Automated Mapping and Spatial Information Management

for

Open Pit Mines

by

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Abstract

Mining operations require maps for each phase of project development. The filing and organisation of maps and drawings is cumbersome; revision of plans and maps necessitates the production of new documents to prescribed scales. **Automated Mapping (AM)**, combined with **Geographic Information Systems (GIS)** provide new facilities for the management of plans and sections with access to mine archives of textual information.

In **vector** mapping, a user is able to reproduce maps at a variety of scales and projections, but remains unable to examine or analyse the displayed information in the manner of a database. **Raster** mapping offers these facilities and the additional capabilities of **image processing**, necessary to perform more advanced map manipulation.

Ideas for the manipulation of map overlays have received renewed attention with improvements in data management and automated draughting. The **overlay** technique provides versatility, speed and accuracy in map processing.

A combination of hierarchical links (for maintaining different levels of resolution) and relationship tables (for storing spatial features and attributes) has been found to be appropriate for the development of a spatial database management system.

A prototype package, **DIRECT** (Dynamic Information REtrieval and Cartographic Tools) has been developed employing the aforesaid concepts and techniques, which involves the following functions:

1. *Data capture/collection;*
   - *digitised data*
   - *survey data from field*
   - *other textual data*
   - *data created interactively*
2. *Processing of raw data;*
3. *Conversion from vector map to raster map;*
4. *Map processing and mapbase management;*
5. *Raster mapping and restoration of vector outline from raster maps;*
6. *Interactive information management.*

The package consists of four main modules coded in standard **FORTRAN 77**; graphics interface has been written around **GKS**. This can serve as an automated mapping system, a **mapbase manager**, a **map processor** and as a **Spatial Information System**, and has the additional capability of solving some mining problems involving minability, visibility, blasting vibration assessment, pit merging, dump site selection, locational enquiry, area calculation etc. The scope of the package embraces:

- *Map generation;*
- *Storage and retrieval of maps;*
- *Storage and retrieval of sections;*
- *Interactive draughting;*
- *Ordinary map processing (superimposing maps, scaling maps etc.);*
- *Advanced map processing (spreading features, visibility study etc.);*
- *Storage and retrieval of textual information using spatial keys;*
- *Interactive and non-interactive information management;*
- *Picture generation (raster plotting).*

The capabilities listed above find immediate application in:

- *on-line communication;*
- *short-term and long-term planning;*
- *meetings and conferences;*
- *monitoring the rapid change in landscape;*
- *teaching and training;*
- *integration of geographic information.*

An algorithm has been developed for vector to raster conversion of complicated map features, which can deal with convex, concave, isolated and fenestrate polygons. **Run encoding** and a **quadtree** structure have been used for saving space in storing raster maps. **Security, integrity, privacy**, and **concurrency** as expected in an implementation of such a system, have been addressed comprehensively.

Basic **software engineering** guidelines have been followed in developing the package; the norms followed are the use of standard code, standard graphics library, modular structure and documentation in coding and also in documentation files.

Further enhancement proposed to the system includes, real time section generation, a blasting management subsystem using an expert system, 3D modelling and display using **octree encoding**. Integration of remotely sensed data (directly compatible) to form an **Integrated Geographic Information System (IGIS)** is proposed. **Parallel processing** using **transputer arrays** and use of **erasable optical disks** for storage are anticipated to play vital rôle in these endeavours.

TO MY PARENTS

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My greatest reward for completing the Thesis is my happiness for being able at last, to fulfil my long longing to archive my appreciation for things which can not be separated from the completion of my thesis.

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While I thank all my well wishers for congratulating me for the package I have developed, I humbly apologise to ***them;***

"Full many a gem of purest ray serene
The dark unfathom'd caves of ocean bear:"

Above all, I wonder as always, why am I, as a nano entity, here on this tiny earth, developing an infinitesimal system, in the infinite space and time? What is the ***Truth,*** *or what could be the* ***Truth,*** *beyond the quasars, before the 0.0001 second of the big bang, or over the bubbles on the river of time? I hit the blind end of my imagination, and then pay tribute to the* ***Supreme System.***

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Abbreviations and acronyms

AI	:	Artificial Intelligence
ALF	:	Automated Line Following
AM	:	Automated Mapping
BCCL	:	Bharat Coking Coal Limited
CAD	:	Computer Aided Design
CAM	:	Computer Aided Manufacturing
case	:	computer aided software engineering
CG	:	Computer Graphics
CIL	:	Coal India Limited
CME	:	Chief Mining Engineer
CMPDIL	:	Coal Mine Planning and Design Institute Limited
CMRS	:	Central Mining Research Station
DBMS	:	DataBase Management System
DGMS	:	Director General of Mine Safety
DIRECT	:	Dynamic Information REtrieval and Cartographic Tools
DPR	:	Detailed Project Report
EDM	:	Electronic Distance Measurement
EEC	:	European Economic Community
EMS	:	Electronic Mailing System
ES	:	Encryption System
FS	:	Facsimile System
GIS	:	Geographic Information System
GKS	:	Graphical Kernel System
GRD	:	Ground Resolution Distance
GSI	:	Geological Survey of India
HLL	:	Higher Level language
HQ	:	Head Quarters
IBM	:	Indian Bureau of Mines
		(underlined to distinguish from more familiar IBM the computer manufacturer)
IGIS	:	Integrated Geographic Information System
IMS	:	Information Management System
I/O	:	Input/Output
IR	:	Information Retrieval
ISM	:	Indian School of Mines

ISO	:	International Standard Organisation
IT	:	Information Technology
ITG	:	Independent Testing Group
I/S	:	Information System
JANET	:	Joint Academic Network
JCFRS	:	Jharia Coal Field Reconstruction Scheme
KBES	:	Knowledge-Based Expert System
LAN	:	Local Area Network
LIS	:	Land Information System
MB	:	Mega Byte
MEC	:	Mineral Exploration Corporation
MIS	:	Management Information System
MLD	:	Million Litres per Day
mmi	:	man machine interface
MMIS	:	Mining Management Information System
MPS	:	Mine Planning System
MRS	:	Mining Regulation System
OB	:	OverBurden
OCP	:	Open Cast Project
ODD	:	Optical Digital Disk
OMS	:	Output per Man Shift
PDBS	:	Pictorial Database System
pixel	:	picture element
RM	:	Raw Materials
ROM	:	Read Only Memory
RPG	:	Report Program Generator
RQD	:	Rock Quality Designation
RSM	:	Royal School of Mines
R-V	:	Raster-to-Vector
SDMS	:	Spatial Database Management System
TISCO	:	Tata Iron and Steel Company
V-R	:	Vector-to-Raster
WAN	:	Wide Area Network
WORM	:	Write Once Read Many
2D	:	Two Dimension
3D	:	Three Dimension

Chapter 1

GENERAL INTRODUCTION

Chapter 1

GENERAL INTRODUCTION

Despite the wide use of the term, there is, as yet in prospect, no such thing as 'automated mapping'. It is true that many mapping agencies automate most of the cartographic activities previously carried out manually, using computing hardware and software; but computers will not, at least in near future, replace the cartographers. Computers will, however, relieve the cartographers of many onerous, repetitive tasks, and will free a great deal more time for the design and creation of maps. 'Automated cartography' rather suggests the creative use of machines by cartographers. Technically there is a fine distinction between **mapping** and **cartography**. 'Mapping' includes all the activities of map making, starting from surveying, whereas 'cartography' is mostly confined to presentation. This technical difference has not been taken into consideration in the scope of this research. The term **Automated Mapping (AM)** has been used rather than **Automated Cartography** because the system described is dedicated to a mining application, and in mining, 'mapping' is the term which is familiar and used conventionally. However, in this thesis, both the terms have been used synonymously. Chapters 1 and 2 define terms and summarise some of the techniques employed in this work.

Progress in any field of science and technology is achieved both by improving existing techniques, in order to obtain better results, and by addressing subordinate problems within the same field through radically different approaches. Computing in mining has trailed behind the mainstream of applied computing, not because of any limitation of appropriate applications, but through reticence to accept new computing techniques.

The wide-spread employment of computers and the increasing power of hardware have opened the possibility of using 'new technology' to address complex cartographic applications. For example, the techniques for manipulation of map **overlays** have been established since the early part of this Century, but have recently attracted renewed attention as a practical method using computing power. Overlay structures provide a logical and intuitive way to organise cartographic information.

Image processing is another field which has grown rapidly in recent years, and has found important applications in remote sensing, as well as in medical sciences and manufacturing. This growth in application is associated with the ability to input a 'picture' into a computer in digital form and to then manipulate the image mathematically. Mathematical operations on pixels, as practised in digital image processing, are of great potential benefit in map processing. Employment of image processing techniques for manipulating maps largely involves the use of vector-to-raster conversion algorithms; special applications of these methods form part of the subject of this thesis.

The use of computer mapping is not yet common place in management of day-to-day mining. There are four main reasons why this situation has arisen:

- Available packages cater for a limited range of mine mapping needs, and none are presently adoptable to the requirement of a full mine mapping system; for example, cartographic standard surface mapping is not yet available.
- The general packages developed are not easy-to-use for mining purposes.
- Provision for storing, retrieving and processing maps and plans has been unsatisfactory.
- CAD facilities are rarely provided in the packages.

The integration of standard **Computer Aided Design/Computer Aided Manufacturing (CAD/CAM)** facilities with automated mapping is essential to the success of any mine mapping system, especially for a dynamic process such as open cast mining involving continuous revision of plans. (In mining, the term 'computer aided production' may be more appropriate than 'computer aided manufacturing'). Conventional CAD/CAM packages are not suitable for production processes in mining because the products, unlike other products of industrial manufacturing, are predefined in natural occurrences. Moreover, the real configuration

of a mineral deposit and distribution of minable grades is not fully conceived as a three dimensional body. Even with the best available evaluation technique, an orebody can not be precisely infered until a certain amount of development work has been carried out. The criteria for minability can also change depending on the market conditions which involves remodelling the orebody.

Logically, any cartographic system is an **Information System (I/S)**, as it essentially retrieves information from a cartographic database and presents the information graphically. However, these systems can be made easy-to-use and powerful with the use of interactive graphics and a sound database (or mapbase in this context). Recent advances in information management of spatial data make provision for interaction with maps or plans on a graphics screen. One of the applications developed using these techniques is the **Geographic Information System (GIS)** which has potential in mine planning and management. Cartographic techniques are successfully used in geographic information systems in many disciplines such as, forestry (Tomlin, 1983a; MAP, 1983), urban planning (MAPS, 1984), and demography (ODYSSEY, 1983).

Spatial data management involves techniques for accessing, indexing and representing data through a graphics display. A database interrogated through a **spatial data management system (SDMS)**, provides access to data through a key reference to displayed locations. Users of a conventional **Database Management System (DBMS)** can access data only by asking questions in a formal query language. In contrast, users of spatial data management systems benefit from the ability of accessing computer-resident information while exploiting a user's three familiar senses of perception in the realms of visual, auditory and haptic space (the space of tactile sensation). Spatial data management techniques have been successfully applied in a geographic database (Frank, 1982), navigation (Friedell, 1982) and a government mapping information system (ODYSSEY, 1983).

With the growth in software development in almost all fields, it is often possible to benefit from existing software. However, in the modern climate, it is essential that the innovative developer follows some standards and guidelines so that software can be adopted or adapted systematically, as a safeguard against rapid and costly software obsolescence. From its early beginnings, software development has moved from a haphazard 'cottage industry' to more disciplined practice of modern **Information Technology (IT)** called **Software Engineering**. Software

Engineering involves the application of methodologies for the design, development and management of complex software. The latest **computer aided software engineering (case)** is a further development in this direction.

The object of this research has been to 'formulate' an automated mapping system which may be used for information retrieval through visual keys, and to provide some built-in features relevant to surface mine planning and management.

Chapter 2

MINE MAPPING, AUTOMATED CARTOGRAPHY AND SPATIAL INFORMATION SYSTEMS

Chapter 2

MINE MAPPING, AUTOMATED CARTOGRAPHY AND SPATIAL INFORMATION SYSTEMS

2.1 MINE MAPPING AND AUTOMATED CARTOGRAPHY

2.1.1 Mine mapping

Mining operations require maps for each phase of project development. Engineering plans, cross sections, and isometric drawings at various scales, are also needed. The production and maintenance of such material is however a major undertaking. The filing and organisation of maps and drawings is cumbersome, and revisions necessitate the production of new maps or plans to prescribed scales. On the other hand, the development of an optimal production sequence in a mine is a complex procedure, due to the large number of variables and constraints. Maps are the most commonly used medium in the analysis of mine design variables and the comparison of strategies. Maps and mapping therefore, represent an important element in planning and management, since mining involves a continuous process of design.

Open pit mining involves a continuous change in the pit contour or form and there are many feasible plans of extraction which may lead to a similar final pit shape. Various plans depicting several designs help the open pit operators in the decision making processes of long and short term planning. Maps of different combinations must be prepared regularly (yearly, monthly, weekly, or sometimes, on a daily basis) depending on the type of operations to be performed and the requirements of regulating authorities. However, in open pit operations, as opposed to underground mining, accurate maps of high resolution are not essential. For example, ± 0.5 m accuracy has been found to be generally acceptable for most feature maps in surface mining (Samaddar, 1986).

2.1.2 Cartography and thematic mapping.

Modern cartography involves a great variety of mapping activities which may be classified into two major groups. The first group of activities carries on the early tradition of mapping and charting geographic features; oceans, mountains, and lakes etc. There are maps that depict as much as the surface features of a particular area as is possible within the limitations of scale. Such maps are called **'topographic maps'** (Lawrence, 1979). Road maps or wall maps – the so-called **'reference maps'**, are not made directly from primary work, aerial photographs or surveys. They are compiled instead from topographic and other maps. Another class of maps, the **'thematic maps'** are based on existing maps which may include reference maps. They are distinguished further by the subject matter which does not usually relate directly to geographic locations (Cuff and Mattson, 1982). The subject may be average annual rain-fall, birth rate or sales figure etc.

2.1.3 Automated cartography

It is possible to distinguish in map production between two different types of computer-assisted cartography: **automated mapping** and **computer mapping** (Taylor, 1980). Automated mapping is defined as the automation of the map-making process with the objective of producing maps, not inherently different in style, design or content from topographic maps. Computer mapping, on the other hand, is defined as the production of maps utilising primarily the analytical power of the computer. Such maps tend to be thematic or socio-economic in nature, and rarely require the high standard of precision involved in automated mapping and may in fact be a quite different from a conventional map. However, with the enhancement of computer and graphics hardware-software, precision line drawing using computer is becoming realistic. The subject under consideration will mainly deal with computer mapping.

It is unlikely that map production will be made completely automatic in the coming years. However, computer assistance can relieve a cartographer of much tedious work, and increase his response to requests for maps which differ both in scale and feature combination, some of which would have been rather impossible to be achieved without employing computer techniques. The term 'automated' is used to emphasise this idea of assistance, and involves storage of map data in digital form; locations and lines being represented by coordinate strings with appropriate label descriptors.

Automated cartography consists of four basic activities :

- Display and interactive editing;
- Automated draughting;
- Digitising;
- Storage of data.

Display and interactive editing: Any establishment adopting automated cartography must, as a primary objective, have a means of converting digital data to a visual form in order to allow the data to be checked, possibly modified, and to be used for interpretation and analysis. The technology employed is relatively new, the most important activity being the interactive display and editing, without which the user can not manipulate data – an essential element of the primary man/machine interface (mmi).

Automated draughting: Automated draughting is the aspect of automated cartography that has received the most attention so far. Most systems, however, did have a draughting facility that would allow cartographic lines of high quality to be created. Many X–Y plotters are available, but not all of them provide the precision required for making maps for certain application. Generally the term 'plotting' refers only to 'locational symbology' and labelling while the term 'draughting' is used for precision line work. The precision required depends on the application. For underground mining the precision maintained is ± 0.1 m (Bak and Smith, 1987). However, in surface mining applications, ± 0.5 m accuracy has been found to be accepted (Samaddar, 1986). The accuracy mentioned above refers to that in plotting. The accuracy maintained in surveying is ± 0.006 m usually independent of surface or underground mining.

Digitising: The digitising of existing maps is still one of the major problems in the practical application of automated cartography; there is no indication as yet, that the manual processes can be fully automated. An intermediate method, which may be economically viable during the next few years, is Automatic Line Following (ALF) (Laser Scan, 1987).

Storage of data: One overlay sheet may well have 500000 co-ordinate pairs of line data; usually two 4 byte integers are required to store a pair of coordinates. However, these can be reduced by using bit manipulation techniques, and by compromising with some accuracy. 'Storage' is discussed further in Section 2.8.1.

There are not many general purpose mapping packages presently available. GEOMAP (Heggli, 1984) is a mapping package which generates a map from survey data and can superimpose different maps. The package has been developed for automated map creation from survey data. Recently developed packages such as, INTERGRAPH (AUTOCARTO, 1986), SYSTEM 9 (AUTOCARTO, 1986) manage mapbases using different attributes for different map elements and therefore are able to plot maps with different combinations of features. MAPS (1984) is a general mapping package oriented towards urban planning.

InforMap III (Carlson, 1987) from Synercom Technology, Inc, is a system for urban mapping and associated information management. This system combines interactive graphics, relational database management, rule-based data capture, and specialised cartographic functions into a single integrated package. However, the cartographic capabilities offered do not include the map manipulation functions.

Ordnance survey departments often have dedicated mapping systems. One such system is Project'88 (1988).

2.1.4 Automated mapping/computer aided design

Automated Mapping (AM) and Computer Aided Design (CAD) have become integral elements in cartography and engineering. AM/CAD systems use computers to store, manipulate, produce and update drawings and maps in two and three dimensions. However, the present capabilities of many CAD systems are oriented largely towards the design of regular components and structures found in manufacturing industry.

Versatile CAD systems are in use today at defence establishments and large industrial research centres. They employ expensive packages, built around specific computer systems and peripherals, and frequently are custom-made. General CAD systems do not form a part of this review. Although there are some general draughting packages, such as DOGS (Level 3.2a) for 2D draughting, PIGS (Level 3) for 'finite element' draughting, AUTOCAD (Version 2.6) and BOXER (Level 3.2) for 3D draughting are available on different computer systems. They are mainly designed for modelling regular geometric objects. The mapping subsystem of DOGS offers the capability of storing, displaying and draughting of maps, however without processing functions. Similar mapping capability has

been developed around AUTOCAD, by some vendors. The combination of modern mapping methods with CAD facilities and processing functions offers a substantial advance in mine design techniques; this research examines the potential that modern methods in Information Technology (IT) offers to mapping and CAD.

2.2 MAP PROCESSING TECHNIQUES

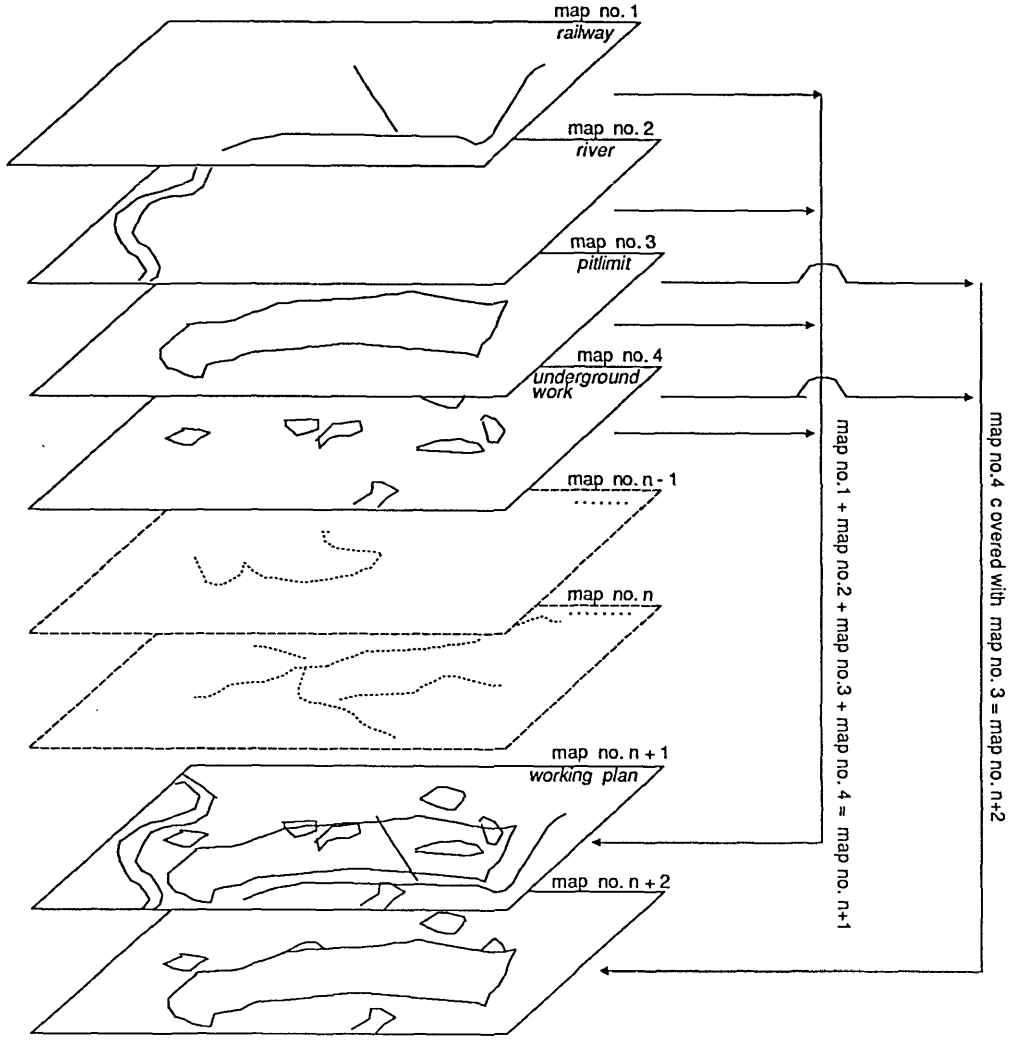
2.2.1 Basic cartographic data manipulation

The basic concept of cartography and automated cartography has been discussed in Sections 2.1.2 and 2.1.3. In the context of map processing, the basic operations of cartography are listed below:

* accessing
* inserting
* deleting
* searching
* sorting
* copying
* combining
* separating

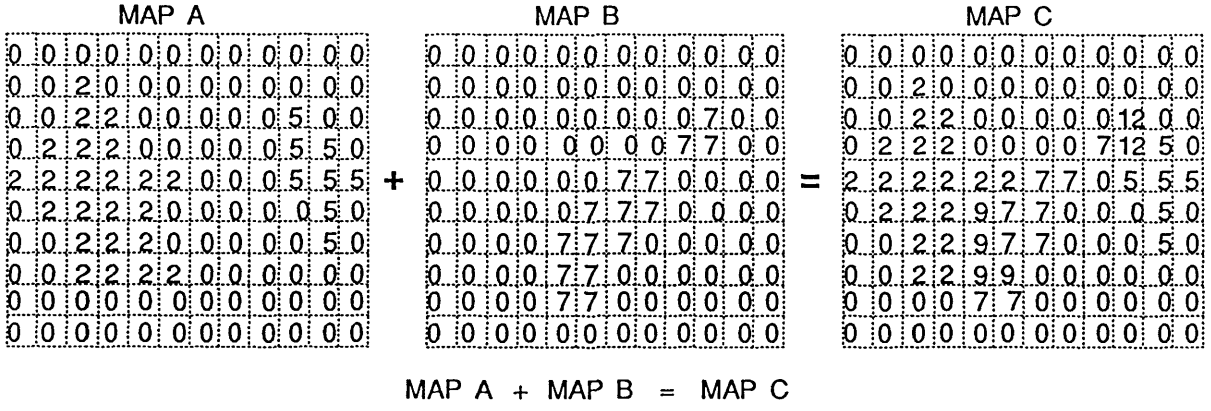
2.2.2 The overlay technique

If a general purpose map, into which all the necessary data are incorporated, was drawn, it could provide all the information that might be requested by the users. However, it may prove difficult, or even impossible, to fabricate such a map, and even if available, its maintenance might be unacceptably cumbersome. Moreover, it might require much effort to extract the data necessary, for a specific type of planning, from a large volume of data integrated in the general purpose map. The overlay technique (Tomlin, 1983a) provides a solution to the problem. Figure 2.1 illustrates the overlay concept. Overlaying is a long established technique, but there was no significant usage until McHarg (1969) brought the method to the attention of cartographers. Figure 2.1(b) shows how raster overlaying is performed. 'Raster map' is discussed in the next Section.



(a) Simple overlay technique :

(Creation of new maps by adding several maps, and by covering one by another).



(b) A simple raster overlay operatio n.

Figure 2.1

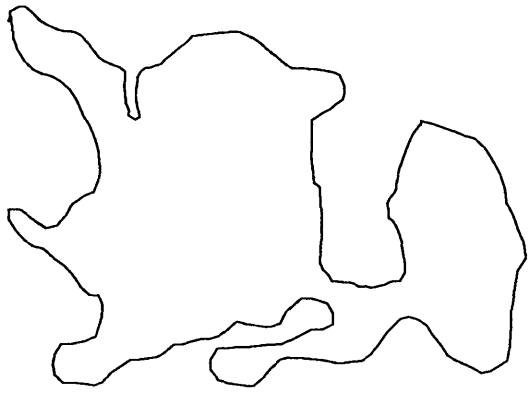
The 'overlay' also has been referred to variously as a 'single-factor map', an 'image', a 'picture function', a 'coverage', a 'surface', a 'variable', a 'data element' and a 'data plane' (Tomlin and Berry, 1979). The technique provides a versatile means of map processing which can be utilised to create maps to aid in different mining activities.

In computer graphics terms, an overlay is a form of map compiled such that each cartographic location is explicitly characterised in terms of a single attribute through the use of colour, pattern, or symbolism. This is in contrast to the format of a conventional map on which each location might be characterised in terms of elevation, water feature, development, mineral, geological designation or some other properties. In overlay format, each of these individual characteristics is presented separately in a manner analogous to the use of colour-separation negatives used in certain printing processes.

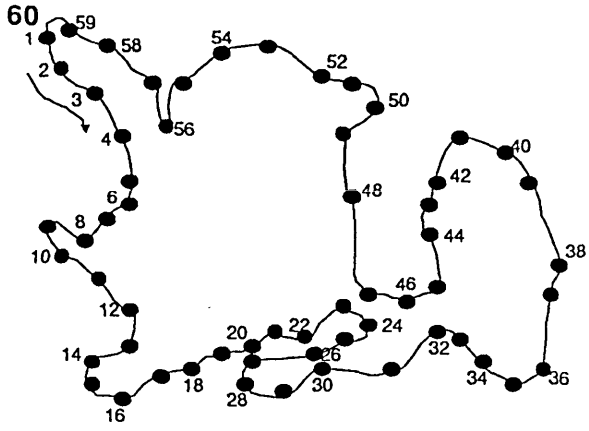
2.2.3 Vector and raster modes of mapping

There are two modes of representation for geographic features, – **raster mode** and **vector mode**. Using vector mode, it is possible to reproduce maps at a variety of scales and projections, but a user remains unable to examine or analyse the displayed information in the manner of a database (Sinton, 1979). In vector mapping, a technique which is commonly employed involves the generation of different map categories by the superimposition of existing maps; a method analogous to the conventional use of transparent master copies used in dyeline reproduction. Such methods preclude the use of the more refined cartographic techniques of selective subtraction of individual attributes from composite maps or preferential addition.

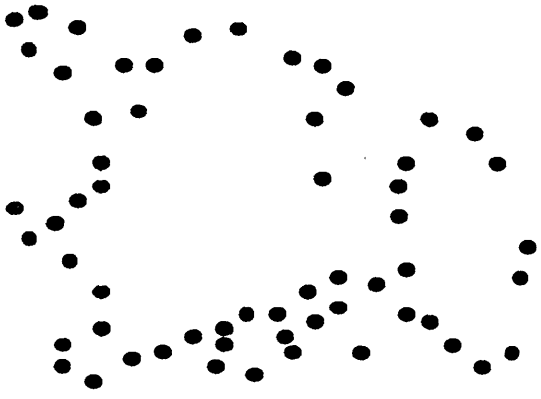
In a raster representation of a map, the geographic area of interest is divided into a matrix of cells which completely fill the area. Each cell is assigned a single value associated with it describing the coverage and nature of space enclosed by the area known as a grid cell. Figure 2.2 and Figure 2.3 show a 'real' feature in geographic space, as represented in vector and raster modes, and the interrelations between these forms of representation. The raster feature in Figure 2.3(e) has been highlighted by shedding the feature area with dots in Figure 2.3(e). The 'raster map' and 'grid cell map' have been used synonymously; the fine technical distinction between these two terms is discussed in Section 4.3.1. In



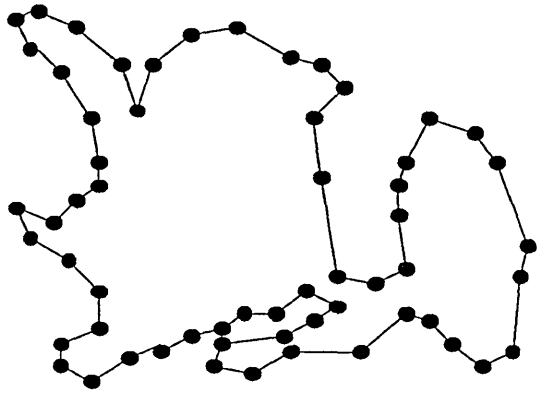
(a) Map feature in geographic space.



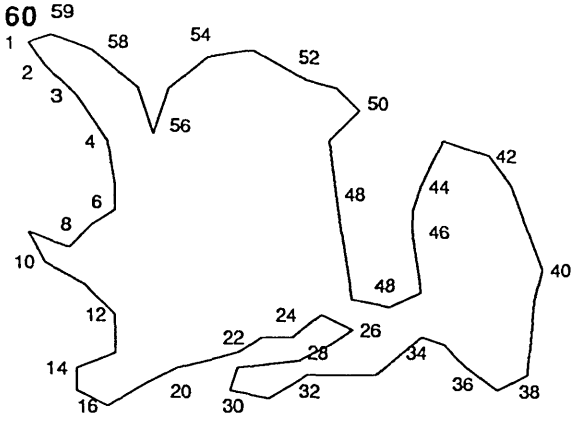
(b) Points digitised on the map feature, and the sequence of digitising.



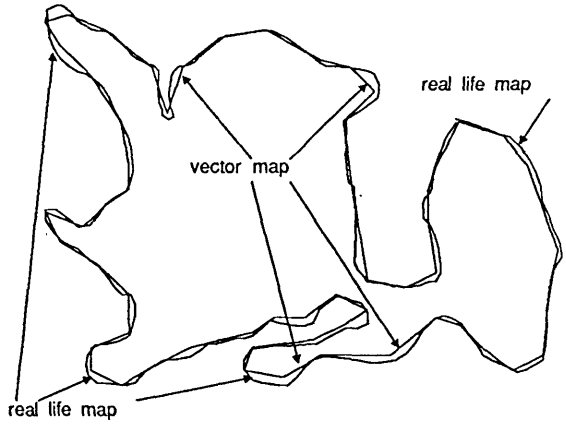
(c) Map feature represented by the digitised points, or survey stations.



(d) Digitised points and the vectors connecting consecutive points.

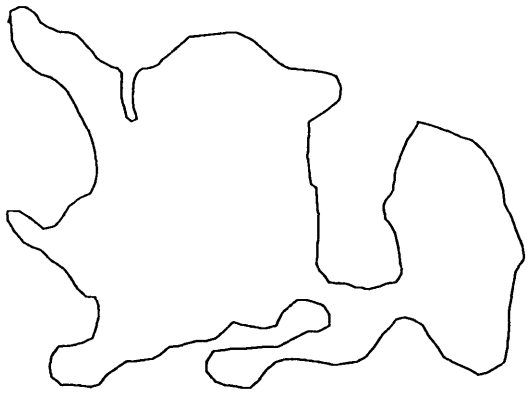


(e) Map feature in vector (geometric) space.

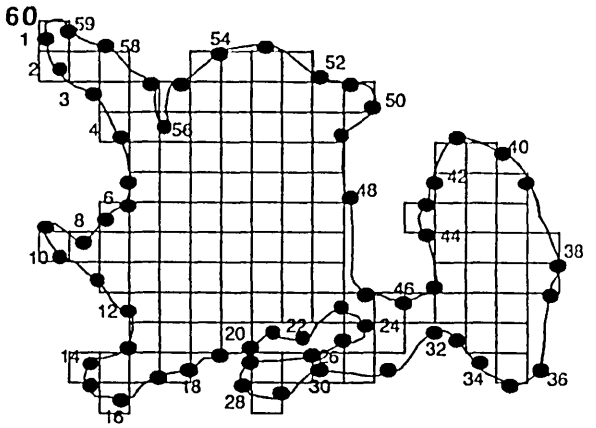


(f) Map feature in geographic space and in vector space, superimposed.

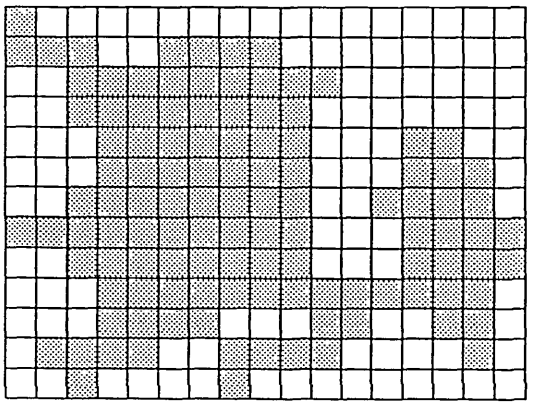
Figure 2.2



(a) The real map feature.



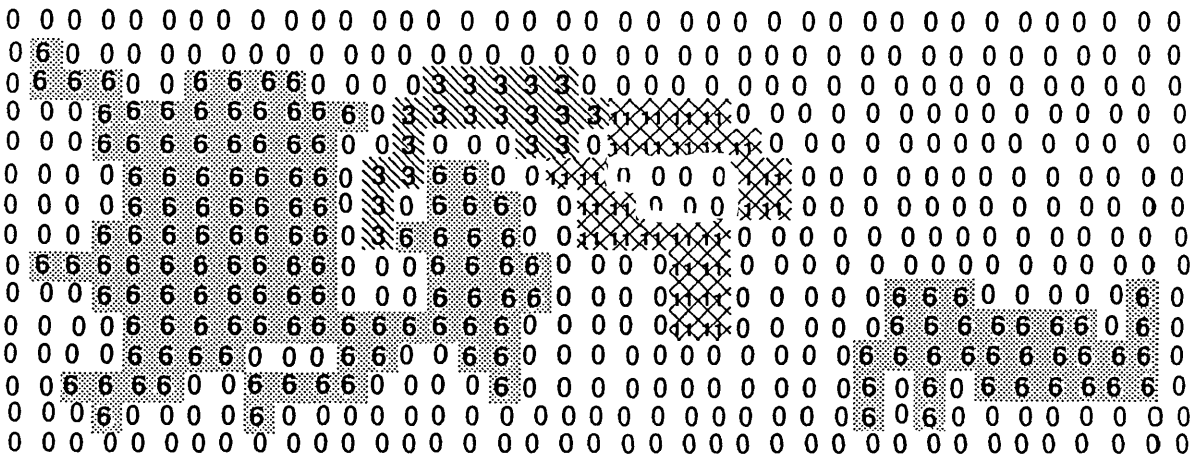
(b) Grid cell map and real map superimposed.



(c) Map in raster space at certain resolution.

1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0
0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0
0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0
0	0	0	1	1	1	1	1	1	1	0	0	0	1	1	0
0	0	0	1	1	1	1	1	1	1	0	0	0	1	1	1
0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1
1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1
0	0	1	1	1	1	1	1	1	1	0	0	0	1	1	1
0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0
0	0	0	1	1	1	1	0	0	0	1	1	0	0	1	1	0
0	1	1	1	1	0	0	1	1	1	1	0	0	0	0	1	0
0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0

(d) Digital representation of the raster map in black and white ie. exists (1) or not (0).



(e) A digital representation of a grey-scale raster map (shades superimposed to show the features).

Figure 2.3

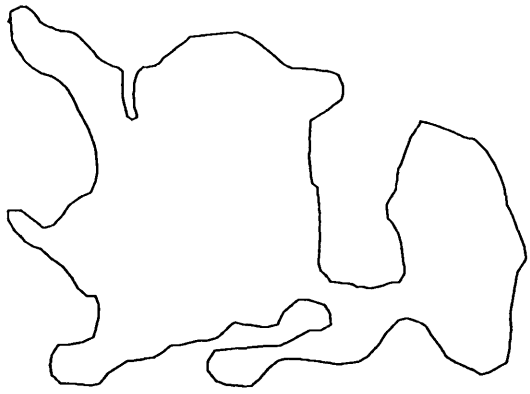
grid cell representation, the scale is expressed by **Ground Resolution Distance (GRD)** which is the area on land represented by a pixel of a raster map. Typical GRDs are 120 cm^2, 360 cm^2 and 600 cm^2 per pixel. The grid, or raster format usually uses rectangular grid cells to represent points or lines or the interiors of polygons. The major advantage of this format is that map layers can be analysed efficiently. Relatively complex map overlaying, processing and analysis is possible with improved efficiency over processing with polygon format processing as done in INTERGRAPH (AUTOCARTO, 1986), MAPS (1984). The major disadvantage of the grid format is that the points and lines must be represented by rectangles, resulting in loss of accuracy and rather unrealistic maps relative to a polygon format.

The polygon, or line segment format uses sequences of lines and points to represent points, lines or the boundaries of polygons. The major advantage of the polygon format is that points and lines are more accurate, and more realistic maps are produced. Generally, the polygon format requires less storage for primary inventory data and is more efficient for searches resulting in tabular summaries. The major disadvantage is that complex analysis is limited and can be computationally expensive. Figure 2.4 summarises the concepts and highlights the advantages and disadvantages of the vector and raster modes of mapping.

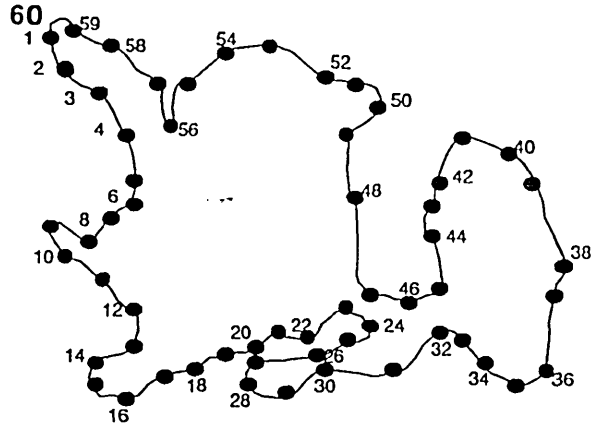
2.2.4 Image processing techniques for map manipulation

Picture or image processing, pattern recognition, and scene analysis are some of the terms used to describe the methods of extracting information from three dimensional representation, usually in the form of digital pictures, or images.

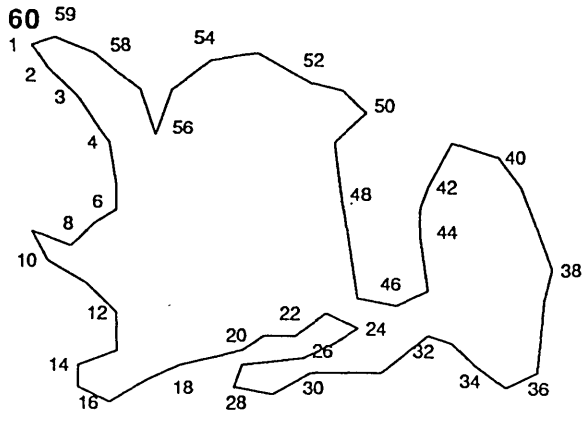
In image processing the picture is stored in a raster form, and then manipulated mathematically. The result is often an improved picture which is more easily manipulated than the original; improvements or enhancements can be of several kinds with varying degrees of complexity. They include edge enhancement, simplification, histogram equalisation, noise removal, region detection and deblurring. Image processing is also used in aerial surveying, remote sensing, and in interpretation of 3D information of an object where appropriate. These mathematical operations, as practised in digital image processing, can in many instances provide useful map processing capabilities.



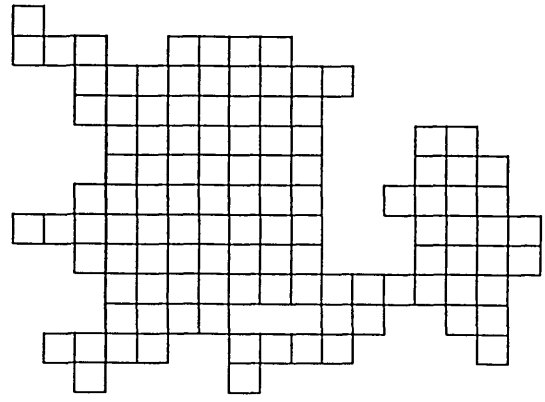
(a) Map feature in geographic space.



(b) Digitised points on the map feature or survey stations.



(c) Vector representation of the map feature in (b).



(d) Grid cell representation of the map feature.

Advantages

- Accuracy of original data.
- Can be converted to any grid cell size for analysis.

Disadvantages

- Sophisticated encoding required.
- Analysis and processing involves more computing overheads.
- Typical remote sensing digital images can not be used.

Advantages

- Less computer overheads to perform analysis.
- Less complicated software for same type of processing.
- Data structure can be constructed more systematically.

Disadvantages

- Loss in spatial accuracy.
- Difficulty in representing points and line features.
- Loss in flexibility in scale of display.

Figure 2.4

Image data take the form of positive integers arrayed on a square lattice; this is the conventional raster form of representation. When in this form, the matrix elements are termed as pixels, an abbreviation for 'picture elements'; the term 'pels' is also occasionally used (Tobbler, 1984). However, in this context the term pixel differs from the more familiar usage in referring to an addressable area of a display screen; this distinction is further discussed in Section 4.3.1. There are generally a large number of pixels in a digital image (from 256^2 to 3000^2), each normally is assigned an integer value in the range of 0 – 255. This large volume of data may cause the processing tedious and expensive. On the other hand, the processing is immensely simplified with uniform sized matrix representing the pixel array.

2.3 SPATIAL DATA HANDLING

2.3.1 Grid cell data structure and map matrix

Advanced map manipulation techniques were developed in IMGRID (Sinton, 1979) by using grid cell data structure. The system was mainly aimed at thematic mapping where the high accuracy is not essential. Since then, the increase in computer power has been manifold and computing techniques have improved; it is now practical to contemplate applying grid cell or raster techniques to reference maps, political maps and also high resolution local maps of a mine or a mining township.

In a grid cell data structure, the area under consideration is to be fully covered by grid cells of different values (Figure 2.3(d)) depending on the category values of the regions. The background must be filled with grid cells (with a special value, usually 0). The smallest addressable unit of space corresponds to a square parcel of land or a point. Spatial patterns are then represented by labelling all points within a particular region according to the numeric value of the region. A two dimensional array of cells represents the geographic feature or certain theme on the land area under consideration; each cell is assigned a numeric value. Thus, the 2-dimensional array of the numerals forms a matrix. This will be addressed as a 'map matrix' in future reference.

2.3.2 Run-length encoding

A large storage capacity is required for grid cell matrices; data compression therefore becomes very important. Run encoding (or run-length encoding) is a technique of compressing a file by extracting redundant data. The simplest type of redundancy in a file is caused by long runs of repeated characters. For example, a string of characters,

DDDDDDDDAAAAACCCCCCCCCCCCAAAAAA

can be compressed as 8D5A11C6A. Here, let us refer to, D, A, and C as 'values' and 8, 5, 11, and 6 as 'lengths'. Even, if the values are integer or real numbers, the compression can be carried out in the same way, but the lengths and the values are mixed, and must be read in a proper format. A row of numbers,

1 1 1 1 0 0 0 0 0 0 22 22 22 22 22 10 10 10 10 10 10

i.e. four '1' five '0' five '22' six '10', can be represented by 4150522610, which does not make any sense unless the 'lengths' (4, 5, 5, and 6) and 'values' (1, 0, 22, and 10) are read in a format which distinguishes lengths and values. This can be done in various ways. One method is to use a technique to code and uncode the two numbers, the length and the value, into and from a single number by using simple decimal divisions and multiplications. For example, the value, 22 and the corresponding length 5 can be coded into the number 522. Another method which is more efficient is to use a part of the bit string representing an integer to store the length and the rest of the bits to store the value. The technique is suitable for most applications provided a 2 byte (16 bit) integer can be used to store a length (8 bits from the left) and a value (remaining 8 bits). A length must not be negative and must be in the range of 0 to 255. The remaining 8 bits may represent −128 to +127 for a value. Length, 5 (00000101) and value, 22 (00010110) in this way is stored as the 16 bit (2 byte) binary string '0000010100010110' which in decimal is +1302 (the left most bit is reserved as a sign bit which is 0 for '+'). In the same fashion, in a 4-byte integer (32 bit), the maximum possible length is 65536 and values may range between −32768 to +32767. There are other methods available; such as use of 'bit strings' other

than standard 8 or 16, and storing the set of the lengths and values, coded in overlapping consecutive integers. Bit manipulation functions are available on most of the systems, which make these operations easier and faster.

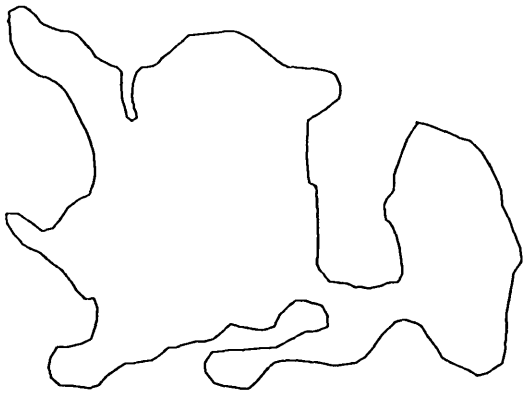
2.3.3 Variable-length encoding

This technique may save a substantial amount of space in text files. It is also known as Huffman encoding (Sedgewick, 1983). The basic principle is not to use all the (usual) seven or eight bits of a computer word to represent a character since only six bits are needed to represent 26 english alphabets in lower and upper case and 10 numerals. However, this may not be of great use to a cartographic database where most of the data are numeric, unless a huge amount of textual information is also stored (not uncommon in GIS databases).

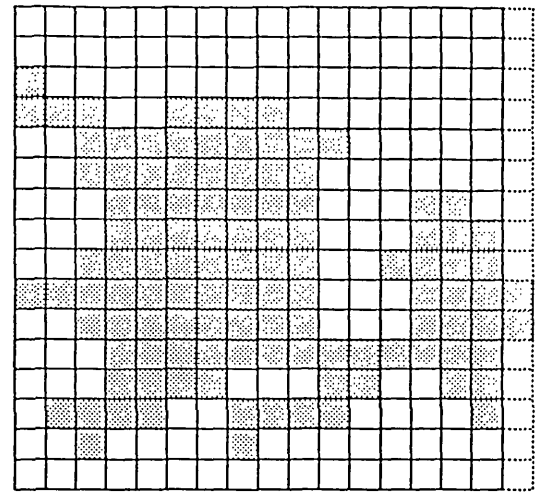
2.3.4 Quadtree encoding

Quadtrees were introduced as a form of raster picture encoding that could reduce storage space requirements, while exploiting two-dimensional coherence (Klinger and Dyer, 1976). Samet (1984) has extensively revealed the history and use of quadtrees in picture encoding. In the most general context, the term quadtree is used to describe a class of hierarchical data structures whose common property is that they are based on the principle of recursive decomposition.

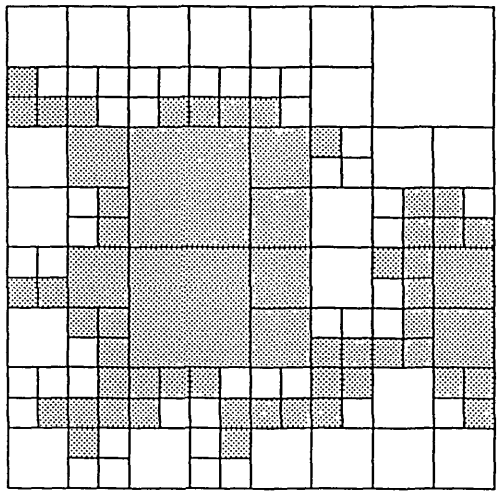
A quadtree is a data tree in which each node is either a terminal node or a partial node (Figure 2.5(e)). A terminal node is also called a leaf node or in short a leaf which is further classified as either 'empty' or 'full'. A partial node may have four children each of which may be again classified as a terminal or partial node in the lower branch of the tree (the quadtree). A quadtree may be associated with a picture that is composed of $2^n \times 2^n$ pixels (n is the level of decomposition starting from the top level or universe as Level 0). If all pixels of the picture have the same colour, the quadtree consists of one node only; the colour of the node is that of the pixel's. If the pixels do not have the same colour, the quadtree consists of one node with its four subtrees (quadrants), where the subtrees are the quadtrees of the four subpictures, obtained by partitioning the former picture into its four quadrants. The quadtree that results, is called the **quadtree of the picture**. Figure 2.5 shows a black-and-white picture composed of $2^4 \times 2^4$ pixels, the labelling concept, indexing techniques, and a quadtree representation.



(a) Map feature in geographic space.



(b) The map area converted into grid cells (raster).



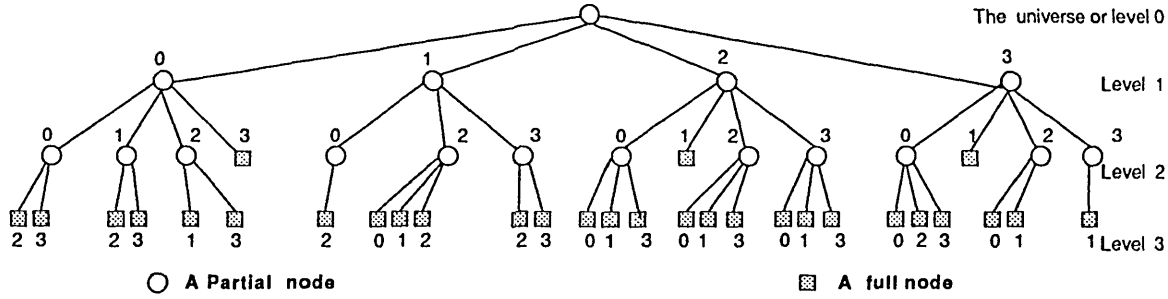
(c) Quadrant decomposition of the feature 16X16 grid down to level 4. Area in (b) has been considered for demonstration. Two cells at the right are out.

N

W ← → E

000 NW	001 NE	010	011	100	101	11X
002 SW	003 SE	012	013	102	103	
020	021	03X		120	121	130 131
022	023			122	123	132 133
200	201	21X		300	301	31X
202	203			302	303	
220	221	230	231	320	321	000 331
222	223	232	233	322	323	332 333

(d) Indexing the quadrants at different levels (down to level 3) and referencing in world coordinate.



(e) Quadtree representation of the blocks in (c).

{ 002 003 012 013 021 023 03X 102 120 121 122 132133 200 201 203 21X 220 221 223 230 231 233 300 302 303 31X 320 321 331 }

(f) A simple quadtree encoding for the decomposed quadrants in (c).

Figure 2.5

The quadtree illustrated in Figure 2.5, is of a fundamental kind and known as 'linear quadtree'. Several other quadtree encoding techniques have been suggested by researchers. A normalised structure (Chien and Aggarwal, 1983) has been developed for better translation and rotation. The Virtual quadtree or compact quadtree has been suggested by Jones and Iyengar (1983) for 85% space saving compare to 66% space saving with linear quadtree (Gargantini, 1982s), of the simple raster map storage. Forest-of-quadtree (Guatier *et al.*, 1985) has been another approach used to save more space than ordinary quadtrees. However, these can not be used to be a decisive criteria for employing in storing map because the saving depends on feature type. If map features on an overlay are numerous, and change frequently within short distances, storage requirements may even exceed (though such circumstances are rare) that required by ordinary raster storage. Practically, when individual map features are stored as discrete overlays in a mapbase, an overall space saving is almost assured, although the power of a quadtree data structure lies in the speed with which a search can be performed.

Some operations on quadtrees are easy to perform, for example separations and intersection. Operations such as, translations and linear transformations present some complications.

2.3.5 G-quadtree

The quadtree techniques discussed above are all for black and white pictures which are binary encoded and are therefore not appropriate for grey-scale maps. A G-quadtree has been proposed for representing colour images (Kunii, 1986). G-quadtree is an extended quadtree each full leaf of which holds a multi level-value (representing the colour value). In a G-quadtree the image is stored as several quadtrees each on a single bit plane in a bit string, usually 5 to 8 bit, depending on the range of grey scale required. With 5 bit strings, 16 grey scale can be represented; with one bit the picture appears in black and white. From the storage point of view, it is not efficient, but efficient for interrogation i.e. 'search'.

2.4 INFORMATION SYSTEMS AND MINING

2.4.1 Information system (I/S)

Information description and information retrieval (IR) form the long established principles of librarianship. Today, information retrieval methods are applied not only to document retrieval systems, but also to office information systems, software documentation, pharmacy, engineering design, management information, decision support systems, mapping and many other fields. Such examples are testimony of the general applicability of modern **Information Technology (IT)**.

Literally, Information Retrieval (IR) is the process of searching for specific information stored among a great number of information items. The users of an IR services receive information-bearing entities from a database; the stored entities are transformed in order to be presented as an answer to a user request.

Data are facts collected from observations or measurements. Information properly embraces meaningful interpretation and correlation of data that allows the foundation of decision-making. Information retrieval or information storage and retrieval systems usually comprise compound items containing unformatted elements of information. Examples include texts, pictures and images, chemical structure formulae and sound; however, formatted attributes can also be included. An information item consists of both the description that characterises it, and the stored information.

2.4.1 The rôle of I/S in mining

Like other assets, information requires careful management. **Information System (I/S)** development requires the same careful planning and management attention as other corporate activities. Existing computational methods within mining and operational research, allied to modern information management and process control techniques, may be anticipated to make a significant contribution in planning and administration within the Mineral Industry (Mill, 1985). However, there exists a need to present this wealth of information in the most comprehensive manner, to distinguish between fact and inference and to avoid user saturation leading to distraction from an otherwise obvious course of action.

2.5 DATABASE SYSTEMS

There are some terms conventionally used for describing databases; it is important to discuss some of the common terms such as:

- data item
- data record
- schema

These three terms may be explained with reference to the example of a telephone directory. A **data item**, in this case, would be the number, the address, or the telephone number. Data items may be 'entities' or 'attributes'. A **record** would be one complete entry in the directory, comprising of a name, the corresponding address and telephone number. A **schema** is a way of describing the components of a record, and the relationship of one record to another.

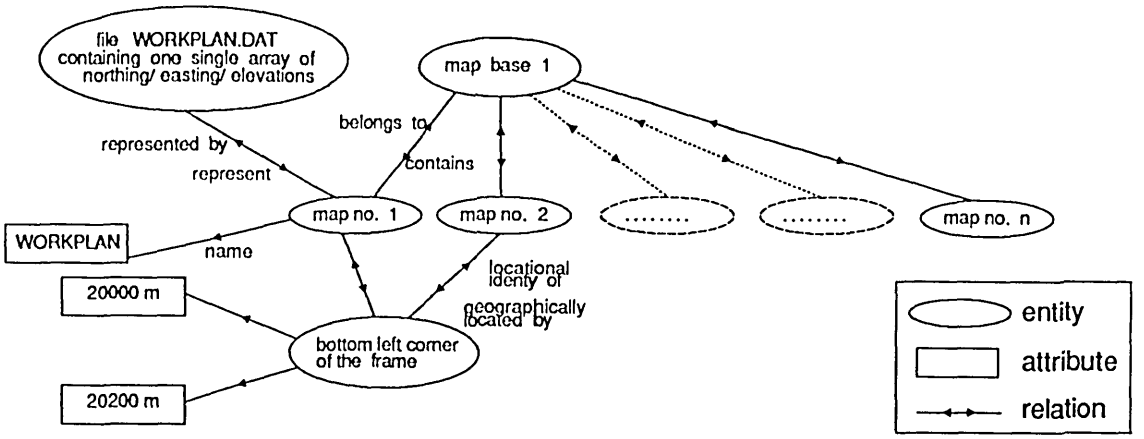
2.5.1 Major database models

A variety of systems have been developed to manage databases; they can be broadly classified into three groups;

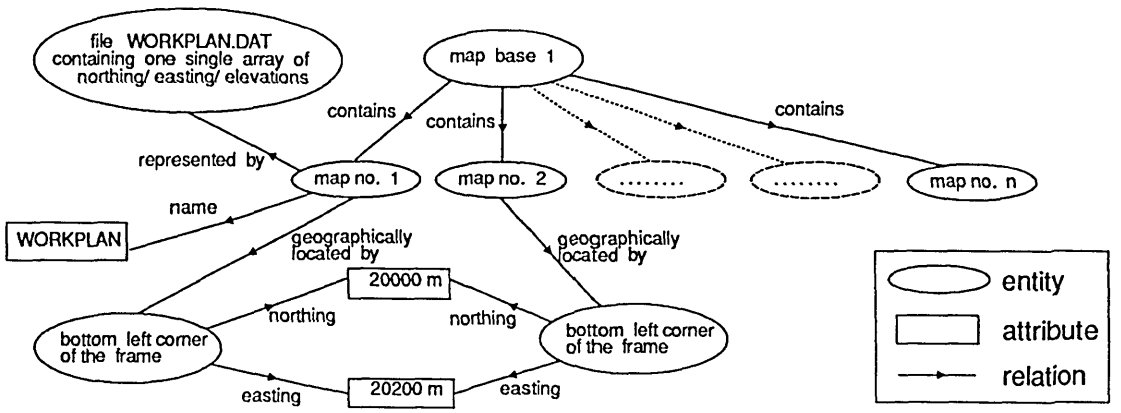
- Network model.
- Hierarchical model.
- Relational model.

Network model: A network database is a network of records with links from one record to another; entities may be related to any number of other entities. A key concept of this kind of model is that a navigation path is required to get to the data item or record of interest. Network schema can be drawn with comparative ease to represent most organisational structure. However, actual implementation of such models are more complicated and inflexible relative to other data models, and must be planned carefully. Figure 2.6(a) shows the diagrammatic schema of the network view of a possible vector map database. An example of a network database is CODASYL (ICCC, 1985).

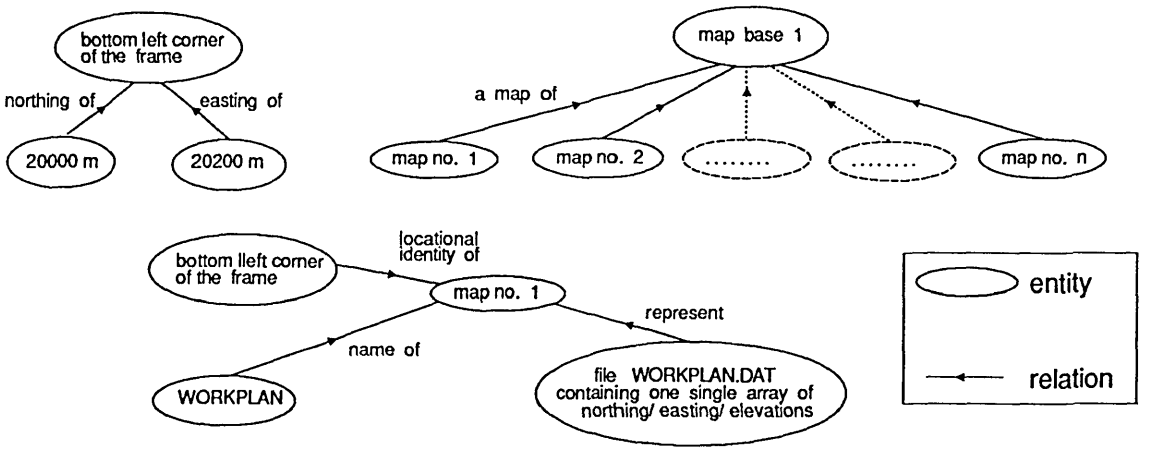
Hierarchical model: A hierarchy is simply a network that is a 'forest' (collection of trees) in which all links point in the direction from child to parent. The hierarchical view regards the universe as consisting of entities, attributes and relationships. An entity may be related to many attributes and an attribute



(a) A network view.



(b) A hierarchical view.



(c) A relational view.

Figure 2.6 Conceptual schemas for different views of a possible mapbase map no.2, ... , map no. n have same model as map no. 1

may be related to many entities. Though the schema definition needs careful thought, it is less complicated. Figure 2.6(b) shows the diagrammatic schema of a hierarchical view of a possible vector map database. Some examples of hierarchical models are IMS (ICCC, 1985) SIR (1982).

Relational model: The relational view regards the universe as consisting of entities, entity sets and relations (Codd, 1970). The key concept with a relational system is the view of the data as a table of records. A full record in a relational table is called a tuple. Figure 2.6(c) shows the diagrammatic schema of a relational view of a possible vector map database. The collection of relations and tables are shown in Figure 2.7. Some examples of relational model are RIM (1983), Oracle (1987).

2.5.2 Database system design

The database system design process may be thought of as consisting of eight stages (Frost, 1984):

- specification of the conceptual schema
- specification of the input/output requirements
- specification of the database schema
- specification of the physical storage structure
- design of the privacy sub-system
- design of the integrity sub-system
- design of the back-up and recovery sub-system
- design of the database interrogation media or query language

2.5.3 Retrieval mechanisms - query languages and menus

An important problem in connection with the computer graphics application is the form in which an user can express his information needs. 'Menus' usually in the form of text or icons have been commonly employed to guide a user through a complex system. With the development of graphics and screen-pixel addressing capability high standard so called 'user friendly' graphics menus are also in common use today. However, these menus restrict the flexibility of a query and under utilise the strengths of the sophisticated databases now available.

The aim of an information retrieval system is primarily to identify and meet an information need. Queries may be formulated in a natural language, as a set

Data base	Map
Map base 1	Map no. 1
Map base 1	Map no. 2
.....	.....
.....	.....
Map base 1	Map no. n

(a) Relation is a collection of n-tuples; Example of a tuple (Map base 1, Map no.1).

Map	Geographical location identifier	Northing	Easting
Map no. 1	Bottom left corner	20000 m	20200 m
Map no. 2	Bottom left corner	21100 m	23400 m
.....	.....	.....	.....
.....	.....	.....	.....
Map no. n	Bottom left corner	20000 m	23400 m

(b) Relation is collection of n-tuples; example of a tuple (Map no.1, bottom left corner, 20000 m, 20200 m).

Map	Name	Storage file
Map no. 1	WORKPLAN	WORKPLAN. DAT
Map no. 2	RIVER	RIVER. DAT
.....	.....	.....
.....	.....	.....
Map no. n	TEMP1	TEMP1. DAT

(c) Relation is collection of n -tuples; example of a tuple (Map no. 1, WORKPLAN, WORKPLAN. DAT).

Figure 2.7 Collection of relation tables for a possible vector mapbase

of query descriptors, or as descriptors combined by operators (eg. Boolean or contextual operators) that follow a certain syntax. Query formulation research focuses on four questions:

* How are the information needs best expressed?
* How should information structures be presented?
* How does one specify sensible query terms?
* Which combination of query items are sensible (both to specialists and casual users) and powerful enough to retrieve objects and reject irrelevant ones?

2.5.4 Appraisal of a database

DBMS performance is related both to reliability and to the efficiency of operations. These factors, in turn, affect the cost effectiveness of a DBMS operation. The efficiency of a DBMS is a function of both space and time.

The space aspect of efficient performance means that a DBMS has to provide a capacity for efficiently storing large volumes of data. In order to reduce storage space, it is obviously desirable to minimise data redundancy. This implies that data are not duplicated just because two applications require different structures.

The time aspect of efficient performance of a DBMS is affected by the order in which multiple searches are implemented. For example, if a search is to be made in a archive of people in London, who speak English, German and Greek, it is better to start isolating people who speak Greek because this will result in the selection of the fewest records.

Some other special aspects which are important in evaluating the performance of a DBMS, are:

Integrity: Preserving the integrity of data involves the safeguarding of data from malicious or erroneous tampering, faulty equipment, etc. A provision is therefore required to maintain all of the data and cronicle changes to the data so that the database can be reconstructed in event of partial or total destruction. The typical approaches to the problem include journaling, check-points, backtracking, access control, and monitoring (Tsichritzis and Lochovsky, 1979). A DBMS must also be able to protect the integrity of the data during modification.

Security: The issue of security is crucial especially in the era of the centralised database. The term 'data security' means protection of the data in the database against unauthorised or accidental disclosure, alteration or destruction. According to Atre (1980) this can be controlled by dividing the access into the following categorises of authorisation:

* Partial retrieval but not change
* Retrieval of all types of records but not change
* Insertion of certain types of records but not change
* Insertion of all types of record but not change
* Deletion of certain record types
* Deletion of all record types
* Updating of certain record types
* Updating of all record types

Privacy: 'Privacy' and 'Security' has been treated separately by Atre (1980). However, they are not discontinuous. Information privacy includes the right of individuals to know about certain information. The privacy constraints to a system finally depend on the policy and functionality of the organisation where the database may be implemented.

Concurrency: Concurrency is a prerequisite almost in all circumstances where databases are used in commercial environment. If only one interrogation a time is processed in a database and other requests must wait until it has completed, then bottlenecks result. This shortcoming limits the application of a database. So concurrency aspect is to be considered carefully during design of a database system.

2.6 SPATIAL INFORMATION SYSTEMS

With the advances and new applications in picture processing, such as computer tomography, whole-body scanner, earth resources survey satellites, image processing, cartographic application etc., the economical storage and retrieval of vast amounts of pictorial information becomes more important and requires careful considerations. The list of new applications in digital picture processing has grown to include interactive computer aided design (Kunii and Kunii, 1979), geographic data processing (Nagy and Wagle, 1979), remote sensing of

earth resources (Fu, 1976), regional economic and health data processing, and cartographic application (Kobayashi, 1980).

2.6.1 Graphical information representation

Computer graphics involves the generation, representation, manipulation, processing, and evaluation of graphics objects as well as the association of graphics objects with related nongraphic information residing on computer files. Graphics objects may be photographic images, or they may be created with the aid of hardware and software in the form of alphanumeric characters, special symbols, line drawings or grey-shaded areas. Such artificially created objects may be rendered in black and white or in colour. Computer graphics can be divided into three main categories:

* Generative graphics
* Image analysis
* Cognitive graphics

Generative graphics involves artificially created graphic objects, usually in the form of line drawings. The main tasks of generative graphics are:

* Model (object) construction and picture generation.
* Model and picture transformation.
* Object identification and information retrieval.

Image processing and analysis, as has already been described in Section 2.2.4, involves photographic images or, more precisely, discretised representations of images given in the form of an array of numbers representing the grey-scale values of the corresponding picture elements. Therefore, the image must first be scanned and sampled; i.e. its grey levels at certain points are measured and the measurements are converted into numbers.

Cognitive graphics or 'scene analysis' is connected with abstract models of graphics objects and the relations between them. An 'abstract model' embodies the concept of an object or organisation regardless of its instantaneous appearance (e.g., a triangle is a triangle regardless of the length of its sides, its location and orientation in a particular space, etc.). Cognitive graphics may involve artificial graphic objects as some objects in photographic images. A diagrammatic schema of a database system, may be described as a cognitive graphics.

2.6.2 Interactive graphics

Graphics allows us to exceed the bounds of the syntactic power of simple typed commands to achieve much higher bandwidth of man-machine interaction using a judicious combination of text with 2D display. This makes a significant difference in our ability to understand data, perceive trends, and visualise real or imaginary objects. Computer graphics is best exploited interactively, where the user can exploit a more familiar senses of perception in the realm of visual space.

2.6.3 Pictorial database systems

The Pictorial DataBase System (PDBS) is the core of a pictorial information system (or a spatial information system). Substantially different types of data storage and graphic representation are employed in such systems:

- retrieval of previously stored complete pictures is usually in raster format (Chang and Fu, 1981; Chang and Kunii, 1984)
- display, in graphic form, of data which is usually shown in tabular form (Donelson, 1978; Herot *et al.*, 1980)
- retrieval and representation of data, usually presented in the form of maps (MAPS, 1984; ODYSSEY, 1983; MAP, 1983)

Two basic tasks are faced in designing a pictorial system. The first is the storage, retrieval, and processing of large numbers of pictures; the second is the storage, retrieval, and processing of a very large picture or picture of great complexity. Another consideration is the intended use of the system: is it mainly for retrieval of pictures, or for processing and manipulating of pictures?

Traditional database management methods are not fully applicable to pictorial data. First, the data under consideration are not distinct discontinuous strings or numbers but usually two-dimensional, continuous data. A picture file is a logical entity itself, rather than a normal data file which can be broken up into records and fields. The output expected mostly is graphic, rather than alphanumeric. Finally and perhaps most important, the operations to be performed are feature extraction, clustering and preprocessing among others which differs fundamentally from sorting files and updating records. The varying requirements of the pictorial database have led to modifications and extensions of the three traditional database models discussed earlier; among these the relational and hierarchical models have attracted the most attention.

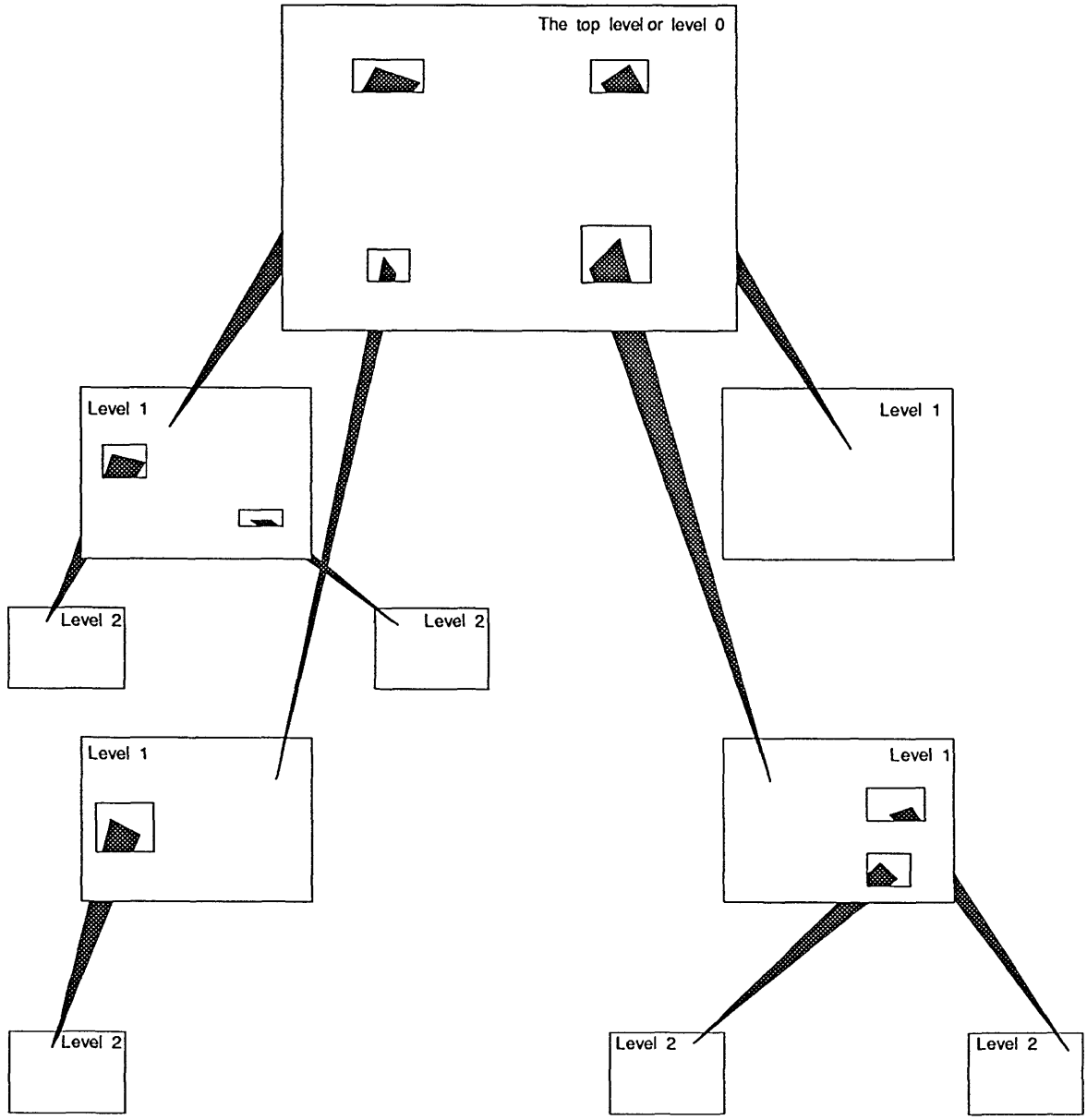


Figure 2.8 The tree model of a spatial data management system.

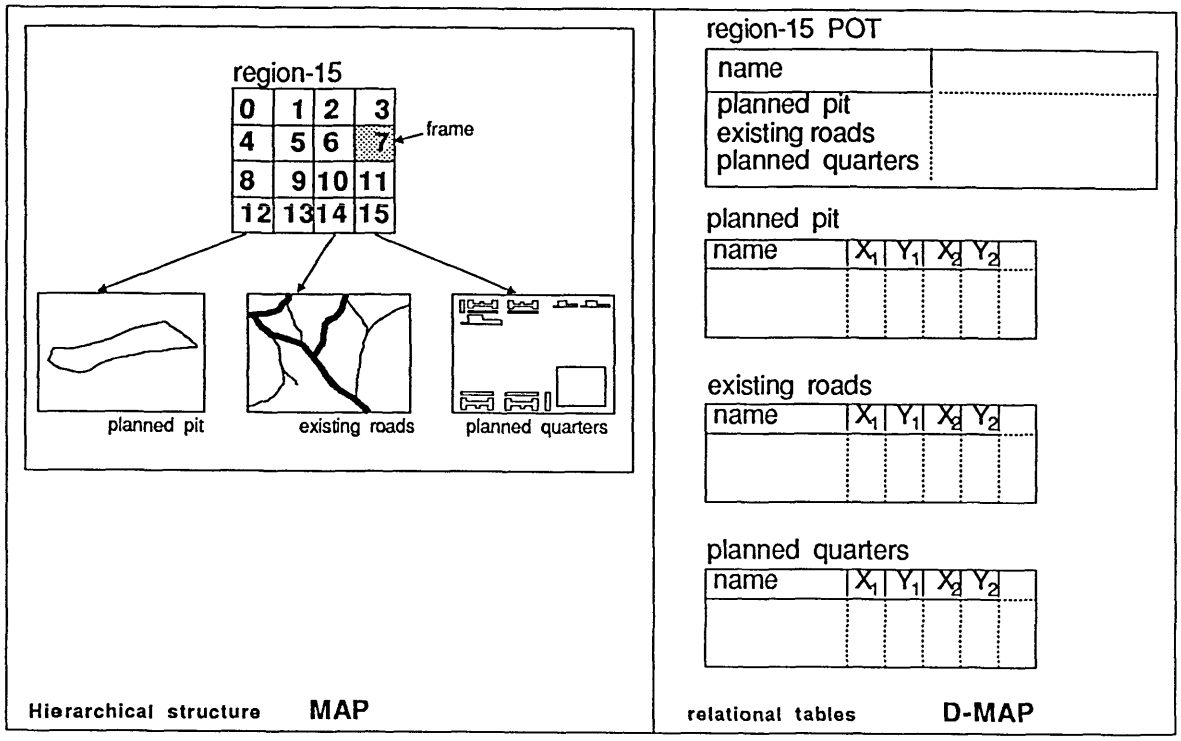
Tree structures have been used by many for spatial data management (Frank, 1982; Woo, 1984)); quadtree (Dyer, 1982; Samet, 1984), forest of quadtrees (Guatier *et al.*, 1985; Jones and Iyengar, 1981; Ramani and Iyengar, 1983) and linear quadtree for GIS (Abel, 1985). Donelson (1978) has stored images as the nodes of a tree with certain areas of each image being the ports by which the lower branches of the tree were traversed (Figure 2.8).

The relational approach to pictorial database systems was first proposed by Kunii *et al.* (1974), which provides application of structure independence, modularity, associativity, and machine independence to describe complex pictures. GIS can be considered as an example of application. McIntosh (1978) proposed that a relational database may be used as an underlying structure for a geographic information system with cartographic output.

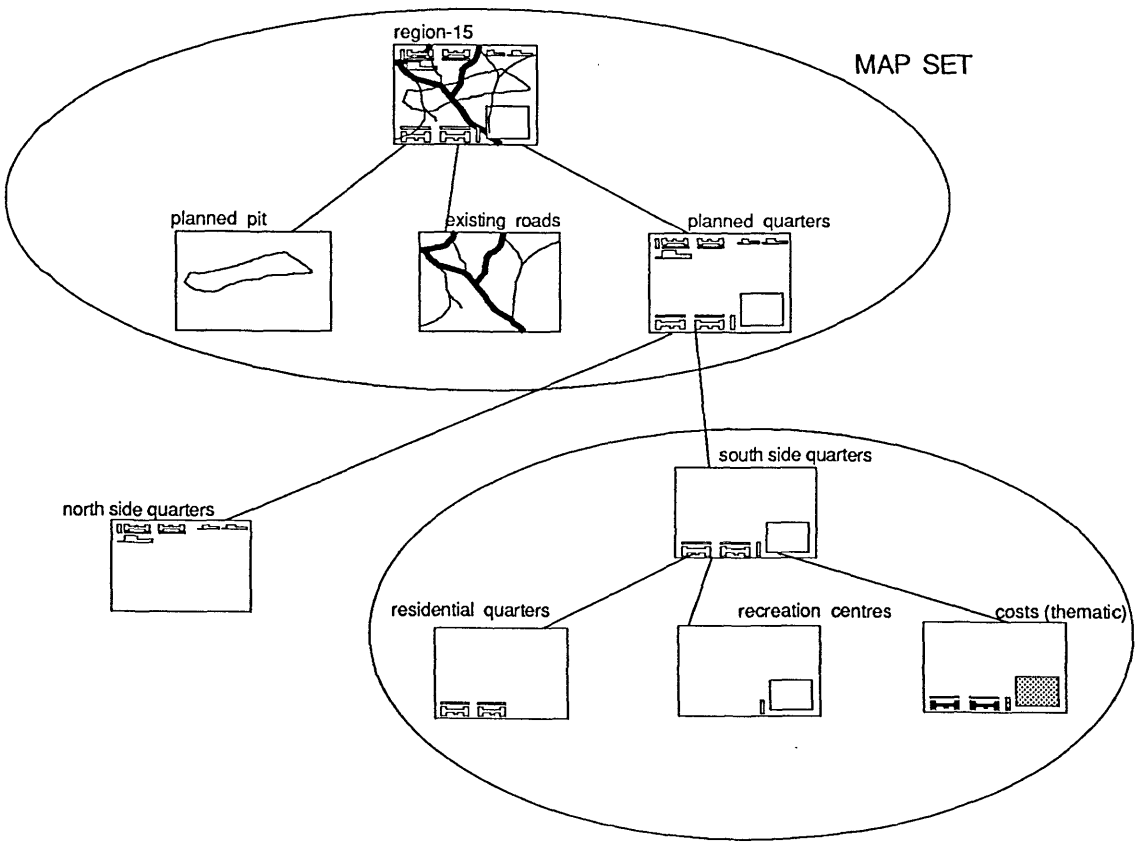
Sties *et al.* (1976) described an image information system in which an object is defined in terms of shape, symbolic description, and relation with other objects. Objects in a picture can be retrieved in terms of symbolic description and/or object relations.

Chang *et al.* (1977) has suggested that the relational data model can be combined with the hierarchical approach. Figure 2.9(a) illustates such a combination (for a mining area). A 'map set' is a hierarchical collection of maps, whose logical representation is called a 'd-map set'. For example, region-15 consists of a planned pit, existing roads, and planned quarters. In the map of planned quarters, there are three enlargable picture objects, north side quarters, south quarters, and a thematic representation of costs (Figure 2.9(b)). The smallest unit for visual display is called a 'frame'. Picture Object Table (POT) of the map set has been shown in the right side of Figure 2.9(a). Each node in the hierarchical structure on the left corresponds to an image that can be materialised from a collection of pictorial relations of corresponding node on the right.

However, the design of pictorial information systems depends very much on the application areas, functions required, intended usage of the system and size and the complexity of the database.



(a) Map hierarchy and the relational tables.



(b) Hierarchy in mapset; image description.

Figure 2.9

2.6.4 Mapping and other graphics packages for mining

To date, mine planning and management systems have been confined to the use of mainly generative graphics. Table 2.1 briefly summarises most of the known packages/software developed for mining use. There are several commercial microcomputer graphics packages for mine planning. Some of them are listed (Gibbs Associates, 1986) below;

COALSYSTEM, from Mintec, Inc. can create geological plans.

GEOPLOT, from Geoglobal Systems, Inc is also a mine planning package.

BLAST, from Gemcom is an interactive graphics package for fragmentation analysis and blast design.

POLYCALC, from Colorado School of Mines offers reserve estimation, mine planning and sequencing.

DRAG, from Montana State University is available for designing of raw spoils and opening cuts.

The above packages address specific design tasks and cannot be used in general mine mapping and information management. These systems fail to provide an adequate spatial database. Their principal deficiencies stem from a failure to address the fundamental mechanisms of access to spatial data.

The above mentioned packages deal with rather static maps. The interactive facilities offered in current mine mapping packages, are rather limited and do not provide a map processing capability. In mining, maps and plans need to be updated regularly. Available packages can not be adopted to meet the needs of day-to-day mining activity or forward planning or generation of up-to-date plans and to store or retrieve a wide variety of maps and other information.

In the context of a pictorial information system for a mine, the generative graphics of these systems combined with image analysis and cognitive graphics, may be considered further. An important problem in connection with the application of computer graphics is the form in which a casual user with little training can express his information needs. A query language adapted to the special requirements of graphic representation is an essential prerequisite.

Table 2.1 Existing graphics software/packages for mining

software/package, machine	Company, Reference	capability-highlights
CPS3, on VAX, PRIME, and others	Radian Corp. (CPS3, 1987)	Sophisticated general purpose contouring. Interfaces with several graphics libraries; DI3000, GKS, UNIRAS etc.
DATAMINE, on PCs	Mineral Industries Computing Limited (DATAMINE, 1986)	Uses block model for reserve estimation, displays contours, kriged variance on kriged grade in '4D', wire frame model for 3D display of orebody, uses UNIRAS for advanced functions.
ENCORE	— Lefeuvre *et al.* (1984)	Stores, retrieves and interacts with the drill-hole database and produces surface topography and isopach maps, and cross sections.
ESIS	— (Ershov and Ermolov, 1986)	Uses SIR database package to handle drillhole database, performs statistical calculation and produces contours, base maps, symbols and generates reports.
GEOMATH, on VAX, IBM PC, and others	Geomath Inc. (Seltrust, 1985)	Database, plans-sections showing drillholes or block model, symbolic display of the geological sequence.
GEOMIN, on VAX and others	Lynx Geosystem Inc. (Houlding, 1987; Lynx, 1987)	Uses interactive graphics, produces 3D orebody models, cross sections, and development and mining excavations, limited CAD facilities.
GEOSTAT, on VAX, IBM PC, and others.	Geostat Systems International Inc. (Seltrust, 1985)	A geostatistical package; open pit design using floating cone pit limit optimisation. Interfaces with AUTOCAD for graphics output.
KENNECOTT, on IBM mainframes, VAX and PC.	KENNECOTT (Seltrust, 1985)	Floating cone pit limit optimisation, short term planning system through Interactive graphics.

software/package, machine	Company, Reference	capability-highlights
MEDSYSTEM, on VAX	Mintec Inc., (Seltrust, 1985)	Geostatistical analysis, orebody modelling, open pit and strip mine design, production scheduling, financial analysis.
MICROMODEL, on IBM PC, and compatibles	Pincock, Allen and Holt (Seltrust, 1985)	Surface modelling, open pit generation, and reserve estimation. Limitations on no. of samples restricts its applications. Data transfer possible to LOTUS and SYMPHONY.
MINEPAK, and **SEAMPAK**, on IBM, VAX, and others	The Earth Technology Corp. (Seltrust, 1985)	Data storage and retrieval, geo-statistical analysis, open pit and strip mine design. Interfacing with INTERGRAPH has been suggested for better graphics display.
MINICOM (DTMS and **SURPASS)**, on VAX, PRIME, and HP machines	MINICOM Mining Systems (Seltrust, 1985)	Digital terrain modelling, surface mine planning, analysis and simulation.
MPASS 2	— Knoebel *et al.* (1982)	Simulates a simple board and pillar mine layout and produces graphical representation using regular geometry; used mainly for training purposes.
POLYMAP, on VAX, DEC20	Amax Engineering and Management Services (Seltrust, 1985)	Systematic storage and retrieval of digitised polygon, and shedding. Generates block model, produces composite map by superimposing several layers.
SEAMSYS and **MINEVAL**, on VAX and CDC machines	Control Data Corp. (SEAMSYS, 1982; MINEVAL, 1983)	A bulky package which generates contours, surface topography and cross sections from borehole data. Uses drill-hole data as input and creates polygon bench maps; uses 3D block model.

Table 2.1 Existing graphics software/packages for mining

software/package, machine	Company, Reference	capability-highlights
SEDCAD	—— Nebgen and Warner (1986)	Deals with the water movement management in surface mining.
SIGMA, on TEKTRONIX desktops	Golder Associates (Hinde *et al.*, 1984)	Uses linear kriging through interactive graphics to produce variance and block model for geological reserve estimation.
STEPS and **DMPIS**, on IBM PC, and compatibles	Steffen, Robertson and Kirsten (BC) (Skelton and Franklin, 1984; Franklin, 1985)	Uses interactive graphics for grade distribution analysis, pit evaluation and representation of orebody block model and composite bench plan.
STPM with **MPIG**	—— Barua and Kim (1984)	Is a short-term coal mine planning package, uses interactive graphics in decision making, the final output is 3D surface topography, contours superimposed by proposed cuts.
TORRES, on HP machines	Peko-Wallsend Operations Ltd. (Seltrust, 1985)	Database, drill hole plots, sections annotated with assay and stratigraphic data Interactive mine design.
——	—— Mooney *et al.* (1979)	Generates contours, 3D surface, topography, casting diagrams etc.
——	—— McMorran and Dotson (1982)	Reproduces a digitised map, produces sections and 3D representations, calculates volume, shows two merging pits in 3D.
VULCAN, on VAX	K Robert Johnson and Associates (VULCAN, 1987)	Interactive mine evaluation and planning tool, grouped in modules. Database, drillhole graphics, digitising mapping, modelling and reserves. High quality graphics screen needed to take full advantage of the graphics capabilities; uses ISIS-DB database system.

2.7 GEOGRAPHIC INFORMATION SYSTEM (GIS)

2.7.1 Introduction

An emerging area of the application of computer graphics is the storage and retrieval of spatial information through visual keys. This is achieved through graphic interfaces to a cartographic database. One such system, the **Geographic Information System (GIS)**, is being used successfully in forestry (Tomlin, 1983a), environmental planning (Tomlin and Berry, 1979; Tomlin, 1983b), landscape architecture (MacDonald and Crain, 1985), navigation (Herot *et al.*, 1980) etc. In some cases, the term **'Land Information System (LIS)'** has been used; the distinction between GIS and LIS is not clearly defined (AUTOCARTO, 1986). Most automated geographic data processing is accomplished through the use of specialised computer hardware and/or software configurations. A GIS is a system designed to capture, manipulate, retrieve, and display data that are referenced by spatial locations. Such systems are distinct from automated cartography, where the primary goal is to produce printed graphics output.

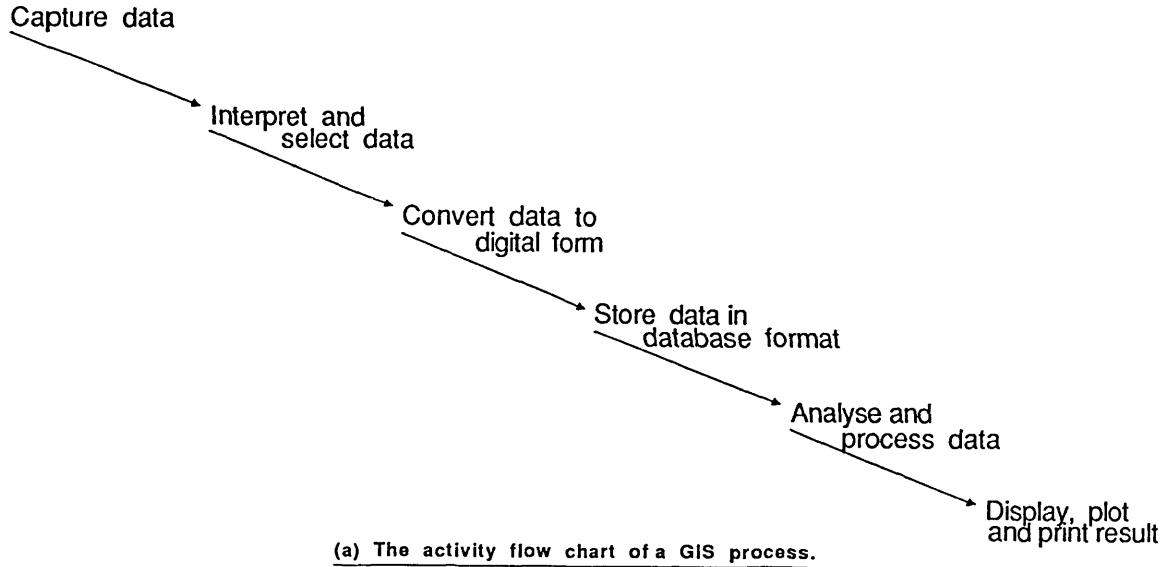
2.7.2 The components of a GIS

In a GIS, graphics output represents only one mode of data retrieval and only a subset of the system function. Like most automated data processing systems, a GIS contains three major components including,

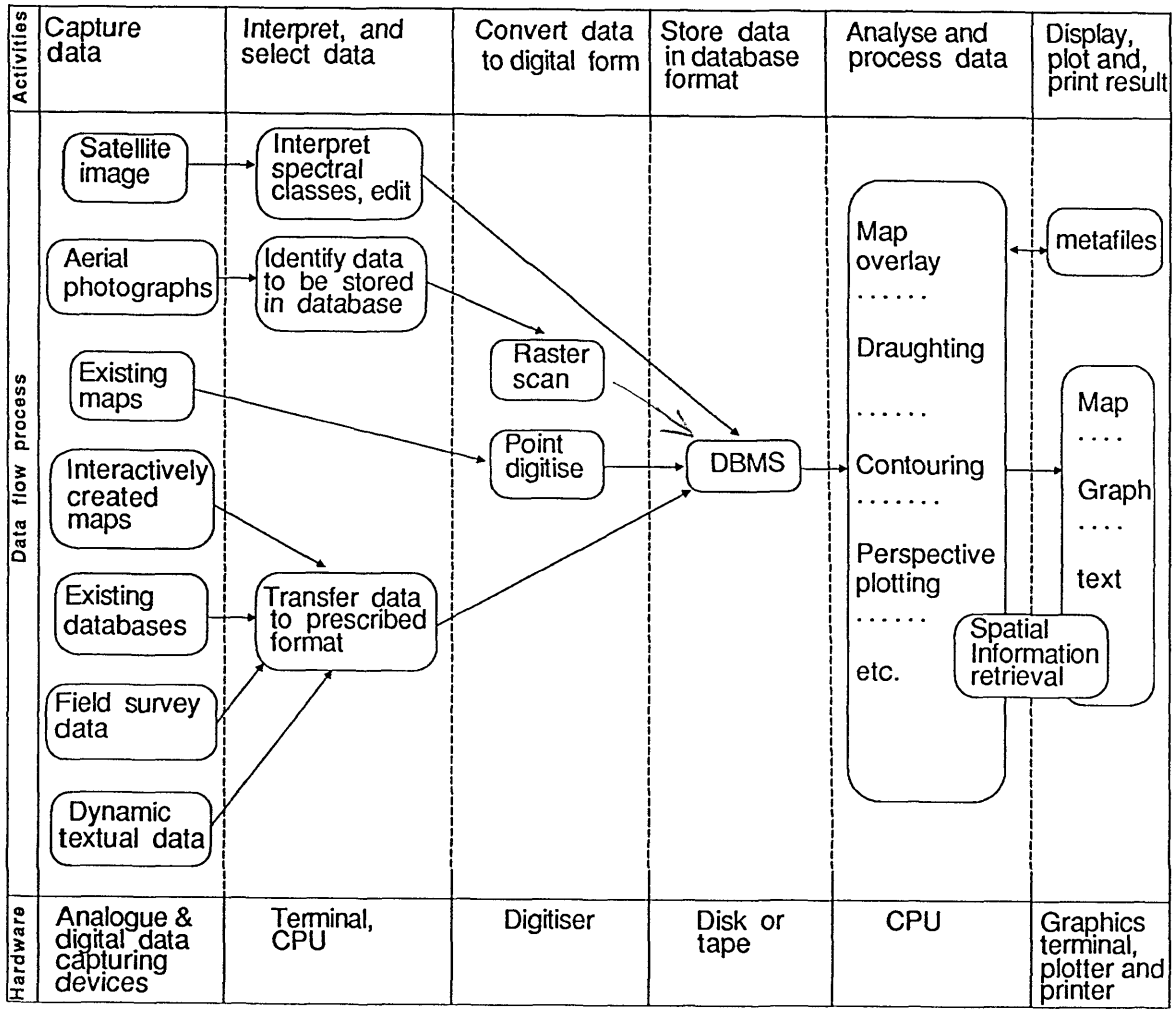
- A data structure;
- A set of data processing capabilities;
- A mechanism for controlling data processing.

Of these, spatial data processing most distinguishes geographic information systems from other types of computer software. The nature of data processing capabilities also markedly distinguish one geographic information system from another. A schematic of a GIS process is given in Figure 2.10.

Most advanced GIS systems include both grid and polygon format. Data is captured in polygon format and converted to grid format for advanced analysis. The user is able to select either grid or polygon format, depending on the task.



(a) The activity flow chart of a GIS process.



(b) Data flow process in activity-hardware domain of a GIS.

Figure 2.10

2.7.3 Some GIS packages

The Canada Geographic Information System (CGIS), claimed to be the world's first GIS (MacDonald and Crain, 1985) has now grown into the Canada Land Data System (CLDS). It provides extensive interactive and hardcopy graphics on a daily basis. MOSS (Craine *et al.*, 1987) is a system for building digital models in the form of spatial co-ordinates with associated attributes. However, it does not allow users to select and view any part of a data set interactively and to design and preview planned hardcopy output.

The Mapping and Planning System (MAPS, 1984) is an interactive GIS; MAPS uses ARC's (Applied Research Centre, Cambridge) General Draughting System (GDS) and the Information System, EROS. It has been primarily developed for use in urban planning. ODYSSEY (1983) is another GIS package developed specifically for thematic mapping which displays a number of capabilities for demography. GIMMS (Waugh, 1980) is a large computer program with a wide range of user defined cartographic options each of which is supported by system default settings as an aid to the novice user. MAP (1983) is another GIS package which provides some powerful processing capabilities employing grid cell data structure. However, the graphics interface provides simple outlining of the features and the vector-to-raster conversion is not satisfactory (discussed in details in Section 4.3).

2.7.4 GIS potential in mining

In mining, the product (ore) and by-product (waste rock) are 3D geographic entities related to many attributes such as mineral type, grade and strength of ore and associated rock. 'Real' orebody configuration is established when the orebody is physically reached. Cut-off grade also changes with the market condition. The local geography changes continuously as the extraction progresses. In such a dynamic environment, where timely access to locational information is vital for short-term and long-term planning, GIS promises to be a powerful tool in planning, design and management. A GIS backed by advance map processing capabilities, will allow the mine operators to access to more meaningful information in less time. Rock-type, grade information, geological structural information, equipment locations and related information will help the management to plan more comprehensively.

Some attempts have been advocated to use GIS in mining. DIGIGRAPH and MESUGRAPH from Geo-graphic Corp. are microcomputer GIS packages for mine planning (Gibbs Associates, 1986). The group, Spatial Information Systems has been working to develop a microcomputer implementation of MAP (1983). No further information has been reported.

2.8 HARDWARE-SOFTWARE REQUIREMENTS FOR A GIS

A GIS represents an arrangement of hardware and software. A **GIS workstation** is build around a minicomputer, a computer workstation or a terminal of a mainframe. The system can be expanded with options to suit individual needs. Figure 2.11 shows the hardware layout of an 'ideal' GIS workstation. The capabilites of small modern machines now readily meet the specification of a GIS workstation, independent of a mainframe, and are able to cater for a medium size mapbase such as mining mapbase should be.

2.8.1 Storage requirements

GIS storage requirements are large, with most operational systems requiring well over one hundred megabytes of storage (Boyle, 1984). The storage facility of a system is also important; cartography involves handling huge quantities of data. Floppy disc, hard disc, magnetic tapes (and recently optical disks), are the general means of storage. To date there has been no serious problem in the storage of digital map data, since few have in fact been produced, owing to the cost and inefficiency of manual digitising. However, with the semi-automated digitising costs are reduced and information storage becomes a major difficulty; accordingly data compaction and reduction methods assume a renewed importance.

The most effective compaction methods require an average of about one computer word per co-ordinate pair, and an overlay sheet may well have 500,000 co-ordinate pairs of line data. A typical storage requirement for a cartographic database might therefore involve 1000 million computer words (Boyle, 1984).

With the fall in price of storage devices, it is possible to contemplate interactive access and manipulation of such volumes of data. The **Optical Digital Disc (ODD)**, some time known as **Write Once Read Many (WORM)**, offer the storage of much greater quantities of data (static data) than that of a magnetic medium.

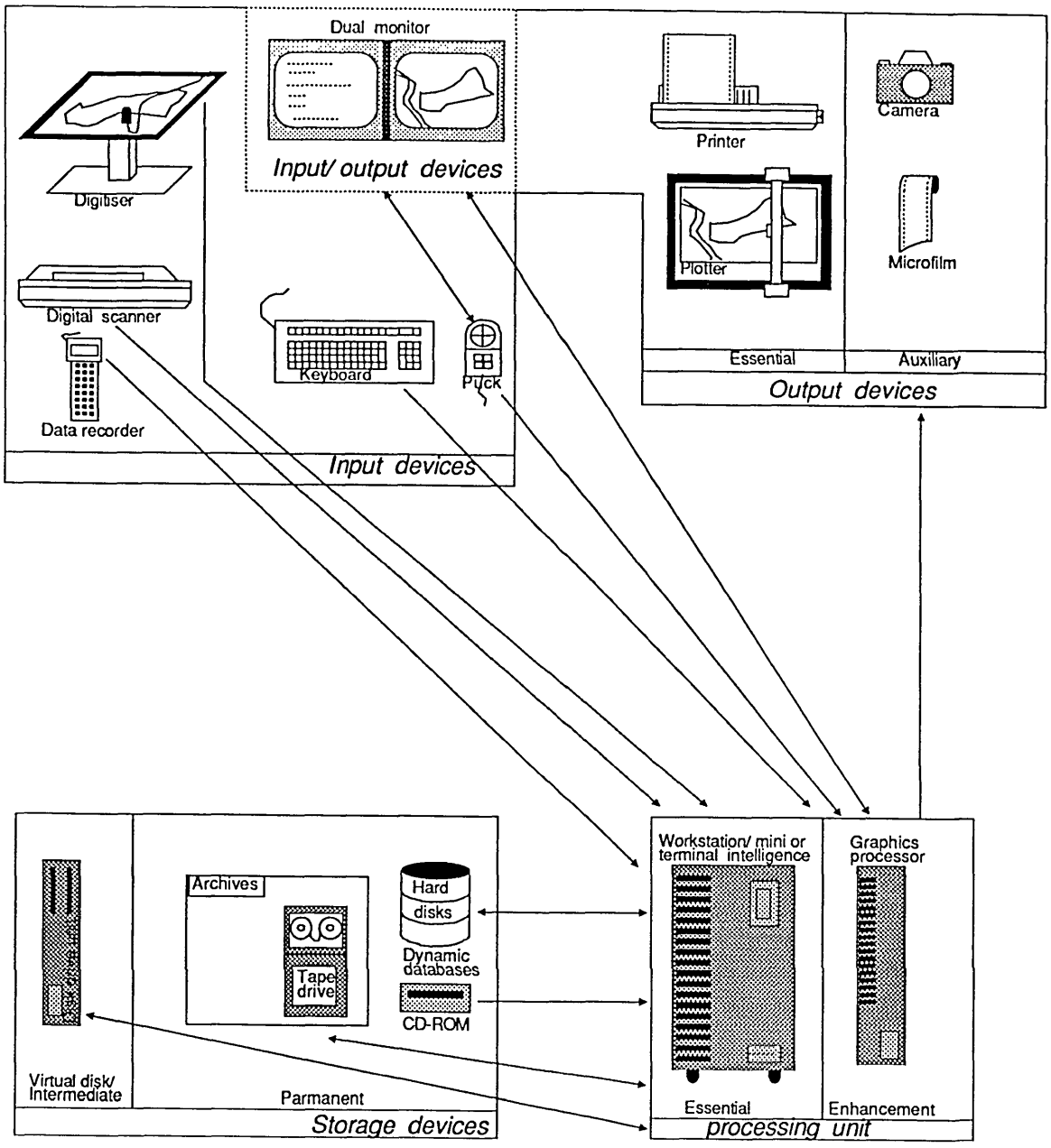


Figure 2.11 An ideal GIS workstation layout.

The development of erasable ODDs (Maxtor, 1988) now offers further potential for compact, high density data storage suitable for GIS applications.

2.8.2 Software requirements

Besides the operating systems and compilers, the most important software needed by a GIS is graphics software. Almost all computers, micro, mini or mainframe, are supplied with basic graphics facilities. There are some basic graphic software which are versatile for draughting, but are not suitable to be used with a High Level Language (HLL), some examples being, AUTOCAD (1986), DOGS (Level 3.2a) and PIGS (1986). Some well known packages (or libraries), which are usually interfaced with HLL programs, include CALCOMP (1985), GKS (1985), DI3000 (1987), PHIGS (1988), and UNIRAS (1986). Requirements for software depend on the users' specific need.

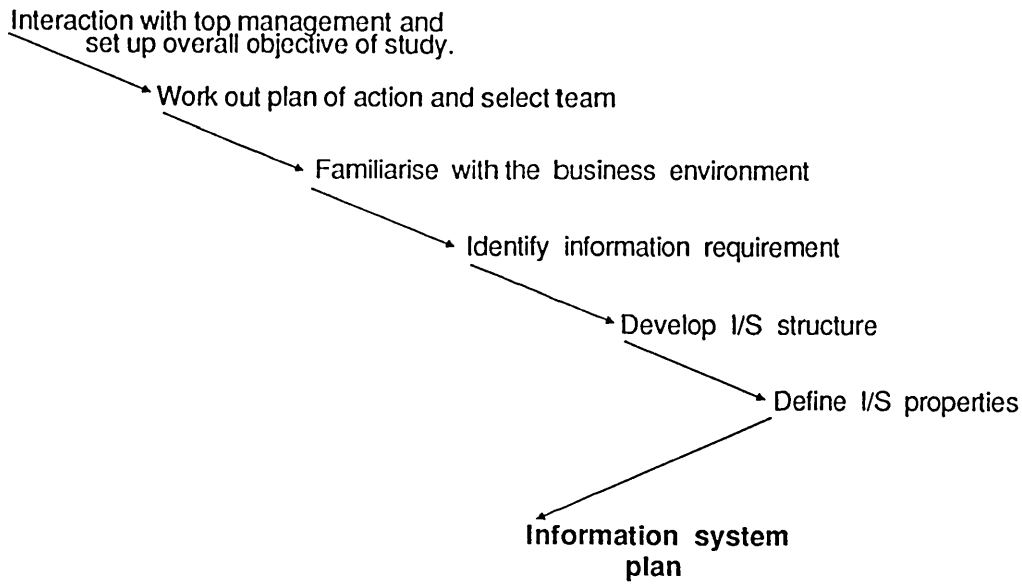
2.9 PLANNING FOR A MINING INFORMATION SYSTEM

An Information System (I/S) plan is a component of the overall business plan of a mining company. It provides a means to ensure that the information needs of the Company are met in a cost effective manner. The I/S plan is a formal vehicle for establishing and communicating the direction an organisation intends to take, to satisfy the information requirements needed in achieving organisational goals and objectives. A broad guideline for information system planning is shown in Figure 2.12(a).

2.9.1 Information system requirement study

The purpose of an I/S plan is to provide direction to the system development process. So, a thorough assessment of an organisation's information requirements should be made prior to preparing the plan itself. An information system requirements study is the means of performing the assessment. Such an assessment involves developing the I/S plan or a major revision of the plan and providing the necessary guidance for future system development.

Gaining and keeping Management support: The most useful form of management support is the actual involvement of management in the study as it progresses. To support the goals and objectives of the business successfully, the I/S



(a) Information system study flow chart.

ORGANISATION / FUNCTION	Exploration	Mining	Processing	Smelting	Refining	Shipping	Materials management	Maintenance	Engineering	Quality control	Environmental control	Safety	Marketting	Planning	R & D	Administration	Personnel	Finance
Corporate headquarters :																		
Sales department						●							●	●				
Exploration department	●																	
Finance department							●							●		●	●	●
Planning department														●				
R & D department									●		●	●			●			
Northern division :																		
Divisional general office						●	●		●		●	●		●		●	●	●
Mine - A		●	●					●			●	●						
Mine - B		●						●			●	●						
Mine - C		●	●					●			●	●						
Smelter				●				●			●	●						
Refinery								●										

(b) An organisation versus function matrix (after Kass, 1979).

Figure 2.12

plan must reflect the needs of management at all levels of the organisation. Gaining and keeping the interest and participation of key personnel throughout the organisation often becomes difficult. One means of gaining and maintaining management support is through an executive sponsor. The executive sponsor must be a high-level member and the executive sponsor should formally be announced for such an I/S requirement study.

Understanding the business environment: Development of an overall understanding of the business environment is the first line of investigation before examining the information requirements. An organisation versus function matrix helps in understanding the business environment. Figure 2.12(b) (Kass, 1979) shows such a matrix for a mining company.

Evaluating existing I/S support: Understanding the degree to which existing information system supports business functions is essential to the success of the study. Executive interviews are one useful source of information by which the effectiveness of existing systems, manual and/or computerised, may be evaluated.

Defining the information requirements: Defining the information required to support the business consists of two principal activities; data gathering, analysis and interpretation of the data. A well-structured series of interviews with key personnel who are involved in the information transaction, and an evaluation of existing and planned I/S need to be performed in collection of data.

Interviews: The objective of the interviews is to obtain first-hand information from each member regarding:

- An understanding of his responsibilities,
- The information needed to meet his responsibilities,
- How information needs are meet, and
- His assessment of any problems that may exist in meeting his needs.

2.9.2 Developing an information system structure

Kass (1979) as well as Ramani and Frantz (1984) have provided some mining information system structures which is based on easily conceivable network models. For an advanced information system, such as a spatial information system, a relational or a combination of hierarchical and relational data structures are

more appropriate (Chang *et al.*, 1977, Kunii *et al.*, 1974). However, information system primitives described by Kass and Ramani provides a base for developing the I/S system for mining.

2.10 SOFTWARE ENGINEERING

From its early beginnings, software development has moved from a haphazard 'cottage industry' to the more disciplined practice of advance IT. Software Engineering is a part of IT, to support IT. It involves the application of methodologies for the design, development and management of complex software. Macro and Buxton (1987) have defined software engineering as,"The establishment and use of sound engineering principles and good management practice, and the evolution of applicable tools and methods and their use as appropriate, in order to obtain within known and adequate resource provisions – software that is of high quality in an explicitly defined sense."

Although other comprehensive definitions have been proposed, all reinforce the importance of principles and guidelines in software development. With the growth in software development in almost all the fields, it is often possible to benefit from existing software. However, in the modern climate, it is essential that the innovative developers follow standards and guidelines, so that software can be adopted or adapted systematically, as a safeguard against rapid and costly software obsolescence. The latest **computer aided software engineering (case)** is a further development in this direction. Software, in the mining industries, has been unable to maintain with the standard of latest software standard. Considerable amount of investment is required for using the latest software engineering techniques in engineering of mining software. However, there is a need for appreciation and adoption of basic principles of software engineering to initiate any endeavour for developing advance software for mining industries.

Chapter 3

THE RESEARCH PROGRAMME

Chapter 3

THE RESEARCH PROGRAMME

3.1 THE REVIEW SUMMARY

Information plays a vital rôle in the progress and prosperity in any discipline. The speed of advancement of modern Information Technology (IT) makes the fact more apparent. Though some progress has been made in utilising computer software in mine planning and management, the mining industry has been unable to take the advantage of many modern IT techniques which are otherwise appropriate for mining. The object of this research has been to examine the potential for a number of IT techniques in mining and to develop new methods/algorithms in interactive graphics to meet specific difficulties related to the generation and management of plans and associated information.

There is no known software presently available to produce the standard maps; maps submitted to the regulating authorities, and governmental department, or used for routine internal purposes. There has been no noticeable attempt to computerise the day-to-day map draughting whereas sophisticated data acquisition systems has been developed for surveying and are used in mining along with the Electronic Distance Measurement (EDM) instrumentation and on-line data acquisition systems.

Among the general purpose mapping packages, such as, MAPS (1984), INTERGRAPH (AUTOCARTO, 1986) and SYSTEM 9 (AUTOCARTO, 1986), many are system dependent and few are within the budgets of small to medium sized mines. The special mapping requirement associated with mining, also preclude the use of normal cartographic processes embodied within the systems. Mine mapping is dynamic in nature and therefore creates additional demands for speed, clarity and modification.

Spatial Information Systems, such as GIS already have had an impact in many fields of engineering and other disciplines (discussed in Section 2.4.1 and 2.4.3), and promise to be a powerful tool in mining and mineral resources management. General purpose mapping packages have many shortcomings in a mining application as a combined Automated Mapping/Geographic Information System (AM/GIS) tool, and fail to address a number of special requirements of mining, in a number of ways which can be listed as:

1. Most of the programs are designed with integration of one application in mind and are available only as expensive turnkey systems;
2. Data management is not geared to mining requirements;
3. Most of the systems are either built on a particular computer system, which may not be used on existing systems or offered as turnkey hardware-software systems.

The benefit of raster map manipulation techniques has not yet been fully explored in mapping although the potential of these methods has been recognised (Gibbs Associates, 1986). Information storage and processing time also have been identified as specific shortcomings which remain to be mastered. There remains a challenge as to how storage requirements may be minimised and how the processing and search time may be accelerated, using new techniques such as, raster mapping, run encoding, quadtree encoding, vector-to-raster conversion and vice versa. The scale and rate of development of a mine, combined with the requirement to examine a wide range of design options, presents a special challenge in IT research combined with pragmatic objective in mining CAD.

The existing mine mapping packages, neglect many aspects such as, integrity, security and privacy of data and concurrency, which are the essentials of a mapping system in day-to-day mining. In the dynamic environment of mine mapping, a sound CAD interface is another important system requirement. There is also a need for a powerful, flexible but easy to use information retrieval mechanism. Menu driven programs, even with graphical menus, may also become cumbersome if different levels of menus must be traversed to reach certain utilities or functions. Query languages which augment a menu interface have been found to provide further versatility and in addition to menus may offer an enhanced method of information retrieval.

Many current mining CAD packages may be regarded properly as information representation systems. In contrast, spatial information systems allow information to be retrieved via spatial keys. Perception of complex systems, either physical or abstract is enhanced by the use of graphics which may be used to produce readily interpreted symbols or exact representation of images.

A trend in the development of graphics software for mining, has been the use of system specific routines or higher level language extensions to achieve improved processing speeds. Such systems are restricted in the range of host devices which may be used and are therefore of diminished utility. The demand for improved management/display of growing, complex and diverse data would appear to militate against such a trend which offers a short term expedient to a long term problem. These practices are predominant especially in I/O operations and particularity in graphics operations. To achieve comparable results on other machines becomes difficult even impossible.

None of the software surveyed attempts to manage comprehensive mapping; mapping the surface features, with proper annotation, title block, north point, grid overlaying and other capabilities which fully exploit the capabilities of a modern computer graphics and system specification.

All the three concepts described in Section 2.6.3 (Pictorial database systems), can be utilised in the context of planning and management of mines. The first of these concepts, retrieval of stored picture, finds a ready application: in storing and consulting the map of old workings (if any), the original geographic map of the area and any other maps or plans which are to be kept intact. The second concept, display of data stored in a tabular form, addresses a need to visualise the various statistical data, like production, demand and shipment of mineral, in quantitative and qualitative manner and maintain their relations with machinery-inventories, employees' records, mines regulation compliances etc. The third principle, retrieval and presentation of data usually in the form of map, is of value in the planning of the excavation. An interactive capability is essential for creating section plans as desired for visualising the future progression for the mining excavations.

3.2 THE PROBLEM DEFINITION

Research work was planned towards developing a prototype package which would have a range of utilities which may be broadly divided into three parts;

- Automated mapping for day-to-day mining activities;
- A robust mapbase structure to provide efficient spatial data retrieval with the desired integrity, security, privacy, concurrency, and a powerful and intelligent query language for map retrieval and processing;
- Information retrieval through spatial keys and indices.

3.3 RESEARCH ACTIVITIES PLANNED

The following activities were planned in the line of the research objectives set:

1. To adopt/adapt software for vector-to-raster (V-R) conversion, raster map manipulation tools, and raster-to-vector (R-V) conversion;
2. To develop a database system and retrieval mechanisms for managing map data and controlling the operations; digitising, V-R conversion, map manipulation, storage and retrieval, R-V conversion, and graphics display;
3. To establish an experimental mapbase of an open pit mine for testing the system and modifying the database system;.
4. To carry out an information system study at an open pit mine for collecting maps and related information, and to interact briefly with the mine management and open pit experts about information requirements.
5. To modify and integrate developed software to form a prototype package for improved map resolution, and to add the spatial information retrieval functions;
6. To make observations on any operational constraints of the prototype;
7. To lay down guidelines for future enhancement of the package.

Chapter 4

SYSTEM DEVELOPMENT

Chapter 4

SYSTEM DEVELOPMENT

4.1 INTRODUCTION

In the recent years, simple 'programming' has given way to 'software engineering' in accordance with the enhancement of computer architecture and computing techniques. Developing software is distinctly different from developing algorithms. Today, many existing algorithms/software tools are available, and operating systems have also become more flexible allowing greater versatility in system programming. 'Engineering' software from existing software/algorithms involves both the development and design of software and also the exploitation of system programming to integrate tools and programs into coherent packages. A software engineering approach is essential to establish a system to meet latest standards.

In this undertaking, the relevant software tools were developed/engineered in the initial stage. Then they were integrated to form a 'paper prototype'. In continuation, the prototype was tested and modified by using the maps and related information collected in an information system study carried out in a newly-opened, mechanised, open pit mine. Eventually a 'working prototype' was established. A brief account of the work is given in this Chapter.

Software is the mechanism to harness and tap the hardware potentials of the computers. Analysis of hardware requirements and hardware specifications can not be made to the exclusion of all considerations of a software system development, especially in the case of a GIS which itself is a hardware/software system (Section 2.8). Hardware specifications and requirements have been examined where appropriate.

4.2 MAP ALGEBRA AND MAP PROCESSING PRIMITIVES

The basic map manipulation techniques defined by Tomlin and Berry (MAP, 1983) were adopted in the development of the map processing subsystem; they include different matrix operations such as, addition, subtraction, multiplications, rotations, translations and transformations. Matrix algebra extends the basic arithmetic functions to operate on matrices, hence, is applicable to grid cell maps represented by matrices, and provides the foundation for **map algebra**. A number corresponding to each map is used to identify a particular matrix (map matrix) which represents the raster map or grid cell map under consideration. Map processing is carried out by retrieving and then manipulating the relevant map matrices.

Map algebra, in an analogous manner, operates on groups of maps using fundamental functions to express interrelations among map variables. By manipulating either a single map matrix or several map matrices, a new map overlay may be created. Addition, subtraction, multiplication, exponentiation, and other operations may be performed. In effect more than one map may be added, multiplied, or manipulated in various other ways to generate different map overlays (Figure 2.1) either of geographic features or thematic information. Each of these operations is called a **map processing primitive**. There are other primitives which do not directly involve any map manipulation, but are important for maintaining the map database; for example, removing, copying or protecting a map from any inadvertent deletion or amendment. One or a set of primitive(s) may be used for a certain process. Query commands and modifiers are used to perform these operations, which are discussed in Sections 5.6.2 and 6.2

4.3 VECTOR-TO-RASTER CONVERSION ALGORITHM

Map processing operations are important factors in manipulation of geographic and thematic information. These, however, are carried out with raster maps, whereas maps are usually available in vector form; digitised maps, interactively draughted maps, or maps created from survey data. Vector to raster conversion is therefore an essential precursor to map manipulation. The power and the efficiency of a GIS system using vector and raster maps, depends heavily on the

reliability and efficiency of the underlying vector-to-raster conversion or 'area fill' subsystem employed.

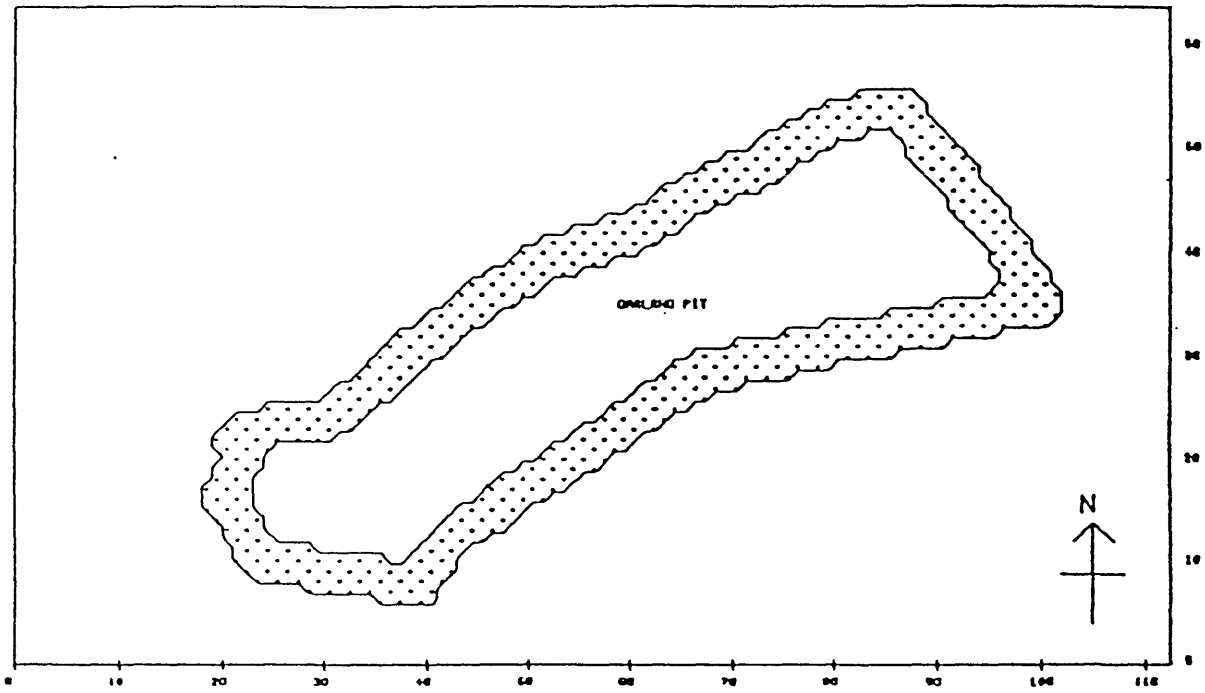
4.3.1 Pixel and grid cell representation of maps

Before discussing 'area fill' algorithms, it is important to discuss the concepts of the 'pixel' and the 'grid cell'. Pixels are the 'dots' on the displayed screen/plotted map, which collectively represent a map or a picture. A grid cell is the smallest square on the surface of a raster map; a set of these squares represents a map. One grid cell can be represented by either one or several pixels, on the other hand, one pixel may represent several grid cells depending on the size of the raster array and the resolution of the screen. For example, the normal map matrix used in the system developed, has an typical configuration of 400 rows $\times$ 700 columns. If such a map is plotted on a raster screen with a resolution of 1248 $\times$ 1440, then one grid cell will be represented by more than one pixel. If the screen resolution were 200 $\times$ 300, then a pixel would have represented more than one grid cell. The difference between the raster map and a grid cell map may be similarly defined. However, both the terms 'pixel' and 'grid cell' are commonly used synonymously or even termed simply a 'cell'. The term 'graphics cell' is also in use (Hanley, 1982). During the discussion of the vector-to-raster conversion algorithm developed for the system, these terms will be used interchangeably.

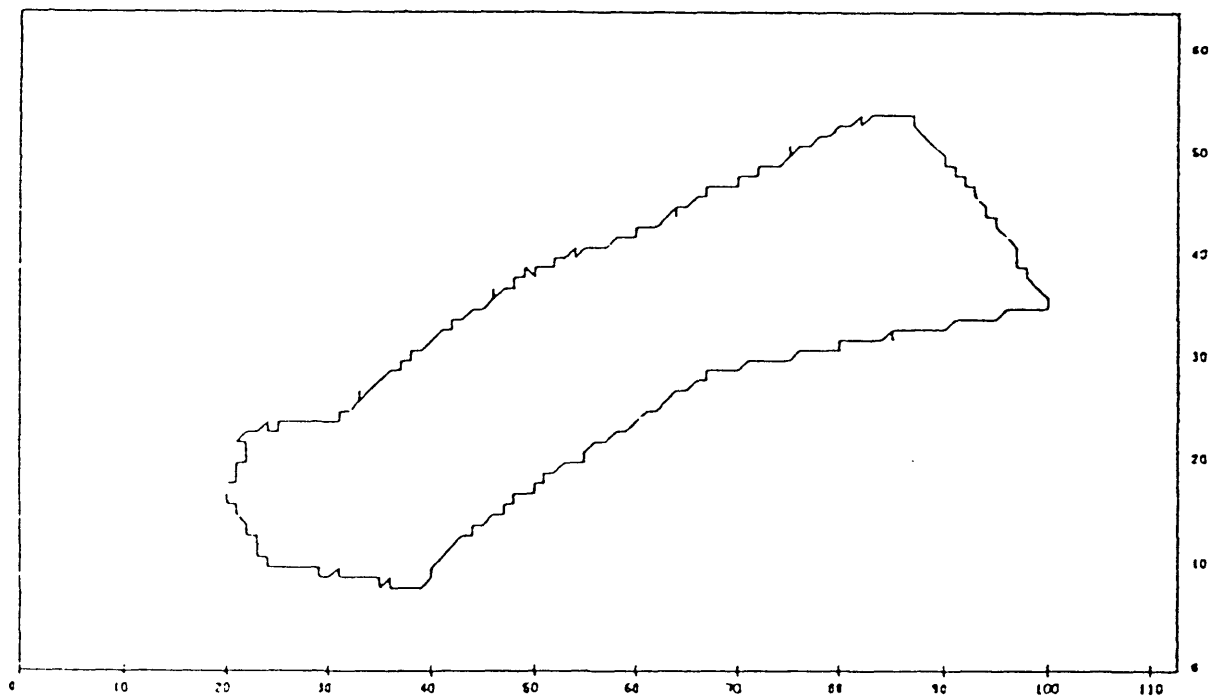
The term **scale factor** or simply 'scale' has been used to refer to the length in geographic space, represented by the side of a grid cell (square), eg. 32 m or 8 m per grid cell.

4.3.2 The existing algorithms

Initially, the polygon fill program of Sailor (1980) was employed. The program is based on the **flood fill algorithm**. Initially all the cells in the raster frame are assigned 0 value. Then each of the cells of the digitised feature are compared with the six nearest neighbour cells and are assigned the value of the current cell under consideration. This process is repeated until a cell is encountered with value other than 0. Attempts to fill some maps using the algorithm were not successful and the approach. Figure 4.1(a) shows one such result, which may be compared with the actual vector plot (Figure 4.1(b)) of the corresponding data set. The performance of the algorithm is dependent upon the manner in which data is digitised and is therefore not generally applicable to cartography. The



(a) The pit limit area (a garland) incorrectly filled by the flood fill algorithm of Sailor (1980).



(b) Simple vector plot of the digitised polygon (the pit limit)

Figure 4.1

algorithm uses several 'hard coded' constants which are not documented, and is confusing. Moreover, flood fill technique requires adequate stack space. So, this algorithm was not investigated further.

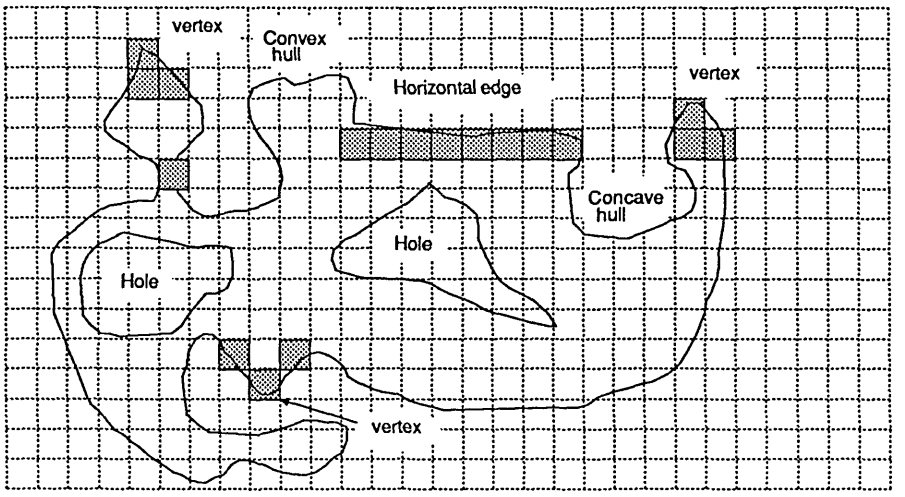
Other polygon filling algorithms (Rogers, 1985) were examined. The **edge list algorithm**, the **ordered edge list algorithm**, the **edge fill algorithm**, and the **edge flag algorithm**, – they use the basic principle of scan conversion, though vary in execution time because of differences in the amount of scanning involved. However, all these algorithms were found to break down when a scan line intersects a polygon at a vertex or when any limb of a polygon is pinched or too narrow to give rise to only one cell (Figure 4.2(a)). Moreover, fenestrate polygons are not considered.

Seed fill technique assumes that a cell (seed pixel) inside the closed contour is known (Figure 4.2(b)). The algorithm then proceeds to search for points adjacent to the seed point that are inside the contour. If the adjacent point is not inside the contour, then the boundary of the contour has been found. If the adjacent point is inside the contour, then it becomes a new seed pixel and the search continues recursively. This process may impose of significant computing overhead when the map is very complicated by convoluted features. Complication does not appear to be eased even if multiple seeds are used (Figure 4.2(c)).

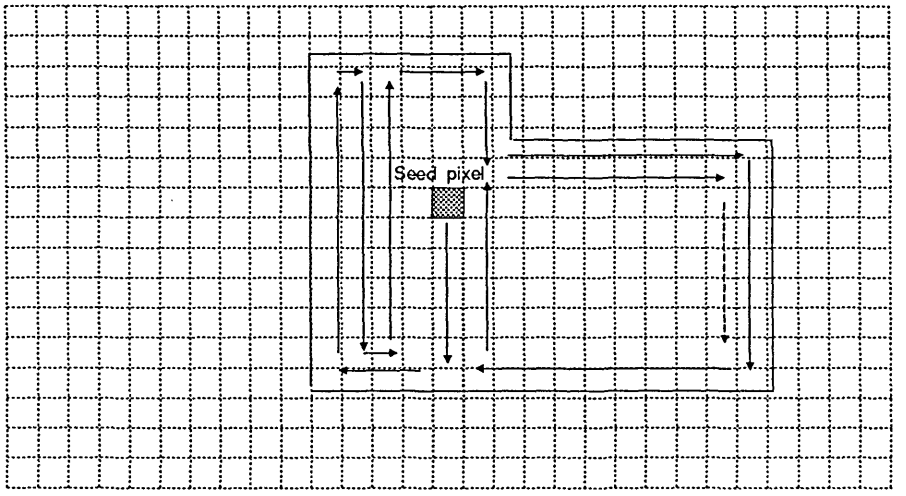
For any of the algorithms discussed above, the conversion will give incorrect representation of detail, if there is a leek in the chain of cells describing a feature boundary (Figure 4.3(a)). Figure 4.3(b) shows a erroneous map created due to this problem. The result may be compared with the vector plot of the pit limit map, shown in Figure 4.1(b). The immediate means of overcoming this failure is to digitise map features at very close intervals. But, many redundant points must then be recorded, and may still not be adequate if higher resolution maps are required subsequently. The whole process degenerates into a heuristic, tedious and time consuming exercise with large, inefficient storage requirements involving a considerable amount of computer time.

4.3.3 The new (grey-scale) area fill algorithm

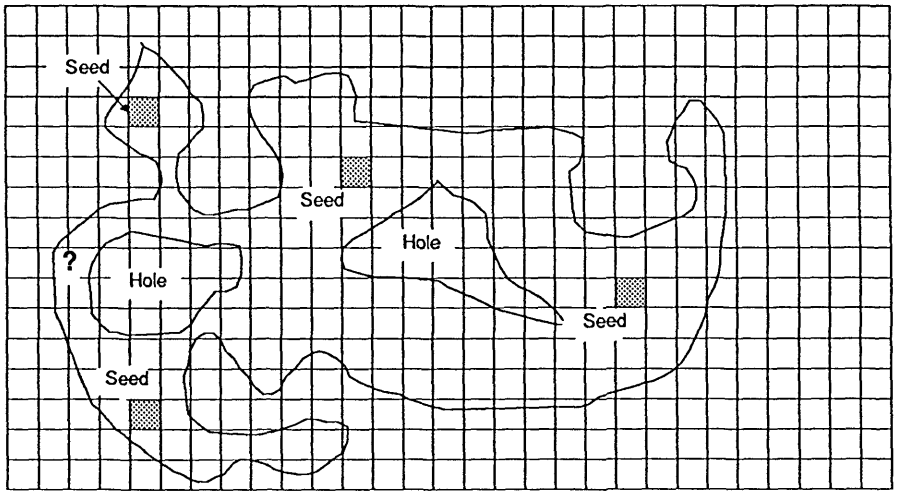
This algorithm was developed during the research, for vector to raster conversion of digitised maps consisting of complicated polygons representing the fine detail in map features. Cases involving more than one polygon in the same map having



(a) Complicated map feature with narrow limbs, horizontal edges, holes, and concave hulls.

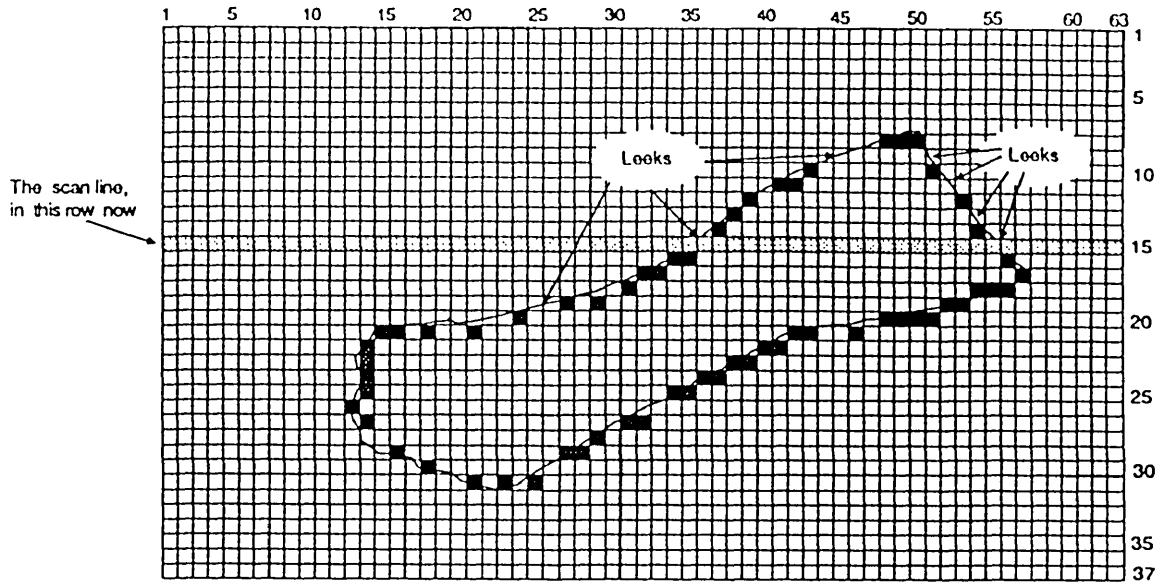


(b) Seed fill process for a simple polygon with regular geometry.

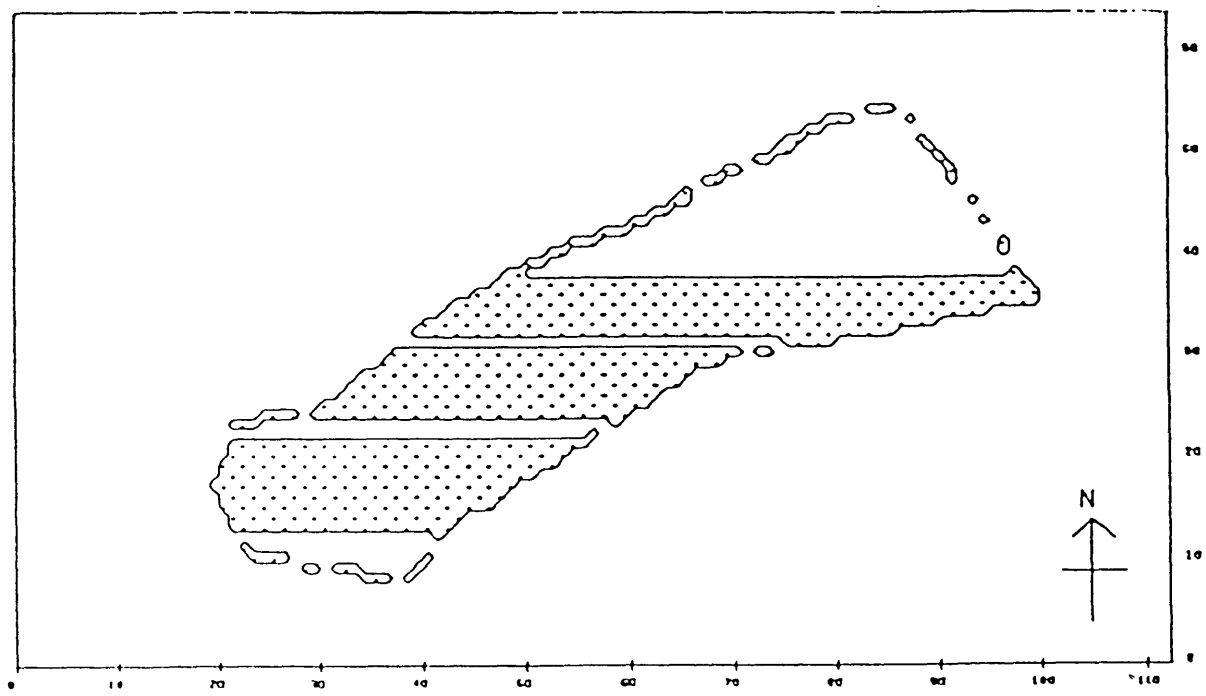


(c) Complication in seed fill algorithm even with multiple seeds, for a complicated map.

Figure 4.2



(a) The polygon is not described by a continuous chain of cells; the scan line is leaking through cells.



(b) The falsely filled area for the feature PITSURF shown in figure 4.1 due to leaking of scan line through discontinuous cells as shown in (a).

Figure 4.3

the same or different polygon values, also have been considered; hence, the 'grey-scale' term has been used to describe this method. Polygon values refer to the attribute values assigned to polygons and are equivalent to category values, cell values, or pixel values. In this discussion, the term 'colour value' will be used in general.

The input data to the algorithm are the northings, eastings and the attribute values (colour values) of the points describing the polygon(s). These northings, eastings and attribute values can be obtained by digitising map features or from field survey data. Map features drawn interactively, also may be filled using this algorithm. A unique colour value (say, −9999.0) is used as a sentinel for the last point of a polygon to indicate that the next set of points belong to another polygon. Obviously, this particular value can not be used as a colour value.

The new algorithm uses the scan line filling principle, but has been enhanced to provide 'intelligent' interpretation of detail and to preserve the topology of the 'real life' map-features, such as internal voids, horizontal edges, and convex/concave hulls. The algorithm also considers a vertex or a narrow limb which may give rise to a single cell resulting in an odd number of cells in a row (Figure 4.2(a)).

In summary, the algorithm considers:

- Complicated polygons as in map feature(s);
- More than one polygon with same colour value;
- More than one polygon with several colour values;
- Polygons with concave and convex hulls;
- Polygons with internal voids;
- Polygons with vertices;
- Polygons with narrow limbs;
- Polygons with horizontal and vertical edges;
- Digitised maps with any reference grid;
- Clipping of the feature(s) in the map window;
- The creation of a raster map of any size at any scale.

The coded algorithm fills the map as a series of rows of cells. While scanning row by row, it fills each row before going to the next row. However, the colour values for the cells of the previous row which have already been filled, are sometimes

used for nearest neighbour testing, in the row under scan. Thus, the colour values for two consecutive rows only need be stored in memory.

If the bottom of the map window is higher than the bottom of the map feature (Figure 4.4, window 2 in (b)), then the map feature below the map window need not to be scanned at all. The whole filling operation is carried out through a sequence of operations. A pseudo code implementation of the algorithm is given below:

---

declaration and initialisation

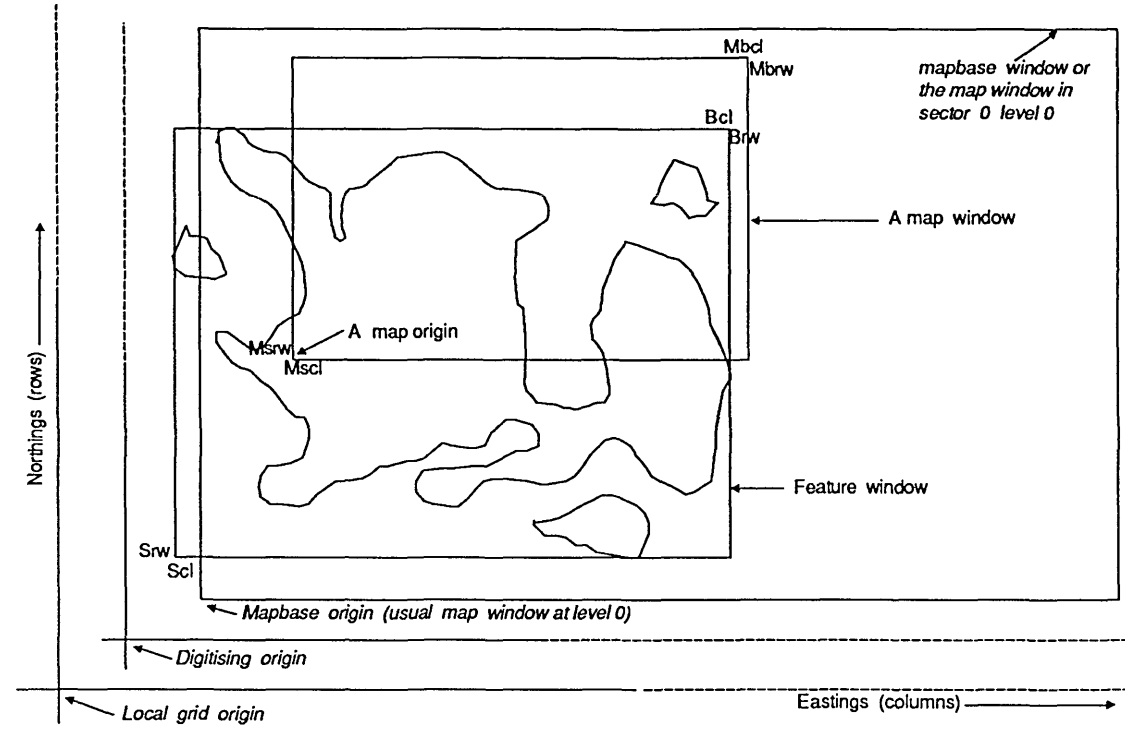
Point(,1)	*is the northing of a point*
Point(,2)	*is the easting of a point*
Point(,3)	*is the colour value associated to a point*
Dgtorg(1)	*is the northing of the digitising origin (Figure 4.4(a))*
Dgtorg(2)	*is the easting of the digitising origin (Figure 4.4(a))*
Maporg(1)	*is the northing of the map origin (Figure 4.4(a))*
Maporg(2)	*is the easting of the map origin (Figure 4.4(a))*

The map area will be addressed by rows, each consisting of equal numbers of cells, effectively there will be a map matrix (Figure 2.3(e) in Chapter 2).

Ipoint(,1)	*is the row no. of a cell in a map feature*
Ipoint(,2)	*is the column no. of a cell in a map feature*
Ipoint(,3)	*is the colour value associated with a point in a map feature*
Ctgy()	*are the colour values for the cells in a current row*
Ctgp()	*are the colour values for the cells in a preceding row*
Nr	*is the no. of rows in a map matrix*
Nc	*is the no. of columns in a map matrix*
Scale	*is the length of a side of a grid cell; the scale factor. The scale factor depends on no. of rows and columns in the map matrix and the area covered by the map window*

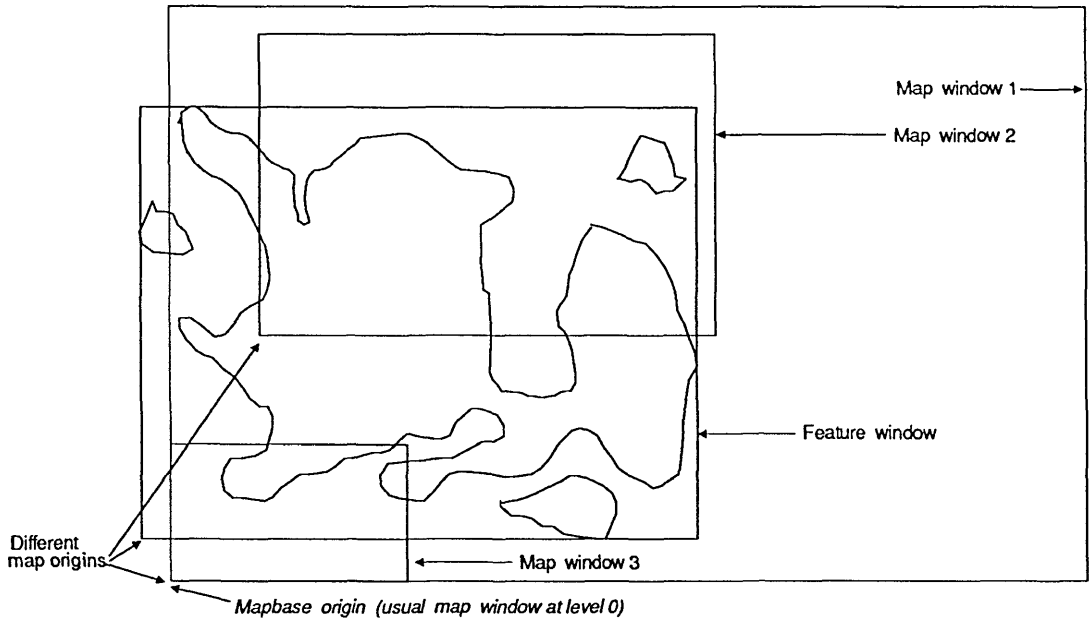
real Point(,3)

integer Srw, Brw, Scl, Bcl, Msrw, Mbrw, Mscl, Mbcl, Coltl, Rowtl, Scale
integer Dgtorg(2), Maporg(2)



Srw →	The smallest row no. in all the cells (points) in the feature window	Msrw →	The smallest row no. in all the cells in the map window.
Scl →	,, ,, column ,, ,, ,, ,, ,, ,, ,,	Mscl →	,, ,, column ,, ,, ,, ,, ,, ,, ,,
Brw →	,, biggest row ,, ,, ,, ,, ,, ,, ,,	Mbrw →	,, biggest row ,, ,, ,, ,, ,, ,, ,,
Bcl →	,, ,, column ,, ,, ,, ,, ,, ,, ,,	Mbcl →	,, ,, column ,, ,, ,, ,, ,, ,, ,,

(a) The physical representation of some variables used in vector-raster conversion algorithm



(b) Feature window, and map window concept used in vector-to-raster conversion algorithm

Figure 4.4

The dimensions of subscripted variables need to be adjusted according to the maximum number of digitised points, the size of the map matrix, and the minimum scale factor to be used.

```
integer Ipoint(,3), Ctgy(),Ctgp()
integer Col(), Row(), Ctg(), Colt(), Rowt(), Ctgt()
```

input digitised data, processed survey data, or interactively created data, northings and eastings of project origin and Nr *and* Nc

```
input Points, Dgtorg, Maporg
input Scale, Nr, Nc
```

converting the digitised points into cells, where Npoints *is the number of points read from the digitised file.*
'Int' *is a function to convert real to integer by truncating the fractional part.*

```
for i = 1, Npoints
    Ipoint(i,1) = Int((Point(i,1) − Dgtorg(1))/Scale + 0.5)
    Ipoint(i,2) = Int((Point(i,2) − Dgtorg(2))/Scale + 0.5)
    Ipoint(i,3) = Int(Point(i,3))
next i
```

after conversion of the digitised points to cells (Figures 4.5(a) and 4.5(b))

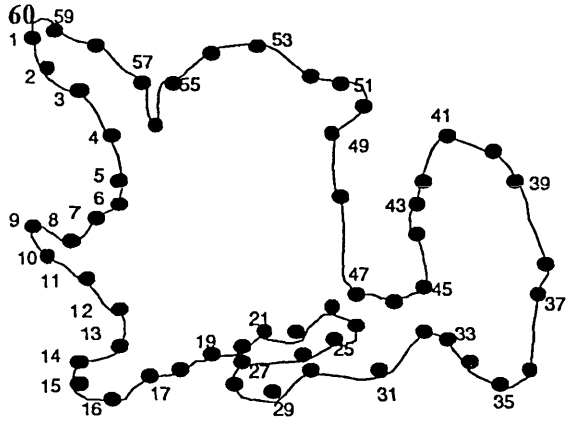
Ncells — *is the number of continuous cells describing the polygon(s) (after call to* Dscntfl); *will be different from the number of digitised points except in the rare exceptions where no cell needs to be generated.*

```
call Dscntfl(Ipoint, Ncells)
```

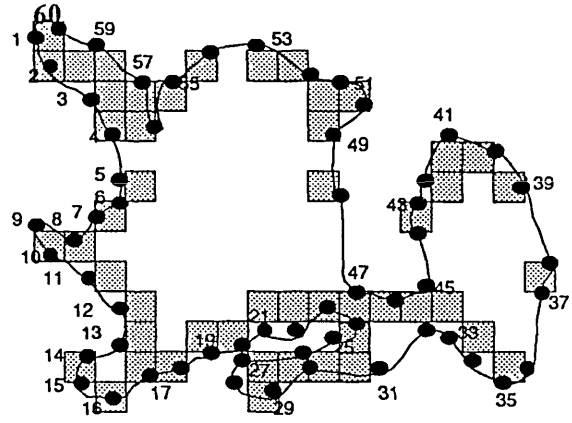
After the areas have been described by continuous cells, the 'bounding box' ie. the smallest rectangle (Figure 4.4) containing the feature(s) under consideration, is established to minimise the scanning area.

Srw — *is the smallest row number in the total number of cells*
Scl — *is the smallest column number in the total number of cells*
Brw — *is the biggest row number in the total number of cells*
Bcl — *is the biggest column number in the total number of cells*

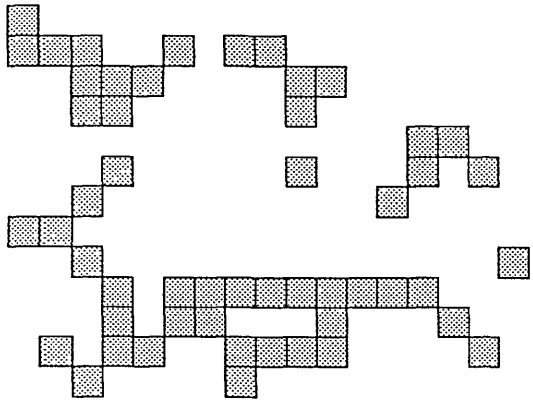
Rowtl — *is the total no. of rows in the feature frame,* Srw *inclusive*
Coltl — *is the total no. of columns in the feature frame;* Scl *inclusive*



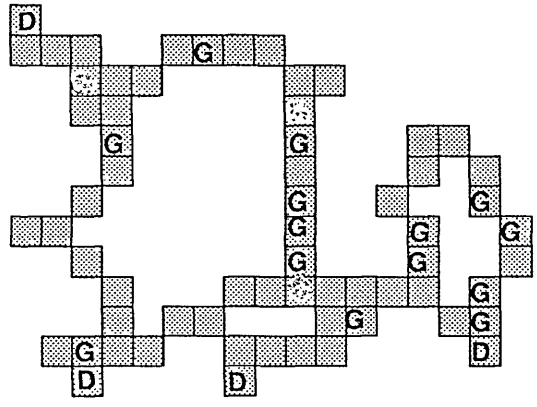
(a) Sequence of digitising or the survey stations on the map.



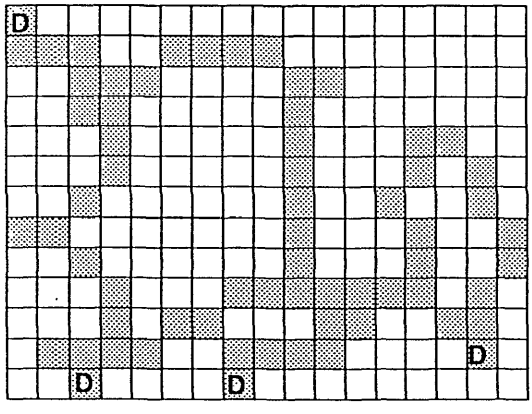
(b) Digitised points on the map feature and the corresponding grid cells.



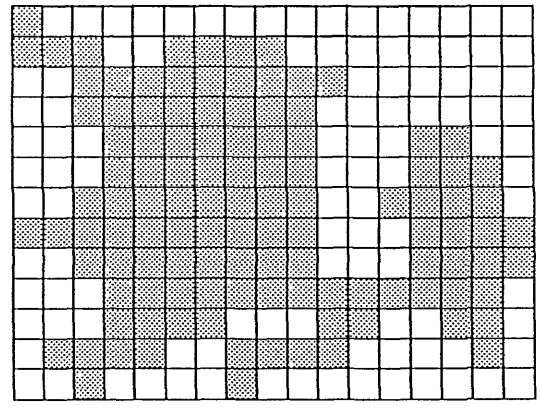
(c) The grid cells converted from the digitised points.



(d) Map feature represented by a continuous chain of cells. 'G' cells are generated and 'D' cells are duplicated at the vertices.



(e) Map feature represented by a continuous chain of cells. 'D' indicates presence of a duplicate cell.



(f) Filled polygon feature in raster space, 17 X 13 raster block.

Figure 4.5 Different stages of digitised vector map to raster map (grid cells) conversion

Min *is a function to find the smallest number in an array*
Max *is a function to find the largest number in an array*

Srw = Min(Ipoint(,1))
Scl = Min(Ipoint(,2))
Brw = Max(Ipoint(,1))
Bcl = Max(Ipoint(,2))
Rowtl = Brw − Srw + 1
Coltl = Bcl − Scl + 1

defining the map window

Msrw *is the row no. of the origin of the map window*
Mscl *is the column no. of the origin of the map window*
Mbrw *is the row no. of the top corner of the map window*
Mbcl *is the column no. of the top corner of the map window*

Msrw = Int((Maporg(1) − Dgtorg(1))/Scale + 0.5)
Mscl = Int((Maporg(2) − Dgtorg(2))/Scale + 0.5)
Mbrw = Msrw − 1 + Nr
Mbcl = Mscl − 1 + Nc

when no part of the feature lies in the map window, the algorithm stops

if Brw < Msrw and Bcl < Mscl **then**
    stop
else if Srw > Mbrw and Scl > Mbcl **then**
    stop
end if

scanning starts from the top of the map feature ie. the largest row no.
0 (zero) is the background colour for filling.

filling the cells in the rows outside the feature window (when the top of the map window is higher than that of the feature window)

if Mbrw > Brw **then**
    call Zerof (1, Mbrw−Brw)
end if

j = 1

```
for Ir = 1, Rowtl
    initialising all the cells for the row with the background colour value, 0
    for Ic = Scl, Bcl
        Ctgy(Ic) = 0
    next Ic

    empty cell   is a cell having the colour value, 0 (zero); no feature exists
    coloured cell  is a cell having a colour value other than 0; feature exists

    Colt()  stores column numbers of all the coloured cells of the row under scan
    Ctgt()  stores colour values of all the coloured cells of the row under scan

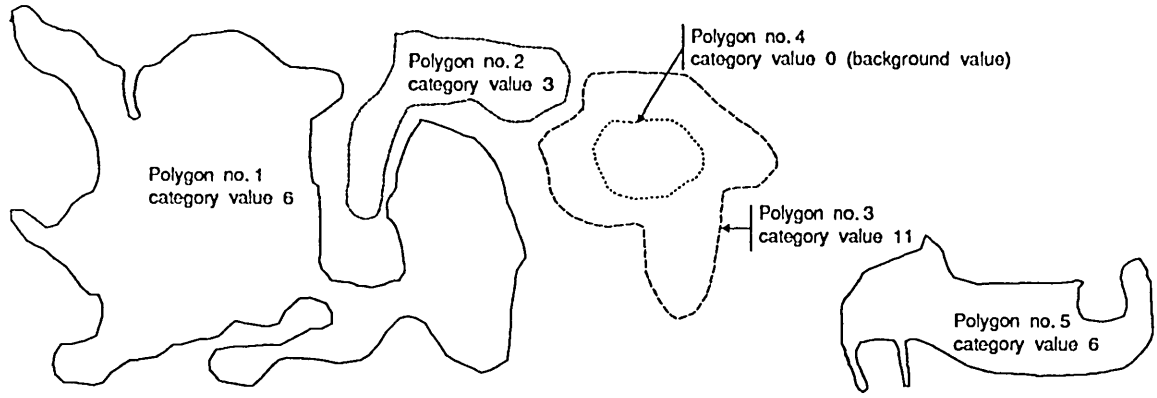
    for i = 1, Ncells
        if Ir = Ipoint(i,1) and Ic = Ipoint(i,2) then
            a coloured cell is found
            j = j + 1
            Colt(j) = Ipoint(i,2)
            Ctgt(j) = Ipoint(i,3)
            if more than one coloured cell found consecutively then
                one of them taken, the rest discarded
            end if
        end if
    next i
    Ninsec  is the no. of coloured cells found in the row
    Ninsec = j - 1

    scanning in the feature window and filling starts for the current row.
    if no coloured cell is found, all the cells of the row are filled with the back-
    ground colour, 0 (zero)

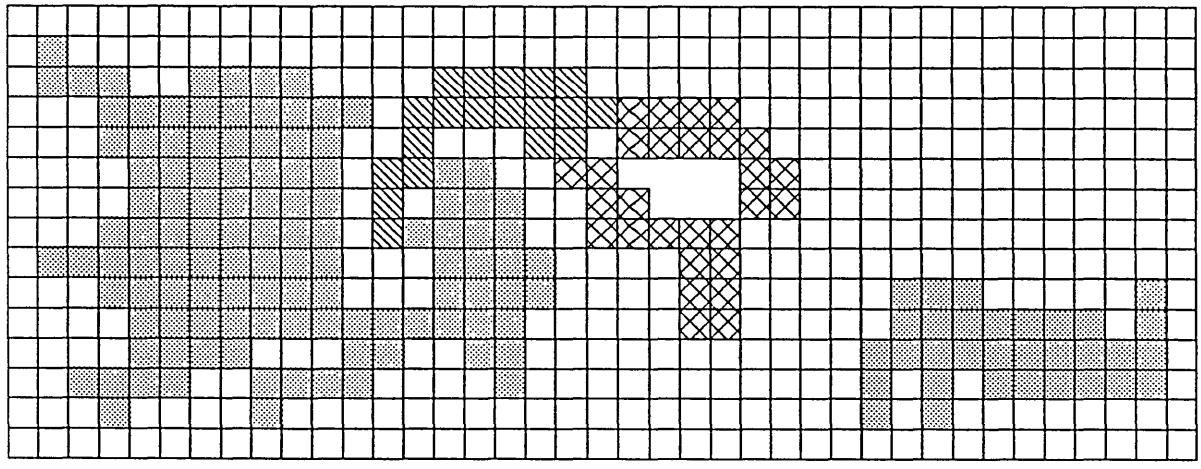
    if Ninsec = 0 then
        call Zerof (Ir, Ir)
    end if

    Now, the column numbers of all coloured cells of the row are arranged in the
    ascending order. The algorithm for this is elementary, and is not discussed.

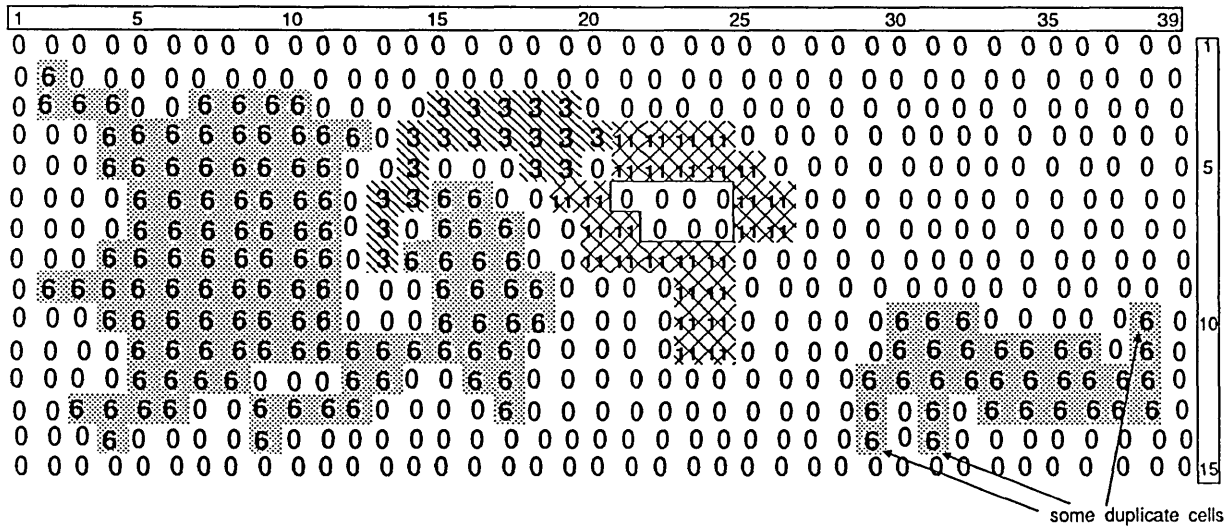
    The pairs of extreme left and right of the groups of different coloured cells,
    are identified. In row no. 10 (Figure 4.6(c)), these will be 6-6, 6-6, 11-11,
```



(a) Three polygonal map features with three different category values.



(b) The three categories of polygonal map features represented by grid cells.



(c) The map matrix (15X39)representing the features shown in (a).

Figure 4.6

6-6 and 6-6. To satisfy pairing, duplicate cells are considered to be left and also the right; usually in the case of narrow limbs (eg. column 13 in row 7) or a vertex (eg. column 13 in row 8, column 4, 9, 29 & 31 in row 14).

Col() *stores column numbers of all the processed cells in the current row*

Ctg() *stores colour values corresponding to all the* Col()

l = 1 *means the cell is the left most cell in a group of continuous like-coloured cells, in the row*

```
l = 1
j = 1
for i = 1, Ninsec
    if i ≠ 1 and i ≠ Ninsec then
        if l = 1 then
            l = 0
            Col(j) = Colt(i)
            Ctg(j) = Ctgt(i)
            j = j + 1
        else if (Colt(i+1) − Colt(i)) > 0 then
            for Ic = Colt(i) + 1, Colt(i+1) − 1
            comparing with colour values of the cells of the previous row
                if Ctgp(Ic) ≠ Ctgt(i) then
                    l = 1
                    Col(j) = Colt(i)
                    Ctg(j) = Ctgt(i)
                    j = j + 1
                    goto 10
                end if
            next Ic
        end if
    else
        l = 0
        Col(j) = Colt(i)
        Ctg(j) = Ctgt(i)
        j = j + 1
    end if
10  continue
```

```
next i

Nj  is no. of coloured cells in the row (after pairing)
Nj = j − 1

to fill up all the cells of the row with appropriate colour value

j = 1
for Ic = Scl, Bcl
    if Ic ≥ Col(1) or Ic ≤ Col(Nj) then
        if (j is odd and Ic ≥ Col(j)) or (j is even and Ic ≤ Col(j)) then
            Ctgy(Ic) = Ctg(j)
            if j < Nj then
                when duplicate cells encountered
                if Ic = Col(j) then
                    if Col(j+1) − Col(j)) = 0 then
                        j = j + 2
                    else
                        j = j + 1
                    end if
                end if
            end if
        end if
    end if
next Ic

filling all the cells of the row of the map matrix : cells outside the feature
window are assigned the value 0, cells beyond the map window are ignored

If the top of the map window is not reached, nothing is written to the map
matrix, and scanning starts for the next row

if (Scl−Mscl) > 0 then
    j = Scl
    for i = 1, Nc
        if i > (Scl − Mscl) and j > Bcl then
            Ictg(i) = Ctgy(j)
            j = j + 1
        else
```

```
                Ictg(i) = 0
            end if
        next i
    else
        if (Scl − Mscl) < 0 then
            when (Scl − Mscl) is negative, −(Scl − Mscl) will result in addition.
            j = Scl − (Scl − Mscl)
        else if (Scl − Mscl) = 0 then
            j = Scl
        end if
        for i = 1, Nc
            if j > Bcl then
                Ictg(i) = 0
            else
                Ictg(i) = Ctgy(j)
                j = j + 1
            end if
        next i
    end if

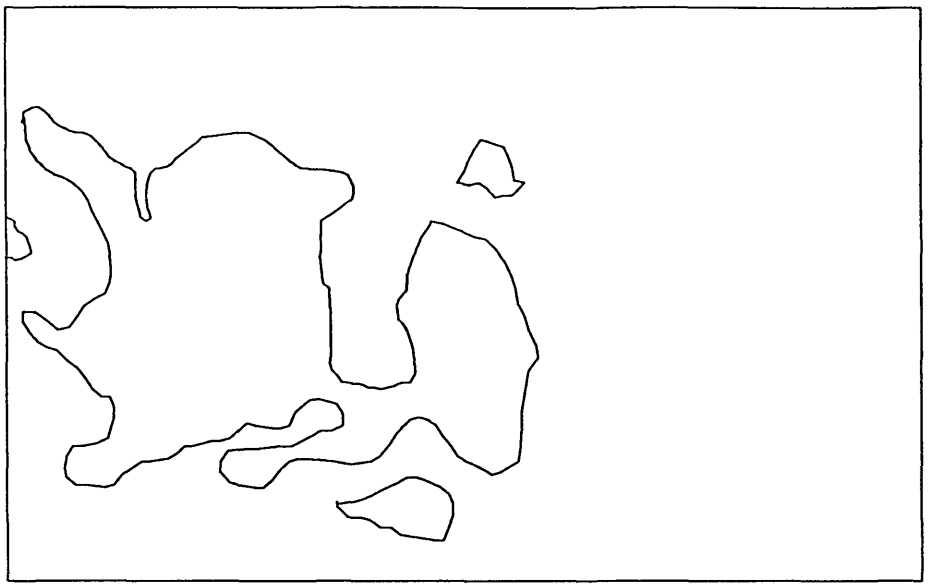
    if the bottom of the map window is reached scanning stops

    storing all the colour values of the row for comparison in the next row
    for Ic = Scl, Bcl
        Ctgp(Ic) = Ctgy(Ic)
    next Ic

next Ir
```

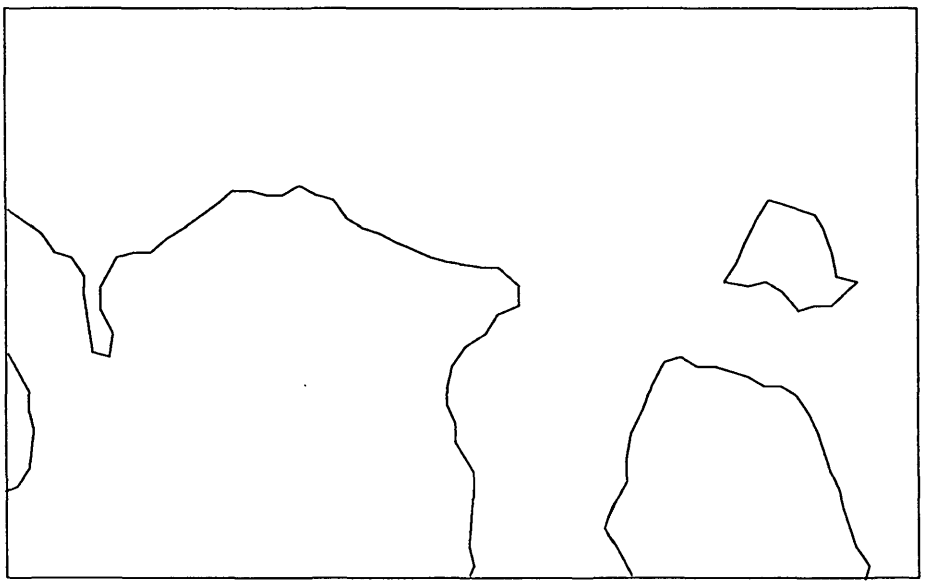
filling the map matrix when the bottom of the map frame is lower than the feature frame (window 1 in Figure 4.4(b) and in Figure 4.7(a)) with respect to northing.

```
if Msrw < Srw then
    call Zerof (1, (Srw − Msrw))
end if
finish
```



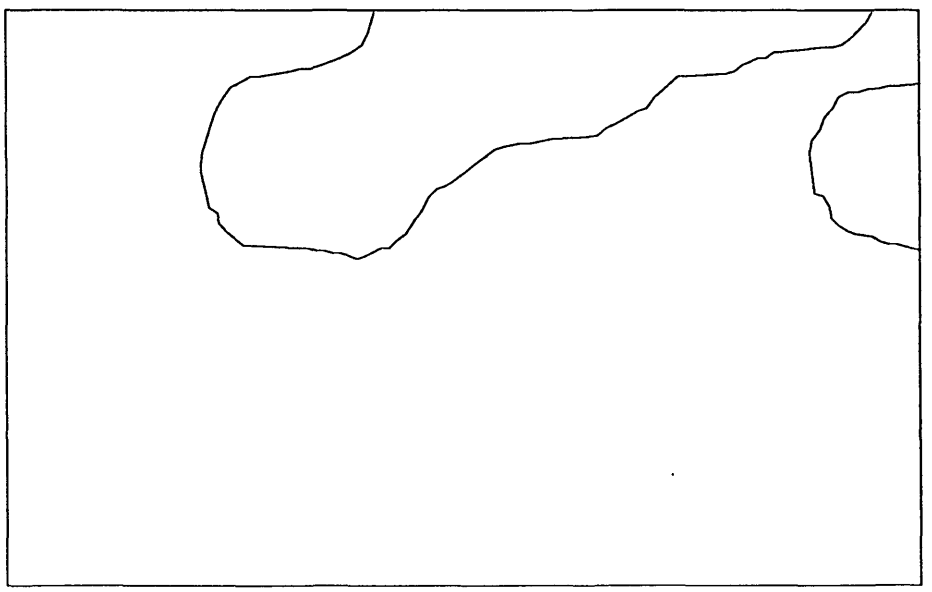
(a) The part of the feature in the map window 1

Scale at the top level (0), is 8M/ grid



(b) The part of the feature in the map window 2

scale : 1/2



(c) The part of the feature in the map window 3

Scale : 1/4

Figure 4.7 Clipping a feature in various map windows at defferent levels.

subroutine Dscntfl (Ipoint, Ncells)

identifies the discontinuous cells (Figure 4.5(c)), and fills up the intermediate cells to give a continuous chain of cells (Figure 4.5(d)) to describe the boundary of the feature(s).

In a single polygon, if the last cell is not a duplicate of the first cell, then the polygon has not been closed, and additional cells are generated to effect closure.

The algorithm also identifies all the vertices in the upward or downward direction, and generates a duplicate cell at each of these vertices (Figure 4.5(d) & 4.5(e)).

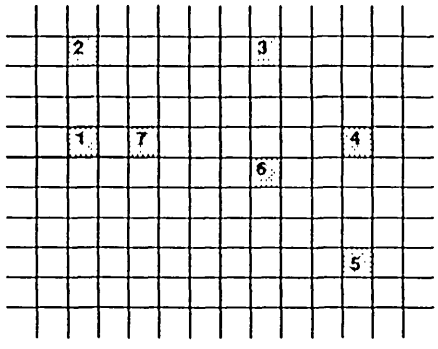
This subroutine discards unnecessary cells; more than two points giving rise to the same cell (i.e. the same row and column number) will not be considered. Bresenham's concept (Rogers, 1985) has been used to connect the discontinuous cells. In a situation as shown in Figure 4.8(b), whether the cells marked with 'g', or the cells marked with 'G' (Figure 4.8(c), will be generated, depends upon the way the test is carried; row first or column first, and which of the two cells comes first. Since there is no 'real' information available between these two points, any of these may be accepted. The implementation of this algorithm tests row first. The last point of a polygon is marked by assigning a unique colour value to it, say −9999.0. Point no. 60, 75, 92, and 99 are such points in Figure 4.9(b).

return
finish

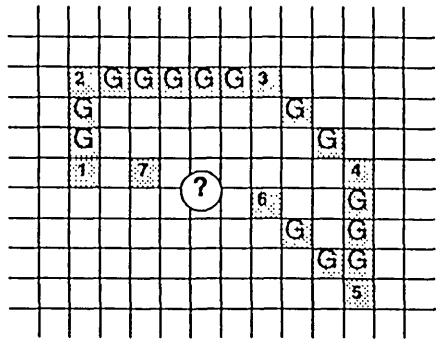
subroutine Zerof (Ir1, Ir2)

integer Ictg()

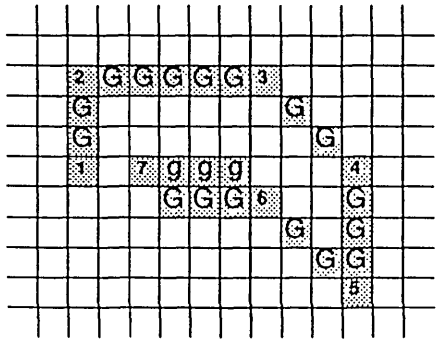
for I = 1, Nc
    Ictg(i) = 0
next I
for Irr = Ir1, Ir2
    call Pretap(Irr, Ictg)
next Irr
return
finish



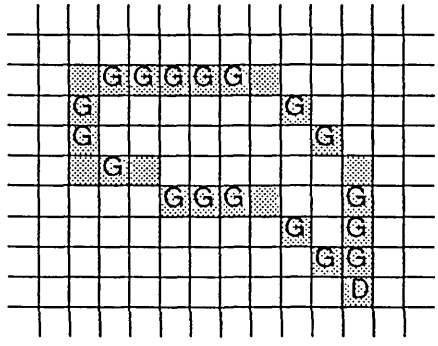
(a) A polygon represented by discontinuous cells.



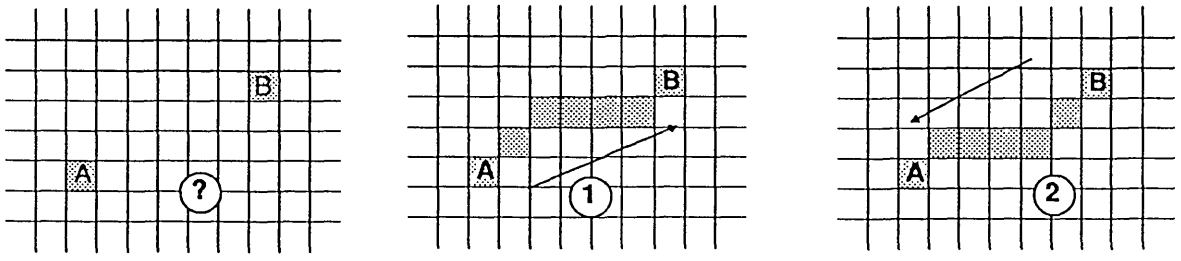
(b) Different cases of generating intermediate cells. Which cells are generated between 6 and 7?



(c) The cells marked with 'g' will be generated, or the cells marked with 'G' ?

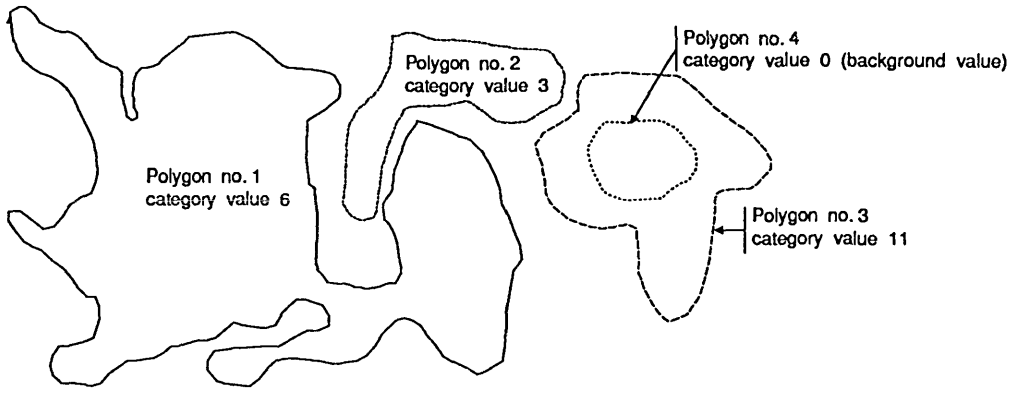


(d) Intermediate cells have been generated between all the points. The vertex cell, cell no. 5 has been duplicated.

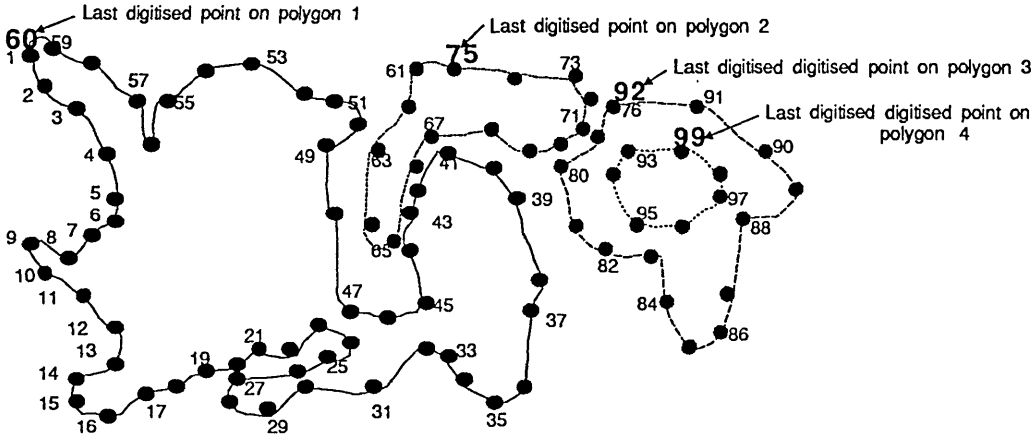


(e) Which cells will be generated between these points depends on which one comes first in the polygon. This is shown as case ① if 'A' comes first and as case ② if 'B' comes first.

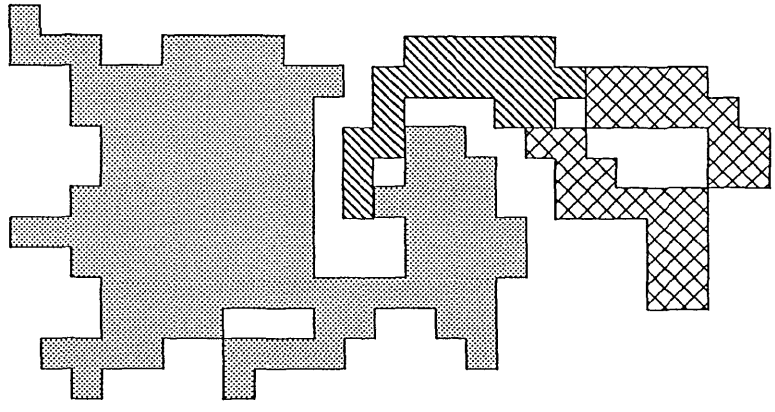
Figure 4.8



(a) Three polygonal map features with three different category values.



(b) Three polygon features with different category values digitised, the sequence of digitising has been shown in ascending order.



(c) The three polygonal map features after the 'area fill'.

Figure 4.9

```
subroutine Pretap(Irr, Ictg)
integer Ictg()

for Irr = Ir1, Ir2
    write to map matrix (Ictg(i), i = 1, Nc)
return
finish
```

4.3.4 Consideration of line features and some special cases

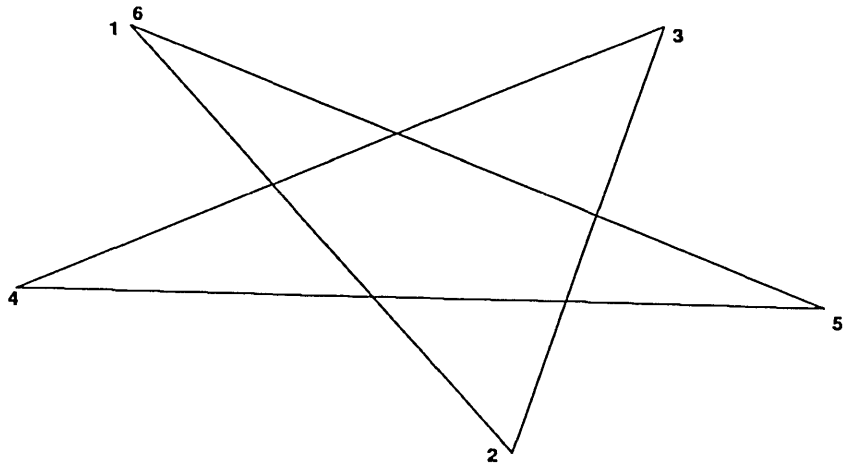
Polygons whose edges cross (refer to Figure 4.10(a)), need not to be considered in the application under consideration. However, such a polygon also may be filled by splitting it into a number of polygons (Figure (4.10(b)), or by considering its outer edges (refer Figure 4.10(c)).

A polygon enclosing holes or islands, is split up into more than one polygon, as shown in Figure 4.9(a) & (b) with different line types; polygon 3 and 4. These two polygons have two different colour values. Polygon 4 is in fact, a hole with the background colour, and hence, has been assigned a colour value of 0.

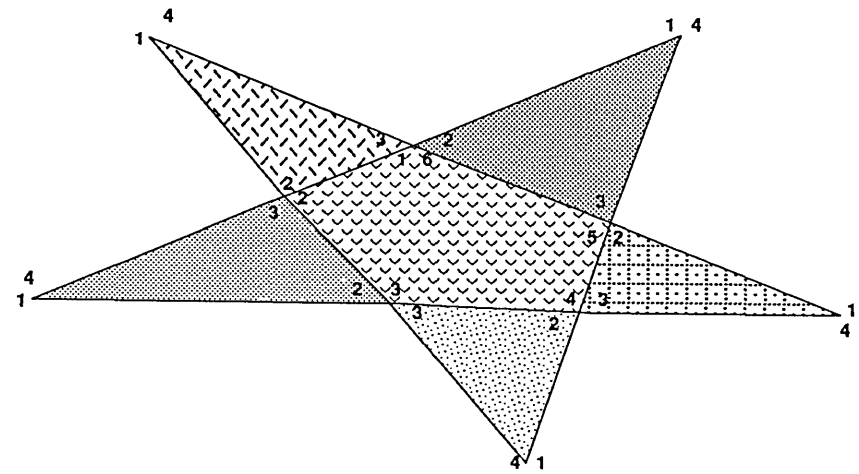
The vector-to-raster conversion of the polygons is an important preparatory procedure in raster map manipulation. The linear features must also be considered for map processing. Cells are generated between two discontinuous cells of a line feature. This task is performed in the subroutine DSCNTFL. However, for a linear feature, no duplicate cell needs to be generated. Isolated lines are identified by employing a unique cell value (here, it is -9999.0) in the last cell (point) of a line. Line features are clipped in the map frame, cells outside the window are discarded; refer to Figure 4.11.

4.3.5 Some important aspects of the algorithm

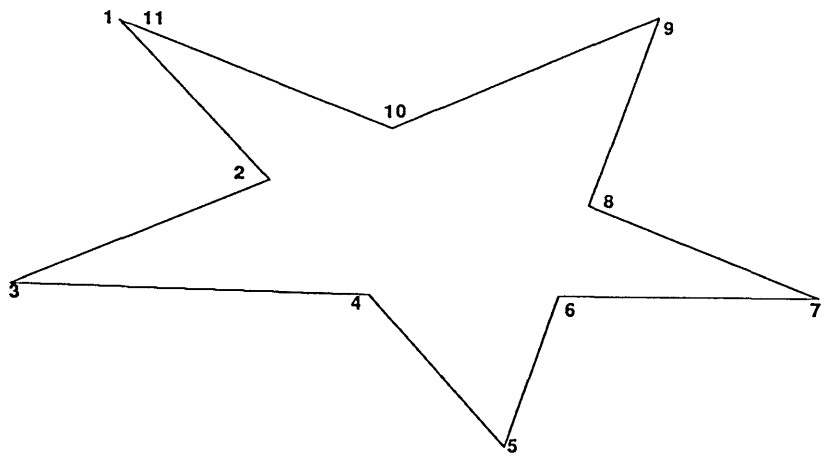
By restricting the scanning in the smallest rectangle containing the feature, and by scanning and filling one row at a time, significant reductions in the processing time are achieved. Another important aspect of this algorithm is that it clips the map feature in the map window. This is an essential, requirement, especially for using digitised maps from different sources with different reference grids.



(a) The polygon with edges crossing each other.

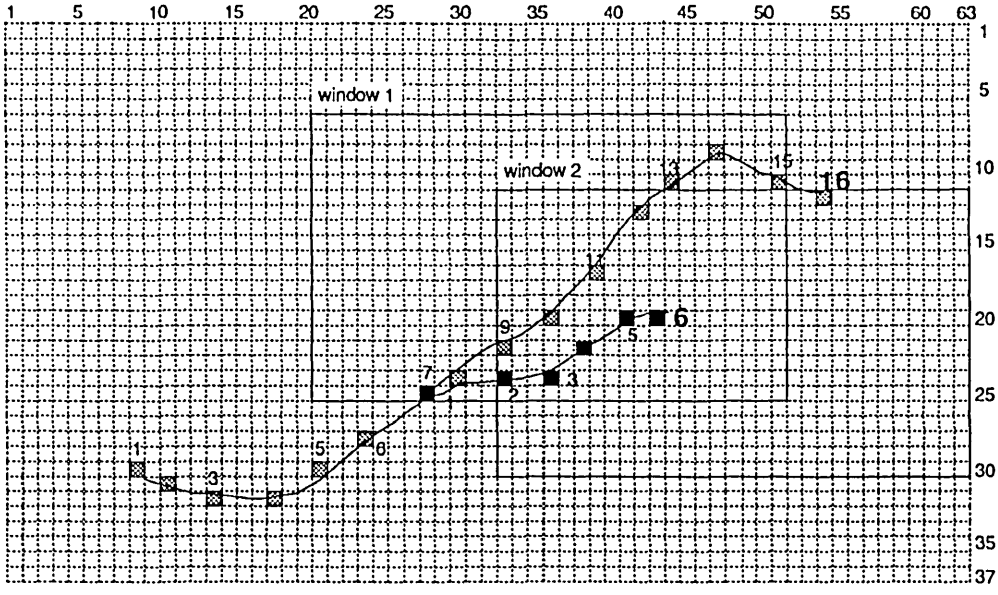


(b) Splitting the polygon in (a) into several polygons

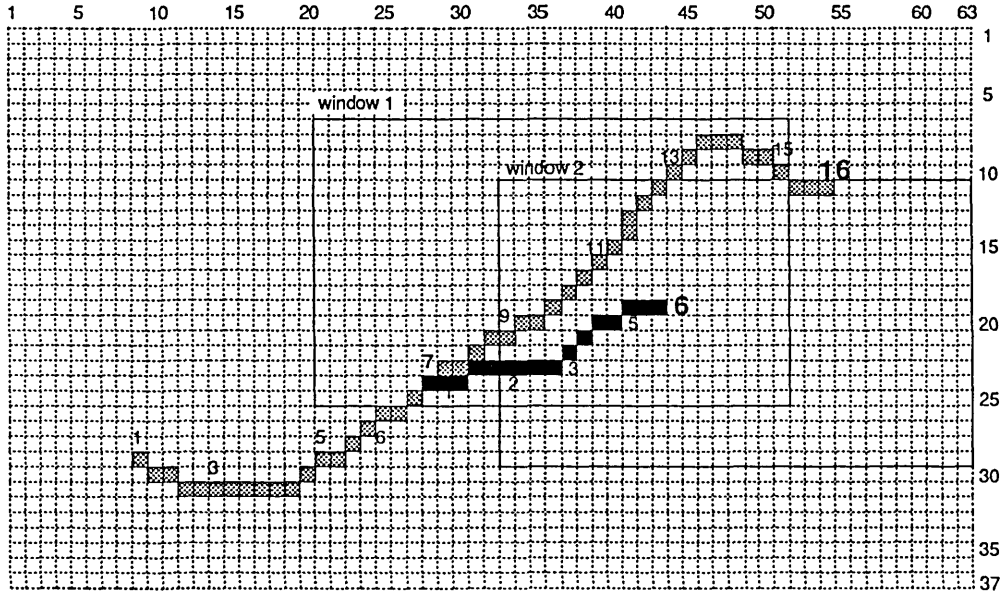


(c) Outer edges of the polygon(s) in (a) are considered.

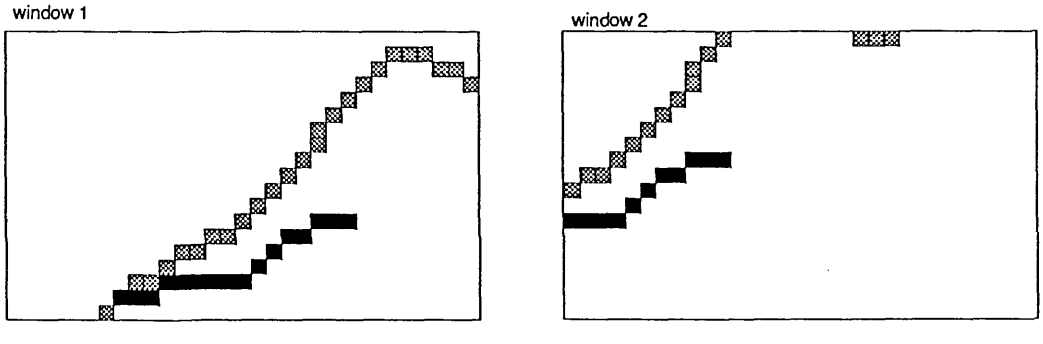
Figure 4.10 Considering polygon with crossing edges



(a) Cells representing the digitised points or field survey points

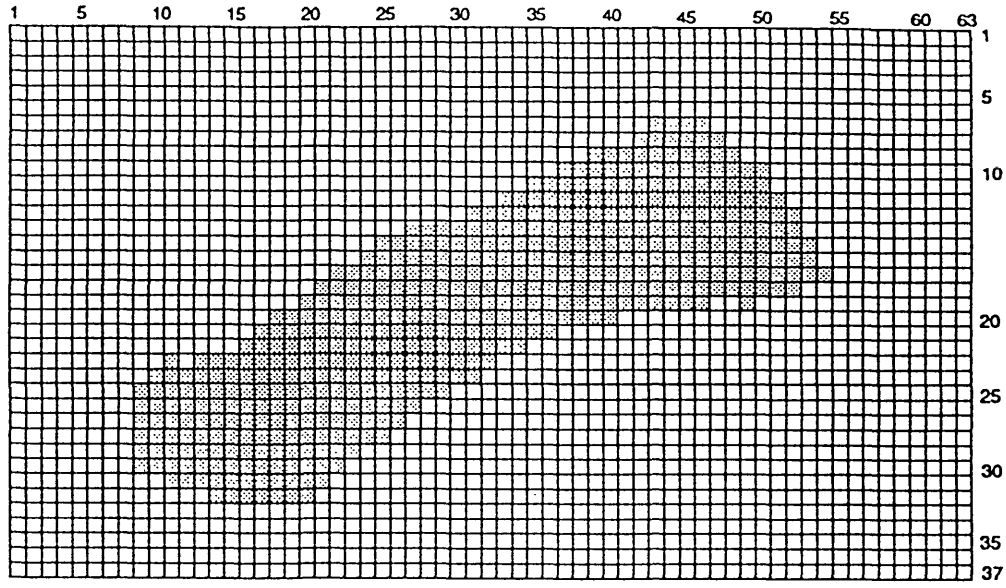


(b) Cells are generated between the discontinuous points

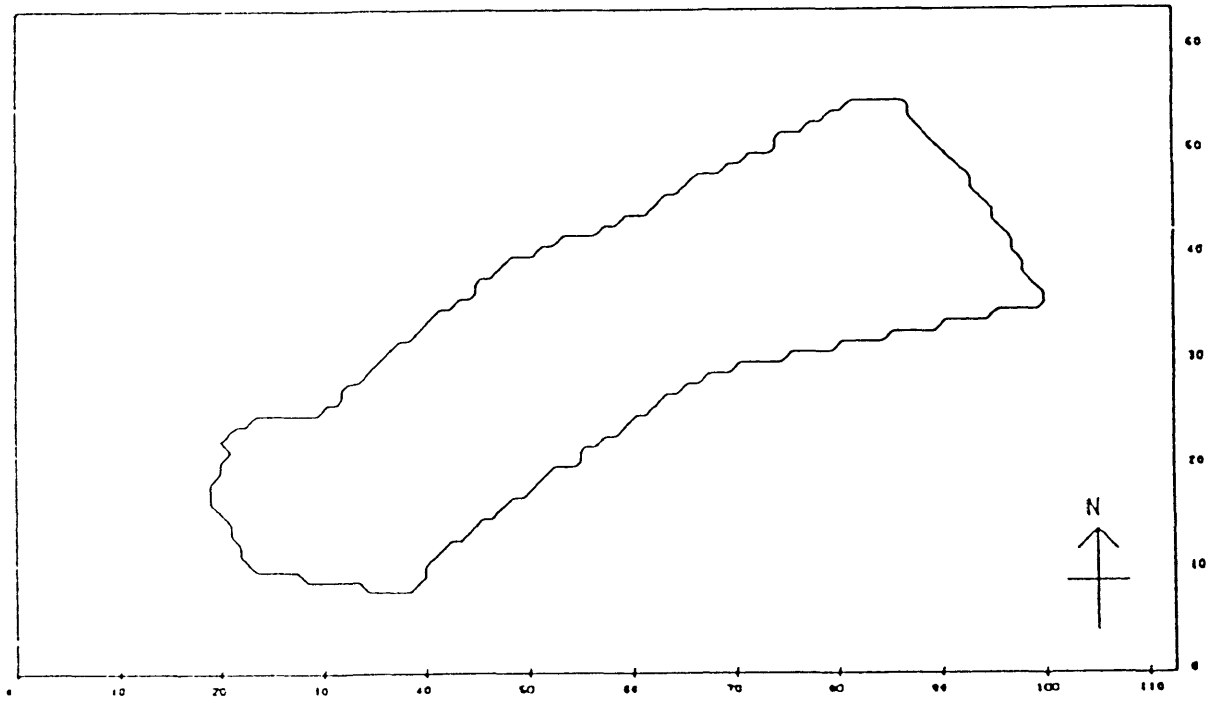


(c) Line features clipped in the map windows

Figure 4.11



(a) A grid cell map of the feature, pit limit in a 37 rows X 63 columns raster space.



(b) The vector plot generated by outlining the grid cell map of pit limit in 64 rows X 112 columns grid space.

Figure 4.12

For direct visual inspection, a map of the pit limit (Figure 4.1(b)) drawn simply by connecting the digitised points, may be compared with the map of the pit limit drawn (in low resolution) by outlining the boundary of the filled polygon (refer to Figure 4.12). High resolution plots of the same feature appear in various plates in Chapter 6.

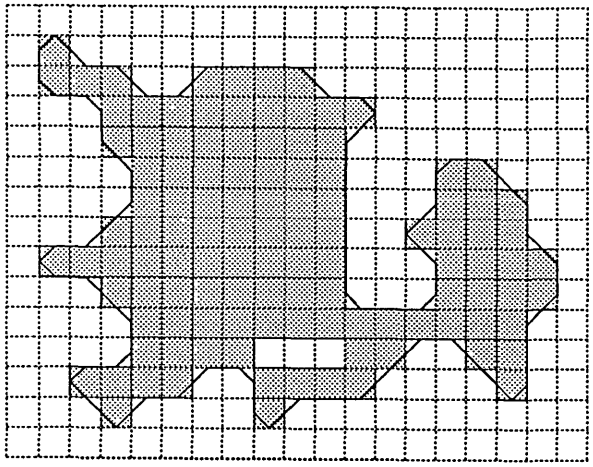
4.4 RASTER-TO-VECTOR CONVERSION ALGORITHM

The raster-to-vector conversion algorithm of Withcombe (1982) was modified. This algorithm outlines all the different categories (colours) and smoothens the cell corners with diagonal lines (Figure 4.13(a)). The basic logic of the conversion technique is illustrated in Figure 4.13(d). The procedure involves scanning of a raster (grid cell) map column by column; for each grid cell the algorithm examines five neighbouring cells, N, S, E, NE, and SE (refer to Figure 4.13(c)), and draws edge, half of edge or a diagonal at the cell corner. In the next step, the other three neighbouring cells, NW, W, and SW are examined and the appropriate vector is drawn. If all the neighbouring cells have the same colour value as the cell under consideration, no vector is drawn. When some of the neighbouring cells are of the same colour value, in some cases no vector is drawn (refer Figure 4.13(d) no. 5). Special consideration is given to cells of the first row, the last row, and the first and last columns in all rows (Figure 4.13(d) no. 9, 10, 14, 15).

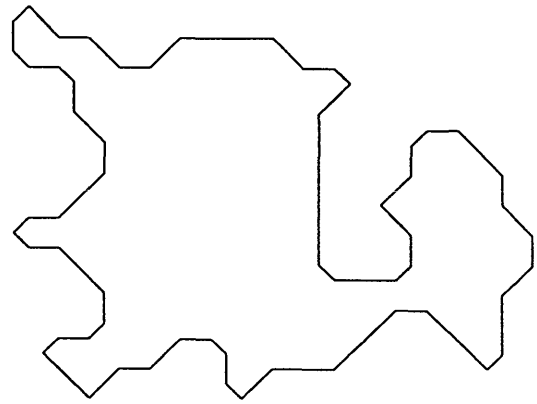
In the implementation of Withcombe's algorithm, the map matrix is scanned column by column, and gives a display of a map with the geographic east oriented towards the top of the screen. The algorithm was therefore modified so that a map may be displayed with a cartographic standard display of north conventionally oriented towards the top of the display; in the modified algorithm, scanning for raster-to-vector conversion is carried out in a row by row order.

4.5 DEVELOPMENT OF THE MAPBASE STRUCTURE

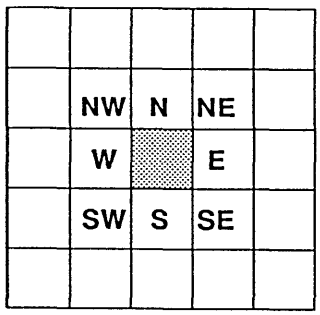
The concept of the quadtree has been used to build the structure of the mapbase. The conventional linear quadtree encodes whether a feature exists (1) or not (0) at a given location, and as such is not suitable for grey-scale features. The G-quadtree (Kunii, 1986) offers a solution to this problem. However, due to the following practical difficulties none of these techniques could be used:



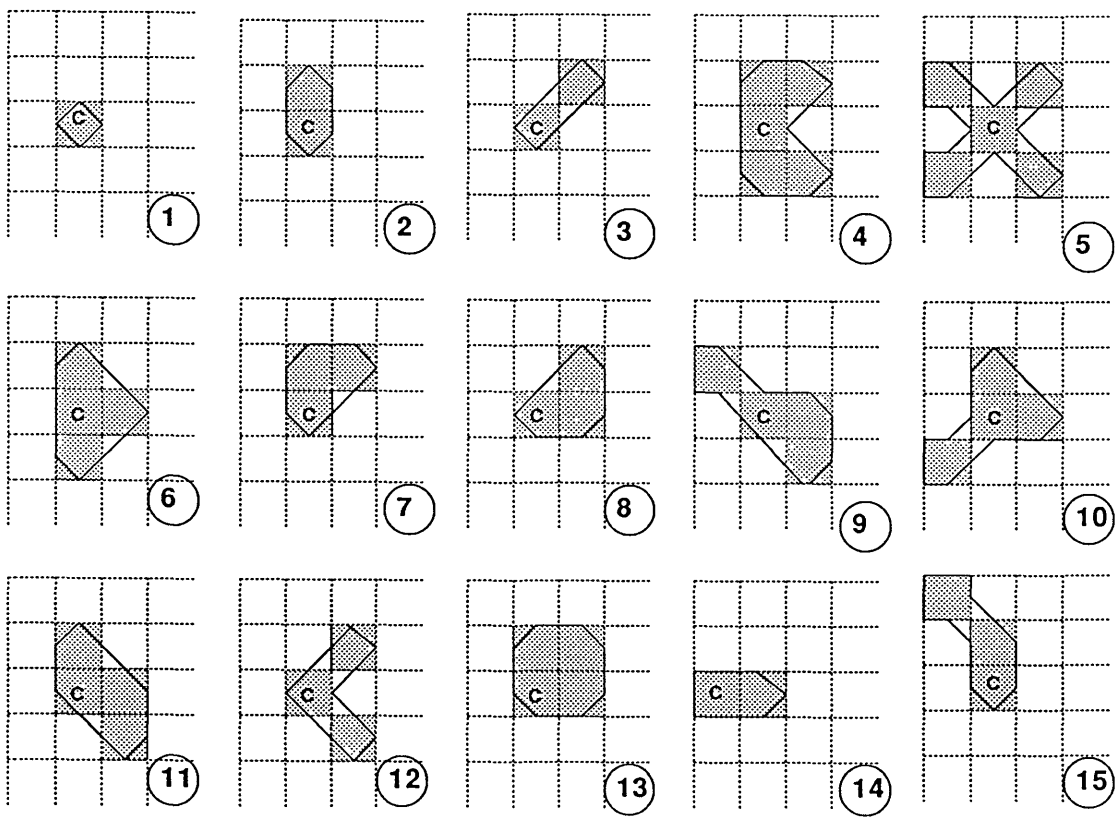
(a) Raster to vector conversion.



(b) Vector map converted from the grid cell map.

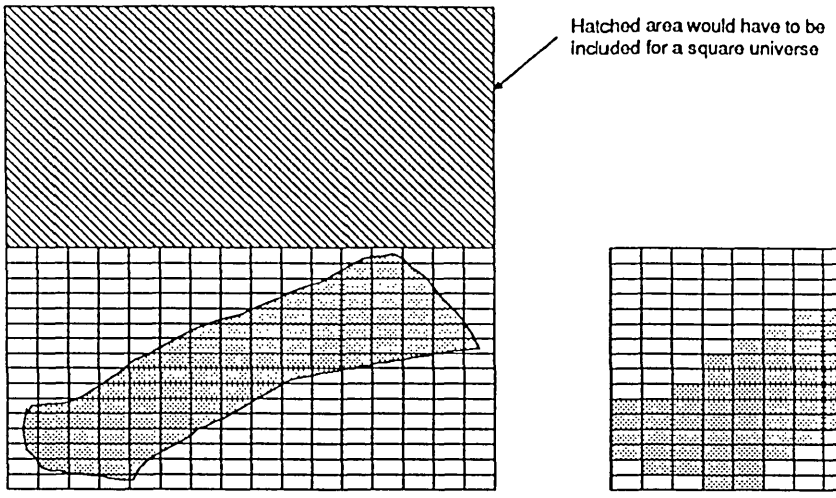


(c) Indexing the neighbouring cells



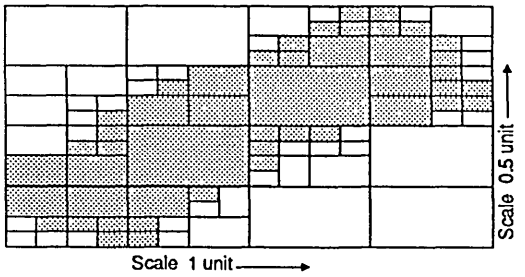
(d) Instances of raster to vector conversion depending on the neighbouring cells; 'C' is the cell under consideration.

Figure 4.13 Raster to vector conversion; the basic technique.

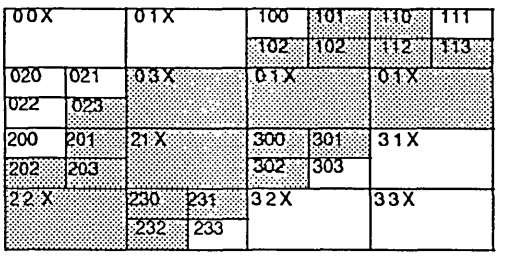


(a) Map feature in geographic space.

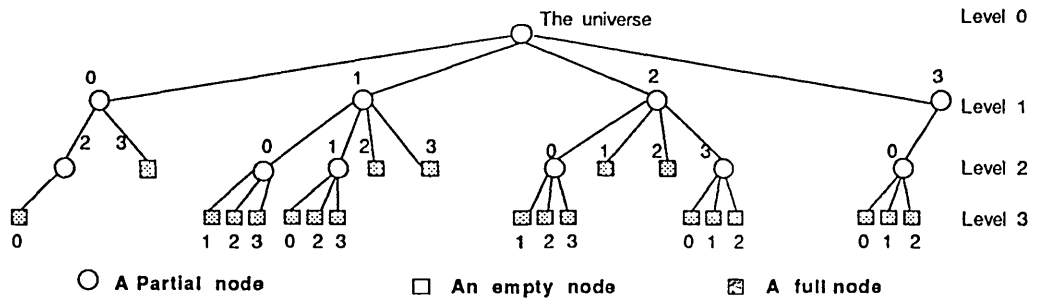
(b) Map area converted into rectangular grid cells (raster).



(c) quadrant decomposition (down to level 4).



(d) indexing of the quadrants (down to level 3).



(e) Quadtree representation of the blocks in (c) & (d).

{ 023 03X 101 101 103 110 112 113 12X 13X 201 202 203 21X 22X 230 231 232 300 301 302 }

(f) A simple quadtree encoding for the decomposed octants in (c) & (d).

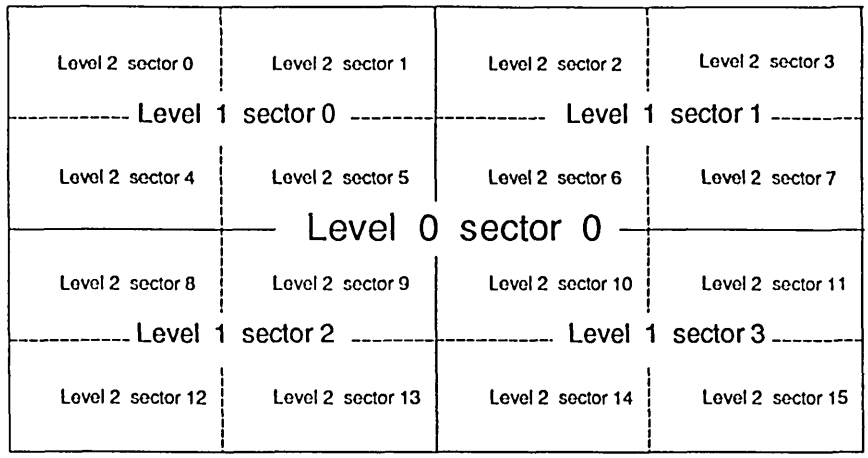
Figure 4.14 If the quadrants were rectangular in a quadtree

1. In a quadtree, a square area (the universe) is considered; in such a case unnecessary display and processing may be used for a large proportion of land areas which may not be of any interest (refer to the hatched area in Figure 4.14(a)). If a rectangular universe is considered (Figure 4.14(b)), the scale factors used must be different in east and north directions. Quadtree encoding with a rectangular universe further complicates the representation of geographic features, especially when the displaying and retrieving of information is involved, referring to screen co-ordinates equating to the geographic scale.

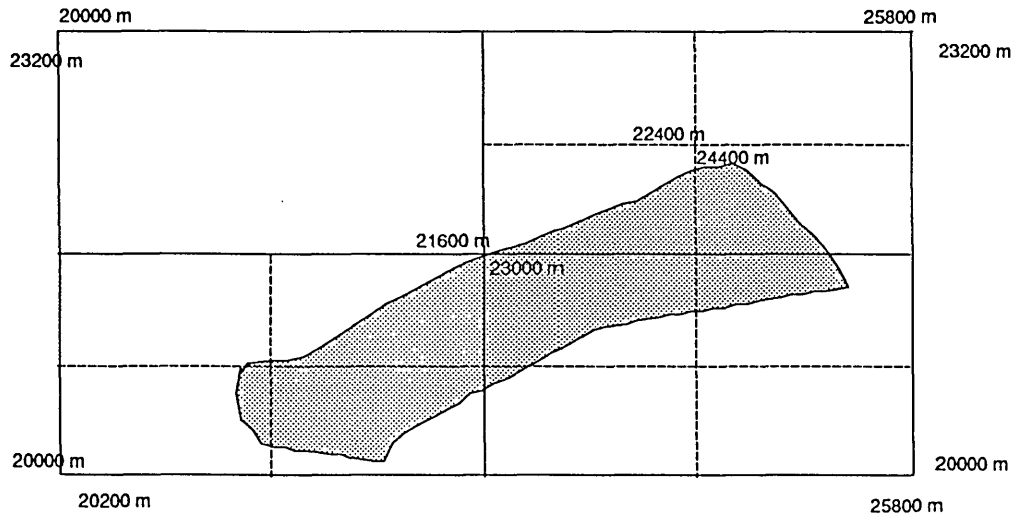
2. Map manipulation is carried out using the relevant maps in raster form. Some of these operations are complicated and sometimes impossible to perform with quadtree representations. These problem can be solved by decoding and coding quadtree to and from map matrix representations. However, these claim a considerable amount of computing time.

3. It is not possible to represent a map of any flexible scale with a quadtree structure. The nature of the quadtree structure requires that an area upon decomposition is recursively divided into 4 quadrants, the scale factor being halved each time. However, there is a requirement to meet a special need and to provide maps with a particular scale for comparison with an existing map.

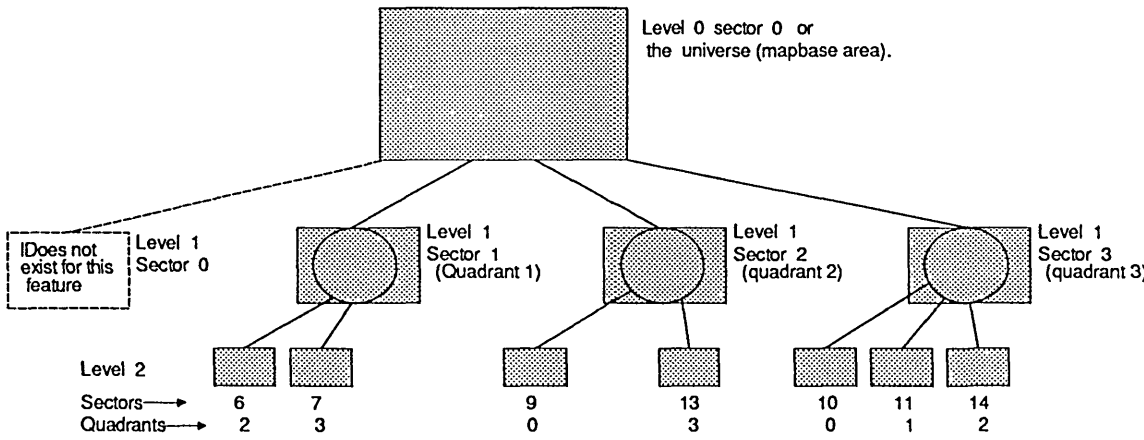
Under these circumstances, a modified approach was adopted which uses a quadtree concept where each sector is a partial or terminal node. In the case of the map PITSURF (Figure 4.15), at Level 1, Sectors 1, 2 and 3 are partial node whereas Sector 0 is a terminal node (an empty leaf since no part of the feature lies in this sector). Each terminal node points to four sectors at next level of resolution. However, at each terminal node there exists a 'duplicate' node, a full terminal node to store the raster map of that sector at that level. This raster map however may be compacted by using run encoding technique. Figure 4.15(a) illustrates the sector arrangement in a quadtree structure. Level 0 is divided into 4 sectors at Level 1, each of these four sectors is further divided into 4 at Level 2. Each of the sectors references a sub-mapbase. No part of the feature in Figure 4.15(a) lies in Sector 0 at Level 1 (Figure 4.15(c)), and so no information is stored in Sector 0 at Level 1 for the this particular feature. At any



(a) The hierarchical level and sector arrangement and indexing of the sectors.

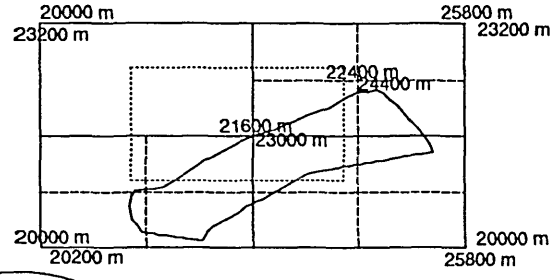


(b) The different levels and sectors, area filled map of the feature pit limit, and the northings and eastings of the map origins for diffferent sectors at different levels.



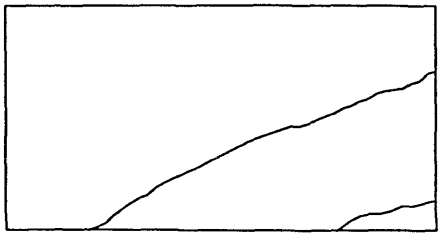
(c) The quadtree representation of the sectors at different levels for the map PITSURF Each of sector 1, sector 2, sector 3 at level 1 has a full terminal node and a partial node.

Figure 4.15 Hierarchical level and sector arrangement in a quadtree structure



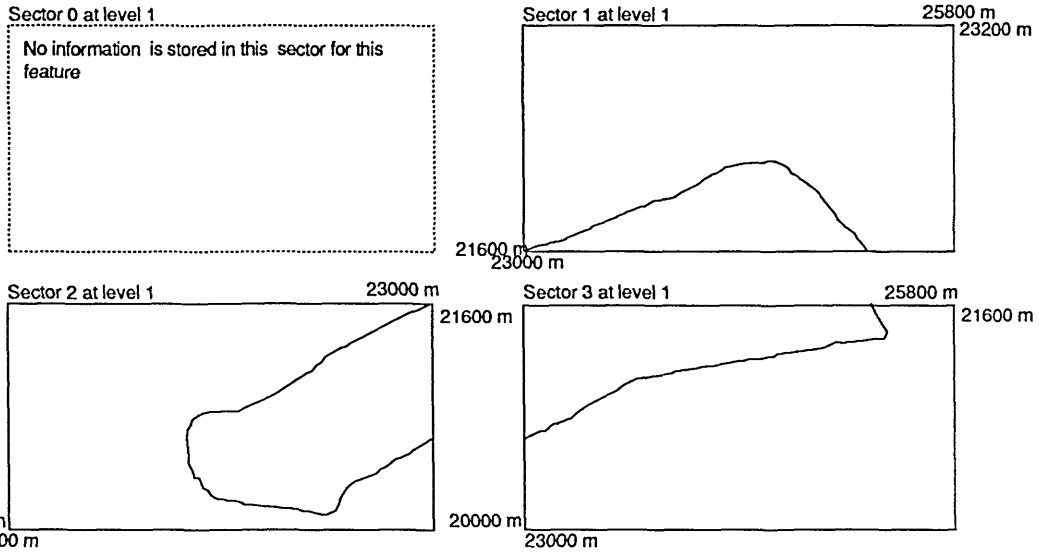
Level 0

(a) Map of pit limit at level 0.



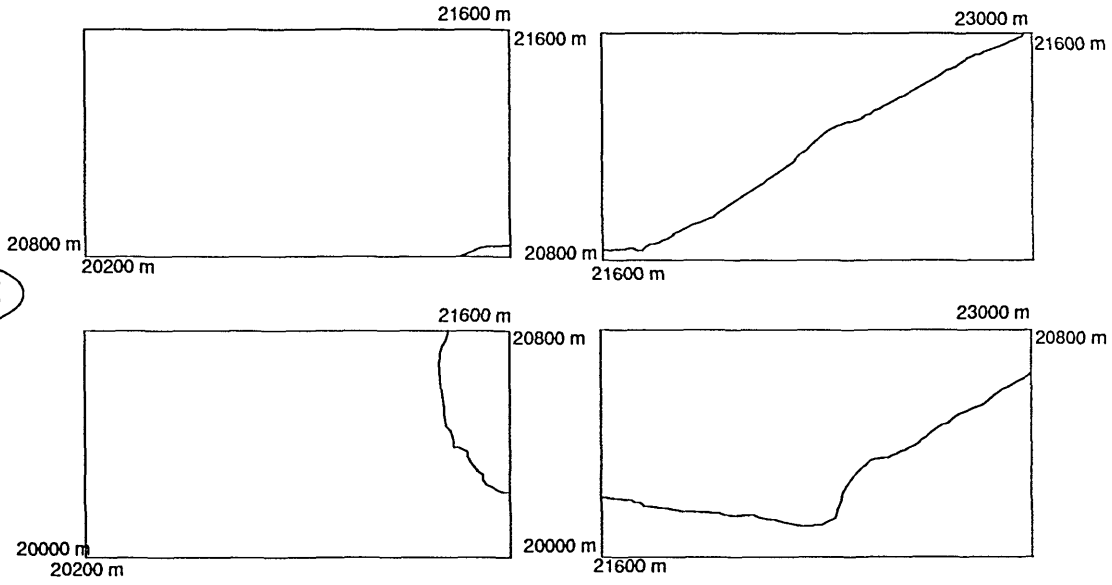
(b) The window area in (a), of pit limit map at level 1.

Level 1



(c) The maps of pit limit in sector 1, 2 and 3 at level 1.

Level 2



(d) Sector 2 at level 1 further divided into 4 quardants.

Figure 4.16

time, it is possible to work in a sub-mapbase of any sector at any level. For an area covering parts of four sectors, a map can be generated by creating a window at that level. Figure 4.16(a) shows a map at Level 0, whereas Figure 4.16(c) shows the fractions of the map in four sectors at Level 1. Figure 4.16(d) shows that the Sector 2 at Level 1 is further decomposed into four quadrants at Level 2. Figure 4.16(b) shows one part of the map at level 0 in a window at Level 1, and covering Sectors 0, 1, 2, and 3. The rectangular box (dotted) superimposed on the map feature in Figure 4.16(a), shows the area which has been displayed in Figure 4.16(b). (The surface area of the mining project, represented in the example at level 0, is 3.2 km $\times$ 5.6 km). Data structure for data entities and relations for map is discussed in Section 5.4.2.

4.6 THE GRAPHICS INTERFACE

Initially, a CALCOMP standard plotting library was used for graphics output and interactive information retrieval. Graphics menus were developed in addition to a query language and text menu. Graphics menus and sub-menus, in addition to the options for plotting different components of a cartographic standard map, such as the title block, the north point, reference grid lines were added. When the map generation is complete, menus are automatically deleted from the screen. The plates used in the Thesis, are generated on a Mitsubishi G650 thermal wax transfer printer. Some plates were generated with the graphics menu at the bottom, with the purpose of demonstrating some of the options.

4.7 THE SPATIAL INFORMATION RETRIEVAL INTERFACE

Maps are plotted mainly in vector form. But the underlying raster form provides a powerful mechanism for the retrieval of numerical or textual information associated with a particular location. The screen co-ordinate captured by the cursor, converted into northing (row) and easting (column) of any geographic location, can be used as the index for storing and retrieving relevant information; annotations are managed in this manner. A text string, its display colour index, and the alignment angle are stored and retrieved through the row and column number (ie. the northing and easting of the text location in geographic space). A generalised algorithm has been developed for this technique, and can be extended

to different information retrieval subsystems, such as equipment management or locational enquiry.

4.8 THE INFORMATION SYSTEM STUDY

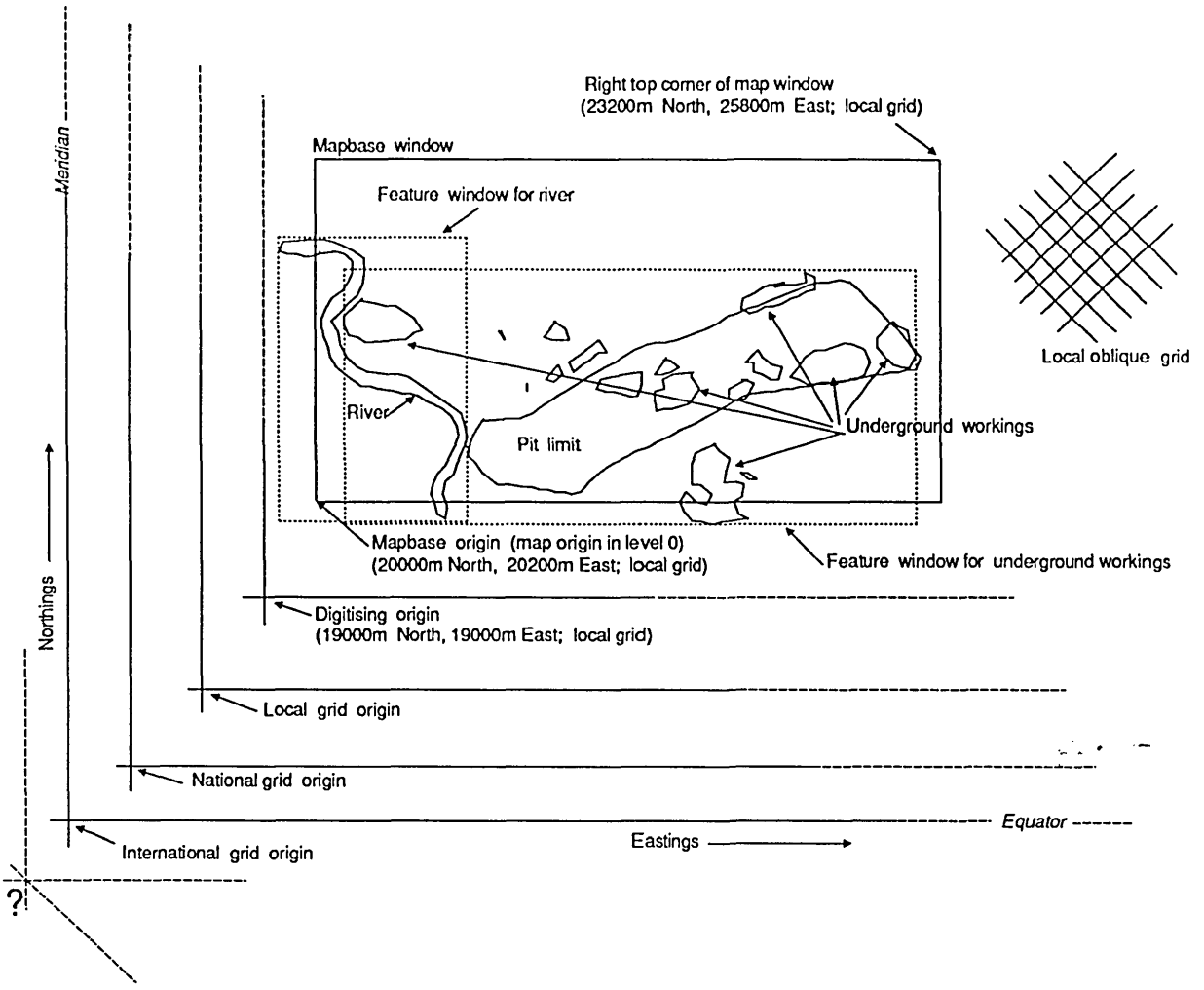
4.8.1 I/S study summary

An Information System Study was carried out at the BLOCK–II open Cast project (Block–II OCP), Bharat Coking Coal Limited, Coal India Limited (CIL). The mine situated in the Jharia coalfield in India, is at its initial stage of development; the World Bank has funded the project partially. This is a large open pit project, designed to produce 2.5 million tonnes of coking coal per year with a combination of shovel, dumper and dragline. The mine will be opened for a second phase, for mining non-coking coal. A brief description of the project is given in Appendix 4A.

To start the I/S study, the top management was contacted, as arranged through earlier correspondence, and the proposed plan of action was outlined and revised following a discussion. The implementation of the package calls for a time-consuming, detailed I/S study at all the levels of management. The prime objective of the I/S study was to collect some of the typical mine maps, and related information. However, a study was conducted to understand the overall information flow within the organisation and to outside bodies, at four different sites of the two sister organisations involved; the Central Mine Planning and Design Institute Limited (CMPDIL), and the Bharat Coking Coal Limited (BCCL). The four sites are CMPDIL Head Quarters (Ranchi), CMPDIL Regional Office (Dhanbad), BCCL Head Quarters (Dhanbad), and Block–II OCP (Jharia). A summary of the principal queries and the findings is given below:

1. What types of maps are mostly required?

   Plans of different combination of surface features, pit boundary, bench layout, geology, other maps typically used in mining, and sections were assembled. Expectation of maps of visibility, blasting vibration assessment, and waste rock dumping were observed. Land area to be covered in the mapbase window was established after discussions with various managers. Figure 4.17 illustrates the established mapbase window, the digitising origin etc.



Digitising origin : The left bottom corner of the rectangular area beyond which no map has been digitised. The northing or easting of the mapbase origin will be smaller than the northing or easting of any map feature in the map base. In the example mapbase, the northing and easting are 19000m and 19000 m respectively with reference to the local grid.

Mapbast origin : The left bottom corner of the project area ie. the area to under consideration for information management In the example mapbase, The northing and easting are 20000m and 20200m respectively with reference to the local grid.

Map origin : The left bottom corner of the map area under consideration. In level 0, the map origin for maps usually are the mapbase origin. In other levels, they will be usually different.

Local grid origin : A point which is used as the reference origin for local mapping. Sometime a local grid system is designed which is oblique to the national or international reference grid. (In author's opinion, this is a bad practice, because the correlation becomes very complicated, and may reduce accuracy).

National grid origin : A point which is used as the national grid reference. This will be required, when the mapbase and related information is to be integrated into the national information system, such as national mineral inventory.

International grid origin : The point where the meridian and the equator intersect each other near Greenwich. This is of not much of interest in the scope of mineral mapping. Beyond mine mapping, if may be relevant, such as integration of international digital ordnance maps.

Figure 4.17 The concept of different reference grid origins and windows for correlation of map

2. How maps are to be displayed, plotted; size?

   Maps used are usually 1 m × 1.2 m in size which is a convention rather than a requirement. Small maps in quality print are acceptable for 'table top' discussions. It was acknowledged that some maps need not to be plotted and that a screen display would be of help, especially those used for trials.

3. The accuracy required?

   Data accuracy is maintained at 1:15000. ± m accuracy is widely accepted. Maps with scale factor of 1:4000 are usual, and one point on a map sheet usually represents 1m on land.

4. The display resolution desired?

   No preference was expressed concerning display resolution.

5. The level of expertise available to utilise a mapping package?

   Computer skilled personnel are not available, except in a few positions.

6. The availability of computer system?

   An ICIL (Indian ICL) 8 MB mini computer and an IDM (IBM AT compatible). However, it was learnt that in future other systems would be available, including a VAX supermini computer.

7. The investment available for a mapping and I/S package?

   There is no specific information available. It appears, that the investment on computerisation will increase considerably in response to government policy.

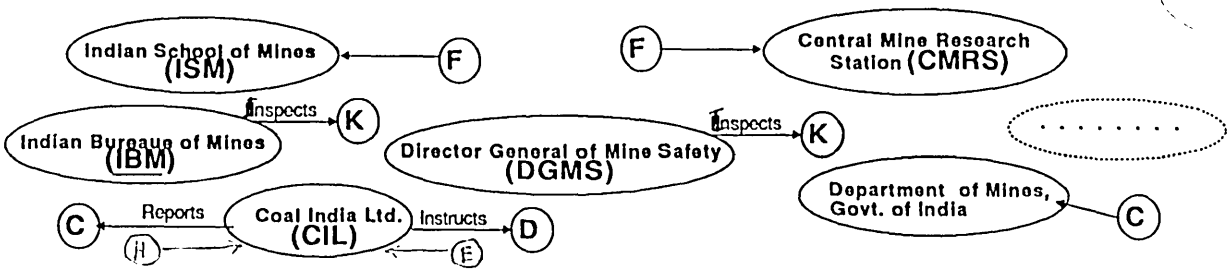
8. The information expected to be managed through map(s)?

   Equipment position, locational enquiry, borehole log, area and volume calculation and coal inventory.

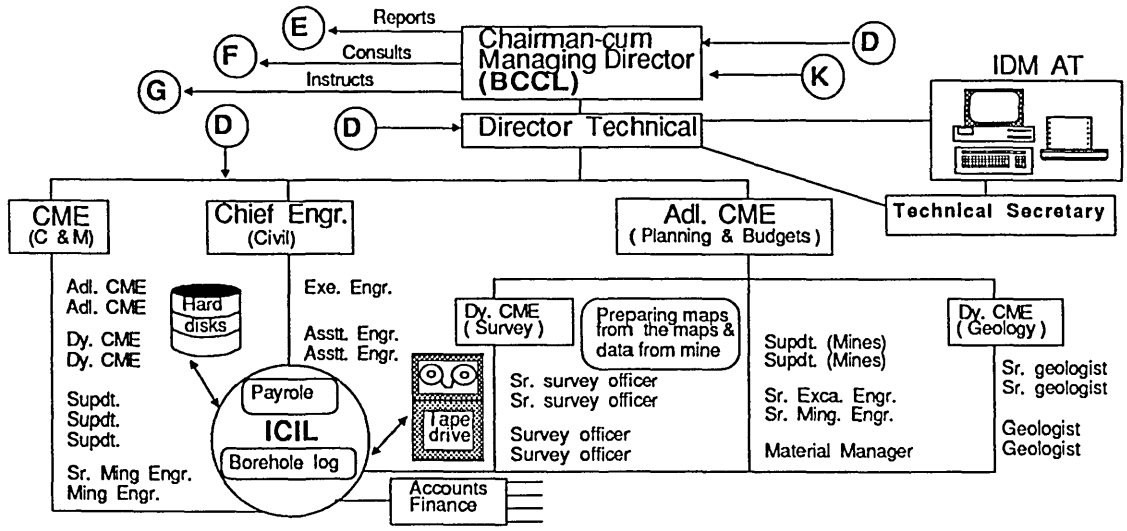
9. The overall practice in information flow?

   Figure 4.18 shows the overall management set up, and its co-ordination with sister organisations and governmental regulating authorities.

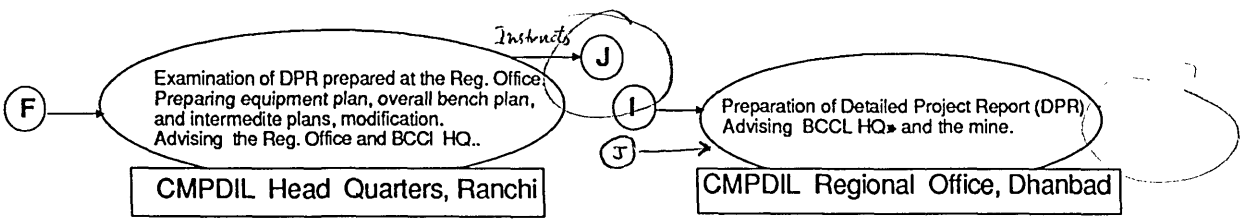
10. The availability of digital communication among the organisations?



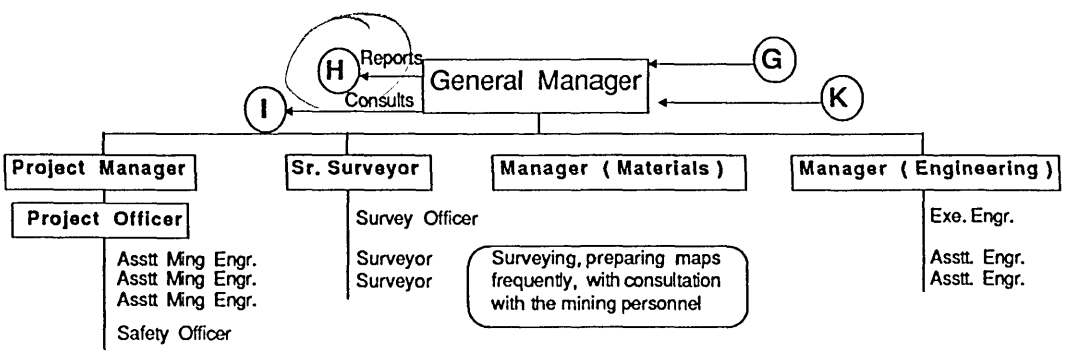
(a) CIL, and various reporting and consulting government organisation for CIL, BCCL, and the mine.



(b) The management structure at the head quarters of Bharat Coking Coal Ltd. (BCCL), a subsidiary of Coal India Ltd.



(c) Coal Mine Planning and Design Institute Ltd. (CMPDIL), a subsidiary of Coal India Ltd.



(d) Management structure at BLOCK II Open Pit Project

Figure 4.18

A Local Area Network (LAN) is already available at the BCCL Head Quarters. In present circumstances, the Block–II OCP may be connected to the BCCL Head Quarters through the telecommunication lines. However, on materialisation of the Jharia Coal Field Reconstruction Scheme (JCFRS) it may be possible to have extensive wiring to include Block–II OCP in the LAN for faster digital communication. For communication among the computers at BCCL, CMPDIL, CIL, and IBM may be obtained soon through several WAN such as COALNET and INDONET. COALNET is installed for transaction within CIL and the concerned government departments; it uses a dedicated channel in Landsat (a communication satellite). SAILNET, another dedicated WAN for Steel Authority of India limited is available to CIL for coordination of coking coal supply to the steel plants.

11. Miscellaneous

Site specific constants for blast vibration study was collected from author's earlier work (Samaddar, 1983). This work was carried out in a different mine where the rock type is of a similar nature and formation. The same site-specific constant may be used for the demonstration of blasting vibration assessment; the constant may be evaluated at specific sites.

4.8.2 Information compilation

The specific input from the field study peculiar to the mine were not used to dictate the modifications to the package, since general applicability to mine planning was a stipulated objective in prototype development. However, the basic concepts and the expectations of the mining personnel have been used to modify the package. The basic data structure, mapbase concept, graphics interface, information retrieval interface, and the overall concepts of the system integration have been developed in accordance with this principles of surface mining as infered from the field study. The maps, sections and related information have been used to build up the example mapbase which is described in Chapter 6.

4.9 MODIFICATION OF THE PACKAGE

Initially the software was developed on a **Cyber 170/855** mainframe. It allowed a maximum of 131 kwords (64 bit) of memory. In addition to the program space and other variables, two duplicate integer arrays (dimensioned according to the number of cells in a map) represented the raster form of each map, demanded most of the central memory requirement. Array size was therefore a critical limitation in the early stage of program development. It was found that a matrix of maximum of a 64 rows × 112 columns could be used with a suitable integer scale factor which could be halved repeatedly into integers for obtaining convenient integer scale factor down to certain level. To cover an area of approximately 3 km × 5 km, the scale factor was 48 m per grid cell which obviously did not provide an acceptable level of accuracy for mine planning.

Higher resolution display called for a map matrix of greater size. The Cyber 170/855 did not provide adequate memory for this purpose. Moreover, the number of map levels, the accuracy required for mine planning, the number of files associated with all sectors in several levels proved prohibitive with the static memory of the Cyber mainframe.

A virtual memory environment is required for computer applications involving map matrices and raster processing. A **DEC VAX 8600** machine was installed at the College Computer Centre in 1986. The software was installed on this machine for further modification and extention. The map matrix was configured as a 400 row × 700 column arrangement as the most appropriate compromise between the display quality, processing time and the suitable resolution for available display screen. The display resolution or visual resolution is not improved beyond the capabilities of the display screen. (Two pixels are required for drawing a vector and the graphics terminal used, a **SIGMEX 6165**, has a screen resolution of 1248 × 1440).

The run-encoding interface of the package was removed at this stage and the maps were stored in a full raster form storing all the elements of the map matrix. However, this was not a modification but rather a temporary expedient. This was done because, the run-encoded maps were stored in the 'map-file' as a sequential file. As a result, the 'map-file' had to be read sequentially making the input very slow, especially when the 'map-record' was at the end of the file. The

performance of the prototype was degraded further when a modified map was stored; it was necessary to rewrite the whole file resulting a large I/O overhead. In such a condition, one measure to improve I/O is to break up the map file into several files each representing a map. Such a procedure creates many files, specially when several levels of resolution exist. Eventually, all the maps were kept in a single file; a FORTRAN direct access file. For a direct access file, all the records need to be of same length. To comply with this, all the maps were stored in simple raster form. That obviously required more storage space. To save storage space, 1 byte integers (BYTEs available on VAX) were used. A 1 byte integer can store a number in the range of -2^{8-1} (ie -128) to $+2^{8-1}$ - 1 (ie $+127$), i.e. 256 unsigned numbers. It was found to be inadequate at some stage for storing elevation, mineral grade represented by integer. So, 2 byte integers were used to store cell values in a higher range. A 2 byte integer offers to store a number in the range of -2^{16-1} (ie -32768) to $+2^{16-1} - 1$ (ie $+32767$), or a total of 65536 unsigned numbers.

Chapter 5

SYSTEM DESCRIPTION

Chapter 5

SYSTEM DESCRIPTION

5.1 INTRODUCTION

After the information system study had been carried out, and maps collected, the System was tested and further modified. An enhanced user interface with mining oriented features, was developed to provide a working prototype which can be implemented to assist day-to-day mine mapping and information management. The prototype **DIRECT-1 (Dynamic Information REtrieval and Cartographic Tools, version 1)** represents an automated mapping package and spatial information system.

5.2 THE OVERALL SYSTEM CONCEPT

The overall hardware-software concept of the system is illustrated in Figure 5.1. Data can be entered from the keyboard, read from a data recorder or a tape, or digitised from existing plans; most digitisers provide software for recording data into a computer file. In addition, the system provides its own digitising option. Commands may be entered from the keyboard or read from a command file and of course through interactive pointer devices such as a mouse, a puck or a light pen. Graphics output may be directed to various devices, including a pen plotter (using an appropriate device driver), 'screen-dump plotter' (for example, a thermal wax transfer plotter) and metafiles. Textual outputs may be directed to output files and/or the screen.

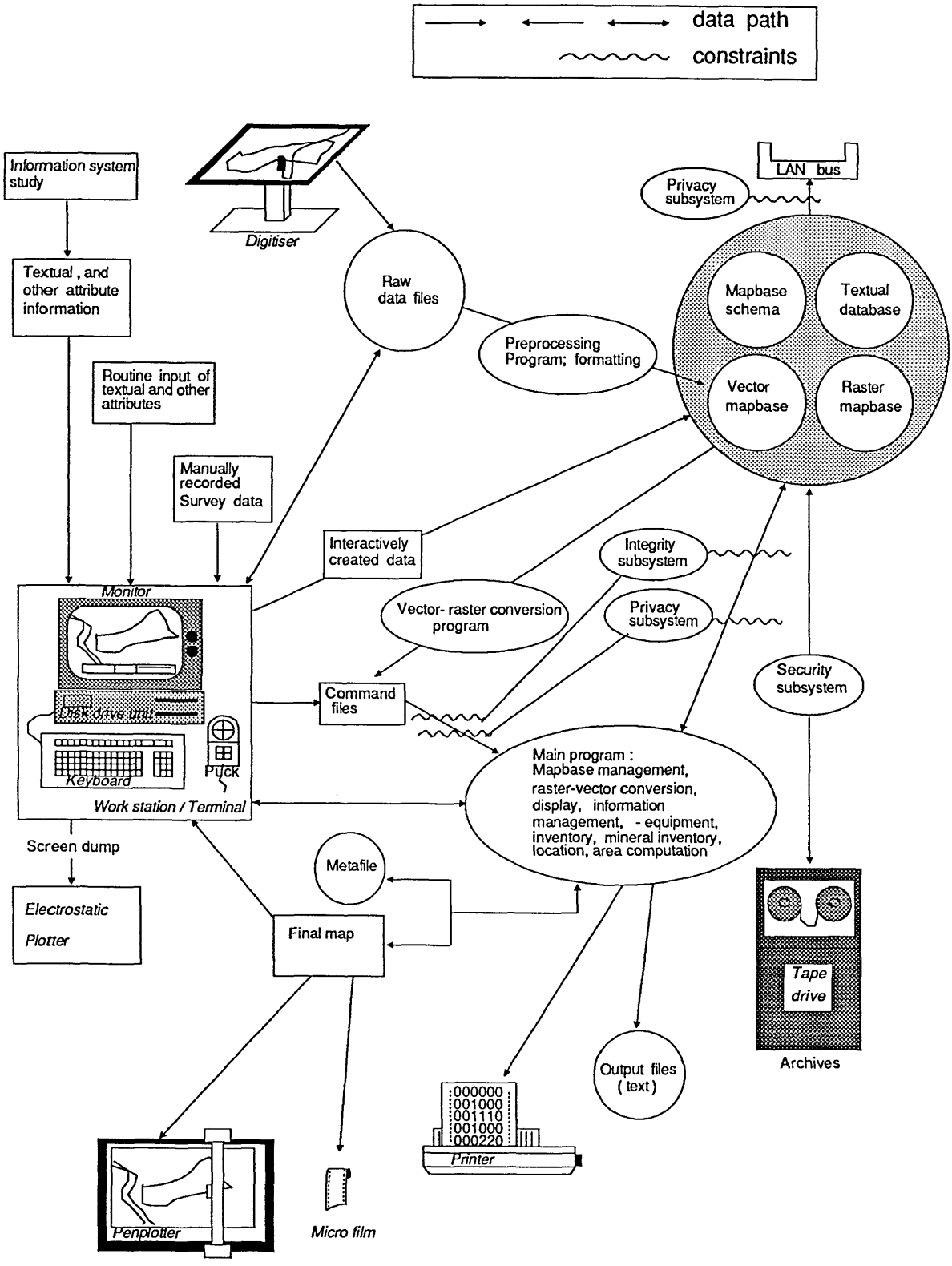


Figure 5.1 The overall hardware - software system concept of DIRECT-1

5.3 FUNCTIONAL COMPONENTS OF THE SYSTEM

The system performs six principal functions;

5.3.1 Data Capture/collection

Various input data can be handled, which is grouped into four types:

* *digitised data;*
* *survey data from field measurements;*
* *textual data;*
* *inferred data generated during interactive use or planning.*

Standard digitised data from any source may be used. The package itself offers a digitising facility as one of the number of graphics I/O options. Data in user's specified formats can be used, in the creation of a mapbase from archives of vector outlines. Data from field survey and interactive draughting also may be used. Textual data may be entered from the keyboard or read from files.

5.3.2 Processing of raw data

Raw data are read from files and reformatted for storing in the vector database, in an internal standard format. Data sets may be read from files in a wide range of formats. The text preamble at the beginning of a reformatted data file in the vector database refers to the information regarding the digitised data or survey data, such as, date of digitising, subject, type of feature (polygon, line, or point), reference grid and any other remarks. This is important for 'transportability' and integrity of data. One such comment set is given in Appendix 5A.

5.3.3 Conversion from vector maps to raster maps

Conversion of the vector maps to raster images is an important feature of the system. If a feature is linear such as, a power line or narrow roads, then the cells representing the line will be linked with continuous cells, by generating intermediate cells each assigned an appropriate category value. A category value is a value associated with each digitised point, referring to the feature's attribute such as colour index, or other thematic parameter. If the map feature is a polygon or a combination of polygons, then the polygons will be filled and stored as

a raster map i.e. a map matrix, and will be written to a file for the next step of entering the map into the mapbase.

5.3.4 Map processing and mapbase management

The main component of the package consists of a relational database system for storage and retrieval of maps and their status, scale, category values and other attributes. This sub-system also processes the raster maps using various matrix operations.

5.3.5 Raster mapping and restoration of vector outline

The fifth component provides the graphics interface and interrogation mechanism : raster mapping, conversion of a raster map to a vector form for display or plotting, the generation of maps, and interactive draughting.

When maps are vector plotted in magnified size (1 m), some features appear 'staircases'. This may be avoided by using a sophisticated device driver with antialiasing capability. This satisfies the aesthetic requirements, but does not improve accuracy; the antialiasing technique merely generates artificial points to smoothen the display. Of course, a map matrix of higher dimension improves the quality of display and also the accuracy of representation. This will slow down the whole process. However, the fast enhancement in speed and display devices is expected to improve upon this limitation very shortly.

5.3.6 Information management

Information management may be performed in batch mode or as part of an interactive session, using query command with the text and graphics menus. Spatial information retrieval of course may be performed only in an interactive session.

5.4 THE SYSTEM ARCHITECTURE

A system architecture may be illustrated with reference to:

- The structure of procedural components (modules) or programs, and
- The data structure employed.

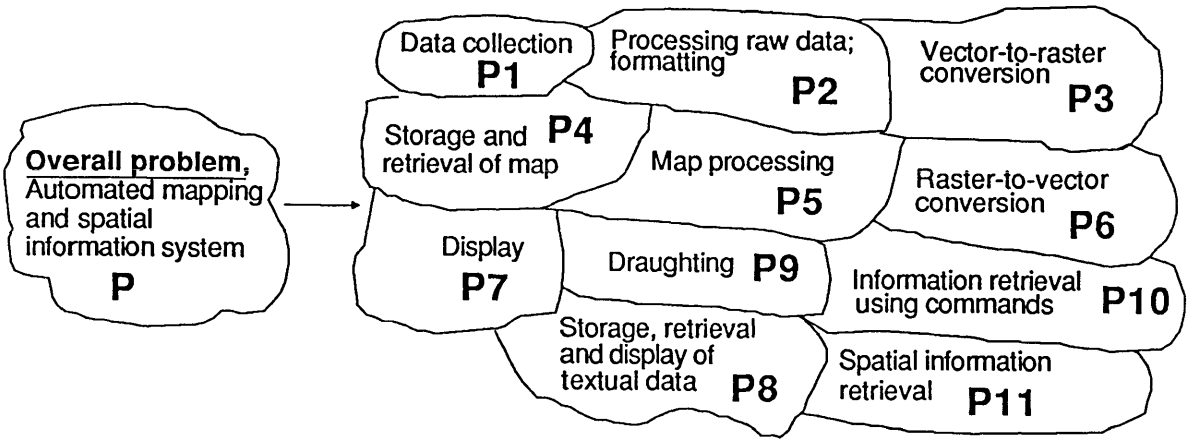
A 'program chart' or 'structure chart' or the logical arrangement of the problem-solutions is presented in Figure 5.2(c) which was derived from the isolated solutions, S1 to S11 (Figure 5.2(b)) of the problem areas, P1 to P11 (Figure 5.2(a)).

The package consists of four main modules coded in FORTRAN 77. The general system layout is shown in Figure 5.3. Figure 5.4 shows the system installed on a VAX 8600 super-minicomputer, in a VMS environment with the GKS graphics library. The modularity of the system provides multi-tasking options to speed-up the overall execution of an operation. This arrangement will exploit the potential of multi-process environment, a common feature in the UNIX operating system. The modularity is also important for software maintenance, modification, and reuse or adaption. The use of the system by remote users on Joint Academic Network (JANET), has not been tried. In principle, it should work, so long as the slow communication does not pose a problem in the I/O buffering.

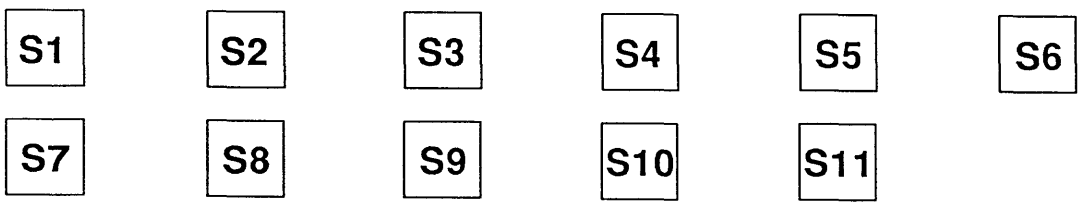
5.4.1 Program structure

Raw data processor (Module 1): Although maps may be created from survey data or by interactive draughting, the cores of most of the mapbases are created from digitised data from existing maps. Similarly, map related information also is extracted initially from existing maps and related information.

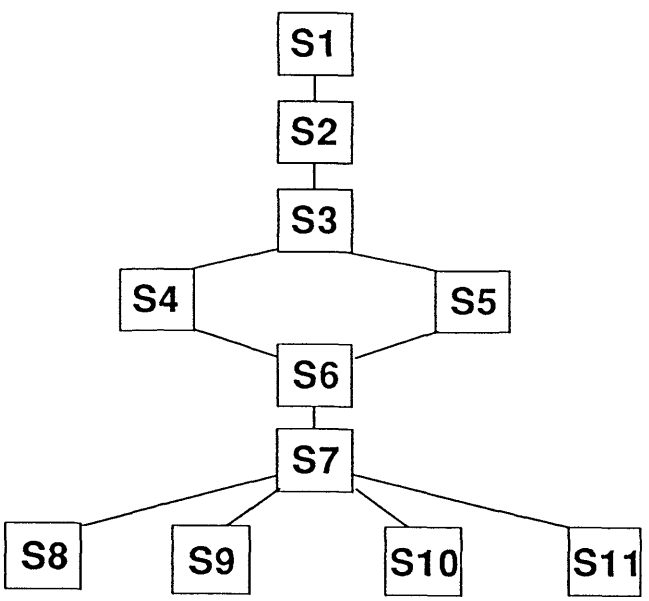
Module 1 is a single program (nearly 200 lines) which reads alphanumeric data from a file and writes the whole or part, in a specified internal format, to another file to be used in Module 2. The module adds some standard digitising documentation to the top of the file followed by the format in which the processed digitised data is written to the output file. This module is independent and does not involve any graphics, and offers convenient batch processing; occupies only 3.5 KB of memory and needs approximately 0.35 MB of work space. It reads the northings, eastings and attribute values of the data points and outputs them in a prescribed format.



(a) Breakdown of problems (users' problems are hardly well defined until a solution is derived)



(b) Solutions to the problems in (a)



(c) Structure chart of the developed system

Figure 5.2

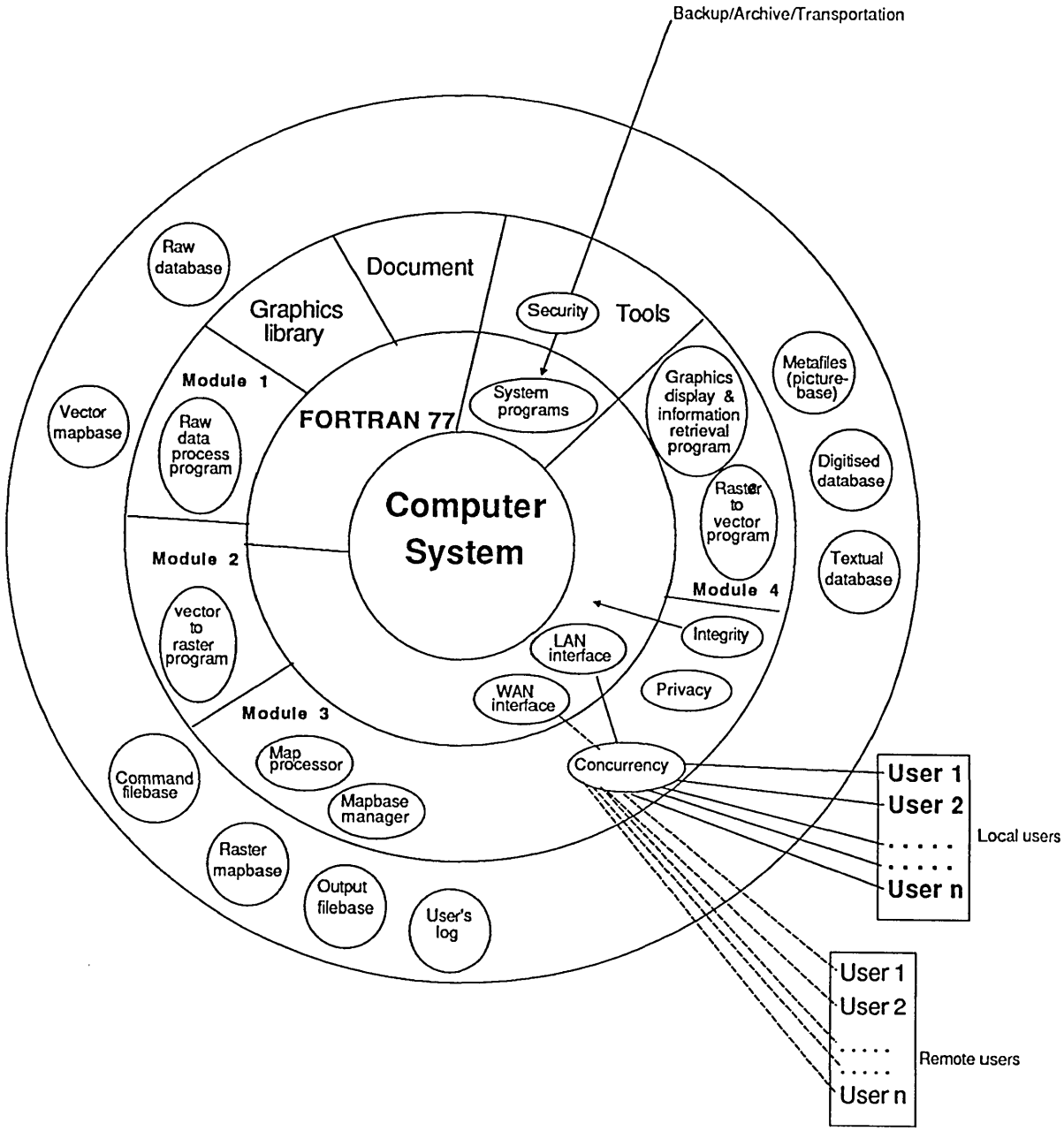


Figure 5.3 The system architecture

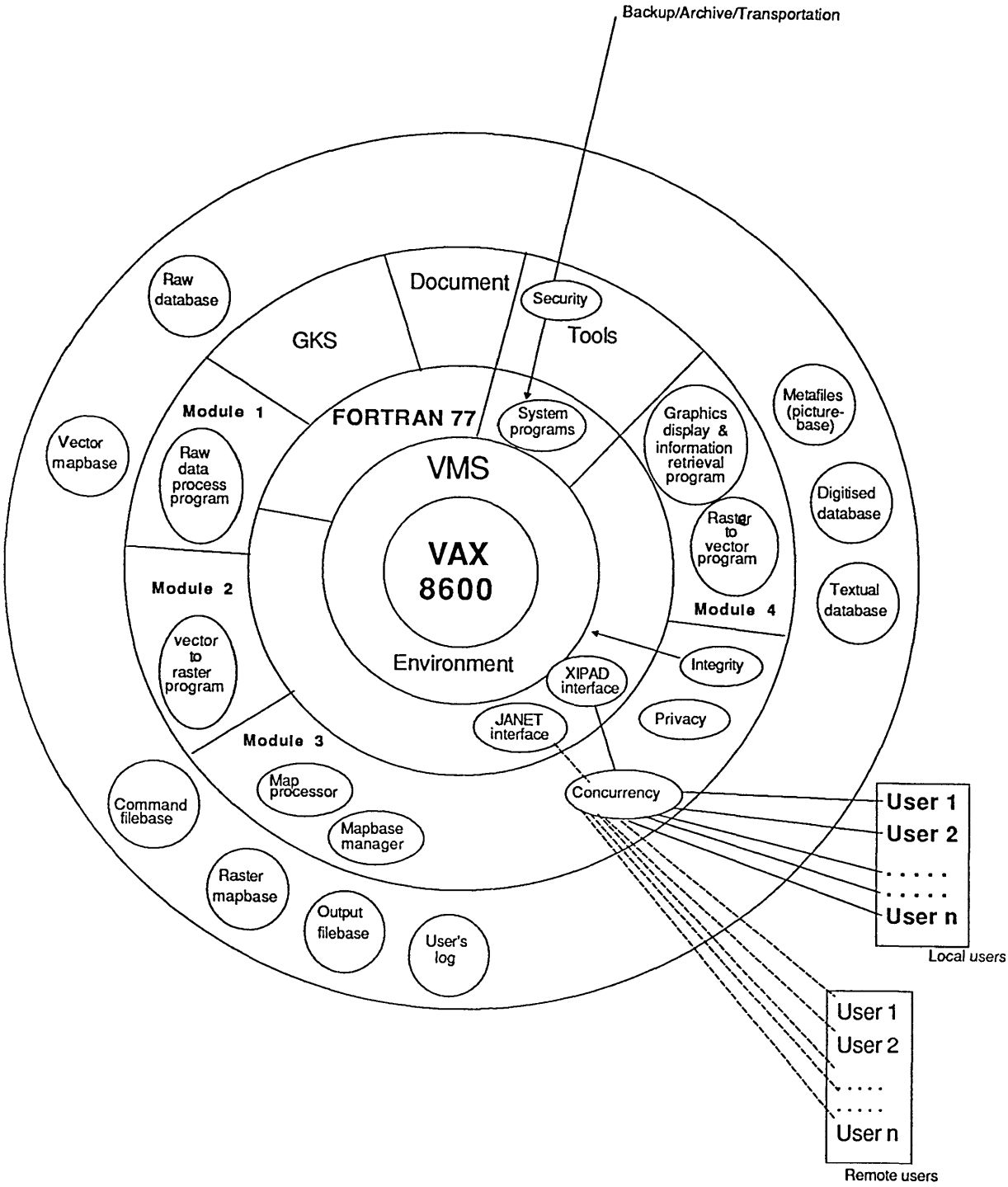


Figure 5.4 The system installed on a VAX machine

Vector-to-raster converter (Module 2): Module 2 consists of a driving program, and five subroutines amounting to approximately 700 lines of code; it reads formatted data created by Module 1 and creates an output file to be used by Module 3. This Module also offers convenient batch processing. Only 10 KB of memory is occupied by this Module, but needs 0.30 MB of work space. It reads northings, eastings and a single attribute value, the value for identifying a feature.

Mapbase manager and map processor (Module 3): Module 3 involves storing, retrieving, and processing maps. Creation of a primary map is usually performed through a command file generated by Module 2. The Module consists of the driving program and 52 subroutines, amounting to some 5000 lines of code, and is used with the graphics interface of Module 4.

Graphics and information system manager (Module 4): Module 4 consists of 30 subroutines dedicated to graphics display, draughting, and spatial interrogations, amounting approximately 3500 lines of code, and makes calls to graphics library routines. This discrete module makes calls to routines in a Graphics Kernel System (GKS) standard graphics library. Besides, displaying maps, the Module also may create picture files which can be displayed and/or plotted later as full size mine plans. (Another version using the CALCOMP plotting library is available but does not provide many enhanced facilities). This module has been designed for use with Module 3.

Modules 3 and 4 together occupy 0.45 Mb of memory space and use another 1.3 MB of workspace. The storage space used for the mapbase depends on the implementation. Each raster map of 280,000 cells occupies approximately 1.12 MB of storage space for FORTRAN standard integers (4 bytes). Presently on the VAX machine, the system uses 2 byte integers for storage of a raster map, occupying 0.56 MB of storage space. Using 1 byte integer (which will allow a category value in the range of -128 to $+127$), the storage space can be halved further to 0.28 MB. The memory required to store vector maps and textual information is small in comparison; around 10 MB (may grow if many attributes are stored) for one hundred maps.

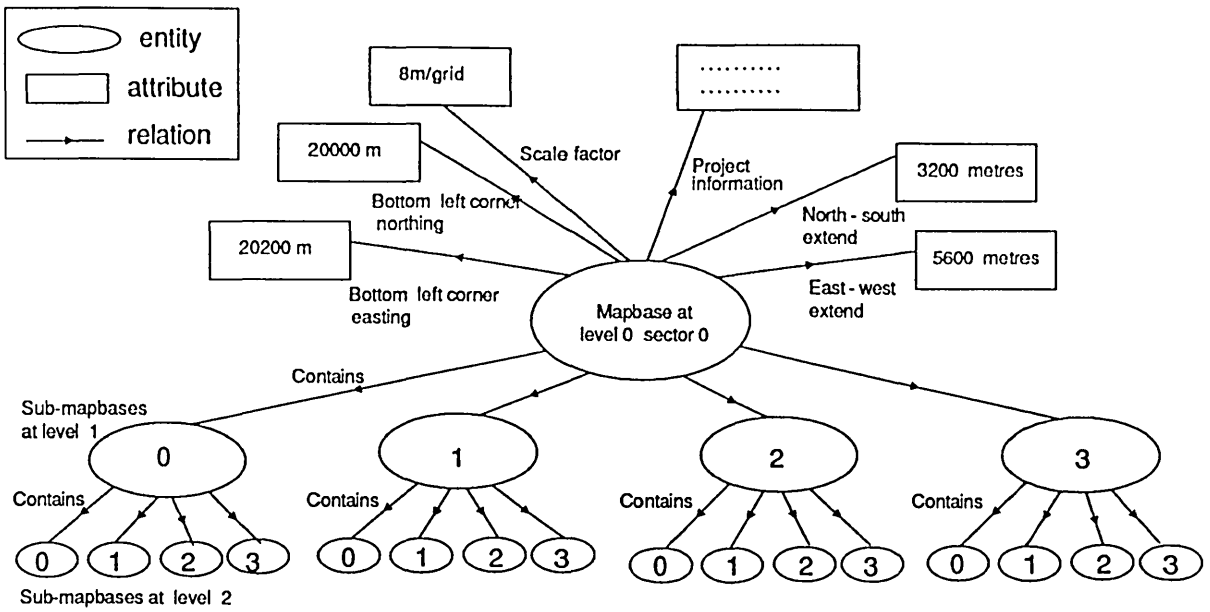
Tools: The tools developed include system programs (procedures) for compiling linking the modules, for running batch job and for archiving mapbases and

programs. Besides, some FORTRAN program have been developed for supporting software transportation and installation. One program reads source code in mixed cases and creates a output file in upper cases; some machines do not support mixed case FORTRAN code, such as CYBER. Programs has been developed to be able to read a variety of data in a wide range and to create raster map. One such program has been used to create a thematic raster map from the kriged grade value and variance (refer to Section 6.6.2).

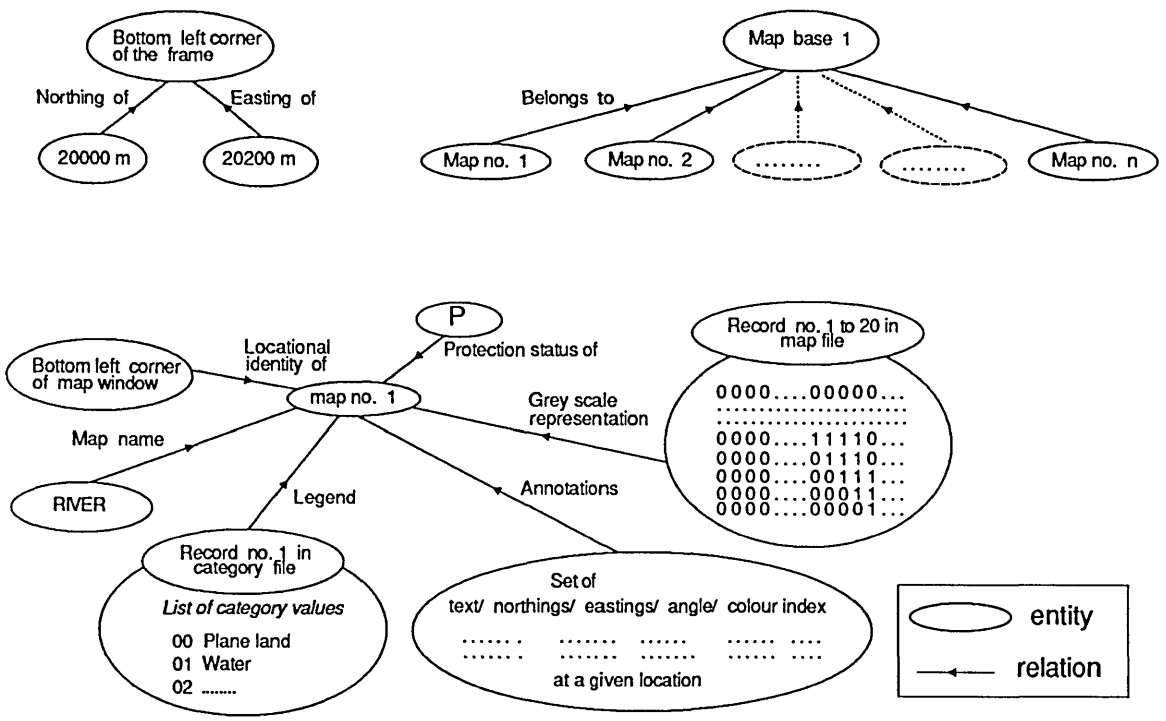
Documentation: The programs and the subroutines are documented with necessary notes for the key variables, functions, and specially the system specific statements. Documentation files also have been created for the system installation. Besides the documentation available in 'on line help', all the commands and brief description of their functions have been listed (refer to Appendix 5B). More elaborate documentation will be produced in future enhancements.

5.4.2 Data structure

The mapbase/database forms the core of the system. It comprises of vector maps, raster maps, numeric and textual information. The mapbase and submapbases for different sectors in different levels have been arranged in a hierarchical structure whereas, a relational model has been used for the management of the map entities and the related attributes, such as, protection status, category value, scale factor, annotation, and map origin. The combined structure of the mapbase is illustrated in Figure 5.5 (also refer to Section 4.5). The top Level or Level 0 mapbase and the sub-mapbases (Figure 5.5(a)) are the entities related through the relationship 'contains'; the mapbase (parent) at Level 0 contains the sub-mapbases (children) at Level 1 and the sub-mapbases at Level 1 contain the sub-mapbases at Level 2. The attributes to the top level mapbase also are shown in Figure 5.5(a). As shown in Figure 5.5(b), none of these attributes is stored for the submapbases; these attributes are computed logically from the attributes of the top level mapbase, or adopted directly, when common to all the levels. (According to classic database theory, this single phenomenon may characterise a network model). For example, the northings and eastings of the bottom left corner and top right corner of the rectangular areas (see Figure 4.15 in Chapter 4) of the sub-mapbases will be calculated from the top level mapbase attributes. Common attributes include information such as the project name, the data for the mapbase icon etc.; icon data is graphics data for drawing the



(a) Hierarchical mapbase and sub - mapbase arrangement and relations to top level mapbase



(b) Conceptual schema of the relational view of a map.

Figure 5.5

corporate emblem or other symbols. The diamond seen in the title block of maps in Chapter 6 is the emblem of the Coal India Limited (CIL).

The maps reside in a mapbase in a hierarchical structure where the mapbase and the maps are connected through the relation 'consists of'. Maps are stored in a relational model. Each map is viewed as a collection of relations (refer to Figure 5.6(a), (b), (c) & (d)). The entity, legend for each map (refer Figure 5.5(b)) consists of several categories. However, within the system, they are manipulated as a single entity (single multi-dimensional array) by using direct access unformatted files having mixed records of texts and digits.

5.5 TRANSPORTATION AND INSTALLATION

5.5.1 Transportation

Care has been taken to keep the package highly transportable. Coding has been done in widely used standard FORTRAN 77. A very few unavoidable machine dependent FORTRAN statements, such as, OPEN (used for opening FORTRAN I/O files) has been used which may be different on different machines. However, necessary comments has been added, so that the alteration can be made easily for other systems like CYBER, IBM, PRIME or a workstation (SUN, APOLLO, Micro VAX). The programs and subroutines were initially developed on CYBER machines, and were interfaced with CALCOMP standard graphics libraries. The maps in Figures 4.1 and 4.3(b) (in chapter 4) were generated with this combination in the development stage. Later, it was installed on a VAX 8600 machine, and was interfaced with international standard graphics library GKS (1b implementation). The software can still be interfaced with CALCOMP standard graphics library, but advanced graphics facilities will be left unutilised. The package can be run without any graphics library or a graphics terminal, but the graphics display will not be available, although maps can be generated as printer graphics and textual information can be printed on the screen. The package deals with advanced graphics display/interaction and has been designed primarily to be used in a GIS environment. The non-graphics option has been kept to support the multi-user distributed system, where a user may not have access to a proper graphics terminal (typical example; if an user wants to access the mapbase from his residence or remote site on emergency). The package has been already installed on a PERKIN-ELMER machine and a SUN workstation,

Map	Geographical location identifier	Northing (metre)	Easting (metre)
Map no. 1	Left bottom corner	20000	20200
Map no. 2	Left bottom corner	21100	23400
.....	.....	.....	.....
.....	.....	.....	.....
Map no. m	Left bottom corner	20000	23400

(a) Map/ geographical location relation; a collection of m-tuples.
Example of a tuple (Map no. 1, Left bottom corner, 20000, 20200).

Map	Name
Map no. 1	RIVER
Map no. 2	PITSURF
.....	.....
.....	.....
Map no. m	WORKPLAN

(b) Map/ name relation; a tuple.
A tuple (Map no.1, RIVER)

Mapbase	Map	Mapfile	Record no.
Map base 1	Map no. 1	BLOCK2L0S00MAP	1 to 20
Map base 1	Map no. 2	BLOCK2L0S00MAP	21 to 40
.....	.....	.....	.....
.....	.....	.....	.....
Map base 1	Map no. m	BLOCK2L0S00MAP	.. to mX20

(c) Mapbase/ map relation
A tuple (Mapbase 1, Map no. 1, BLOCK2L0S00MAP, 1 TO 20)

Map	Annotation	Colour index	Alignment angle (deg)	Northing (metre)	Easting (metre)
Map no. 21	GOAF	1 (Blue)	0	21720	22104
Map no. 21	FIRE ZONE	2 (Red)	25	21208	22544
.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....
Map no. 21	QUARRY	5 (Violet)	45	21944	22288

(d) Map/ annotation relation; A tuple (Map no.21, GOAF, 1, 0, 21720, 22104)

Figure 5.6 Collection of relation tables for the mapbase and a map

without the graphics interface. (Work is under progress to interface SUNGKS; a version of GKS).

5.5.2 Installation

The package consists of three programs; FMTNG (Module 1), PREMAP (Module 2), and PITMAP (Modules 3 and 4) coded in FORTRAN 77. The first two programs need not to be linked with any external routines except the systems libraries. The third and the main program must be linked with a GKS standard graphics library. No system specific elements have been utilised and possible alterations have been documented internally. If a GKS library is not available, other standard graphics libraries may be utilised, by using the equivalent routines; DI3000 (1987), PHIGS (1988), UNIRAS (1986), are some examples of alternative libraries.

5.6 SYSTEM USAGE

5.6.1 Preliminaries

The package can be used as a dedicated single user system, or in a multi-user rôle, in an interactive session or in batch. For running in batch, input and output may be directed to and from files. In an interactive session, query commands can be read from prepared input files or macros and the output held for post processing; graphics interrogation obviously can not be performed in a batch job. Nevertheless, graphics output can be written from a batch job, to files (known as metafiles) to be displayed and/or plotted latter on suitable devices. Metafiles can be generated also in an interactive session.

Overall management such as the creation of a mapbase, system security, data access, revision, and map processing is carried out in the text mode of the system. However, graphics display and information retrieval is provided in graphics mode, the two operations are performed alternately. In future enhancements of the package, provision will be made for graphics windows and/or overlapping text display. Such features are available with modern workstations and negates the use of a text mode operation. Some options shown in dot-boardered rectangles in Figure 5.7 are not fully implemented and are anticipated in a fully implemented system.

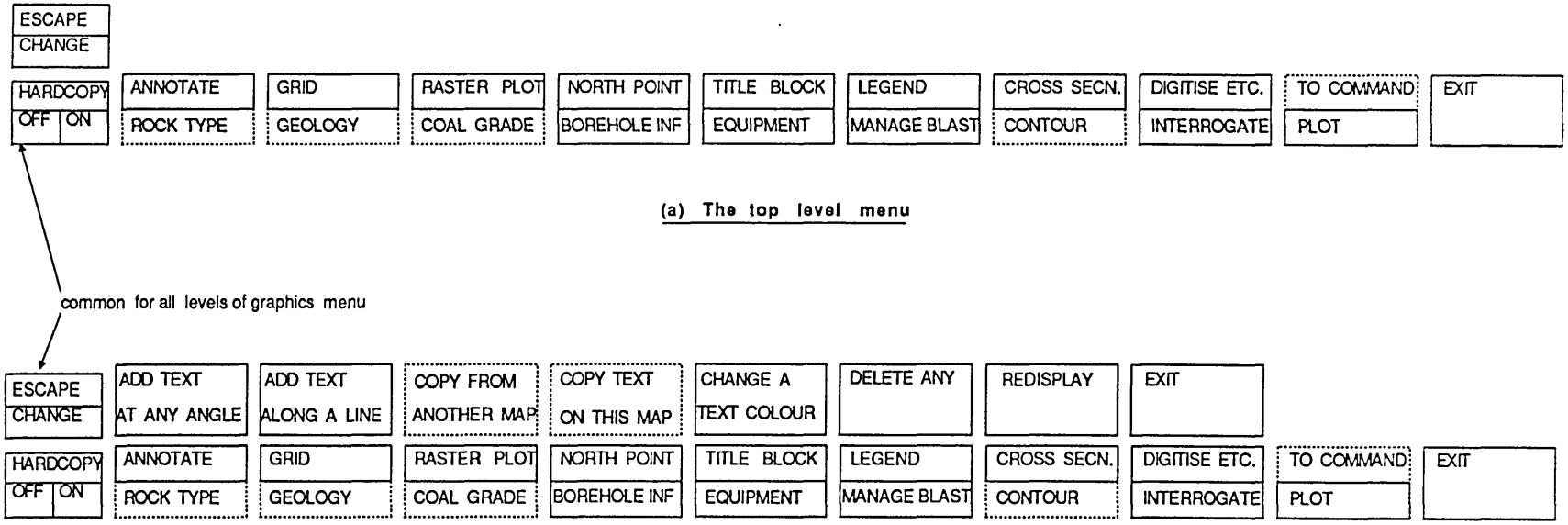


Figure 5.7 Some of the graphics menus (option in dotted boxes not yet implemented)

5.6.2 Query commands

The map processing operations are carried out using a set of query commands (constructed using the system's query language), supported by text and graphics menus, and by a pointer to geographic space as represented on a displayed map. Query commands, their modifiers or their minimum abbreviations (as specified in a help facility), are used to direct the package. For example, to create a new map of mine infrastructures, INFSTRUC composed from a map of special structures (SPLSTRUC) and a map of mine quarters and offices (QUARTERS) the command language used is:

ADD SPLSTRUC TO QUARTERS FOR INFSTRUC

Some other examples are;

PURGE INFSTRUC
RECOVER 3 AS TEMP

PURGE will delete the map INFSTRUC from the location 3 in the map file (3 is the location in the map file where the image, INFSTRUC was stored before being PURGEd. The command, LIST had showed the names and location of the maps before it was PURGEd). RECOVER will recover the purged map (earlier named as INFSTRUC) from the location 3 as TEMP, provided the location 3 has not been subsequently used for storing another map. Here, **addition**, **purging**, and **recovery** are three separate primitive operations.

5.6.3 Graphics display, menus and interaction

The graphics module is used mainly through two levels of graphics menus. Figure 5.7(a) shows the first level menu and Figures 5.7(b) and 5.7(b) shows subordinate menus. Although graphics menus usually provide a better **man machine interface**, it is not true in all circumstances and may be tiresome or confusing if many levels of menu must be traversed to reach to a certain menu option or function. An attempt to provide on optimum combination has been made by using graphics menus supported by some textual input requests.

5.6.4 Creating a new mapbase

When the package is initialised, a prompt is issued to invoke the creation of a new mapbase or the retrieval of an existing mapbase. If a mapbase is to be

created, then passwords and other essential information is supplied in response to appropriate prompts. The relational structure of the new mapbase is generated automatically. The mapbase is established, as maps and related information are added eventually.

5.6.5 On-line help

An on-line help facility provides the list of commands available, and in brief, the function, and syntax of any command. Like other standard help facilities, 'HELP <command name>' will explain that particular command; 'HELP' alone entry will list the names of the commands available with corresponding serial number; entering the serial number will print out the 'help' for the corresponding command. Text menus and graphics menus are self explanatory.

5.6.6 Some recommendations

It is recommended that a GIS workstation is employed for better utilisation of the package. A typical GIS workstation essentially consists of a digitiser, a high resolution, colour graphics monitor/terminal with a pointer device such as a mouse and a plotter (refer to Figure 2.11 in chapter 2). Dual monitors or window system would provide a more effective interaction. For use of the package as a distributed system, appropriate networking must be available with corresponding security control operating at network, terminal and process levels.

5.7 THE SYSTEM APPRAISAL

5.7.1 Security

For security of maps and data, the files associated with the mapbase must be backed up regularly. If the mapbase is corrupted by machine fault, power failure or user's error, then information may be restored from the previous level in the modification process from journal files. Since all the files related to a mapbase are logically derived from the name of the mapbase, the backup reload operations may be performed on a routine basis. Procedures have been written to provide this facility to the users.

5.7.2 Integrity

Several check points have been provided in the package to avoid corruption of the mapbase due a user's mistake or inadvertence. For example, the command for removing a map from the mapbase is PURGE, but no map can be PURGEd if it has been PROTECTed; attempts to purge or to modify such a map initiate an error message. Such a map can be modified or removed when it is EXPOSEd by an authorised user. However, a purged map can be recovered, provided its storage location in the mapbase has not been used for a new map, by using a command RECOVER. Those in-charge of the mapbase are naturally expected not to grant system permission to an unskilled user, to modify the mapbase. For the enforcement of such a policy, the package enables the mapbase manager to set the appropriate permission which restricts usage of potentially disruptive commands.

5.7.3 Privacy

Four levels of system privacy have been provided, which are maintained through four different passwords associated with a mapbase. The user with the highest priority password (password no. 1) can perform all operations on a mapbase including the changing of the passwords and corresponding lists of permissible commands. Users with the lowest priority password (password no.4) are expected to have the minimum privilege and access to information. There are two other intermediate passwords (password no. 2 & 3), usually with intermediate priorities. Passwords and the corresponding lists of allowable commands may be changed by the user with the highest priority password whenever required. In fact, the strategy used for password allocation, overlaps the policy adopted on 'privacy', 'security' and 'integrity' of the the mapbase.

A log file is created each time a user signs on to the system. Attempts to open a mapbase without a valid password or to perform an unauthorised operation, will cause the program to stop running after three futile attempts. Such failures to perform any classified operation is logged and reported automatically whenever the mapbase manager opens the mapbase.

5.7.4 Concurrency

More than one user may use the same mapbase at the same time, but only one can open the mapbase with the modifying option. Later, the package will be

modified so that more than one user can open the mapbase with the modifying option and can save the modification (i.e. write to the map files) alternately. However, careful systems synchronisation is required for such concurrent use of a mapbase with read and write options to common disk files. The provision of access to remote users would necessitate a Local Area Network (LAN) and/or a Wide Area Network (WAN) and more sophisticated journaling of activity with a rigorous policy of archiving and database rollbacks.

5.7.5 Software maintenance and reusability

Each subroutine has been developed with a single primitive operation/function to be performed such as matrix addition, trapping keyboard entry fault, creating a map with point feature or polygon feature etc. This is the basic 'building blocks' concept of software engineering and offers greater flexibility in maintaining of software and reusability. The four modules consisting of subroutines have been kept distinct and independent, but can be integrated to achieve desired functions (DIRECT–1 is such an integrated system). Adequate documentation has been maintained in coding and also in document files. These are the basic steps in software engineering.

5.8 SYSTEM INTELLIGENCE

Besides the embedded intelligence provided for maintaining integrity, security, privacy, and concurrency, the system has the 'intelligence' for understanding abbreviation (ranging from a minimum unique abbreviation to the full command) of query commands and modifiers. It warns and/or advises the user when a mistake committed. It also supplies suggestions to rectify the mistake and a map name if the user forgets to supply one while trying to create a new map, and such prevent the command from going astray or from corrupting the mapbase.

The system has been also provided a limited capacity to learn. For example, it can learn from the mapbase supervisor (with the highest priority password) what commands are to be permitted to a particular password. It can vary from 0 to 65 (the number of commands) for each password. Once it is learnt, the system will abide by the same guidelines while checking the 'right' of any user to execute a command or to access a mapbase, until the system is given further instruction by the user of the highest password.

5.9 SYSTEM TESTING AND VALIDATION

5.9.1 System testing

It is a prototype package, and full implemented testing could not be applied. The supervisor of the PhD programme and the colleagues in the CAD group at RSM have worked as the Independent Testing Group (ITG), during the modification. Practising mining engineers and other map users from various organisations also have helped in testing during various demonstrations of the package.

5.9.2 System validation

The foundation provided in the package has been well accepted by BCCL where the maps and related information was collected, and the author will be implementing the system shortly for them on an experimental basis. The Tata Iron and Steel Company Ltd., a large private organisation in India has proposed to adopt this approach. This has been discussed in chapter 6. The package also has been adopted for an EEC research project at the Department as a start. Some other organisations outside mining, have shown keen interest in the general system approach. Such organisations includes a remote sensing agency, a space research organisation, and a government information system.

Chapter 6

IMPLEMENTATION AND APPLICATION

Chapter 6

IMPLEMENTATION AND APPLICATION

6.1 IMPLEMENTATION

This chapter describes the applications and proposed implementation of the package, DIRECT–1. The package has been developed primarily for use in surface mining, and some applications have been illustrated with maps generated and plotted through DIRECT–1. Most of the maps relate to Block–II OCP, BCCL where the the package is proposed to be implemented first on an experimental basis. The planned organisation of users at the Bharat Coking Coal Limited (BCCL) Head Quarters and at the Block–II Project is discussed. Network links with regulating and consulting authorities such as, Coal India limited (CIL) and Central Mine Planning and Design Institute Limited (CMPDIL), also are shown.

The Tata Iron and Steel Company (TISCO), a large private sector company in India, is one of the organisatons who is proposing to adopt the general system approach of DIRECT. The author has suggested an IT strategy for TISCO; a schematic for the same is presented showing the potential rôle of the AM/GIS system in it.

6.1.1 Organisation of users

The user interface of this package has been designed in such a way that computer skilled personnel are not essentially required in the day-to-day usage. However, a system policy must be adopted and the team of users must be organised. There must be in charge, a system manager for the mapbase. The manager himself will initialise the mapbase (Section 5.6.4) and will set up the passwords and the corresponding set of permissible commands. The manager himself only will use the highest priority password which will allow him to access the passwords in future and change them if required (refer to Section 5.7.3). The Manager will also arrange a code number for each user. These, like passwords, are also confidential.

However, the Manager can set the strategy in any manner in compliance with an agreed corporate policy.

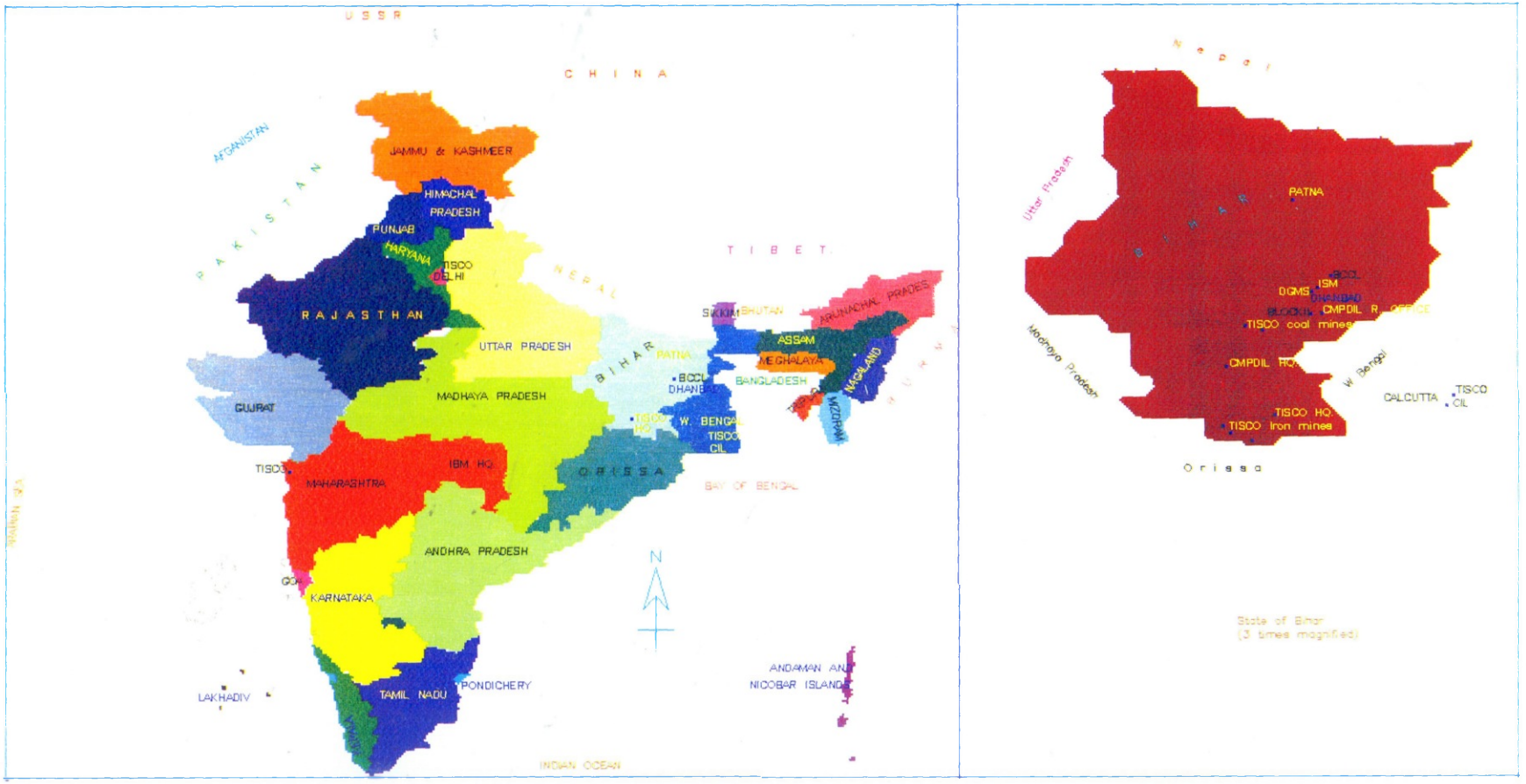
One possible configuration of the system implementation, designed according to the organisation of the BCCL, is illustrated in Figures 6.1. and 6.2. Figure 6.1 shows the set up at the BCCL Head Quarters at Dhanbad, and Figure 6.2(a) shows the arrangement at the Block–II Project. Figures 6.2(b) and 6.2(c) show the computer system and the network links at CMPDIL Head Quarters at Ranchi, CMPDIL Regional Office at Dhanbad, and the CIL Head Quarters. For implementation of the system, an appropriate Local Area Network (LAN) would be installed at each of the establishments. In a geographically widely spread management environment, a Wide Area Network (WAN) needs to be provided. Figure 6.3 shows the schematic of the overall IT structure and the network requirements suggested for TISCO, Jamshedpur, India, which involves a broader and more sophisticated management environment spread over a wider area. (A list of the abbreviations and acronyms used in the Thesis has been provided under 'Abbreviation and acronyms').

Plate 6.1 shows the location of the Block–II project, BCCL, CMPDIL, IBM and CIL, and some establishments of TISCO in India. This map has been generated using DIRECT–1, and demonstrates the geographic scale of of the organisations (other subsidiaries of CIL have not been shown) and the context in which the package might be applied in resources management.

6.1.2 Establishing the mapbase/database

First of all, the land area to be represented by the mapbase must be defined. The scale i.e. the scale factor, depends on the area to be covered and the number of rows and columns of a map. The mapbase which has been used for the illustration, relates to the Block–II Open Pit Project (Appendix 4A). The mapbase uses a matrix of 400 rows $\times$ 700 columns covering 3200 m in a N–S direction and 5600 m in a E–W direction. This gives a Ground Resolution Distance (GRD) of 64 m^2 at the top level (Level 0) and 4 m^2 at Level 2 of the mapbase i.e. each grid cell represents a square with sides 8 m at Level 0; the scale is properly stated by 8 m per grid cell. It is recommended that the same scale is used in both the N–S and E–W direction. It is recommended also that a convenient integer scale is chosen, as the scale is maintained within the mapbase as an integer and recursively halved to derive the scale in the lower levels of the mapbase. However, the

Plate 6.1



LEGEND	COMMENT
	This map shows BLOCK II Project in India and BCCL, CIL, CMPDIL, IBM, and DGMS. Some TISCO establishments are also shown. The scale shown below is not applicable. 200 400 500 SCALE IN METER

Coal India

OPENCAST DIVISION
CENTRAL MINE PLANNING & DESIGN INSTITUTE
RANCHI 834008

PROJECT : BLOCK-II OCP
SUBJECT : LOCATIONAL MAP
ENGNR/UM : ..... EX. ENGR : .....
DRG. NO. :
DRAWN BY : A. B. Samaddar DY. CME (OC)

MAPCODE : BHARAT
BCCL
GEOLOGIST : .....
DATE : 13 July 1999

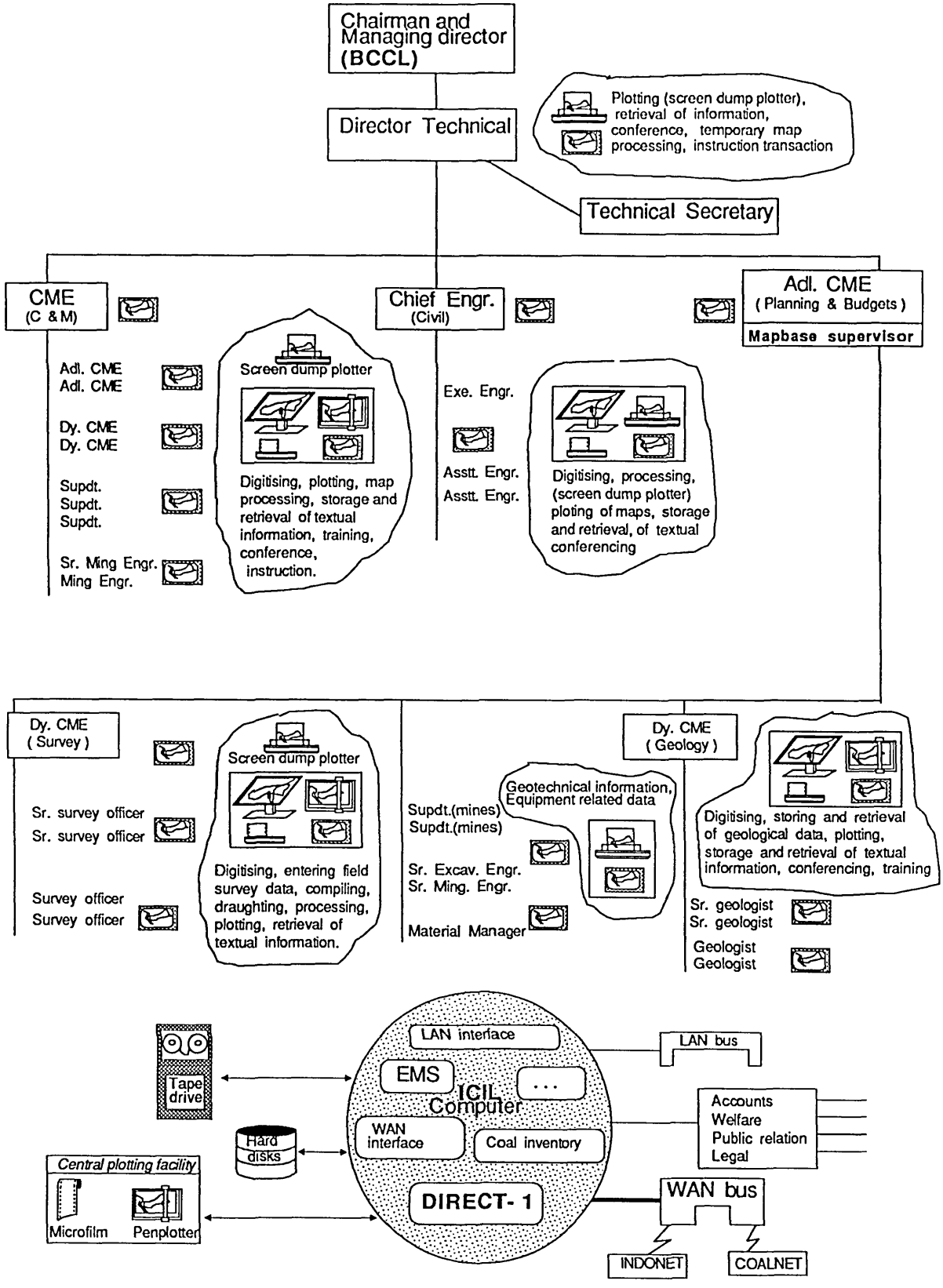
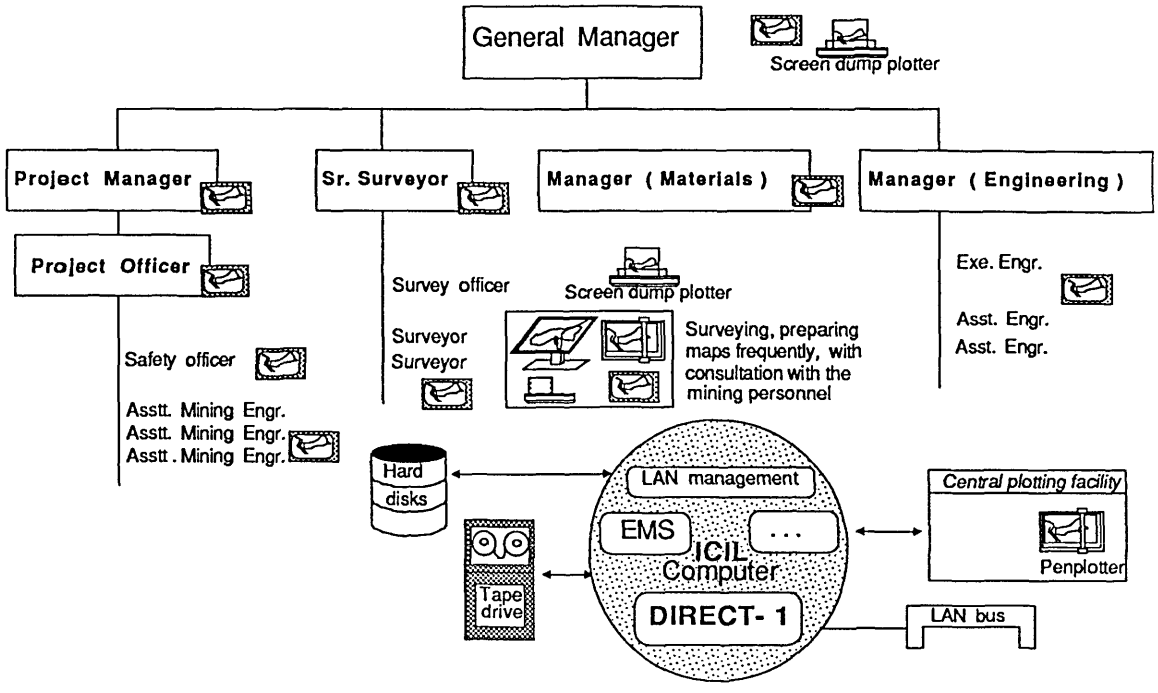
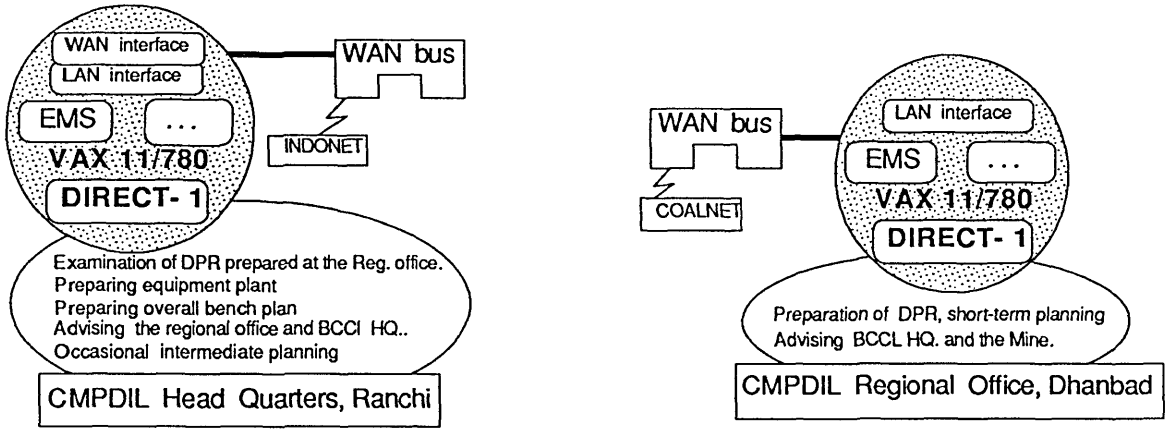


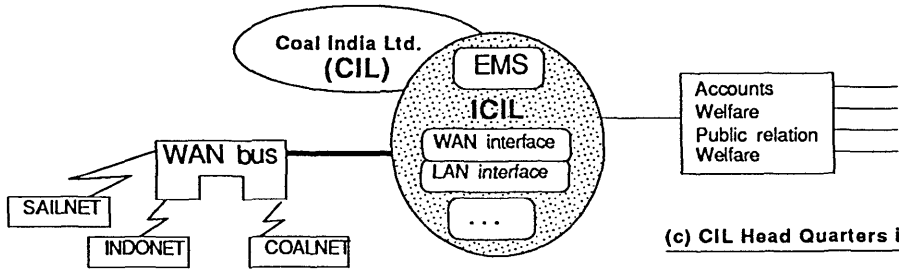
Figure 6.1 Proposed organisation of users for the implementation of DIRECT at the Head Quarters of BCCL, Dhanbad



(a) Management structure at BLOCK II Open Pit Project

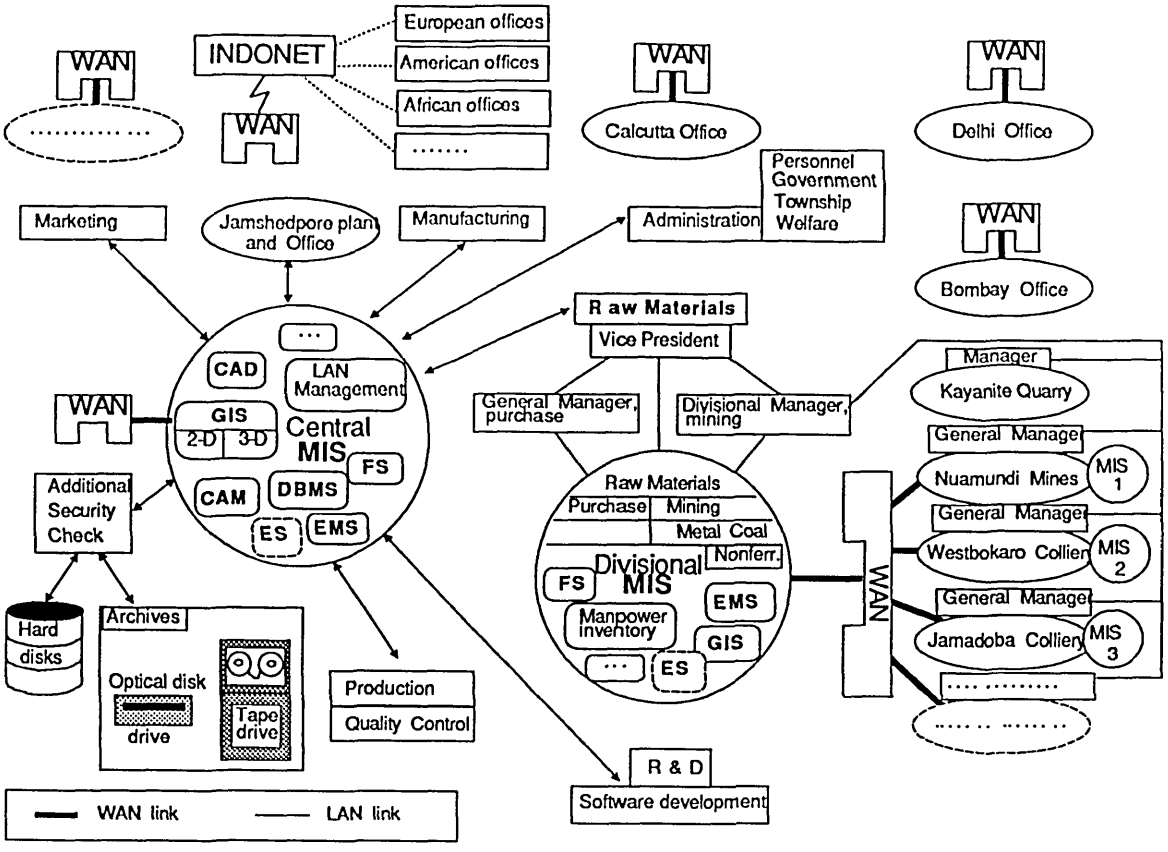


(b) Coal Mine Planning and Design Insttute Ltd. (CMPDIL), a subsidiary of Coal India Ltd.

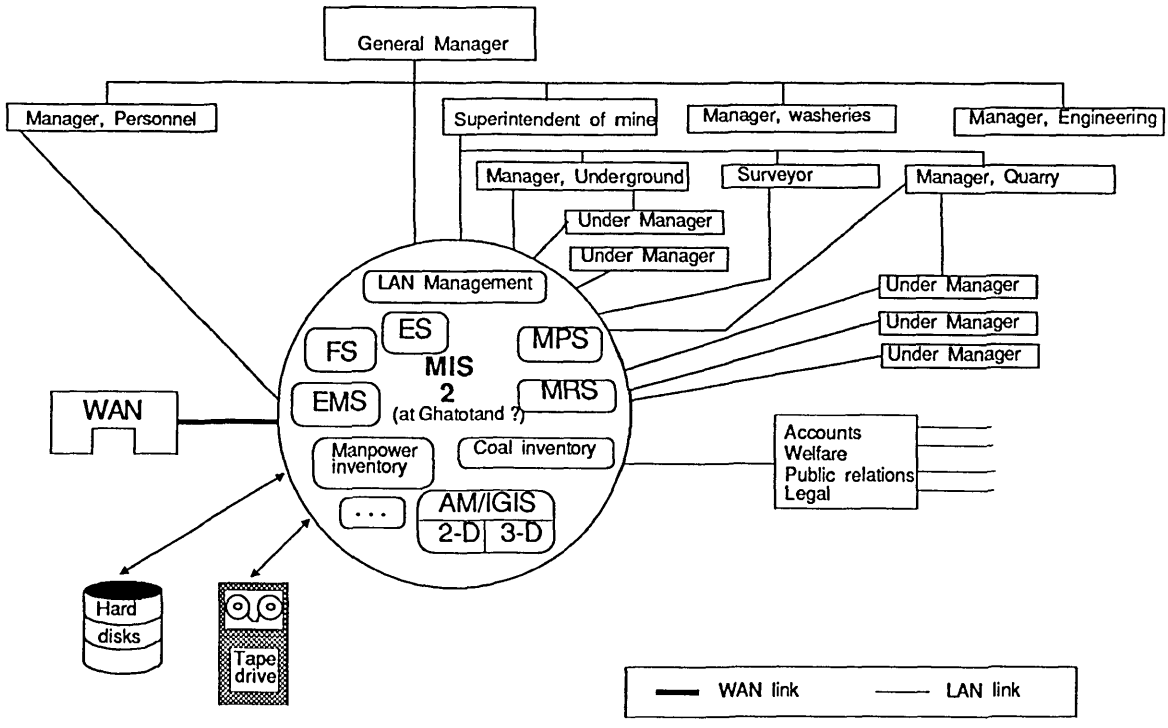


(c) CIL Head Quarters in Calcutta.

Figure 6.2



(a) The scope of the system in proposed I/S in the organisation of the Tata Iron and Steel Company.



(b) Management Information System no. 2 at the Westbokaro colliery

Figure 6.3

scale of display or plotting depends on the dimensions of the display window, or more meaningfully the dimensions of the plot. The scaling ratio of the length on the displayed or plotted map and the geographic distance may be calculated by using grid cells or directly from the device co-ordinates. In this connection, the difference between the 'grid cell' and 'pixel' may be called (Section 4.3.1). The aspect ratio of the maps displayed on screens or output on plotting devices must be preserved.

The rectangular land area covered by the mapbase is identified by the bottom left corner (in this example it is 20000 m North, 20200 m East with reference to the local grid origin), and the top right corner (23200 m North, 25800 m East). The project origin is the map origin at Level 0. The northings and eastings of map-origins for all the sectors at Level 1 and the subordinate levels are derived from the northing and easting of the top level (Level 0) map-origin. However, any map having an arbitrary origin, may be created from the vector map or by WINDOWing the raster maps in relevant sectors (refer to the discussion on 'mapbase structure' in Section 4.5). The current mapbase or sub-mapbase for any sector at any level may be set by using the command:

SET LEVEL <n> SECTOR <n>

An information file must be provided along with a mapbase, containing information about project origin, mapbase origin, graphics data for plotting the project emblem (for example, the diamond emblem for CIL appears on most of the plates used in this chapter). Graphics data defining the emblem can be created through the draughting facility of the package.

6.2 CARTOGRAPHIC MODELLING OR PROGRAMMING

Cartographic modelling is analogous to conventional algebraic evaluation in which primitive mathematical operations are logically sequenced to solve complex expressions. Six classes of fundamental operations may be identified:

- Storage, retrieval and removal of maps.
- Scaling and windowing of maps.
- Changing map category values.
- Overlaying maps.
- Measuring geographic and weighted distances.

- Characterising cartographic neighbourhoods.

A single or a sequence of **map processing primitives** (refer to Section 4.2) used to generate, process, store and retrieve map(s), and map related information, is called a **cartographic model.** Often this requires careful planning depending on the complexity of the operation. This may also be referred to as map manipulation program. A file containing such program(s) may be used as 'macros' and in fact, works as a Report Program Generator (RPG). For example, the following set of commands forms a simple cartographic model:

```
SPREAD PIT TO 80 F TEMP
GROUP TEMP INTO 6 F TEMP
DESCRIBE TEMP
```

This model spreads the features in map PIT uniformly by 80 grid spaces in 80 stages to create a new map TEMP, groups the 80 stages into 6 stages, and describes the category values including the number of cells (which gives the idea of the surface area which is a product of number of cells and the grid resolution distance) for each of the 6 stages for map TEMP.

Once a cartographic model has been created, operations can be carried out conveniently in a batch job. Within a Cartographic model, each primitive operation may be regarded as an independent tool. Some models for various manipulations are shown later in this Chapter.

6.3 SYSTEM CAPABILITIES

The package has been developed to integrate automated cartography, and spatial information management with the additional capability of providing some mining oriented features, such as pit expansion, waste dump planning, blasting vibration assessment etc. The overall scope of this package includes:

- *Map generation;*
- *Storage and retrieval of maps;*
- *Storage and retrieval of sections;*
- *Interactive draughting;*
- *Ordinary map processing (superimposing maps, scaling maps etc.);*
- *Advanced map processing (spreading features, visibility study etc.);*
- *Storage and retrieval of textual information using spatial keys;*

- *Interactive and non-interactive information management;*
- *Picture generation (raster plotting).*

6.3.1 Map generation

Maps have been classified as **primary maps, secondary maps** and **processed maps.** Secondary maps are created by using simple arithmetic operation(s) on primary map(s), such as, addition, subtraction and scaling. The processed maps are created by manipulating one or more primary or secondary map(s). Primary maps are usually generated from digitised data. A primary map may be created by interactive draughting and manual entry of survey data through the keyboard or a data recorder. The commands for generating primary maps are POINT, GRID and STRIP. Single or multiple map features may be digitised to create a single primary map; for example PITSURF in Plate 6.2 has been created by the command;

```
GRID FOR PITSURF
```

RIVER (Plate 6.3) and UG-WORK (Plate 6.4), have been similarly created with the command GRID.

The 'title block' is drawn automatically once it has been designed and stored for a specific mapbase. After consultation (Samaddar, 1986; Smith, 1986) with mining and surveying experts, the title block has been positioned to be drawn outside the map frame so that no information is obscured. The northpoint (or the north directing arrow), and other 'furnishings' may be positioned anywhere on a map; any choice may be made from a number of arrow styles and other symbol tables. Grid lines and grid reference numbers may be superimposed automatically on the map at any interval, and separately or simultaneously for both northings and eastings. Annotations are plotted on a displayed map automatically with predefined colours, locations and angles, once they have been written interactively and stored.

6.3.2 Storage and retrieval of maps

Whenever a suite of maps is processed, relevant maps are automatically retrieved from the mapbase, and modified on occasions. Similarly, newly created maps are automatically stored if the user has the necessary system privilege. Graphics

Plates 6.2 – 6.4

Plate 6.2



LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008	
Plane land Surface pitlimit N	200 400 800 SCALE IN METER	PROJECT : BLOCK-II OCP SUBJECT : ENGNR/UM : ..... EX. ENGR : ..... DRG. NO. : DRAWN BY : A DY. CME (OC)	MAPCODE : PITSURF BCCL GEOLOGIST : ..... DATE :



LEGEND	COMMENT
	THIS IS A MAP OF RIVER JAMUNIA AT LEVEL 0 I.E. AT I.E. AT THE TOP LEVL.
	200 400 800 SCALE IN METER

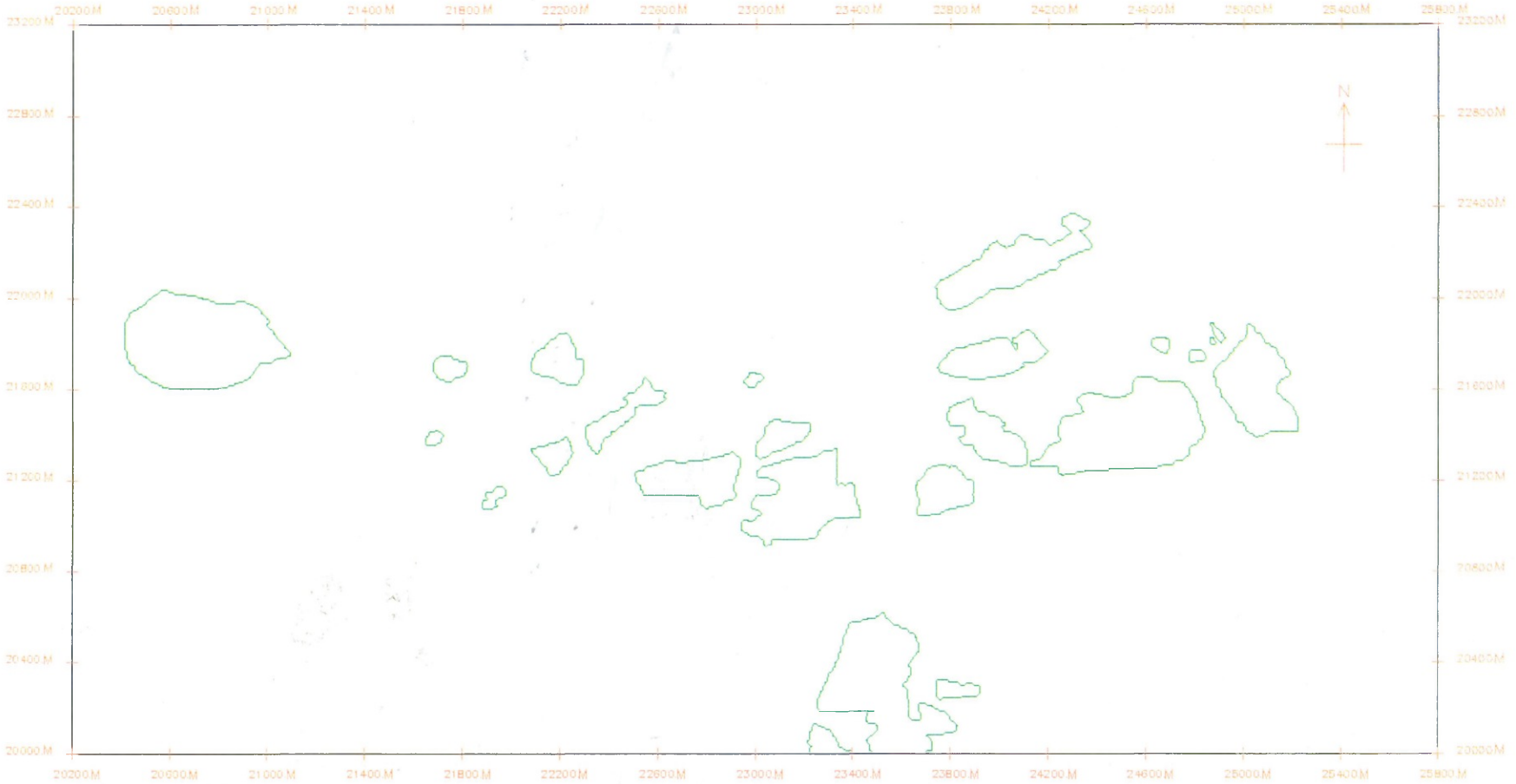
Coal India

OPENCAST DIVISION
CENTRAL MINE PLANNING & DESIGN INSTITUTE
RANCHI 834008

PROJECT : BLOCK-II OCP
SUBJECT : RIVER JAMUNIA
ENGNR/UM : ..... EX ENGR : .....
DRG. NO. :
DRAWN BY : A B Samaddar DY CME (OC)

MAPCODE : RIVER
BCCL
GEOLOGIST : .....
DATE : 19 July 1988

Plate 6.3



LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008	
N	THIS MAP SHOWS THE OLD UNDERGROUND WORKINGS 200. 400. 800. SCALE IN METER	PROJECT : BLOCK-II OCP SUBJECT : UNDERGROUND WORKINGS ENGNR/UM : ..... EX ENGR : ..... DRG. NO. : DRAWN BY : A. B Samaddar DY CME (OC)	MAPCODE : UG-WORK BCCL GEOLOGIST : ..... DATE : 10 July 1988

Plate 6.4

output may be sent to any plotter connected to a network using appropriate interface and device driver.

6.3.3 Storage and retrieval of sections

Geological sections may be stored, retrieved and displayed. Numbered section lines are displayed on a map, and any section can be selected for display. Section lines may be superimposed on any map of the mapbase. Plate 6.5 shows EXTND-PIT, a map of the extended pit, with section lines superimposed. Plate 6.6 shows a display of one of the stored sections identified from a line in Plate 6.5. (An improved section display capability with a legend should be added in future along with real time section generation (see conclusion in Chapter 7).

6.3.4 Interactive draughting

Features can be drawn on a displayed map interactively. Two or more features can be merged and unified. For example, the pit limit shown on Plate 6.5 was created by superimposing the present pit limit map with the plan of a proposed expansion for non-coking coal mining. This composite feature shows, how the pit may look like when non-coking coal has been mined in the second stage operation extending the pit further towards the south. The two features which are separated by a line, may be unified by assigning the same category value to each of them. The three waste dumps (Plate 6.7), dump 1, dump 2 and dump 3 were created by interactive draughting; then they were spread, which is discussed in Section 6.4.6.

6.3.5 Ordinary map processing

Ordinary map processing is carried out by using simple arithmetic operation on map matrices; the products are secondary maps. Two or more maps can be ADDed to create a composite map, in essence this involves the superimposition of maps. WORKPLAN (Plate 6.8) has been created by addition. The cartographic model used is:

```
ADD SPLSTRUC TO QUARTERS FOR INFSTRUC

ADD PITSURF TO UG-WORK TO QUARRIES TO RIVER TO /
  INFSTRUC FOR WORKPLAN
```

Similarly, one or more maps may be SUBTRACTed from a composite map. SUBSDNCE (Plate 6.9) has been created by subtraction; the model being:

```
SUBTRACT WORKPLAN MINUS PITSURF MINUS RIVER /
  MINUS QUARRIES FOR SUBSDNCE
```

The "/" at the end of a line is used to indicate that the command has not yet been completed, and will be continued in the next line. The system will respond accordingly.

6.3.6 Advanced map processing

Advanced map processing is carried out by employing various matrix operations on primary or secondary maps or processed maps. One or more maps may be covered with others in succession by giving priority to some maps over other(s). UG-WORK1 (Plate 6.10) and UG-WORK2 (Plate 6.11) have been created by;

```
COVER UG-WORK WITH PITSURF FOR UG-WORK1
COVER PITSURF WITH UG-WORK FOR UG-WORK2
```

In UG-WORK1, PITSURF has been given priority over UG-WORK whereas, in UG-WORK2, UG-WORK has been given priority over PITSURF.

A map may be multiplied or divided by one or many other maps. This may be useful in creating thematic maps showing, for example, the projected growth of market price or mineral stripping ratio or overburden removal cost. Maps also can be SPREAD (alone, or over one or more maps) to a desired distance either uniformly constrained, unconstrained, or selectively constrained within a given limit.

STAGE1 in Plate 6.12 shows three isolated pits, at an initial stage, which are spread to simulate some future stage, STAGE2 (Plate 6.13). The pits have been further spread to STAGE3 (Plate 6.14). It may be noted that the isolated pits have been expanded within the bounds of the pit limit (refer to Plate 6.2). The macro for creating STAGE2 from STAGE1 is:

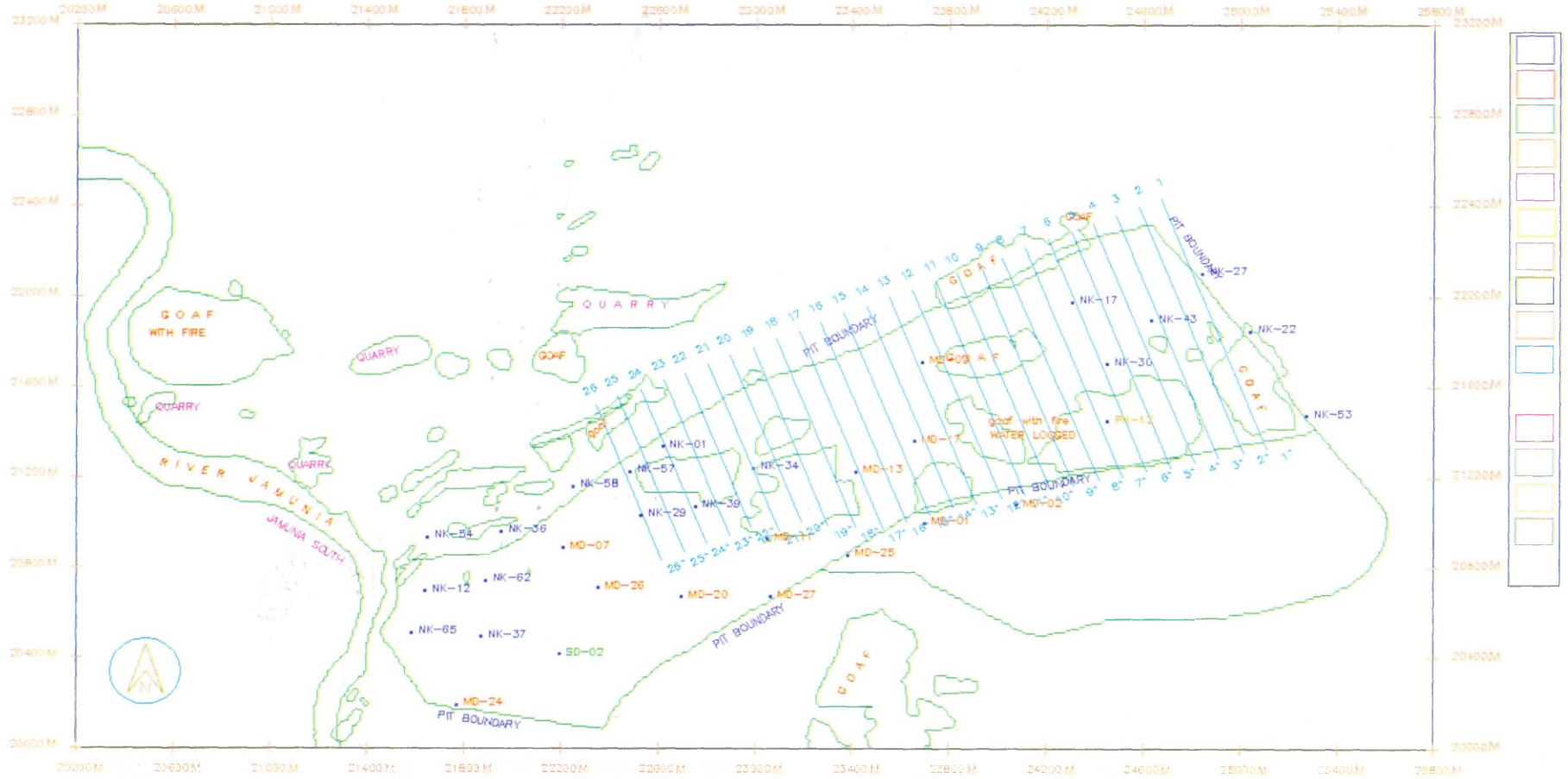
```
SUBSTRACT STAGE1 MINUS RIVER F TEMP

SPREAD TEMP OVER PITSURF TO 50 F TEMP

RECA TEMP F TEMP A 1 TO 0 TH 1 A 0 TO 50
GROUP TEMP INTO 4 F TEMP
ADD TEMP TO RIVER F STAGE2
PURGE TEMP
```

Plates 6.5 – 6.14

Plate 6.5



LEGEND	COMMENT
N	This map shows the final pitlimit when the second phase of extracting non-cokin coal is over. Section lines are superimposed on the ma
	200 400 800 SCALE IN METER

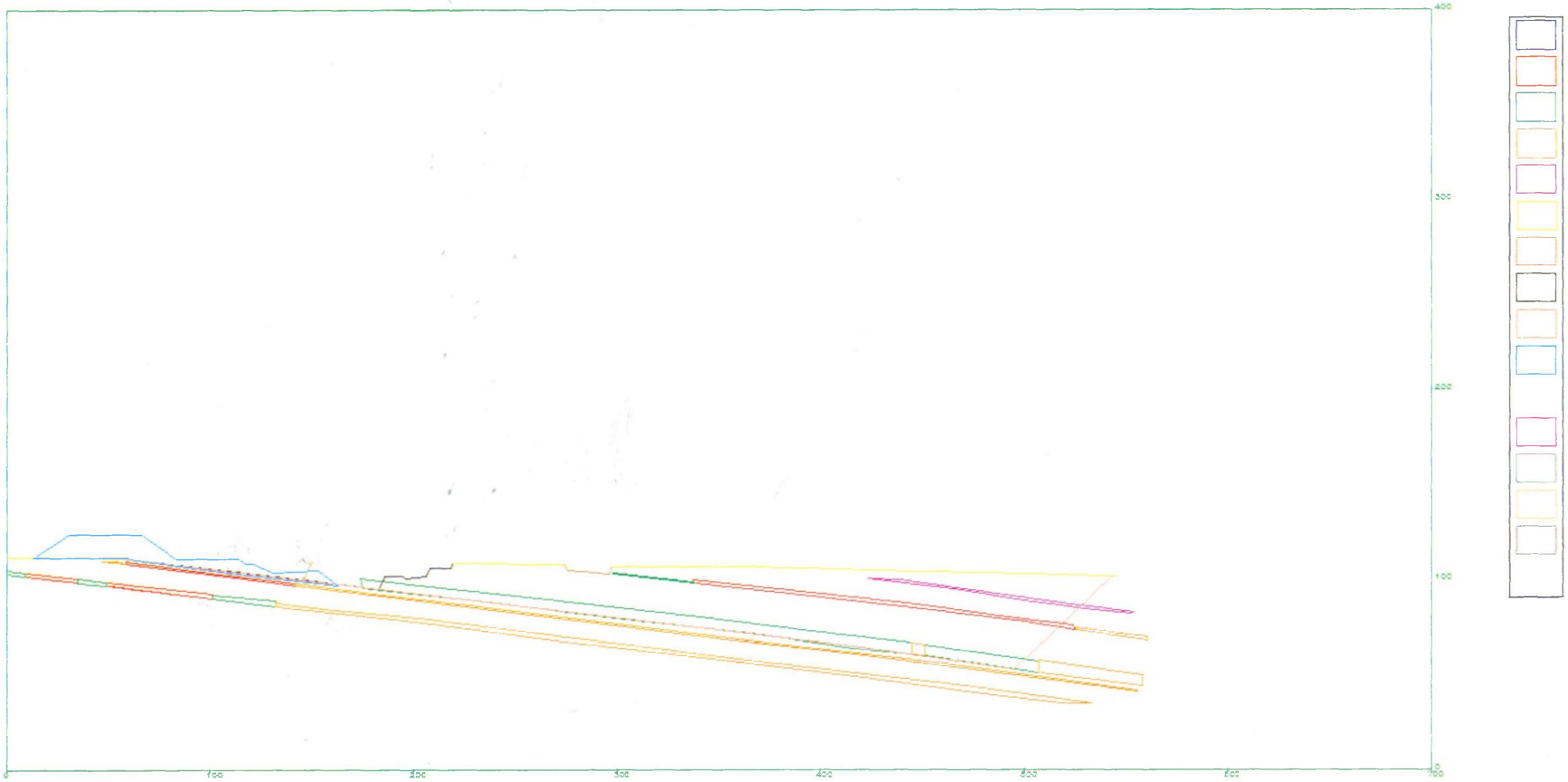
OPENCAST DIVISION
CENTRAL MINE PLANNING & DESIGN INSTITUTE
RANCHI 834008

PROJECT : BLOCK-II OCP
SUBJECT : FINAL PIT LIMIT AND SECTION LINES
ENGNR/UM : B.K. ROY EX ENGR : .....
DRG. NO. :
DRAWN BY : A. B. Samaddar DY CME (OC)

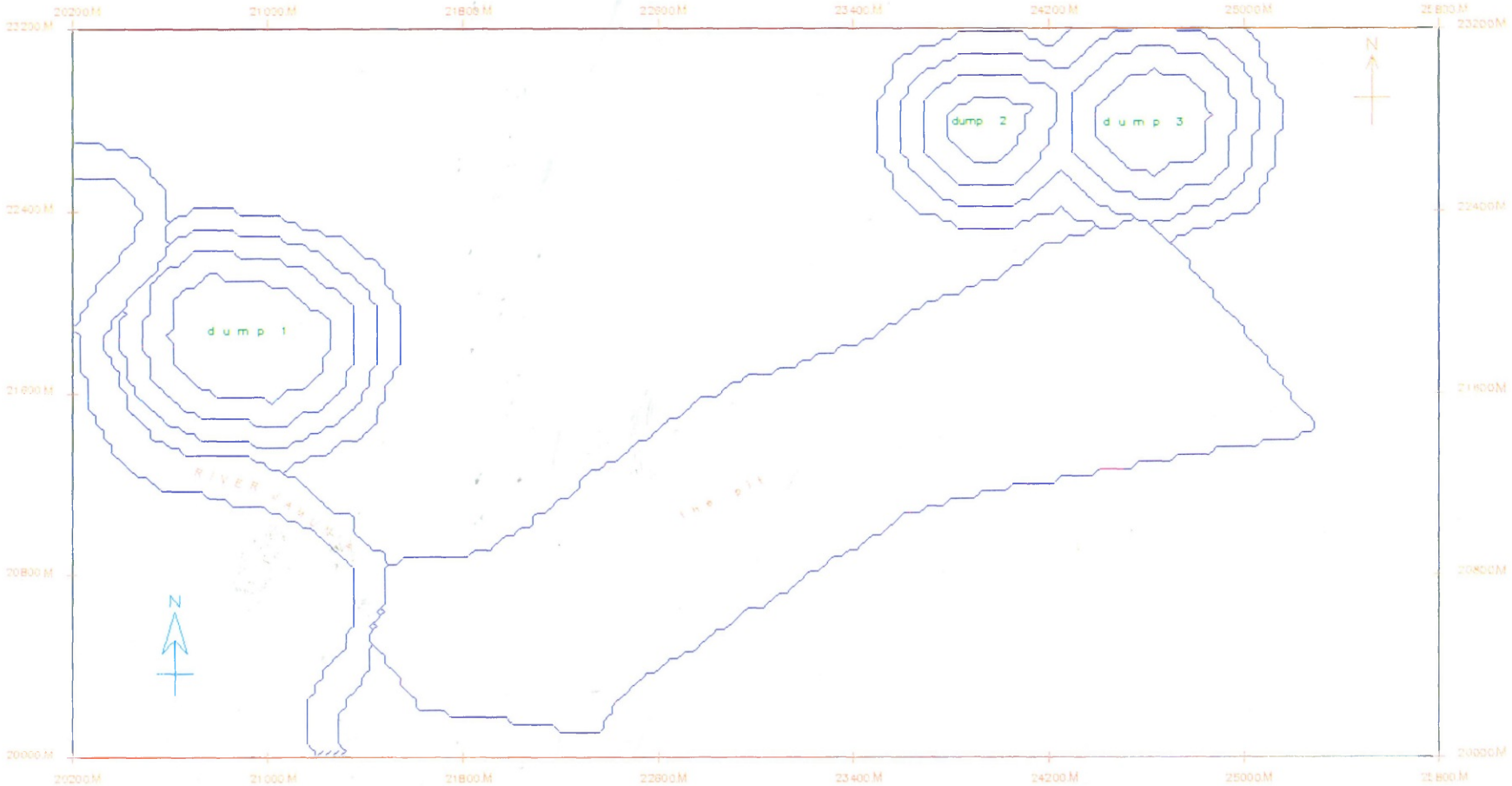
MAPCODE : FINALPIT
BCCL
GEOLOGIST : B.C. SARKAR
DATE :

END	SEC LINES	STORED SEC	ARBITARY SEC	DELETE	EXIT					
CHANGE										
HARDCOPY	ANNOTATE	GRID	RASTER PLOT	NORTH POINT	TITLE BLOCK	LEGEND	CROSS SECN.	DIGITISE ETC	TO COMMAND	EXIT
OFF ON	ROCK TYPE	GEOLOGY	COAL GRADE	BOREHOLE INF	EQUIPMENT	MANAGE BLAST	CONTOUR	INTERROGATE	PLOT	

Plate 6.6



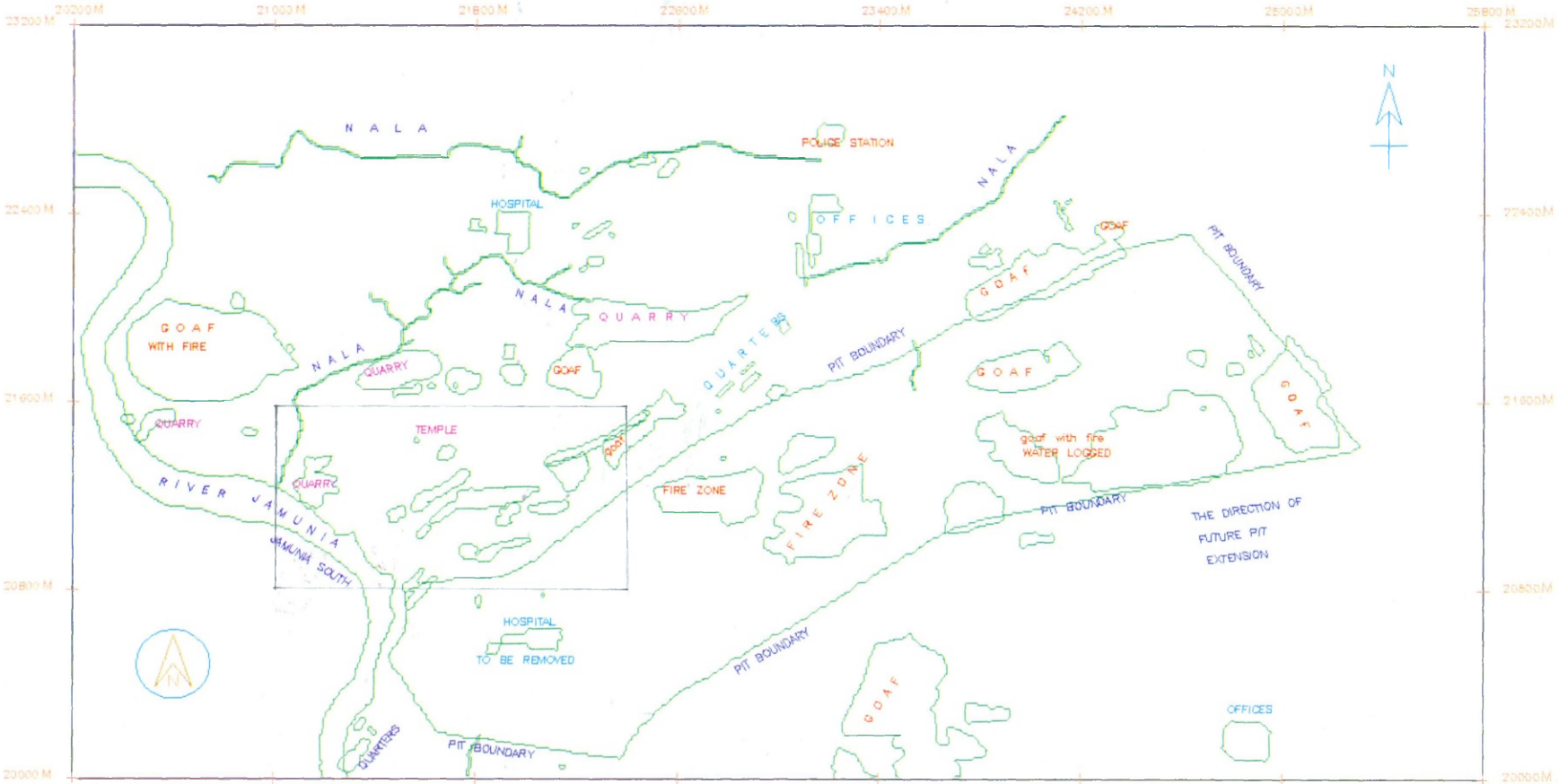
END	SEC LINES	STORED SEC	ARBITARY SEC	DELETE	EXIT					
CHANGE										
HARDCOPY	ANNOTATE	GRID	RASTER PLOT	NORTH POINT	TITLE BLOCK	LEGEND	CROSS SECN.	DIGITISE ETC	TO COMMAND	EXIT
OFF ON	ROCK TYPE	GEOLOGY	COAL GRADE	BOREHOLE INF	EQUIPMENT	MANAGE BLAST	CONTOUR	INTERROGATE	PLOT	



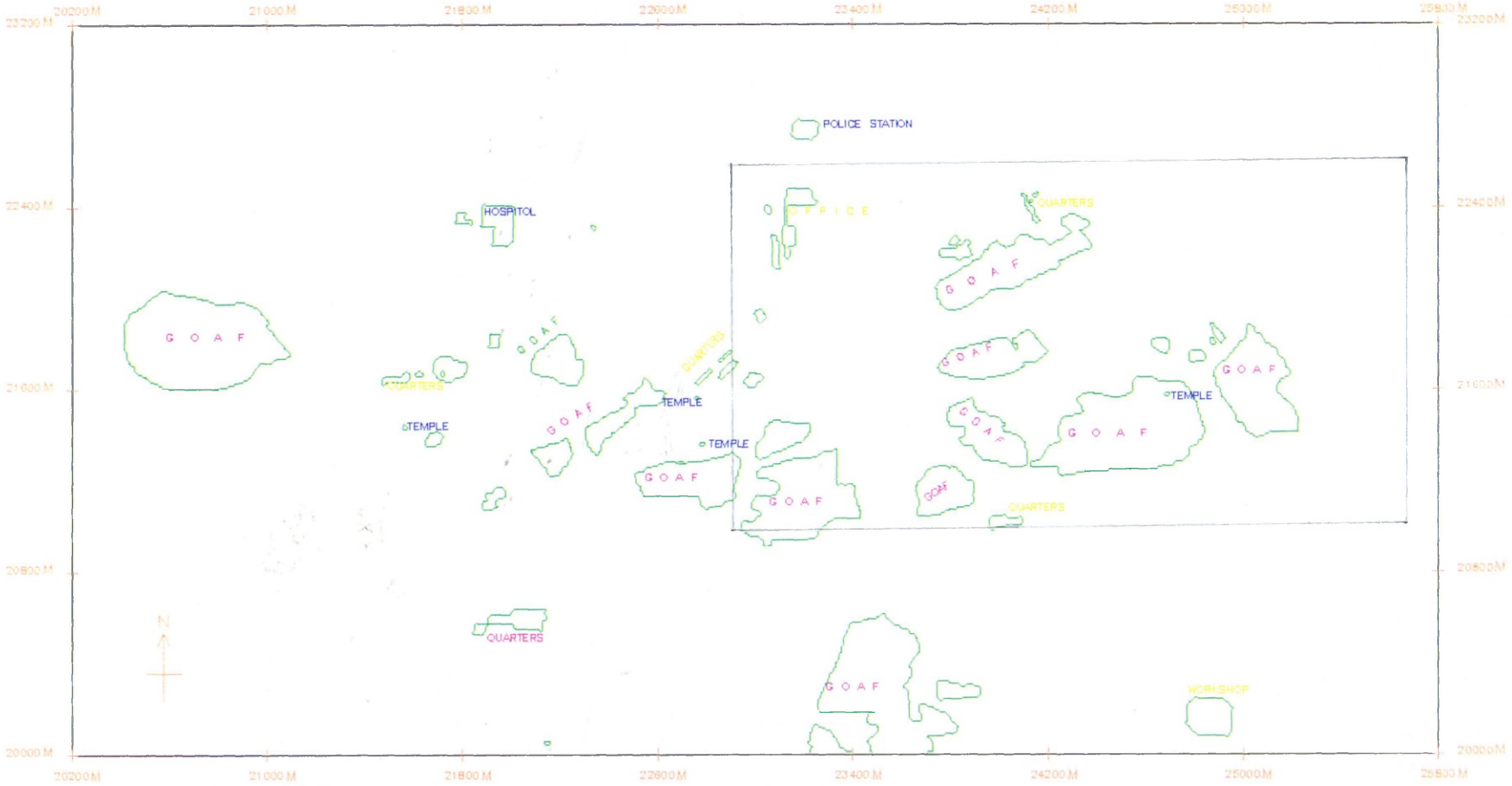
LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI: 834008	
	This map was created to study, how far the waste dumps if located as they are, can be dumped before they start poring into the river or into the excava -ted. Surface used covered or volume can be found out through INTERROGATE opt THIS IS A LOW RESOLUTION MAP 200 400 800 SCALE IN METER	PROJECT : BLOCK-II OCP SUBJECT : WASTE DUMP STUDY ENGNR/UM : ..... EE ENGR : ..... DRG. NO. : DRAWN BY : A. B. Samaddar DY. CME (OC)	MAP CODE : WASTEDMP BCCL GEOLOGIST : ..... DATE : 18 August 1988

Plate 6.7

Plate 6.8



LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008	
	This map has been created by adding PITSURF, RIVER, NALA, UG-WORK, QUARRIES, AND INFSTRUC	PROJECT : BLOCK-II OCP SUBJECT : ENGNR/UM : ..... EX ENGR : ..... DRG. NO. : DRAWN BY : A B Samaddar DY CME (OC)	MAPCODE : WORKPLAN BCCL GEOLOGIST : ..... DATE : 17 July 1988
	200 400 800 SCALE IN METER		



LEGEND	COMMENT
	THIS MAP HAS BEEN CREATED BY SIMPLE SUPERIMPOSING THE TWO MAPS, "UG-WORK" AND "INFSTRUC" TO EXAMINE THE SUBSIDENCE THREAT TO THE RESIDENTIAL BUILDINGS AND OTHER STRUCTURES
	200 400 800 SCALE IN METER

Coal India

OPENCAST DIVISION
CENTRAL MINE PLANNING & DESIGN INSTITUTE
RANCHI 834008

PROJECT : BLOCK-II OCP

SUBJECT : SUBSIDENCE THREAT

ENGNR/UM : ..... EX ENGR : .....

DRG. NO. :

DRAWN BY : A B Samaddar DY CME (OC)

MAPCODE : SUBSDNCE

BCCL

GEOLOGIST : .....

DATE : 10 July 1988

Plate 6.9



LEGEND	COMMENT
N	THIS MAP HAS BEEN CREATED BY COVERING THE UNDERGROUND WORKING MAP "UG–WORK" BY THE PITLIMIT MAP "PITSURF" IE GIVING HIGHER PRIORITY TO "PITSURF"
	200 400 800 SCALE IN METER

Coal India

OPENCAST DIVISION
CENTRAL MINE PLANNING & DESIGN INSTITUTE
RANCHI 834008

PROJECT : BLOCK–II OCP
SUBJECT :
ENGNR/UM : ..... EX ENGR : .....
DRG. NO. :
DRAWN BY : A B Samaddar DY CME (OC)

MAPCODE : UG–WORK1
BCCL
GEOLOGIST : .....
DATE : 10 July 1988

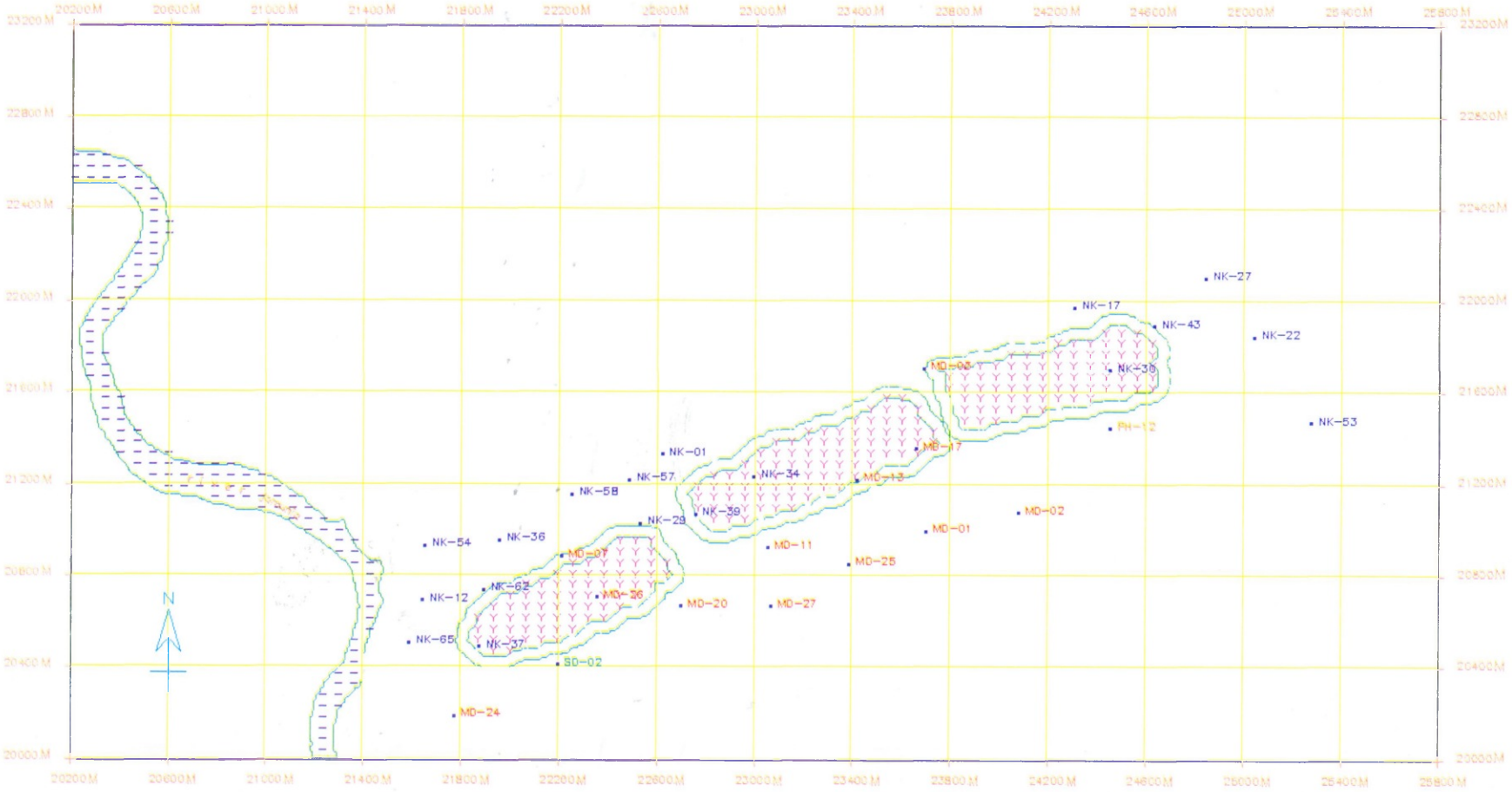
Plate 6.10



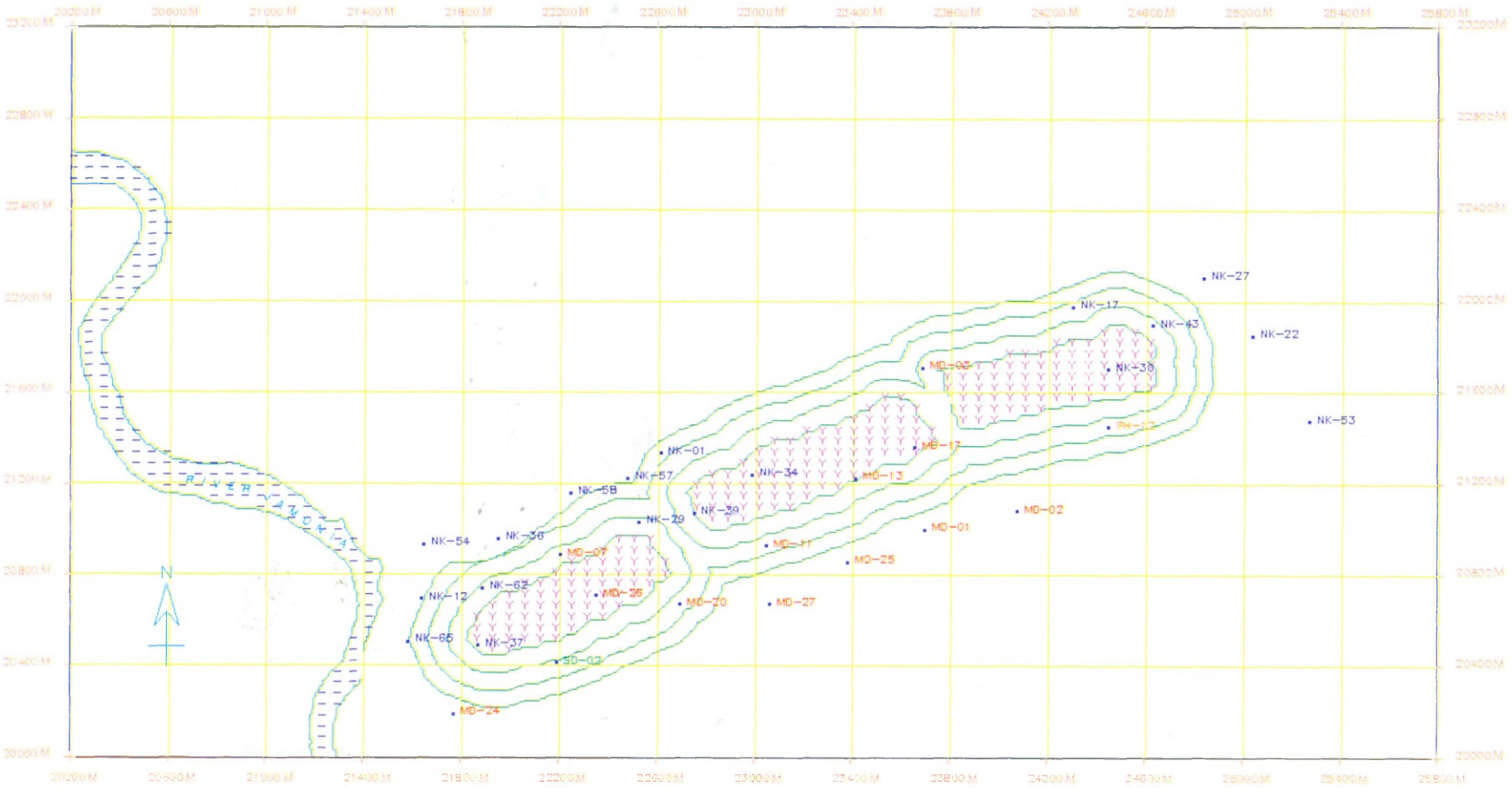
LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008
N	This map has been created by covering the pit limit map, "PITSURF" by the underground working map "UG–WORK" giving giving higher priority to "UG–WORK".	PROJECT : BLOCK–II OCP SUBJECT : ENGNR/UM : ..... EX ENGR : ..... DRG. NO. : DRAWN BY : A B Samaddar DY CME (OC)
	200 400 800 SCALE IN METER	MAPCODE : UG–WORK2 BCCL GEOLOGIST : ..... DATE : 10 July 1988

Plate 6.11

Plate 6.12

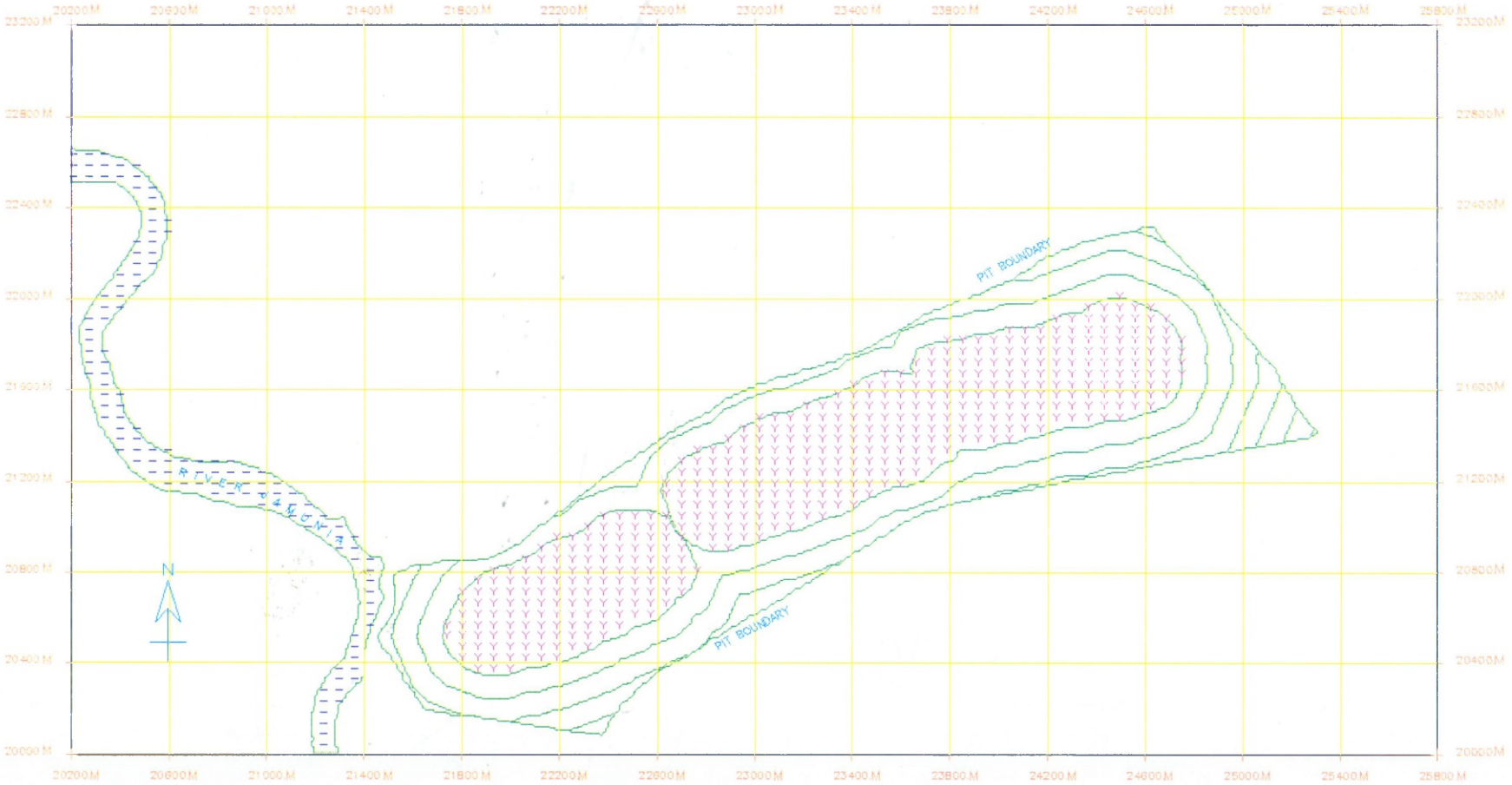


LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008
River Jamunia Present pit-floo	STAGE1 : The mine opens with three isolated pits only one bench has been opened at this stage Boreholes superimposed 200 400 800 SCALE IN METER	PROJECT : BLOCK-II OCP SUBJECT : FIRST STAGE OPENING ENGNR./UM : ..... EX. ENGR : ..... DRG. NO. : DRAWN BY : A. B. Samaddar DY. CME (OC)
		MAPCODE : STAGE1 BCCL GEOLOGIST : ..... DATE : 15 August 1985



LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008
River Jamunia Present pit-floo	STAGE2 : Expansion planned to be completed by September 1991 Three benches will be opened Boreholes superimposed SCALE IN METER	PROJECT : BLOCK-II OCP SUBJECT : SECOND STAGE IN PIT EXPANSION ENGNR/UM : ..... EX ENGR : ..... DRG. NO. : DRAWN BY : A B Samaddar DY CME (OC)
		MAPCODE : STAGE2 BCCL GEOLOGIST : ..... DATE : 15 August 1988

Plate 6.13



LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008
River Jamunia Present pit-floo	STAGE3 : Expansion, planned to be completed by September, 1995 Six benches at this stage Boreholes superimposed 200 400 800 SCALE IN METER	PROJECT : BLOCK-II OCP SUBJECT : THIRD STAGE IN PIT EXPANSION ENGNR/UM : ..... EX. ENGR : ..... DRG. NO. : DRAWN BY : A. B. Samaddar DY. CME (OC)
		MAPCODE : STAGE3 BCCL GEOLOGIST : ..... DATE : 15 August 1988

Plate 6.14

This set of commands forms a 'cartographic model' to simulate a future stage of the pit expansion. The map STAGE3 has been created in the same way, by SPREADing STAGE1 to 80 grid space, and then grouping the resulting map into 8. Here, RECA, A, TH and F are valid abbreviations for RECATEGORISE, ASSIGNING, THROUGH and FOR respectively. The capability of changing the map category values also is illustrated in this example.

Spreading operation can be used in the planning of waste dump or mill tailings disposal. In Plate 6.7, three seperate dumps (the first stage drawn interactively) were spread to simulate 4 different stages. If these dump sites were chosen (perhaps, for stacking different layers of soils before the commencement of backfilling), the question may arise how much waste might be dumped before initiating a slide into the river, or causing an obstruction to pit extension. Upto the second stage, none of these dumps will pose any problem. However, the dump 1 must not be extended beyond the second stage, dump 3 may not be extended beyond the third stage, whereas dump 2 can be used upto the stage 4.

The floor areas for all these dumps at each stage may be computed by using the graphics option, 'interrogate'. Thus, approximate volumes for the dumps for different stages, also may be calculated by using some slope angle or height.

Maps may be spread **ununiformly** through another map consisting of features (medium) with different weightage (category values). Plate 6.15 is an example of a thematic map of rocktype; the theme might be Rock Quality Designation (RQD), Protodyakonov Strength Index, joint classification etc. (No map has yet been made in the Project for such rock classifications; the map shown is a synthetic map of general classification chosen to illustrate the non-uniform spreading operation). Plate 6.16 illustrates the differential spreading. Higher weightage has been assigned to softer rock, assuming the spreading (propagation) phenomenon to be a 'shock' wave. This is useful for simulating mining progress through rock mass characterised by variable excavation conditions. Another application area may be enhanced blasting vibration assessment, where the propagation medium is anisotropic with distinctly different site specific constants.

Visibility is a common consideration in mine planning which would require advanced map processing. Let us assume that the map in Plate 6.15 is a map of spot heights. If an observer stands at a point which is shown on the map (Plate 6.17), and looks towards the East, the eye being at a height of 18 m above

the map datum, the area which will be visible within a distance of 5120 m may be described as shown on Plate 6.18. In the context of surface mining, this study is useful for planning lighting arrangement (many surface mines work in three shift; for example Block–II OCP) and for assessment of environmental impact (aesthesis of landscape).

There are other advanced operations, such as, creating a composite map to show the common area for several features. These common areas can be again assigned specific category values to give certain weightage. In Plate 6.19, the areas in the planned pit, where old quarries or underground workings exist which are believed to be problematic for mining, have been shown to display unreliable floor condition, or bad drilling condition. An area in the planned pit, where the underground workings and ponds exist may represent a further hazard from the blasting and excavation point of view. There may be other criteria specific to a mining condition for different operations of mining: mineral grade, rock type (such as Rock Quality Designation, RQD) and water content are typical examples.

6.3.7 Storage and retrieval of textual information spatially

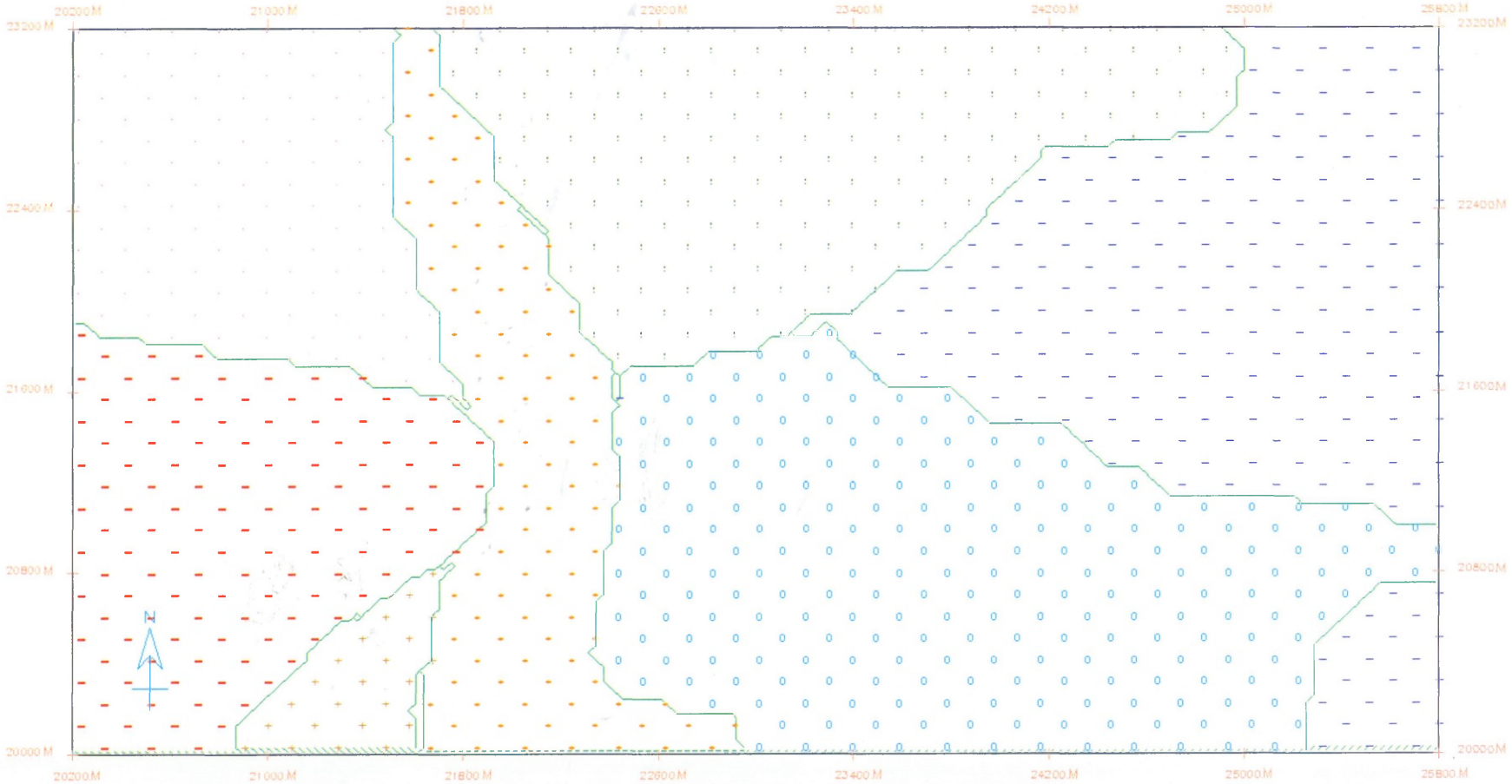
Textual information such as attributes assigned to a geographical location, borehole information or an equipment inventory are stored interactively. Map annotations are stored along with their positioning with reference to the geographic location, the angle of text alignment and the colour index of each text string. Various equipment (which are displayed as a sub-menu in the Equipment Management option), may be stored in the same way. In effect, this works as a user defined menu. Suppliers' names, model number, capacity, hours worked etc. may be stored and retrieved to provide an equipment inventory subsystem.

6.3.8 Interactive and non-interactive information management

Information management is carried out principally during interactive sessions in graphics mode. At present, the information management includes, identification of equipment locations, geographical locations, retrieval of borehole location and related data.

An interactive search can be made within geographic space. The northing and easting of a location on the displayed map will be reported when located by the cross-hair. Similarly, a feature name may be reported, and the area covered by

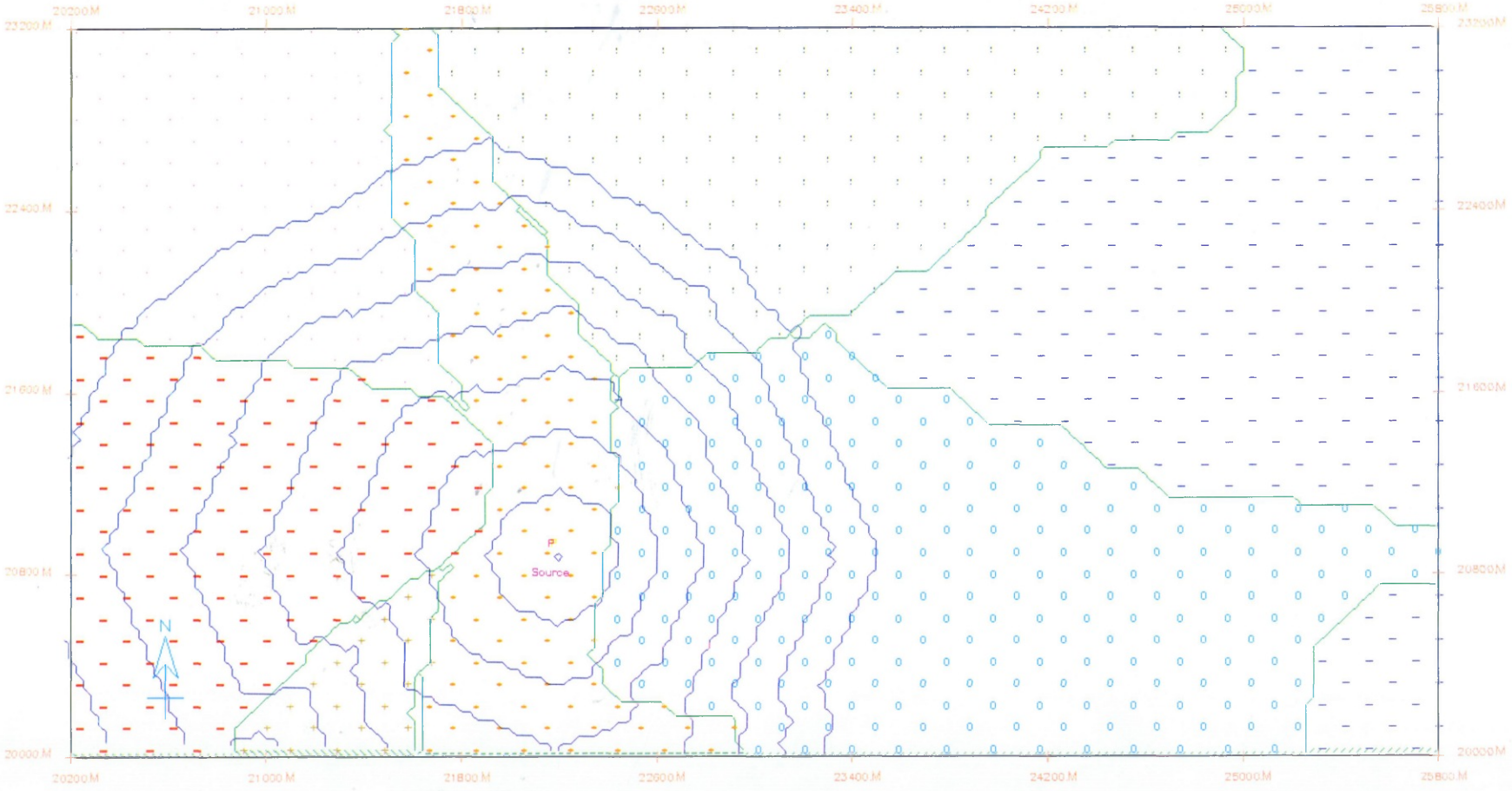
Plates 6.15 – 6.19



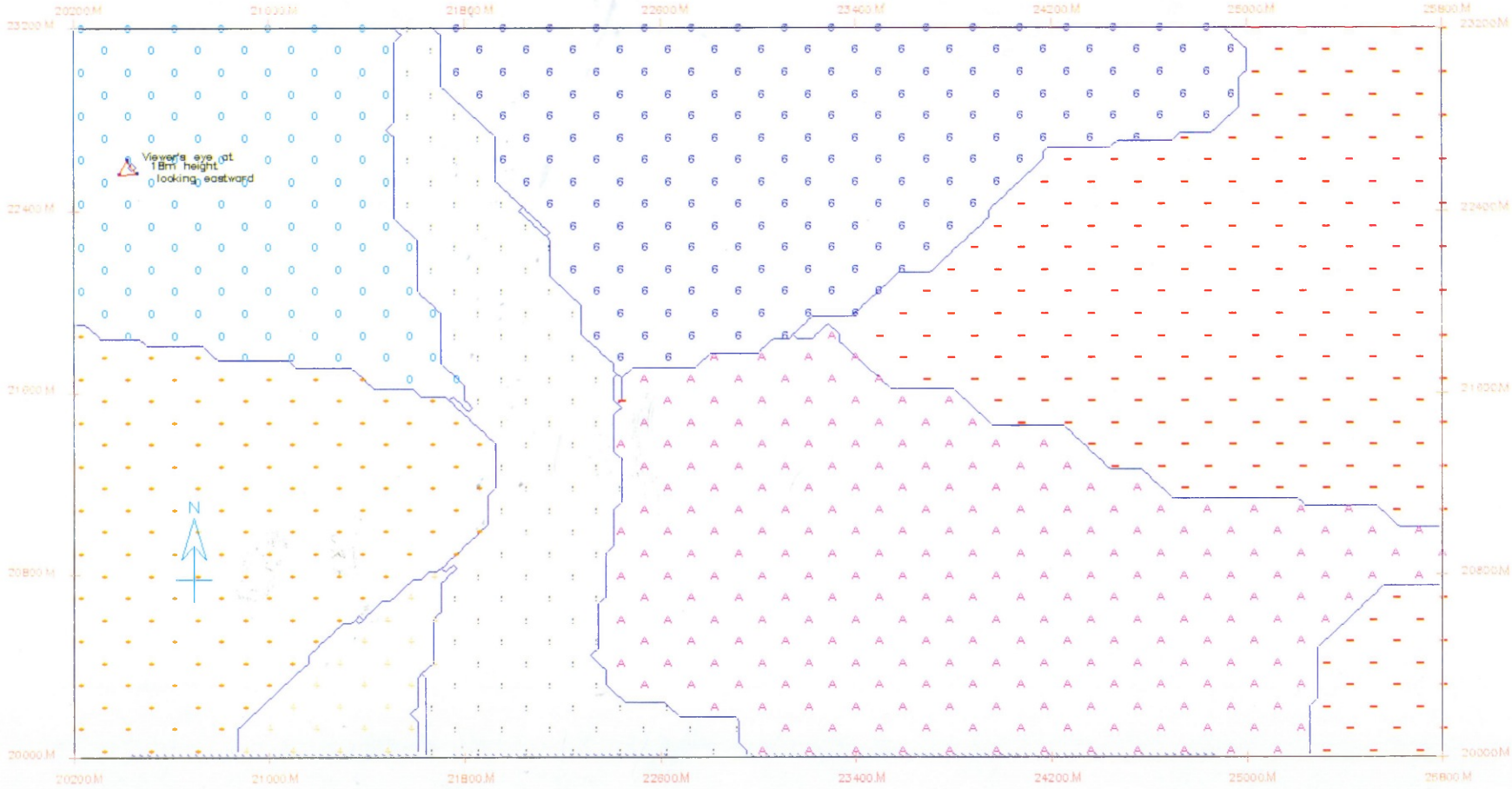
LEGEND	COMMENT	OPENCAST DIVISION
Rocktyp1—v. hard Rocktyp2— hard Rocktyp3—m. hard Rocktyp4— weak Rocktyp5—v. weak Rocktyp6—brittle Rocktyp7— soily	This map has been created by interactive drafting to demonstrate, how the rocktype can be mapped, if the rock is assessed according to RQD, RMQ, joints, site specific constant etc. THIS IS A LOW RESOLUTION MAP SCALE IN METER	CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008 PROJECT : BLOCK—II OCP SUBJECT : ROCKTYPE MAP ENGNR/UM : ..... EX ENGR : ..... DRG. NO. : DRAWN BY : A B Samaddar DY CME (OC) MAPCODE : ROCKTYPE BCCL GEOLOGIST : ..... DATE : 19 August 1988

Plate 6.15

Plate 6.16

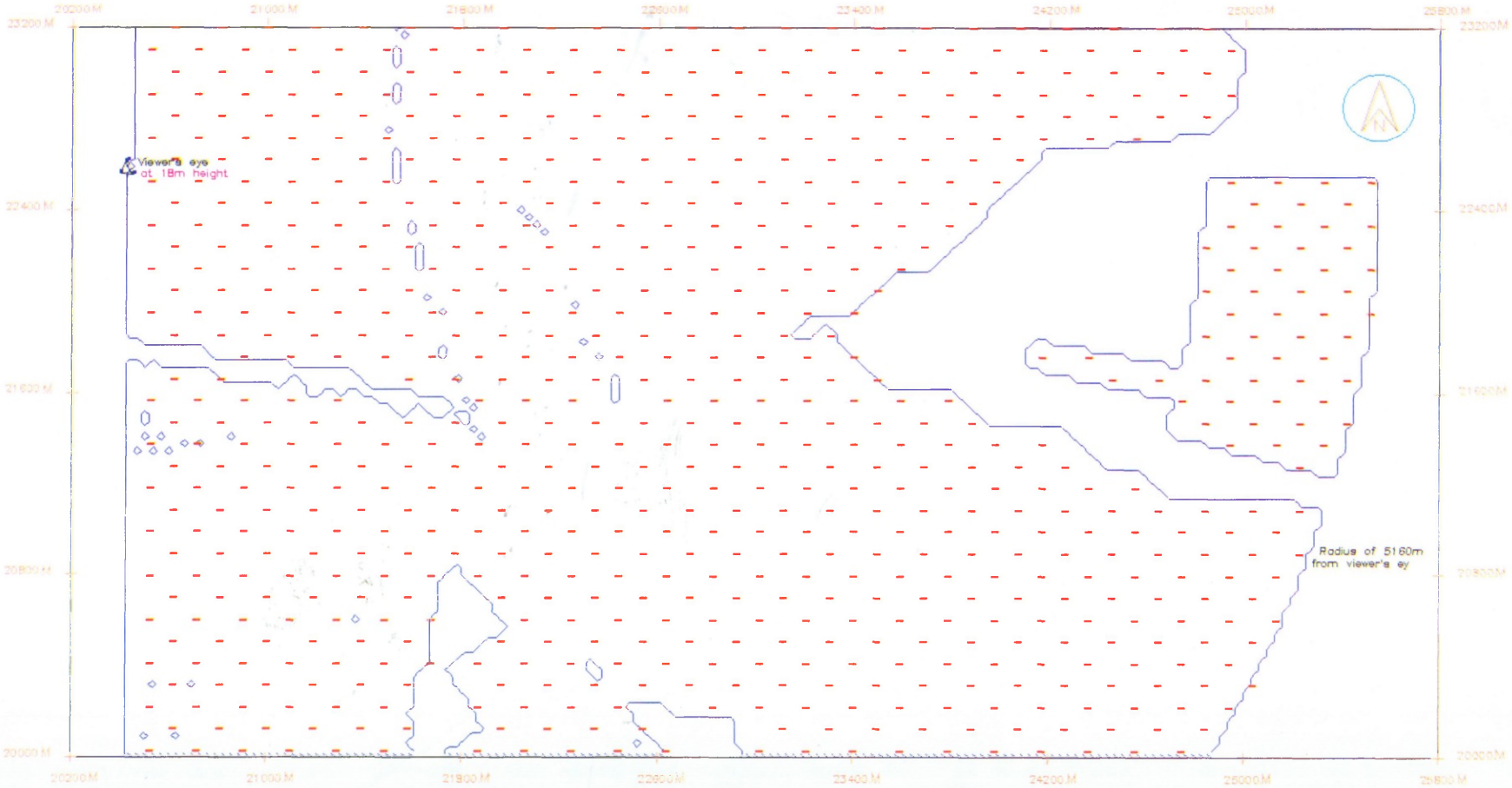


LEGEND	COMMENT	
Rocktyp1—v. hard Rocktyp2— hard Rocktyp3—m. hard Rocktyp4— weak Rocktyp5—v. weak Rocktyp6—brittle Rocktyp7— soily	This map illustrates weighted distance measurement capability of the system. *Propagation from the source, P is different through various rocktypes.* THIS IS A LOW RESOLUTION MAP. 200 400 800 SCALE IN METER	Coal India OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008 PROJECT : BLOCK-II OCP SUBJECT : PROPAGATION THROUGH POSSIBLE ROCKTYPES ENGNR/UM : ..... EX. ENGR : ..... DRG. NO. : DRAWN BY : A. B. Samaddar DY. CME (OC) MAPCODE : PROPAGAT BCCL GEOLOGIST : ..... DATE : 19 August 1988



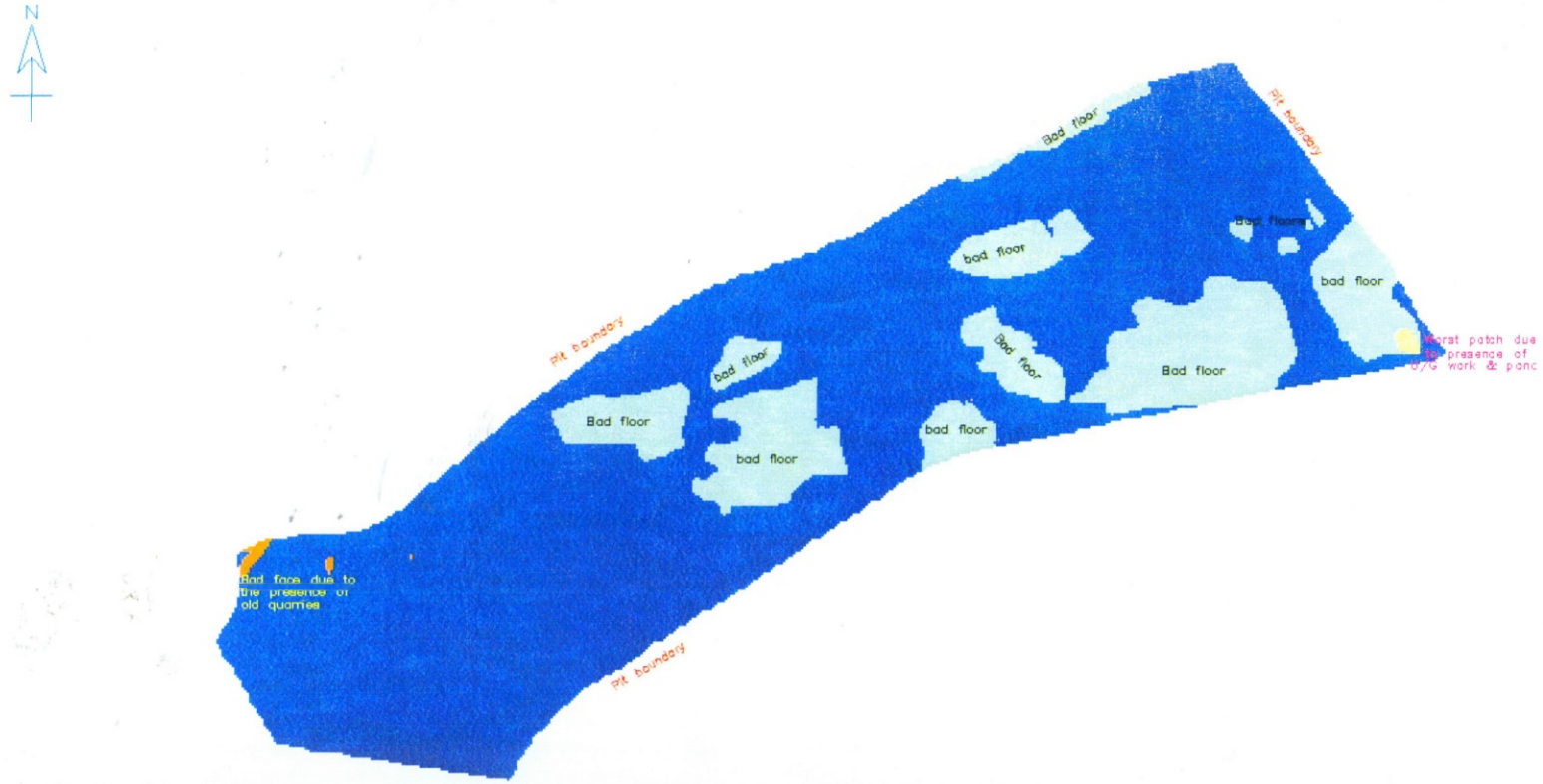
LEGEND	COMMENT		
2 metres 4 metres 8 metres 10 metres 14 metres 16 metres AAA 20 metres	This is a map showing the height at different areas. This is a synthetic map THIS IS A LOW RESOLUTION MAP Ø 200 400 800 SCALE IN METER	Coal India	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008 PROJECT : BLOCK-II OCP SUBJECT : TERRAIN HEIGHT ENGNR/UM : ..... EX ENGR : ..... DRG. NO. : DRAWN BY : A B Samaddar DY CME (OC) MAPCODE : HEIGHT BCCL GEOLOGIST : ..... DATE : 19 July 1988

Plate 6.17



LEGEND	COMMENT	OPENCAST DIVISION
Area not visible Area visible	This map has been created to study as the visibility from a certain point at a certain height over the map area to certain distance This is a low resolution map 400 0 400 800 SCALE IN METER	CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008 PROJECT : BLOCK-II OCP SUBJECT : VISIBILITY MAP ENGNR/UM : ..... EX. ENGR : ..... DRG. NO. : DRAWN BY : A. B. Samaddar DY. CME (OC) MAPCODE : VISIBLTY BCCL GEOLOGIST : ..... DATE : 19 July 1988

Plate 6.18



LEGEND	COMMENT		
	This map has been created to show how the user can prepare a map with any combination with any weightage, defining certain phenomenon, say minability.	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008	
	200 0 200 400 SCALE IN METER	PROJECT : BLOCK-II OCP SUBJECT : USER'S DEFINED MINABILITY ENGNR/UM : ..... EX ENGR : ..... DRG. NO. : DRAWN BY : A. B. Samaddar DY. CME. (OC)	MAPCODE : BADPACH BCCL GEOLOGIST : ..... DATE : 29 August 1998

Plate 6.19

the feature will be computed when identified by the graphics pointer. Geographic locations of equipment may also be reported in a similar way. Plate 6.20 shows the position of some equipment retrieved and displayed superimposed on the working plan of the mine. Borehole locations and numbers may be retrieved and plotted in a similar fashion (refer to Plate 6.5, 6.12, 6.13). Some information regarding the mapbase such as number of maps, and the category values for any map can be retrieved, using query commands in text mode, provided the user has the right privilege to access the information requested.

6.3.9 Picture generation (raster plotting)

The package provides a picture generation facility using raster plotting and different map categories may be 'painted' with different colours. Plate 6.21 shows such a plot of a map, SURFIMAG consisting of some surface features, old underground workings, and the planned pit limit. Plates 6.1, 6.19 also are generated using raster plotting.

6.4 ZOOMING OPTIONS

Usually, zooming is performed by activating one of the sub-mapbases. Plate 6.22 shows a map WATER (consisting of two features, the pit limit and the river) in Sector 2 at Level 1 (refer to the mapbase structure in Section 4.5). A map of a feature at Level 1 or lower, in an area which is not covered by a single sector, may be created by WINDOWing. Plate 6.23 shows a map of subsidence at Level 1 covering all the four sectors. The window area has been shown with a rectangle on the subsidence map at Level 0 (Plate 6.9). Plate 6.24 shows a window at Level 2 of the map, WORKPLAN (Plate 6.8 on which the window area has been shown with a superimposed rectangle).

6.5 GENERAL APPLICATION AREA

The maps and other information used in the illustrations has been collected from an open pit mine because the package has been developed with the primary objective of applying in the surface mines. However the package can be used as a general AM/GIS system to perform standard cartographic functions and for advanced map manipulations; the application extends to mining township, national resources management, environment and others. The spatial information

retrieval capability of the system makes it a powerful tool as/in a Management Information System (MIS), applied to any organisation involved in land management and/or thematic mapping, such as, forestry, various census agencies, bureaux of mines or land usage. Besides storage and retrieval of maps, some of the advanced capabilities available include weighted distance measurement and characterisation of neighbourhoods which find application in many other disciplines. The spatial information retrieval capabilities including computation of the surface area of a feature, reporting feature identities, plotting geographic locations, and reporting the locational identity of geographic space on a displayed map, find application in environment monitoring, land management, government administration etc.

6.6 SURFACE MINE APPLICATIONS

The capabilities listed and illustrated may find many uses in mine management and planning. Some of the capabilities may find immediate application in:

- *on-line communication during mining;*
- *short-term and long-term planning;*
- *meetings and conferences;*
- *monitoring the rapid change in landscape;*
- *teaching and training;*
- *integration of geographic information.*

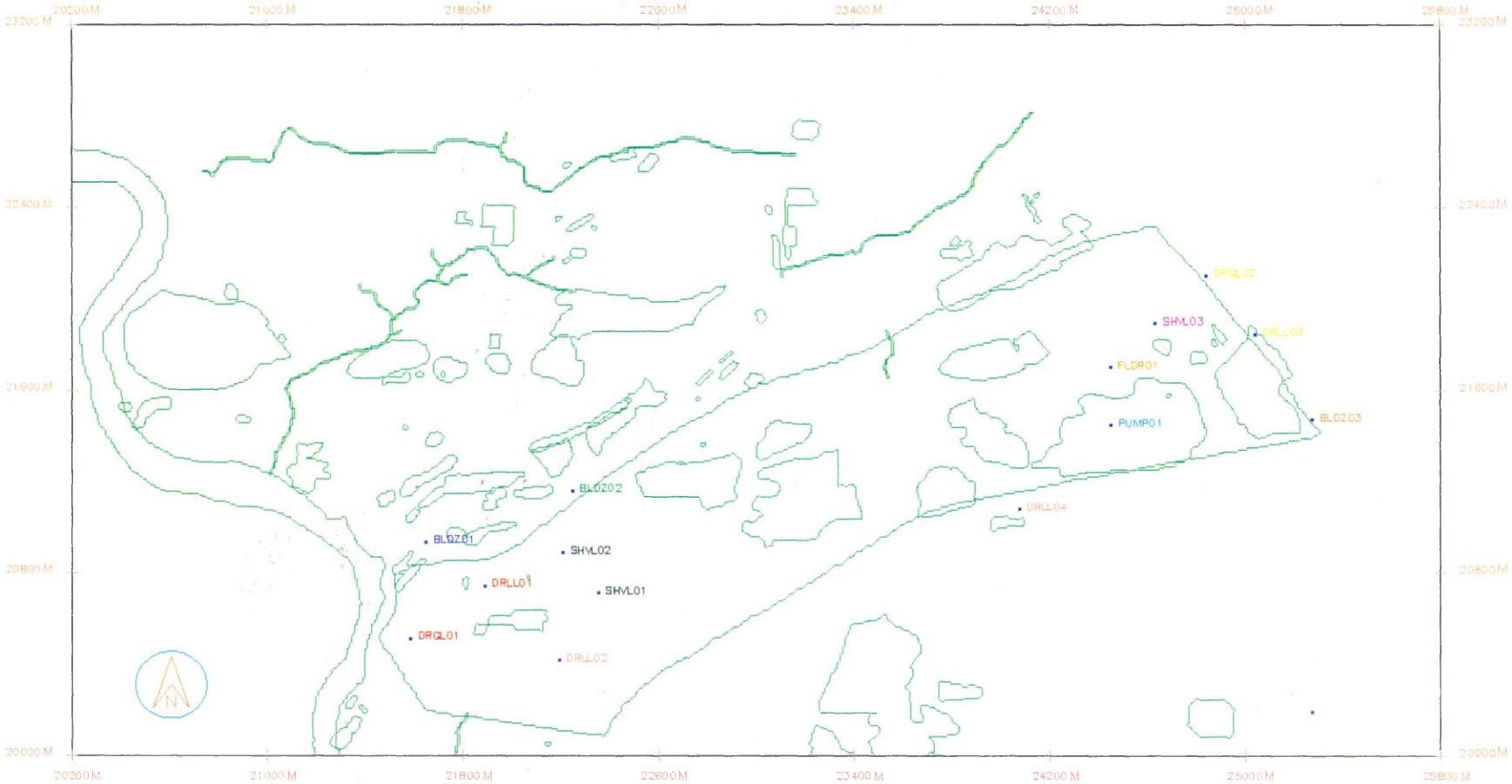
6.6.1 on-line communication during mining

On a LAN (Local Area Network) or in a multi-user rôle, the same mapbase may be used by different users. The package allows information or instructions to be conveyed through maps reflecting a plan proposal or additional information, and bearing necessary comments, which can be displayed or plotted for examination by another remote user.

6.6.2 short-term and long-term planning

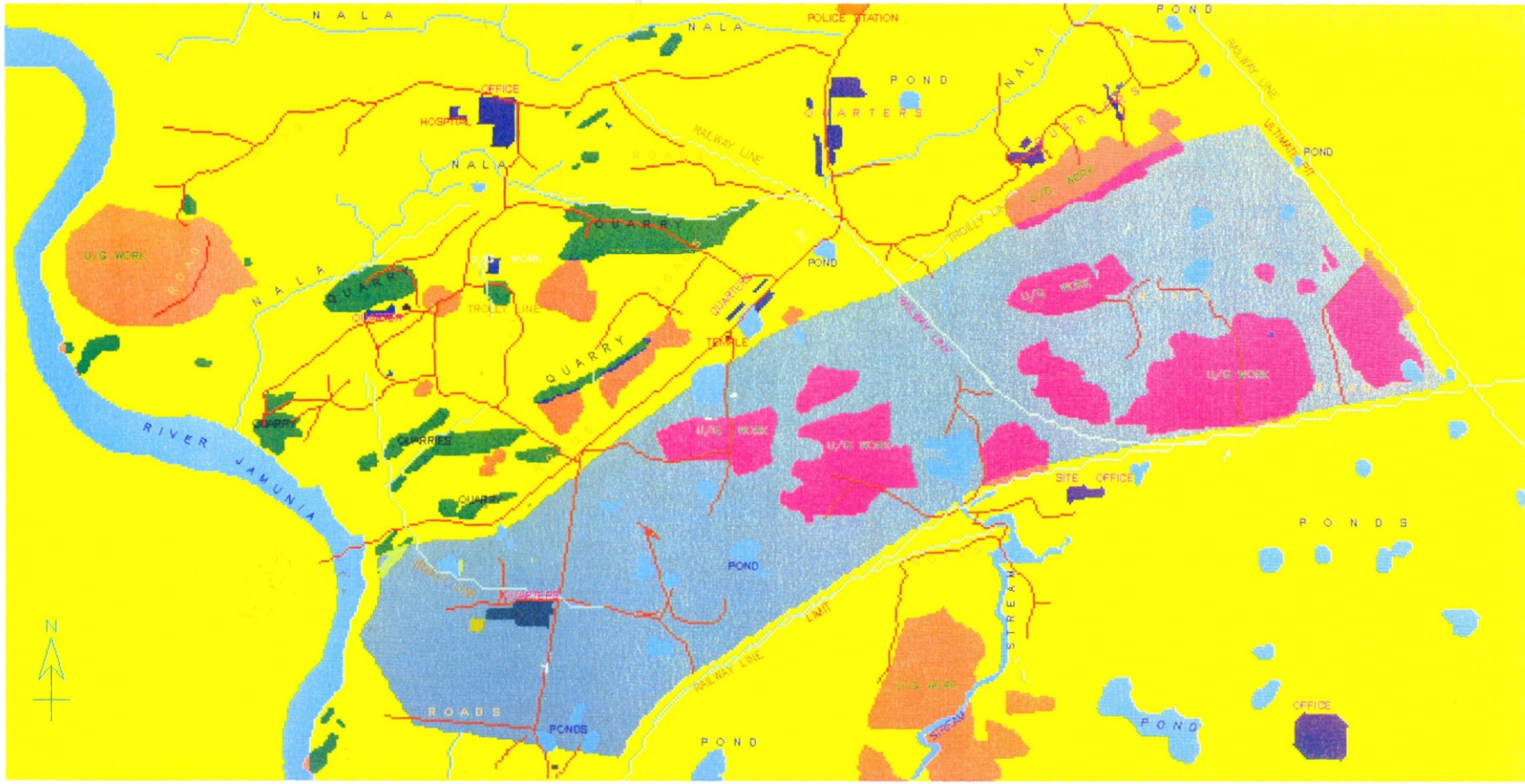
Thematic maps plays an important rôle in mine design and planning. In the scope of mining, thematic maps may be of ore grade, rock quality, slope angle or some other property of engineering or managerial importance. An example of a metal mine has been used for presenting grade map(s). Plate 6.25 shows features of

Plates 6.20 – 6.24



LEGEND	COMMENT	
DRGL – Dragline excavator SHVL – Shovel BLDZ – Bulldozer DRLL – Drilling machine FLDR – Front-end loader PUMP – Electric pump	This map shows the position of the equipment as on date 200 400 600 SCALE IN METER	Coal India OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008 PROJECT : BLOCK-II OCP SUBJECT : EQUIPMENT POSITION AS ON DATE ENGNR/UM : ..... EX. ENGR : ..... DRG. NO. : DRAWN BY : A. B. Samaddar DY. CME (OC) MAPCODE : WORKPLAN BCCL GEOLOGIST : ..... DATE : 22 July 1988

plate 6.20



LEGEND	COMMENT
	THIS IS TO SHOW RASTER PLOTTING CAPABILI –TY OF 'DIRECT–1'. SOME IMAGE PROCESSING TECHNIQUES HAVE BEEN USED TO ANALYSE AND MANIPULATE DIFFERENT MAP CATEGORIES. LOGICAL OVERLAYING MAY BE NOTICED. THE STREAM IS OVER U/G WORK, THE ROADS ON STREAM, AND SO ON. 200 400 800 SCALE IN METER

Coal India

OPENCAST DIVISION
CENTRAL MINE PLANNING & DESIGN INSTITUTE
RANCHI 834008

PROJECT : BLOCK–II OCP

SUBJECT : IMAGE OF A SIMULATED SURFACE

ENGNR/UM : ..... EX. ENGR : .....

DRG. NO. :

DRAWN BY : A B Samaddar DY CME (OC)

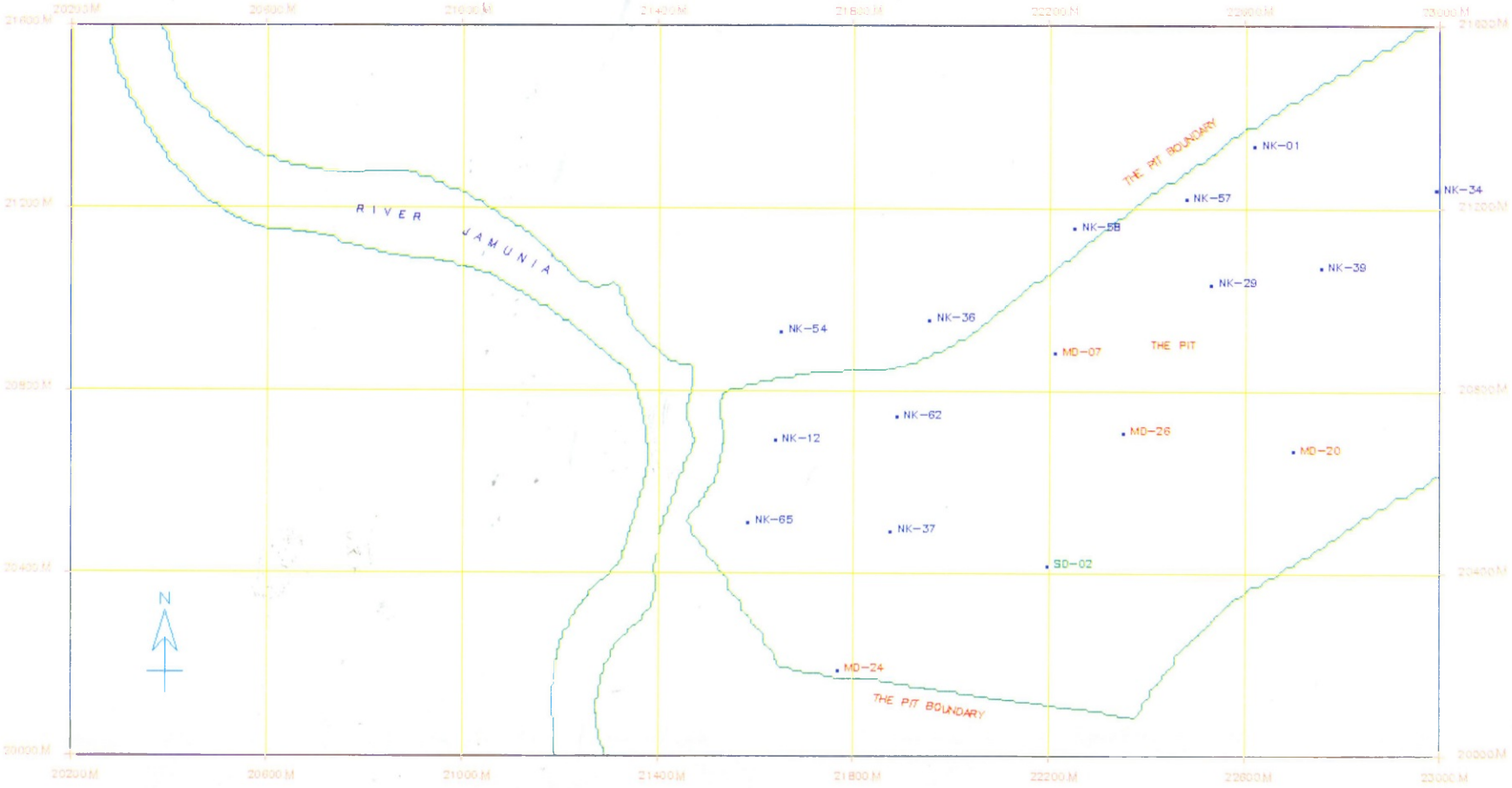
MAPCODE : SURFIMAG

BCCL

GEOLOGIST : .....

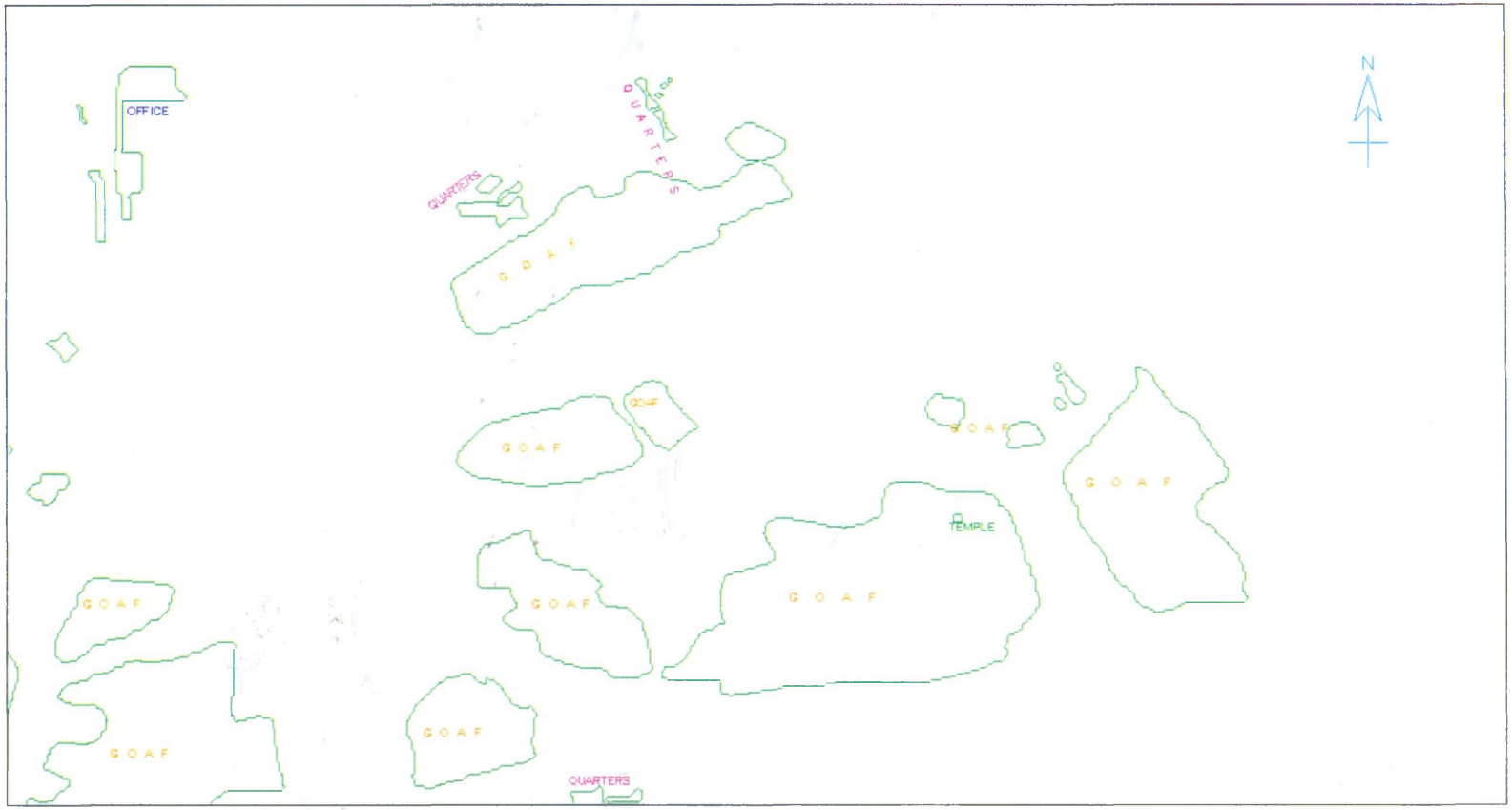
DATE : 07 March 1988

Plate 6.21



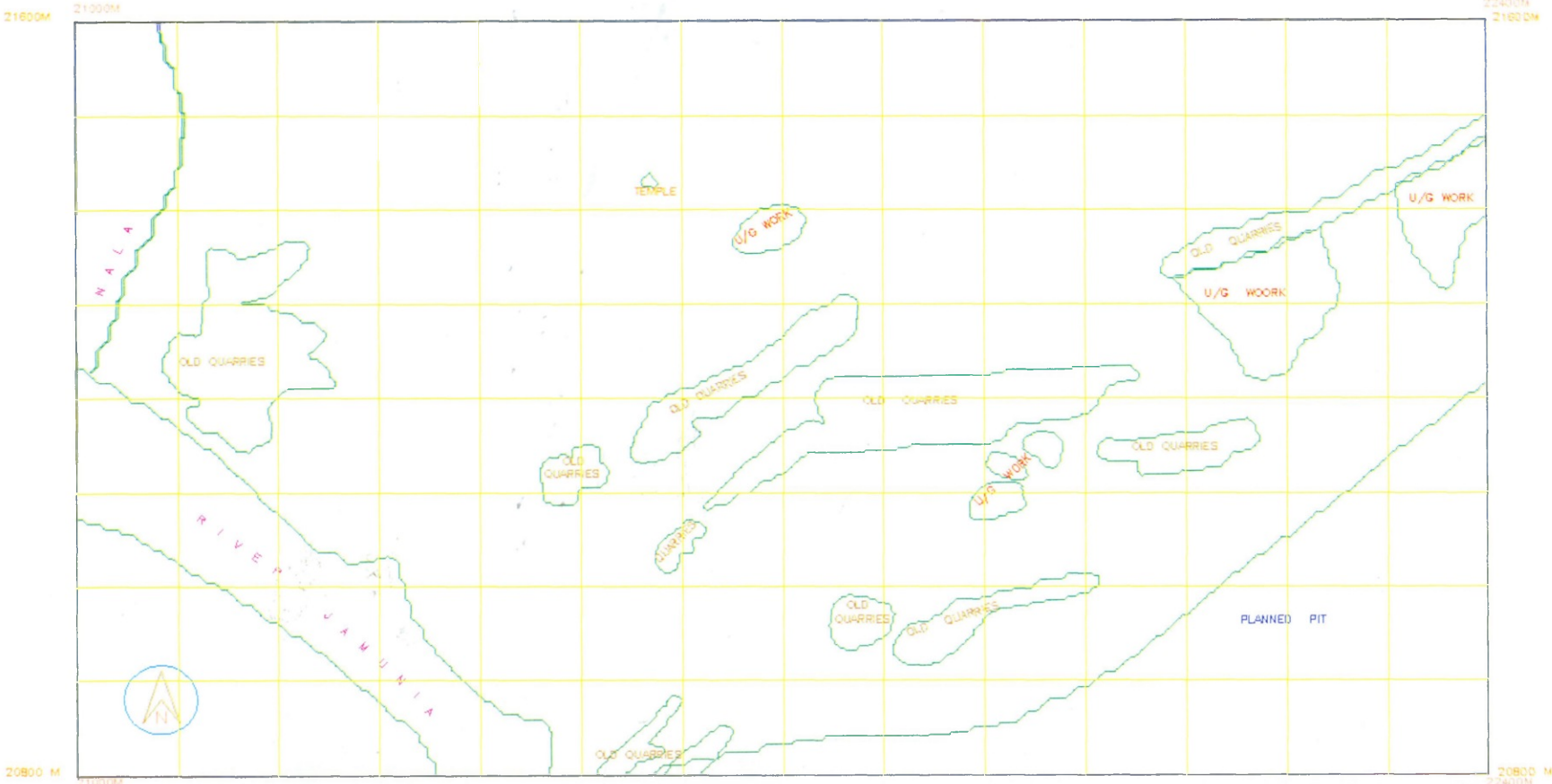
LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008	
	THIS IS SECTOR 2 AT LEVEL 1. This map has been created by adding two maps, 'RIVER' and 'PITSURF'. The change in scale representation and the grid reference may be noted SCALE IN METER	PROJECT : BLOCK-II OCP SUBJECT : RIVER AND THE PIT ENGNR/UM : ..... EX. ENGR : ..... DRG. NO. : DRAWN BY : A. B. Samaddar DY. CME (OC)	MAPCODE : WATER BCCL GEOLOGIST : ..... DATE : 19 July 1988

Plate 6.22



LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008	
	THIS MAP IS SUBSIDENCE MAP AT LEVEL 1 SHOING MORE DETLS THAN LEVEL 0 HAS BEEN CREATED BY WINDOWING THIS ILLUSTRATE ZOOMING FACILITY	PROJECT : BLOCK-II OCP SUBJECT : LOCAL SUBSIDENCE THR EAT ENGNR/UM : ..... EX ENGR : ..... DRG. NO. : DRAWN BY : A B Samaddar DY CME (OC)	MAPCODE : SUBSWNDW BCCL GEOLOGIST : ..... DATE : 10 July 1988
	200 400 600 SCALE IN METER		

Plate 6.23



LEGEND	COMMENT
	This map has been created at level 2, the scale being 2M per grid cell. This gives an accuracy of 1 metre. If compared with the WORKPLan map at LEVEL 0, it can be clearly seen how much details has come o out at lower level (higher resolution). 200 400 800 SCALE IN METER

Coal India

OPENCAST DIVISION
CENTRAL MINE PLANNING & DESIGN INSTITUTE
RANCHI 834008

PROJECT : BLOCK-II OCP

SUBJECT : WORKING PLAN

ENGNR/UM : ..... EX ENGR : .....

DRG. NO. :

DRAWN BY : A. B Samaddar DY CME (OC)

MAPCODE : LVL3WNDW

BCCL

GEOLOGIST : .....

DATE : 8 August 1988

Plate 6.24

grade and the variance, placed side by side. The copper grade and variance were estimated by Sarkar (1988), for Quellaveco porphyry copper deposit (at 3900 m level) in Peru. The raster map is created with the thematic values by using one of the 'tools' of the system (refer to Section 5.4.1); values up to two decimal places and blocks of 40 m × 40 m size have been used. The variance is classified into two groups if the data is used with a precision of 2 decimal places. It is different on Plate 6.26, where values are considered upto three decimal places, and the blocks are 20 m × 20 m. As a result, a wider range of grade and variance is revealed. This forms an example how the system may be used for visual examination in a sensitivity analysis. For planning, however, the grade needs to be grouped into a fewer classes. Any classification of this kind can be accomplished by using the command, GROUP. On Plate 6.27, the left feature shows the grade grouped into 5. Legend of the grades is not provided, since no interface has been yet developed for this type of application. The feature at the right, on Plate 6.27, a specific range (0.450% to 0.756%) has been shown in a single group. It may represent an economically minable orebody if 0.450% is considered to be cut off grade (which is unusual for copper; this is just an assumption for the illustration).

Besides the map making functions, the other functions such as retrieval of sections, spreading of pits or dumps, are useful in medium to long-term planning. Blast design and blasting vibration assessment may be of significant value in short-term planning, or day-to-day mining. Plate 6.28 shows the plan of a 'blast round' designed using the interactive draughting facility. In the map BLSTVIB (Plate 6.29), the simplified assessment of blasting vibration zones has been shown in circular areas for some planned blasts. The different surface areas covered by the circles show the damage prone zones for three different type of structures. The assessment is carried out on the basis of the weight of the explosive charge per delay, the site specific constant (determined by experimental crater blasting, refer to I/S study in Section 4.8), the maximum allowable particle velocity for different structures (as set by the State Government), and the location of the blast (marked interactively by the cross-hair or display pointer).

6.6.3 communication in meetings and conferences

In any planning meeting, interactive map display and information retrieval will obviously create a better understanding among participants. The DIRECT system therefore, embodies some features for interactive conferencing. In the context of conference discussions, multiple access to data and plans may be provided to

resolve planning issues. The information stored provides an essential archive to support reconciliation between forecast and actual production.

6.6.4 monitoring rapid change in landscape

It is a dynamic system; geographic or spatial data (usually from surveying) or other information could be input directly to automatically update the mapbase and associated information. The system might therefore perform a continuous monitoring rôle within the planned mine.

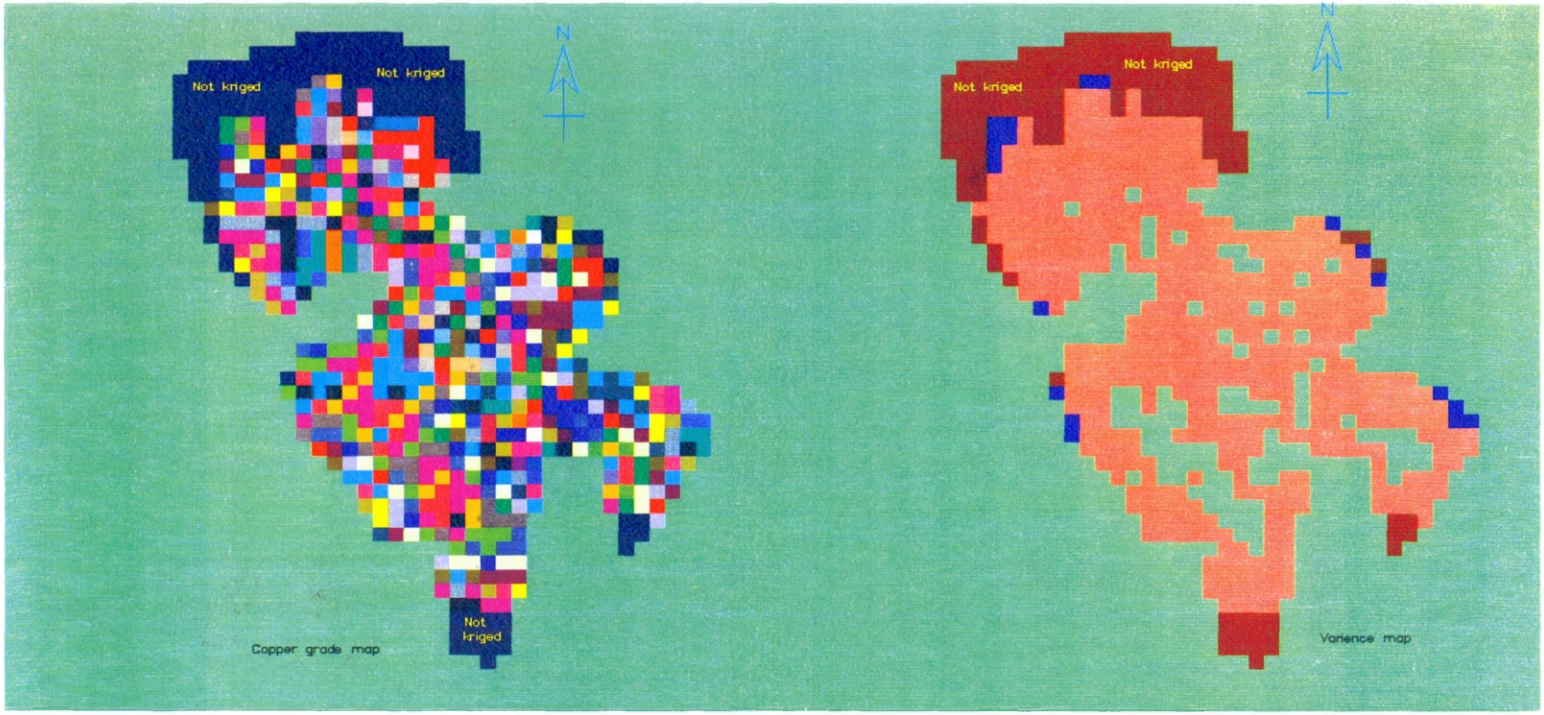
6.6.5 teaching and training

The package can provide a vehicle for demonstrations, teaching, and training. Several maps can be displayed in quick succession and visual answers to many speculative planning matters may be provided by creating or modifying plan(s) relevant to a design. The system is therefore valuable in training and allows users to cultivate design skills and explore innovative planning schemes. Beyond, teaching and training in the System's applications, the package can be used to demonstrate the underlying grid cell structure of any map. Plate 6.30 shows such an example where the grid cells (100 row $\times$ 175 column) have been made apparent by superimposing grid lines, at an interval of one grid cell, on a raster plot of the surface.

6.6.6 integration of geographic information

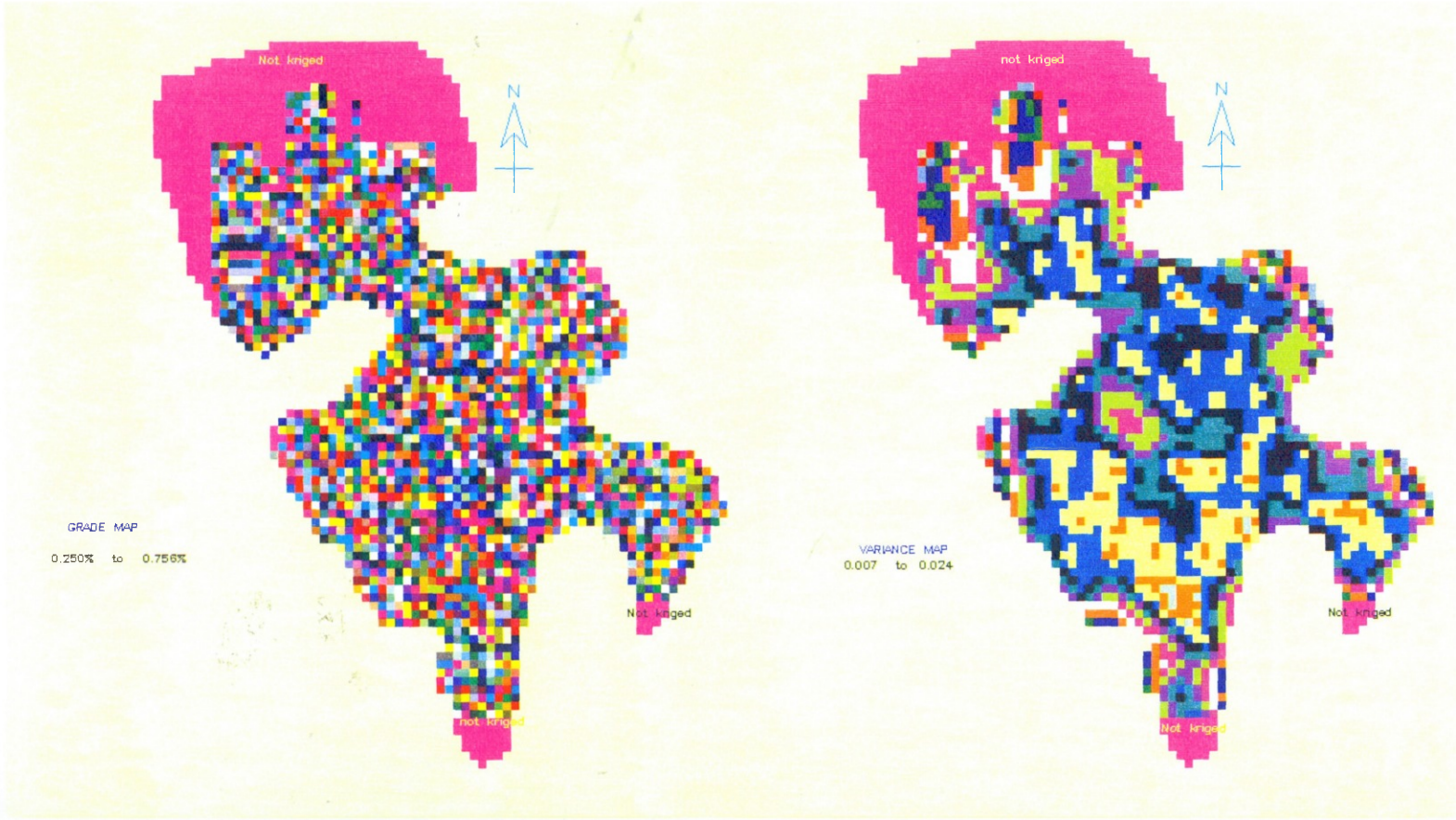
Raster plots of vector maps allow the user to compare various sources of geographic information and provide a cross validation of data as well as a means of interaction between thematic and geographical information. Satellite images or aerial photographs, such as thermal gradient maps which may be utilised more meaningfully to monitor spontaneous ignition or in general ergonomic studies using overlays. Specially, in an area like Jharia Coal Field, where underground fire and water logged areas are abundant, temperature (fire) and water maps, which may be derived by geophysical means may be of additional value.

Plates 6.25 – 6.30



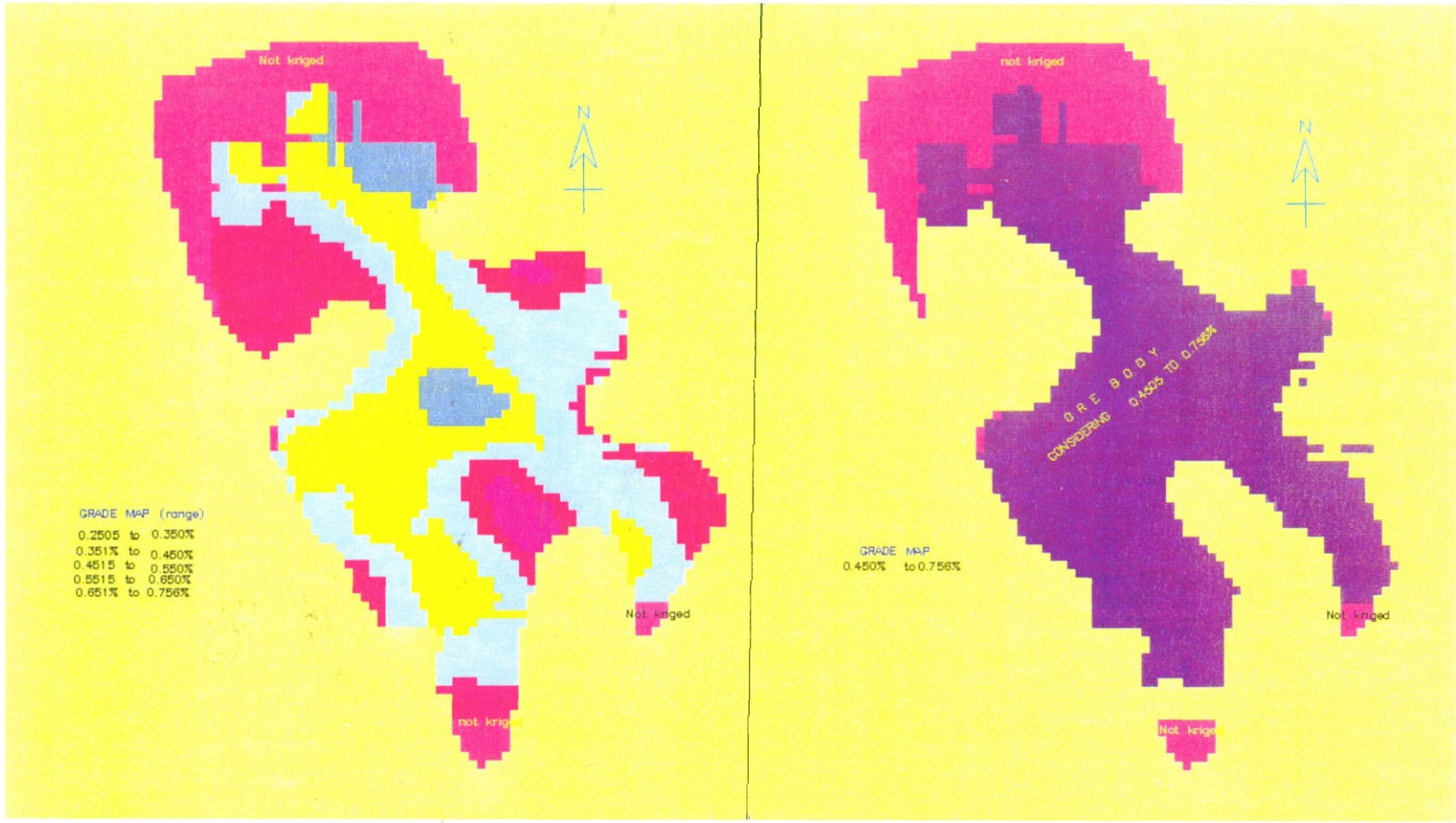
LEGEND	COMMENT	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008
	This is a thematic map of two themes; Copper grade and the variance a result of kriging. The scale given below is not applicable 0 SCALE IN METER	Porphyry Copper PROJECT : PORYPHRY MINE SUBJECT : COPPER GRADE AND VARIENCE GEN. MANAGER : ..... MANAGER : ..... DRG NO. : DESIGNED : A. B. Samaddar DY. CME (OC) MAPCODE : CU_GRD_V BCCL SR. GEOLOGIST : ..... DATE : 19 July 1988

Plate 6.25



LEGEND	COMMENT		MINING DIVISION QUELLAVECO COPPER LIMITED
	the scale below is not applicable	Pryhry Cpr.	PROJECT : PORYPHRY MINE SUBJECT : GRADE AND VARIANCE GEN. MANAGER : ..... MANAGER : ..... DRG. NO. : DRAWN BY : A. B. Samaddar DY. CME (OC)
	200 400 800 SCALE IN METER		MAPCODE : GRD–VRN QCL SR. GEOLOGIST : ..... DATE : 15 August 1998

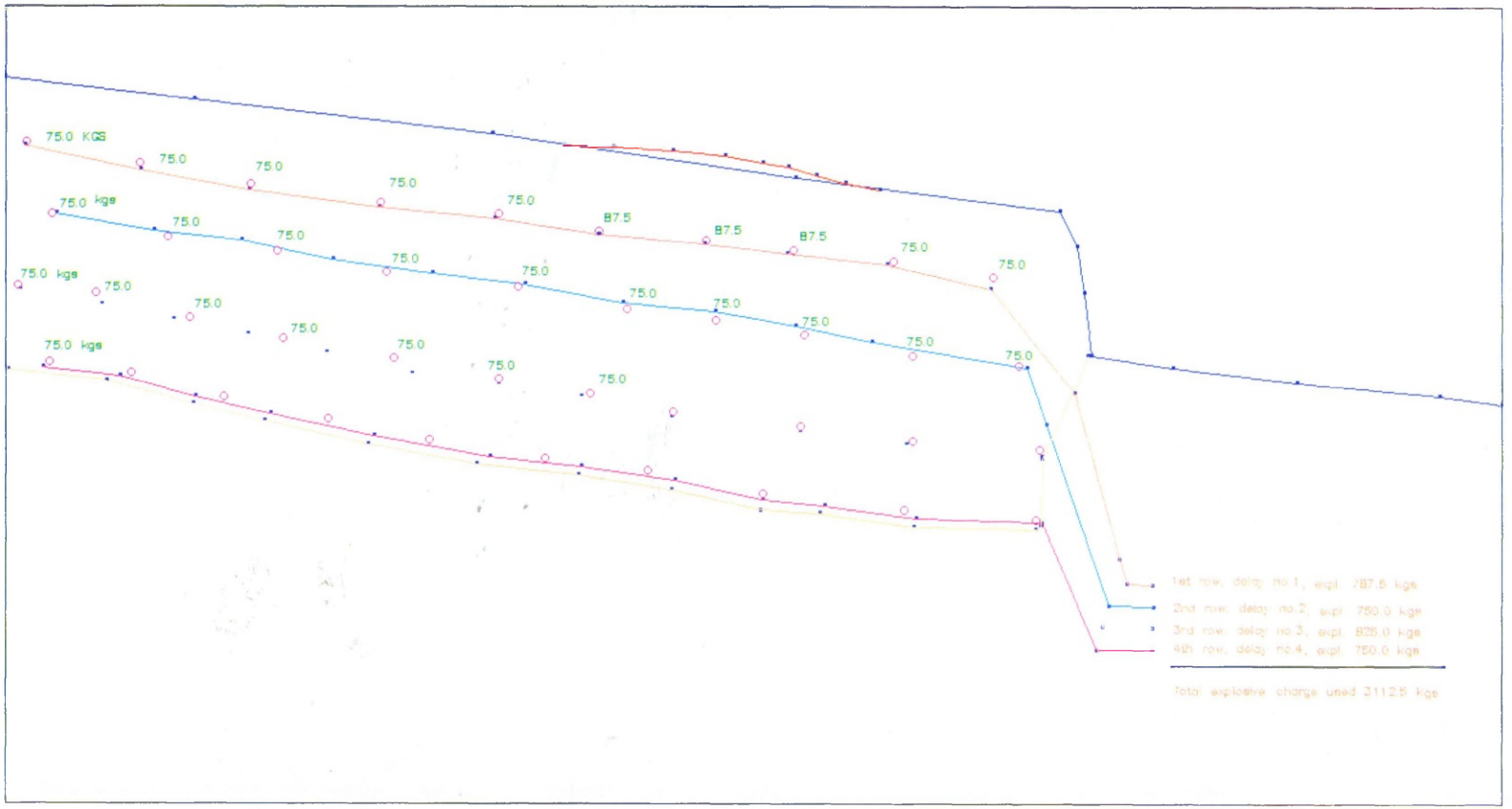
Plate 6.26



LEGEND	COMMENT		MINING DIVISION QUELLAVECO COPPER LIMITED	
	This map shows the copper grade grouped into wider ranges (left map). The map at the right shows the economical minable orebody if 0.450 to 0.7565 is considered to be economic (unusual for copper). The scale below is not applicable 200 400 800 SCALE IN METER	Prphry Cpr.	PROJECT : PORYPHRY MINE SUBJECT : GRADE MAP WITH DIFFERENT RANGE GEN. MANAGER : ..... MANAGER : ..... DRG. NO. : DRAWN BY : A B Samaddar DY CME (OC)	MAPCODE : GRD—VRN2 QCL SR. GEOLOGIST : ..... DATE : 15 august 1988

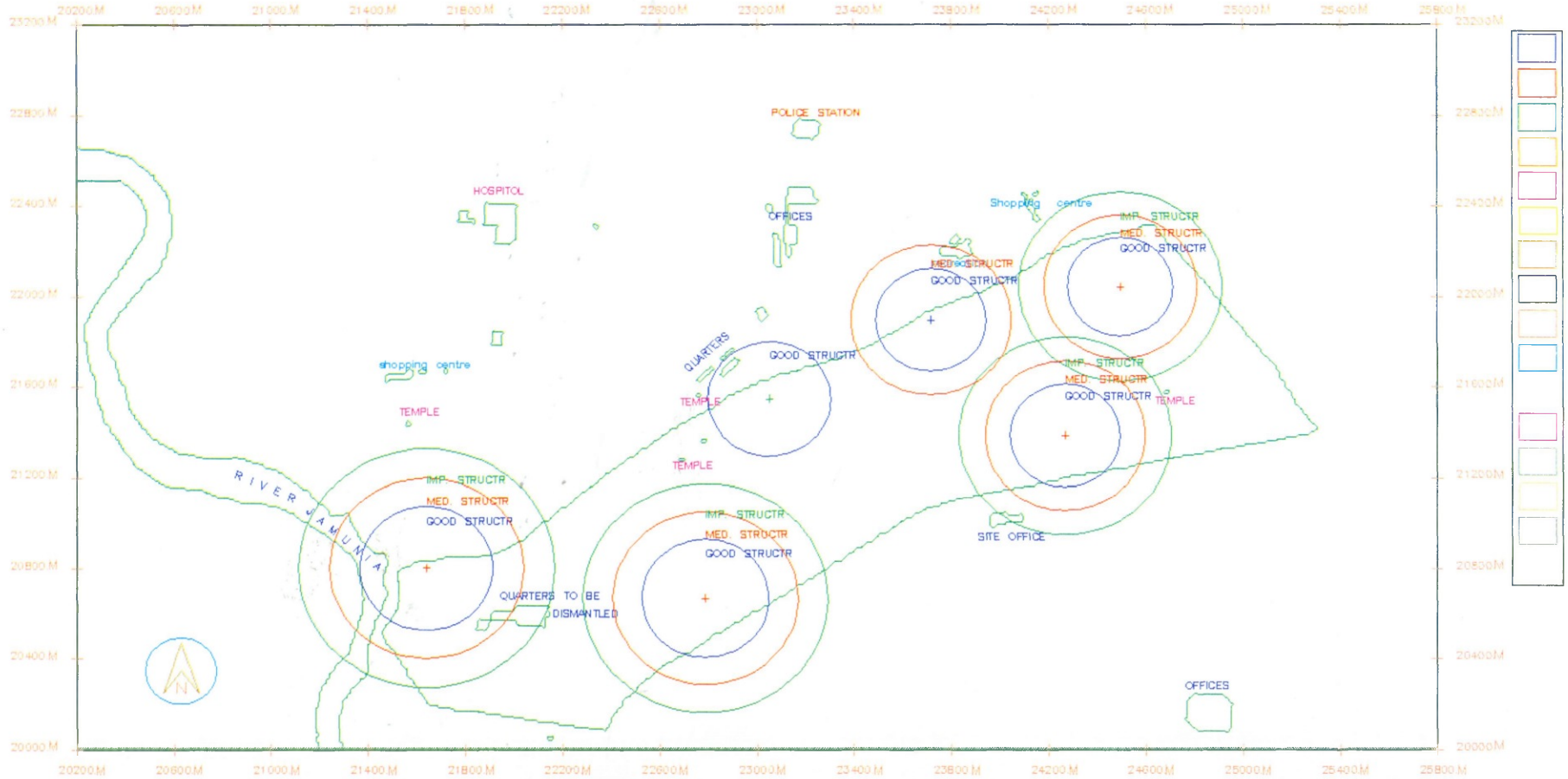
Plate 6.27

Plate 6.28



LEGEND	COMMENT	
Blasting face Toe Blast holes Expected face after blast Burden = 4m approx. Spacing = 6m approx. Bench height = 9m Blast hole dia = 250mm Explosive type: ANFO	This is a plan of a small blast in the over burden in the top bench The scale shown below is not applicable SCALE IN METER	Coal India OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008 PROJECT : BLOCK-II OCP SUBJECT : BLAST PLAN, 5TH BLAST, 28 AUGUST ENGNR/UM : ..... EX. ENGR : ..... DRG. NO. : DRAWN BY : A. B. Samaddar DY. CME (OC) MAPCODE : BLS28AUG BCCL GEOLOGIST : ..... DATE : 19 August 1988

END	ADD TEXT AT ANY ANGLE	ADD TEXT ALONG A LINE	COPY FROM ANOTHER MAP	COPY TEXT ON THIS MAP	CHANGE A TEXT COLOUR	DELETE ANY	REDISPLAY	EXIT		
CHANGE										
HARDCOPY	ANNOTATE	GRID	RASTER PLOT	NORTH POINT	TITLE BLOCK	LEGEND	CROSS SECN.	DIGITISE ETC	TO COMMAND	EXIT
OFF ON	ROCK TYPE	GEOLOGY	COAL GRADE	BOREHOLE INF	EQUIPMENT	MANAGE BLAST	CONTOUR	INTERROGATE	PLOT	



LEGEND	COMMENT
	This map shows the pitlimit, the river and the structure, living quarters, hosp hospitol, office etc. Blasting vibration effect zone (for various type of structure) have been superimposed.

SCALE IN METER

Coal India

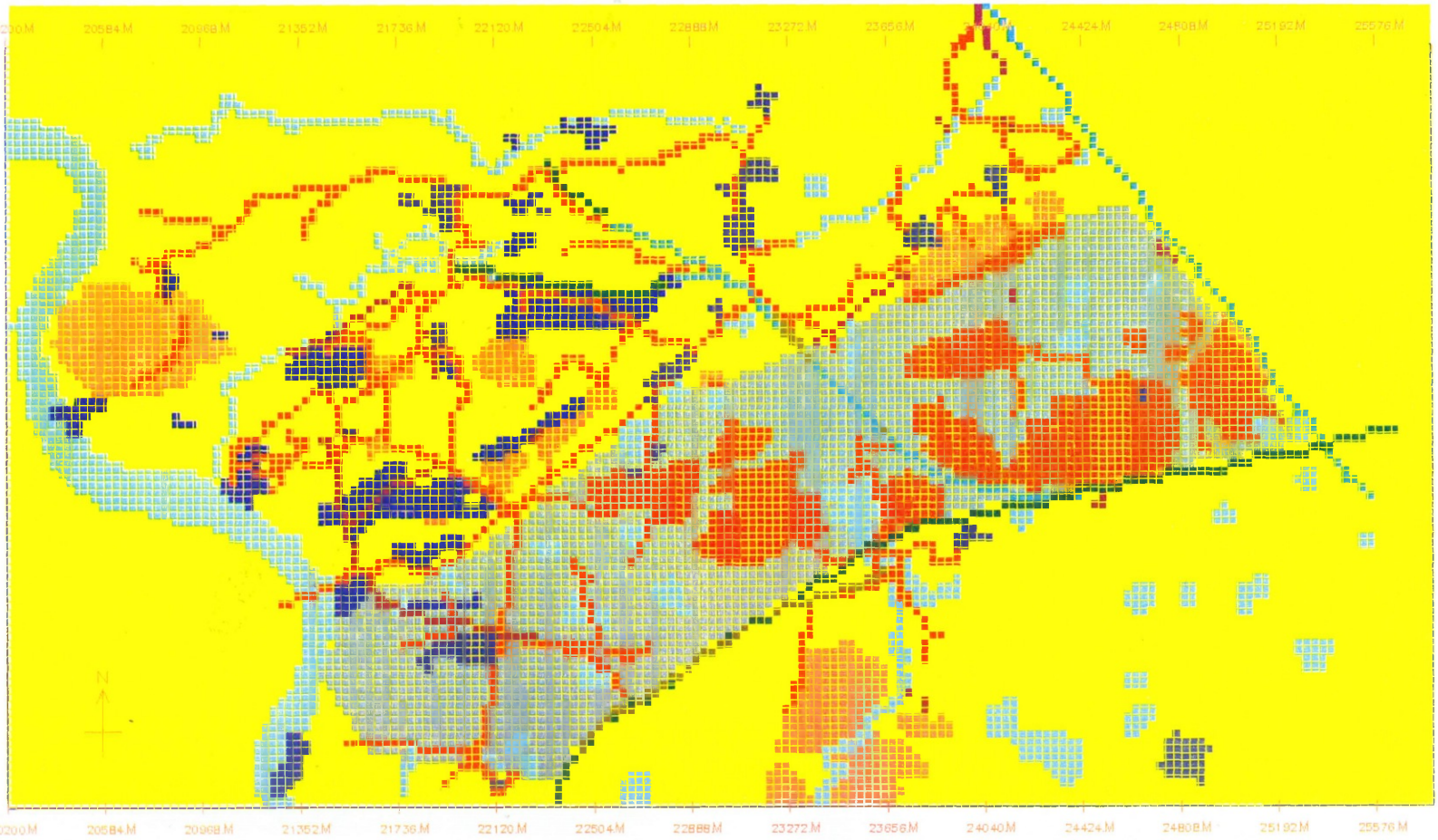
OPENCAST DIVISION
CENTRAL MINE PLANNING & DESIGN INSTITUTE
RANCHI 834008

PROJECT : BLOCK-II OCP
SUBJECT : BLAST VIBRATION EFFECT
ENGNR/UM : ..... EX ENGR : .....
DRG. NO. :
DRAWN BY : A. B. Samaddar DY. CME (OC)

MAPCODE : BLSTVIB
BCCL
GEOLOGIST : .....
DATE : 22 July 1988

END	BLAST DETAIL	GOOD STRUCTR	MED. STRUCTR	IMP. STRUCTR	DELETE	EXIT				
CHANGE										
HARDCOPY	ANNOTATE	GRID	RASTER PLOT	NORTH POINT	TITLE BLOCK	LEGEND	CROSS SECN.	DIGITISE ETC	TO COMMAND	EXIT
OFF ON	ROCK TYPE	GEOLOGY	COAL GRADE	BOREHOLE INF	EQUIPMENT	MANAGE BLAST	CONTOUR	INTERROGATE	PLOT	

Plate 6.29



LEGEND	COMMENT
N	This map was created by adding several feature maps and then by overlaying on the map closed interval grid lines to illustrate the raster map — grid cell map Low resolution has been used for the illustration 200 400 800 SCALE IN METER

Coal India

OPENCAST DIVISION

CENTRAL MINE PLANNING & DESIGN INSTITUTE

RANCHI 834008

PROJECT : BLOCK-II OCP

SUBJECT : TEMPERATURE MAP

ENGNR/UM : ..... EX. ENGR : .....

DRG. NO. :

DRAWN BY : A. B. Samaddar DY. CME (OC)

MAPCODE : SURFIMAG

BCCL

GEOLOGIST : .....

DATE : 22 July 1988

Plate 6.30

Chapter 7

CONCLUSION AND DIRECTION OF FUTURE RESEARCH

Chapter 7

CONCLUSION AND DIRECTION OF FUTURE RESEARCH

7.1 SUMMARY OF THE WORK

A system has been established for providing AM/CAD software for mining and other land users. A prototype package has been developed to demonstrate this system, by integrating mapping and draughting capabilities with a Geographic Information System (GIS). Query language, text menus, graphics menus and spatial keys have been used for storage, retrieval and processing of maps and related information. Enhanced map retrieval schemes used in the package are provided through a hierarchical system of submapbases, whereas each mapbase is created on a relational model. The prototype provides the foundation for a multiuser planning system and database with applications both within and beyond the mining industry.

Efficient algorithms for conversion and restoration of vector to and from raster representation, have been developed to exploit image processing techniques to provide advanced methods of map manipulation.

An information system study has been carried out at an open pit mine, and the general requirements of maps and the user's interface were identified; an enhanced user interface has been written. Local area network (LAN) and wide area network (WAN) requirements for implementation of the system, has been suggested. Special aspects of a database system, 'integrity', 'security', 'privacy' and 'concurrency' have been addressed comprehensively in developing the package.

Basic software engineering guidelines have been followed in developing the package and recommendation have been made for the future modification and enhancement.

7.2 FUTURE MODIFICATION AND EXPANSION

7.2.1 Planned Extension

Some modification and expansion have been planned for immediate enhancements. The prototype will be modified and expanded to offer :

1. Real time geological and geo–technical section generation from octree encoded deposit models derived from borehole, adit or blasthole sampling data. Octree encoding technique is briefly discussed in the next Section.
2. Correlation of any oblique grid with a standard local or national grid.
3. Display of borehole log; geotechnical (RQD, compressive strength etc.) and lithology.
4. Integration of software for generation of real time contours of surface topography, isopaches and tessellation plot. Plate 7.1 shows a cross hatched, colour, surface topography contour. Plate 7.2 shows contour lines superimposed on a raster plot of the surface. These have been generated by interfacing a contouring program with DIRECT–1.
5. Geo–technical information management.
6. Detailed mineral grade information management and control.
7. Detailed equipment inventory.
8. 3D representation and display. Plate 7.3 shows the perspective view of the surface produced from borehole collar elevations. The plot was generated by interfacing SOLID, a 3D plotting package with the database system of DIRECT–1; this is a so called $2\frac{1}{2}$D representation. For advance 3D modelling and spatial indexing, **octree encoding** will be adopted.
9. An extended symbol library.
10. A blasting management subsystem using a Knowledge-Based Expert System (KBES) (Samaddar, 1983).
11. An Integrated Geographic Information System (IGIS) to utilise aerial photographs, satellite imagery and geophysical data directly. Figure 7.1 illustrates the hardware-software concept of the proposed enhanced system.

Plates 7.1 – 7.3

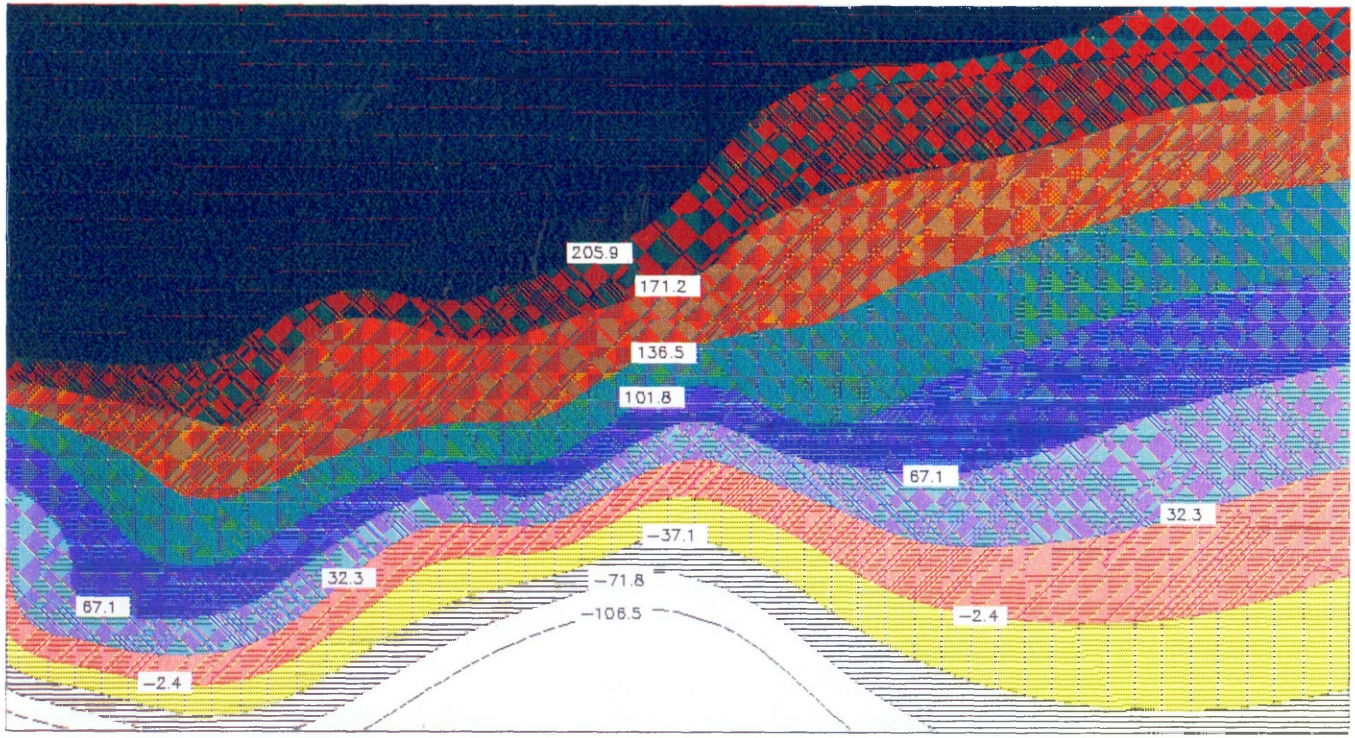
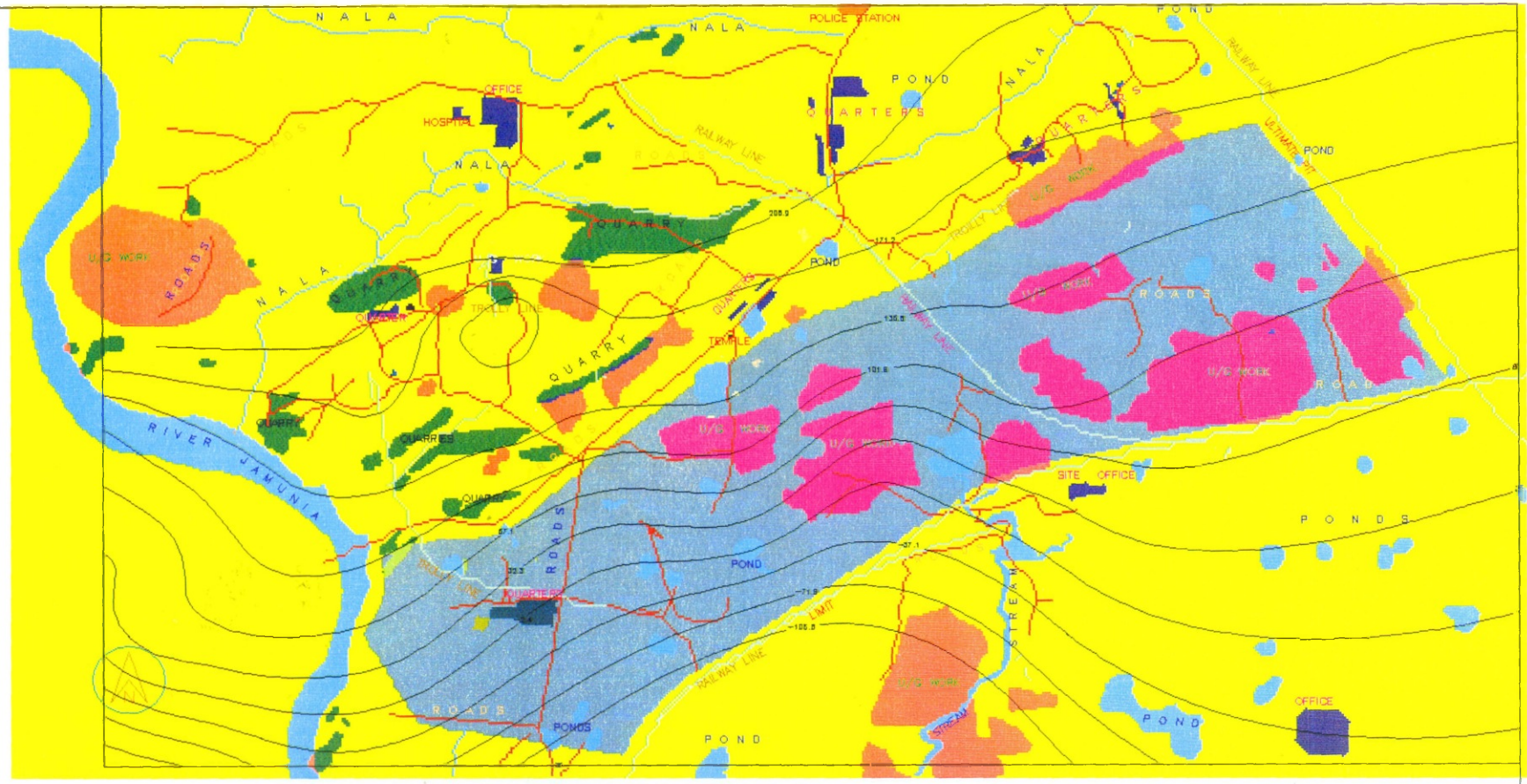


Plate 7.1



LEGEND	COMMENT		
N	THIS IS A RASTER PLOT OF THE SEMI-SIMULATED SURFACE SURFACE ELEVATION CONTOUR GENERATED FROM BOREHOLE COLLAR HEIGHTS, HAVE BEEN SUPERIMPOSED 200 400 600 SCALE IN METER	Coal India	OPENCAST DIVISION CENTRAL MINE PLANNING & DESIGN INSTITUTE RANCHI 834008
		PROJECT : BLOCK-II OCP SUBJECT : SURFACE IMAGE & CONTOUR SUPERIMPOSED ENGNR/UM : ..... EX ENGR : ..... DRG. NO. : DRAWN BY : A B Samaddar Dy CME (OC)	MAPCODE : SURFIMAG BCCL GEOLOGIST : ..... DATE : 1 August 1988

Plate 7.2

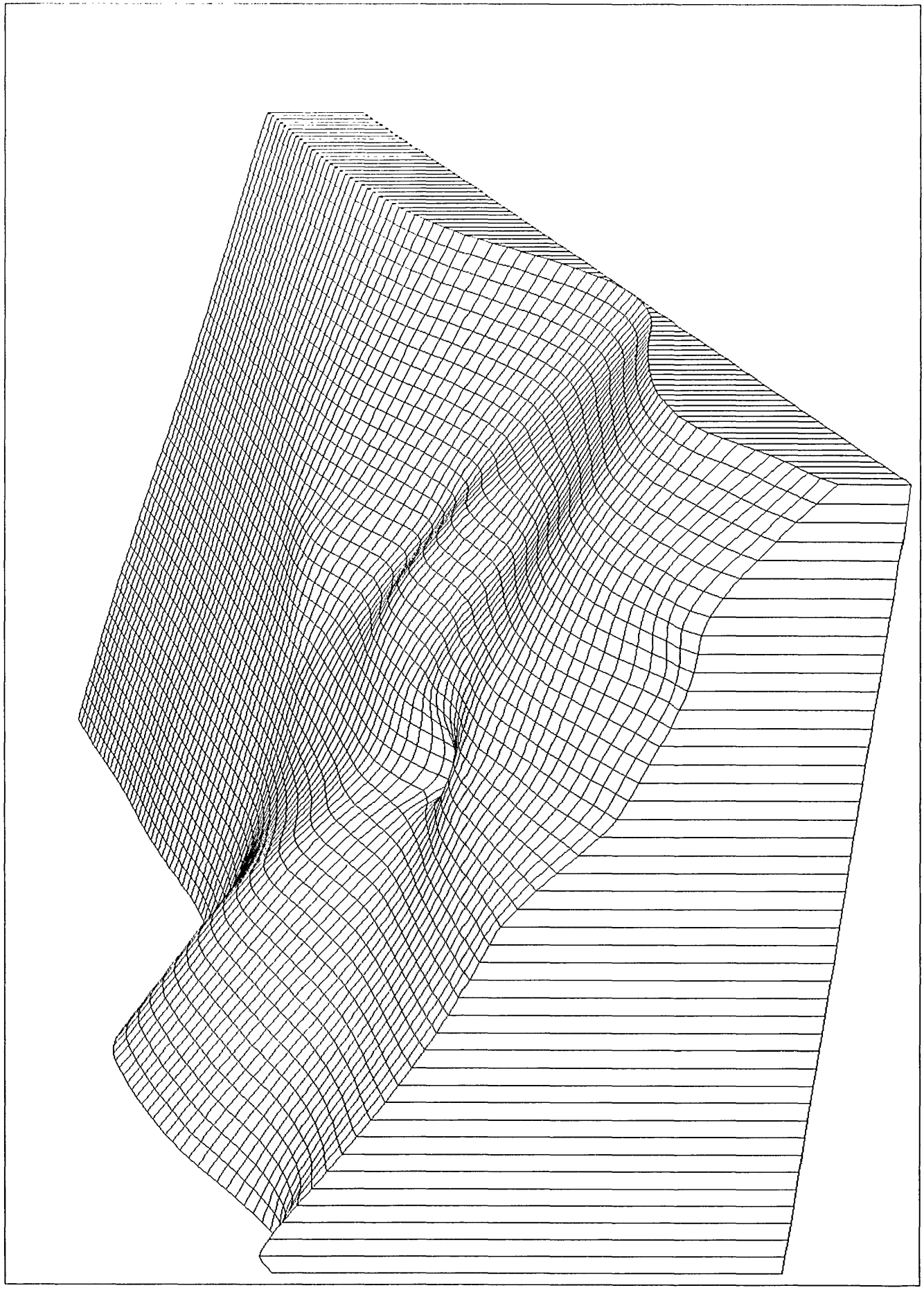


Plate 7.3

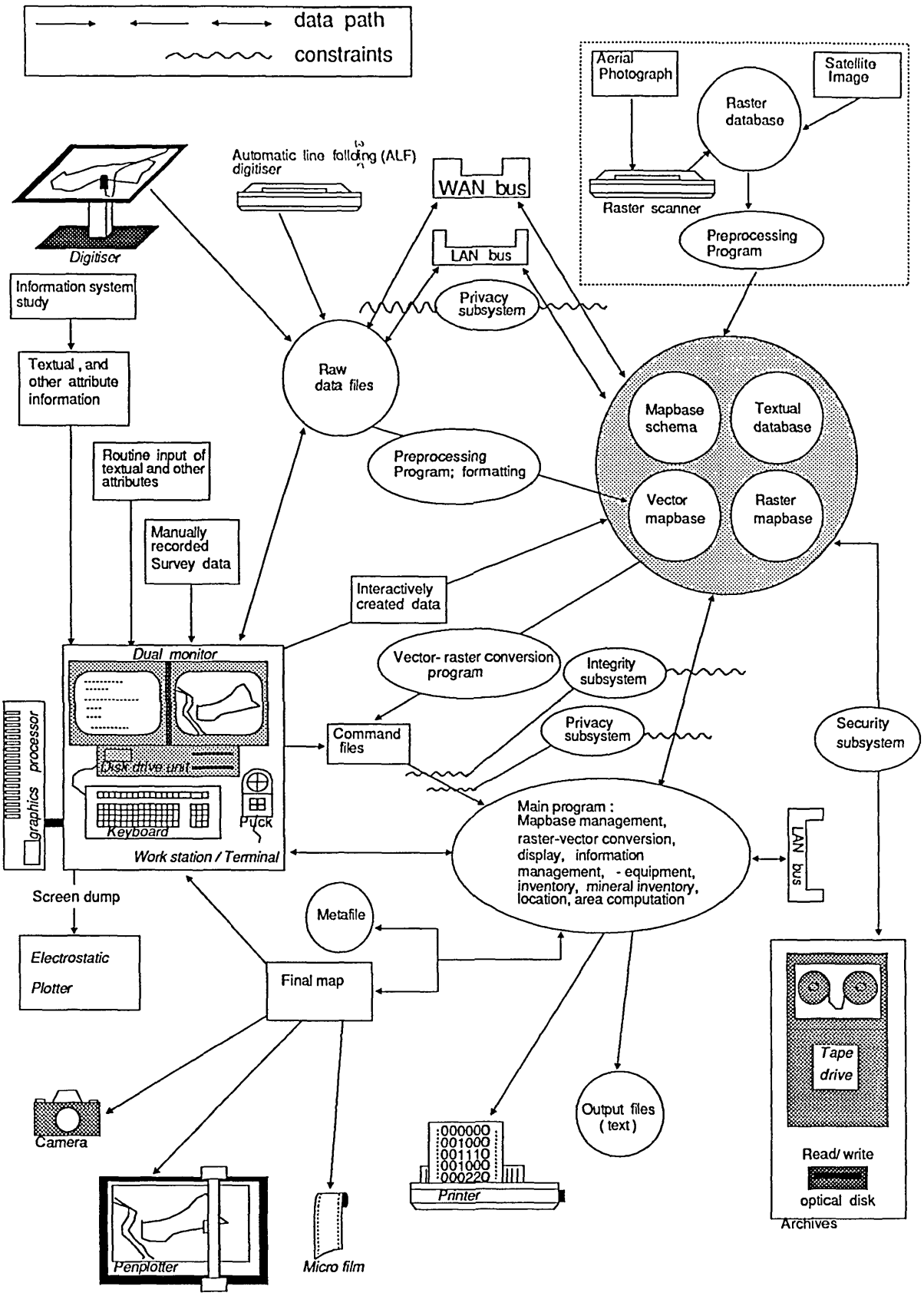


Figure 7.1 The overall hardware - software concept of the proposed enhanced DIRECT

7.2.2 Future research requirement

The project will continue with investigations into:

1. The scope for modification of the G-quadtree as interfaced with grid cell maps.
2. The display of different feature boundaries in different colours, which is presently accomplished by considering one feature at a time while converting from raster-to-vector.
3. Handling typical line features, such as power and water supplies, in vector mode during display to provide improved displays.

7.2.3 Special features for underground mining applications

The following developments are proposed for underground mining applications:

1. Increased resolution of fine detail (for example up to ± 0.1 m display accuracy) with accelerated rate of information retrieval.
2. The use of a 3D Geographic Information System (3D GIS) as a database interface allowing a user to 'migrate' within a stoping system, and access data relating to design specification or production. **Octree encoding** will play a major rôle in this endeavour.

7.2.4 Some important observations

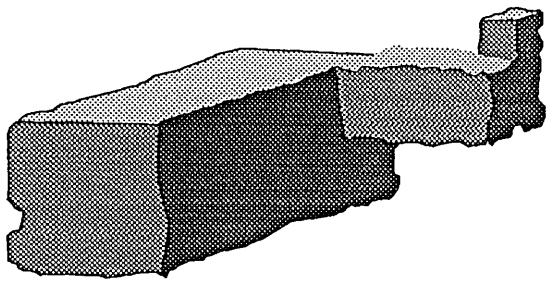
- Geographic reference to the attributes stored spatially at the top Level is less accurate compared to lower levels. This does not have a significant impact in surface mines or similar applications; but in some applications (such in underground mining), this may be vital. In these situations, attributes must be stored through the maps in the lower or possibly the lowest level.
- At present, the polygons having common edges are considered in this package, by digitising the edges in both the polygons and giving priority to one over other, for example the different provinces i.e. polygons in the map of India (Plate 6.1). An edge matching algorithm is to be developed for applications where common edges are critical.
- In future enhancements, employment of any **antialiasing** should be carefully examined. Antialiasing generates artificial cells to smooth the display of lines or boundaries. In a spatial information system,

where the information is stored and retrieved addressing the screen spatially (through addressing the screen pixels), there lies the possibility of referencing information erroneously; a systematic error which may accumulate.

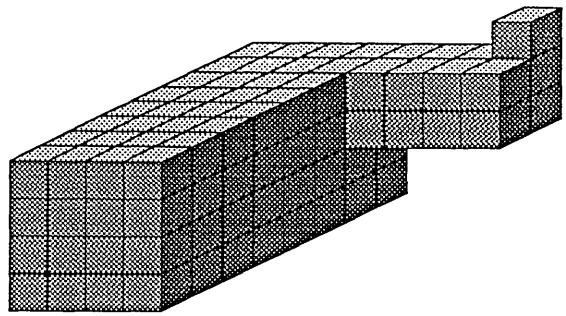
7.3 OCTREE ENCODING TECHNIQUE

Octree encoding is a 'hierarchical representation' technique for modelling a three-dimensional object in space. Octrees are a natural extension of the quadtree concept of hierarchically representing two-dimensional shapes (Kunii *et al.*, 1985). To create hierarchical indices for octree representation a cubic 'object space' is considered, which is large enough to accommodate the object to be modelled. The object space is then divided into eight equal cubes called 'octants', (sometimes also referred as 'voxels') as shown in Figures 7.2(c). and 7.2(d). Figure 7.2(d) shows the indexing order for addressing the octants. Each of these octants is a 'partial node' or a 'terminal node'. Partial nodes are partially full (eg. octants 1 and 5 at Level 1 and 5 at Level 2; Figure 7.1(e)), and each is divided further into eight octants. This operation is performed recursively until a level of decomposition arrives where all the octants are either full or empty and none are partially filled. These nodes are called terminal nodes or leaves, and are classified as either a 'full node' or an 'empty node' (Figure 7.1(e)). The number of recursive division or decomposition of octants depends on the resolution required and/or the precision of the basic data describing the object. Three levels of decomposition are shown in Figure 7.1(c); if the resolution is required at level 2 then the decomposition stops at level 2 and the partial node 15 is considered as a full terminal node.

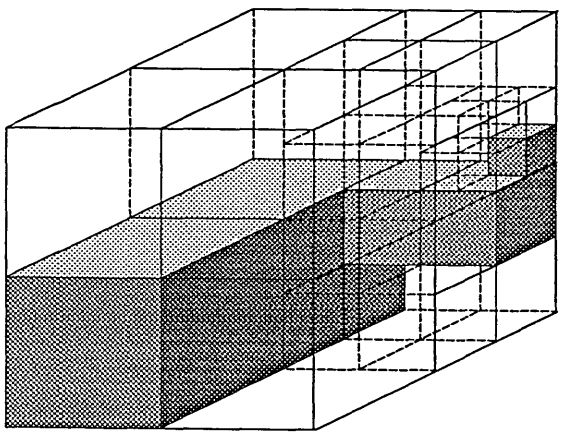
The position of octants in an integer coordinate system is identified by an octal system using octal numbers (0–7). For modelling an object in geographic space (which is essential for a geographic object such as an orebody) the full terminal nodes may be indexed with reference to geographic directions, north, south, east and west. Figure 7.3 shows one such indexing scheme. Different conventions have been used; Gargantini (1982b) classified the octants as 'front' and 'back' rather than 'top' and 'bottom'.



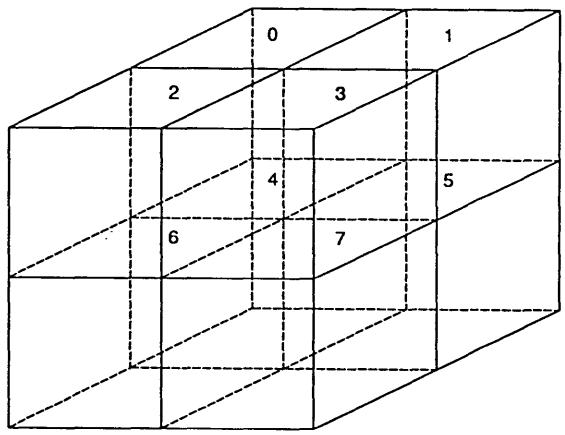
(a) 'Real' object in 3D space



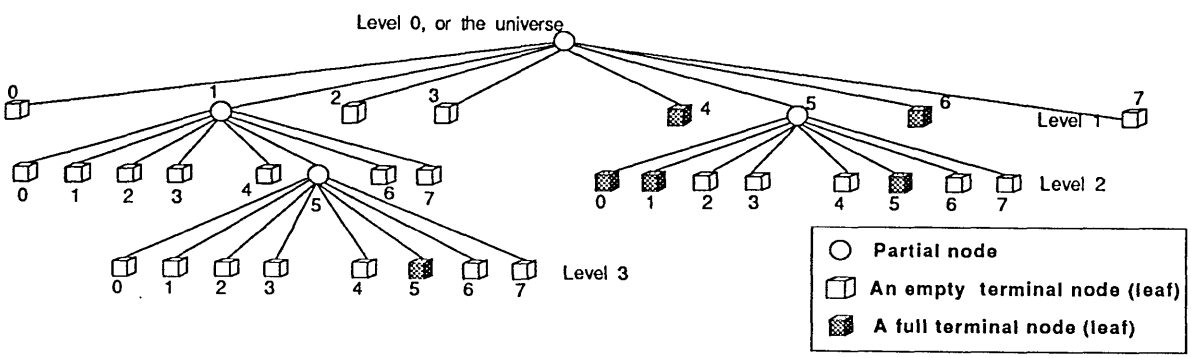
(b) Object represented by voxels at highest resolution



(c) Octant decomposition of the feature in (b)



(d) Indexing of the octants

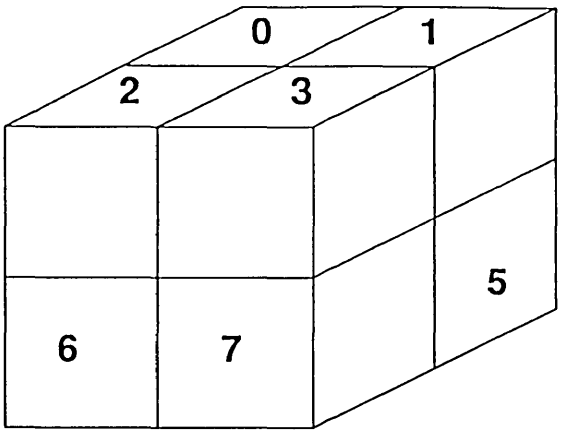


(e) Octree representation of the voxels in (c) (usually empty leaves are not shown).

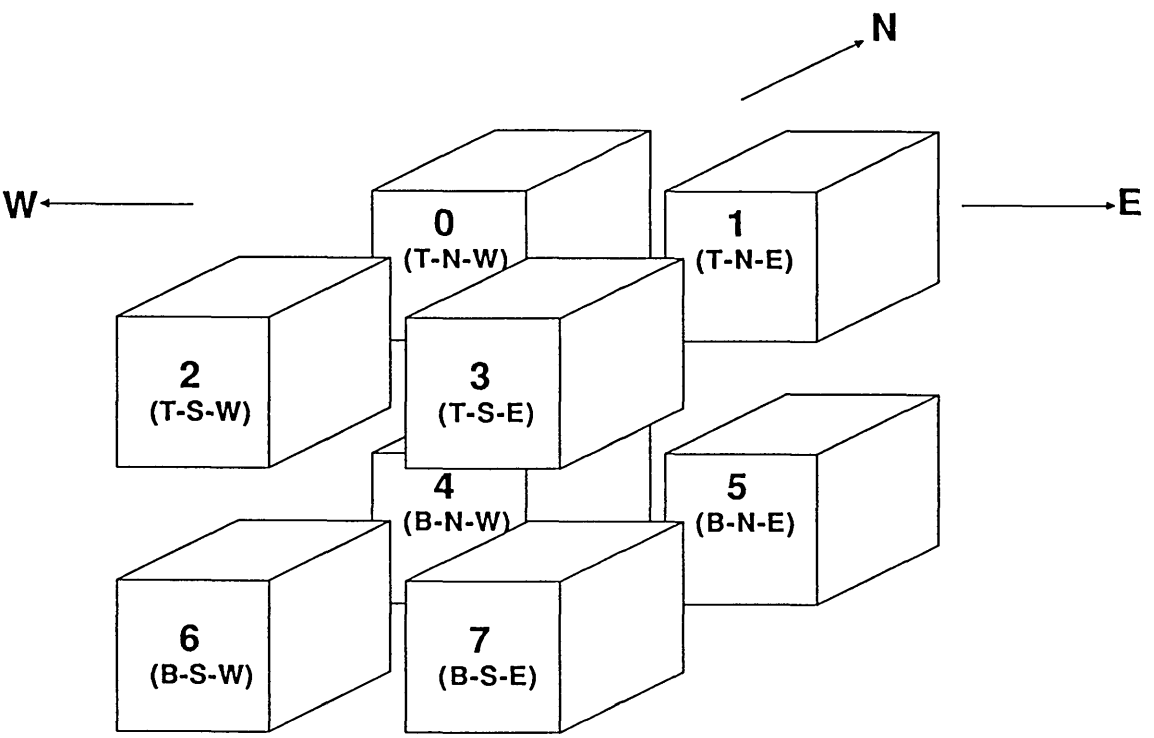
{ 155 4X 50X 51X 6X }

(f) A simple Octree encoding for the decomposed voxels in (c); only full leaves

Figure 7.2 Octree encoding



(a) Octant Indexing (octal notation)



(b) Octant Indexing and world coordinate reference

Top - North - East	≡ 1	Top - North - East	≡ 5
Top - North - West	≡ 0	Top - North - West	≡ 4
Top - South - East	≡ 3	Top - South - East	≡ 7
Top - South - West	≡ 2	Top - South - West	≡ 6

(c) World coordinate and corresponding octal notation

Figure 7.3 Octal notation in an integer co-ordinate system and world coordinate reference

The octree described, as such, models black and white objects with a binary encoding of volumes as either present or absent. For colour representation, attributes must be associated with the full leaves. A modified octree called the Grey-scale octree or 'G-octree' has been developed at Kunii's laboratory (Mao *et al.*, 1986) for modelling colour objects.

Kavouras (1987) has developed a prototype spatial information system for mines using octree encoding for representing solid object, combining with other techniques for representing surfaces, lines and points. Bak (1988) has made some progress in modelling and performing advanced operations such as rotation, transformation displaying perspective view and shading 3D objects. He has modelled an orebody with the main tunnels, shafts and ramp tunnels with 'synthetic' data, using the linear octree encoding technique developed by Gargantini *et al.* (1986).

7.4 SOFTWARE ENGINEERING ELEMENTS

A basic software engineering approach has been used to develop the package, such as use of standard code, maintaining modularity and documentation. The author recognises that some of the techniques which have emerged very recently should be considered to address the requirements of continuous software enhancement in the realm of modern IT. One of these development is of profound importance for systematic software development and maintenance – namely, **computer aided software engineering (case)**.

7.5 CONCLUDING REMARKS

GIS is not a panacea to problems in information handling, although, a GIS has the potential for cost savings and to be an extremely versatile tool. To realise this potential, a long term investment must be planned and managed carefully. However, the field of IT is changing fast with the arrival of the more and more powerful small machines. It is quite possible today, to build a GIS workstation around a computer workstation (a GIS workstation is different from a computer workstation) independent of a mainframe to cater for a medium size mapbase such as a mining mapbase.

UNIX promises to be a ubiquitous open system and a more suitable environment for graphics and data retrieval. System programming facilities may be extensively used since they will be portable to a wide range of machines using UNIX; almost all the computer manufactures are now providing some version of UNIX with their machines and a standard UNIX system is expected in the coming years despite protracted controversy. UNIX also provides a better multi-processing, muti-user environment which will add further versatility to DIRECT.

Artificial Intelligence (AI) has advanced far from the early days of Cybernetics (Wiener (1948)). The most successful application of AI has been the **Expert System**; the essence of the expert's/experts' knowledge can be embodied in software, using the new techniques of knowledge engineering, and can be used by others. In mining, where the rule of thumb and experience dominates, expert systems find a ready application; Prospector (Duda *et al.*, 1982) may be sited for an example. AI can make software more robust and easy-to-use, and provide near fool-proof or fail-safe system. The partial surrender of decision making to AI software reinforces the need for sound software engineering techniques. For example, blast round design in surface mines is still judged mostly by the local experts who are unlikely to be displaced by a Knowledge-Based Expert System (KBES), never-the-less their experience related to spacing, burden, charge per hole, delays and other relevant design parameters may be converted into an expert system by a knowledge engineer using an inference engine.

These days, high resolution terminals are within the financial reach for most of industries. Previously, the highest-resolution video display has been one with 2000 lines, each 1700 dots wide. Recently, Megascan, Gibson, Pennsylvania has demonstrated (New Scientist, 1987) a colour terminal with a resolution of 2560 $\times$ 2488; the price of the terminal with controller has been reported to be well within £10000. Such devices may provide the basis for more advanced GIS and AM/GIS systems and offer the prospect of conferencing facilities supported by interactive displays.

With faster workstations, faster high resolution display screens and enormous storage devices combined with new programming environments, and AI/Expert systems, the techniques of mapping and CAD are going to be well within reach of organisations large and small. Recent developments in **Parallel processing** using

transputer arrays and use of **erasable optical disks** (Maxtor, 1988) for storage are anticipated to play vital rôle in future systems.

DIRECT is a structure to which only the potential of few capabilities has been demonstrated using power of the new IT techniques. The database cemantics, the data structure and the retrieval media (natural language query, graphics menus and spatial keys) used in DIRECT, provide new dimensions in human-geographic space interaction. Around this system a large integrated mapping and information management system can be built up for mining or any planning involving land and land related information.

Appendices

Appendix 4A

JHARIA BLOCK-II OPEN PIT PROJECT

INTRODUCTION

BLOCK-II is one of the priority opencast blocks contemplated in the Feasibility Report on Reconstruction of the quarry in two places, namely, from the outcrop of seam IX/X (i.e. coking coal quarry) and from the outcrop of Seam I (i.e. non-coking coal quarry). The present proposal is to exploit the coking coal seams of the block with certain modifications as under :

i) The extent of the quarry has been restricted to Gomoh-Mahuda line of S.E. Railway on the east, Jamunia river on the west, D.B. Road connecting Dhanbad-Chandrapura line of E. Railway on the south.

ii) Backfilling of the quarry with use of draglines has been suggested to have economic advantages. On the top of dragline spoil, a part of overburden, excavated by shovel, will also be dumped.

The quarry area comprises of parts of Kessurgarh, Nudkrukee, Benedith and Madhuband Collieries of Area I of BCCL and is well connected by both road and railway.

CIVIL WORKS

A total of 833 residential houses for a total peak manpower strength of 1514 has been provided. This gives an average percentage satisfaction of 55%. A total provision of 1.36 MLD water has been made for adequate water supply arrangement for domestic and industrial purposes, excluding requirements for washery.

GEOLOGY

The area, located in the western part of Jharia Coalfield, comprises the Barakar formation of Lower Gondwana rocks and has an area of 3.46 sq.km. The topography of the area is undulating with a gentle slope towards south and south-west.

Lithology and the sequence of coal seams considered in the present quarry proposal is given below:

Coal seams and parting	Lithology	Range of thickness (m)
XVIC Seam	Coal, Jhama, M.P.	2.26 – 3.50
Parting	Shale, sandstone	4.10 – 22.85
XVI AB Seam	Coal	0.91 – 3.35
Parting	Sandstone, interbanded shale	20.59 – 23.46
XVI Seam	Coal	0.70 – 3.20
Parting	Sandstone, interbanded sandstone and shale	22.70 – 30.20
XV Seam	Coal, Jhama, M.P.	3.60 – 5.74
Parting	Sandstone and shale	9.25 – 23.00
XIV Seam	Coal, shaly coal	1.00 – 5.17
Parting	Sandstone, interbanded sandstone and shale	14.46 – 27.43
XI/XII Seam	Coal, Jhama, M.P.	4.07 – 7.60
Parting	Sandstone and shale	23.66 – 41.25
IX/X Seam	Coal	3.65 – 12.00
Parting	Arenaceous shale, interbanded shale and sandstone.	0.55 – 12.78
Local Seam	Coal	0.65 – 3.03

The dip of the formation varies between 7° to 15° due SSE and south. The average dip above the fault F14F14 varies from 7° to 12° while that below the fault F14F14 varies from 12° to 15° .

Major part of the area is free from faults.However, a number of faults appear in the South–Western and western part of the project area.

RESERVE, STRIPPING RATIO, PRODUCTION CAPACITY AND LIFE

The net geological reserve of coal in the area is estimated as 41.36 m.t. taking into account the coal lost in quarry batters. Net quarriable reserve after deducting mining losses works out to 39.29 m.t. The total volume of overburden (OB) removal is

estimated at 161.4 million m^3 of top soil. The overall stripping ratio works out to 4.11 m^3 /t

With production capacity of 2.5 million tonnes per year, the production life of the mine will be 17 years including the production build-up period in the initial years. The life of the mine at full production comes to about 15 years. However, by implementation of the Jharia Coal Field Reconstruction Scheme (JCFRS), this can be further extended by 13 years, by shifting of Dhanbad-Chandrapura railway line of Eastern Railway, releasing thereby about 33 million tonnes of quarriable coking coal.

MINING

There are nine coal seams of average thickness varying from 1.61 m to 9.90 m. Most of the seams are developed and standing on pillars. The average gradient of seams has been taken as 1 in 6.5 (9°) for the purpose of designing the mining system.

The quarry will reach full production i.e. 2.5 mt/year in the 3rd year. The rate of OB removal will increase from 1.3 million m^3 in the 1st year to 9.50 million m^3 in the 4th year. Thereafter, the rate of OB removal will be within the range of 11.0 million m^3 to 12.4 million m^3 upto 14th year, before finally tapering down to 7.50 million m^3 in the 17th year.

The mine will work 300 days a year, 3 shifts a day and 8 hours per shift. The quarry will be backfilled simultaneously with the mining operation, inspite of the presence of a series of seams below the quarry floor, to avaoid costly transport for large distances to the metamorphics. The backfilled material will be subsequently rehandled during quarrying of the lower seams.

Extraction of coal will be done by hydraulic shovels in conjunction with bottom dump coal haulers 0.9 m^3 and 4/4.5 m^3 hydraulic shovels with 29 t and 40 t coal haulers will be used.

A consolidated statement of main mining equipment and their number displayed in the project is given below:

Sl. no.	Description	Total no.
1.	Dragline 24 m^3 /88 m R	2
2.	Dragline 6 m^3 /45 m R	1
3.	Rope shovel 11 m^3	4
4.	Hydraulic shovel 4/4.5 m^3	1
5.	Hydraulic shovel 3 m^3	2
6.	Hydraulic shovel 0.9 m^3	1
7.	385 mm	2
8.	Rotary blasthole drill 243–269 mm	4
9.	Rotary blasthole drill 160 mm	5
10	Rotary blasthole drill 100–125 mm	1

PUMPING

The maximum make of water has been estimated at 0.52 million m^3 in 24 hours. A total pumping capacity of 125 m^3 /min has been provided to deal with the above quantity in 5 days with 18 hours of pumping per day. Two sizes of pumps, namely, 5 m^3 /min and 10 m^3 /min discharge have been provided. In addition, 3 borehole pumps, each of 1.2 m^3 /min capacity, have been provided for advance dewatering of developed seams.

COAL HANDLING PLANT AND DESPATCH

The coal from the quarry will be crushed to 200 mm size by a rotary breaker of 800 tph capacity located at the quarry top. One standby crushing unit has also been kept. From the pit-head crusher, coal will be transported by a 2.5 km long. 1000 mm wide cross country belt conveyor to two ground bunkers each of 8000 t capacity located on the metamorphics near the siding.

MANPOWER AND PRODUCTIVITY

The total peak requirement of manpower has been estimated at 1541. This gives a productivity of 6.25 t per manshift at full production level. The adjusted O.M.S at 4.11 m^3 /t stripping ratio comes to 7.13 t.

Appendix 5A

HEADER TO DIGITISED FILES

COMMENT STARTS:
These comment lines are for understanding the data structure in
this data file. These lines will be read, but will not be used.
After the 'END' of the comment lines, the first line is to input feature type,
and the next line specifies the format for reading
Y(Northing), X(Easting), Z-Value (attribute value).
The northings and eastings are in metres, Z-value is the category number.
-9999.0 as the Z-value indicates the end of an isolated feature.

Reference grid : 'local grid origin'.
Name of the project : Block-II Open Cast Project
Owner : Bharat Coking Coal Limited, a subsidiary of Coal India Limited.
The subject : The ultimate pit limit (phase 1).
Feature type : Polygon.
Digitised by : A B Samaddar
Date of digitising : 25th May 1987
Location of digitising : Dpt. of Minrl. Res. Engg., Imperial College, London.
END

POLYGON
(3(F8.1))
20506.7 21464.8 21.0
20481.8 21477.5 21.0
. . . .
. . . .
20512.9 21462.4 21.0
20512.9 21462.4 -9999.0

Appendix 5B

LIST OF COMMANDS IN DIRECT-1

1. **ADD** creates a new map by adding the values of two or more maps on a cell-by-cell basis.

2. **ACCESS** allows the user to access the mapbase for performing highest priority operations on them, such as deleting, copying or renaming, and to access password and associated list of permissible commands, for alteration.

3. **AVERAGE** creates a new map by averaging the map-weighted values of two or more maps on a cell-by-cell basis.

4. **BLOCK** reproduces text at a specified graphics size.

5. **CLUMP** creates a new map by identifying contiguous groups of cells associated with each category of a map and assigning a unique value to each group.

6. **COPY** creates a map by reproducing a map.

7. **COVER** creates a new map by replacing the value of one map with the non-zero values of another map on a cell-by-cell basis.

8. **CROSS** creates a new map by pairing the values of one map with those of another map and assigning a new value to each pair on a cell-by-cell basis.

9. **DESCRIBE** generates a tabular listing of the value, name, and amount of area associated with each category of a map.

10. **DIVIDE** creates a new map by dividing the values of one map by those of another map on cell-by-cell basis. Division may also involve an extended sequence of maps.

11. **ECHO** sets a message handling indicator such that descriptive messages are issued during system operation.

12. **EXPONENCIATE** creates a new map by raising the values of one map to the powers represented by those of another map on a cell-by-cell basis. Exponentiation may also involve an extended sequence of maps.

13. **EXPOSE** sets the protection indicator associated with a map such that the map is no longer protected from being modified.

14. **GRID** creates a new map by assigning new values to the cells of a map on a row-by-row basis.

15. **GROUP** creates a new map by dividing a range of values from a map into equal intervals and redefining each value according to the ordinal position of its interval.

16. **LABEL** assigns names to the categories of a map.

17. **LIST** generates a tabular listing of all maps currently on files, their location on files, protection status and geographic scale.

18. **MAP** creates a new map by assigning a constant value to all cells of a map.

19. **Maximises** creates a new map by comparing two or more maps and retaining whichever value is greatest on a cell-by-cell basis.

20. **MINIMISE** creates a new map by comparing two or more maps and retaining whichever value is smallest on a cell-by-cell basis.

21. **MULTIPLY** creates a new map by multiplying the value of two or more maps on a cell-by-cell basis.

22. **NOTE** provides for the inclusion of non-command text within a command sequence.

23. **OVERLOOK** sets an error handling indicator such that outstanding errors do not prevent execution of subsequent commands.

24. **OUTLINE** displays a map graphically and allows interactive draughting and spatial information management.

25. **POINT** creates a new map by assigning new values to the individual cells of the map.

26. **PRINT** generates a printer representation of a map in which each cell is represented according to its value by a symbol of upto four overprinted characters.

27. **PROTECT** sets the file protection indicator associated with a map such that the map is protected from being modified.

28. **PURGE** erases the name associated with a location in the map file thereby making that location available for storage of a map.

29. **QUIET** sets a message handling indicator such that descriptive messages are supressed during system operation.

30. **RADIATE** creates a new map by computing a value for each cell according to the visibility of that cell from an area or a point on a map. Visibility may be modified by intervening barriers and/or distance and the height of viewers eye.

31. **READ** provides input of commands from alternative sources.

32. **RECOVER** recovers a map which has been purged when the storage location has not yet been utilised to store another map in the mapbase.

33. **REMEMBER** sets an error handling indicator such that outstanding errors prevent execution of subsequent commands.

34. **REMIT** erases all outstanding errors.

35. **RENAME** assigns a new name to an existing map.

36. **RECATEGORISE** creates a new map by assigning new values to the categories of a map.

37. **SCALE** defines the geographic scale of a map.

38. **SHOW** generates a tabular listing of the current values of certain system parameters.

39. **SIZE** creates a new map by assigning new values to the categories of a map according to the size of the area associated with each category.

40. **SKIP** causes written output to continue beginning at the top of the next page.

41. **SET** allows the user to set password and current mapbase or sub-mapbase

42. **SPREAD** creates a new map by computing a value for each cell according to the length for the shortest path between that cell and an area outlined on a map. Path length and direction may be modified by intervening barriers.

43. **STOP** Logs out from the system.

44. **STREAM** creates a new map which indicates the steepest downhill path from an area outlined on one map over a continuous, three-dimensional surface represented by another map.

45. **STRIP** creates a new map by assigning new values to horizontal sequences of cells across a map.

46. **SUBTRACT** creates a new map by substructing the values of two or more maps from those of another map on a cell-by-cell basis.

47. **WINDOW** will allow the user to create a map at lower level, which overlaps four sectors. In short, it provides a zooming facility

48. **WRITE** provides for the writing of output to alternative destinations.

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