operations which require access to locational information for a single class of objects only is added as an additional operational category. Categories three and four, operations which create object-pairs and analyze their attributes, are combined into a single operation.

With these modifications, the categories of spatial operations are organised as follows:

- A. Operations which require access to locational information only.
- B. Operations which require access to attributes of one class of objects only.
- C. Operations requiring access to attributes and locational information for a single class of objects.
- D. Operations which create object-pairs from one or more classes of objects and analyze their attributes.
- E. Operations requiring access to attributes and locational information for more than one class of objects or object-pairs.
- F. Operations which create a new class of objects from an existing class.

Several operations can be associated with each group. These are described in some detail below with example applications to geology.

3.3.1 Category A: Operations Requiring Access to Locational Information Only for a Single Class of Objects

Operations in this class act upon locational information only. If access to attributes are required, or if attributes or topology are affected in any manner, then the operation belongs to another group. Operations falling in this category can be divided into four areas; affine transformations, curvilinear transformations, cartographical transformations, and spatial measurements. These operations can be applied to vector and raster representations of spatial data. There may appear to be some overlap with editing operations such as line generalisation or edgematching. However Category A operations affect entire classes of geographical objects.

3.3.1.1 Affine Transformations

Affine transformations include translation, rotation, and scaling of geographical information; combined these provide a universal set of transformations for conversion between any two Euclidian coordinate spaces (Clarke, 1990). In translation, the origin of the coordinate system is changed to a new position. Rotation involves rotating the axes of the coordinate system. A scaling operation would see the unit distance of a coordinate system multiplied by a common factor.

3.3.1.2 Statistical Space Transformations

Rubbersheeting is a statistical space transformation commonly found in commercial GIS. In some information types such as air photos and satellite imagery, relationships between scale, area, shape, and direction may be spatially distorted due to topographical variables or weather and weather conditions (Clarke, 1990). By using a number of control points for which the precise ground coordinates are known, an image or map can be mathematically 'stretched' in order to comply with new reference parameters.

Rubbersheeting is better suited to vector rather than raster data, because the new coordinates may result in distortion of the regular grid (Burrough, 1987). Thus, in a raster structure all grid coordinates must be redefined.

3.3.1.3 Cartographical Transformations

Geo-referenced data must be converted from the three-dimensional surface of the globe into a two-dimensional planar surface. Many map projections are available for this purpose; the choice of one over another often involves preserving one property (eg. shape) at the expense of others (eg. area, distance). Since map information is not produced everywhere to a standard map projection, and since it may be desirable to take advantage of the distortion factors of other projection types, the ability to transform information from one projection into another would be an asset. To

maintain the positional accuracy and integrity of locational data, four factors must be taken into consideration. They include projection type, reference grids or coordinate systems, datums, and reference spheroids.

With the national topographic series (NTS) and the B.C. geographical series (BCGS) both supporting the Universal Transverse Mercator (UTM) projection, these are default requirements for Canadian organizations wishing to take advantage of digital base map material. Support of the Transverse Mercator, used for extended north-south mapping, may also be useful for British Columbia. Both of these projections preserve shape at the expense of distance and area.

Coordinate systems are reference grids superimposed upon the map such that locations can be referenced in terms of standard X-Y units. Latitude-longitude and UTM grids are included as information on NTS maps available for the province. Translation between these grids is an important function for organizations using NTS OR BCGS digital base map information.

The coordinates of a given point on earth are defined according to a geoid, or reference spheroid, which defines the three dimensional shape of the earth. A datum is the reference point from which all other points are referenced within a given geoid. The Clark-66 geoid, using a centre in Kansas as its datum (the NAD-27 datum), has, until recently,

been the standard datum for North America. In 1980, the Geodetic Reference System was established employing a geoid (GRS-80) with a datum at the centre of the earth (NAD-83). Maps based upon the NAD-83 datum will portray a more accurate representation of the earth (White, 1990). However since most maps in existence are based upon the former, an automated system should support each datum as well as translation between them. The difference between the datums may result in UTM changes of up to 215 metres in northings and 120 metres in eastings in British Columbia (B.C. Ministry of Crown Lands, 1988). Ideally, an algorithm will translate between these datums. However the relationship between these datums is a variable one and is difficult to define mathematically. A rubbersheeting operation, in which one datum is literally stretched to fit the second based upon common control points, can be employed to translate between datums. Scale and density of control points must be taken into consideration when performing such a transformation. Data accurate to a scale of 1:2,000,000 will require far fewer control points per unit area than data accurate to a scale of 1:20,000. More detailed discussions on the factors controlling cartographic representation can be found in Robinson (1988) and Snyder (1987).

3.3.1.4 Spatial Measurements

General measurement of locational data also falls into this category, as long as access to associated non-locational attribute data is not required. Among these measurements, Smith et al. (1987) include distances, perimeters, areas, and volumes in both the vector and grid cell formats. It is relatively simple to calculate such measurements in Euclidian geometry, but if the projection is one that has conceded area or distance for shape, then projection factors must not be overlooked during measurement. Measurement of convoluted lines through three dimensions (eg. folding super-imposed upon a plunging structural axis) present additional problems as both datum and projection factors will affect these distances.

3.3.2 Category B: Operations Requiring Access to Attributes of One Class Only

This category includes operations performed upon two-dimensional tabular data and are ordinarily handled by statistical packages (eg. SAS, SPSS) or commercial data base managers (eg. dBASE 3+). These operations are often incorporated into a GIS through interfaces with commercial data base managers or statistical packages. The statistical analyses performed upon regional geochemistry data are

examples of operations from this category.⁴ Detailed coverage of these operations lies outside the scope of this study as justified in chapter two. However, it is assumed that a full choice of boolean, arithmetic and statistical operations will be available to the user. An informative discussion on geological applications of these operations is provided by Davis (1986).

3.3.3 Category C: Operations Requiring Access to Attributes and Locational Information for a Single Class of Objects

Operations in this category include spatial statistics and location based measurements. Goodchild (1987a) lists location of mean centre, dispersion, and nearest neighbour statistics as among those falling within this category. Other applications falling within this group include runs testing and quadrat analysis. A more detailed discussion on these and other techniques is provided by Unwin (1981). Although these techniques are not widely used for geological purposes, operations in this category may be useful for determining descriptive indices for geological data. For example, geological polygons may be characterised by combining shape or orientation (locational) with grain size or mineralogy (attribute) into a single descriptive indice. Discussions on the application of these operations to

⁴ See the National Geochemical Reconnaissance 1:250,000 Map Series jointly published by the B.C Geological Survey Branch and the Geological Survey of Canada as Open Files.

geography can be found in Selkirk (1982) and the CATMOG series. Davis (1986) describes some operations, the variogram for example, which have been developed for geoscience purposes.

3.3.4 Category D: Operations Which Create Object-Pairs From One or More Classes of Objects and Analyse Their Attributes

Conceptually, this operation is difficult to understand. The object-pair is not an actual physical entity, rather it is the relationship, as perceived by the user, between objects, or classes of objects. Object-pairs differ from topological relationships (adjacency, connectivity) in that there need not be a physical connection or relationship binding the objects. The connection in object-pairs often is one of spatial proximity implied through semantics. The flow of goods between countries is an example of object-pair relationships. In geology it may be the proximal relationship that intrusive bodies or faults have with mineral deposits, for example. In the creation of object-pairs, distance between objects is an important attribute, and should be stored as one for future reference and analysis.

Since proximal distance is a primary factor in the creation of object-pairs, spatial autocorrelation coefficients and indices, and nearest neighbour analysis are operations which can quantify and test relationships between

the objects in question. Some operations listed in section 3.3.5 may be adaptable for use in this category. It is unclear how this operation can be applied to geology; there is no question that the object-pair exists as a relationship to geologists, but there is a lack of tradition and few (if any) methodologies for the quantitative treatment of object-pairs in geology.

3.3.5 Category E: Operations Which Require Access to Attributes and Locational Information for More Than One Class of Objects or Object-Pairs

As among the operations falling within this category, Goodchild (1987a) lists spatial interaction modelling, network analysis, spatial autocorrelation, and location-allocation analyses. These operations are popular for municipal and facilities management but are not typically used by geologists. Spatial autocorrelation has potential to be used for quantifying and testing geological hypothesis in which spatial location is a factor in the correlation between two variables (eg. a spatial relationship between deposit types and stratigraphy), in a similar manner that correlation is performed upon tabular non-spatial attribute data. Potential for this category of operations in geology can best be described in terms of primitive operations.

Primitive operations include all possible spatial intersections between object types. Considering that objects can occur in four separate dimensions, then sixteen

dependent-independent object combinations are possible; these are illustrated in Table 3.2. These operations commonly are found in commercial GIS as point-in-polygon overlays, line-in-polygon overlay, and cross-tabulation and area analysis overlays. In these operations a class of objects, or the attributes thereof, is summarized in terms of a second class of objects based upon spatial intersections. For example, results from a line-in-polygon operation may summarize the density of linear features occurring in geological polygons. Put in mathematical terms, these operations can be expressed as:

$$\text{Class A} = f(\text{Class B}).$$

Where A represents the dependent class, B the independent class, and the functions operating upon the independent class includes a full range of boolean, mathematical and statistical operators. A class of objects can fall on either side of the equation according to the needs of the user. For example, geochemical points samples (the dependent class) may be 'overlain' with geological polygons (the independent class) in order to update an attribute field describing the geological environment of the geochemical sample site. The reverse of this operation can be used to characterise geological polygons according to some function of geochemistry.

Raster processing offers several advantages over vector processing in performing these operations. In a raster

		DEPENDENT OBJECTS			
		Point	Line	Area	Volume
I N D E P E N D E N T	Point	Contin. Surface Overlay	Point Line Summary	Point Area Summary	Point Volume Summary
	Line	Point Line Overlay	Line Line Intrsect	Line Area Summary	Line Volume Summary
	Area	Point Area Overlay	Line Area Overlay	Area Area Overlay	Area Plane Intrsect
	Volume	Point Volume Overlay	Line Volume Overlay	Area Volume Overlay	Volume Volume Overlay

Note: Summary is used where the dependent object is of a higher dimension than that of the independent object. Overlay is used where the dependent object is of a lower or equal dimension than that of the independent object.

Table 3.2: Combinations of dependent-independent object interactions.

model, objects from all dimensions are constructed from grid cells, therefore it can be argued that one type of intersection, grid cell intersections, exists. In a vector model, objects from different dimensions are structurally distinct from one another, therefore the sixteen intersection combinations apply. Secondly, it is possible to arrange the grid cell dimension and configuration of raster layers such that grid cells precisely overlap. Locational coordinates of vector layers tend to be unique, therefore more complex rules for integration are required. Intersections involving continuous surfaces and volumes are practical with raster structures only. Grid cells occupy the entire area for a given theme while an array of discrete points, theoretically, occupy no area at all. Thus spatial intersections between continuous phenomena or between

model, objects from all dimensions are constructed from grid cells, therefore it can be argued that one type of intersection, grid cell intersections, exists. In a vector model, objects from different dimensions are structurally distinct from one another, therefore the sixteen intersection combinations apply. Secondly, it is possible to arrange the

continuous and linear data will be remote using vector structures.

It is important to note that this operation does not result in the creation of new objects or classes of objects; instead output may consist of tabular reports or an added or updated attribute field for the dependent object class. Thus a report on spatial overlap between two thematic classes through polygon overlay can be placed into this category. Appendix A contains a list of primitive operations in this category with some example applications.

3.3.6 Category F: Operations Which Create a New Class of Objects From an Existing Class

Creating a new class of objects from an existing class is an important group of operations in geology. Included among these operations are point interpolation, polygon overlay, and proximity characterisations. Recognizing point, line, area, and volume as four object types, Clarke (1990) lists a matrix of sixteen possible object transformations. These are listed in Table 3.3.

As with the preceding category, it is possible to perform transformations in either raster or vector formats. It will be assumed that it is also possible, during object transformations, to have a raster structured object created from a vector and vice-versa. This implies raster-to-vector and vector-to raster conversions respectively. The former are much less difficult to perform, in terms of algorithm

		FINAL STATE			
		Point	Line	Area	Volume
I N S T A B I L E	Point	Point To Point	Point To Line	Point To Area	Point To Volume
	Line	Line To Point	Line To Line	Line To Area	Line To Volume
	Area	Area To Point	Area To Line	Area To Area	Area To Volume
	Volume	Volume To Point	Volume To Line	Volume To Area	Volume To Volume

Table 3.3: Object transformation matrix of four object types (adapted from Clarke, 1990:145).

complexity and processing requirements, than the latter.

The importance of operations in this category to spatial analysis in geology warrants a closer examination.

Transformations for each object type are therefore looked at in some detail in the ensuing subsections.

3.3.6.1 Transformations Originating From Points

Examples of point to point transformations include centographic measures, point interpolations to continuous surfaces, and all operations performed upon continuous data (keep in mind that continuous data, including digital elevation models, may be considered to be point data). Creating links between points, determining a stream network or ridge lines from an array of elevation points, projecting the axis of a plunging linear geological feature into three dimensional space from a point describing its orientation,

and extracting structural features from remotely sensed data are some examples of point to line conversions.

Proximity characterisations, discrete point interpolations (eg. thiessen polygons), continuous data classified into polygons, and the extraction of polygonal data from continuous surfaces, such as watershed boundaries, are examples of point to area transformations. In geology, this type of object conversion has been used to define catchment basins from geochemical point samples (Dwyer and Nash, 1987; Rogers et al., 1988).⁵

An extension of point transformations can be extended into the third dimension to include the creation of discrete objects or continuous variation through three dimensions. Potential applications to geology include ore deposit characterisations and interpolation of geochemistry into continuous or discrete volumes.

3.3.6.2 Transformations Originating From Lines

Creating a continuous corridor, the proximal influence of a fault for example, is an example of a line to point transformation. Similarly, a discrete corridor is an example of a line to area transformation. Bonham-Carter et al. (1989) have employed such an operation to characterise the proximity to linear geological features derived from air

⁵ See Fabbri (1984) for examples of point (grid cell) transformation using a geological image analysis system.

photos. Line to line operations may include merging or reclassifying several line types into a new set. Three dimensional buffers and corridors are examples of line to volume transformations.

3.3.6.3 Transformations Originating From Areas

There appear to be few applications in geology which require the transformation of a polygon into a point or line. The calculation of centroids from polygons is used in other areas of geography and may find some use in geology. Also the generation of cross-sectional profiles is a potential area to line transformation.

Area to area transformations, including polygon reclassification and merging, and polygon overlay, have several applications to geology. A new class of polygons may be created through a reclassification of existing polygons based upon some combination of attributes, for example geological units can be reclassified according to relative or absolute time, according to rock type, or according to some other attribute. Polygon overlay for the purposes of creating a new class of polygons can be used for updating existing maps, mineral potential and ore deposit modelling, and environmental geology applications, for example.

3.3.6.4 Transformations Originating From Volumes

Capabilities found in commercial systems currently do not include operations in this subcategory. This is partially due to technological limitations; but a lack of conceptual developments with respect to data models and structures is also a contributing factor. A lack of three dimensional geological data, both discrete and continuous, is another inhibiting factor. Although geological phenomena extend in three dimensions, it is only feasible to define them in two dimensions, information pertaining to the third is largely inferred according to structural measurements or through associated attributes. Nevertheless, it is possible to extrapolate and interpolate to the third dimension according to available data, current theories, and knowledge of the geoscientist.

Assuming that the technical and data availability problems associated with three dimensional data are solved, then there is potential for reclassification, merge and overlay to be performed in three dimensions (volumes).

3.3.7 SECTION SUMMARY

With modification to a classification scheme initially put forth by Goodchild (1987a, 1987b), most analytical, manipulative, and integrating operations found in commercial GIS can be placed into a logical framework. There is overlap between some categories; for example it may be possible to

obtain the results of a category E operation through an overlay in category F, however the reverse would not be true. There is also some overlap with editing functions; for example line generalisation, listed as an editing function, can be performed upon an entire class of locational objects at once. Thus it could also be placed into category A.

Vector structures can accommodate operations in categories A, C, and D relatively easy, but are awkward for integration (category E) and transformation (category F). The inherent complexity of vector structures is the underlying cause of these difficulties. Objects of different classes and dimension tend to be structurally unique; thus it is difficult to integrate various classes of objects or to transform them into new object classes. An additional limitation of vector structures is their limited ability to handle continuous data (eg. geochemistry, geophysical data, transitional stratigraphic sequences). Raster structures, using grid cells as basic structural units, can accommodate operations in category E and F, including those requiring the manipulation of continuous data. The primary drawback to raster processing, apart from the inherent problem of lack of precision, is in the manipulation of explicit relationships, for example network analysis and perhaps some cartographical transformations.

If an agency's tasks can be accurately identified and placed within the framework of the model proposed, then a

direct link is established between mandates and capabilities and limitations of data models currently in use. This strengthens the importance of the data model as a foundation upon which to organise spatial information.

3.4 OUTPUT

GIS output can be divided into two general areas, product and query (Goodchild, 1987a; 1987b). Products include anything in a hardcopy format including maps, tabular lists, and graphs. Query requires an answer from the system in response to a particular question. There is some overlap between product and query since the results of a query may be in hardcopy format. However they can best be distinguished from each other in terms of access time and processing requirements. It is assumed that queries will require quick, interactive access to spatial information, thereby ruling out object transformations and other analytical operations which may require extensive processing. Products are the planned output of analytical and cartographic processes, and do not require immediate, interactive results. This difference may be partially attributed to technological limitations as the combined effects of increased storage capabilities, the development of efficient data structures, and advances in computer technology result in more rapid access times. It can be expected that many operations now requiring extensive

processing will soon be available on a more interactive basis.

Information in digital formats can be considered a third type of product. A mandate for many government organizations is to make information available for public usage. Traditional modes of information distribution in a geological survey include paper maps, files, and reports. Assuming that clients have the technical capabilities, digital information represents another distribution format. To this end, the agency, as the supplier of information, will need to support various digital formats to suit the needs of its clients.

3.4.1 Products

Output of products, possibly more than any other operation, is dependent upon the development of new technologies. Currently, hardcopy output is restricted to a number of relatively few specialized devices. Due to dependence upon technology, development of such devices are characterized by rapid change; notably increasing functionality and decreasing costs. An organization would therefore be ill-advised to base system acquisition upon such capabilities. However there are some aspects of this operation which are subject to the constraints of data models and, more recently, there have been efforts to

establish standards for the transfer of information to output devices.

Without standards for communication between graphics and output devices, a new program, or device driver, must be written for every output device to be used. This can result in substantial effort as such devices are technological in nature and tend to change almost yearly. This also leaves clients dependent upon software vendors as many do not supply access to source code. In response to this problem, a graphics standard, the graphics kernel system (GKS), has been developed and adopted by international standards agencies (Burrough, 1987; Chorley, 1988). While adoption of the standard will see reduced dependence upon technology, Clarke (1990) notes that the standard results in a trade off of flexibility for drawing speed. GKS appears to have gained only limited acceptance among GIS vendors. A 1989 survey of GIS products lists only thirteen of sixty-one GIS vendors which have adopted the standard (Parker, 1989).

The choice of data models also has some effect upon output capabilities. Output devices supporting raster-based models are able to represent filled polygons and continually varying surfaces, but have limited capabilities for portraying detailed line work and annotation. Output devices designed to support vector models are able to accurately plot line work and annotation but are awkward for polygon fill. Common output devices and products are listed in

Appendix A. Detailed coverage of cartographical operations such as colour, annotation, and placement of features is not covered here as justified in Chapter Two.

3.4.2 Query

Query has been distinguished from products in terms of access time and processing requirements. Query generally requires quick access time and low processing requirements in support of, for example, land use decisions, or for routine queries of a general nature. According to Frank (1988), an interactive operation response must be faster than thirty seconds, thus elaborate manipulation and analysis is ruled out, although advances in technology can be expected to change this situation.

Query is divided into three categories - elementary, complex, and metadata queries - based upon the type of information which must be accessed. Elementary queries generally do not require data manipulation or the use of logical operators. Location is generally the primary criteria for accessing the desired information. Such queries are probably best handled through the use of graphical interfaces where the user is allowed the choice of pointing to the desired location or feature, specifying grid coordinates, or perhaps indicating some attribute. Intuitive knowledge of the data is not a requirement for this type of query. Example queries might include measurements of

distance, height, area, perimeter and volume, or an answer to the question "What is here?". Most commercial systems support this type of query in some form.

The second type of query is more complex in that it involves the application of logical and spatial operators upon the data. The user is required to have some knowledge of the data as well as the ability to construct a query according to logical and spatial parameters. To assist with queries, a language is required with which the user can pose questions to the system. A standardized language for such queries, the structured query language or SQL, was developed by IBM in the 1970's, and appears to be accepted as a standard for use in relational DBMS's. SQL was developed for non-spatial attribute tables and is not well suited for spatial queries (Aronoff, 1989) as it cannot handle spatial operators such as 'within' and 'adjacent to' (Egenhofer and Frank, 1987). Maguire (1989) lists the distance between objects, the angle between objects, the overlap between objects, and whether one object lies within another as four types of spatial searches; these capabilities are currently not available as query operators in commercial systems.

Metadata queries require access to neither attributes nor locational information for individual records within a database. Instead access to information concerning the characteristics of the database is required. Metadata is normally stored in a data dictionary and can be considered a

database unto itself (Star and Estes, 1990). An index of publications, an NTS location map showing national coverage, and library card catalogs are analog examples of metadata dictionaries. According to Nyerges (1987), metadata is important because it allows an organization to know the nature of a database. Thus a geoscience metadata dictionary for British Columbia will allow a user to query a given area according to geographical/geological criteria, and be able to determine what data sets are available, what they contain, the accuracy of the information, and how to obtain it. The handling of metadata in a GIS context has not yet been fully addressed. Tiles may be a logical unit for the organisation of metadata; Goodchild (1989) explains that tiles may be manipulated through a tile manager or map librarian and Aronson (1989) describes a commercial system developed for this purpose. The Spatial Archive and Interchange Format (SAIF) proposed for British Columbia includes the structuring of metadata within an object-oriented based structure (Ministry of Crown Lands, 1990), but it should be noted that SAIF is still in the developmental stages.

3.4.3 Digital Products

With trends towards decreasing computer hardware costs and increasing software capabilities, it is reasonable to expect that an increasing number of users of geoscience data

will require information in digital as well as traditional analog formats. To meet this need the supplying agency will require the capability to supply digital information in a variety of formats. Several format standards currently are in widespread use in North America. These include CAD formats (DXF), topological formats (eg. arc-node, Arc, DLG), and raster formats (eg. Landsat, Erdas). There are also several government standards for spatial data including the proposed Format (SAIF) for British Columbia. Appendix A contains a list of some common data formats.

To support existing formats, including possibly formats not yet developed or in use, will require that information be stored in a format which is generic, yet maintains maximum explicitness of the information's characteristics. Topological structures define spatial data in a more explicit manner than both CAD and raster formats; therefore topological structures support, in theory, CAD and raster formats. However, it will be difficult to convert from a CAD or raster structure to a topological structure.

3.4.4 Section Summary

If the requirements for a GIS data model are specified strictly from a product point of view, then the following points can be expressed. If the only products are maps, then capabilities provided by a cartographic system will suffice. If elaborate query capabilities and the support of various

digital formats are required in addition to map products, then a more elaborate topological structure will be required.

3.5 SPATIAL DATA BASE MANAGEMENT SYSTEMS

The differences between DBMS and GIS were explored in Chapter Two; DBMS are able to manipulate attribute data organised into two dimensional tables, but lack the ability to handle more complex spatial data and related operations. Non-spatial attributes are an important component of geographical information and DBMS are incorporated into commercial systems in one of two manners: (1) through external linkages with commercial DBMS (eg. Oracle, dBASE III+), or (2) development of proprietary DBMS functions, (eg. INFO). However most GIS vendors employ a combination of the two approaches, using proprietary software to add spatial functions not covered by commercial DBMS. Spatial data are linked to their associated non-spatial attributes in a DBMS by means of a pointer, or indexing key, thus the concept of separating spatial from non spatial data is maintained. By combining with DBMS, GIS have the capabilities for managing both spatial and non-spatial data and may therefore be considered spatial DBMS.

Various models for the design of DBMS's are reviewed in Chapter Two (section 2.2.5). Currently, DBMS organised around the relational model dominate the market. However

there are several weaknesses, namely representation of complex data, ability to perform spatial queries, and the ability to generalise (change scale). These drawbacks can be attributed to the need for separating spatial data from non-spatial attributes in a relational-based GIS. Object-oriented DBMS's offer potential for overcoming these limitations but, as outlined in Chapter Two (section 2.2.5), they also have limitations due to complex structures and have not yet gained widespread acceptance.

In addition to the capabilities of input, output, storage and processing, a DBMS can provide some important capabilities for data management and access to operations (see, for example, Aronoff, 1989; Frank, 1988; Star and Estes, 1990). Included among these are the following:

1. A generic interface between the database and application program such that the physical details of storage and retrieval are transparent to the user.
2. Standardised storage and retrieval of spatial and non-spatial data.
3. The enforcement of data quality, security, and consistency, in effect to make it as difficult as possible for a user to enter erroneous data.

It is noted that the interface has received less attention than other components in the design of GIS (Egenhofer and Frank, 1988). This is best demonstrated by a lack of continuity between commercial systems and time required to become familiar with them. The interface usually involves a graphical component (pop-up menus), or keyboard

input commands. Query languages (eg. SQL) are also an integral part of the interface. Ady and Currie (1989) argue that such a language must incorporate interpretive geoscience concepts in a natural language environment so that the complexity of underlying data structures is hidden to the user.

The interface must also allow the use of logical and mathematical operators to combine various analytical operations such that the results of one operation become an input to subsequent operations. In this manner, elementary operations can be combined into more complex modelling and analytical procedures. According to Tomlin (1990), a GIS modelling syntax should be a high level computational language which is concerned with the formation and transformation of geographical data, and it should be independent of hardware and data structures. A spatial modelling language has been developed (Tomlin and Berry, 1979) in which primitive spatial operations can be organised into higher level functions. Using this language, entire maps can be treated in the same manner as variables are in algebra or statistics (Berry, 1987). A recent book entitled "Geographic Information Systems and Cartographic Modelling" (Tomlin, 1990) shows that this is a powerful language suitable for a broad range of applications. Many commercial systems offer similar capabilities, but there is little

continuity and standardisation of modelling syntax between systems.

The capability to combine operations, especially those in categories E and F (section 3.3.5, 3.3.6), allows for complex modelling and analysis procedures. Such capabilities allow tasks traditionally handled using qualitative methods to be performed in a spatial-quantitative framework. The following section will examine the incorporation of quantitative models and analysis in geology into a GIS framework.

3.6 GEOLOGICAL ANALYSIS, GEOMATHEMATICS, AND EXPERT SYSTEMS

The publication of Design With Nature (McHarg, 1969) was influential for promoting manual overlay of various resource and land-use themes as a technique for land-use planning and resource analysis, and to assist with resolving land-use conflicts. To perform such tasks in a digital environment, in effect to quantify tasks traditionally handled in an intuitive, qualitative manner, requires the employment of proper quantitative theories and methodologies. However, Ehrlich (1988:39) observes that "Thoughtful application of statistical procedures in the geosciences is still rare.", and Hohn (1990) questions: "...why geostatistics has not been more widely practised, dealing explicitly as it does with spatial relationships among samples.". A recent United Kingdom enquiry into the handling of geographic information

similarly concludes that statistical methodology applied to spatial data is underdeveloped (Chorley, 1987). Hohn (1990) attributes the problem to a lack of suitable computing power and to a limited understanding of the techniques among geoscientists.

GIS presents an ideal environment for combining spatial variables in a quantitative framework. However, there has been much recent criticism that current GIS developments are lacking in formal spatial analytical techniques (see, for example, Openshaw, 1987; Openshaw et al. 1987; Waters, 1989a, 1989b). Commercial products often contain the basic operations upon which theoretical methods of analysis can be constructed, but often fall short in providing more complex operations based upon analytical theories. For example, Waters (1989a) complains that currently available GIS systems are at least one generation behind in locational modelling. Goodchild (1987b) rationalises this situation, explaining that theory and philosophy traditionally lag behind research activity.

In geology, there is methodology established for the quantitative treatment of non-spatial information, such as multivariate analysis, and for the interpolation of point based measurements into continuous surfaces (see, for example, Agterberg, 1982, 1989; Davis, 1973; Rich, 1990). Methodologies for the probabilistic treatment of variables in ore deposit models for mineral exploration purposes have

been described by Bonham-Carter et al. (1988) and Agterberg (1989). Wignall and De Geoffroy (1987) outline several geomathematical models for optimizing exploration programs, and there is considerable literature on the application of artificial intelligence and expert systems for geological exploration (see, for example, Maslyn, 1986; McCammon, 1987). Many of these applications have been performed more or less as case studies with little prospect of more widespread application. Although current GIS capabilities are insufficient for scientists in many disciplines (Burrough, 1990), the GIS structured database provides a framework for applying geomathematical theories and techniques in a more widespread manner. For example, Oliver and Webster (1990) feel that kriging, an interpolation technique initially developed for mining purposes, can be integrated within a GIS. However, due to a somewhat limited market, there is little economic incentive for development of GIS dedicated to geological analysis and applications.

3.7 CHAPTER SUMMARY

The objective of this chapter were to determine, as far as is possible, a standardized list of GIS operations such that an agency's tasks can be put into a generic GIS framework. Operations were divided into five general sections, including input, output, storage, analysis, and data base management functions. Strengths and weaknesses of

raster and vector spatial data models for handling the operations were assessed wherever appropriate. This approach allows for two objectives. An inventory of GIS functionality can be completed, and the raster and vector models can be compared with each other.

Input to vector structures is labour intensive, thus it tends to be more expensive and time consuming than input to raster structures which are well suited for automated input. Major advantages of vector encoding include preservation of topological relationships, efficiency of storage, its ability to incorporate high spatial precision, and its ability to mimic cartographical quality maps. The structural complexity of vector structures and its limited ability for capturing continuously varying phenomena can make analysis difficult.

Structural simplicity and the ability to portray continuous variation make the raster model well suited for spatial data analysis and manipulation. The primary drawbacks to raster structures include high storage space requirements, lack of precision, and poor cartographical capabilities. Raster structures also have severe limitations for dealing with topological analysis involving networks and explicit relationships.

It is important to note those components which are subject to rapid technological change versus those which have a basis in theory and models. Hardcopy output is an

example of an operation governed by technological changes. It can be divided into raster and vector devices, but classification beyond this falls into innovative technology. Query output is distinguished from analysis in that it requires a quick response, and from hardcopy output in that map products are not required. These differences are largely controlled by technological factors, and so the distinction between query and analysis, and query and hardcopy output will likely become increasingly blurred as technological advances take place. Keeping in mind the goal of eliminating all vestiges of technology, a list of 'generic' GIS operations has been presented in table 3.3. To those familiar with GIS capabilities, the list will seem barren. To demonstrate how this list can be applied, and also to keep in touch with reality, Appendix A has been included. This Appendix contains an extended list of functional capabilities with common functional names and example applications. The common names and some of the applications are sure to change as technological advances take place and standards are implemented. However at the level used in table 3.4, the operations should have some immunity to technological change. Using such a list as the basis for GIS design far exceeds that of using an 'amorphous' list of operations based upon one's observations of vendor systems.

-
- 1: INPUT AND STORAGE
 - 1.1: Input Mode
 - 1.1.1: Automated
 - 1.1.2: Manual
 - 1.2: Storage
 - 1.2.1: Vector
 - 1.2.2: Raster
 - 1.3: Editing
 - 1.4: Physical Storage

 - 2: ANALYSIS
 - 2.1: Operations requiring access to locational information only.
 - 2.2: Operations requiring access to attributes of one class only.
 - 2.3: Operations requiring access to attributes and locational information for a single class of objects.
 - 2.4: Operations which create object-pairs from one or more classes of objects and analyze their attributes.
 - 2.5: Operations requiring access to attributes and locational information for more than one class of objects or object-pair.
 - 2.6: Operations which create a new class of objects from an existing class.

 - 3: OUTPUT
 - 3.1: Hardcopy
 - 3.2: Query
 - 3.2.1: Elementary queries.
 - 3.2.2: Complex queries.
 - 3.2.3: Metadata queries.
 - 3.3: Digital Products

 - 4: DATABASE MANAGEMENT FUNCTIONS
 - 4.1: User Interface
 - 4.1.1: Support of a structured query language with spatial capabilities.
 - 4.1.2: Support of a spatial modelling language.
 - 4.2: Data Quality Protection
-

Table 3.4: Geographical information systems functionality defined at an elementary level.

CHAPTER 4

THE GEOLOGICAL SURVEY BRANCH

4.0 INTRODUCTION

It is argued in Chapter Two that the foundations of a requirements analysis must be based upon the mandate of an organization. From an understanding of the mandate, the tasks of an organization, and the information required to support them, can also be determined. Thus, assuming that the tasks have been correctly recognised, the operations to support these tasks in a GIS can be identified, and can subsequently be used as a basis for system selection. In Chapter Three a list of GIS operations was defined which transcends vendor specific operations. In this chapter the mandates, tasks, information requirements, and other pertinent information for the B.C. Geological Survey are summarized. Operational requirements for the Survey are determined and presented in Chapter Five.

There is a historical basis to the mandate and many of the activities of this organisation; therefore a brief background to the history of the B.C. Geological Survey is presented.

4.1 HISTORICAL BACKGROUND

The origins of the Geological Survey can be traced back at least to the mid-eighteenth century. In 1852 Governor

Douglas, recognizing the importance of the Nanaimo coalfields, stressed the need for a survey of the Gulf Islands (Thompson, 1966). And in 1853, Douglas formally recognized mining as a significant Provincial industry (Walker, 1937a; Carlyle, 1951). The discovery of placer gold in 1858 along the Fraser River attracted thousands of miners, primarily from the western United States. Up to this point in history, the Hudson's Bay Company held control over natural resources in the territory, but was not empowered to legislate and enforce laws and regulations. The influx of foreign miners was perceived as a threat to British authority. The Hudson's Bay monopoly therefore was revoked and governing authority was transferred to Governor Douglas. White (1961) explains that with respect to mining, Douglas was instructed to:

1. Establish laws, taxes and regulations.
2. Assist the miners in every way possible, in effect,
3. to follow a policy of non-interference.

Douglas perceived transportation to be an immediate need of the emerging mining industry, and a policy of assisting prospectors through road building was established. Routes to the interior of British Columbia from the United States were also seen as a threat to British authority; this added further incentive for road building, especially for roads leading from the coast to the interior.¹

¹ The information for this section is summarised from correspondence between Governor Douglas and Sir Edward Lytton, British Secretary of State for the colonies,

From 1858 until 1874, mining regulations were administered by agents under authority of member(s) of the executive council.² In 1874 the Office of the Minister of Mines was created and held, without salary, by a member of the Executive Council. This office is also referred to as the Department of Mines (DoM) (BC LIST, 1982), but it was not until 1899 that the DoM was formally established as a government department with a separate portfolio and an independent minister.

In 1895 the Bureau of Mines (BoM) was established, apparently as a separate authority to that of the DoM, with a 'Provincial Mineralogist' appointed as its head. (This position is the forerunner of the current Chief Geologist and Director position of the present-day Geological Survey Branch.) According to Walker (1937b), this created some tensions as there was considerable overlap in mandates of the two agencies.

Starting in 1874, the DoM compiled annual reports summarizing mineral production statistics and reports from government agents, which the BoM was responsible for editing and publishing. In 1917 the Mineral Survey and Development Act was passed, and this resulted in the DoM gaining a staff of mining engineers, or 'resident engineers', one for each

contained in Beggs (1894) and Howay (1914).

² B.C. LIST (1982) reports that the Provincial Secretary's Department administered mining laws, however no references were cited to support this.

of the provincial mining districts. According to Carlyle (1951:47), the activities of each resident engineer includes to:

...carry on continuously a mineral survey of his district, keeping records of the same and of its mining and mineral developments and at the same time assist prospectors and others with such advice as may be necessary and come within the scope of a mining engineer's work.

The resident engineers worked directly under the Minister of Mines, but the Deputy Minister instructed on matters related to the 'Mines and Development Act', and roads and trails. Moreover, the Chief Mineralogist was responsible for editing the Resident Engineers' contribution to the Annual Report publication. The engineers were therefore receiving directions from up to three separate authorities and, according to Walker (1937b), this ultimately led to chaos. Carlyle (1951) also reports that there was little cooperation between the DoM and BoM, and that the engineer's work suffered due to this. This situation and other significant stages in the early development of the Department of Mines are listed in Table 4.1.

The internal conflict of authority involving the mining engineers was resolved in 1934, when the Bureau of Mines Act was repealed and the DoM was reorganized to include a mineralogical branch to be headed by the former Provincial Mineralogist from the now defunct BoM. The formation of the Mineralogical Branch can be considered the beginning of the modern Geological Survey.

-
- 1853: Governor Douglas recognizes mining as an important industry.
- 1858: Mining laws and regulations are administered through the executive council.
- 1874: The office of the Minister of Mines is created - occupied by the Provincial Secretary's Department.
- 1877: Mines Inspectors added to the office of Minister of Mines.
- 1895: Bureau of Mines created as a separate department from the Ministry of Mines.
- 1899: Department of mines is established as an independent government portfolio with its own minister.
- 1917: The Mineral Survey and Development Act brings six resident engineers to the Ministry.
- 1934: Bureau of Mines dismantled and replaced by the Mineralogical Branch under the authority of the Minister of Mines.
-

Table 4.1: Key events in the formation of the British Columbia Department of Mines.

The DoM was loosely organized into four sections, the mineralogical branch, the administrative branch, the inspection branch, and the analytical and assay branch. In 1955 the petroleum and natural gas branch was added as a fifth administrative section. In 1975 the department was reorganized into three sections; petroleum resources, administrative operations, and mineral resources. Mineral resources was further subdivided into divisions of Geology, Mineral Titles, and Mines Inspection and Engineering. Another reorganization in 1978 saw the addition of an energy

section to the Ministry. The most recent change occurred in 1989 when energy and petroleum were merged into one. The organisation is currently known as the Ministry of Energy, Mines and Petroleum Resources. The development of the Ministry from 1874 to the present is detailed in Table 4.2.

In summary, many of the current functions and activities can be traced to the early history of the Geological Survey. A tradition of working closely with the mining and mineral exploration industries was established early through programs of assistance, and regional offices. The ministry, and all levels within the ministry, has been characterized by constant changes and reorganization. This is especially true for the Geological Survey Branch of the ministry as depicted in Table 4.3, showing developments since 1967. Also indicated by tables 4.2 and 4.3 is a trend towards increasing size and specialization. This trend is likely to continue as the Survey is considering diversifying into marine geology and geophysics.³

4.2 SURVEY METHODOLOGY

To obtain the required information about the B.C. Geological Survey, unstructured, personal interviews as described by Stoddard (1982) were employed. The flexibility offered by this type of survey was deemed necessary given

³ Further reorganization took place in the spring of 1990 when the Mineral Landuse section was moved into the Mineral Policy Branch of the Mineral Resources Division.

Table 4.2: Organization and changes in the British Columbia Ministry of Energy, Mines and Petroleum Resources.

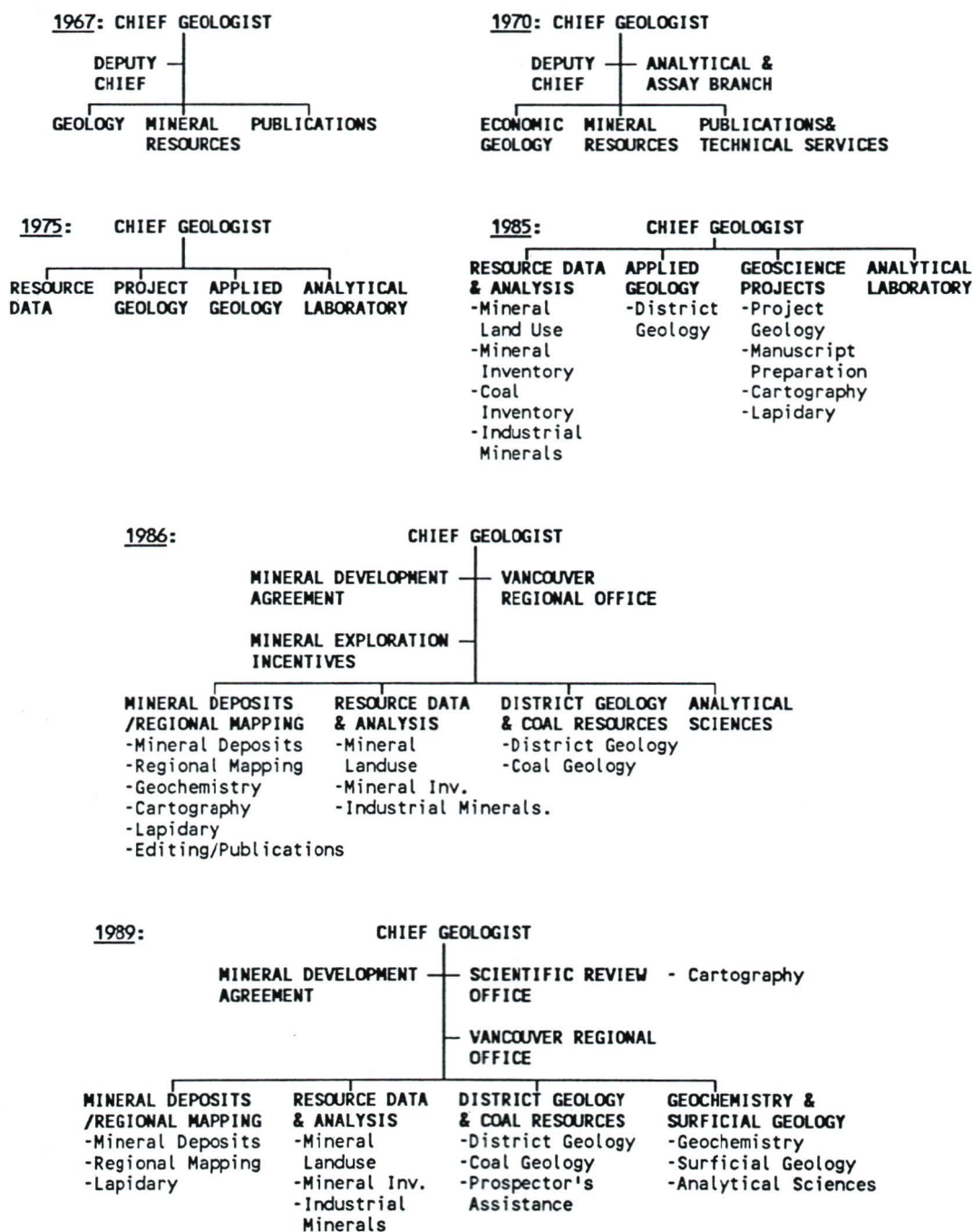
1874: <u>EXECUTIVE COUNCIL</u> -Office, Minister of Mines	1895: <u>EXECUTIVE COUNCIL</u> <u>BUREAU OF MINES</u> -Office, Min. of Mines	
1899: <u>DEPT. OF MINES</u> ... <u>BUREAU OF MINES</u>	1917: <u>DEPT. OF MINES</u> ... <u>BUREAU OF MINES</u> <div style="text-align: center; margin-left: 100px;"> Minister Deputy Minister Resident Engineers </div>	
1934: <u>DEPUTY MINISTER</u> -Mineralogical Br. -Assays and Analysis -Mines Inspection -Administration	1943: <u>DEPUTY MINISTER</u> -Mineralogical Br. -Administrative Br. -Inspection Br. -Chemical Lab.	1948: <u>DEPUTY MINISTER</u> -Mineralogical Br. -Administrative Br. -Inspection Br. -Assay and Anal. Br. -Grubstaking
1955: <u>DEPUTY MINISTER</u> -Mineralogical Br. -Administrative Br. -Inspection Br. -Assay and Anal. Br. -Petroleum & Nat. Gas Br.	1967: <u>DEPUTY MINISTER</u> -Gen. Admin., Titles & Accts -Mineralogical Br. -Inspection Br. -Assay and Analytical Br. -Petroleum and Natural Gas Br.	1970: <u>DEPUTY MINISTER</u> -Administration Br. -Personnel -Inspection Br. -Mineralogical Br. -Petroleum & Natural Gas Br.
1973:	<u>DEPUTY MINISTER</u> <div style="display: flex; justify-content: space-around;"> <div style="width: 45%;"> MINERAL RESOURCES BRANCH -Inspection & Engineering Div. -Geological Div. -Titles Div. </div> <div style="width: 45%;"> PETROLEUM RESOURCES BRANCH -Engineering Div. -Geological Div. -Titles Div. </div> </div>	
1978:	<u>DEPUTY MINISTER</u> <div style="display: flex; justify-content: space-between;"> <div style="width: 22%;"> ENERGY RESOURCES BR. -Policy Dvlpmt -Forecasts, Special -Project Analysis -Conservation & Tech </div> <div style="width: 22%;"> MINERAL RESOURCES BR. -Inspection & Engineering -Geological Survey -Mineral Titles -Mineral Policy & Eval. </div> <div style="width: 22%;"> PETROLEUM RESOURCES -Engineering -Geological Survey -Petroleum Titles </div> <div style="width: 22%;"> FINANCE & ADMINISTRATION </div> </div>	
1987:	<u>DEPUTY MINISTER</u> <div style="display: flex; justify-content: space-between;"> <div style="width: 33%;"> ENERGY RESOURCES DIV. -Forecasts & Special Projs. -Petroleum Titles -Petroleum Geology -Engineering & Operation -Policy Development -Mediation & Arbitration Board </div> <div style="width: 33%;"> MINERAL RESOURCES DIV. -Geological Survey -Engineering & Inspection -Mineral Titles -Mineral Policy & Evaluation </div> <div style="width: 33%;"> REVENUE AND OPERATIONAL SERVICES -Administration -Information Systems -Personnel Services -Resource Revenue -Financial Services </div> </div>	

Sources: British Columbia Ministry of Mines, Annual Report of the Minister of Mines, 1934, 1943, 1948, 1955, Queen's Printer Victoria, B.C.

British Columbia Ministry of Mines and Petroleum Resources, Annual Report of the Minister of Mines and Petroleum Resources, 1967, 1970, 1973, 1978, Queen's Printer Victoria, B.C.

B.C. LIST, 1988, 7th ed.

Table 4.3: Organization and key changes in the Geological Survey Branch since 1967.



Sources: B.C. Ministry of Mines and Petroleum Resources, 1967, 1970, 1975: Annual Report of the Minister of Mines and Petroleum Resources, Queen's Printer, Victoria, B.C.

B.C. Ministry of Energy, Mines and Petroleum Resources, Mineral Resources Division, 1986, 1987, 1990: Geological Fieldwork, Queen's Printer, Victoria, B.C.

the confusion often encountered between GIS, automated cartography, remote sensing and image analysis, and database management systems. If information is to be solicited on matters concerning GIS, it is important that the responses are understood and placed in the proper context. Interviews were initiated in June, 1989 and completed by September, 1989. All section and subsection managers were interviewed, thus ensuring that all working groups in the organization are represented. A schedule of the interviews can be found in Table 4.4. Details of individual interviews are summarized in Appendix B. All interviews were performed by the author.

Each interview adhered to a general format in order to ensure consistency in responses. The following discussion topics formed the basis of each interview.

1. Program mandate, goals, and objectives.
2. Activities in support of the mandate, goals, and objectives.
3. Program information requirements.
4. Program products and services.
5. Users of the program's products and services.
6. Proposed and desired enhancements to the program.
7. Perceived requirements for a GIS.

Information pertaining to the first six categories is summarised according to actual responses from the interviewees. The seventh category is also summarised according to interviewee's responses, but includes additions

<u>Program and Interviewee</u>	<u>Notes</u>	
<u>Chief Geologist's Office:</u> R. Smyth, Chief Geologist	Sept. 7	Interview
<u>Scientific Review Office:</u> B. Grant, Geological Editor	July 11	Interview
<u>Mineral Deposits & Regional Mapping:</u> W. McMillan, Manager	July 13	Interview
<u>Regional Mapping Unit</u> D. MacIntyre, Unit Head	June 29	Interview
<u>Mineral Deposits Unit:</u> A. Panteleyev, Unit Head	July 19	Interview
<u>Geochemistry & Surficial Geology:</u> P. Matysek, Acting Manager	July 17	Interview
<u>Geochemistry Unit</u> P. Matysek	July 17	Interview
<u>Surficial Geology Unit:</u> V. Levson, Surficial Geologist	July 31	Interview
<u>Resource Data & Analysis:</u> G. McArthur, Manager	July 24	Interview
<u>Mineral Land Use Unit:</u> R. Schmitt, Geologist J. Fontaine, Coordinator	July 14 July 25	Interview Interview
<u>Mineral Inventory Unit:</u> T. Kalnins, Unit Head	Aug. 1	Interview
<u>MINFILE/Property File:</u> L. Jones, Geologist	July 5 July 13	Interview Interview
<u>Industrial Minerals Unit:</u> D. Hora, Unit Head	Aug. 1	Interview
<u>District Geology & Coal Resources:</u> V. Preto, Manager	July 28	Interview
<u>Coal Resources Unit:</u> W. Kilby, Unit Head	Aug. 1	Interview

TABLE 4.4: Requirements analysis interview schedule with personnel of the Geological Survey Branch of British Columbia.

and interpretations from the author in order to incorporate the terminology from Chapter Three. All summaries can be found in Appendix B.

4.3 MANDATE OF THE GEOLOGICAL SURVEY BRANCH

In order for the mandate of the Survey to be fully evaluated, all levels of government authority must be taken into account. As described in previous sections, the Geological Survey is situated within the Mineral Resources Division of the Ministry of Energy, Mines and Petroleum Resources. If the executive council of the British Columbia government is included, then four levels of authority exist under which the Geological Survey must operate. The mandate of the B.C. Geological Survey will be described in the context of this authority hierarchy. Each authority level is considered as it relates to the B.C. Geological Survey.

Considering the highest level of authority, it is an implied mandate for the government of a democratic society to assure equal treatment in the distribution and allocation of products and services. Chrisman (1987b) notes that strict equality is rarely sought and that equity, or the fair allocation of resources and services, is often an acceptable goal. Implications of this mandate for developments related to GIS may require that information is available in multiple formats, including traditional analog maps and paper files, such that one segment of society is not favoured over

another. This is explained in more detail in the following Chapter.

According to B.C. LIST (1988: section 8-1), the mandate of the Ministry of Energy, Mines and Petroleum Resources is:

To continuously develop and manage energy policies, goals and programs to maximize energy security ... and to develop policies and programs for provincial Mineral Resources to achieve the greatest economic advantages while protecting the environment.

The 1989-1990 Business Plan for the Ministry (B.C. Ministry of Energy, Mines and Petroleum Resources, 1989:1) states that its mission is that of custodian of energy and mineral resources, but also to:

...ensure that they are developed in a safe, efficient and environmentally sound manner for the economic benefit of the province.

In attaining these goals, the Ministry adheres to values of:

1. Efficiency and effectiveness such that the public gains maximum benefit.
2. Excellence in service to the public, industry and government.
3. Positive communications with clients.

(B.C. Ministry of Energy, Mines and Petroleum Resources, 1989).

The Mineral Resources Division of the ministry represents the third level of authority; according to the 1989 annual report (B.C. Ministry of Energy, Mines and Petroleum Resources, 1989:18), this division:

...oversees the operations of British Columbia's mining industry and facilitates the orderly development of mineral, coal and aggregate resources in the province.

An early reference defines the mandate of the modern Geological Survey as follows:

It is our function to collect, collate, and store data, to report on the activity of the industry, and to disseminate information in the public realm. We should not be blind to the research and educational value of our work, and should aid wherever possible all those whom we may benefit.

(Hedley, 1969:2). The mandate of the Survey are stated in more explicit terms in the 1988-1989 Branch Plan (B.C. Ministry of Energy, Mines and Petroleum Resources, 1988:2).

The Geological Survey is to:

Assemble, maintain, and disseminate an up-to-date, comprehensive geoscience database...so as to provide a sound base for private sector exploration and development of the province's mineral resources and for resource management decisions by government.

Taking into account all four levels of authority, the various components of the Geological Survey mandate can be summarized into six basic categories.

1. Equity and Equality.

Idealistically, a fundamental goal of democratic governments is to attain equality in the distribution of products and services that it provides. Strict, absolute equality is difficult to accomplish and it does not ensure fairness. Therefore equity, or the fair distribution of services, may be a more realistic and acceptable goal.

2. Inventory and Stewardship.

The Geological Survey is charged with the collection, management, and maintenance of geological and related geoscience data for the province. This mandate is clearly stated at the Geological Survey level of authority.

3. Environmental Stewardship.

This is the recognition that geology is part of a system which includes all aspects of the environment, and that geology and activities related to it, such as mineral exploration and mining, may have an affect which extends beyond geology. The goal therefore is to seek a balance between mineral resource exploitation and human needs such that disturbance to the environment is minimized. This implied mandate is manifest by the usage of phrases such as 'orderly development' and 'environmentally sound manner'. This mandate is neither stated clearly nor is it explicit to any level of authority.

4. Research and Analysis

The Geological Survey is committed to research and development in several fields such as ore deposit modelling, geochemical sampling and mineral resource evaluation. The Survey administers much of the research itself, but external research is also directed and supported, in universities for

example, through grants support and technical assistance. This study is a case in point.

Much of the research and analysis is performed within a spatial framework, although the spatial dimension is often implied, and much of the work is qualitative in nature. Viewed in this manner, a direct link between the organisation's mandates and a need for spatial analysis can be identified.

5. Efficiency and Effectiveness.

An explicit Ministry wide mandate is to pursue its goals in an efficient manner. This will include exploring the feasibility of automating some tasks by implementing GIS and other technologies. However, efficiency should not succeed at the cost of effectiveness. The tasks it performs should be practical, constructive, and provide meaningful benefits to its clients.

6. Dissemination of Information.

It is an objective of the ministry in general, and the Geological Survey Branch in particular, to maintain a visible presence within the mining and exploration industries for the purposes of promoting mineral exploration and development. This is achieved through the dissemination of information and communications with clients.

Mandates of the various units within the Survey are summarised in Appendix B. They are variations of those described above and need not be restated in detail here. The first, fifth and sixth components apply more or less equally to all sections, however the others may apply in varying degrees to individual units. For example, some units do not partake in research, while research is a primary function to others.

4.4 ACTIVITIES PERFORMED IN SUPPORT OF THE MANDATE

To support its mandate, the Geological Survey engages in five basic activities. These include:

1. The collection of geoscience information.
2. The management of geoscience information.
3. Processing and analysis of geoscience information.
4. The publication and distribution of geoscience information.
5. Promotion of the province's mineral economic potential.

Geological information is collected in two manners. Primary data is collected through field activities such as geological mapping and sample gathering. Secondary data is obtained from mineral and coal assessment reports submitted by industry. The majority of information is stored and maintained in traditional formats; namely paper files, reports, and analog maps. Several automated systems have been developed (eg. MINFILE, COALFILE, RGS) to support

management and access to information. Other data is stored or backed up backed via microfiche technologies. Geological data is published and distributed in hardcopy formats (maps, reports, tabular listings), and in digital formats (floppy diskettes, magnetic tapes).

Information collected by the survey are analyzed by various methods including chemical, metallogenic, structural, and statistical techniques. Analyses may involve determining relationships between two variables, or it may involve more elaborate investigations, such as mineral deposit modelling or mineral potential assessments. These investigations currently employ a combination of quantitative (eg. statistical analyses) and qualitative techniques (eg. the geologist's intuitive knowledge of a region's geology).

To support the distribution and publicisation of its research and data, the organization performs several functions. Information is published as reports, open-files, maps, circulars, and digital files. Members routinely interact with all facets of the public by giving lectures, talks, putting on displays, attending conferences, and publishing in professional journals. Survey members also routinely respond to queries submitted by the public.

4.5 PRODUCTS AND SERVICES OF THE GEOLOGICAL SURVEY

The organization provides published results of all fieldwork activities and data analysis in various formats, including reports, open-files, maps, and tabular listings. Data stored in digital files are available in floppy disk or magnetic tape formats, but also as hardcopy listings. Information from all field activities are made available on an annual basis.

An important element in the daily operations of the Survey includes providing information, upon request, to industry, government, educational institutions, and the public in general. Members of the Survey also maintain an active presence with these groups by giving lectures, presentations, and displays.

Appendix C contains administrative and technical information for each data set and systems administered by the B.C. Geological Survey. Included in the description are information pertaining to data structures, format, volume, frequency of update, accuracy, uses and users. It is recognized that the B.C. Geological Survey utilizes many external data sources, but they are too numerous to include, nor do they fall within the scope of this study. As well, management of this data falls beyond the mandate of the B.C. Geological Survey.

The B.C. Geological Survey's management of geoscience data, according to program contributions and usage, is

listed in Table 4.5. Several comments can be made.

Information for data sets frequently originates from several programs. There are strong interdependencies between various programs; each depends upon all others for data.

4.6 USERS OF THE PRODUCTS AND SERVICES

Users of the Survey's products and services can be divided into four groups. In order of relative importance, these include the mining and mineral exploration industries, government agencies involved with land management, research institutions, and the general public. The mining and mineral exploration industries constitute the largest and most important client. To provide assistance to this group was a primary reason for the creation of the Survey. Accordingly, the Survey has a long, well established tradition of working closely with this group to assist with mineral resource development. Most products and services offered by the survey are related in some manner to this client group.

The next largest group of users include government agencies from all levels of federal, provincial, and local governments. Geological resource data is employed to assist other government agencies with resource policies and land-use conflicts. With expanding recreational and tourism industries encroaching upon land traditionally open for mineral exploration and development, this group is becoming a more frequent and important user of the Survey's output.

Table 4.5: Program usage and contributions to geoscience databases managed by the Geological Survey Branch.

CONTRIBUTING PROGRAMS													
CR	Coal Resources	MI	Mineral Inventory	DG	District Geology	MP	MINFILE/Property File	GCM	Geochemistry	RM	Regional Mapping	SG	Surficial Geology
IM	Industrial Minerals	SRO	Scientific Review Off.	I	Industry	UR	University Research	LU	Landuse	MD	Mineral Deposits		
												UR	I
DATABASES	SRO	RM	MD	GCM	SG	LU	MI	MP	IM	DG	CR	EXTERNAL	
<u>Dataseystems</u>													
MINFILE	C 3	B 1	B 1	C 1	B 1	B 1	A 3	A 1	A 1	B 1	B 2	B 2	A 1
ARIS	D 3	D 2	D 2	D 2	D 2	D 2	D 1	D 1	D 2	D 2	D 2	D 3	A 1
COALFILE	D 3	D 3	D 3	D 2	D 3	D 2	D 3	D 2	D 3	D 2	A 1	D 3	A 1
RGS	D 3	C 1	C 1	A 1	C 1	C 1	D 3	D 3	D 2	C 1	D 2	D 2	D 1
GDS	D 3	A 2	A 2	C 3	B 3	B 3	D 3	D 3	C 3	B 3	B 3	C 3	C 3
<u>Maps</u>													
Open File	C 3	A 2	A 2	A 2	B 2	B 2	C 3	B 2	B 2	A 2	A 2	B 2	B 1
Preliminary	D 3	B 3	A 3	C 3	C 3	C 3	C 3	C 3	C 3	C 3	B 2	C 3	C 1
MDLU	D 3	D 3	D 3	D 3	D 3	A 2	D 3	D 3	D 3	D 3	D 3	D 3	D 3
Sand/Gravel	D 3	D 3	D 3	D 3	D 2	D 2	D 3	D 3	A 2	D 3	D 3	D 3	D 3
<u>Maps/Reports/Files</u>													
Bulletins	D 3	A 2	A 2	A 2	B 2	B 2	C 3	C 2	B 2	C 2	A 2	C 2	C 1
Papers	D 3	A 2	A 2	A 2	B 2	B 2	C 3	C 2	B 2	B 2	A 2	B 2	B 1
Open Files	D 3	A 2	A 2	A 2	B 2	B 2	C 3	B 2	B 2	B 2	A 2	B 2	B 1
Property File	D 3	B 2	B 2	C 2	C 2	B 2	A 3	A 1	B 2	B 2	B 2	B 3	A 2
Min. Ass. Rpt.	D 3	D 2	D 2	D 2	D 2	D 2	D 3	D 1	D 2	D 2	D 3	D 3	A 1
Coal Ass. Rpt.	D 3	D 3	D 3	D 2	D 2	D 2	D 1	D 1	D 3	D 2	D 2	D 3	A 1
<u>Miscellaneous</u>													
Fieldwork	C 3	A 2	A 2	B 2	B 2	B 2	C 3	C 2	C 2	B 2	A 2	B 2	C 1
Expl. in B.C.	C 3	B 2	B 2	B 2	C 2	C 2	A 3	C 2	C 2	B 2	B 2	C 2	C 1
<u>Contributing Information Sources</u>							<u>Program Usage</u>						
A	Primary Source						Very Frequent	1					
B	Frequent Source						Frequent/Occasional	2					
C	Infrequent Source						Infrequent/Rare	3					
D	Rarely/Never												

* Appendix C contains detailed descriptions for each data set.

Government and university research institutions are the third major group of users. Usage by this group includes independent research projects and research sponsored by or in conjunction with the Survey. Amateur prospectors, tourists, out of province users, special interest groups and the general public are included among the final group of users.

4.7 PROPOSED CHANGES AND DESIRED ENHANCEMENTS

With respect to automated systems, the organization is dedicated to exploring all possibilities which offer the potential for increased efficiency, an expansion of existing products, and enhanced analytical capabilities. GIS, automated cartography, remote sensing and image analysis systems are foremost among these. Interest in these technologies varies from program to program and according to individuals within programs. A system for automating cartography was acquired in 1989, and is in various stages of usage according to program interest and resources. It is anticipated that this system will see expanded usage as individuals become familiar with it, and realize the benefits it has to offer.

There is considerable potential for expansion from traditional areas of data collection and evaluation into new areas. A desire was expressed that the Survey acquire the capabilities to quantitatively define mineral potential on a

regional basis. There are also studies looking into the feasibility of expanding into offshore geology, geothermal resources, geophysical surveys, and environmental and hazard geology.

The changes outlined above are consistent with the mandate components listed in section 4.3.

4.8 CONCERNS REGARDING GIS IMPLEMENTATION

With respect to geographical information systems and associated development of digital databases, several concerns were expressed during interviews. They are summarized below.

1. Several sections expressed that GIS implementation should be accompanied by personnel with appropriate expertise for system management and operation.
2. Virtually all personnel interviewed voiced concern that the system acquired should have a friendly, easy to use interface, and should require minimal effort to learn.
3. Several sections expressed that strong analytical capabilities would be an asset. The capabilities were often not explicitly specified, and there was uncertainty as to how they might be used.
4. Some interviewees expressed concern that, due to staffing constraints and limited expertise within the section, the benefits offered by the system may not be accessible to their program.
5. It was voiced that new systems development should be compatible with existing systems to protect the effort and resources spent developing them.
6. Some expressed new data base developments should not compromise accuracy and quality of existing products and services. Others expressed compromises could be made for the sake of efficiency and cost savings.

However, all expressed that no products or services should be entirely lost.

7. The clientele of some units are not equipped to handle information in digital formats. It was therefore a concern that they might suffer if products were made available in digital format only.
8. There is some concern that new technologies will allow the survey to come too close to actual mineral deposit discovery, when it is in the mandate only to assist with this process.

4.9 CHAPTER SUMMARY

The mandate and many of the activities of the B.C. Geological Survey can be traced to the early stages in the province's history. The Survey has particularly strong traditions in assisting the mining and mineral exploration industries, and promoting the mineral potential in the province for development purposes. These traditions arose from the need to assert sovereignty from the threat posed by an influx of American miners. Another characteristic of the Survey, and the Ministry, displayed by Tables 4.2 and 4.3, is that these organizations are continually adapting to change by restructuring. Within the restructuring, a trend can be identified towards expansion and specialization. There are indications that these trends will continue at least into the near future with the addition of an environmental geology unit being considered (Smyth, 1990).

CHAPTER FIVE

GENERAL REQUIREMENTS FOR A GIS: THE GEOLOGICAL SURVEY BRANCH OF BRITISH COLUMBIA

5.0 INTRODUCTION

GIS functionality necessary to support activities of the B.C. Geological Survey are identified in this chapter. Specifications for data input and storage are assessed according to the spatial characteristics of geoscience information managed by the Geological Survey. Output and analytical requirements are assessed based upon the general activities and functions performed by the organisation. The characteristics for a data model can be described taking into account the combined requirements for input and storage, analysis, and output, but keeping in mind the long term goals and mandates of the organisation as well. Functionality for all components are described according to the classification and terminology introduced in Chapter Three.

The chapter concludes with a discussion of various strategies for the B.C. Geological Survey to acquire the capabilities and apply them to the needs of the organisation. Mandates, restrictions imposed by information requirements, and limitations of current technology, are factors taken into consideration in the discussion. The basic tasks to be supported by an automated system are summarised below.

5.1 GEOLOGICAL SURVEY TASKS

It was noted in Chapter Two that the requirements analysis may identify as few as ten per cent of the tasks eventually supported by a GIS. This situation may also apply to geology; it is difficult to isolate specific tasks as there is little tradition for the treatment of geological activities in a spatial-numerical framework. Therefore individual tasks are not dissected into the specific GIS operations necessary to support them, rather they are identified at a more fundamental level. In Chapter Four it was determined that the B.C. Geological Survey engages in five basic activities to support its mandates. The activities include:

1. The collection of geoscience information.
2. The management of geoscience information.
3. Processing and analysis of geoscience information.
4. The publication and distribution of geoscience information.
5. Promotion of the Province's mineral economic potential.

Operations required to support these tasks will be assessed by examining the general nature of the work within the organisation and the characteristics and spatial relationships of the geoscience data used to support this work.

Presently, there is not a direct role for GIS to assist with data collection although related technologies, namely

global positioning systems (GPS), may affect the manner in which geographical field coordinates are recorded and entered to digital data bases. Digital storage of geological information can provide a platform for more efficient and effective management, processing, and analysis of geoscience information. Inquiries of a general and scientific nature can be performed on a more interactive basis thus providing decision makers with details required for land use disputes and other issues. GIS data structures provide the necessary platform to permit integration and analysis of diverse information types (point, line, polygon; discrete, continuous; locational data and non-locational attributes). GIS data structures can also support related cartographical systems to facilitate the publication of geoscience information. Promotion of the province's mineral economic potential can be facilitated through more effective analysis and presentation of information, and through the generation of entirely new products and information.

In the following sections, specific requirements of the five basic functions outlined in Chapter Three (input, storage, analysis, output and data base management) are assessed according to the general needs of the B.C. Geological Survey.

5.2 SPATIAL DATA INPUT AND STORAGE CONSIDERATIONS

To determine input requirements, it is first necessary to identify the spatial characteristics of data to be encoded. Table 5.1 summarises the spatial characteristics of data sets listed in Appendix C. Of the characteristics listed in Chapter Two (section 2.2) only discrete, continuous, and topological properties need to be identified. Metric information is a default component associated with both discrete and continuous data types; it is necessary to describe their spatial position and must therefore be supported by all data structures. Non-locational attributes are assumed to be present in all cases. However, detailed coverage does not fall within the scope of this thesis. Some data sets, for example geochemistry, may consist of only a single theme while other data sets may contain several. Open-File maps, for example, potentially contain several themes including polygonal (bedrock), linear (faults and structural axis), and point (structural measurements). The responsibility of interpreting and organising the data into appropriate themes belongs to the Geological Survey. Spatial relationships include both topological (adjacency and inclusion) and implied relationships (proximity, object-pairs).

According to each data set described in Appendix C, the characteristic is listed as (1) existing and available for direct encoding, (2) existing or implied to exist and may be

directly encoded, or (3) the property does not exist for the data set. Miscellaneous data sets are left out of Table 5.1 because the information is too diverse to be classified according to this scheme. As well, information contained in these data sets is often summarised from other data sets and therefore does not represent a potential input source.

Only the properties which can be physically measured, the explicit properties, are candidates for direct encoding. Implied characteristics must be obtained through some other means. For example, the proximal area of influence associated with a fault can be generated through a buffering operation (line to area, line to surface), or a continuous geochemical surface can be generated through point interpolation.

According to Table 5.1 the only explicit characteristics are discrete point, line, and polygonal entities, and topological relations. To strictly preserve these properties in a digital environment, the capabilities for inputting zero, one, and two dimensional objects, and a means for encoding the properties of adjacency and inclusion must be present.

Both raster and vector data models have the capabilities for input and storage of point, line and areal entities. However only topological-vector encoding is able to explicitly preserve topological properties. If a data model were to be chosen based upon input and storage requirements

DATA SET PROPERTIES		DATA SET, REFERENCE TO APPENDIX C															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Discrete Data	Point	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Line				▨	■	■	■	■	■	■	▨	▨	▨	■	■	
	Area				▨	■	■	■	■	■	■	▨	▨	▨	■	■	
	Volume				▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
Continuous Data	Area				▨							▨	▨	▨			
	Volume				▨							▨	▨	▨			
Topology	Adjacency					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
	Inclusion					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	

■ The property exists and can be directly encoded.

▨ The property exists, or is implied to exist; may be directly encoded.

□ The property does not exist.

Table 5.1: Spatial properties of information collected and managed by the Geological Survey of British Columbia.

alone, then a vector model with topological structuring will suffice. But the choice of a data model cannot be based upon input requirements alone. Analytical and output requirements must also be considered to determine if all the properties need to be encoded.

5.3 REQUIREMENTS FOR ANALYSIS, MANIPULATION, AND INTEGRATION

Requirements for analysis, manipulation, and integration will be described according to the classification outlined in Chapter Three, section 3.3. The operations include:

- A. Operations requiring access to locational information only.
- B. Operations which require access to attributes of one class only.
- C. Operations requiring access to attributes and locational information for a single class of objects.
- D. Operations which create object-pairs from one or more classes of objects and subsequently analyze their attributes.
- E. Operations requiring access to attributes and locational information for more than one class of objects or object-pairs.
- F. Operations which create a new class of objects from an existing class.

Specific operations included with each category can be found in Appendix A. Group B operations are handled by commercial statistical packages or database management systems and, as justified in Chapter Two, they will not be included in this study. According to this classification the defined and potential analytical requirements for each program are described in Appendix B. The relative importance of each operation to each unit is summarised in Table 5.2. The application of each category of operation is discussed in some detail in the following sections.

5.3.1 Group A Operations

Cartographic transformations and manipulations are an important group of operations. The ability to transform spatial information between various projections, reference grids, datums, and reference spheroids is necessary before

<u>PROGRAM</u>	<u>CLASS OF OPERATION</u>				
	A	C	D	E	F
1	■				
2	■	■	■	■	■
3	■	■	■	■	■
4	■	■	■	■	■
5	■	■	■	■	
6	■	■	■	■	■
7	■	■		■	
8	■	■		■	
9	■	■	■	■	■
10	■	■	■	■	■
11	■	■	■	■	■


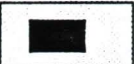
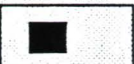


-  Required for existing use on frequent basis.
-  Required for existing use on an infrequent basis.
-  Not currently used but potential for use is identified and falls within mandate.
-  The potential for use exists, but is not within the mandate.
-  No use is foreseen.

Table 5.2: Potential for use of GIS analytical operations in the B.C. Geological Survey. Program reference to Appendix B.

it can be utilised for integration and analysis in a GIS. The location of geological information is currently recorded according to topographic maps based upon the NAD-27 datum. The recent implementation of the NAD 83 datum will require capabilities to transform between these datums. This may be performed through curvilinear transformation or through a datum conversion algorithm specific to this task.

The Scientific Review Office perhaps has the strongest need for operations in this group as cartography falls under its authorization. However, all units of the Survey have elements of cartography involved in their activities, and these operations will see varying use according to programs and individual projects.

The use of perspective and orthographic projections for generating three dimensional block diagrams of topographical surfaces is an application in which the third dimension can be added to geological themes. Similarly projection transformations can be used to generate profiles as an initial step towards the construction of cross sections.

5.3.2 Group C Operations

Descriptive spatial measurements appears to be the most useful application of this category. For example a geological map can be summarised according to the area occupied by rock type, stratigraphy or according to some combination of attributes. Other applications may include

describing object subclasses in terms of shape, orientation, length, perimeter, or some other spatial property.

5.3.3 Group D Operations

This operation presents some difficulties since this relationship has traditionally been handled in a qualitative manner, and there are no methodologies developed for treating it in a numerical manner. Nevertheless, the potential for this type of operation exists. Assuming that the relationship(s) upon which the creation of object-pairs is based includes spatial position, attributes, or some combination thereof, then object-pairs can be created from information maintained by the topological-vector model. Use of operations in this category will depend upon the development of appropriate analytical techniques.

5.3.4 Group E Operations

Of the four object types only discrete objects of zero, one, and two dimensions directly exist within data managed by the Geological Survey. Continuous (point) and three dimensional information are implied and must be obtained through group F object transformations. As a task unto itself, this operation can automate many operations that are currently performed in a manual or descriptive manner, all units of the Survey can potentially benefit from this operation. Applications according to individual units are

summarised in Appendix B. Some application areas are described to illustrate the potential for this operation.

1. Point-Polygon Interactions

The survey manages several point-based database systems which contain fields based upon the occurrence of points within a defined boundary, or polygon. MINFILE, for example, contains at least ten fields of this type including, geological and administrative boundaries. These fields are currently added and updated on a manual basis. If boundary information were available in digital formats, these fields could be added and updated automatically through point-in-polygon operations. This would also make it possible to add additional fields to these data systems, for example land use status, MDLU rank, or other information that occurs in polygonal format. The reverse of this operation could be employed to summarising polygonal information in terms of points falling within polygon classes. For example geological classes may be summarised according to some function of the value of geochemical points falling within them.

2. Line-Polygon Interactions

In a manner similar to that described above, polygonal information can be summarised in terms of line data falling within them. For example, classes of bedrock can be

summarised according to the density of air photo linear features. The reverse of this will see linear information updated with attribute data from spatially coincident polygons.

3. Interactions Involving Polygons

The information managed by the Geological Survey contains few polygonal themes. There are stratigraphic and alteration polygons, and polygons may be obtained through classification of interpolated geochemical, geophysical, or remotely sensed data. Polygonal data may be obtained by characterising proximal influences of points and lines (eg. mineral deposits, faults) using group G operations. The primary themes are stratigraphic polygons, and there is considerable potential to characterise these according to other polygonal types.

5.3.5 Group F Operations

Physical characteristics of geoscience data managed by the B.C. Geological Survey play an important role for determining which operations among this group are needed and how they are to be used. As noted, discrete data existing as points, lines, and polygons are present, continuous and three dimensional characteristics are implied to exist only. Object transformations represent a powerful technique for characterising implied properties of geoscience data.

Proximity is an important property of some data; thus proximal influences associated with contacts, faults, or mineral deposits can be characterised as discrete polygons through point-to-area and line-to-area operations, or as continuous variation through point-to-point and line-to-point operations. Geochemistry may be considered a continuously varying phenomena; but geochemical data must be collected through discrete sampling methods. Point interpolation (point-to-point transformation) is a technique capable of transforming discrete observations into continuously varying surfaces (according to user-defined constraints and with resolution limitations). These operations can be extended into a three dimensional framework to produce discrete volumes or continuous variance through three dimensions. Classifying a continuous surface into discrete polygons is another example of a Group F operations.

These operations have potential for supporting the work of several units within the B.C. Geological Survey. Various operations within this group are singled out in Appendix B according to the needs (or potential needs) of individual units within the Survey. Among these, point interpolation, the transformation of point and linear data to polygon and continuous surfaces, hold the greatest potential. Point interpolation is important because it can bring the implied characteristics of geochemistry to reality, thus

facilitating greater use and enhanced understanding of this information. The transformation of point and linear information is important for portraying proximal relationships.

5.3.6 Section Summary

Identifying analytical requirements presents some difficulties. The identification of functionality based upon an evaluation of existing tasks performed by the agency has been ruled out for various reasons discussed in earlier sections. It is possible though to define the basic relationships upon which these tasks are based. For example, mineral potential studies are based upon the relationships between object types and their attributes (eg. geochemistry-geology, geology-faults, geology-mineral occurrences) which are group F operations. The relationship between an interpolated geochemistry and geology would require group F and G operations combined. Many of the tasks can be described in this general manner without specifying their exact conditions. By specifying the importance of various operations in a general manner, it is possible to identify basic analytical requirements for the organisation. However, utilisation of these operations for 'real world' problems will ultimately depend upon the geoscientist's understanding of spatial processes and his/her ability to identify the operations necessary to complete the project.

5.4 OUTPUT REQUIREMENTS

Output of products is an important function of the B.C. Geological Survey. In Chapter Four this function is described in terms of either products or services. According to Chapter Three, products generally correspond with hardcopy outputs, and services with query. Digital output can be considered an additional product type. The requirements for each output type is assessed below.

5.4.1 Hardcopy Products

Hardcopy products can be divided into maps and reports. Maps include formal cartographical productions (Bulletins), informal maps (Open-Files), and sketch maps which may or may not be registered to a projection. Reports include tabular listings of numerical, text, and graphical information. It is difficult to characterise the format of these products; it is often a matter of style and user preference. As well detailed coverage of cartographical operations are excluded from the scope of this study. However, the ability to output numerical and text information to a generic ASCII format will be useful as most complementary systems (spreadsheets, statistical packages and wordprocessors) will accept an ASCII format. Similarly, spatial data maintained in a generic format will facilitate use of complementary systems specialising in automated cartography.

5.4.2 Query

The Geological Survey spends considerable time and resources retrieving information from geoscience data sets in response to requests from its clients, or for internal purposes. Often there is a geographical element to these retrievals; they are often designed around administrative boundaries, NTS map sheets, or in proximity to a mining region. Geographical queries are divided in Chapter Three into three types; elementary, complex, and metadata queries. The generic form of many information requests can be characterised as 'What exists at this location?' and generally falls into the elementary and metadata query categories. Both query types are ideal for referrals, for supporting management decisions, and for allowing a more interactive response to land use and environmental concerns. Example queries include determining land use status, the status of a project, or the information available for a given area.

Complex queries require knowledge of the database, usage of logical operators, and tend to be more scientific in nature. Typically, they will require the extraction of information based upon a combination of spatial and non-spatial conditions. An example query may be to locate all mineral occurrences which meet the following conditions; (1) contain certain concentration levels of gold and silver, but no arsenic, (2) exist within 1000 metres of a road, (3) no

land use restrictions exist, (4) are located in Jurassic extrusive rock, and (5) lie within 250 metres of a Cretaceous intrusion whose areal extent exceeds five square kilometres. Queries of this nature will tend to originate from within the organisation for support of field projects and other research activities.

Raster based structures are better able to access information of continuous areal coverage and coverages which are continuously varying. Topological-vector structures will be required for searches involving boundaries, adjacency and inclusion. The nature of metadata queries, that is they are often organised according to administrative boundaries and map sheets, suggests they can best be handled using raster based structures.

Responding to queries is an important function and service of the Geological Survey and will likely become more so as information volumes rise, management decisions demand a more multi-disciplinary context, and land use conflicts require a more interactive response to queries. Access to multi-dimensional, multi-thematic information via locational criteria will facilitate these tasks.

5.4.3 Digital Products

It is suggested in Chapter Three that information in digital format may soon be an important product as technology becomes more accessible and numerical techniques

are developed for handling digital geoscience data. Satisfying the needs of all clients presents difficulties as there are presently multiple formats supported by agencies supplying spatial information and by vendors of commercial software products. It is argued therefore that the information must be in a generic format, independent of both technology and commercial idiosyncrasies. A topological-vector format is best able to preserve spatial elements of geometry, topology, and metrics at a primitive level. A spatial data base structured thus, and assuming that thematic components are organised correctly, should allow restructuring to formats of less detail.

5.5 STORAGE: CONSIDERATIONS FOR A DATA MODEL

Determining an appropriate format for data storage is perhaps the most important phase in developing an organisational GIS. Input and storage is recognised as being the most expensive step for GIS development. It therefore is important that the storage format is able to withstand technological changes, support the operations which must be performed upon it, and be able to adapt to changing needs of the organisation and its clients. Various factors will be used to determine the storage format; they include characteristics of the data sets, analytical requirements, and output requirements.

If preservation of physical characteristics of the geoscience data sets is used to determine a storage format, then the following is valid. Geoscience data are collected and recorded as discrete entities. Points and lines are well defined, areal boundaries tend to be abrupt, even when there is associated uncertainty. Vector encoding is designed to preserve such characteristics. Encoding to a raster structure will compromise the accuracy and integrity of the information. If topological consistency is enforced upon the vector information then interpretive relationships associated with adjacency and inclusion can be included as well.

If storage is looked at in terms of analytical requirements, then raster encoding offers more advantages. Many of the operations, especially integration and transformation operations described in categories E and F respectively, cannot be easily performed using vector structures. Moreover, analysis and integration involving continuously varying data sets is feasible only in a raster environment. However, it is relatively easy to convert from vector to raster structures, therefore it can be argued that vector encoding does support raster analysis. Furthermore, some analytical applications, namely network analysis and overlay operations requiring high positional accuracy, are best performed in the vector environment. A vector structure with topological enforcement therefore is capable of

supporting both raster and vector analysis. The same cannot be said for raster structures as conversion from raster to vector structures is difficult and usually results in a loss of information and accuracy.

Taking output into consideration adds further support for topological-vector encoding and storage. As custodian of geological information for the province, the Geological Survey will be expected to provide that information in a variety of formats to suit the needs of various clients. Topological-vector encoding preserves the geometric properties of spatial elements at a primitive level. Information stored in this format can therefore be restructured, in theory, to any other format. This includes CAD structures, therefore automated cartography is supported as well.

Query is more difficult to address. The structural simplicity and continuous coverage offered by grid cell structures make it ideal for many geographical queries. Other queries, such as those involving spatial relationships between classes of spatial objects, are better handled using vector structures. The ease with which vector information can be converted to raster formats suggests that it covers both cases; however, query of continuously varying phenomena is feasible with raster structures only.

A topological structure is clearly the best option for structuring the organisation's geoscience data base.

However, it should be stressed that this applies to current data bases only. Future data sets may include remotely sensed, geophysical and other information which is better suited to raster formats. This should not pose any problems for integration and analysis with topological-vector data as the latter can be easily reformatted to a raster structure.

5.6 SOME CONSIDERATIONS FOR GIS DEVELOPMENT

The data model is the foundation upon which a geographical information system is built. It will determine the current and eventual tasks which commercial software can support, therefore determining the appropriate data model is the first step in implementation. Assuming that a data model has been chosen and the semantics and details of information to be stored in the model are defined, then an implementation scenario can be discussed.

5.6.1 Phases in GIS Development

Based upon experiences with the Canadian Geographical Information System (CGIS), Crain and MacDonald (1984) describe three stages, inventory, analysis, and management, that an information system must go through to be successful. To these, Keller (1990d) adds planning as a fourth stage. The four phases are illustrated in Figure 5.3, showing their relative relationship with time and required effort.

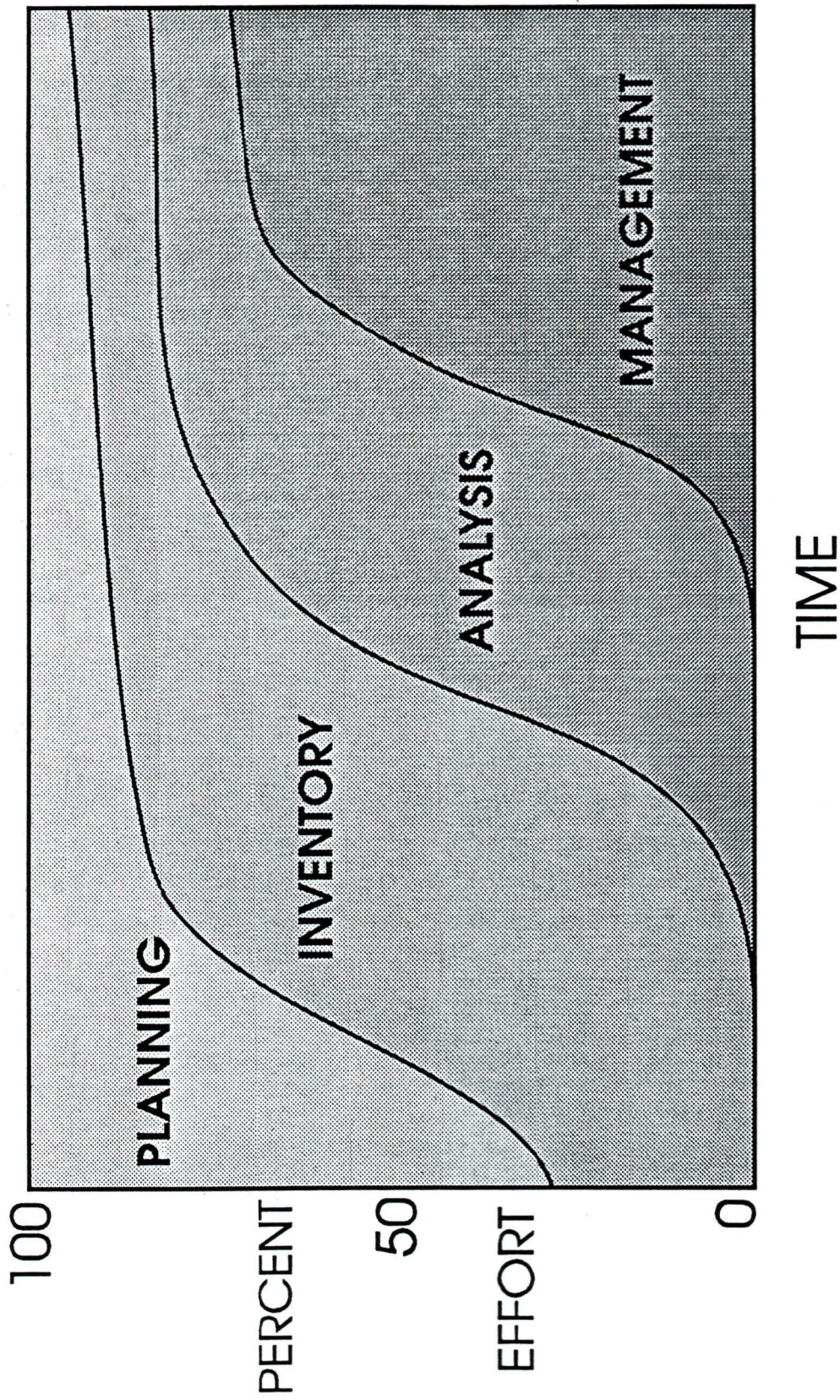


Figure 5.1: Four phases in the evolution of a geographical information system (after Keller, 1990).

In the planning phase an organisation goes through a period of awareness and recognition of the potential for GIS to assist with its work (Keller, 1990d). During this phase acquisition of hardware and software takes place, and the required personnel are trained or acquired. The logical organisation of the GIS data base is also determined.

The inventory phase is characterised by data collection, data input, and data editing. During this stage, the agency ensures that the flow of information and level of service to its clients is maintained. Some new services such as specialized map products or customised queries may be added.

In the third phase the organisation is becoming familiar with the capabilities of the software, complex queries become routine, and the system generates several products on a routine and on-demand basis for clients. Although inventory is not yet complete the primary efforts are now directed towards developing techniques for analysis and modelling.

In the fourth phase basic inventory of data sets has been completed, inventory now consists largely of updating existing data sets and the development of new ones. All sectors of the organisation now routinely use the system to assist with production of maps and reports. Techniques for routine analysis have been developed, thus allowing the organisation to be more interactively involved with environmental and land use issues. Personnel are able to

perform routine queries for clients or in support of research projects and management decisions. Crain and MacDonald (1984) characterise this as the management phase.

5.6.2 Comments Regarding GIS Development in the B.C. Geological Survey

If the B.C. Geological Survey is assessed according to the pattern described above, several observations can be made. The organisation has completed, or is nearing the completion of, several data sets in digital format. These are used for various management, analytical and inventory purposes and, taken as information systems unto themselves, the Geological Survey is into the management phase with these data sets. Using these data sets in a GIS environment should pose few problems as the information exists as points and therefore is structurally uncomplicated. Input into a GIS framework of more complex one and two dimensional variables has not yet begun, the organisation is in the planning phase with respect to these. Completing the inventory stage presents problems because, while the B.C. Geological Survey has a considerable base of historical map information, it was not until 1986 that a systematic effort for mapping the province's geology at a consistent scale (1:50,000) was established. Province wide completion of this information may take several decades. This does not rule out progress to the analytical and management stages. Development of analytical and modelling techniques can begin

almost immediately. However, for management the organisation must work within the limitations imposed by available information, and will be dependent upon surrogate geological data which may not be as accurate. The Geological Survey of Canada, for example, maintains an inventory of geological maps for the province, but at a scale of 1:250,000. Initially, applications will be limited to NTS map boundaries. These boundaries are imposed by administrative concerns and have little, if any, geological significance. However, if the provincial data base is developed according to seamless concepts, then analysis can be based upon boundaries with more geological significance, say geological terrane or physiographical boundaries.

Upon completion of inventory of primary geoscience data sets coupled with development of appropriate analytical, modelling, and data integration techniques, the following benefits can be envisioned. It will be possible to supply clients with up-to-date products in standardised or on-demand formats. The organisation will be able to deal with land-use and other issues on a more interactive or, in some cases, on a proactive basis. Information will be available to support management decisions and to perform mineral potential determinations. The analytical and integrating capabilities of GIS will support research projects through ore deposit modelling, helping to define relationships

between geoscience variables, and by providing geoscientists with a tool to experiment with and to test hypothesis with.

5.8 CHAPTER SUMMARY

A comprehensive enumeration of Geological Survey tasks and related GIS subtasks have not been identified. There simply exists too big a risk of overlooking current tasks and omitting future tasks from the process. Additionally, the numerical and spatial methodologies for handling many tasks, including mineral potential and ore deposit modelling, have not been developed, nor are they fully understood. It is speculative to define requirements under the conditions imposed by these limitations. A different approach has been employed here.

It is argued in Chapter Two that the storage format is the most important element as it will determine the long term usefulness of the data base and ultimately which operations it can support. More importantly, a direct link was established between the storage format and an agency's mandate. Based upon discussions of general requirements for input, analysis and output, it is recommended that the Geological Survey adopt topological-vector encoding and storage for its geoscience data base. It is argued that this format will maintain the characteristics of the information, support required analytical operations, and that it can support all output products. Because it is based upon

established principles it minimises the volatility associated with evolving technology and offers flexibility for future enhancements.

CHAPTER SIX

CONCLUSION

6.0 SUMMARY AND DISCUSSION

While GIS have existed for some time, it is only recently that geological surveys have begun to attempt to develop and implement them. It is noted throughout this study that potential applications of GIS to geology include more efficient and effective management of geo-referenced information, enhanced research capabilities, automating cartography, improved capabilities for addressing environmental concerns, and improved access to geo-referenced data. It was also suggested that GIS can provide a framework for more widespread application of mathematical theories and artificial intelligence techniques developed specifically for geoscience applications. This study examined the implementation of GIS into geoscience organisations.

GIS was defined in Chapter Two as an automated system with capabilities for input, output, storage, and analysis of geographically referenced information. Apparently, this definition can apply in two contexts. From a commercial viewpoint, there is pressure to supply a product that is profitable and that attracts new clients. In turn potential clients, through requirements analysis, stress functionality and technical efficiency as criteria for system selection

and design. Thus the commercial context emphasises GIS development based upon technology and functionality.

Commercial GIS tend to be characterised by vendor specific data structures and terminology, a lack of standardisation, and functional capabilities which, although often specialised towards a particular market niche, are promoted for general purpose use. This view is consistent with early GIS development where implementation was driven by advances in technology and a general need for improved handling of large and diverse geographical data bases.

Alternatively, GIS can be viewed from the needs of a government agency with a long term mandate involving the collection, management, and analysis of resource data. The primary effort involved with corporate GIS lies in developing the spatial data base; thus there is emphasis upon data integrity and long-term stability. This view is consistent with current academic research and stresses spatial data models, generic data standards to facilitate data usage and sharing, and technological independence.

Development of corporate GIS according to the commercial viewpoint creates problems. In particular, spatial data bases, developed at considerable cost and effort, are often made obsolete by technological change, or can not be applied beyond the purpose for which they were developed. This view was criticised for favouring technology over organisational mandates as a basis for GIS development, and commercial

products over spatial data models as a basis for organising a spatial data base. Accordingly, an alternate implementation strategy was put forth and pursued in this thesis, using the B.C. Geological Survey as a case study. This strategy stresses a link between the spatial data model and an organisation's mandate. In response to a defined mandate, data is collected and managed, and various operations are performed upon the data base. In turn, spatial data must be stored to a model which preserves all characteristics of the data, supports all operations to be performed upon the data base, is independent of technology, and allows for flexibility for future operations.

Data models for GIS were reviewed in Chapter Two. It is noted that two key concepts underpinning current GIS development include the separation of locational data from associated non-locational attributes, and the organisation of spatial information according to themes, or layers. Organisation of locational data has focused upon raster versus vector data models. The raster model views space as continuously varying, while in the vector model geographical space is viewed as containing discrete boundaries. Relational DBMS's are widely used for organising spatial data into layers. However, both relational DBMS and the theme concept are being challenged by the object-oriented paradigm. This paradigm questions the thematic assumption that continuous coverage exists for a given theme, asserting

instead that discrete objects exist. DBMS based upon object-orientation also are posing a serious challenge to relational DBMS by addressing some of the weaknesses of the former model. The main points of the raster-vector and object-layer debates were presented in Chapter Two with further discussion in other sections of the thesis. These discussions touched upon the problem of managing the third spatial dimension, the temporal dimension, and seamless data bases. These topics are worthy of further research, but fall beyond the scope of this thesis and must be dealt with by others.

GIS functionality was defined in Chapter Three at a level independent of vendor terminology. Chapter Four has examined the B.C. Geological Survey, summarising its mandate, work, and data management practices. In Chapter Five the potential of GIS to assist this organisation was described by giving examples of how work of the Geological Survey can be supported according to operations described in Chapter Three. A data model has been suggested which will support the work of the B.C. Geological Survey and preserve characteristics of the organisation's data sets. The model is based upon established principles and should therefore allow for flexibility and long term stability.

6.1 CONCLUSION AND RECOMMENDATIONS

Based upon the examinations of this study, several recommendations can be advised. These apply not only to geological surveys, but to other resource agencies as well.

Geoscience data are currently collected and managed by natural resource agencies such that they support a well-defined and long-term mandate. This principle should extend to digital data base development for GIS purposes.

The digital database is the key to a corporate GIS. It will require considerable development effort; its format will determine which operations can be supported, and how robust the digital data can survive technological change and advances. It is argued that a spatial data base structured to the vector model and according to topological principles will best preserve the spatial characteristics of the data, allow for future flexibility, and be independent of changing technologies. The importance of explicitly storing topology is stressed.

Current implementation of GIS in the corporate setting stresses development based upon commercial products. This is clearly inappropriate as commercial products tend to stress operations and algorithms which act upon a data base, and tend also to be susceptible to changing technology. There must therefore be a clear and uncompromising distinction between the digital geoscience database and the software which acts upon it.

Adhering to these recommendations will not guarantee success for individual GIS applications. Based upon the author's personal experiences with commercial software, the success of a project depends not only upon the capabilities of the software, but more importantly upon the ability of the geoscientist to put the problem into a GIS framework. Moreover, it is unlikely that any one commercial vendor will be able to provide the functionality required for all possible applications. Given the diversity and complexity of potential geoscience applications, it is possible that several commercial products will be required for analysis and creation of output products. This strengthens the argument that a spatial data base must be independent of software acting upon it.

LITERATURE CITED

- Abel, D.J. and Mark, D.M., 1990: A Comparative Analysis of Some Two-Dimensional Orderings. International Journal of Geographical Information Systems, 4(1):21-31.
- Abler, R.F., 1987: Presidential Address: What Shall We Say? To Whom Shall We Speak? Annals of the Association of American Geographers, 77(4):511-524.
- Abler, R.F., 1988: Letter in Newsletter, Association of American Geographers, 23(7):2.
- Ady, B. and Currie, A., 1989: Incorporating Interpretive Concepts from a GIS: A Geoscience Example. Geological Survey of Ontario, Preliminary transcript of paper to be presented at GIS conference in Orlando, Florida, November, 1989.
- Agterberg, F.P., 1982: Recent Developments in Geomathematics. Geoprocessing, 2:1-32.
- Agterberg, F.P., 1989: Computer Programs for Mineral Exploration. Science, 245:76-81.
- Alberta Research Council, 1988: GIS Technology Review. Alberta Research Council, Edmonton, Alta.
- Aronoff, S., 1989: Geographic Information Systems; A Management Perspective. WDL Publications, Ottawa, Canada, 294 p.
- Aronson, P., 1987: Attribute Handling for Geographic Information Systems. Proceedings, AutoCarto 8, pp. 346-355.
- Aronson, P., 1989: The Geographic Database - Logically Continuous and Physically Discrete. Proceedings, AutoCarto 9, pp. 452-461.
- Barker, G.R., 1988: Remote Sensing: The Unheralded Component of Geographic Information Systems. Photogrammetric Engineering and Remote Sensing, 54(2):195-199.
- Beggs, A., 1984: History of British Columbia. William Briggs, Toronto, Ont., 568p.
- Berry, J.K., 1987: Fundamental Operations in Computer Assisted Map Analysis. International Journal of Geographical Information Systems, 1(2):119-136.

- Bliss, J.D., Menzie W.D., Orris G.J. and Page N.J., 1987: Mineral Deposit Density - A Useful Tool for Mineral-Resource Assessment in USGS Research on Mineral Resources. Abstract in Circular 995, U.S. Geological Survey, Reston, VA, p.6.
- Bodechtel, J. and Sommer, S., 1989: Use of a Geographic Information System and Image Processing Techniques to the Integration of Remote Sensing Data and Different Geoscientific Datasets to Mineral Exploration in the Iglesias Mining District (SW Sardinia), in Summaries: 7th Thematic Conference on Remote Sensing for Exploration Geology, Calgary, Alta., Environmental Research Institute of Michigan, p. 47.
- Bonham-Carter, G.F., Agterberg, F.P. and Wright, D.F., 1988a: Integration of Gold Datasets for Gold Exploration in Nova Scotia. Photogrammetric Engineering and Remote Sensing, 54(11):1582-1592.
- Bonham-Carter, G.F., Rencz, A.N., and George, H., 1988b: Combining Geoscience Datasets Using a Spatial Analysis System on a Microcomputer, Abstract from Joint Annual Meeting, GAC, MAC and CSPG, St. John's Newfoundland, p. A12.
- Brabb, E.E., 1987: Analyzing and Portraying Geologic, Cartographic, and Hydrologic Information for Land Use Planning, Emergency Response, and Decision Making in San Mateo County, California. Abstract in Open File Report 87-314, U.S. Geological Survey, Reston, VA, p. 20.
- British Columbia List, 1982: First Edition, B&C List, Vancouver, B.C.
- British Columbia List, 1988: Seventh Edition, B&C List, Vancouver, B.C.
- British Columbia, Province of, 1989: Update from the Government of British Columbia, Summer, 1989, p.7.
- British Columbia Ministry of Crown Lands, 1988: NAD 83. Distributed information circular.
- British Columbia Ministry of Crown Lands, 1990: British Columbia Spatial Archive Interchange Format, Release 0.1, Victoria, B.C.
- British Columbia Ministry of Energy, Mines and Petroleum Resources, 1988, Geological Survey Branch 1988-1989 Plan, Victoria, B.C.

- Buchanan, R. and Steeples, D., 1990: On-Demand Map Publication. Geotimes, 35(2):19-21.
- Burrough, P.A., 1987: Principles of Geographical Information Systems for Land Resources Assessment, Cleardon Press, Oxford, 193p.
- Burrough, P.A., 1990: Preface, Methods of Spatial Analysis in GIS. International Journal of Geographical Information Systems, 4(3):221-223.
- Buttenfield, B.P., 1985: Treatment of the Cartographic Line. Cartographica, 22(2):1-26.
- Carlyle, E.J., 1951: The British Columbia Department of Mines: A Record of its Origin, Development, and Functions. Western Miner, May, 1951:47-51.
- Chauvin, L., 1989: A Geographic Information System at the Ministere de l'Energie et des Ressources du Quebec (Secteur Mines). PRO 89-01, Distributed publication, Government du Quebec.
- Chin, F.L. and Lee, Y.C., 1989: Object-Oriented Database Approach in Geographic Information Systems. Unpublished paper presented at Student Paper Competition, Canadian Cartographic Association, Annual General Meeting, Halifax, N.S.
- Chorley, 1987: Handling Geographic Information: Report of the Committee of Enquiry Chaired by Lord Chorley. Her Majesty's Stationary Office, London.
- Chrisman, N.R., 1987a: Efficient Digitizing Through the Combination of Appropriate Hardware and Software for Error Detection and Editing. International Journal of Geographical Information Systems, 1(3):265-277.
- Chrisman, N.R., 1987b: Design of Geographic Information Systems Based on Social and Cultural Goals. Photogrammetric Engineering and Remote Sensing, 53(10):1367-1370.
- Chrisman, N.R., 1990: Deficiencies of Sheets and Tiles: Building Sheetless Databases. International Journal of Geographical Information Systems, 4(2):157-167.
- Clarke, K.C.; 1990: Analytical and Computer Cartography. Prentice-Hall, Englewood Cliffs, NJ, 290 p.

- Coppock, T. and Anderson, E., 1987: Editorial Review. International Journal of Geographical Information Systems, 1(1):3-11.
- Cowen, D.J., 1988: GIS vs. CAD vs. DBMS: What are the Differences?. Photogrammetric Engineering and Remote Sensing, 54(11):1551-1555.
- Crain, I.K., and MacDonald, C.L., 1984: From Land Inventory to Land Management. Cartographica, 21(3,4):40-46.
- Crosswell, P.L., and Clark, S.R., 1988: Trends in Automated Mapping and Geographic Information System Hardware. Photogrammetric Engineering and Remote Sensing, 54(11):1571-1576.
- Currie, A., 1986: Spatial Information Systems and Their Potential for Mineral Exploration. CAME '86, Extended Abstracts, Program & Exhibition Guide, CIM, Toronto, Ont. pp. 66-68.
- Currie, A. and Ady, B. 1989: Extended GIS-an Enriched Model used to Represent Geoscience Spatial Data. Proceedings of National Conference, Challenge for the 90's, Geographic Information Systems, Canadian Institute of Surveying and Mapping, Ottawa, Canada, pp. 978-995.
- Dangermond, J., and Freedman, C., 1983: Ontario User Needs Study - A Description of the Project Methodology and Analysis Procedures. Proceedings of Seminar on Land-Related Information Systems, Ministry of Natural Resources, Ontario, pp. 28-76.
- Dangermond, J., 1989: GIS Data Structures: Objects vs. Layers, GIS Sourcebook, Denver, CO, pp. 18-20.
- Davis, J.C., 1986: Statistics and Data Analysis in Geology, Wiley, New York, 646p.
- De Man, W.H.E., 1988: Establishing a Geographical Information System in Relation to its Use: A Process of Strategic Choices. International Journal of Geographical Information Systems, 2(3):245-261.
- Dickinson, H.J. and Caulkins, H.W., 1988: The Economic Evaluation of Implementing a GIS. International Journal of Geographical Information Systems, 4(2):307-327.
- Dobson, J.E., 1988: Letter in Newsletter, Association of American Geographers, 23(7):2.

- Dueker, K.J., 1985: Geographic Information Systems: Toward a Geo-Relational Structure. Proceedings, AutoCarto 7, Washington D.C., pp. 172-178.
- Dueker, K.J., 1987: Geographic Information Systems and Computer-Aided Mapping. Journal of the American Planning Association, 53(2):383-390.
- Dueker, K.J. and Kjerne, D., 1987: Application of the Object-Oriented Paradigm to Problems in Geographic Information Systems. Proceedings, International Geographic Information Systems (IGIS) Symposium: The Research Agenda, NASA, Washington, D.C., II:79-87.
- Duntemann, J. and Marinacci, C., 1990: New Objects for Old Structures. BYTE, 15(4):261-266.
- Dwyer, J.L. and Nash, J.T., 1987: Spatial Analysis of Geochemical and Geologic Information From the Tonopah, Nevada, CUSMAP Project. Abstract in Open File Report 87-314, U.S. Geological Survey, Reston, VA, pp. 9-10.
- Egenhofer, M.J. and Frank, A.U., 1987: Object-Oriented Databases: Database Requirements for GIS. Proceedings, International Geographic Information Systems Symposium: The Research Agenda, NASA, Washington, D.C., II:189-211.
- Egenhofer, M.J. and Frank, A.U., 1989: Object-Oriented Modelling in GIS: Inheritance and Propagation. AutoCarto 9, pp. 588-598.
- Ehlers, M., Edwards, G. and Bédard, Y., 1989: Integration of Remote Sensing With Geographic Information Systems: A Necessary Evolution. Photogrammetric Engineering and Remote Sensing, 55(11):1619-1627.
- Ehrlich, R., 1988: Mathematical Geology & Computers. Geotimes, 33(2):39-40.
- Ellen, S.D. and Mark, R.K., 1988: Automated Modelling of Debris-Flow Hazard Using Digital Elevation Models. Abstracts: Integrating Technology and Geoscience Applications, National Academy of Sciences, Denver, CO, p.134.
- Elliot, J.E., Trautwein, C.M., Dwyer, J.L. and Moll S.H., 1989: Mineral Resource Assessment of the Butte 1° X 2° Quadrangle Using Geographic Information System Technology, in Circular 1035, U.S. Geological Survey, Reston, VA, pp 16-17.

- Energy, Mines and Resources Canada, 1989: Federal Geomatics Bulletin, Editorial note on inside cover, 1(2):2.
- Fabbri, A.G., 1984: Digital Processing of Geological Data. Van Nostrand Reinhold Co. Inc., New York, NY, 244p.
- Federal Geomatics Bulletin, 1989: Geographic Information Systems Division, Energy, Mines and Resources Canada, 1(2):2.
- Fisher, P.F. and Lindenberg, R.E., 1989: On Distinctions Among Cartography, Remote Sensing, and Geographic Information Systems. Photogrammetric Engineering and Remote Sensing, 55(10):1431-1434.
- Frank, A.U., 1987: Towards a Spatial Theory. Proceedings, International Geographic Information Systems (IGIS) Symposium: The Research Agenda, NASA, Washington, D.C., II:215-227.
- Frank A.U., 1988: Requirements for a Database Management System for a GIS. Photogrammetric Engineering and Remote Sensing, 54(11):1557-1564.
- GEOSIS Newsletter, The Scientific Review Office of the Ontario Geological Survey. John Ernsting, ed., Issue nos. 1-8.
- Gilmartin, P.P., Kamlesh, K.P. and Mark, D.M., 1988: Letter in Newsletter, Association of American Geographers, 23(7):2.
- Goodchild, M.F., 1985: Geographic Information Systems in Undergraduate Geography: A Contemporary Dilemma. The Operational Geographer, 8:34-38.
- Goodchild, M.F., 1987a: Proceedings, International Geographic Information Systems (IGIS) Symposium: The Research Agenda, NASA, Washington, D.C., II:67-77
- Goodchild, M.F., 1987b: A Spatial Analytical Perspective on Geographical Information Systems. International Journal of Geographical Information Systems, 1(4):327-334.
- Goodchild, M.F., 1989: Optimal Tiling for Large Cartographic Databases. Proceedings, AutoCarto 9, pp. 444-451.
- Goodchild, M.F. and Rizzo, B.R., 1987: Performance Evaluation and Workload Estimation for Geographic Information Systems. International Journal of Geographical Information Systems, 1(1):67-76.

- Goodchild, M.F. and Grandfield, A.W., 1983: Optimizing Raster Storage: An Examination of Four Alternatives. Proceedings, AutoCarto 6, pp. 400-407.
- Green, G.N. and Pratt, W.P., 1987: The Paducah Project: A Digital CUSMAP. Abstract in Open File Report 87-314, U.S. Geological Survey, Reston, VA, p. 34-35.
- Green, K.A., 1987: Critical Management and Technical Considerations When Planning for a GIS Acquisition. Proceedings, International Geographic Information Systems (IGIS) Symposium: The Research Agenda, NASA, Washington, D.C., III:245-256.
- Guptill, S.C., 1988: A Process for Evaluating Geographic Information Systems. Open-File Report 88-105, U.S. Geological Survey, Reston, VA.
- Guptill, S.C., 1989a: Evaluating Geographic Information Systems Technology. Photogrammetric Engineering and Remote Sensing, 55(11):1583-1587.
- Guptill, S.C., 1989b: Designing an Enhanced Digital Line Graph. Proceedings, Autocarto 9, pp. 252-261.
- Guptill, S.C., 1989c: Personnal Communication. October 20, 1989, U.S. Geological Survey, Reston, VA.
- Guptill, S.C., 1989d: Speculations on Seamless, Scaleless Cartographic Databases. Proceedings, AutoCarto 9, pp. 436-443.
- Guptill, S.C., 1990: Benchmark Scenarios for Geographic Information Systems. Technical Papers, ACSM/ASPRS Annual Convention, Denver, CO, p.91.
- Hammen, J., 1988: Letter in Newsletter, Association of American Geographers, 23(7):2
- Harvey, D.W., 1969: Explanation in Geography. Butler & Tanner Ltd., Frome and London, 519 p.
- Hedley, M.S., 1969: Internal Memorandum, Mineralogical Branch. Department of Mines and Petroleum Resources, February 7, 1969, 3p.
- Herring, J.R., 1989: A Fully Integrated Geographic Information System. Proceedings, AutoCarto 9: 828-837.
- Hohn, M.E., 1990: Mathematical Geology. Geotimes, 35(2):39.

- Hohn, M.E., Smith, C.J., Ashton, K.C. and McColloch, G.H., 1987: Computer Mapping for Coal Grade Evaluation. Proceedings, International Geographic Information Systems (IGIS) Symposium: The Research Agenda, NASA, Washington, D.C., III:499-508.
- Howay, F.W., 1914: British Columbia: From the Earliest Times to the Present. S.J. Clarke, Vancouver, B.C., 727p.
- Hyndman, 1990: The Collective Impact of Federal Withdrawals and Land Management Plans on the Federal Mineral Estate and Known Mineral Deposit Areas in Idaho. Proceedings, GIS for the 1990's, Canadian Institute of Surveying and Mapping, Ottawa, pp. 365-372.
- Joint Nordic Project, 1987: Digital Map Data Bases, Economics and User Experiences in North America. Publications Division, National Board of Survey, Helsinki, Finland.
- Jones, C.B., 1989: Data Structures for Three-dimensional Spatial Information Systems in Geology. International Journal of Geographical Information Systems, 3(1):15-31.
- Jordan, T.G., 1988: President's Column: The Intellectual Core. Newsletter, Association of American Geographers, 23(5):1
- Keaton, J.R., and Anderson, L.R., 1988: Mapping Earthquake-Induced Landslide Potential With GIS. Abstracts: Integrating Technology and Geoscience Applications, National Academy of Sciences, Denver, CO, p.126-29.
- Keller, C.P., 1990a: Issues to Consider when Developing a GIS Curriculum. Proceedings, GIS 90, Vancouver B.C.
- Keller, C.P., 1990b: Planning Geographical Information Systems Installation. Manuscript prepared for the Planning Institute of British Columbia.
- Keller, C.P., 1990c: Personal Communication, Department of Geography, University of Victoria, British Columbia.
- Keller, C.P., 1990d: GIS Management Seminar Series Developed for the B.C. Ministry of Forests.
- Krumm, R.J., Pool, R.R., McKay, E.D. and Smith, L.R., 1988: Geologic Applications of an Extensive GIS Database: Examples From Illinois in Abstracts: Integrating Technology and Geoscience Applications, National Academy of Sciences, pp 70-71.

- Lai, P., 1990: Feasibility of Geographic Information Systems Approach for Natural Resource Management. Environmental Management, 14(1):73-80.
- Langran, G., 1989: A Review of Temporal Database Research and Its Use in GIS Applications. International Journal of Geographical Information Systems, 3(3):215-232.
- Langran, G. and Chrisman N.R., 1988: A Framework for Temporal Geographic Information. Cartographica, 25(3):1-14.
- Logan, T.L. and Bryant, N.A., 1987: Spatial Data Software Integration: Merging CAD/CAM/Mapping with GIS and Image Processing. Photogrammetric Engineering and Remote Sensing, 53(10):1391-1395.
- Loudon, T.V., 1986: Digital Spatial Models and Geological Maps. Proceedings, Auto Carto London, 2:60-65.
- Madigan, M.E., Sturdevant, J.A. and Roberts, C.A., 1988: Using GIS to Evaluate Map Data. Geotimes, 33(4):14-15.
- Maffini, G., 1987: Raster Versus Vector Data Encoding and Handling: A Commentary. Photogrammetric Engineering and Remote Sensing, 53(10):1397-1398.
- Maffini, G. and Saxton, W., 1987: Deriving Value from the Modelling and Analysis of Spatial Data. Proceedings, International Geographic Information Systems (IGIS) Symposium: The Research Agenda, NASA, Washington, D.C., III:271-290.
- Maguire, D.F., 1989: Computers in Geography. Longman Group (FE) Ltd., Hong Kong, 248p.
- Marble, D.F., 1984: Geographic Information Systems: An Overview in GIS for Resource Management: A Compendium, American Congress on Surveying and Mapping and American Society for Photogrammetry and Remote Sensing, Falls Church, VA. pp. 2-8.
- Mark, D.M., 1990: Neighbour-based Properties of Some Orderings of Two-dimensional Space. Geographical Analysis, 22(2):145-157.
- Mark, D.M. and Cebrian, J.A., 1986: Octrees: A Useful Data-Structure for the Processing of Topographic and Sub-Surface Data. ACSM/ASPRS Technical Papers, 1:104-113.

- Mark, D.M. and Lauzon, J.P., 1984: Linear Quadrees for Geographic Information Systems. Proceedings, Symposium on Spatial Data Handling, Zurich, Switzerland, II:412-430.
- Mark, D.M., Lauzon, J.P. and Cebrian, J.A., 1989: A Review of Quadtree-based structures for Interfacing Coverage Data With Digital Elevation Models in Grid Form. International Journal of Geographical Information Systems, 3(1):3-14.
- Marsh, S.P., Sandoval, E. and Plesha, J.L., 1989: A Simplified Geological Map of Nevada for Regional Gold Resource Assessment in USGS Research on Mineral Resources. Abstracts in Circular 1035, U.S. Geological Survey, Reston, VA, pp. 44-45.
- Maslyn, R.M., 1986: EXPLOR and PROSPECTOR - Expert Systems for Oil and Gas and Mineral Exploration. in Microcomputer Applications in Geology, Hanley, J.T. and Merriam D.F., eds. Pergamon, Oxford, pp. 89-103.
- McCannon, R.B., 1987: Artificial Intelligence Applications Using PROSPECTOR. Abstract in Open File Report 87-314, U.S. Geological Survey, Reston, VA p. 40.
- McHarg, I., 1969: Design With Nature. Doubleday, Garden City, New Jersey, p.
- McKay, E.D. and Leighton, M.W., 1988: GIS Utilization by State Geological Surveys: Results of a 1988 AASG Questionnaire. Unpublished Report, Illinois State Geological Survey, Champaign, IL.
- McMaster, R.B., 1987: Automated Line Generalization. Cartographica, 24(2):74-111.
- McPhee, J., 1982: In Suspect Terrain. McGraw-Hill Ryerson Ltd., Toronto, Canada, 210p.
- Meckley, B., 1987: Determining Your GIS Requirements: The Critical First Step. Proceedings, International Geographic Information Systems (IGIS) Symposium: The Research Agenda, NASA, Washington, D.C., III:257-269.
- Mennim, K.C., 1986: Raster Techniques in Geologic Map Production. Proceedings, Auto Carto London, 1:267-271.
- Moellering, H., 1988: Fundamental Concepts That Form the Basis of the Proposed American Cartographic Data Exchange Standard. Cartography, 17(2):9-14.

- Montgomery, G.E., 1989: Guide To Project Implementation. in GIS SOURCEBOOK, pp. 133-146.
- Montgomery, G.E., 1990: GIS Planning & Implementation. GIS WORLD, November/December, 1990, pp.37, 57-58.
- Morgan, J.M.III, 1987: Academic Geographic Information Systems Education: A Commentary. Photogrammetric Engineering and Remote Sensing, 53(10):1443-1445.
- Muller, J.C., 1985: Geographic Information Systems: A Unifying Force for Geography. The Operational Geographer, 8:41-43.
- NCGIA, 1990: Introduction to GIS. Goodchild, M.F. and Kemp, K.K., editors, National Center for Geographic Information and Analysis, University of California, Santa Barbara.
- Nicholson, R.L., 1988: Letter in Newsletter, Association of American Geographers, 23(7):2.
- Nyerges, T.L., 1980: Representing Spatial Properties in Cartographic Databases. Proceedings, ACSM Spring Meetings, St. Louis, pp. 29-41.
- Nyerges, T.L., 1987: GIS Research Needs Identified During a Cartographic Standards Process: Spatial Data Exchange. Proceedings, International Geographic Information Systems (IGIS) Symposium: The Research Agenda, NASA, Washington, D.C., I:319-329.
- Nyerges, T.L. and Chrisman, N.R., 1989: A Framework for Model Curricula Development in Cartography and Geographic Information Systems. The Professional Geographer, 41(3):283-293.
- O'Donnell, J.H., 1989: The Role of the Federal Government in GIS. CISM Journal, 43(3):233-236.
- Olimpio, J.C., and Flynn, E.C., 1988: Assessing Risk to Water Quality at Public Water-Supply Sites, Cape Cod, Massachusetts. Abstracts with Programs 1988, Geological Association of America, 20(1):59.
- Oliver, M.A. and Webster, R., 1990: Kriging: A Method of Interpolation for Geographical Information Systems. International Journal of Geographical Information Systems, 4(3):313-332.
- Openshaw, S., 1987: Guest Editorial: An Automated Geographical Analysis System. Environment and Planning A, 19:431-436.

- Openshaw, S., Charlton, M., Wymer, C. and Craft, A., 1987: A Mark 1 Geographical Analysis Machine for the Automated Analysis of Point Data Sets. International Journal of Geographical Information Systems, 1(4):335-338.
- Parker, H.D., 1988: The Unique Qualities of a Geographic Information System: A Commentary. Photogrammetric Engineering and Remote Sensing, 54(11):1547-1549.
- Parker, H.D., 1989: GIS Software 1989: A Survey and Commentary. Photogrammetric Engineering and Remote Sensing, 55(11):1589-1591.
- Peucker, T.K., Fowler, R.J., Little, J.J. and Mark, D.M., 1978: The Triangulated Irregular Network. Proceedings, American Society of Photogrammetry: Digital Terrain Models (DTM) Symposium, St. Louis, MS, pp. 516-540.
- Peuquet, D.J., 1984: A Conceptual Framework for Comparisons of Spatial Data Models. Cartographica, 21(4):66-113.
- Peuquet, D.J., 1988: Representations of Geographic Space: Towards a Conceptual Synthesis. Annals of the Association of American Geographers, 78(3):375-394.
- Pountain, D., 1990: Object-Oriented Programming. BYTE, 15(2):257-264.
- Reddy, R.K.T., Bonham-Carter, G.F. and Wright, D.F., 1990: GIS in Mapping and Assessing Mineral Resource Potential: An Application to Base-Metal Resource Evaluation in Manitoba. Proceedings, GIS for the 1990's, Canadian Institute of Surveying and Mapping, Ottawa, pp. 384-400.
- Rich, D., 1990: Mathematical Geology & Computers. Geotimes, 35(2):36-38.
- Richardson, D.L. and Nelms, D.L., 1988: Geographic Information Systems for the Assessment of Contamination by Volatile Organic Compounds in the Triassic Basin of Prince William County, Virginia in Abstracts: Integrating Technology and Geoscience Applications, National Academy of Sciences, p. 137.
- Robinson, A.H., Sale, R.D., Morrison, J.L. and Muehrcke, P.C., 1985: Elements of Cartography. 5th ed. John Wiley & Sons, Toronto.

- Rogers, P.J., Bonham-Carter, G.F. and Ellwood, D.J., 1988: Regional Stream Sediment Geochemistry and Exploration of a Mature Area: Target Selection By Catchment Basin Analysis, Cobeguid Highlands, Nova Scotia in Abstracts: Integrating Technology and Geoscience Applications, National Academy of Sciences, pp. 24-25.
- Rosmeissl, H.J., 1989: The Spatial Data Transfer Standard: A Status Report. ACSM Technical Papers, Falls Church, VA, pp. 129-135.
- Samet, H., 1984: The Quadtree and Related Hierarchical Data Structures. ACM Computer Surveys, 16(2):187-260.
- Samet, H., 1989: The Design and Analysis of Spatial Data Structures. Addison-Wesley, Reading, MA.
- Sawayama, G., 1989: British Columbia, contribution to 'Provincial Progress in GIS'. CISM Journal, 43(3):276.
- Segal, D.B., Tanaka, S.M. and Daniel J.P., 1988: Gold Exploration Using Integrated Remote Sensing/GIS Technology, Round Mountain District, Nevada. Abstracts, Integrating Technology and Geoscience Applications, National Academy of Sciences/National Research Council, Denver, CO, p. 26.
- Selden, D.D., 1987: Success Criteria for GIS. Proceedings, International Geographic Information Systems (IGIS) Symposium: The Research Agenda, NASA, Washington, D.C., III:239-242.
- Selkirk, K.E., 1982: Pattern and Place, An Introduction to the Mathematics of Geography. Cambridge University Press, 203p.
- Sheath, N.J., 1986: Development of an Integrated Map Plotting System for Hydrocarbon Exploration. Proceedings, Auto Carto London, 1:66-75.
- Simpson, J.W., 1989: A Conceptual and Historical Basis for Spatial Analysis. Landscape and Urban Planning, 17:313-321.
- Simpson, R.L., 1989: (in) Provincial Progress in GIS. CISM Journal, 43(3):271-272.
- Smith, L.R., McKay, E.D., Krumm, R.J. and Pool, R.R., 1988: Siting a Low-Level Radioactive Waste Disposal Facility in Illinois: A GIS Approach. Abstracts: Integrating Technology and Geoscience Applications, National Academy of Sciences, Denver, CO, p.66-69.

- Smith, T.R., Menon, S., Star, J.L. and Estes, J.E., 1987: Requirements for Principles for the Implementation and Construction of Large-Scale Geographic Information Systems. International Journal of Geographical Information Systems, 1(1):13-31.
- Smyth, W.R., Chief Geologist, B.C. Geological Survey, 1990: Personal Communication, October, 1990.
- Snyder, J.P., 1987: Map Projections - A Working Manual. Professional Paper 1395, U.S. Geological Survey, Reston, VA, 388 p.
- Sondheim, M., Lowe, G., Menes, R. and Friesen, P., 1990: A Data Model For Geomatics. Surveys and Resource Mapping Branch, Internal Paper, British Columbia Ministry of Crown Lands, 16p.
- Sowerbutts, W.T.C., 1988: Displaying Geological 3-D Surfaces Using Computer Graphics. Geology Today, 4(2):54-56.
- Star, J. and Estes, J., 1990: Geographic Information Systems: An Introduction. Prentice-Hall Inc., Englewood Cliffs, NJ, 303p.
- Stewart, D.B., Unger, J.D., Phillips, J.D. and Wright, B.E., 1988: The Quebec-Maine-Gulf of Maine Global Geoscience Transect Onshore and Offshore in Maine as an Example of a Three-Dimensional Geographic Information System (GIS). Abstracts with Programs 1988, Geological Association of America, 20(1):73.
- Stoddard, R.H., 1982:, Field Techniques and Research Methods in Geography, Kendall/Hunt, Dubuque, IA.
- Stone, C.M. and Hentchel, D., 1990: Database Wars Revisited. BYTE, 15(10):233-242.
- Sturdevant, J.A., 1988: Toward a Federal Land Information System: Experiences and Issues. Bulletin 1852, U.S. Geological Survey, Reston, VA, 15 p.
- Tarr, A.C. and Crane, M.P., 1988: Application of GIS to Assessment of Seismic Hazards in the Pacific Northwest. Abstracts: Integrating Technology and Geoscience Applications, National Academy of Sciences, Denver, CO, p.128-129.
- The American Cartographer, 1988: The Proposed Standard for Digital Cartographic Data, 15(1):144 p.

- Thompson, D.W., 1966: Men and Meridians. Supply and Services Canada, Ottawa.
- Tomlin, C.D. and Berry, J.K., 1979: A Mathematical Structure for Cartographic Modelling in Environmental Analysis. Proceedings of the 39th Symposium, American Congress on Surveying and Mapping, Falls Church, VA, pp. 269-283.
- Tomlin, C.D., 1990: Geographic Information Systems and Cartographic Modelling. Prentice-Hall, Englewood Cliffs, NJ, 249p.
- Tomlinson, R.F., 1984: Geographic Information Systems - A New Frontier. The Operational Geographer, 5:31-34.
- Tomlinson, R.F., 1987: The Current and Potential Uses of Geographical Information Systems. The North American Experience. International Journal of Geographical Information Systems, 1(3):203-218.
- Tomlinson, R.F., 1988: The Impact of the Transition From Analogue to Digital Cartographic Representation. The American Cartographer, 15(3):249-261.
- Tomlinson, R.F., 1989: Presidential Address: Geographic Information Systems and Geographers in the 1990's. The Canadian Geographer, 33(4):290-298.
- Tompa, F.W., 1977: Data Structure Design. in Data Structures, Computer Graphics, and Pattern Recognition, Klinger, Fu and Kuni, eds. Academic Press Inc., New York, pp. 3-30.
- Trautwein, C.M., Pearson, R.C. and Elliot, J.E., 1988: GIS Applications to Conterminous United States Mineral Assessment Program Investigations. Abstracts: Integrating Technology and Geoscience Applications, National Academy of Sciences, Denver, CO, p.20-21.
- Unwin, D.J., 1981: Introductory Spatial Analysis. Methuen, London.
- Unwin, D.J., Blakemore, M.J., Dale, P., Healy, R.G., Jackson, M., Maguire, D.J., Martin, D., Mounsey, H. and Willis, J., 1990: A Syllabus for Teaching Geographical Information Systems. International Journal of Geographical Information Systems, 4(4):457-465.
- Vrana, R., 1989: Historical Data as an Explicit Component of Land Information Systems. International Journal of Geographical Information Systems, 3(1):33-49.

- Walker, J.F., 1937a: Department of Mines. Journal of the Department of Public Works, British Columbia Public Works, 37(2):11.
- Walker, J.F., 1937b: Re-organization of the Department of Mines, Victoria, During the Past Three Years. Unpublished Document, Ministry of Energy, Mines and Petroleum Resources, British Columbia, Victoria, 7p.
- Waters, N.M., 1989a: Edge Nodes, Column in GIS WORLD, November/December, 1989, p.78.
- Waters, N.M., 1989b: Do You Sincerely Want to Be a GIS Analyst. The Operational Geographer, 7(4):30-35.
- Watson, G.P., Rencz, A.N. and Bonham-Carter, G.F., 1989: Computers Assist Prospecting. GEOS, 18(1):8-15.
- Wernecke, L., 1988: Geographic Information Coordination in the States. Information Management Review, 3(4):27-38.
- White, E., 1985: Assessment of Line-Generalization Algorithms Using Characteristic Points. The American Cartographer, 12(1):17-27.
- White, M.S., 1984a: Technical Requirements and Standards for a Multipurpose Geographic Data System. American Cartographer, 11(1):15-26.
- White, M.S., 1984b: Tribulations of Automated Cartography and How Mathematics Helps. Cartographica, 21(2&3):148-159.
- White, R.C., 1990: The Effect of the North American Datum of 1983 on Oil Exploration Maps. Denver Geotech '89, Denver, CO, pp. 110-119.
- White, W.H., 1961: An Historical Outline of B.C. Mining. Western Miner, June, 1961.
- Wignall, T.K. and De Geoffroy, J., 1987: Statistical Models for Optimizing Mineral Exploration. Plenum Press, N.Y., 432 p.
- Wilcox, D.L., 1990: Concerning 'The Economic Evaluation of Implementing a GIS'. International Journal of Geographical Information Systems, 4(2):203-210.

Wright, B.E. and Stewart, D.B., 1989: Digitization of a Geologic Map for the Quebec-Maine-Gulf of Maine Global Geoscience Transect. Circular 1041 (Preliminary draft obtained from authors), U.S. Geological Survey, Reston, VA, 37p.

APPENDIX A: GIS FUNCTIONALITY

Note: The following generally applies. Operations with numerical prefixes (eg. 2.6.1.2) are defined at a level which can be considered independent of vendor bias. Operations preceded by a letter may represent vendor specific terminology. Terms preceded by a '-' are examples added for illustrative purposes.

1: INPUT AND STORAGE

1.1: INPUT MODE

1.1.1: AUTOMATED INPUT

- a. Video scanning
- b. Analog scanning
- c. Remote sensing
- d. Rasterisation of vector structures
- e. Data structure reformatting
 - see section 3.3.1, this Appendix

1.1.2 MANUAL INPUT

- a. Keyboard Entry
- b. Digitising

1.2: STORAGE

1.2.1: VECTOR

1.1.2.1: Zero Dimensional Objects (Points)

- a. entity points
- b. label points
- c. area points
- d. nodes

1.1.2.2: One Dimensional Objects (Lines)

- a. line segments
- b. strings
- c. arcs
- d. links
- e. directed links
- f. chains
- g. complete chains
- h. area chains
- i. network chains
- j. rings (created from strings, arcs, links, chains)

1.1.2.3: Two Dimensional Objects (Areas)

- a. interior areas
- b. polygons
- c. complex polygons (one containing inner rings)

1.1.2.4: Three Dimensional Objects (Volume)

1.2.2: RASTER

1.2.2.1: Raster Scan Orders

- a. Row
- b. Row prime
- c. Morton (Employed by recursive structures)
- d. Pi order

1.2.2.2: Storage Structures

- a. Run-length encoding
- b. Recursive techniques (eg. quadtree)
- c. Block encoding

1.2.2.2: Encoding of Three Dimensional Arrays

- a. Voxel
- b. Octree

1.3: EDITING CAPABILITIES

1.1.3.1: Object Manipulation

- a. Move objects
- b. Rotate objects
- c. Copy objects
- d. Delete objects
- e. Break objects

1.1.3.1: Topological Editing

1.1.3.2: Edgematching

1.1.3.3: Line Generalisation

1.1.3.4: Merge and Dissolve

1.4: DIGITAL STORAGE CAPABILITIES

1.4.1: MAGNETIC STORAGE FORMATS

- a. Tape
- b. Disc

1.4.2: OPTICAL STORAGE

2: SPATIAL ANALYSIS, MANIPULATION, AND INTEGRATION

2.1: OPERATIONS REQUIRING ACCESS TO LOCATIONAL INFORMATION FOR ONE CLASS OF OBJECTS

2.1.1: CARTOGRAPHIC TRANSFORMATIONS

2.1.1.1: Projections

- a. State Plane
- b. Mercator
- c. Polar Stereographic
- d. Transverse Mercator
- e. Orthographic
- f. Perspective
- g. Others

- 2.1.1.2: Reference Spheroids
 - a. Clark 1866
 - b. Miller
 - c. U.S.G.S. 7.5
 - d. Geodetic Reference System
 - e. World Geodetic System
 - f. Others

- 2.1.1.3: Datums
 - a. NAD 27
 - b. NAD 83
 - c. Others

- 2.1.1.4: Coordinate Systems/Reference Grids
 - a. Latitude-Longitude
 - b. UTM
 - c. State Plane
 - d. Rectangular
 - e. Others

2.1.2: CURVILINEAR TRANSFORMATIONS

- 2.1.2.1: Rubbersheeting

2.1.3: AFFINE TRANSFORMATIONS

- 2.1.3.1: Rotation
- 2.1.3.2: Scaling
- 2.1.3.3: Translation

2.1.4: METRICAL MEASUREMENTS

- a. Distances
 - Straight Line
 - Convoluted Line
 - Measurement Incorporating Projection and 3-Dimensional Factors
- b. Area
- c. Perimeter
- d. Volume
- e. Angles/directions
- f. Shape indexes/analyses
- g. Bearings
- h. Line of sight

2.2: OPERATIONS REQUIRING ACCESS TO ATTRIBUTES OF ONE CLASS ONLY

2.2.1: STATISTICAL ANALYSES

- a. Interface with statistical packages (eg. SPSS, SAS, Minitab)
- b. Internal statistical operations

2.2.2: RELATIONAL DATABASE OPERATIONS

- a. Support external database manager (eg. dBASE 3+, Oracle etc.)
- b. Support internal database manager (eg. INFO)

2.3: OPERATIONS REQUIRING ACCESS TO ATTRIBUTES AND LOCALITIONAL INFORMATION FOR A SINGLE CLASS OF OBJECTS

2.3.1: SPATIAL STATISTICS AND MEASUREMENTS

- a. Centographic Measurements
- b. Dispersion measurements
- c. Nearest neighbour statistics
- d. Sinuosity ratios
- e. Runs testing
- f. Location-based measurements specified by attributes (see 2.1.5 above).

2.4: OPERATIONS WHICH CREATE OBJECT-PAIRS FROM ONE OR MORE CLASSES OF OBJECTS AND ANALYZE THEIR ATTRIBUTES

2.4.1: AUTOCORRELATION INDICES

2.4.2: NEAREST NEIGHBOUR ANALYSIS

2.5: OPERATIONS REQUIRING ACCESS TO ATTRIBUTES AND LOCALITIONAL INFORMATION FOR MORE THAN ONE CLASS OF OBJECTS OR OBJECT-PAIRS

2.5.1: DEPENDENT-INDEPENDENT INTERACTIONS BETWEEN OBJECT CLASSES

2.5.1.1: The Dependent Object Class is Zero Dimensional

- a. Point in polygon coincidence
 - MINFILE, RGS fields updated with polygonal data
- b. Spatial coincidence between continuous data sets
 - geochemistry-geophysics combinations

2.5.1.2: The Dependent Object Class is One Dimensional

- a. Line in polygon coincidence
 - polygonal attributes added to linear features

2.5.1.3: The Dependent Object Class is Two Dimensional

- a. polygon overlay
 - geology summarized in terms of slope, soil classes
- b. polygon-point coincidence
 - polygons are summarized according to the values of points falling within them
 - geological polygons are summarised according to a continuous surface (eg. geochemistry, geophysics, elevation).

- c. polygon-line coincidence
 - geological units may be summarized according to the density of air photo linears

2.5.1.4: The Dependent Object Class is Three Dimensional

2.5.2: SPATIAL INTERACTION MODELLING

2.5.3: NETWORK-BASED ANALYSIS

2.6: OPERATIONS WHICH CREATE A NEW CLASS OF OBJECTS FROM AN EXISTING CLASS

2.6.1: TRANSFORMATIONS ORIGINATING FROM ZERO DIMENSIONAL OBJECTS

2.6.1.1: Point To Point

2.6.1.1.1: DEM Operations (Continuous surface to continuous surface)

- a. Slope
- b. Aspect
- c. Sunshading
- d. Curvature
- e. Interviewability

2.6.1.1.2: Point Interpolations (Point to Continuous Surfaces or Volumes)

- a. Moving averages
- b. Contour
- c. Optimal interpolation
- d. Trend surface
- e. Fourier
- f. Continuous corridors

2.6.1.2: Point to Line

- a. Drainage network, ridge lines from continuous elevation surface.
- b. Extraction of structural features from continuous surfaces.
- c. Projection of Geological Structures

2.6.1.3: Point To Area

2.6.1.3.1: Discrete Point Interpolations

- a. Thiessen/voronoi/proximal polygons
- b. Classifying continuous data
 - classified geochemical interpolations
 - Slope, aspect classes
- c. Watershed boundaries

2.6.2.3.2: Point corridors and buffers

- 2.6.1.4: Point To Volume
 - a. Three-Dimensional Interpolations (Classified continuous, discrete)
- 2.6.2: OBJECT TRANSFORMATIONS ORIGINATING FROM LINES
 - 2.6.2.1: Line To Point
 - a. Reduction of dimension as a result of scale changes
 - b. Continuous proximity corridors
 - 2.6.2.2: Line To Line
 - a. Reclassification and merging
 - 2.6.2.3: Line To Area
 - a. Discrete corridors and buffers
 - 2.6.2.3: Line To Volume
 - a. Three dimensional corridors and buffers
- 2.6.3: OBJECT TRANSFORMATIONS ORIGINATING FROM AREAS
 - 2.6.3.1: Area To Point
 - a. Centroid calculations
 - 2.6.3.2: Area To Line
 - a. Creating profiles and cross sections
 - 2.6.3.3: Area To Area
 - a. Polygon overlay
 - b. Polygon reclassification and merging
 - 2.6.3.4: Area To Volume
 - a. Proximity characterisations
- 2.6.4: TRANSFORMATIONS ORIGINATING FROM VOLUMES
 - 2.6.4.1: Volume To Point
 - a. Centroid calculations
 - b. As a result of scale changes
 - 2.6.4.2: Volume To Line
 - 2.6.4.3: Volume To Area
 - a. Two dimensional profiles
 - 2.6.4.4: Volume To Volume
 - a. Reclassification and Merging
 - b. Three dimensional overlay

3: OUTPUT

3.1: HARDCOPY PRODUCTS

- 3.1.1: GRAPHS
 - a. Bar Graphs
 - b. Scatter Graphs
 - c. X-Y Profiles
 - d. Histograms
 - e. 3D Graphs
 - f. Business Graphs
- 3.1.2: STATISTICAL REPORTS

3.1.3: OUTPUT DEVICE SUPPORT

3.1.3.1: Vector Devices

- a. pen plotters

3.1.3.2: Raster Devices

- a. inkjet
- b. laser

3.2: QUERY

3.2.1: ELEMENTARY QUERIES

- a. Query by location; by defined coordinates, regions or interactive graphically
- b. Elevations; spot heights, vertical drops, elevation along lines (stream, rail, road, etc.)
- c. Query continuously varying surfaces
- d. Query by proximity
- e. Query by hierarchy
- f. Query several themes (maps) simultaneously

3.2.2: COMPLEX QUERIES

- a. Queries combining location and attribute using boolean/arithmetic/spatial operators.

3.2.3: METADATA QUERIES

3.3: DIGITAL PRODUCTS

3.3.1: REFORMATTING CAPABILITIES

- a. SAIF (Standard Archive Interchange Format), proposed for B.C.
- b. SIF (Standard Interchange Format)
- c. DXF (CAD)
- d. IGDS (Intergraph Digital System)
- e. ASCII (Generic Data Exchange)
- f. DLG (Standard) (U.S. Geological Survey)
- g. DLG (Optional) (U.S. Geological Survey)
- h. DLG Enhanced (U.S. Geological Survey, in development)
- i. MINFILE (Mineral Inventory File, Geological Survey Branch, B.C.)
- j. ARC (Environmental Systems Research Institute Format)
- k. SDTF (Standard Data Transfer Format)

4: DATABASE MANAGEMENT FUNCTIONS

4.1: USER INTERFACE

4.1.1: SUPPORT OF STRUCTURED QUERY LANGUAGE (SQL)

4.1.2: SUPPORT OF SPATIAL MODELLING CAPABILITIES

4.2: DATA QUALITY, PROTECTION

APPENDIX B: INTERVIEW SUMMARIES

Summaries are presented according to the organisational structure (January, 1990) of the B.C. Geological Survey. Organisational structure, personnel interviewed and interview dates are summarised in Table 4.4. Each summary is organised into the following headings.

1. Unit Mandate
2. Supporting Activities
3. Supporting Systems
4. Information Requirements
5. Products and Services
6. Users of Products and Services
7. Proposed/desired Changes and Enhancements
8. Program Concerns
9. GIS Requirements/potential

APPENDIX B.1: SCIENTIFIC REVIEW OFFICE

MANDATE

This office is charged with the responsibility of editing all Geological Survey publications and ensuring that they are published and publicised in a timely manner.

SUPPORTING ACTIVITIES

The unit is organized into two sections: an editing and compilation section, and a cartography and drafting section. These sections perform several activities to support the mandate. These include:

1. The compilation, editing and publishing of all data and research of the organization including Bulletins, Open Files, Papers, Circulars and all cartographic products including sketches.
2. Providing cartographic services to the rest of the Survey and ensuring that all map products are published according to cartographic standards.
3. Compiling and maintaining an index of Survey publications.
4. Compiling and maintaining an index of bibliographic information related to the geosciences in British Columbia.
5. Answering public queries as to the status and availability of geoscience data, products, and services.

PRODUCTS AND SERVICES

This unit is not directly involved with collection or processing of primary geoscience data, rather it is concerned with the publication quality of output for the entire organisation. To this end, output of other programs may be considered products of this section. Informational circulars are often compiled and produced by this unit.

USERS OF PRODUCTS AND SERVICES

Users of output and services for this unit include, in order of relative frequency of use:

1. The mining and mineral exploration industries. Usage is primarily for mineral exploration and mining development.
2. Government agencies involved with land management including the Geological Survey and its parent Ministry, other Provincial Ministries, Federal Ministries, and Municipal governments.
3. By universities and colleges for geoscience and related research, often in conjunction with or sponsored by the Geological Survey.

4. The general public including amateur prospectors, public schools, out of province users, and special interest groups.

This description of usage of products and services applies more or less equally to all units and is not repeated in descriptions of the remaining units.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

Automating cartography is a desired enhancement even if it requires relaxing traditional standards.¹ To meet this objective a CAD based system was acquired in 1988 and is fully operational or close to being so. The primary function of this system is to automate existing cartographic processes and to assist with production of colour maps.

PROGRAM CONCERNS

With respect to automated systems, staff emphasized the need for friendly system interfacing, compatibility with existing hardware/software, a long term commitment with attendant budget support from upper management, a dedicated staff system specialist, and the maintenance of data quality, security, and accuracy. Ease of cartographic manipulation and quality cartographic output are seen as the most important functions for this program.

GIS REQUIREMENTS/POTENTIAL

A. INPUT/STORAGE: This section has little need for primary input of data. However, with respect to cartographic responsibilities there is a distinct need for editing and manipulation of spatially referenced information. The capability for translating data from GIS (topologic, raster) to existing CAD systems would be a useful capability.

B. ANALYSIS: Group A operations will be required for cartographic, affine, and curvilinear transformations. Translating from the NAD-27 to the NAD-83 datum may become an important function as latter becomes more widespread. The use of other analytical operations have limited potential for assisting this unit as research and data integration are not an important component of the mandate.

C. OUTPUT

¹ Reported on page 21 of the Geological Survey Branch, 1988-1989 Plan (B.C. Ministry of Energy, Mines and Petroleum Resources, 1988).

1. Hardcopy: Compatibility with existing cartographic systems (CAD) is an obvious requirement. Support of both raster and vector output devices will be required.
2. Query: Considerable resources are dedicated towards retrieving information about information maintained by the survey. Often there is a geographical element to these queries. Time and manpower savings could be realized if this process could be automated through a geographical referencing system or data dictionary.
3. Digital Products: It is assumed that this unit's responsibility of publishing and publicizing geological information will be extended to products in digital formats. Therefore the ability to reformat to commonly used digital standards used by Survey clients should be a requirement. This responsibility may include ensuring that the outgoing information adopts to some standard affecting data quality and accuracy.

APPENDIX B.2: REGIONAL MAPPING

MANDATE

This program has a mandate to provide a 1:50,000 scale bedrock geology base for the Province. A related objective is to evaluate economic mineral potential at this scale for the purpose of promoting mineral exploration in B.C.

SUPPORTING ACTIVITIES

Geological fieldwork is the primary activity in support of the mandate. Specific activities include bedrock mapping, sample collection and analysis, petrological studies, age determinations and other studies which will enhance the understanding of a region's geology.

SUPPORTING SYSTEMS

The geological point database for inventorying geological field observations is currently under development. Although it is available for general public usage, it is used primarily used within the Survey for inventory purposes. See Appendix C for a detailed description of the system.

INFORMATION REQUIREMENTS

A. INTERNAL: This unit makes use of all internal data sources; MINFILE, RGS data, and existing geological map products were singled out as being the most important.

B. EXTERNAL: Virtually every mapping project begins with the use of 1:50,000 scale NTS topographic series maps, air photos and available Geologic Survey of Canada (GSC) maps. The latter generally are available at a scale of 1:250,000. Other external sources include geoscience publications of the GSC including geophysical data, fossil and regional geological studies. Forestry maps are also used when available.

PRODUCTS AND SERVICES

The output of this program can be divided into four products:

1. Descriptive text in the form of Papers, Open-File Reports or Bulletins.
2. Preliminary draft maps and sketches.
3. Tabular data.
4. Poster sessions, talks, and other activities which promote the mineral exploration and geology in B.C.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

Improvements and enhancements are planned for the Geological Database System. There is considerable interest in expanding present capabilities to include those offered by GIS, remote sensing and image analysis, and automated cartography. It was also expressed that there will, at some future time, be a need for geological map data in digital formats.

PROGRAM CONCERNS

Pertaining to the development of digital map bases and GIS, the following concerns were expressed:

1. Future developments should be compatible with existing systems, namely MINFILE.
2. The system(s) should reside on a PC-based DOS platform.
3. A question was raised as to whether topological data was necessary for geological data.

GIS REQUIREMENTS/POTENTIAL

A. INPUT: Digital input of geological maps are the primary input requirement. These maps contain zero, one, and two dimensional object types and it is possible to have several classes of each (for example lines could represent faults, unconformities or synclinal axes). In addition there exists adjacency and inclusion relationships which may be encoded.

B. ANALYSIS: Describing relationships between various geological phenomena (eg. geochemistry and geological polygons; faults and geological polygons) are common operations to this unit, group E operations will be required to extract the nature of such relationships. The relationships often include spatial proximity; Group F operations are required to characterise this relationship. Group A and C operations can be used for spatial descriptions and data visualisation.

C. OUTPUT

1. Hardcopy: Three types of map output are produced by the unit. Cartographic quality colour maps, rough draft maps for quick release of fieldwork to the public, and generalized sketch maps. A CAD system could adequately handle all three tasks. Analytical queries will result in graphs and tabular reports.
2. Query: Both elementary and complex queries can assist with routine geological enquiry. Metadata queries are required both for internal project support and to facilitate answers to public enquiries.

APPENDIX B.3: MINERAL DEPOSITS

MANDATE

The objective of this program is to: "Conduct geologic and metallogenic studies of metallic mineral deposits in mining camps and areas with potential mineral wealth to determine the distribution, origin, mode of occurrence and exploration guidelines for deposits."²

SUPPORTING ACTIVITIES

To support its objectives, members of this unit perform activities similar to those of Regional Mapping. However this section places more emphasis upon mineral deposit modelling and mineral potential studies.

SUPPORTING SYSTEMS

Field observations from this unit's activities are recorded in the Geological Point Database System.

INFORMATION REQUIREMENTS

A. INTERNAL: MINFILE, RGS, and geological maps are important to the activities of this section. Due to the emphasis upon mineral deposit modelling, assessment reports are widely used too.

B. EXTERNAL: NTS 1:50,000 topographic base maps, air photos, and all GSC maps and material are utilized by this section. Other important information sources include university thesis, maps from remotely sensed sources and reports from private companies.

PRODUCTS AND SERVICES

A. OUTPUT: Every field project produces a paper and attendant open file map on an annual basis. Maps scales are mainly at 1:50,000, in support of the 1:50,000 scale mapping initiative but may range from less than 1:20,00 to 1:2,000,000. Field projects generally range from 3-5 years, at the end of which a Bulletin is produced incorporating the work of each field season into a final product. Mineral Deposits personnel also contribute to MINFILE and the Geological Point Database System.

² Ministry of Energy, Mines and Petroleum Resources, 1988: Geological Survey Branch 1988-1989 Plan, Victoria, B.C., p.6.

B. SERVICES: In promoting the mineral potential and ore deposit models, members of this section frequently sponsor workshops and poster sessions, give talks and lectures and answer public queries. This section forms a collective pool of expertise for consultation to the public on matters pertaining to geology and mineral deposits.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

There are no enhancements planned with respect to the handling of geographical information. It was expressed that there needs to be improved access to information maintained by the B.C. Geological Survey.

PROGRAM CONCERNS

The respondents expressed concern in several areas concerning the automation of map data.

1. It was expressed that developments affecting products and services supplied by the section do so such that quick access by clients is possible. Some clients currently have to wait several weeks before receiving maps or bulletins. New methods of storing and outputting information must therefore do so in a timely manner.
2. If existing maps were to be put into a digital format, then the existing quality of the data should be maintained, a compromise in quality would not be acceptable.
3. Concern was expressed over the learning curve involved with new technology, it was expressed that a dedicated in-house system expert would be desirable to assist users. Existing personnel levels leave little time for pursuing new initiatives.
4. There is a lack of consistent quality base map information.

GIS REQUIREMENTS/POTENTIAL

A. INPUT: Input requirements are identical to those described for Regional Mapping.

B. ANALYSIS: By definition, metallogenic studies include the integration and analysis of virtually every existing type of geologic data. Group E and F analytical operations will be required for this purpose. Cartographical modelling capabilities will be necessary for combining these operations according to the specifications of a given model. Group C operations can be used for descriptive spatial characterisations. The potential for applying Group D operations exists, however appropriate methodologies will need to be developed.

C. OUTPUT

1. Hardcopy: Hardcopy output requirements are similar to those summarised for Regional Mapping.
2. Query: Query requirements are similar to those outlined for Regional Mapping, however there is an increased emphasis upon complex queries to assist with metallogeny related inquiries.

APPENDIX B.4: GEOCHEMISTRY

MANDATE

The mandate of this unit is to provide a Province-wide base of geochemical data.

SUPPORTING ACTIVITIES

To support its goals this program performs four activities:

1. Systematic orientation surveys and follow up testing are performed in order to determine the most appropriate methodology for geochemical surveys.
2. Regional geochemical surveys are carried out.
3. Evaluation of survey data and techniques in order to determine their effectiveness.
4. Development of techniques for the statistical and analytical treatment of geochemical data.

INFORMATION REQUIREMENTS

A. INTERNAL: The section makes extensive use of all geological maps, MINFILE data, and assessment reports.

B. EXTERNAL: NTS topographical and 1:250,000 GSC geological maps were singled out as being important to the unit's activities.

PRODUCTS AND SERVICES

A. MAPS/REPORTS: Typical output from this section consists of statistical reports, element and location maps at 1:250,000 scale (geology generalized from GSC maps is included on these maps). The unit also publishes analytical reports, papers and informational circulars.

B. SERVICES: The unit sponsors poster sessions and talks and answers queries from government, education and industry.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

No enhancements to the program were indicated, however a desire was expressed for obtaining GIS capabilities to assist with determining relationships between geochemistry and other variables such as terrain related themes, geology, and other resources data.

PROGRAM CONCERNS

No concerns were expressed with respect to GIS acquisition and implementation.

GIS REQUIREMENTS/POTENTIAL

A. INPUT AND STORAGE: This unit has limited input requirements. Points or zero dimensional objects are the only input requirement and there is software in place which can perform this task efficiently.

B. ANALYSIS: The need for manipulating and analyzing point data is an obvious requirement; group E and F operations will be required for this. Among group F operations, point to point transformations can be used to interpolate geochemistry into continuous surfaces, point to area transformations can similarly be used for classifying or creating discrete geochemistry polygons. Group E operations can be used for integrating geochemistry with hydrological and terrain themes, and also to determine relationships between geochemistry and various geological themes.

C. OUTPUT

1. Hardcopy: Maps and tabular listings are required outputs for this unit. Map products include both raster and vector type maps. Vector maps are used for displaying geochemical points sample locations with selected geological and topographical data; raster maps can display the continuous variance of geochemistry or geochemical patterns.
2. Query: The need for elementary and metadata queries is a requirement for routine information retrieval. There does not appear to be a strong a need for more complex queries.

APPENDIX B.5: SURFICIAL GEOLOGY

MANDATE

Surficial geology is charged with the responsibility for "...the development of a comprehensive surficial geology database to stimulate and focus industry evaluation and development of surficial and buried mineral deposits in areas of thick overburden."³

SUPPORTING ACTIVITIES

Activities in support of these goals include mapping and evaluation of surficial stratigraphy and deposits; development and assessment of drift prospecting techniques; mapping and identification of geological hazards; and development of a placer deposit database.

INFORMATION REQUIREMENTS

A. INTERNAL: It is anticipated that this unit will make extensive use of geology maps, MINFILE data and mineral occurrence maps, and geochemical maps and data. A concern was expressed over the lack of available documentation/information on historical and current placer occurrences and production.

B. EXTERNAL: Accurate, up to date topographic maps and air photos will be required to support the activities of this section.

PRODUCTS AND SERVICES

A. MAPS, REPORTS: Initially, two map types will be produced by this section; terrain hazard maps, and surficial geology maps. Reports will outline information on the potential for surficial exploration and include placer deposit models.

B. DATA FILES: A point sampling database, containing information pertaining to sample environments and analyses is planned for this section.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

Although this unit has just been initiated (1989), it was expressed that future activities be expanded to include

³ Geological Survey Branch, Ministry of Energy, Mines and Petroleum Resources, 1989: Internal Memo entitled 'Survey Creates New Program in Surficial Geology'. 1p.

economic placer potential mapping, and environmental geology (hazards, earthquakes, slope failure).

PROGRAM CONCERNS

It was expressed that although some would benefit from data in digital format, especially government agencies, the largest user group, small placer operators, would suffer if information were to be made available in digital format only.

GIS REQUIREMENTS/POTENTIAL

As the unit has just recently been initiated, it is difficult to state with certainty what its requirements will be. However based upon the proposed mandates and activities of the unit and due to the applications of GIS to surficial geology by other agencies, it is possible to describe requirements in a general manner.

A. INPUT AND STORAGE: It is expected that maps pertaining to surficial geology will contain zero, one and two dimensional data. Three dimensional data exists as an additional type if surficial geology thickness and drill-hole data are included. Surficial geology is unique from the other sections in that time may not be a static attribute of the data. Some applications, slope stability studies for example, may benefit from a data scheme which can store and analyze the time component.

B. ANALYSIS: It can be anticipated that this unit will have data manipulation and integration requirements similar to those described for the Mineral Deposits and Geochemistry units. Group E and F operations for data integration and transformation will be required for various applications.

C. OUTPUT: Hardcopy output for this unit includes cartographic quality maps and tabular data tables. Metadata and elementary query capabilities can assist with answering public questions and supporting research projects. More complex queries may be useful for assisting with more in-depth deposit modelling and research projects.

APPENDIX B.6: MINERAL LANDUSE UNIT

MANDATE

The mandate of this section includes two basic functions:

1. Evaluate the mineral potential of land areas proposed for alienation.
2. Aid in the development of mineral land-use policies.

SUPPORTING ACTIVITIES

To support the goals outlined, several activities are carried out by Mineral Landuse personnel. They include:

1. Resource evaluation through field mapping, sample collection and analysis.
2. Resource evaluation through literature searches.
3. The monitoring of land use status as it relates to mineral land-use.
4. Collation and analysis of all pertinent geological information.
5. The modelling of geological information to determine mineral potential.
6. Service requests for information pertaining to the status of a region's mineral potential and mineral landuse status.

INFORMATION REQUIREMENTS

In short, this section makes use of all information from government, industry and private sources as it pertains to mineral land-use. Some of the more common information sources include: all geological research output by the Survey and the GSC; mineral assessment reports, MINFILE, RGS, Mineral Titles, mining claim information, natural gas and petroleum data, industrial minerals, legal and administrative information, ecological reserve boundaries.

PRODUCTS AND SERVICES

A. MAPS: From field mapping activities, this section produces 1:50,000 scale bedrock geology maps identical to those put out by the regional mapping program. In addition at least one map has been compiled, at 1:100,000 scale, integrating geology, mineral occurrence data, geochemistry and interpretive geological knowledge, to produce an ordinally ranked mineral potential map. This section is also responsible for maintaining the Mineral Deposit Land-Use map series (MDLU).

B. DATA FILES: Field mapping data is input to the geological point database system. Results from geochemical and

lithological analyses are maintained as paper files or on floppy disk.

C. SERVICES: According to the section's mandate, personnel in this section spend considerable time and effort researching and answering queries pertaining to mineral land-use. The majority of these queries come from within the Ministry, other Provincial Ministries and from the federal government. The number of these queries is reportedly rising.

USERS OF PRODUCTS AND SERVICES

The primary users of this unit's output include government agencies involved with land management and resource policies.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

It was expressed that the capabilities provided by a GIS could assist in the collation, analysis and modelling of geological variables for mineral potential evaluations.

GIS REQUIREMENTS/POTENTIAL

A. INPUT AND STORAGE: As part of mineral land use investigations, the unit collects and processes field data in the same manner as the regional mapping and mineral deposits units and therefore has similar input requirements.

B. ANALYSIS: Mineral potential determinations are a primary component of this unit's mandate. Group E and F operations will be required for data transformations and integrating capabilities.

C. OUTPUT

1. Maps/reports: Cartographic quality geological maps and mineral potential thematic maps may require both vector and raster output support.
2. Query: Queries to land use issues often require quick interactive responses. Full query capabilities would allow the unit to accommodate such responses in a more interactive manner. Complex query capabilities could also potentially facilitate mineral potential evaluations.

APPENDIX B.7: MINERAL INVENTORY UNIT

MANDATE

This unit is responsible for collecting, compiling, and approving mineral assessment reports submitted by industry.

SUPPORTING ACTIVITIES

All data is submitted in the form of mineral assessment reports from industry sources. Compiling mineral exploration statistics, indexing reports, and producing map products showing annual mineral exploration activity are the primary tasks. Mineral exploration data is also collated for determining mineral exploration trends. Location is a primary consideration for each of these activities.

SUPPORTING SYSTEMS

Information from mineral assessment reports are summarised and maintained in the Assessment Report Indexing System (ARIS); it is described in Appendix C.

INFORMATION REQUIREMENTS

This section has few data requirements external to mineral assessment reports. A 1:2,000,000 scale outline map of British Columbia is used for displaying annual exploration activity. Mineral Title maps at 1:20,000 are used but it was expressed that, as this scale does not match the NTS series (1:50,000), they are difficult to work with. To this end it was expressed that 1:20,000 scale base topographic maps would be useful, but not necessary to the program.

PRODUCTS AND SERVICES

Mineral Inventory is involved with the following output:

1. An annual mineral exploration compilation map of the province at a scale of 1:2,000,000.
2. Statistical data on mineral exploration in British Columbia.
3. The annual publication "Exploration in British Columbia", a description of industry exploration projects in the province.
4. Responding to queries from industry, government, and educational sources.

USERS OF PRODUCTS AND SERVICES

Within the Survey, MINFILE is the largest user of this unit's output. The products are also used selectively by other Survey units. Externally, the output is important to

the Mineral Titles Branch, and the Attorney General's office for assisting with mineral title disputes. Other enquiries come from a broad range of offices within the provincial and federal governments for administrative and policy purposes.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

No enhancements concerning the handling of geo-referenced information were indicated. A desire for greater searching capabilities was expressed.

PROGRAM CONCERNS

Several concerns were noted that pertain to this study.

1. There is an increasing number of reports claiming expenses from remote sensing and image analysis activities. A concern was expressed that the subsection lacks the expertise to properly evaluate such work. Increased awareness of how these technologies relate to mineral exploration is desirable.
2. It was expressed that a province-wide digital geological map at a scale of 1:2,000,000 would be useful as a base for future map products.
3. Future efforts towards automation should ensure that there is compatibility with existing software and data systems; interfaces must be user-friendly in order to reduce time spent learning the system.
4. Greater access to data sources of all types and improved map production facilities would be an asset.

GIS REQUIREMENTS/POTENTIAL

A. INPUT AND STORAGE: This unit currently has minimal input requirements as geographical coordinates are already stored digitally as attributes in ARIS. Future enhancements for handling geochemical, geophysical or remotely sensed data may require storage of linear or areal features.

B. ANALYSIS: Non-spatial attribute handling is the primary requirement of this unit and there is adequate software for performing these tasks. Data analysis and manipulation are not an important component of this unit's mandate, however point-in-polygon operations (Group E operations) offer potential for updating or adding attribute fields to ARIS records.

C. OUTPUT

1. Hardcopy: The primary output of this unit consists of tabular listings and statistical summary reports. Existing capabilities are installed for handling these tasks. Cartography requirements are minimal; a single 1:2,000,000 scale map is output on an annual basis.

2. Query: There is a need for metadata query capabilities to handle routine information requests. More complex queries requiring access to attribute fields are adequately handled by existing systems or could be without the aid of spatial-based systems.

APPENDIX B.8: MINFILE/PROPERTY FILE

MANDATE

This section has several objectives, they include:

1. To develop and maintain a Province wide computer-based inventory of mineral occurrences.
2. Make the database available to resource companies, government agencies, researchers and others.
3. Market to other agencies the technology acquired in developing the system.

SUPPORTING ACTIVITIES

To support its objectives, this section collects and inventories all documentary, tabular, map and other information pertaining to mineral occurrences in the province (Property File). Information is catalogued according to indexed mineral occurrences. Filed information is then summarized, recorded and stored according to the specifications of the MINFILE database system.

SUPPORTING SYSTEMS

An entity-relational structured database, MINFILE, has been developed by the Survey in conjunction with Systemhouse Ltd. in order to meet program objectives. The database is maintained on a VAX mainframe system and distributed to clients on 5 1/4 " floppy diskettes. Data is released in blocks corresponding to 1:250,000 NTS map sheets. In map sheets with a high density of mineral occurrences, the data may be released by 1:125,000 (or 1 inch to 1 mile) or 1:50,000 map sheets. The primary activity involves geocoding current and historical mineral occurrences maintained in Property File. Detailed specifications of the system can be found in Appendix C.

INFORMATION REQUIREMENTS

A. INTERNAL: The section incorporates all internal data sources into its files and products. Foremost among these are information derived from assessment reports and other information pertaining to mineral occurrences.

B. EXTERNAL: External information is obtained from the following sources:

- Geological Survey of Canada publications.
- University thesis.
- Press releases.
- Journal articles.

In short, information from any source which pertains to mineral occurrences in the province may be incorporated into the files of this program.

PRODUCTS AND SERVICES

The products and services available from the program include the following:

- 5 1/4" data diskettes.
- Mineral occurrence maps.
- Hardcopy printouts of occurrences on 1:250,000 scale NTS map sheets with generalised geology and commodity data.
- MINFILE/pc search program.
- MINFILE/pc user manuals.
- Province-wide searches.
- Custom searches.

MINFILE products are available from MINFILE and Maps BC only. MINFILE/pc and custom searches are provided by MINFILE personnel. The search and report capabilities of the MINFILE/pc system are also used to facilitate the publication of Survey Open-Files, bulletins and papers.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

Pending enhancements include the addition of a work history field and BCGS map sheet references. An interface to facilitate data entry to the MINFILE system is expected to be approved in the near future. It is expected that this enhancement will improve data input efficiency and reduce input errors by allowing for direct input by geologists.

It is a desire to include a module employing artificial intelligence technology for automating some coding process, thus eliminating the need for frequent reference to coding manuals and facilitating data input by field geologists.

The MINFILE database system references all occurrences as points; the current structure precludes referencing data from a higher dimension (eg. geochemistry, geophysics). GIS structures and input capabilities offer the possibility of including areal and linear data with MINFILE occurrences.

PROGRAM CONCERNS

Concerning the implementation of geographical information systems, no concerns were expressed. It is viewed as a positive enhancement for the section.

GIS REQUIREMENTS/POTENTIAL

A. INPUT AND STORAGE: The section has adequate input capabilities for point data, expansion to higher dimensions will require more complex input and storage capabilities. 1:250,000 scale GSC geology maps, are currently generalized and used as a base for displaying MINFILE information in map format. Assuming the GSC will soon offer geological maps in digital formats, then a temporary need exists for inputting this information.

B. ANALYSIS: Group B operations are the main requirement and there is application software, installed and operational, which efficiently handles these tasks. Group E operations (point in polygon) hold considerable potential for automating and updating fields containing polygonal data. In a similar manner, entirely new fields could be added with minimum effort.

C. OUTPUT

1. Hardcopy: Displaying mineral occurrences in their geological setting is an important map product for this section. This often involves cartographic manipulations such as creating insets to display areas of high mineral occurrence density. This process is already partially automated by CAD type software. It is important that future developments be able to interface with these systems.
2. Query: Elementary queries hold considerable potential for checking the validity of some attribute fields that presently require timely searching of maps and files by geocoders. (Group E analytical operations could be used to completely automate the input and updating of such fields as discussed above.) The need to access and query metadata is important to this unit. It is both an internal requirement to assist with the encoding of occurrences, but it is also required as a service to clients. It was also mentioned that some client queries involve a combination of cultural data, administrative boundaries, and geological variables. To answer such queries will require elementary and possibly more complex query capabilities.

APPENDIX B.9: INDUSTRIAL MINERALS SUBSECTION

MANDATE

The goals of this program include the following:

1. To study the distribution and abundance of industrial minerals.
2. To facilitate the development of industrial mineral resources.
3. To support policy development as it pertains to industrial minerals.

SUPPORTING ACTIVITIES

Activities in support of these goals include:

1. Fieldwork activities including mapping, sample collection and deposit evaluation.
2. Report writing, compilation and collation of existing information sources.
3. Public displays, talks and other activities which will promote the potential of industrial minerals.

INFORMATION REQUIREMENTS

A. INTERNAL: MINFILE is identified as an important source of data for all projects. Geological maps of all types are also important to the program. According to the project type, RGS may also be an important data source, for example, RGS fluorium analyses were an important data source for a provincial fluorspar project.

2. EXTERNAL: NTS base map information and GSC data are used extensively. No other external information requirements were indicated.

PRODUCTS AND SERVICES

The output of this subsection cannot be characterized by a standard product. Due to the nature and distribution of industrial mineral commodities, map products are often at a Province wide scale with frequent reference to individual localities at larger scales. Output from this unit appears in open-files, papers and bulletins.

USERS OF PRODUCTS AND SERVICES

With the exception of MINFILE/Property File industrial mineral products are not widely used within the Survey due to the specialty nature of the products. The products of this unit are targeted specifically towards the industrial minerals industry. Other users include various government offices and research interests.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

There are no desired or planned enhancements planned with respect to the handling of locational data.

PROGRAM CONCERNS

The following concerns were noted with respect to GIS and related enhancements:

1. There is currently not enough manpower to support the use of a system.
2. In-house expertise would be an asset.
3. There was uncertainty as to how GIS could be useful to the program, an experimental pilot project was suggested as a solution to this problem.
4. Traditional users would not benefit from information if it were to be made available in digital format only, they generally are not equipped to handle information in digital formats.
5. Information on transportation and infrastructure were noted as an important information source for industrial minerals. These are important factors in determining the economic feasibility for producing bulk, low priced commodities. In this respect, demographic studies are also important.
6. Updating of databases is not seen as a priority.

GIS REQUIREMENTS/POTENTIAL

A. INPUT AND STORAGE: Input requirements for the unit are minimal. Much of the map data required by the section can be obtained from other sections within the organization.

B. ANALYSIS: Group E operations will be useful to assist in determining relationships between industrial minerals and other variables such as geochemistry or regional geology. Group F operations will be required should methodologies be developed for modelling industrial mineral variables in a digital environment.

C. OUTPUT

1. Hardcopy: The production of variable scale map products is the primary requirement. Output from Group E operations, should this capabilities be obtained, would be in tabular format.

APPENDIX B.10: COAL RESOURCES UNIT

MANDATE

The goals of this unit include:

1. To collect and publish information on the Province's coal geology.
2. To promote and publicize the coal potential of the province.

SUPPORTING ACTIVITIES

Activities in support of the unit's goals include:

1. 1:50,000 geological mapping in coal producing regions or in areas of high coal potential.
2. Update existing geology maps previously prepared in these areas.
3. Integrate and compile existing data from industry.
4. Perform coal quality studies and maintain a catalog on coal quality for the Province.
5. Explore and develop methods of deposit modelling employing digital methods including the use of geographic information systems.

SUPPORTING SYSTEMS

The COALFILE computer database system is a fully functioning digital system for storing, accessing, and outputting information pertaining to coal assessment reports.

INFORMATION REQUIREMENTS

A. INTERNAL: The subsection is self-sufficient for internal information requirements, it collects the required information through fieldwork activities and from assessment reports submitted from industry.

B. EXTERNAL: 1:50,000 NTS topographic base maps and 1:250,000 GSC geological maps are important for the fieldwork of the subsection. The NTS maps are used as a base for fieldwork activities.

PRODUCTS AND SERVICES

Geological maps, at a scale of 1:50,000, with attendant documentation (bulletins, open-files and reports) constitute the primary output of this unit. Maps are compiled from existing sources and from ongoing fieldwork. Coal assessment reports are summarized in a digital database, COALFILE, which is available in both hardcopy or digital formats. Customized searches are performed upon request. Members of

the unit routinely answer queries from industry and government concerning coal resources public.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

It is a stated objective to examine methods of applying automated systems, including GIS, for assisting with resource calculations and for modelling coal deposits.

PROGRAM CONCERNS

It was expressed that future implementation of digital systems, namely GIS and related systems, be able to accept files and to interface with applications software developed internally by the unit. This software is functioning well for the purposes and activities it was designed for, there is no desire to interrupt this process; future enhancements should enhance and expand upon these capabilities.

Other concerns include:

1. The system is accessible to, and does not require excessive time from users.
2. It is important to have a system available for general usage, primarily as an educational tool to expand awareness of the capabilities of such a system.

GIS REQUIREMENTS/POTENTIAL

A. INPUT AND STORAGE: Geological maps constitute the primary input requirement. Input requirements are identical to those summarised for other units.

B. ANALYSIS: Group E and F operations will be required for determining relationships between various geological variables and for more complex modelling. The Coal Resources unit contains considerable expertise in numerical modelling techniques and may realize benefits much quicker than other units. Volumetric calculations are an important component of coal geology, these are included among group A or C operations.

C. OUTPUT

1. Hardcopy: Cartographical quality map output is a basic requirement.
2. Query: Metadata and elementary queries will be useful for routine queries from within the unit or from industry and government sources. Complex queries can assist with more involved research and modelling procedures.

APPENDIX B.11: DISTRICT GEOLOGY**MANDATE**

This section has a mandate to maintain an up to date inventory of geology, mineral deposits and exploration trends and developments; to maintain a public presence in the mining and mineral exploration communities; and offer consultations to industry and government agencies in their respective districts.

SUPPORTING ACTIVITIES

Members of this section engage in various fieldwork and data collection activities similar to those performed by the Regional Geology, Mineral Deposit and other units. Section members also give talks, support prospector training courses, and engage in other activities related to the promotion of mineral exploration. This section also publishes geological maps, mineral deposit studies, mineral property descriptions and other publications to support the understanding of geology in respective districts.

INFORMATION REQUIREMENTS

A. INTERNAL: This unit makes use of all internal information produced by the Survey as it pertains to individual districts.

2. EXTERNAL: Topographical base map information, GSC publications, local information sources, such as forestry access road maps, are utilized by the section.

PRODUCTS AND SERVICES

A. HARDCOPY: The program contributes maps and reports to the Survey's information products. Important among these are contributions to the Geological Fieldwork, Exploration in British Columbia, and the Open-File, Paper, and Bulletin series. Members also contribute information to the MINFILE database system.

B. SERVICES: An important component of the program's mandate is to maintain a public presence and to assist its clients. In doing so, members engage in public talks, sponsor local conferences and are generally available as a source of local expertise on matters pertaining to all aspects of geology, including mineral exploration and land use matters.

PROPOSED/DESIRED CHANGES AND ENHANCEMENTS

There are no enhancements planned with respect to geographical information handling, however it was expressed that improved access to all information in general would be beneficial.

PROGRAM CONCERNS

Members of this section maintain offices separate from the rest of the organization. A concern was expressed that due to this isolation, the section may not benefit from the enhancements a GIS may offer.

GIS REQUIREMENTS/POTENTIAL

A. INPUT: Input of geological maps constitute the primary requirement, therefore geological map input requirements described for previous units apply to this section as well.

B. ANALYSIS: Many of the tasks performed by this section are similar to those in Mineral Deposits, Regional Mapping and Coal Resources. Accordingly, group E and F analytical operations will be required.

C. OUTPUT

1. Hardcopy: This section produces cartographic quality maps, preliminary draft maps and sketches.
2. Query: Metadata and elementary queries are potentially important for quick access to information of a district in support of internal projects or to facilitate answering of public queries. Complex queries hold potential to assist with research related questions.

APPENDIX C: GEOSCIENCE DATA SET DESCRIPTIONS

This Appendix includes detailed technical descriptions of data sets managed by the British Columbia Geological Survey.

APPENDIX C.1: MINERAL INVENTORY DATABASE SYSTEM

Administration

Acronym: MINFILE
 Custodian: MINFILE/Property File
 Manager: Gilbert McArthur/Larry Jones
 Storage Location: 247-541 Superior Street, Victoria, B.C.
 Source of Information: L. Jones

Database Purpose Document and provide mineral, geological and bibliographical information for mineral occurrences in B.C.

General Description MINFILE contains in excess of 10,000 metallic, industrial mineral and coal occurrences covering the entire province. Each occurrence is maintained as a unique record and is geographically distinct from all other occurrences. Associated with each occurrence are 43 data fields describing mineral deposits in terms of geographic location, geologic setting, and mineralogical content and economic production.

System Output

Products: Data is available in both hardcopy and digital formats. Hardcopy products include tabular listings of the data associated with each occurrence and 1:250,000 scale maps showing mineral occurrences within their geological settings.

Other Products: Custom searches available upon request. The searches are capable of combining geographical specifications with geological relationships. These can be performed to local specifications or on a province-wide basis. The system is also used for Provincial wide commodity reports and bulletins.

Supporting Documentation: Documentation on system usage is available.

Complementary Datasets: ARIS, Property File.

Database Usage

Internal Use: MINFILE is widely used by all sections.

External Use: 170 clients using MINFILE/pc.
 520 clients on the MINFILE mailing list.
 Clients include government and industry in N. America, New Zealand, England and Switzerland.

Tasks Performed: Update, append, query, plot, report and searches. Used widely to assist with planning for field season activities. MINFILE/pc application software allows for customized searches by combining the key attributes with logical operators.

TECHNICAL DESCRIPTION

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: The information in some fields does change temporally.
 Topology: None.
 Other: Proximal relationships with geological entities in other data sets are an integral component of mineral occurrences.

Geographical Reference

Projection: Universal Transverse Mercator
 Coordinate Grids: UTM; Latitude/longitude
 Reference Spheroid: Clarke-1866
 Datum: NAD-27

System Structure

Geographical Objects: Stored as X-Y single coordinate pairs in the UTM and latitude-longitude coordinate systems. Elevation is stored as a separate field.
 Attribute Structure: Entity-relational schema. Relationships between interpretive geological and physical characteristics are defined.
 Unique Identifier: Each record has a unique MINFILE number.
 Secondary Identifier(s): Name of occurrence. Also Canminindex no. and National Mineral Inventory no.
 Key Attributes: Lithology, production, reserves, references, location, commodity, status, name, Deposit character, deposit class.

Data Quality

Current Status: Under development, 60% of province complete (1989).
 Volume: 10,085 records; in excess of 25 Megabytes. 71 mineral occurrence maps will complement this database upon its completion.
 Rate of Growth: Approximately 7 Kilobytes per month.
 Record Revision: Occurrences are revised annually as incoming information dictates.
 Database Update: New records are added annually as new occurrences are recorded.

Scale of Input: According to 1:250,000 scale NTS maps. Reference to location is often made to 1:50,000 scale maps.
Range of Effectiveness: 1:50,000 to >1:2,000,000
Geographical Coverage: Province wide.
Geographical Accuracy: A three tiered ordinal classification is employed in which the point is accurate to within 500m, 1km or 5km respectively. This information is contained by a unique field.

Data Security

Protection: VAX password.
Backup System: B.C. Systems Corporation, daily backup.
Internal Access: VAX, 10-15; PC, unlimited.
External Access: VAX, none; PC, unlimited.

Operating Platform

Hardware: DEC-VAX 8650 mainframe; 283/386 microcomputers
Management Software: ULTRA, SPECTRA, COBOL.
Support Software: MINFILE/pc, Foxbase, R&R, Friendly Finder
Operating Systems: VAX, DOS

APPENDIX C.2: ASSESSMENT REPORT INDEXING SYSTEM

Administration

Acronym: ARIS
 Custodian: Resource Data & Analysis Section
 Manager: L. De Groot, (604) 356-2282
 Storage Location: B.C. Systems Corporation, Victoria, B.C.
 Source of Information: L. De Groot

Database Purpose ARIS is a computer index to the mineral assessment report library which contains in excess of 18,500 reports. Its primary purpose is to assist users to locate specific information pertaining to exploration programs, resource management/landuse studies, or geoscience research projects. It is also used to assist geological survey staff with the administration tasks associated with assessment reports.

General Description ARIS contains information on assessment reports submitted by industry since 1947. Each assessment report forms the basis of a unique record. Fields consist of locational information (NTS, lat/long, etc.), toponomy, geological key words, detailed work data and administrative information.

System Output

Products: Several products are produced by the system.

1. Assessment Report Index on 360 K diskette in ASCII unspecified format.
2. Assessment Report Index on COMfiche.
3. Assessment report Index on paper files.

Complementary Datasets: MINFILE; Assessment Reports.

Database Usage

Database Users: GSB personnel, searches performed for the general public and mining industry in person and by telephone.

Performed on Database: ARIS is capable of supporting searches by assessment report numbers, NTS, claim name, author, operator, owner, lat/long, MINFILE no., mining division and other database fields.

TECHNICAL DESCRIPTION

Geographical Properties

Discrete Data: The location of each record is recorded as a point.

Continuous Data: None.
 Temporal Variation: None.
 Topology: None.
 Other:

Geographical Reference

Projection: Universal Transverse Mercator.
 Coordinate system: UTM, Latitude/Longitude.
 Reference Spheroid: Clarke-1866
 Datum: NAD-27

Data Structures

Geographical Data: Points are stored as X-Y coordinate pairs.
 Attribute Data: Entity-relational.
 Unique Identifier: Assessment Report Number, numeric, 5 digit.
 Key Attributes: Assessment report number, claim name, owner, operator, author, lat\long, NTS, mining division, MINFILE number.

Data Quality

Current Status: 90% complete, minor database changes required due to elimination of one major report and enhancement of another.
 Storage Format(s): Digital, paper files and maps.
 Volume: 70 M-Bytes, >18,000 records.
 Rate of Growth: 1400 new reports added annually.
 Record Revision: Assessment reports are static therefore record revision is rare.
 Frequency of Update: New records are added on a daily basis as assessment reports are submitted by industry.
 Scale of Input: 1:250,000 with reference to 1:50,000.
 Range of Effectiveness: 1:50,000 and larger.
 Geographical Coverage: Province.
 Geographical Accuracy: Recorded as significant figures.

Data Security

Protection: Passwords, inquiry mode only.
 Backup System: Tapes by B.C. Systems Corporation
 Internal Access: GSB staff - 10, BCSC - 3.
 External Access: Access by authorization of database manager.

Operating Platform

Hardware: VAX mainframe, dummy terminals.
 Management Software: ULTRA
 Support Software: Mantis, COBOL, Fortran, Spectra
 Operating Systems: VMS

APPENDIX C.3: COALFILEAdministration

Custodian: Coal Resources Subsection.
 Manager: C. Kenyon, (604) 356-2277.
 Storage Location: Rm. 123, 525 Superior St., Victoria
 Source of Information: C. Kenyon

Database Purpose To provide access to the most recent exploration information available from the coal assessment reports in a computerized format.

General Description Six separate files are cross-referenced by unique keyed code at the beginning of each record: 1) Exploration record- a summary of the data in the record. 2) Comment record - Title and author- any necessary comments concerning the report. 3) Map File. 4) Trench file. 5) Bulk File. 6) Borehole File. Files 3-6 contain details about the boreholes, adits, maps, pits, bulk samples etc.

System Output

Products: Hardcopy printouts of raw data or for customized retrievals; digital format (diskettes and tapes) of raw data.
 Supporting Documentation: Detailed manuals cover all aspects of the system from coding to updating.
 Complementary Datasets: Coal Assessment Reports.

Database Usage

Internal Use: Widely used by the coal resources, MINFILE and Landuse units. Sparingly used by other units.
 External Use: Users include the coal mining and exploration industry, academia and government.
 Performed on Database: Data searches and retrievals. Reports are generated on yearly basis to inform users of the information available.

TECHNICAL DESCRIPTIONGeographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Universal Transverse Mercator
 Coordinate system: UTM'S, Latitude/Longitude
 Reference Spheroid: Clarke-1866

Datum: NAD-27, NAD-83

Format

Geographical Data:

- Attribute Data: Sequential files of single records (maximum length of 250 characters).
 Unique Identifier: Assessment report number (file number).
 Key Relations: The data is raw and unorganized beyond the separation into COALFILE numbers.
 Storage Format(s): Computer library tapes and on diskette.

Data Quality

- Current Status: System is up to date, updating is performed annually.
 Volume: Approximately three megabytes.
 Rate of Growth: Fairly small on a yearly basis. New records are added on a yearly basis.
 Record Revision: Revision of records is rarely required.
 Frequency of Update: Updated on an annual basis, corrections and modifications performed when required. Load/edit programs used for updating.
 Scale of Input: UTM easting and northing to 1 metre should make the data amenable for use at virtually any scale.
 Range of Effectiveness: Variable
 Geographical Coverage: All coal occurrences in the Province of B.C.
 Geographical Accuracy: Not recorded.
 Attribute Accuracy: Accuracy of data is stated to be 93% as determined by data entry mistakes. There is little control over the quality and accuracy of information submitted in assessment reports.

Data Security

- Protection: Two levels of passwords required. Access to confidentiality files is limited to management only.
 Backup System: Six generation master back-up tape.
 Internal Access: The database manager and the unit head are the only GSB members with authorized access.
 External Access: None.

Operating Platform

- Hardware: IBM mainframe and microcomputers.
 Management Software: VMS, DOS
 Support Software: PL1 is used for the programs necessary to run the programs.
 Operating Systems: IBM, PL1, WYLBUR, FOCUS

APPENDIX C.4: REGIONAL GEOCHEMISTRY SURVEY

Administration

Acronym: RGS
 Custodian: Geochemistry & Surficial Geology
 Manager: Paul Matysek/Wayne Jackaman, (604)
 387-6249/387-3232
 Storage Location: 756 Fort St., Victoria, B.C.
 Source of Information: P. Matysek.

Database Purpose

To provide industry and government with high quality reconnaissance geochemical data (stream sediment sampling).

General Description

Sample locations, geographical reference, field observations on sample site physiography and sample textural characteristics; analysis for up to 25 metals.

System Output

Output Formats: ASCII, fixed format.
 Other Products: 1:250,000 element maps, and paper file data listings.
 Supporting Documentation: User documentation comes with all products.
 Complementary Datasets: None.

Database Usage

Internal Use: Important to field mapping programs.
 External Use: Developed for and widely used by the mining and mineral exploration industry. Government and education are also important users.

Tasks Performed on Database: The identification of anomalous samples reflecting mineralized areas, to assist geological mapping and to provide baseline data for more detailed studies. Statistical summaries and correlations are performed on all data.

TECHNICAL DESCRIPTION

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Universal Transverse Mercator
 Coordinate system: UTM; Latitude-longitude.
 Reference Spheroid: Clarke-1866.
 Datum: NAD-27.

Format

Geographical Data:
 Attribute Data:
 Unique Identifier: RGS sample number (numerical).
 Key Attributes: Sample number, geographical coordinates, underlying rock type, chemical analysis, field observations.

Storage Format(s): Floppy diskettes, 1:250,000 scale hardcopy maps, paper files.

Database Structure: ASCII fixed format by sample number.

Data Quality

Current Status: 50% of Province completed. Total coverage of the Province is expected by 2000.

Volume: 6 M-bytes. Approximately 700-1200 records per 1:250,000 NTS map sheet.

Rate of Growth: 2-3 1:250,000 map sheets per year.

Scale of Input: 1:250,000

Range of Effectiveness: 1:5,000 to 1:2,000,000.

Geographical Coverage: Province of B.C.

Geographical Accuracy:
 Attribute Accuracy:

Data Security

Accuracy: Digitized from plots on 1:50,000 NTS base maps to 1 metre accuracy.

Frequency of Update: Updated annually with new data, revisions to existing data rare.

Protection: No protection mechanism in place.

Backup System: Floppy Diskette.

Internal Access: Widely accessed by all GSB personnel.

External Access: Widely accessed by other government, by industry, education and the general public.

Operating Platform

Hardware: PC AT's, XT's.

Management Software: Dbase 3+

Support Software: In-house mapping and statistical package.

Operating Systems: DOS

APPENDIX C.5: GEOLOGICAL DATABASE SYSTEMAdministration

Custodian: Geological Survey Branch
 Manager: D. MacIntyre. (604) 356-3235
 Storage Location: 756 Fort St. Victoria, B.C.
 Source of Information: D. MacIntyre.

Database Purpose Inventory of descriptive and analytical data from field mapping projects.

General Description Station Identifiers, UTM coordinates, rock and map codes, structural information, geochemical sample analyses, mineralogical information, alteration, age dates and fossils.

System Output

Output Formats: Limited to those available for dBASE 3+; ASCII-Delimited/undelimited, DXF
 Output Mediums: Floppy, hardcopy formats.
 Supporting Documentation: None indicated.
 Complementary Datasets: Open file maps and reports.

Database Usage

Performed on Database: Produce inventory of stations, tables of data for final publications, create DXF files for use in AUTOCAD.

TECHNICAL DESCRIPTIONGeographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Mercator
 Coordinate system: UTM, Latitude/Longitude.
 Reference Spheroid: Clarke-1866
 Datum: NAD-27

Format

Geographical Data: Stored as UTM coordinates.
 Attribute Data: Relational fields.
 Unique Identifier: Station number.
 Secondary Identifier(s): NTS map sheet name(s).
 Key Attributes: Geological data.
 Storage Format(s): Floppy diskettes, hard drives.

Data Quality

Current Status: Active.
Volume: Approximately 8-10 Megabytes.
Rate of Growth: 14,000-17,000 records per annum, one megabyte per project.
Record Revision: Revision of records is generally not required after initial input.
Frequency of Update: Database is updated on an annual basis.
Scale of Input: 1:50,000
Range of Effectiveness: 1:50,000 to 1:2,000,000. Accuracy increases with decreasing use of scale.
Geographical Coverage: Eventual Province-wide coverage is expected.
Geographical Accuracy: Digitized from field maps (NTS 1:50,000), accuracy varies accordingly.
Attribute Accuracy: Unavailable.

Data Security

Protection: A mechanism for protection is not in place.
Backup System: Daily on floppy disc.
Access: Uncontrolled, open to public.

Platform

Hardware: PC AT's
Management Software: Dbase 3+
Support Software: In-house digitizing and input software.
Fastback V. 5.0.
Operating Systems: DOS

APPENDIX C.6: GEOLOGICAL BULLETINS

Administration

Custodian: Scientific Review Office.
 Manager: B. Grant.
 Storage Location:
 Source of Information: B. Grant.

Database Purpose Bulletins are formal reports of field and other research projects which may have been reported in preliminary form through the open-file maps and reports series.

General Description Bulletins typically contain textual material, colour and sketch maps, diagrams, tables, bibliography and analytical information.

Usage

Internal Use: Selectively used depending upon topic and area of coverage.
 External Use: Widely used by industry, government and education.
 Complementary Datasets: Open-file maps and reports.

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Universal Transverse Mercator
 Coordinate system: UTM's; latitude/longitude.
 Reference Spheroid: Clark 1866.
 Datum: NAD-27.

Format

Storage Format(s): Paper reports, files and maps.
 Geographical Object: Several classes of point, line and polygonal object types may be present.
 Geographical Relations: Proximity, adjacency and inclusion relationships are common to geological maps. It is possible to have several classes of each.
 Unique Identifier: Bulletin number.
 Secondary Identifier(s): Title.

Data Quality

Current Status: Up to date.
 Volume: There are 27 bulletins of the old series (1896-1934) and 84 included in the new series (1940-present). A total of 111, 1989.

Rate of Growth: Approximately 1-3 per year but this varies significantly from year to year.

Scale of Input: Maps scales have varied greatly in the past. There is a trend towards 1:50,000 scale maps following the 1986 1:50,000 initiative.

Range of Effectiveness: Unless indicated otherwise, generally not less than 1:50,000 as this represents the scale of data collection in the field.

Geographical Coverage: Bulletins cover portions from all regions of the province.

Accuracy: To the scale indicated, generally 1:50,000.

Frequency of Update: Yearly, as bulletins are completed.

Revision: Bulletins are rarely revised once published.

Data Security

Protection: Not necessary.

Backup System: Hardcopy.

Access: Unlimited once Bulletin are released.

APPENDIX C.7: PAPER SERIES

Administration

Custodian: Scientific Review Office.
 Manager: B. Grant.
 Storage Location: 122-525 Superior St., Victoria B.C.
 Source of Information: B. Grant.

Database Purpose The paper series was created in 1978 to organize an increasing number of unspecified publications. Papers typically contain reports of geological research from major project activity or from annual reviews of the geological Survey.

General Description Text, maps, sketches, tables, statistical, diagrams, analytical and summary data can be found in papers.

Usage

Internal Use: Selectively used according to topic and geographical coverage.
 External Use: Industry, government, education.
 Complementary Datasets: Open file maps and reports.

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Universal Transverse Mercator
 Coordinate system: UTM's; latitude/longitude.
 Reference Spheroid: Clark 1866.
 Datum: NAD-27.

Performed on Database: Miscellaneous geological.
 Unique Identifier: Year of publication and sequential numbering (eg. 1989-1).
 Secondary Identifier(s): Paper Title.
 Current Status: Up to Date.

Format/Technical Information

Storage Format(s): Paper reports.
 Geographical Objects: Several classes of point, line and polygonal object types may be present.
 Geographical Relations: Proximity, adjacency and inclusion relationships are common to geological maps. It is possible to have several classes of each.
 Volume: Approximately 42 (1989).
 Rate of Growth: Variable.
 Geographical Coverage: All regions of the province are included.

Quality, Accuracy, Security

Accuracy: As indicated by the scale, scale of initial data collection may be different than the final compiled scale.

Frequency of Update: Annually as papers are completed.

Frequency of Revision: Papers are rarely changed once released for publication.

Protection: None necessary.

Backup System: Hardcopy.

Access: Unlimited.

APPENDIX C.8: OPEN FILE MAPS AND REPORTS

Administration

Custodian: Regional Mapping and Mineral Deposits
 Manager: W.J. McMillan, (604) 356-3235
 Storage Location: 756 Fort St. Victoria, B.C.
 Source of Information: W.J. McMillan, D. MacIntyre.

Contents Description

Database Purpose: Initiated in 1986 as a means to deliver preliminary results of geoscience field projects and data to the public.

Database Contents: Descriptive text, maps, analytical results, tables, sketches and photographs are some of the common data types found in open files.

Performed on Database: Various tasks related to geological research, landuse issues, economic geology.

Unique Identifier: Open file number (eg. 1987-3).

Secondary Identifier(s): Title; NTS 1:50,000 map sheet name/number; Authors.
 1:50,000 NTS map sheet name(s).

Current Status: Initiated in 1986; current status is 'ongoing'.

Complementary Datasets: Geological Database System (see appendix C.2); a point database system containing descriptive information and analytical data from field work. Also Bulletins and Papers.

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Universal Transverse Mercator
 Coordinate system: UTM's, Latitude/Longitude.
 Reference Spheroid: Clarke-1866.
 Datum: NAD-27; NAD-83 as NTS maps are updated.

Format/Technical Information

Storage Format(s): Analog map format only on paper and mylar; DXF (AUTOCAD) potentially available as early as 1990. Reports are maintained in hardcopy formats.

Geographical Objects: Several classes of point, line and polygonal object types may be present.

Geographical Relations: Proximity, adjacency and inclusion relationships are common to geological maps. It is possible to have several classes of each.

Data Structure: Analog relationships.
Volume: 91 Bulletins (1989).
Rate of Growth: Approximately 25-30 per year.
Scale of Collection: Mainly at 1:50,000, but 1:20,000 and 1:2,500,000 are common.
Range of Effectiveness: 1:50,000 to 1:2,000,000; accuracy decreases with larger scales.
Geographical Coverage: Open files include portions from all regions of the province.

Data Quality and Security

Accuracy: As per scale of data collection. Open files are preliminary publications with limited editorial examination prior to release and are subject to rapid printing and distribution. Related bulletins and papers may contain updated and more accurate information.

Frequency of Revision: Open files generally are not revised once released. Any revisions are likely to appear in related bulletins or papers.

Access: Maps and reports are available for public distribution approximately six months after the initial fieldwork.

Protection: No protection mechanism is necessary, maps are available for public use.

Backup System: Original Maps are maintained on mylar by Maps B.C.; reports are in hardcopy format.

Products and Usage

Internal Use: Used extensively by all units.

External Use: Widely used by industry, government and education.

Output Formats: Hardcopy maps (black and white) and reports.

APPENDIX C.9: PRELIMINARY MAPSAdministration

Custodian: Scientific Review Office
 Manager: B. Grant
 Storage Location: 122-525 Superior St., Victoria, B.C.
 Source of Information: B. Grant

Contents Description

Database Purpose: Inventory of geological maps.
 Database Contents: Geological data in map format.
 Performed on Database: Miscellaneous geological and resource related tasks.
 Unique Identifier(s): Sequentially numbered, currently (November, 1989) at 67.
 Secondary Identifier(s): Title, Author, NTS 1:50,000/1:250,000 map numbers.
 Current Status: Ongoing.
 Complementary Datasets: Geological Database System, Coal and Mineral Assessment Reports.

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Universal Transverse Mercator.
 Coordinate system: UTM's, Latitude/Longitude.
 Reference Spheroid: Clarke-1866.
 Datum: NAD-27.

Format/Technical Information

Storage Format(s): Analog map and paper files.
 Geographical Objects: Several classes of point, line and polygonal object types may be present.
 Geographical Relations: Proximity, adjacency and inclusion relationships are common to geological maps. It is possible to have several classes of each.
 Database Structure: Analog relationships.
 Volume: 67 maps (1987).
 Rate of Growth: This map series has been superseded by the Open-File series.
 Scale of Input: From 1:12,000 to 1:2,000,000.
 Range of Effectiveness: According to scale of input.
 Geographical Coverage: Maps are from all regions of the Province.

Data Quality and Accuracy

Accuracy: According to scale.

Frequency of Revision: Maps are generally superseded by new maps if updating is required. Potential maps and those with administrative boundaries are subject to updating.

Access: All maps are available to the general public.

Protection: None required.

Backup System: Analog and paper file backup.

Products and Usage

Internal Use: Usage variable, according to the geographical location of current projects.

External Use: Widely used by industry, government and education.

Output Formats: Analog and paper files.

Supporting Documentation: None.

APPENDIX C.10: MINERAL DEPOSIT LAND-USE MAP SERIES

Administration

Acronym: MDLU
 Custodian: Land-Use Unit (Transferred to the Mineral Policy Branch, Spring, 1990).
 Manager: J. Fontaine, (604) 356-2288
 Storage Location: 756 Fort Street, Victoria, B.C.
 Source of Information: J. Fontaine

Database Description

Database Purpose: Evaluation of mineral potential for planning purposes (community plans, bylaws) park proposals etc.
 Database Contents: Analog maps with ordinal ranked areas indicating relative mineral potential ranging from 1 (excellent potential) to 4 (potential unlikely or unknown).
 Performed on Database: Updating and combining with MINFILE occurrences.
 Unique Identifier(s): NTS map sheets, 1:250,000 series.
 Current Status: 90% of B.C. completed.
 Complementary Datasets: None.

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Universal Transverse Mercator
 Coordinate system: UTM's Lat/long.
 Reference Spheroid: Clarke-1866
 Datum: NAD-27.

Format/Technical Information

Storage Format(s): Maps are stored in analog format.
 Geographical Objects: Several classes of point, line and polygonal object types may be present.
 Geographical Relations: Proximity, adjacency and inclusion relationships are common to geological maps. It is possible to have several classes of each.
 Volume: Approximately 50 maps.
 Rate of Growth: All maps were completed during 1973-74, no growth or changes since.
 Accuracy: Highly interpretive ordinal classification based upon data that is now outdated.
 Scale of Input: 1:250,000
 Range of Effectiveness: 1:250,000 scale and larger.
 Geographical Coverage: All of B.C. except 82E, F and parts of 82J, K & L.

Quality, Accuracy, Security

Accuracy: Unknown, but potentially very large. The boundaries are highly interpretive and were determined from data which is now outdated.

Frequency of Update: No updating is performed.

Protection: Available for general public use.

Backup System: Hardcopy backup only.

Internal Access: Unlimited.

External Access: Unlimited.

Products and Usage

Internal Use: The land-use subsection are the only consistent user's of these maps.

External Use: Primarily by government agency's concerned with land-use.

Output Formats: Hardcopy maps.

Supporting Documentation: None.

Resources and Costs

Personnel Requirements: None.

Annual Development Costs: None, initial cost of development is unknown.

APPENDIX C.11: SAND AND GRAVEL MAPS

Administration

Custodian: Industrial Minerals
 Manager: D. Hora; J. Fontaine
 Storage Location: 756 Fort Street, Victoria, B.C.
 Source of Information: D. Hora; J. Fontaine

Database Description

Database Purpose: Inventory of sand and gravel resources in B.C.
 Database Contents: Locational information on aggregate materials.
 Performed on Database: Inventory purposes.
 Unique Identifier(s): NTS Map sheet.
 Secondary Identifier(s): Map name.
 Current Status: There is no formal policy in place for the development of this database.
 Complementary Datasets: Air photos, topographical base maps.

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Universal Transverse Mercator
 Coordinate system: UTM's; Latitude/Longitude
 Reference Spheroid: Clarke-1866
 Datum: NAD-27

Format/Technical Information

Storage Format(s): Paper map.
 Geographical Objects: Mainly polygonal, also point and line information (base maps).
 Geographical Relations: Proximity, adjacency and inclusion relationships are common to geological maps. It is possible to have several classes of each.
 Volume: Not available.
 Rate of Growth: Variable, as demand dictates.
 Scale of Input: 1:50,000
 Range of Effectiveness: 1:50,000 and up.
 Geographical Coverage: Various parts of the province, development is ad hoc.

Data Quality and Security

Accuracy: Sand and gravel polygons determined from air photos (1:10,000).
 Frequency of Map Update: Maps have not been updated since initial release.

Protection: None.
Backup System: None.
Internal Access: Unlimited.
External Access: Unlimited but rare; this is an
unadvertised database.

Products and Usage

Internal Use: Primarily for land use issues.
External Use: Rare.
Output Formats: None.
Supporting Documentation: None.

Resources and Costs

Personnel Requirements: Negligible.
Annual Development Costs: Negligible.

Notes: These maps were created in response to
landuse needs, a policy is not in place
to guide the development, set standards
or control distribution of this data.

APPENDIX C.12: PROPERTY FILE

Administration

Custodian: MINFILE/Property File (Resource Data and Analysis).
 Manager: D. Jakobsen, (604) 356-2829
 Storage Location: 247-541 Superior Street, Victoria, B.C.
 Source of Information: D. Jakobsen

Database Description

Database Purpose: It is a hard copy back-up to the MINFILE database system. Documents and geologic information pertaining to individual mineral properties are stored in Property File/Regional File archives.

Database Contents: The contents contain unique documents, newspaper and magazine clippings, prospectuses, annual reports, maps, sketches, plans, cross-sections, photos, thesis, notes, MINFILE coding forms and other miscellaneous geologic documents.

Performed on Database: Constant updating, adding new properties, deleting redundant properties, future microfilming of archival documents, manual searches.

Unique Identifier(s): MINFILE number.
 Key Attributes: The data is raw and unorganized beyond the separation into MINFILE numbers.

Current Status: The file is Province-wide. Approximately 50% is ready for microfilming.

Complementary Datasets: MINFILE, ARIS

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference Due to the large variety in source material, reference varies, however the following are generally valid:

Projection: Universal Transverse Mercator.
 Coordinate system: UTM'S, Latitude/Longitude.
 Reference Spheroid: Clarke-1866.
 Datum: NAD-27, NAD-83

Format/Technical Information

Storage Format(s): Paper Files, paper lists, analog maps.
 Geographical Objects: At 1:50,000 scale, the files can be considered point data. However, at smaller scales the maps and cross-section become relevant. At smaller scales, there is point, line, polygonal and even three dimensional data.

Geographical Relations: Proximal.
Volume: Approximately 10,000 occurrences are maintained in this file.
Rate of Growth: Approximately 200-300 per annum.
Output Formats: Photocopies and photographs available.
Scale: Dependent upon information contained within files, but a minimum scale of 1:50,000 for all properties.

Data Quality and Security

Accuracy: A rough approximation indicates that 80% of the documents are identified with the existing files.
Frequency of Update: Daily updating. Individual files are updated as new information arrives.
Protection: Security consists of sign-in sign-out.
Backup System: No direct back-up is currently in place however microfilming is planned for the near future. The documents are indirectly and selectively backed-up in the MINFILE data system.
Access: All access is supervised.

Products and Usage

Internal Use: Used frequently by most GSB units.
External Use: Used less frequently by industry, government and education.
Supporting Documentation: N/A
Collection/Maintenance: Five FTE's involved with data collection and file maintenance.
Annual Development Costs: Approximately \$21,250 per annum.

APPENDIX C.13: MINERAL ASSESSMENT REPORTS

Administration

Custodian: Mineral Inventory Unit
 Manager: L. De Groot
 Storage Location: 121-525 Superior Street, Victoria B.C.,
 Source of Information: B. Grant.

Contents Description

Database Purpose: Inventory and storage of mineral assessment reports submitted by industry.
 Database Contents: Contents and scale of data vary greatly between individual reports. Common information types include; maps, geochemistry, geophysical data, statistical analysis, petrological data, drill hole data and descriptive text.
 Performed on Database: Manual searches.
 Unique Identifier(s): Assessment report number.
 Current Status: Up to date.
 Complementary Datasets: ARIS, MINFILE.

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Variable but dominantly Universal Transverse Mercator.
 Coordinate system: Variable but UTM's and latitude/longitude dominate.
 Reference Spheroid: Clark 1866; possibly others.
 Datums: NAD-27, NAD-83.
 Note: At very small scales no geographical reference controls are likely to be employed on map data. A cartesian coordinate system is used at these scales.

Format/Technical Information

Storage Format(s): Paper reports, maps and files; microfiche.
 Geographical Objects: Point, line, polygonal and grid cell. 3-Dimensional data where drill holes are included.
 Geographical Relations: As individual records referenced to a single location, there is a proximal relationship. According to information contained within each report, there are unlimited relationships.
 Volume: More than 10,000 reports.

Rate of Growth: Approximately 1400 new reports added annually.
Scale: Variable.
Range of Effectiveness: Variable
Geographical Coverage: Submitted assessment reports cover all regions of the province.

Quality, Accuracy, Security

Accuracy: Variable, no internal control over accuracy.
Frequency of Update: Constant; files added as submitted.
Record Revision: Assess. reports do not require revision.
Protection: Reports are held in confidence for the first year after submission. After this period they are open to the general public.
Backup System: Microfiche
Access: See protection.

Products and Usage

Internal Use: Widely used by all GSB units.
External Use: Widely used by industry, minor usage by other government and by education.
Output Formats: The format of the submitted report remains as the output format.
Output Mediums: Photocopy, microfiche.
Supporting Documentation: N/A

APPENDIX C.14: COAL ASSESSMENT REPORTS

Administration

Custodian: Coal Resources unit.
 Manager: A. Matheson
 Storage Location: 122-525 Superior Street, Victoria, B.C.
 Source of Information: B. Grant.

Contents Description

Database Purpose: Inventory and storage of coal assessment reports submitted by industry.
 Database Contents: Coal exploration information submitted by industry. Data includes descriptive text; maps; cross sections; tabular; analytical and statistical data; drill hole data.
 Performed on Database: Manual searches.
 Unique Identifier(s): Coal assessment report number.
 Current Status: Up to date.
 Complementary Datasets: COALFILE, MINFILE

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Universal Transverse Mercator.
 Coordinate system: UTM's; latitude/longitude.
 Reference Spheroid: Clark 1866.
 Datum: NAD-27; NAD-83.

Format/Technical Information

Storage Format(s): Paper, microfiche.
 Geographical Objects: Point.
 Geographical Relations: Proximal.
 Volume: Not available.
 Rate of Growth: Variable.
 Scale: Variable.
 Range of Effectiveness: Variable.
 Geographical Coverage: Provincial.

Quality, Accuracy, Security

Accuracy: Variable, no internal control on data.
 Frequency of Update: Constant, as reports are submitted.
 Record Revision: N/A
 Protection: Submitted reports are kept confidential for one year, then are available for public inspection.
 Backup System: Microfiche
 Access: See protection.

Products and Usage

Internal Use: Primarily by the Coal Resources unit, MINFILE, and the landuse unit.

External Use: Extensively by industry; less frequently by government and education.

Output Formats: Reports are not changed or modified from original formats when submitted.

Output Mediums: Paper, microfiche.

Supporting Documentation: None

APPENDIX C.15: GEOLOGICAL FIELDWORKAdministration

Custodian: Scientific Review Office.
 Manager: B. Grant.
 Storage Location: 122-525 Superior St., Victoria, B.C.
 Source of Information: B. Grant.

Contents Description

Database Purpose: The premier publication of the GSB. It is edited to release preliminary results of the previous season's fieldwork and research activities.

Database Contents: FIELDWORK volumes contain descriptive text; maps and cross-sections; photos; summary data; statistical and analytical data.

ks Performed on Database: Manual searches.

Unique Identifier(s): Paper no. (FIELDWORK is always assigned the first paper number of each year, eg. 1987-1).

Secondary Identifier(s): Geological Fieldwork (followed by the year).

Current Status: Up to date.

Complementary Datasets: Virtually all other datasets overlap in some way with FIELDWORK.

Geographical Properties

Discrete Data: Point.
 Continuous Data: None.
 Temporal Variation: None.
 Topology: None.

Geographical Reference

Projection: Universal Transverse Mercator.
 Coordinate system: UTM's; latitude/longitude.
 Reference Spheroid: Clark 1866.
 Datum: NAD-27.

Format/Technical Information

Storage Format(s): Paper report.

Geographical Objects: Point, line and polygonal.

Geographical Relations: Several classes of adjacency and inclusion may be present.

Volume: 16; one per year since 1975.

Rate of Growth: 1 per year.

Scale of Data: Variable.

Range of Effectiveness: Variable.

Geographical Coverage: Submissions are from all regions of the province

Quality, Accuracy, Security

Accuracy: Accuracy is a secondary consideration. This publication contains preliminary results from field and other research projects. Individual projects are generally followed up with more accurate results in papers, open files and bulletins.

Frequency of Update: Once per year.
Frequency of Revision: N/A
Protection: N/A
Backup System: Paper copies.
Access: Unlimited once released.

Products and Usage

Internal Use: Widely used by all units.
External Use: Extensively used by industry; less commonly by government and education.
Output Formats: Book format only.
Output Mediums: Paper only.
Supporting Documentation: N/A

APPENDIX C.16: EXPLORATION IN BRITISH COLUMBIA

Administration

Custodian: Geological Survey Branch
 Manager:
 Storage Location: 756 Fort Street, Victoria, B.C.
 Source of Information: B.Grant

Contents Description

Database Purpose: Exploration in B.C. is an annual summary of the results of mineral exploration and development in B.C. for the calendar year. This includes the Annual Reports of the Minister of Mines (1974-1969); Geology, Exploration and Mining in British Columbia (1969-1974); Geology in British Columbia (1975-1981); Exploration in British Columbia (1975-1988); Mining in B.C. (1974-1985). The total is 116.

Database Contents: Each volume contains descriptive text; maps and cross-sections; photos and diagrams; analytical and statistical data and summary data from assessment reports.

ks Performed on Database: Manual searches.

Unique Identifier(s): Title and year (eg. Exploration in British Columbia: 1988).

Current Status: Up to date.

Complementary Datasets: MINFILE; ARIS; COALFILE.

Geographical Properties

Discrete Data: Point.

Continuous Data: None.

Temporal Variation: None.

Topology: None.

Format/Technical Information

Storage Format(s): Paper report.

Geographical Objects: Point, line and polygonal.

Geographical Relations: Proximity; several classes of adjacency and inclusion may be present.

Volume: 133; see database purpose.

Rate of Growth: One release per year.

Scale of Data: Variable.

Range of Effectiveness: Variable.

Geographical Coverage: Provincial.

Geographical Reference

Projection: Universal Transverse Mercator

Coordinate system: UTM's; latitude/longitude.

Reference Spheroid: Clark 1866

Datum: NAD-27.

Data Quality, Security

Accuracy: Variable, most of the data is summarized from assessment reports.
Frequency of Update: Once per year.
Frequency of Revision: N/A
Protection: N/A
Backup System: Paper.
Access: Unlimited.

Products and Usage

Internal Use: Widely by all GSB units.
External Use: Extensively by industry; less frequently by government, education and the general public.
Output Formats: Paper volume in book format only.
Supporting Documentation: N/A

APPENDIX C.17: CIRCULARSAdministration

Custodian: Scientific Review Office.

Manager: B. Grant.

Storage Location: 122-525 Superior St., Victoria, V8V 1X9.

Source of Information: B. Grant.

Database Purpose To inform the public of GSB data, research, activities, mandates etc.

Database Contents Variable, but generalized descriptive information pertaining to the GSB.

Unique Identifier: Year and number (eg. 1988-22).

Secondary Identifier(s): Title.

Current Status: Up to date.

Format/Technical Information

Volume: Unknown.

Rate of Growth: Approximately 30 issued in 1989.

Access: Unlimited, as supplies last.

APPENDIX C.18: MISCELLANEOUS REPORTS AND MAPS

Administration

Custodian: Scientific Review Office.

Manager: B. Grant.

Storage Location:

Source of Information: B. Grant.

Contents Description Several data types do not fit into the above sections and are listed along with brief descriptions.

1. General Maps: Currently there are seven maps listed in this category of which two are out of print¹. They include: a) British Columbia Geological Highway Map (4 Coloured Maps, booklet), b) Generalized Geological Map of the Canadian Cordillera, c) Faults, Porphyry Deposits and Showings, and Tectonic Belts of the Canadian Cordillera, d) Faults, Tectonic Belts, and Thermal Springs of the Canadian Cordillera, e) Metallic Mineral Potential of British Columbia, f) Geothermal Potential Map of British Columbia, g) Areas Underlain by Economic Reserves of Coal.

Notes: These maps tend to be large scale (1:250,000 - 1:2,500,000) and will therefore have an accuracy reflecting this scale. The maps contain point, line and polygonal information. At least some of these maps are based upon unique geographical coordinate systems, ie. they will not register to known projections.

2. MDA: The Canada/British Columbia Mineral Development Agreement sponsors market, economic, safety, etc. studies. These tend not to have a geographical component, at least in the context of this study, and are mentioned for completeness only.

3. Indexes: Several indexes are available through the GSB. Several deal with historical publications, namely the Annual report series. An index of assessment reports is maintained with geographical information, status, author and other information available. This index is available in paper files, COMfiche or diskettes. Accompanying this index are 1:250,000 scale simplified base maps containing drainage and reference coordinates. The maps are available in analog format.

4. Miscellaneous Publications: At least 11 publications dealing primarily with exploration guidelines. Two deal with radioactivity in ground water, one is a report on local geology and ore deposits.

¹ Ministry of Energy, Mines and Petroleum Resources, Mineral Resources Division, 1989: Information Circular 1989-19. Reports, Maps and Geoscience Databases Issued by the B.C. Geological Survey Branch, Compiled by D. Fehr, Queen's Printer, Victoria, B.C.

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Title of Thesis: Investigation into Development and Implementation of Natural Resources Geographical Information Systems (GIS): Case Study Geological Survey of British Columbia

Author



Patrick M. Bartier

February 28, 1991