SERIES TECHNOLOGIES Nr 15

GUIDE TO MINERAL EXPLORATION

metallic minerals

Centre for
the Development of Enterprise
ACP - EU

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Mining plays a vitally important role in many ACP economies. It acts as the backbone to economic development and is responsible for making a significant contribution to GDP and foreign exchange earnings. Currently Africa has the fastest growing mineral exploration sectors in the world, and countries in the Caribbean and Pacific countries are experiencing increased levels of activity and interest in mining. Even though mining plays such an important part in ACP economic development, much of the region's mineral resources remain untapped. This can in-part be overcome through continued exploration for new mineral deposits.

The Centre for Development of Enterprise and the European Union have held a number of major mining sector meetings in the recent years. These include the CDE Mining Sector Seminar *European and African Mineral Exploration Expertise and Technology Transfer* held in Dublin, Ireland, 1999, the EU-ECOWAS *Mines'98* Forum in Accra, Ghana in 1998 and the EU-SADC *Fomin '94* Forum in Lusaka, Zambia in 1994. At these events a large number of the African participants identified the strong need for a comprehensive guide to the principles of modern exploration for metallic minerals.

In response to this need it was decided to produce a guide related to Mineral Exploration. This guide is direct result of follow-up of these mining events and has been financed by the CDE and FACT Fund, put in place by the European Commission.

The guide is designed to give a general overview of issues related to Mineral Exploration. It will assist those people wishing to enter the mining business to gain a better understanding of the risks, rewards and time required to develop a mineral deposit. For those already involved in the sector, it will act as a reference guide.

The guide is divided into four parts. Part 1 gives general background information on the global mining industry and examines the critical factors that determine the success or failure of mining projects. The mineral exploration process is then presented in Part 2 which examines the five phases of the Mineral Exploration Cycle (MEC), from programme design to final feasibility. Part 3 looks briefly at the potential benefits of conducting mineral exploration in Africa, while Part 4 contains a large amount of practical information (glossary, list of EU & ACP consultants, exercises etc.) for those wishing to become involved in this sector.

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PROLOGUE – EUROPEAN FEDERATION OF GEOLOGISTS

The European Federation of Geologists, representing over 75,000 geologists across Europe, is working towards the free movement of geologists throughout Europe. Many of its members have, and/or still do, practice in Africa. The EFG encourages high standards of professional practice with a strict code of ethics and awards the professional quality title of EurGeol. (European Geologist).

Mineral exploration is becoming an increasingly demanding science. Professionals operating in the minerals sector, must constantly maintain their standards of expertise through Continuing Professional Development. This can be through a combination of professional practice, private study, attending lectures, and participation in courses and seminars. Various government departments and stock exchanges will only accept reports signed by professionally accredited geologists, not only in Europe and Africa, but across the world.

The CDE Guide to Mineral Exploration for Metallic Minerals brings together the best expertise available from European and African professional geologists and will act as a catalyst for continuing professional development in the ACP mining sector. The guide clearly presents an overview of the global mining industry, examines the critical factors that determine the success or failure of mining projects and gives a detailed account of Mineral Exploration Cycle (MEC). It also contains useful information such as a glossary of mining terminology, a list of EU & ACP mining consultants and a number of practical exercises.

The European Federation of Geologists (EFG) recognizes the quality of this CDE Guide to Mineral Exploration and that it will be both an essential guide for geologists to all aspects of the Minerals Industry and also a vital contribution to their Continuing Professional Development.

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PART I UNDERSTANDING THE MINERALS INDUSTRY

1. INTRODUCTION

Mineral exploration is the term used to describe the process of searching for and discovering economic mineral deposits, using a complex array of scientific and economic disciplines, which may be applied interactively to achieve success.

1.1 BACKGROUND

The Centre for Development of Enterprise and the European Union have held a number of major mining sector meetings in the recent years. These include the EU-ACP Mining Sector Seminar *European and African Mineral Exploration Expertise and Technology Transfer* held in Dublin, Ireland in 1999, the EU-ECOWAS *Mines '98* Forum in Accra, Ghana in 1998 and the EU-SADC *Fomin '94* Forum in Lusaka, Zambia in 1994. At these events a large number of the African participants identified the need for a comprehensive guide to the principles of modern exploration for metallic minerals.

The *CDE Guide to Mineral Exploration* has been developed in response to this demand and is intended as a reference guide to the modern mineral exploration industry. It also includes a review of current techniques employed in the search for minerals.

The application of exploratory techniques to the identification of economic mineralization is not a random process; rather, a logical series of steps is followed to minimize risk and to increase the chances of discovery. Prior to engaging in the search for minerals, however, the explorer must decide on the basis of economic and political factors, which commodity to invest in, where to explore and how to explore for it. The *CDE Guide to Mineral Exploration* also presents the technical, economic and social factors which must be taken into consideration in the global search for mineral deposits.

1.2 OBJECTIVES

The main objectives of the *CDE Guide to Mineral Exploration* are to convey an understanding of the workings of the modern mineral exploration industry in a systematic fashion, for ease of reference for those wishing to become involved in mineral exploration. It is presented in four parts:

Part I : The Minerals Industry

The first part of the guide sets out the factors which must be considered prior to the physical exploration process, such as the role of minerals and mining in society, mineral classification and geological models, together with a section on how to locate suitable mineral projects. In order to develop a mineral deposit into a viable mining enterprise, the technical, financial, environmental and societal considerations must be carefully analysed in advance.

Part II : Mineral Exploration Cycle

The Guide presents a simplified, but generic Mineral Exploration Cycle (MEC), specifically intended for metalliferous minerals. This model demonstrates that mineral exploration is a logical scientific process which facilitates the successful discovery of an economically viable mine.

Part III : Potential Benefits of Mineral Exploration to Africa

The third part of the Guidebook looks at the role which mineral exploration and mining can play in the economic development of Africa. Brief reviews of two modern mining economies, Western Australia and Ghana, are presented to highlight the potential benefits to African countries in developing their mineral sectors.

Part IV : Appendices

The final part of the Guide presents a series of useful Appendices as reference sources for further reading, service providers and geological data templates.

2. THE MINERALS INDUSTRY

The minerals industry has played a fundamental role in the development of societies and civilisation, by providing resources for the growth and maintenance of society. Minerals are essential for the most basic commodities such as paper, salt and plastics, and provide the raw materials for cars, ships, aeroplanes, fuel, agricultural tools and machinery.

2.1 ROLE OF MINING IN DEVELOPMENT OF SOCIETY

The mining industry has a colourful history stretching back to ancient times. Archaeologists relate the development of civilisation to the development of the mining industry: they refer to the Stone Age, the Bronze Age, the Iron Age etc., reflecting the developing awareness of the ways in which people could exploit and work metals, and of the uses to which they could put the mineral products. Historically, mining is not only associated with the exploration and development of remote areas of the World and with the amassing of great fortunes, but also with the negative impacts of invasions, slavery, colonial expansion, economic collapse, human catastrophes and environmental pollution. Nowadays the industry is carefully monitored by environmental and community pressure groups, causing the industry to be more socially responsible in recent years. In western economies, the industry is fundamentally driven by capital-centred economics.

Most items in our immediate environments are derived from minerals. The demand for minerals is huge and the mining industry is correspondingly large - some global statistics are shown in Tables 1-3 to illustrate this point. However, the statistics also show that the consumption of minerals is much lower in developing countries than in developed countries, but as these countries grow economically, so the global demand for mineral products will increase still further.

Table 1: Mineral Statistics 1995

Global Crude Mineral Production
US$ 1,530,000,000,000 (1992)

Global Mineral and Metal Export Trade
US$ 161,223,000,000
(of which Developed Counties = 63%
Developing Countries = 29%)

Global Mineral and Metal Import Trade
US$ 186,492,000,000
(of which Developed countries = 69%
Developing Countries = 28%)

Global Exploration Cost (1996)
US$ 5,100,000,000
(Africa 12% ; Latin America 27% ; U.S. 10% ;
Australia 17% ; Canada 13%....)

Only 12 companies account for 39% of total exploration costs!
RTZ Group: Profits of US$ 906 million

Table 2

PER CAPITA CONSUMPTION OF MINERALS 1996

CRUSHED STONE	3.6 tonnes
SAND & GRAVEL	2.7 tonnes
SALT	163 kg
PHOSPHATE	166 kg
GYPSUM	92 kg
IRON	243 kg
ALUMINUM	22 kg
LEAD	4 kg
COPPER	8 kg
ZINC	4 kg

TABLE 3. PRODUCTION AND RESERVES BY MAIN GEO-POLITICAL GROUPING
% SHARE IN WORLD RESERVES* 1994

	DEVELOPED		DEVELOPING	
	RESERVES	PRODUCTION	RESERVES	PRODUCTION
ALUMINIUM	29	40	65	49
HARD COAL	46	35	16	12
COPPER	26	36	54	46
GOLD	59	59	17	23
LEAD	58	52	13	22
NICKEL	24	34	22	34
PHOSPHATE	22	42	71	42
RUTILE	43	83	48	13
SILVER	44	31	36	49
TIN	5	7	67	56
ZINC	58	49	24	26

* Excluding Centrally Planned countries (e.g. former countries of the U.S.S.R., China, Cuba, etc.)

2.2 MINERAL COMMODITY CLASSIFICATION

Minerals are traditionally divided into commodity groups based on industrial and commercial uses (Table 4).

TABLE 4
INDUSTRIAL CLASSIFICATION - MINING ANNUAL REVIEW

Precious Metals:	*Au, Ag, Pt + PGM*
Other Major Metals:	*Cu, Pb, Zn, Sn*
Light Metals:	*Al, Mg, Ti*
Ferrous + Ferroalloys:	*Fe, Ni, Mn, Cr, Co, Mo, W, V, Nb*
Fuel Minerals:	*Coal, Oil, Gas*
Nuclear Metals:	*U, Zr, Hf, Be, Cs, Rb, REE*
Electronic Metals:	*Cd, Ga, Ge, Hg, Se, Te, Ta, In, Rh*
Chemical Metals + Minerals:	*K, Bi, B, Li, F, S, Ba, Sb, Salt, Gypsum, Phosphate,* $NaCO_3$*, Kaolin,*
Insulants + Refractories:	*Graphite, Asbestos, Sillimanite, Vermiculite*
Gems + Diamonds:	*Diamond, Ruby, etc.*
(Construction Minerals:	*Sand + Gravel, Stone, Limestone, Marble)*

There are a number of variations on this theme, but the widely accepted **Mineral Commodity Groups,** as used by the Mining Annual Review, are as follows:

- **Precious metals** : Au, Ag, Pt, Pd
- **Non-ferrous metals** (or base metals and other major metals) : Cu, Pb, Zn, Sn
- **Ferrous metals and ferro-alloys** : Fe, Ni, Mn, Cr, Co, Mo, W, V, Nb
- **Light metals** : Al, Mg. Ti
- **Nuclear metals** : U, Zr, Hf, Be, Cs, Rb, Rare Earth Elements (REE)
- **Electronic metals** : Cd, Ga, Ge, Hg, Se, Te, Ta, In, Rh
- **Fuel minerals** : coal, oil gas
- **Chemical feedstock elements and minerals** : potash, salt, gypsum, kaolin, phosphate, trona, soda ash, nitrate, barytes, fluorite, S, Li, Bi, B, Sb
- **Insulants, refractories and abrasives** : graphite, asbestos, sillimanite, vermiculite, industrial diamond
- **Gemstones** : precious (diamond, ruby, sapphire, emerald) and semi-precious (amethyst, opal, etc.)
- **Construction minerals** : building aggregate (sand, gravel and crushed rock), brick clays, dimension stone (granite, marble)

The common features of the Mineral Commodity groups are shown in Table 5.

2.3 MINERAL ECONOMICS

To understand the basic economics of the minerals industry, we need to look at how it differs from other industries, such as agriculture, fishing, and manufacturing.

2.3.1 Basic Economic Factors

Five major economic factors are unique to the minerals industry:

I. **Ore deposits are non-renewable,** in contrast to agricultural commodities which are renewable. Ore deposits are mined until they are exhausted whereas crops can be harvested again and again from the same ground. Various consequences springing from this include the fact that mineral exploration and new mine development must continually take place to satisfy demand, and also that towns and communities based on mining must diversify or they will eventually die when the mine closes.

II. **Ore deposits are very unevenly distributed**. We cannot choose where to locate any particular type of mine - nature dictates the location of ore deposits and the mineral endowment of a region. However, ore deposits tend to be clustered in Mining Districts. This is in contrast to other industries where we can choose within broad limitations where to plant certain crops or where to site a factory.

III. **Mineral Exploration carries a very high risk of financial loss.** The science of geology is still in its infancy when compared to other sciences. We simply do not know <u>exactly</u> where to look for ore deposits. Exploration has been compared to gambling and is considered to be a high risk industry due to the large outlays required prior to earning any returns, if any. Explorers demand a

TABLE 5. MINERAL COMMODITY CLASSIFICATION AND CHARACTERISTICS

COMMODITY CLASS	MAJOR EXAMPLES	ORE GRADES & PRODUCT VALUE	EXPLORATION	MINING	PROCESSING AND MARKETING
Precious minerals and metals	Gold (always with silver, sometimes including copper and other metals), diamonds, platinum group metals.	Ore in ground usually has very low grades (parts per million). Product values very high	Relatively expensive and high risk. Includes geological mapping, geochemistry, geophysics and drilling and physical exploration.	Underground, usually small high cost mines. Open cast large or small mines with variable cost range. Alluvial, artisanal to large operations, relatively low cost.	Low cost with high throughput, product made on site and easily transported, Market internationally, although may be State controlled.
Non-ferrous metalliferous minerals	Copper, zinc, lead, nickel sulphides, tin and minor metals (e.g.: cadmium, niobium).	Relatively low grades (a few percent), product values high	Relatively expensive and high risk. Includes geological mapping, geochemistry, geophysics and drilling and physical exploration.	Underground, usually small high cost mines. Open cast large or small mines with variable cost range. No alluvial mining.	Relatively high cost processing. A mineral concentrate is transported and sold to smelters overseas. Marketed internationally.
Bulk minerals	Iron ore, bauxite, phosphate rock, nickel laterite, titanium beach sands.	Grades high (tens of percent), ore value low but metal value high (except phosphate)	Regional reconnaissance, drilling and trenching. Little exploration because extensive deposits already known in West Africa.	Ore lies on the surface. Very extensive open cast operations. Dredging in the case of beach sands.	Little processing on site. Bulk transport to energy intensive overseas smelters and processing facilities. Final product internationally traded.
Solid fuel minerals	Coal, lignite. Uranium.	Low value High value	Regional reconnaissance, drilling and trenching. Little exploration because extensive deposits already known in West Africa	Underground coal mines not economic in Africa. Large open cast operations, low cost. Uranium may be mined underground or open cast, variable cost.	Washing and grading of coal. Bulk transport and international or local markets. Uranium concentrate transported to specialised processing plants. Restricted market.
Industrial minerals	Very wide range of products:- fillers (clays), abrasives (garnet), chemicals (salt), refractories (kyanite).	Specifications rather than grades important. Product values vary from low to high	Exploration usually driven by specialised local demand. Many deposits already known.	Quarrying and open cast mining in small to medium scale low cost operations.	Processing is highly variable and depends on end use. Markets may be local or international depending on product value.
Construction minerals - general	Brick clays, building aggregates, limestone for cement.	Specifications rather than grades important. Product values very low	Exploration only in areas of shortage.	Quarrying and open cast mining in small to medium scale low cost operations.	Very little processing. Distribution costs control location of mines. Markets usually local.
Construction minerals – Ornamental stone	Granite, marble.	Specifications essential. Product has high value	Exploration unusual – driven by specialist international market demand.	Very specialised quarrying techniques unlike any other mining process.	Specialised cutting and polishing on site or from transported blocks. International but small market.

high reward for taking these risks and as a result, the mining industry produces both very wealthy people and big losers.

IV. **There is a very long lead time from discovery to production.** Development of a modest sized mine can take up to ten years and can cost hundreds of millions of dollars. Each mine is unique and needs careful design and control. New roads, power, buildings and other infrastructure are needed in remote areas. The investment which is needed for major mines is so large that few companies can fund the development themselves. In contrast, it is rare for agricultural development and factories to take so long and cost so much before the developers can expect a return on their money.

V. **Mineral deposits almost always contain valuable by-products**. Most gold deposits also have recoverable silver. Zinc mines hosted by limestones usually also produce lead and silver. In general, this means that the economics of mining can be enhanced depending on the value of the by-product and on prevailing market conditions. For example, the *Panguna* copper mine on Bougainville in Papua New Guinea had gold as a by-product, but as the gold price rose, *Panguna* became primarily a gold mine. In other areas, as technology develops, more by-products will be recoverable e.g. as the technology for recovering cobalt from lateritic nickel deposits develops, a huge, previously untapped resource may be defined. In other instances, the by-product can actually reduce the value of the ore, particularly if it is deleterious to the smelting process (see Section 4.2.5 below).

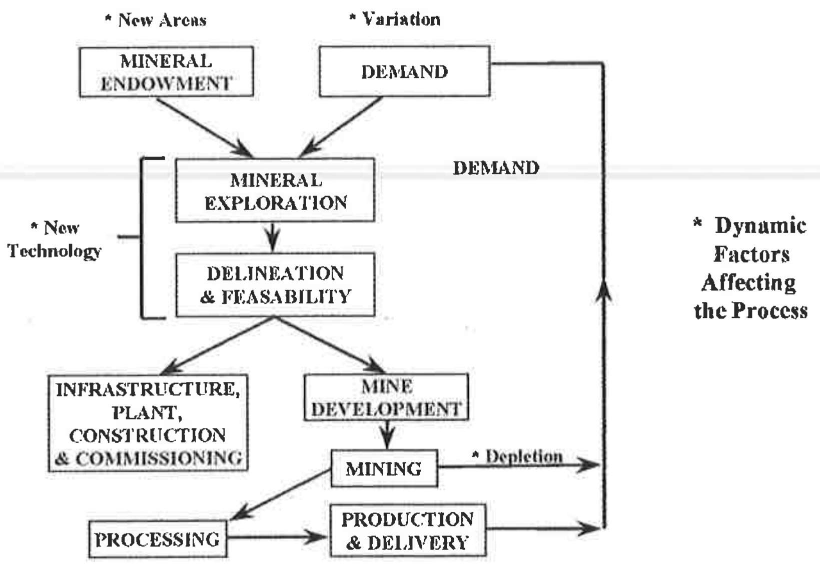
In addition, there are other distinctive features of the mining industry, although they are not unique to it. For example, mineral trading sometimes has political and strategic significance, as with uranium. Scrap metal is an important secondary source of metal, as with lead. Governments benefit directly from mining of state resources through royalties levied on mineral producing companies.

2.3.2 How does the Mining Industry Supply the Demand for Minerals?

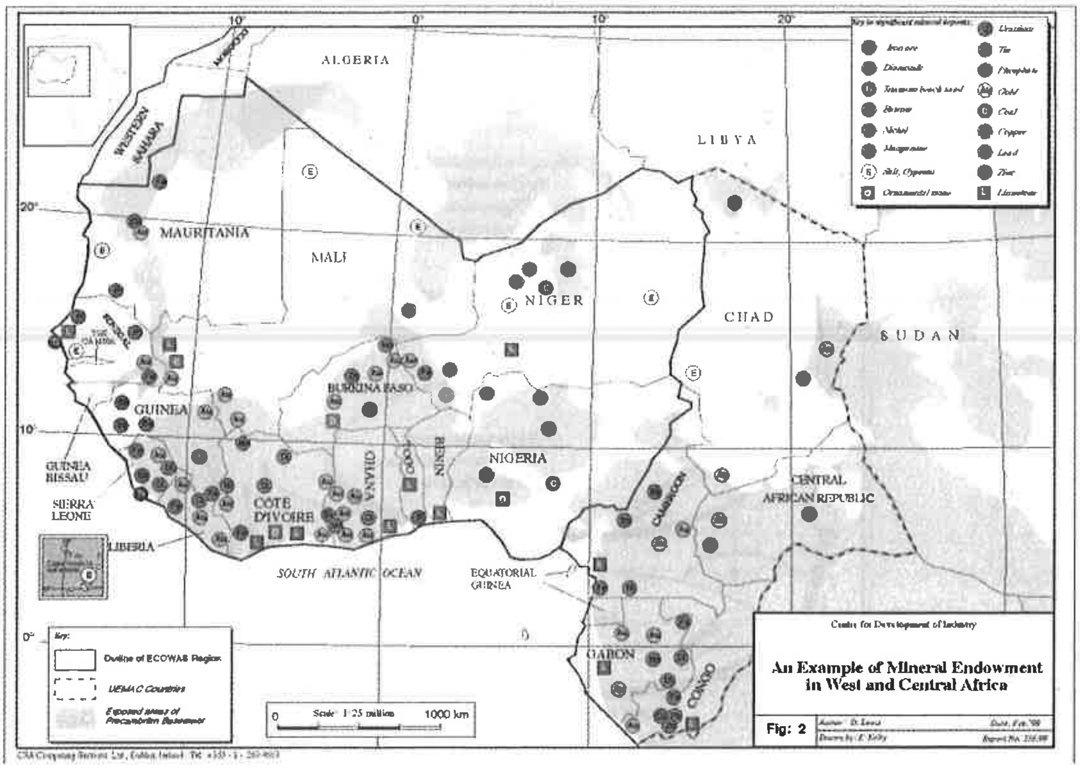
In order to understand the relationship between mineral exploration and the extractive mining industry, one must look at the balance between demand for and supply of minerals. As demonstrated in Tables 1-3, the demand for minerals is continuing to increase, particularly as developing economies expand their industrial bases and experience. Despite economic expansionary and recessionary cycles, such as temporary increases (experienced during World War II) or decreases associated with economic downturn (e.g. Southeast Asia in 1998), the overall trend in demand is upwards. Due to the very high risks and capital expenditures required to explore for and develop mines, state-owned mining companies are becoming a rarity and the responsibility to meet this demand is falling increasingly on the private sector mining industry. The mining industry is becoming increasingly internationalised and controlled by large multinational groups (e.g. Anglo American Corporation (AAC) of South Africa, RTZ-CRA of the UK and Australia, BHP of Australia, INCO of Canada etc.).

The Mineral Supply Process (Fig.1) is a dynamic process in which the *supply* of a mineral commodity is driven by the *demand*, while the balance between them reflects the commodity price.

FIGURE 1 MINERAL SUPPLY PROCESS



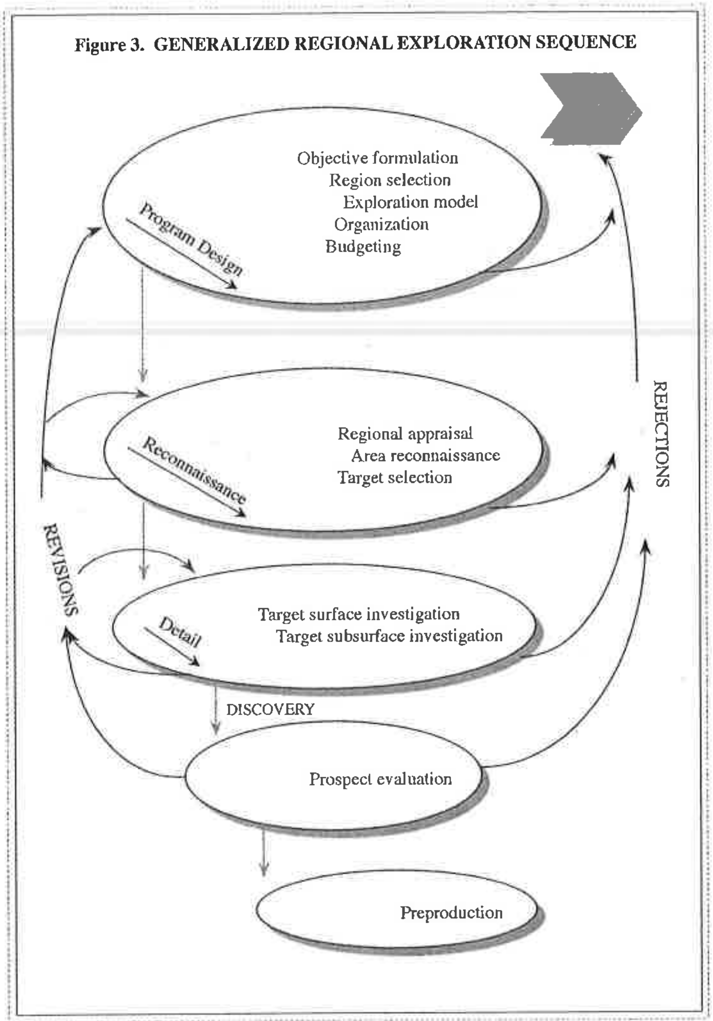
- **Demand** is driven by such things as new technology, wars, shortages and the economics of other related industries and commodities. For example, the spectacular rise and then collapse in the international tin price in 1980 from $7.80/lb to $2.50/lb was driven by a combination of circumstances. Manufacturers began to develop a cheaper process to make tin cans from aluminium. At about the same time, the International Tin Agreement (a cartel of producers) broke up following an attempt to corner the market in tin. Demand for tin fell dramatically while that for aluminium rose strongly.
- **Mineral Endowment** is the term for the natural distribution of minerals within a region (see Fig. 2 as an example of the mineral endowment of west and central Africa). It is due to a wide variety of geological processes and therefore mineral deposits are very unevenly distributed (see also 2.4 below). We tend to look at mineral distribution in terms of mining districts and orefields. Some of them are famous - for example, the Jos Plateau Tin Fields (Nigeria), the Witwatersrand Goldfields (South Africa), the Arabian Gulf Oilfields or the Republic of Guinea Bauxite field. New areas for ore deposits are found as the science of geology and the technology of exploration develops. For example, the huge copper and cobalt resources of the Zambian Copperbelt were unknown to the international mining industry until after 1925 when the first exploration hole was drilled at the Roan Antelope Mine.



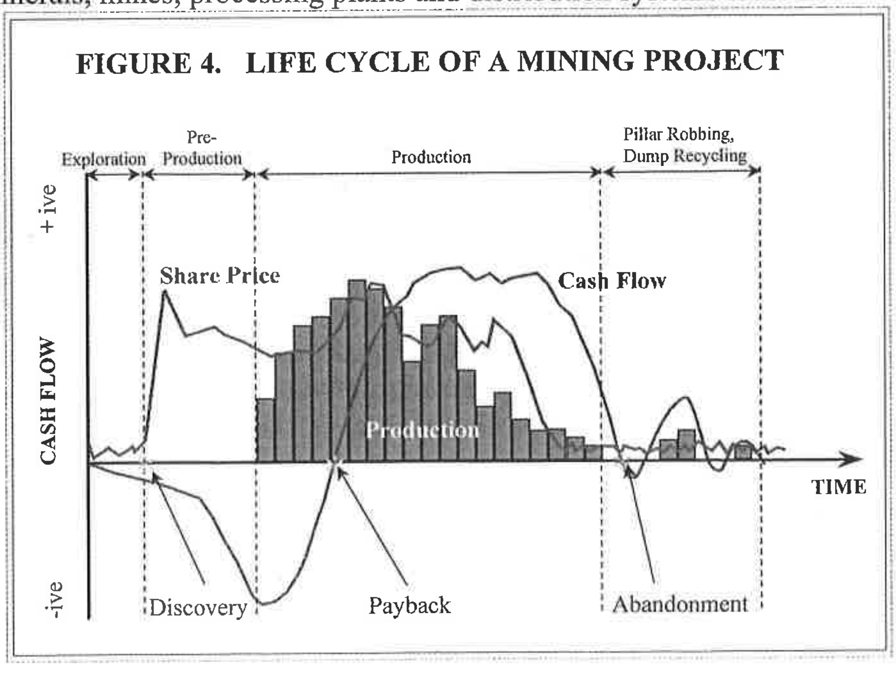
- **Mineral Exploration** is the process of looking for new reserves to mine. Exploration programmes are designed to go through a series of "Stop-Go" stages in order to control the very high commercial risk entailed in the process (Fig. 3). The five stages are commonly described as the *Mineral Exploration Cycle*, presented in detail in Part II of this Guide:

  - Program design - region selection, organization, budgeting
  - Reconnaissance ("grass roots") - regional appraisal, target selection
  - Detailed follow-up surface and sub-surface exploration - potentially leading to discovery of mineralization
  - Prospect evaluation having discovered mineralization
  - Feasibility Study on whether to mine

  Mineral exploration is critical in the supply chain of the minerals industry, so that while known deposits are being exploited to meet current demand, exploration must continue to meet future demand. At the earliest stages of exploration the risk is highest and the expenditure is lowest. The risk decreases and the expenditure increases as the process continues. The odds on success can be altered and the rate of new discoveries increased by scientific research to develop new technologies. For example, the development of electro-magnetic and magnetic techniques of airborne geophysics in the 1960's has contributed to the discovery of more new deposits in Canada and Australia than any other technique.



- **Development** of a mine follows discovery (Fig. 4). This can take many years, depending on the economic infrastructure of the region and the conclusion of agreements between the miners, the community and the government. To extract minerals, mines, processing plants and distribution systems must be developed.



- **Mines**, strictly speaking, are the places where ore deposits are excavated and minerals extracted. The word "***mine***" is used to include not only underground workings, but also open cast mines and quarries; in fact, any location where rock is removed for the purposes of extracting a mineral commodity is a mine.
- **Processing plants** receive the broken ore from the mine and separate out the waste material to concentrate the valuable mineral and produce a tradable mineral commodity. Processing systems vary widely depending on the physical and chemical properties of the ore and waste. Some common processes include crushing and grinding, screening, flotation, chemical leaching, flocculation, dense media separation, drying and bagging.
- **Distribution systems** include loading installations, trucks, railways, pipelines and ships to transport the mineral to the customer. They also include the trading and mineral marketing systems, which are established to ***supply*** the consumers and satisfy the ***demand***. Examples of trading systems are the London Metal Exchange and the New York Comex.

2.4 GLOBAL DISTRIBUTION OF ORE DEPOSITS

An outline of the distribution of mineral deposits in West Africa is shown on the map in Fig. 3. The geological history of any given region determines the mineral endowment, the type of mineralization likely to occur and the distribution of mineral deposits in that region.

The geological record is very complex, but studies have shown that different styles of mineralization can be compared and grouped across continents and general features can be emphasised. For instance, the rocks of Africa can be roughly divided into four main groups, each with its own distinctive suites of mineral deposits.

(a) The Archean and Lower Proterozoic: These very ancient rocks include some of the oldest on the planet dating from about 3,300 million years. Within this grouping there are basically two sub-groups:

Granites and gneisses : intrusive igneous rocks which were once molten and formed under great heat and pressure within the Earth's crust. Mineral deposits include: gold, copper-gold, ornamental stone, rare earth oxides, titanium ores and nuclear metals.

Greenstone belts : irregular areas of volcanic and sedimentary rocks which have been folded into the granites and gneisses. Minerals include some of the world's most important gold deposits (*e.g.* Obuasi in Ghana, Abitibi in Canada and Kalgoolie in Australia, together with new discoveries in the Lake Victoria region of Tanzania), and also zinc, copper, silver, asbestos, nickel, iron ores and manganese deposits.

(b) The Older Sedimentary Basins: Sedimentary rocks, such as shales, sandstones and limestones, were laid down in large troughs in various parts of Africa, such as in the Volta basin in Ghana and the Rokel River Syncline in Sierra Leone. Some of the most important mining districts in southern Africa are found in rocks of this type, as for example in the Copperbelt of Zambia and Democratic Republic of Congo and the zinc mines of Damaraland in Namibia. So far, apart from local supplies of building stones, the Older Sedimentary Basins have not produced many mineral deposits in West and Central Africa, although a few copper deposits are known in these rocks in Mauritania and Congo.

(c) **The Phanerozoic Igneous Rocks:** Small areas of Africa are underlain by a wide range of igneous rocks which were intruded into the Archean and Lower Proterozoic and extruded as volcanic rocks. Despite the small surface area compared to the other rock groups, these igneous rocks together form a very important source of minerals. They include the bauxites of Guinea, the tin fields of Nigeria, Niger and Cameroon, diamonds widely scattered throughout West & Central Africa, and some interesting potential for platinum (*e.g.:* Freetown, Sierra Leone). Some of the volcanogenic massive sulphide zinc and lead deposits in the Maghreb countries of North Africa are associated with Mesozoic volcanic activity.

(d) **The Younger Sedimentary Rocks:** Ranging in age from about 200 million years to the present day, these rocks are geologically the most recent. They are distributed in sedimentary basins around the coasts, in the Niger Delta, the Benue Trough and in the great inland basins of Chad, Niger and Mali. Economically they are of world significance as a source of oil in West and Central Africa. However, the younger sedimentary basins also provide phosphate in Senegal and Togo, coal in Niger and Nigeria, salt and gypsum in Chad and Niger, and limestone for cement and ornamental stone throughout the region. Certain other mineral deposits should be included here although their minerals are actually derived by weathering of older formations - for example: diamonds and gold in river gravels, titanium in beach sands, glass sands, and ceramic clays.

2.5 ORE DEPOSIT STYLES AND SETTINGS

Ore deposits can be classified by the style of mineralization and also by their geological settings. As indicated above, certain groups of minerals tend to occur in certain rock types of certain ages, although many minerals are common to a range of settings. This is due to the fact that broadly speaking, a number of predictable geological processes, confined to particular geological settings, give rise to predictable groups of mineral deposits.

The Mesozoic aged volcanic coastal belts of Chile and Peru predictably host major copper deposits related to that volcanic activity, similar to the copper deposits elsewhere around the Pacific Rim (see Section 2.5.1.2 below). In recent years, it has been discovered that the Lake Victoria Goldfields of Tanzania host significant gold deposits related to the Archaean greenstone rocks there, similar to those recognised many years ago in major gold-producing greenstone belts in Western Australia and Canada (see Section 2.5.1.3 below). Once these relationships are recognised, mining companies can re-evaluate whole districts with new 'eyes' for particular mineral commodities.

2.5.1 Ore Deposit Classification

The following section presents a summary of the main classifications of ore deposits (after Edwards & Atkinson, 1986).

2.5.1.1 Magmatic Deposits

A magmatic deposit is one in which the metal ores have segregated and accumulated during the crystallization of a cooling magma, as it ascends through the earth's crust. This class of deposit forms one of the world's main metal producing groups. Metals associated with magmatic deposits include nickel, copper, platinum group elements (PGEs), chromium, vanadium, titanium and diamonds. Cobalt and gold are significant by-product elements. Examples of this group include the Norilsk nickel-rich deposit in Siberia, the Sudbury nickel-copper ores in Canada and the Bushveldt PGE-chromium-vanadium-titanium rich complex in South Africa and Botswana. Kimberlite pipes with diamonds, such as those mined in South Africa, Namibia, Angola, Botswana, Canada and Australia, are also a very important group of magmatic depsoits.

2.5.1.2 Magmatic Hydrothermal Deposits

This group of ore deposits forms by hydrothermal activity (or hot fluids) associated with igneous bodies emplaced at high levels in the earth's crust. The deposits formed by this process are the world's major copper and molybdenum suppliers, and have enormous economic significance. The major types within the group include (i) porphyry deposits and (ii) volcanic-associated massive sulphide (VMS) deposits. Porphyry deposits also supply a large amount of gold, associated with copper, while the volcanic ore bodies also supply large amounts of zinc and lead. Other by-products include molybdenum, silver, rhenium, tin and tungsten.

(i) Porphyry copper deposits are relatively easy to explore for as they occur in known belts, along tectonically active continental margins, some of the most important lying around the rim of the Pacific Ocean in SE Asia (Indonesia, Papua New Guinea) and the Americas (Canada, USA, Mexico, Chile, Peru). Significant effort and resources are spent globally to find more of these deposits each year. Examples include the giant porphyry copper deposit at Bingham Canyon in Utah, USA, copper-molybdenum at Haib in Namibia, copper-gold at Ok Tedi in Papua New Guinea and copper at El Salvador in Chile. Most porphyry deposits are very large tonnage, low grade deposits, amenable to bulk mining methods. Statistics show that the average size of c. 100 deposits worldwide is 550Mt of ore grading 0.6% copper.

(ii) VMS deposits occur in association with calc-alkaline and basic volcanic rocks, mainly in back-arc and island arc settings, related to particular tectonic activities, such as sea-floor spreading and subduction. Major economic deposits of this type occur in Canada, Japan, USA, Australia, Europe and North Africa, producing large quantities of copper, zinc and lead. Examples include the Kidd Creek and Noranda deposits in Canada, Ducktown in Tennessee, USA, the Iberian Pyrite belt in Spain & Portugal, Matchless and Otjihase in Namibia and the world-famous Cyprus complex in the Mediterranean. In Japan, a number of world-class VMS deposits occur in the Kuroko and Besshi districts, while some recent discoveries suggest that Morocco and Tunisia may also host significant deposits. VMS deposits tend to be much smaller than porphyry deposits, but of higher grade (average <10Mt at c. 6% combined Zn-Cu-Pb); thus, they make popular exploration targets.

2.5.1.3 Hydrothermal Veins

Hydrothermal veins contain metals deposited from hot aqueous fluids into narrow channels in rocks. These were one of the principal styles of mineralization worked by pre-historic people (see Section 2.1 above). Hydrothermal veins remained a major source of metals until the end of the nineteenth century, but more recently only very high grade veins are worked for high value minerals, which are capable of offsetting the expensive mining costs. The main metallic commodities mined from veins include tungsten, tin, gold, uranium, cobalt and silver. Over 50% of tungsten production in the mid-1980s came from vein deposits, while the vast majority of Archaean gold production in Australia, Tanzania and Canada comes from hydrothermal quartz veins, with telluride, arsenide and sulphide associated minerals. Examples of this broad grouping include Hemlo, Val d'Or, and Porcupine in the Superior, Slave and Wabigoon provinces of Canada, Commoner in Zimbabwe, the Barberton district of South Africa and the Yilgarn Block of Western Australia.

2.5.1.4 Placer Deposits

Placer deposits are formed by the mechanical concentration of resistate minerals, which have been released by weathering from their parent (source) rock in which their distribution may have been sub-economic. The most common minerals which concentrate in this form are gold, platinum, tin, diamonds, zircons and titanium, which are found in placer deposits in river beds (alluvial placers) or in coastal dune complexes (mineral sands). Palaeo-placers, or lithified placers, occur mainly in the very old rocks of the Archaean and Proterozoic ages. The latter are a major source of uranium and gold in South Africa and Canada. Tin-bearing palaeo-placers are recognised in Nigeria, Brazil and Malaysia. Placer deposits have been historically worked by artisanal miners in many countries, due to their relative ease of extraction, but grades are generally lower than from hard-rock mining. One of the most famous palaeo-placer deposits in the world is the Witwatersrand goldfield of South Africa, while an example of a more recent placer deposit includes the Quaternary fluvial gold deposits in New Zealand. The Bakwanga diamond field in Democratic Republic of Congo also represents an interesting example of a placer deposit.

2.5.1.5 Sediment Hosted Copper-Lead-Zinc

This group forms one of the most important sources of the base metals, copper, lead and zinc across the globe. The group has been explored extensively in a range of geological environments and although common characteristics can be recognised among deposits, debate still rages as to their exact origin. Three main groups occur:

- *Syngenetic*: In particular geological settings, there is evidence to suggest that ore-bearing fluids issued onto the seafloor to form mineral deposits contemporaneously with sedimentation.
- *Diagenetic*: In some cases, the ore fluid has invaded the rocks while they are still semi-lithified and replaced other minerals.
- *Epigenetic*: In other cases the ore-bearing fluids have penetrated the rocks after they were lithified.

Syngenetic and diagenetic deposits are frequently classified as 'sedimentary-exhalative' in origin or SEDEX in brief.

Sediment-hosted <u>copper</u> deposits are hosted in shales, carbonates and sandstones, and the largest known deposits cluster in age in the Middle to Upper Proterozoic, reflecting major tectonic movements of that time. However, many other deposits are found in much younger rocks of the Permo-Triassic period. The copper deposits are frequently very large, ranging in size from <1.6 million tonnes to >1000 million tonnes, at an average grade of 2.6% Cu. Included in this group are the world famous mines of the Zambian Copper Belt, which are largely considered to be SEDEX in origin.

The sediment-hosted lead-zinc deposits have a more restricted geographical and temporal distribution, occurring almost exclusively in shale and carbonate host rocks. Galena (lead sulphide) and sphalerite (zinc sulphide) are the most common minerals, with by-products of silver, barytes and other metals. Important examples of this group are the shale-hosted Mount Isa and Broken Hill (Australia) and Sullivan (Canada) SEDEX deposits, which typify the giant deposits formed during the Middle Proterozoic period. Examples of carbonate hosted SEDEX deposits include the Navan and Lisheen deposits (Ireland), while epigenetic carbonate-hosted deposits are found in Mississippi-Tennessee (USA). The latter group give their name to one of the main working classifications of this group, the Mississippi Valley-type or MVT. Both SEDEX and MVT deposits have classic characteristics in terms of metal content, alteration, geological settings etc., which allow geologists to classify them to assist in further exploration for new deposits.

2.5.1.6 Weathering Deposits

Many types of minerals deposits form by weathering of existing mineral deposits (of the types described above in Sections 2.5.1.1 - 2.5.1.5) or by enrichment of certain minerals in the weathering profile, over thousands or millions of years. Weathering is defined as the breakdown and alteration of rocks by physical and chemical processes, both of which may be aided by organic activity. The process is due to natural changes in the environmental conditions in the rocks formed, over a period of time, including permeability, climate, relief and drainage. Weathering is the initial stage in the cycle of events leading to the formation of sediments: without it, rock material would not break down to be transported and deposited elsewhere to form sedimentary deposits. Other weathering deposits form *in-situ* whereby other material is dissolved and weathered away, leaving a residual concentration of the economic material in place e.g. the gold 'cap' over the Ok Tedi porphyry copper deposit in Papua New Guinea formed in this way. Another *in-situ* type of deposit forms when a mineral is accumulating and becomes weathered in its upper levels to produce an economically valuable mineral, e.g. bauxite, the ore of aluminium, forms by the *in situ* weathering of aluminous sedimentary and igneous rocks below.

The most important minerals formed by weathering processes include bauxite, e.g. the Guyana-Brazilian Shields, the Caribbean Province, the Guinea Shield in West Africa, the Cameroon Province in Central Africa, the Australian Province and the European Province; nickel laterite (Cuba, Guatemala, Guinea, New Caledonia, Indonesia, Australia) and kaolin (Czech Republic, Guyana, Brazil, USA and UK).

2.5.1.7 Iron Ore

Iron ore is a highly important mineral to international industry as the bulk of iron ore is processed into steel for the vehicle manufacturing industries. World demand increased from 270 million tonnes in 1955 to 1,027 million tonnes in 1997, reflecting the socio-economic changes of that period. Like most mineral deposits, iron ores have a variety of origins, including sedimentary weathering crusts, magmatic sources, contact metasomatism, marine sedimentary and hydrothermal sources among others.

Iron formations of sedimentary origin are largely confined to Precambrian Shield areas, formed 2500-1900 million years ago in the Lower Proterozoic, reflecting major atmospheric and environmental changes taking place at that time of earth's evolution. Iron ores derive from iron-rich sedimentary rocks, forming the minerals magnetite,

3. LOCATING MINERAL PROJECTS

To enter the world of mineral exploration, the explorer or mining company must first decide which commodity to seek, where to focus the search, and how to go about finding that mine. Implicit in this is that the explorer has the technology, the finance and the know-how to start exploring, weighing up all the socio-economic and political risk factors.

3.1 WHICH COMMODITIES TO EXPLORE FOR?

In the international world of mineral exploration, the choice of which minerals to look for depends largely on the demand and the current price. However, the range of commodities can still be very wide (Tables 4, 5), but ultimately any mineral which can be profitably mined is a valid target for exploration. Clearly, there is a great variation in unit price between high value minerals, such as gold which has a current price of about US$285 (early 1999) per ounce (equivalent to about $8,895,000 per tonne) on the one hand, and building aggregate which has a price of about $3 per tonne, on the other hand (Table 6).

TABLE 6

From 100 tonnes of average crust with 100% recovery, theoretically:-

Metal	Weight	Value $
Aluminium	8.2 tonnes	17,835
Iron	5.6 tonnes	2,021
Zinc	7.0 kg	9.37
Nickel	7.5 kg	57.84
Copper	5.5 kg	13.98
Silver	7.0 g	1.21
Gold	0.4 g	3.02
TOTAL		$19,941.42

Note: many other elements not included.

At first sight one might wonder why everyone is not mining gold. The answer is, of course, that the costs of exploration, mining, processing and distribution must be taken into account. Higher unit values for particular minerals reflect rarity and higher costs associated with the various stages of the mineral supply process (Tables 1, 7). What matters is whether or not a mine can be located and developed and the mineral product sold to give a good return on the initial investment.

It is well-known that commodity prices vary, some much more so than others. Fig. 11 and Table 8 show unit prices plotted against market volumes. The causes of price

TABLE 7
Crustal Abundance,
Concentration and Unit Value

Abundant elements - those forming **more than 0.01%**
Scarce elements - those forming **less than 0.01%**

e.g. Abundant: *Al* = 8.13%, *Fe* = 5.0%
Scarce: *Cr* = 0.01%, *Au* = 0.0000008%

The **Unit Value** is **Low** if the element is **abundant** and **requires little concentration** e.g. *Fe, Al*

The **Unit Value** is **High** if the element is **very scarce** and **requires much concentration** e.g. *Au, Hg*

variations lie in the fundamentals of World economics, depending on the volumes traded internationally in various commodity markets.

3.2 HOW TO LOCATE PROJECTS

Having decided on a commodity and a broad region or group of countries, the explorer must attempt to locate suitable projects. This may be done in a variety of ways, including:

(i) by purchasing datasets for a given region(s) or country(s) and evaluating them on the basis of past experience and current perceptions to target conceptual or new projects.
(ii) by developing networks of contacts in the chosen region(s), who may be aware of the availability of existing projects or suitable 'grassroots' terrain.
(iii) by extending the search out from known mineralization, or existing mines, using the premise that one should 'shoot elephants in elephant country'.

Where to locate projects is largely a matter of where the market is located in relation to the mineral deposit, how the market is operating and what relative volumes are traded. For example, the **gold** market is international - an ounce of gold has the same value in London, Tokyo and Accra - and the demand is always there, although the price fluctuates widely. It is expensive and risky to find, the cost of mining and processing is relatively high, but the cost of transportation is low. A year's production from a gold mine can be taken away to market in a single truck or plane. Compare this with **building aggregate**. The cost of producing aggregate by quarrying and crushing is relatively low, but transportation to market is by far the largest fraction of the production cost. This all means that gold can be profitably mined in very remote locations, whereas aggregate can only be quarried profitably if there is a willing buyer nearby, as for example in a new road building or civil engineering scheme.

public can go to the Geological Survey, buy maps and consult files detailing the results of previous surveys and exploration in their country.

- **The Chamber of Mines:** Miners in many countries band together to form a local association to help each other and to lobby government over issues of concern to the industry as a whole. The local Chamber of Mines may have a newsletter or magazine and may hold meetings at which members can interact with one another. Miners are usually very sociable people who enjoy networking and they can easily be encouraged to discuss business wherever they meet.
- **The Mines:** The best place to learn about mining is in a mine. The more experience gained by visiting mines, the better we can understand new situations when they arise. Most major mines will welcome visitors, although hospitality must not be taken for granted. Before visiting, one usually one needs written permission - you should not just arrive at the mine gate and expect to be admitted, but do make the effort to visit them.
- **Artisanal Miners** are a special case. They are frequently operating illegally and in dangerous conditions. Where they do have legal artisanal mining rights, these rights cannot be transferred to foreigners so they are of little interest for investment. However, artisanal miners are good traditional prospectors and so the discovery of a new mining district is often revealed first by artisanal miners. Find out where they are as a guide to where to look.
- **The Press:** Local and national media often carry articles about mining in their area. Look out for names of likely contacts and places to visit. You might consider placing newspaper adverts yourself asking for properties to buy. The international mining press is a very good source of general information about the industry as a whole, although it will not usually give local leads. The best known international publications are the *Mining Journal*, the *Mining Magazine*, the *Engineering and Mining Journal*, *World Mining* and *The Northern Miner*.
- **Agencies:** Other agencies sell internationally available data, such as satellite imagery, TM imagery, etc. which can be purchased directly from companies such as the United States Geological Survey (USGS), EurImage (France), geological surveys or from private imagery companies. The latter tend to be more expensive than the public agencies.
- **Internet:** The 'Net' can be used to source a wide variety of data concerning technical, economic and political factors in the region in which the explorer is interested. A list of useful web-sites and addresses is given in Section 6.1 below.

3.3 SECURING MINERAL RIGHTS

The single most important factor in any mineral exploration programme is the ownership of the mineral rights. This will be clear from a consideration of the basic economics of the mining industry. Virtually the only way an exploration or mining company can secure its investment is to have a clear understanding about its legal rights from the start. Currently, there are a variety of mineral laws applicable in different countries, but the legal situation is moving towards international harmonisation, particularly in African countries, so that the Mining Codes for different jurisdictions will be grossly similar. There are some common legal themes already:

- In almost all African countries nowadays, all minerals are owned by the State and leased out to mining companies as mining tenements.

- It is unusual for local farmers and landowners to own the minerals, although they often think they do. Mineral rights are distinct and separate from all other surface land rights, but nonetheless, care is needed when dealing with local communities.
- Most countries have a **Reconnaissance Licence (RL)** as the starting point. Anybody who wishes to explore for minerals in a region must have this licence; it is relatively inexpensive, but it is non-exclusive (*i.e.* other prospectors can work in the same place).
- An **Exploration Licence (EL)** or a **Prospecting Licence (PL)** is necessary to carry out exclusive exploration over an area. There are different statutory terms in different countries, including fees charged per square kilometre, length of the licencing term (two years is common), renewal conditions, work programme and expenditure requirements, and reporting requirements. Internationally, it is common for exploration companies to enter joint ventures with local licence holders. In these instances, the terms of the joint venture agreement should protect the rights of both parties in the event of a discovery in the lifetime of the joint venture.
- A **Mining Licence (ML)** is required to mine a specified deposit. Again, terms vary from country to country and, commonly, from mine to mine. Investors will want to know about likely mining licence terms in any country they wish to investigate, before coming to that country.
- **A Mining Concession** is found in some countries. It includes exclusive exploration and mining rights together in one package agreed between the company and government before exploration starts. A concession may require consideration and approval by Parliament.
- **Mining Laws** differ in different countries. Francophone African countries have civil law systems derived from French Law and Anglophone countries have common law systems derived form English Law. It is important to understand this in practice, as there may be differences in interpretation of legal concepts.

Any mineral explorer must be aware of the basic mining laws of the country in which they are operating. A consultant operating in the country can be of great assistance to potential investors by giving good independent advice on the mineral rights situation locally, how to acquire mineral rights and which government departments to apply to. Copies of the relevant laws and regulations can be bought from the Government. In particular cases, it will be necessary to find a local lawyer specialising in mineral rights.

4. MAKING A MINE: FACTORS TO BE CONSIDERED

Minerals are everywhere - the definition of a rock is an aggregate of minerals. In theory, 100 tonnes of an average piece of the Earth's rock crust could be mined and a number of metals could be isolated and sold (Table 6), with a value of about $20,000. Why don't we do this? The answer is that it would take more than $20,000 to isolate the minerals and so the operation would make a loss. Thus, when an exploration company has discovered a sizeable mineral deposit, of reasonable grade, there is no guarantee that the deposit will ever become a mine. For example, the massive Duchess phosphate deposit (approx. 1300Mt @ 17.5% P_2O_5) in northern Australia was not developed for years because production costs would have been too high for the price at which it could be sold.

4.1 DEFINITION OF AN ORE DEPOSIT

The above leads to the understanding of the definition of an ore deposit:

> ***An ore deposit is a naturally occurring aggregate of minerals from which mineral commodities can be extracted with the expectation of making a profit.***

or as the Institute of Mining & Metallurgy (IMM) in the United Kingdom define it:

> ***Ore is a solid, naturally-occurring mineral aggregate of economic interest, from which one or more valuable constituents may be recovered by treatment.***

These definitions allow two groups of factors to be identified which distinguish an uneconomic mineral deposit from an ore deposit (Fig. 5):

- Technical factors - those of a geological or engineering nature (*i.e.*: the minerals).
- Economic factors - those which relate to the economics of mining (*i.e.*: the profit).

4.2 MINERAL DEPOSITS: TECHNICAL FACTORS

Technical factors which decide whether or not a mineral deposit becomes an ore deposit are described in the following sections.

4.2.1 Grade

Grade is the degree of concentration of valuable constituents expressed as a proportion of ore mineral (or metal) to waste (or gangue). For each tonne of ore, the ratio of valuable material to waste is closely related to the ratio of income to expense. Clearly, the higher the grade, the more valuable is the deposit. Grade is expressed in many different ways depending on the degree of concentration and the units in which the ore is sold. Metalliferous deposits (*e.g.*: zinc, iron, copper) are quoted in percentage of metal and using the chemical symbol (*e.g.*: 12% Zn). Precious metals, such as gold (Au) and silver (Ag), are quoted in grams per tonne (*e.g.* g/t Au), which is arithmetically equivalent to parts per million (ppm). However gold is still quoted in imperial ounces (oz) in many quarters and the international price is quoted in American dollars per ounce (e.g. US$300/oz Au). Diamonds are in carats per tonne (ct/t) or, in the case of alluvial gravels carats per cubic metre (ct/cu.m). Industrial minerals usually need other information as well as the percentage of valuable mineral, such as the proportion of deleterious constituents, such as cadmium in phosphate deposits or silica in bauxite deposits.

4.2.2 Tonnage

Tonnage is the total mass of ore-bearing rock present in the deposit. It is important to quote this figure as well as the grade because a very small deposit can be high grade and still not worth mining. There must be enough ore present to keep the mine running long enough to pay back the capital expense. The calculation of ore reserves is a specialized process and one which is very liable to error, misleading conclusions and even fraud.

4.2.3 Ore Reserves

One of the greatest risks in mining lies in the limitations of knowledge in the extent and character of the mineral deposit. An important distinction is made between **pre-resource mineralization** (extent unknown) and a **mineral resource** (extent established) on the one hand, and **an ore reserve** on the other. The former terms refer to mineral deposits which have been discovered, but have not yet been proved to be economically viable (Figs. 6, 6A). In contrast the term 'ore reserve' should only be used to refer to a mineral deposit which has been the subject of a feasibility study, establishing its physical extent, mineralogical character and financial viability under stated operating conditions of cost and revenue, to an internationally acceptable degree of accuracy. An Ore Reserve Statement, signed by an appropriately qualified geologist or mining engineer, will be required by an investor at some stage in the negotiation for development projects and operating mines. By definition, no ore reserve statement is possible for exploration areas and pre-development projects, although reliable geological reports of resource assessment and measurement will usually add value to the property.

Figure 6. McKelveys Box Method of Ranking Projects

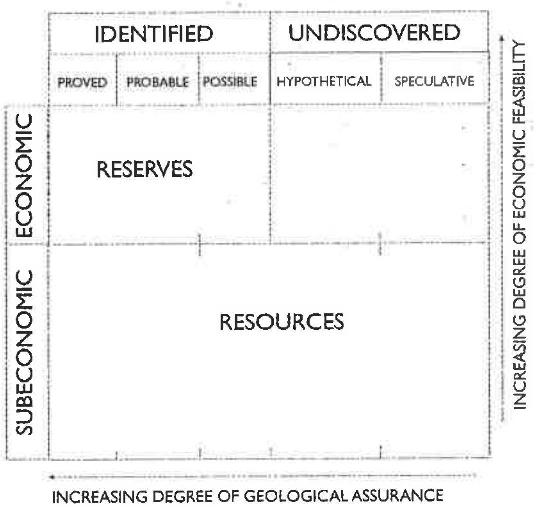
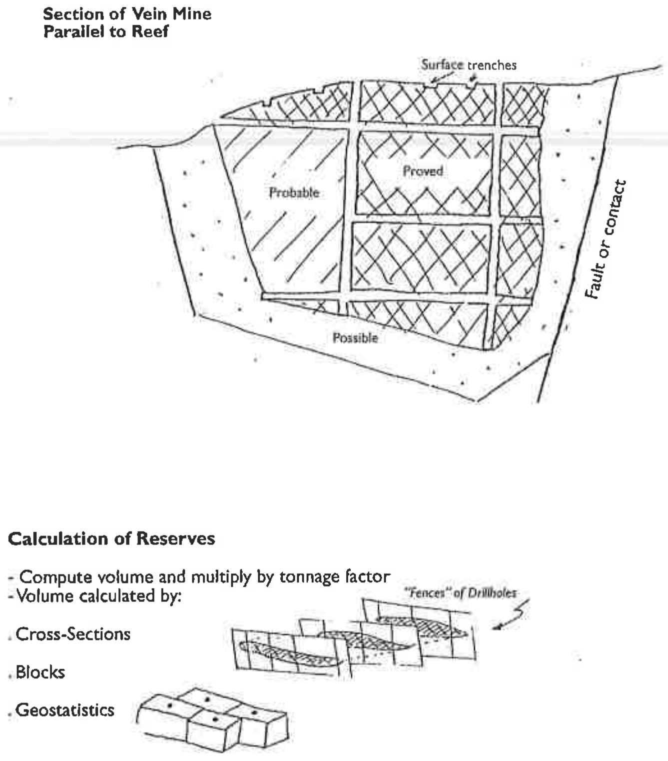


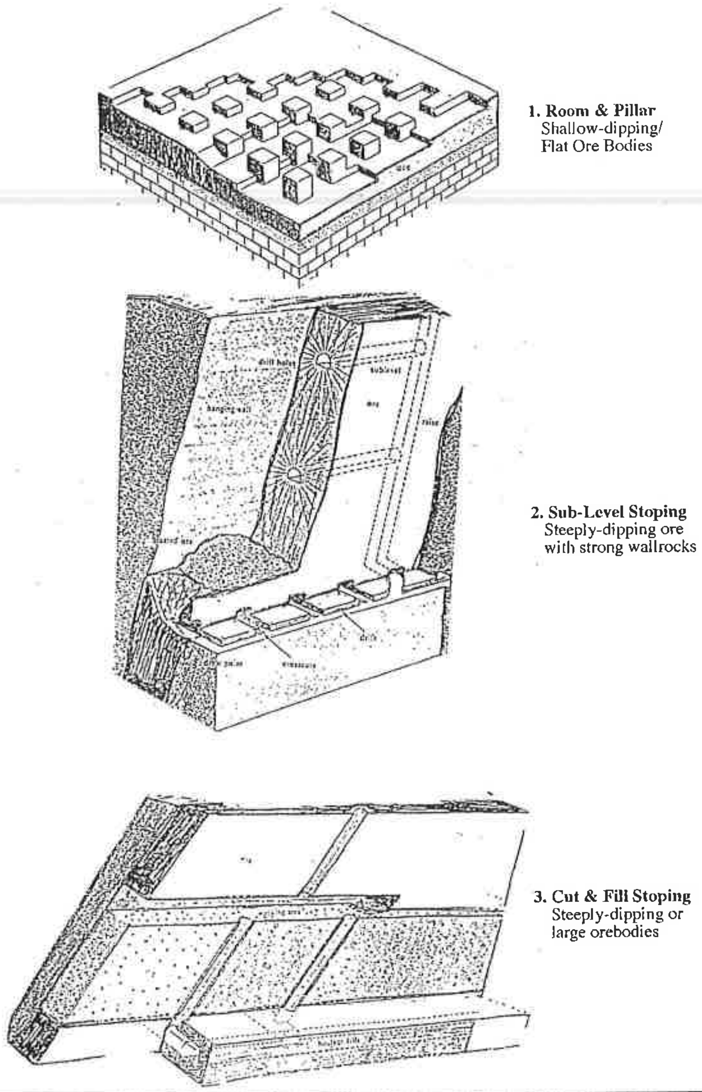
Figure 6A Categories of Ore Reserves



4.2.4 Style

The geology, shape and position of the orebody must be such that ore can be extracted with minimal mining of unpayable waste rock (Fig. 7). In simple terms, a *vein* style deposit is generally shaped like a flat sheet and is often nearly vertical; a *stockwork* is an irregular mass of small veins closely packed together; a *stratiform* deposit is a flat-lying layer with a regular thickness, while a *massive* deposit is an irregular shaped body containing concentrated ore. These factors influence the mining method and hence the cost of mining. Mine design is a subject for mining engineers, but there are certain common-sense rules of thumb. For example, open-cast deposits (those worked from surface) are cheaper to operate than underground mines (those worked sub-surface), and the deeper the mine the more costly the ore and waste handling operations.

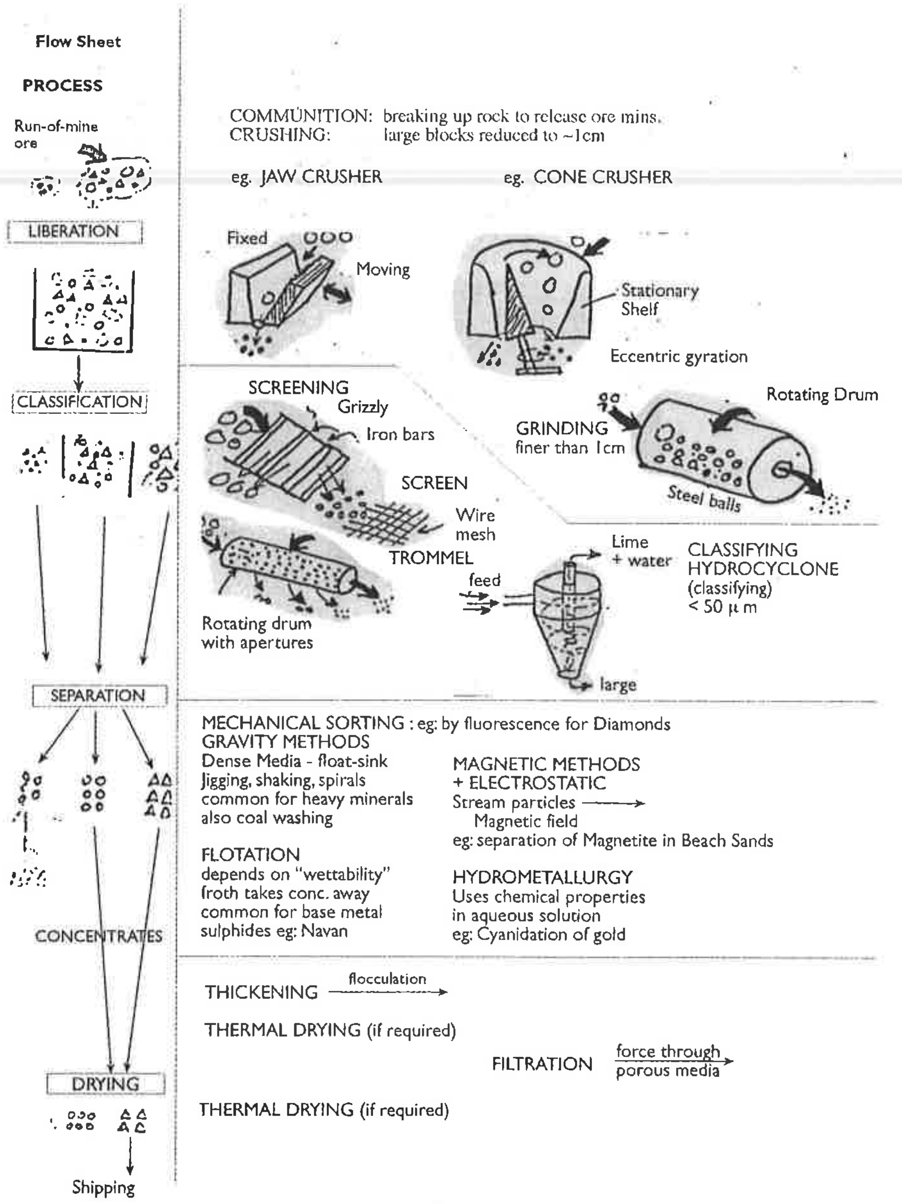
Figure 7. Underground Mining Systems



4.2.5 Metallurgy

Metallurgy refers to the chemical treatment of the ore minerals, depending on the relationship between the valuable and waste minerals at the level of the chemistry of individual grains. It also pertains to how hard or soft the ore is and is important to the economics of mineral processing (Fig. 8). For example, zinc metal in zinc deposits can be combined with sulphur, as zinc sulphide, or with oxygen and other elements, as zinc oxide. It is easier and cheaper to extract zinc from sulphide deposits than it is from oxide. Similarly, gold can occur as native metal (free gold) or microscopically mixed with iron sulphide (complex gold) or telluride metals. Extracting free gold requires little more than crushing and washing, whereas complex gold needs roasting in furnaces after crushing, which is much more expensive.

Figure 8. Mineral Dressing Systems



Many valuable metals also usually contain 'impurities' of other metals, so that for instance silver is frequently associated with lead sulphides and may be a hazard or a bonus, depending on how easy it is to extract metallurgically. In other cases, cobalt, a metal valuable to the paint and aeromotive industries, may be a value-adding metal associated with copper-gold deposits. However, if the cobalt is bonded with pyrite (iron sulphide), it may be highly costly to extract it chemically, such that it has no value or may even add costs to treating the ore. Other elements such as mercury or cadmium may also occur in deleterious amounts for the ore to be extracted economically. However, technological advances in pyro-, bio- and hydro-metallurgy in recent years have meant that ores which were untreatable in the 1960s are now economically viable e.g. the giant zinc-lead McArthur River deposit in northern Australia.

4.2.6 Technical Feasibility Study

Mining companies will always carry out a full technical feasibility study of the mineral deposit/ mine prior to the final decision to go ahead with a project. The ore reserves should be described according to international standards into proven, probable and possible categories (see Table 9). In addition, detailed pilot metallurgical studies, engineering and geotechnical studies, environmental impact assessment and socio-economic impact studies will be addressed in the technical feasibility study.

4.3 MINERAL DEPOSITS: ECONOMIC FACTORS

The return to investors from a mine will be in the form of:

- dividends derived from the positive cash flow of a mining operation (see Fig. 4) and/or
- an increase in the capital value of the investment.

4.3.1 Mineral Rights

Ownership of mineral rights is arguably the single most important economic factor to be considered (see Section 3.3 above). There is no point expending hundreds of thousands of dollars in exploration if you have not secured mineral rights from the outset. In most African countries nowadays, ore deposits, both discovered and undiscovered, are owned by the State. They are leased to miners on payment of royalties, but with clear and transparent rights and responsibilities of each party. Typical responsibilities of the miner would include environmental protection & rehabilitation, while typical responsibilities of the State would include regulation of the latter.

4.3.2 Geographic Location

Location is important in determining many of the external aspects of the economics of a mining project, including material and ore transport costs, together with proximity to smelters and refineries for certain metals, costs of supplying power and water, labour availability, environmental issues and proximity to markets.

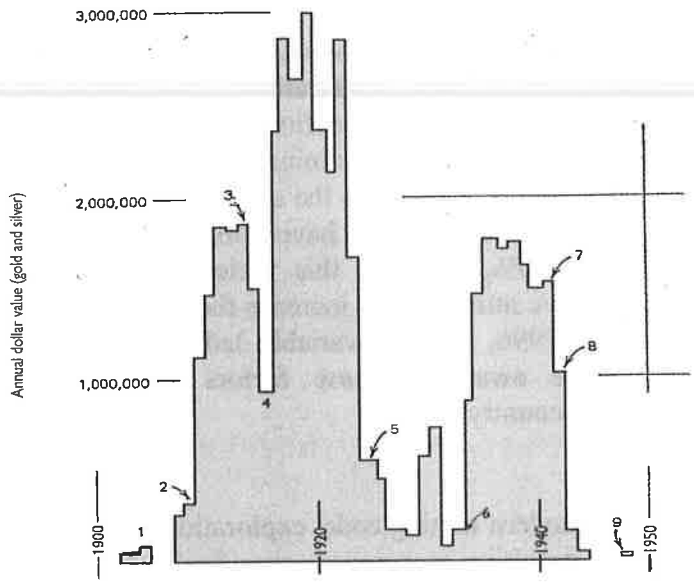
4.3.3 Commodity Market

The price and demand for any commodity is the ultimate determinant of whether or not a deposit can be mined (see Section 4.1 above). Since a tradable mineral product is the ultimate end-point, the marketability and price fluctuations of the product are major considerations for investors (see Fig. 9 for an example of how price fluctuations impact on an ore deposit over a long period of time). Although this is usually outside the control of the producer, mineral products which can be exported and sold in major international markets (for example, gold) will be preferred to those which are traded in restricted or local markets (for example, construction aggregates).

TABLE 9. DEFINITIONS OF MINERAL RESERVES AND RESOURCES (from *Mining Magazine*, February 1994)

RESERVE	RESOURCE
1. A **mineral reserve** is that portion of a mineral resource on which technical and economic studies have been carried out to demonstrate that it can justify extraction at the time of the determination and under specified economic conditions.	2. A **mineral resource** is a tonnage or volume of rock or mineralization or other material of intrinsic economic interest the grades, limits and other appropriate characteristics of which are known with a specified degree of knowledge.
1. A **Proven Mineral Reserve** is that portion of a measured mineral resource as defined on which detailed technical and economic studies have been carried out to demonstrate that it can justify extraction at the time of the determination and under specified economic conditions.	2. A **Measured Mineral Resource** is that portion of a mineral resource for which tonnage or volume is calculated from dimensions revealed in outcrops, pits, trenches, drill-holes or mine workings, supported where appropriate by other exploration techniques. The sites used for inspection, sampling and measurement are so spaced that the geological character, continuity, grades and nature of the material are so well defined that the physical character, size, shape, quality and mineral content are established with a degree of certainty.
1A. A **Probable Mineral Reserve** is that portion of a measured and/or indicated resource as defined on which sufficient technical and economic studies have been carried out to demonstrate that it can justify extraction at the time of the determination and under specified economic conditions.	2A. An **Indicated Mineral Resource** is that portion of a mineral resource for which quantity and quality are estimated with a lower degree of certainty than for a measured mineral resource. The sites used for inspection are too widely spaced or inappropriately spaced to enable the material or its continuity to be defined or its grade throughout to be established.
3. **Mineral Potential** describes a body of rock or mineralization or other material or an area for which evidence exists to suggest that it is worthy of investigation, but to which neither volume, tonnage nor grade shall be assigned.	

Figure 9 Mining Cycles - Oatman Mining District, Arizona



1. Early production from exposed orebodies
2. Major mine production from small orebodies (1909)
3. New company formed to develop deeper ore (1913)
4. Major mine began production from deeper orebodies (1916)
5. Major mine closed. Mills continued operating on custom ore (1924)
6. Price of gold raised from \$20.67 to \$35/oz (January 1934) followed by redefinition of ore reserves and re-opening of mines
7. Wartime shortages of labour and equipment
8. Wartime closing of gold mines (1942)
9. Post-war mining attempt (1948)

4.3.4 Investment Climate

When considering the investment climate for mineral exploration or any future mine development, we usually refer to whole regions and countries rather than to individual deposits, which is why it is also referred to as "Country Risk". Investment climate is a combination of economic, infrastructural, political, cultural and legal factors pertaining to a given country or region. Some countries present markedly higher financial risks, and therefore less favourable investment climates, than others. Governments can do a great deal to ameliorate the country risk.

Ore deposits cannot be moved except by mining. The operation is therefore vulnerable to adverse changes in policy and laws, or civil unrest. Investors will rarely put money into mineral projects in countries which are politically unstable or operate harsh policies towards investors and their own citizens. This factor determines many aspects of ownership, access to markets and exchange control.

4.3.5 Mining, Milling, Refining and Smelting Costs

Mining costs will largely be determined by the physical characteristics of the ore body, including geometry, style, grade, ore-to-waste ratios, metallurgy and geographical location (as described above). In the case of base metals such as copper, lead and zinc, the mined ore will usually be milled and concentrated on-site, but will then have to be transported to be smelted and refined before the metals can be utilised in any practical way. Thus, transportation to the smelter and/or refinery will add costs, while the physical processes of smelting and refining are also costly. If, as outlined in Section 4.2 above, there are deleterious minor metals associated with the main concentrate, smelters may impose penalty taxes on the mining company.

4.3.6 Government Participation /Royalties

In most developed and emerging economies, the mineral rights are held by the State, who administer the licencing of mineral exploration and mining on behalf of its citizens. The recent trend in terms of State benefits from mining developments is to levy a royalty on the mining company, once the mine is fully operational. This varies according to the commodity, but is generally in the order of 3% of the net-back-value of minerals sold. In addition, some countries have obligatory State participation in the project, generally up to 10%, although this varies in different jurisdictions. Occasionally, governments have attempted to increase their participation unilaterally as in Papua New Guinea in 1996, which invariably led to companies quitting the country. It is well to be aware of these factors prior to committing to exploration/mining in a given country.

4.3.7 Environmental Costs

In most jurisdictions with a modern mining code, exploration companies are required to employ environmentally sensitive techniques, specifically through minimisation and avoidance of destructive or unnecessary practices when conducting surveys, drilling programmes, etc. Rehabilitation of exploration sites post-investigation is a normal stipulation. Frequently, a bond will be sought as a guarantee of rehabilitation, as part of the licensing agreement. At the advanced stages of a project, most States will certainly require that an environmental bond be paid in advance of the development of a mining project, so that in the event of default by the company, the State will carry out the necessary rehabilitation.

In scoping the development of exploration or mining projects, the investor should take cognisance of its increasing environmental obligations, which are frequently monitored by international environmental lobby groups. Interestingly, apart from the social and moral obligations to do so, many companies find that by working in an environmentally friendly way, it frequently saves money in the long term.

4.4 FINANCIAL EVALUATION OF A MINERAL PROJECT

Mining companies are constantly looking for new mine development opportunities, which will provide them with an attractive return on their investment at an acceptable risk. In order to do this, they must be able to assess a project's mineral assets and associated technical and financial attributes (Sections 4.2, 4.3 above). Assessment of a project will always be carried out from the mining company's view-point, perhaps in consultation with select interest groups, but will be fundamentally based on an evaluation of risk and return.

Financial evaluation and management are critical factors in (i) deciding to develop a mineral deposit into a mine, and (ii) managing the project responsibly both economically and socially.

4.4.1 Capital Expenditure (CAPEX)

CAPEX is the amount of finance which must be raised for specific mining investment projects, to fund the capital development phase (including engineering and geotechnical design, infrastructure, telecommunications, utilities, equipment, labour costs, service fees etc). The worth of an investment is measured by its ability to produce a flow of cash over the lifetime of the asset, in this case a mine. Most mining companies borrow the CAPEX to develop projects, because the sums of money involved are huge. For instance, the giant *Baja de la Alumbrera* copper-gold porphyry deposit in Argentina cost in the region of US$1000 million to develop, largely because of its geographical remoteness and the lack of existing infrastructure. Invariably, the company which wants to borrow the CAPEX must prepare a detailed bankable feasibility study, to ensure that all aspects of the project are considered, costed and built into the cash flow projections for the project, to avoid cost over-runs down the track.

4.4.2 Cash Flow & NPV

Cash flow is defined as the gross revenue or savings, minus the operating expenses, tax costs and capital costs. **Net Present Value** (NPV) is a method of valuing a project by estimating the current value of future cash flows related to a project. The basic rule is that any projects with an NPV greater than zero (when discounted at the cost of capital) are financially viable, and should go ahead. The NPV method is extremely useful for choosing between alternative options or projects.

4.4.3 Rate of Return

The Rate of Return is calculated from a project's discounted cash flow and estimates the actual yield, or rate of interest earned, on the capital amount invested. The discount factor is expressed as 'the reciprocal of 1 plus the rate of return' (1/ 1 + r.o.r), where the rate of return is the reward that investors demand for accepting delayed payment or payment in the future. A positive rate of return means that the capital amount invested is recouped, plus an effective rate of interest is earned on funds tied up in investment. Many companies use this Rate of Return method to evaluate potential projects.

4.4.4 Inflation, Interest & Exchange Rates

It is important to calculate the effects of inflation, interest rates and exchange rates for any potential development, as failure to do so may lead to serious erosion of future earnings. A number of formulae may be applied, using long term economic projections in order to lower the risk factors of the investment.

4.4.5 Financial Returns

Limit of Investment: The size of the return should be in proportion to the investment. A minimum to start a serious grass roots exploration programme would be of the order of $100,000. In practice, much more will be required for later stages. The upper limit would be the value of the ore body itself, which could be hundreds of millions of dollars for a major mine.

Equity Participation: Major investors will demand significant ownership of the mineral asset in return for their investment. If the interest is over 50%, it becomes a *controlling interest*, and the controlling party would normally assume management of the project.

Currency of payment: Investors will require to have their return, whether capital or dividend, in a freely exchangeable stable currency. An investment in which dividend returns are directly linked to the sale of an internationally traded commodity (such as gold, base metals), with proceeds paid into an offshore account in one of the major currencies, will be more attractive than one in which the mineral commodity is traded in a local currency or bought by the State at a controlled price.
Liquidity and assignment: The ease or difficulty with which an investment can be transferred (assigned) to a third party, together with the expectation of the likely term of the investment, are important aspects in any investment decision, but especially to foreign investors in the mining industry. Liquidity of capital can be facilitated through a stock market listing and therefore quoted companies will be preferred. To some extent this may be controlled by the laws of the country, but a final agreement must take into account not only the interests of the junior (local) partner, but also the requirements of a major (foreign) investor.

4.5 SOCIAL & ENVIRONMENTAL IMPACTS OF A MINERAL PROJECT

The modern world has become an increasingly internationalised work-place, with technology allowing rapid telecommunication across the globe. Similarly, the mining industry has become increasingly globalised, due to the natural geographic distribution of mineral resources and the corporate trend towards trans-national companies (TNCs). Increasingly too, the ease of communications allows community groups and non-governmental organisations (NGOs) to activate social and environmental monitoring operations and campaigns, which are readily communicable to the world media. This has had a largely positive impact on the mining industry, which has had to respond to social concerns in terms of its operations, community relations and environmental rehabilitation.

4.5.1 Community Relations

Exploration and mining operations are situated in regions and countries where mineral potential is highest, having taken into consideration all the technical, political and economic factors described above. However, exploration and mining make a very significant social impact wherever they are located, as frequently a dominantly western-style culture of work is introduced to areas where the prevailing culture may be traditionally based. Unless this cultural meeting is handled sensitively, the potential for conflict is high.

Increasingly, mining companies are taking their responsibilities in terms of social impact seriously, and many companies will appoint a community liaison officer. However, at the exploratory stage, very often it is the field geologists and technical staff of the exploration company who are 'at the coal face' with local communities.

Thus, it is imperative that geological staff consult fully before undertaking exploration by:

- speaking with local people to understand local mores, community structure, traditional ways, etc.
- employing locals as field assistants, to generate jobs and training.
- speaking with farmers/ holders/ agricultural extension officers before entering land.

- taking cognisance of cropping cycles when planning trenching or drilling programmes.
- offering fair compensation for land disturbance.
- being aware of local water demand and perhaps facilitating the needs of local people where ever possible.

Simple measures such as the above can help to build up mutual trust and co-operation between the exploration company and the local community, bringing benefits to all in the longer term.

Similarly, at the mining stage of a project, community liaison is critical to minimise the potential for conflict. Many companies now operate an 'open door ' policy, whereby community members are invited to join working committees and contribute to decision making which will affect their communities. In Australia and Canada, where Native Title issues have become part-and-parcel of mining considerations, it has been proven that with full consultation with aboriginal peoples, mining projects can go ahead bringing training, employment and significant cashflow into isolated communities, allowing them to participate in the rewards of mining activity.

International NGOs such as Greenpeace monitor mining company activities astutely, so it is to all parties' advantage to behave honourably in terms of the social impacts of mining.

4.5.2 Environmental Management

By their very nature, exploration and mining activities disrupt the pre-existing status quo as they are primarily concerned with extraction of minerals from the natural environment. As with social impacts of mining, environmental impacts are coming increasingly under the watchful eyes of the international NGOs and the media. Mining companies in recent years are taking a much more responsible attitude to environmental management, recognising that sustainable development is the key to successful projects. In the past, too many environmentally insensitive mining operations were undertaken, frequently leaving polluted waterways, unsightly dumps and tailings, disturbed land use and divided communities. Looking to the future, as mining codes develop and standardise internationally, statutory guidelines and safeguards for exploration management are becoming the norm. Many countries insist on environmental bonds being levied on issue of licences for both exploration and mining, to guarantee that the operating company will honour its environmental obligations.

The underlying principles of responsible environmental management are very simple:

I. avoidance of unnecessary activity.
II. minimisation of requisite activity.
III. rehabilitation of land as closely as possible to the pre-existing state.

At the exploration phase of mining, the geological and technical staff must ensure that damage to the environment is avoided if possible, and minimised where not. This includes some practical measures such as:

- conferring at all times with the landholders, concerning land-use, animal migrations and cropping cycles.

- establishing camps in sheltered areas, away from other habitation, downstream from potable water sources, with suitable latrine facilities.
- using (biodegradable) wooden pegs for surveys.
- back-filling pits and trenches.
- contouring tracks for vehicle access versus directly up the hill.
- cutting a branch rather the whole tree or shrub, for vehicular access.
- traversing water courses at suitable points.
- plugging drill-holes, particularly if there is artesian groundwater flow.
- avoiding contamination of waterways by drilling fluids/ fuel etc., by proper planning and management of the programmes.
- Good housekeeping around the site.
- Rehabilitation of all sites on completion of work.

Many of these measures are 'common sense', and will save time and effort if adhered to. Indeed, many companies find that responsible environmental management will actually save money in the long term and foster better community relations if the project develops to full scale mining.

At the mining stage, projects are required to provide a full and detailed Environmental Impact Assessment (EIA) prior to the granting of the mining licence. The EIA acts as the template for the company's obligations against which the actual impact of the operation can be measured and monitored. Inherent in EIAs are detailed plans for ultimate rehabilitation once the mine has been worked out, ensuring that the site is restored as closely as possible to its former state. Governments usually exact significant bonds from the operating company to ensure that if it defaults on its obligations, the bond can be used to carry out environmental rehabilitation.

PART II THE MINERAL EXPLORATION CYCLE

5. THE MINERAL EXPLORATION CYCLE (MEC)

Mineral exploration is carried out to achieve one goal: to discover and quantify an economically viable mineral resource. In order to achieve this goal, certain stages and procedures must be followed in a logical fashion in order to ensure a systematic and reasoned appraisal of each mineral prospect. Depending on which mineral commodity is targeted and where that commodity is being sought, mineral exploration programmes can last 10 months or 10 years, can cost less than $0.1M or more than $10M and can be relatively simple or extremely complex. For example, the exploration programme for a commodity such as alluvial diamonds, is very different to that for other commodities such as bedrock gold or dimension stone. This is because the host rock, the style or expression of mineralization, and the techniques appropriate to discovering that commodity are inherently different. However, for most mineral projects, there are 5 key stages in the iterative appraisal of the deposit, named the **Mineral Exploration Cycle** (MEC - see Fig. 2):

- Programme Design
- Reconnaissance Exploration
- Detailed Exploration
- Prospect Evaluation
- Pre-production

The following section of the Guide presents the rationale and practical applications of the 5-staged MEC in mineral exploration. Part IV, Appendix III, presents examples of three key deposit types as an exercise, which the reader may refer to for practical application of the techniques.

5.1 WHY USE THE MEC?

Mineral exploration costs large amounts of time and money. People invest in mineral exploration because there is the potential reward of discovering an economically viable and profitable deposit at the end of the cycle. However, one can never be sure when starting the MEC that the reward will ever be realised.

- There is an inherent risk in exploration. Risk can be economic, political, environmental and geological. The MEC helps manage these risks by gathering and evaluating the relevant information needed to proceed to the next step in the cycle.
- Each step in the cycle increases our knowledge of the prospect. As this knowledge base increases, the cost of acquiring additional knowledge increases. However, with that increase in cost comes a reduction in risk, as the prospect's characteristics become more certain.
- Before moving from one step to the next, data acquired from the previous step must be assessed and a decision on whether to proceed to the next step must be made.

- At the end of each step in the cycle the explorer/mining company wants to have sufficient information to make the decision on whether to continue investing money in the prospect. This can only be done if the relevant data is systematically collected and recorded and can be verified by an independent auditor.

The MEC should therefore be seen as:

1. A process that provides geological and economic information to reduce the size of the search area and eventually locates an ore body, and
2. A *Stop-Go* cycle that controls risk for the investing company or individual.

5.2 STAGE 1 - PROGRAMME DESIGN

Cost: Low
Risk: Very High

Stage 1 of the MEC can be achieved through the acquisition of as much relevant information as possible on the commodity you are looking for, and on the country/region in which you intend to look for it.

However, Stage 1 can only begin once investors have examined the business fundamentals of getting involved in exploration for a particular commodity, in particular regions or countries and have clearly defined objectives. This will largely depend on the ambitions of the investors, their risk profiles and time horizons. In other words, 'How much capital can I raise and am I prepared to invest in this prospect? What risk am I prepared to take and how long can I wait for a return on my investment? Why am I investing in one commodity rather than another? Do I wish to actually develop a mine, or shall I joint venture the prospect to another company?'

Once the objectives have been formulated, the investor must then decide on:

1. <u>Commodity</u>: Am I more likely to make a return on my investment if I explore for gold, or diamonds, or another commodity?

2. <u>Regional selection:</u> Where am I going to look for the commodity of interest and at what scale - continental, country, province or district?

3. <u>Exploration Model</u>: How am I going to look for this commodity? What type of deposit am I looking for? Acquire as much information as possible on all other mineral deposits in the region, or in other countries with similar geological terrains.

4. <u>Organisation:</u> Who should be employed to carry out the work? Use qualified technical experts who have knowledge of the commodity and region you are working in.

5. <u>Budgeting:</u> Design an exploration programme, but what will it cost and how long will it take to complete this work?

At the end of stage 1: the investor should have assessed:

- Whether there is a demand for the commodity you are exploring for, at a suitable price,

- Whether the investment climate of the country you are investing in is suitable to your risk profile e.g. in countries with favourable investment climates, but less availability of ground or perhaps in high risk politically unstable regimes, but with excellent prospectivity?
- What style of mineralization you are looking for (see Section 2.5 above) e.g. gold mineralization in greenstone belts in West or East Africa, or sediment hosted copper mineralization in Zambia, or others?
- Where you are going to conduct mineral exploration and how you will structure your operations logistically?
- How long is it likely to take to discover an orebody and what the associated costs will be?
- Who is going to do the work for you?

Decision: Once these assessments have been made, decide either to reject the programme or carry-on to Stage 2

5.3 STAGE 2 - RECONNAISSANCE EXPLORATION

Cost: Medium
Risk: Very High

Once you have decided what commodity you are looking for and where you want to look, Stage 2 represents the start of the actual physical exploration, where you focus on locating areas of interest to investigate:

1. Regional appraisal: This continues the process of assimilation of all freely available geological data, such as geological maps, open file data in Mines Departments, scientific papers etc. as in Stage 1, to indicate the potential for a particular commodity in a particular area. It does not involve the physical collection of raw data. Having chosen a geographical area of interest, further focusing must take place to identify worthwhile areas for ground exploration. This is completed by taking the geological fundamentals and controls that characterise the type of minerals that you are looking for and applying them to the area of interest. Thus you may wish to concentrate, for example, in areas of Birimian volcano-sedimentary rocks for gold in West Africa, or along regional shear zones for Archaean gold, or in areas of known mineralization with artisanal workings (see Section 3 above).

2. Security of Tenure: Having made this decision, it is necessary then to acquire the right to prospect the ground, under licence to the relevant authorities of that country, by taking out a Prospecting Licence or Permit (see Sections 3.3, 4.3.1 above). There is no value in finding a mine if you have no rights to it!

3. Reconnaissance: Once the regional appraisal and licencing is completed, a number of target zones will have been identified that need investigation. This is the point on the MEC where field work begins in what is called Reconnaissance Exploration. The latter involves taking selected samples of rocks, soils, stream sediments or even termite mounds to define anomalous areas ('narrowing down the field') that justify more detailed follow-up work. This involves sending exploration teams into the field and may involve the collection of geochemical*

and geophysical** data, to confirm the presence or otherwise of the mineral in question.

** geochemistry provides a method of searching for concealed bodies of metallic ores by means of chemical techniques.*

*** geophysics measures variations in the physical parameters of the earth's crust, with the object of gaining information about sub-surface structures or the presence of mineral bodies.*

4. <u>Target Selection:</u> All data from the reconnaissance exploration will have been collected and collated. Geoscientific information will have been interpreted to characterise the geological, geochemical and geophysical signature of each area investigated. Usually 3-4 possible targets will emerge from the reconnaissance phase as being areas worthy of follow-up work. These must be ranked and prioritised, according to the results of the reconnaissance exploration, together with the level of funds available and the time horizon of the investor.

At the end of stage 2: you should have assessed:

- The regional prospectivity for the commodity you are exploring for,
- The results of the reconnaissance exploration in order to decide on where to concentrate further work,
- From the collation and interpretation of the acquired exploration data, at least two targets which appear geologically to be the best targets, with the highest chance of becoming economically viable mineral deposits.

Decision: If the outcome of Stage 2 is negative, reject prospect or revise regional appraisal using alternative techniques. If the outcome is positive, proceed to Stage 3.

5.4 STAGE 3 - DETAILED EXPLORATION

Cost: High
Risk: High

This stage is designed to lead to the actual discovery of a deposit. Today, large deposits are rarely exposed on the surface as most obvious deposits have been found. Although there have been a few notable exceptions, Voisey Bay nickel (Ni) deposit in Labrador, Canada and Citroen Fjord lead/zinc (Pb/Zn) deposit in Northern Greenland, the majority of deposits discovered today are covered by soil, laterite, desert, ice or some other type of 'cover'. These deposits are called 'blind deposits' because they need to be investigated in the unseen sub-surface to find them.

Once Stage 2 appraisal is completed, a number of targets (or anomalous zones) will have been identified which will need further investigation. Because many deposits are 'blind targets', surface investigation normally involves detailed sampling of the material on-surface (soils, outcropping rocks) or measuring electrical and magnetic properties of the surrounding rocks, to help focus where underground testing should take place. To conserve costs, surface exploration is carried out before beginning underground exploration.

1. <u>Target surface investigation:</u> A variety of geochemical, geophysical and geological techniques are used to collect data, in an effort to reduce the search area all the time. These may include detailed soil and rock sampling on constructed

grids, geophysical surveys to measure electrical conductivity or magnetic properties relative to the surrounding rocks, geological mapping to understand the relationships of rock units and possible controlling structures such as faults or shear zones. Results of this work help to locate primary targets, usually buried beneath layers of soil, laterite, or younger non-prospective rocks. In many instances, secondary enrichment may take place above the primary deposit due to weathering processes, so that the laterite/saprolite may itself be mineralized e.g. as at Ashanti Goldfield's mine at Siguiri in eastern Guinea.

2. Sub-surface investigation: Once the sub-surface targets have been identified, they can usually be investigated by pitting, trenching, shallow or deep drilling, or by open-pit quarrying. Once the sub-surface has been sampled, the results of the intersected (drilling) or sampled (trenching) rock will determine whether mineralized bedrock has been located and whether a discovery has been made. In some instances the first phase of drilling may simply penetrate altered rocks, related to mineralization, but not actually locate the mineralization itself. Further drilling may be required in that instance.

At the end of Stage 3: you should have:

- Identified the surface targets in each of your prospect areas,
- Tested these surface targets with sub-surface sampling techniques which are appropriate to the commodity being sought after,
- Made a discovery or convinced yourself that there is nothing there!

Decision: If the outcome of Stage 3 is negative, reject prospect or revise surface and sub-surface appraisals using alternative techniques, geological models and thinking. If the outcome is positive, proceed to Stage 4.

5.5 STAGE 4 - PROSPECT EVALUATION

Cost: Very High
Risk: Medium

Stage 3 should have determined whether or not there is enough encouragement to continue the search for ore reserves in the defined zones. Stage 4 concentrates on evaluating that discovery (as per Section 4 above). Things to determine are:

- ore grade.
- tonnage.
- ore body style and position - how will it be mined?
- mineralogy - how easily can the ore be processed, what other by-products exist?
- likely production and treatment costs.
- market - how will the finished product be received by the market. Can it be sold on the current market?
- societal and environmental costs.

The first three technical criteria (Fig. 5) are almost exclusively decided through carrying out extensive drilling programmes and other sub-surface geotechnical and engineering investigations. The mineralogical issues can be evaluated by taking bulk metallurgical samples of material and processing them through a pilot-plant, while the marketing considerations will be commodity specific and dependent on the prevailing economic climate. Production costs will depend on the geographical location, labour costs, infrastructure and legislative requirements, together with the technical considerations above. The societal and environmental costs will depend fundamentally on the legislative code of the country in which you are situated. Once these criteria have been satisfactorily determined, and the answers to them are all positive, you have discovered a mineral deposit with potential to provide economic returns for your investment.

At the end of stage 4: you should have:

- Completed the prospect's technical evaluation, so that you
    - ◊ know what grade and tonnage your deposit is.
    - ◊ know the geometry and geotechnical characteristics of the orebody.
    - ◊ have identified the most appropriate mining technique.
    - ◊ know what type of processing should be used to beneficiate the ore.
- Completed preliminary environmental impact assessment.
- Completed processing and metallurgical testwork, with estimates of on-costs and royalties.
- Completed hydrogeological studies and impacts on existing land uses.
- Completed cost assessments of transport, infrastructural and labour needs, capital expenditure.
- Completed market evaluation thereby ensuring the viability of the project.
- Completed appropriate negotiations with government, service providers and local interest groups.

Decision: If the outcome of Stage 4 is negative, reject prospect. If the outcome is positive, proceed to Stage 5.

5.6 STAGE 5 - FINAL FEASIBILITY AND PRE-PRODUCTION

Cost: Very High
Risk: Low

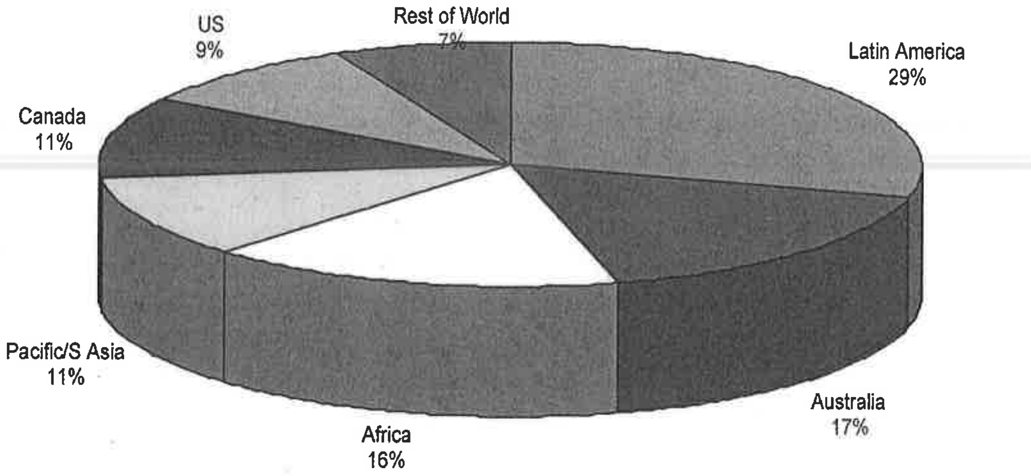
This is the final stage in the MEC. Final feasibility is carried out by independent assessors to determine if all the information collected in Stages 1- 4 is valid, that the deposit you have discovered is technically reasonable and that it is economically viable. The independent auditors will conduct a thorough investigation of every aspect of the exploration carried out on the orebody to determine whether the deposit's technical and economic characteristics make it a viable prospect or not.

The final feasibility study is carried out primarily to satisfy the people who will invest capital in the prospect, to bring it into production. It is therefore commonly known as a 'bankable document', as it is generally used as the supporting evidence for raising capital to bring the deposit into production. The feasibility study will include geological, engineering, environmental, hydrogeological, metallurgical and financial studies on the ore deposit to determine its economic viability (see Sections 3, 4 above).

At the end of Stage 5: you should have:

- A bankable feasibility study allowing you to raise adequate finance for the development of the deposit.

Figure 10. World Mineral Exploration 1997
Total US$5.1 billion. Source: MEG



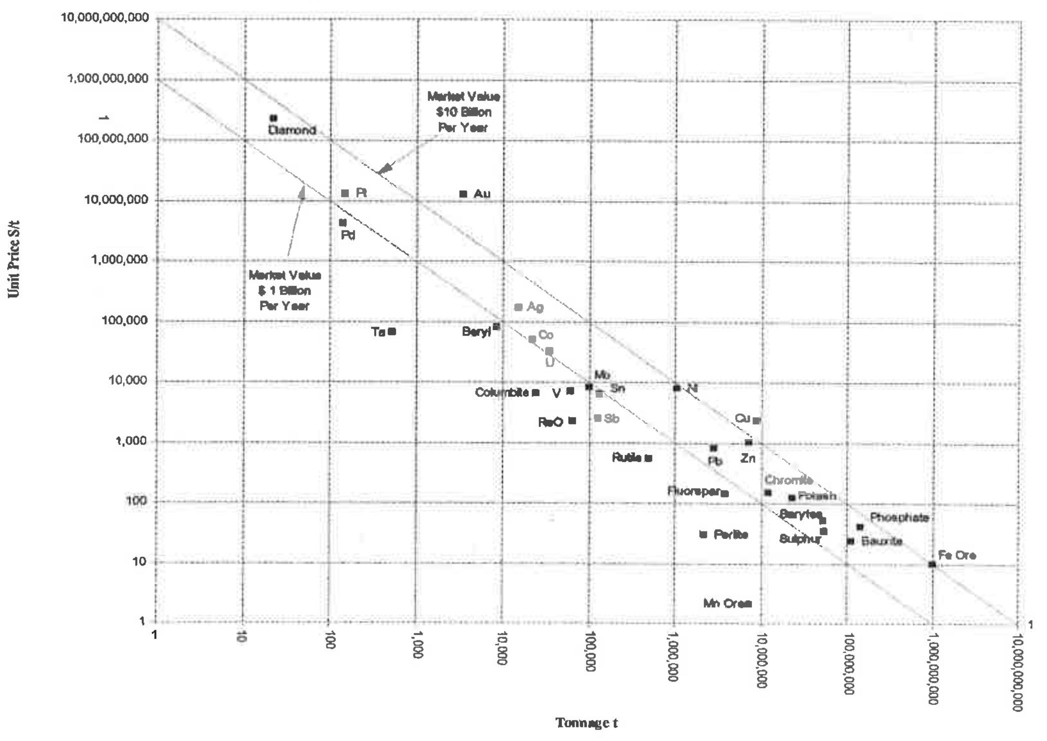


FIGURE 11. MINERAL COMMODITY VALUES 1997

6. PRACTICAL APPLICATION OF MODERN EXPLORATION TECHNIQUES

Over the last decade, the majority of empirical exploration techniques have not changed greatly, although the collection and management of geological, geochemical and geophysical data has advanced dramatically through enhanced use of technology. However, many of the empirical techniques used today have been used over a long period of time.

- ◊ Old style prospecting, which is done throughout Africa, is one of the oldest means of finding ore. Basically quartz veins and shear zones are located on surface and worked manually for gold, often leading to extensive artisanal mining, as in the Tarkwa district of Ghana, or the Lake Victoria district of Tanzania for instance. Elsewhere, alluvial gold mining is carried out by panning and washing as it has been for hundreds of years, as in the Kankan district of Guinea.
- ◊ Geologists still have to go out and physically walk the ground, collect samples, draw maps and make interpretations that lead to mineral discoveries in the same way that they did 50 years ago.

However, in recent years significant progress has been made in the way geological data is collected and handled, mainly due to the increasing processing power of computers. Mineral exploration has benefited dramatically from improved data capture and management techniques, in particular through advances in data acquisition and processing for geophysical aeromagnetic and electromagnetic surveys, enhanced geochemical sampling and laboratory analytical techniques.

Data management has been revolutionised by the advent of Geographic Information Systems (GIS), allowing large quantities of complex data to be manipulated and imaged simultaneously. Dramatic improvements have also been made in remote sensing (satellite imagery) and communications, together with drilling technology, which has allowed investigation and recovery of sub-surface samples unheard of 25 years ago. Each of these developments has revolutionised the way in which exploration is managed and data exploited. Geologists today have portable personal computers (PCs), Global Positioning Systems (GPSs), geophysical and geochemical tools to take into the field, but you can be guaranteed that every geologist will still carry a hammer. Data can be processed easily in the field and transmitted from remote locations to offices anywhere in the world by using satellite phones.

This section of the manual is directed towards highlighting modern exploration techniques that can be applied to each step of the mineral exploration cycle.

6.1 STAGE 1 - PROGRAMME DESIGN

A range of data sources are available in the data gathering stage of a project:

I. Each country in the region has a **Geological Survey** or **Ministry of Mines** which will contain a lot of very useful information regarding the local geology, exploration and mining history, and information of current licence holders, usually referred to as 'Open File' data. A good start is to review records of previous exploration programmes. These include company, institutional or government reports which have recorded exploration work carried out in the past. Even a 100 year old mineral exploration report can provide valuable information about the mineral potential of a region (see Section 3.2.2).

II. **Published topographical, geological and mineral occurrence maps** are available from a range of sources, including Geological Surveys, international co-operative initiatives, United Nations, and so on. These are a requisite tool in anybody's pack for evaluating the potential of a region. Through maps, sites of known mineralization can be assessed, comparisons can be made with other known mineralized districts, and many a good idea has sprung from glancing at a map and seeing an opportunity that no-one else has thought about.

III. **The Internet** provides an easy and efficient method of gathering information on mining and commodities. There is a virtual encyclopaedia of information on a variety of topics related to exploration and mining on the Internet. It is an easy and efficient method of research that can be carried out from anywhere in the world. Table 10 below lists some of the many useful sites on the World Wide Web (WWW) which supply information to anybody wishing to get involved in mineral exploration or mining. Some of the sites charge a subscription for information, others give information free of charge. Each web-site will have links to other exploration and mining web-sites; the options are almost limitless, such that too much information may overwhelm a web researcher. It is predicted that, in 5 years time, practically all freely available information related to exploration and mining will be available on the Internet.

IV. It is important to **review recent developments** in the mining sector of the country, particularly if there has been a mine developed in the commodity you are interested in. Tracking mineral development in this way - which should be well documented - can give a strong indication of:

- How long it is likely to take to develop a deposit,
- How much will it cost to develop a deposit,
- What problems or hurdles were faced (and solved) by the mine developers,
- What licences (mining, environmental etc.) were issued by the government and for how long are they valid,
- What the legislative and fiscal framework is for that country.

This research will provide an overall picture of the mineral exploration and mining industry in the country of choice and is a necessary basic exercise before moving onto the next step of the MEC.

Techniques summary: Stage 1

- **Geological Survey and/or Ministry of Mines - Open File data**
- **Previous records of exploration - even very old records.**
- **Published maps**
- **The Internet**
- **Current / recent mining developments**

TABLE 10 INTERNET : USEFUL ADDRESSES

Country Information
Mines 2000 - *http://www.mines2000.com*
West Africa. Com - *http://www.west-africa.com*
Africa On-line - *http://www.africaonline*
Africa Info - *http://africa-info.ihost.com/accueil.htm*
World Bank - *http://www.worldbank.org*
United Nations - *http://www.un.org*
European Union - *http://www.europa.eu.int/en/comm/dg08/country*
Economic Intelligence Unit - *http://www.eiu.com*

Commodities
World Gold Council - *http://www.gold.org*
International Zn Association - *http://www.iza.com*
AME - Mineral Economics - *http://www.ame.com.au*
Roskill Information Services - *http://www.roskill.co.uk*

Financial Information and Commodity Prices
Kitco - *http://kitco.com/gold.live.html*
CNN*Fn* - *http://cnnfn.com*
Financial Times - *http://www.ft.com*
Wall Street Journal - *http://www.wsj.com*
London Metal Exchange - *http://www.lme.com*

Mineral Exploration & Mining
Info-Mine - *http://www.info-mine.com*
Mining Journal - *http://www.miningjournal.com*
Northern Miner - *http://www.northernminer.com*

Space Agencies (Satellite Imagery)
BNSC - *http://www.open.gov.uk/bnsc/bnschome.htm*
NASA - *http://www.nasa.gov/*
NOAA (Global Programs) - *http://www.ogp.noaa.gov/*
CEO (Centre for Earth Obs) - *http://ceo-www.jrc.it/*
DLR (German Space Agency) - *http://www.dlr.de/*
ACRES (Australian Rem. Sensing) - *http://www.auslig.gov.au/acres/index.htm*
CCRS (Canadian Rem Sensing) - *http://www.ccrs.nrcan.gc.ca/*
India (Rem. Sensing Agency) - *http://www.nrsa.gov.in/*
Aster - *http://asterweb.jpl.nasa.gov/*
Aviris - *http://makalu.jpl.nasa.gov/aviris.html*
JPL imaging radar - *http://southport.jpl.nasa.gov*

6.2 STAGE 2 - RECONNAISSANCE EXPLORATION

The majority of the required data for Stage 2 is usually made available by the Geological Survey or Department of Mines and builds on the data gathered in Stage 1. The following data should be acquired where possible:

- Geological maps (incl. mineral occurrence maps), at both regional and local scales.

- Geochemical or geophysical surveys in the country.
- Aerial photographs.
- List and map of mineral licence holders.
- Open-file data of previous exploration.

These data are available for a reasonable price from the relevant Government agency in any country. Much of it will have been collected over time by the local government, sometimes with the assistance of United Nations, World Bank or EC, or through inter-governmental co-operative initiatives. Increasingly this data is being provided in digital format. The collected data must be interpreted by a mineral exploration geologist who will conduct a regional appraisal by applying his/her own expertise to the available data to determine where exploration should take place. Traditionally, this would have been completed by hand, however if it makes financial and practical sense, important data may be converted to a digital format and the geological interpretation should be aided by exploration software and/or Geographical Information Systems (GIS).

Reconnaissance Exploration - Field Techniques

Reconnaissance exploration involves a series of classic field techniques, carried out by an exploration team, usually from a field base:

- *Regional geological mapping* - typically at a scale of 1: 25,000, utilising air photographs or published base maps if available. Mapping supplements the information collected in the regional appraisal and will record key features relevant to the mineral being sought.
- *Regional stream, soil or rock sampling*, typically at a density of 1-2 samples per sq/km. All samples taken (at any stage of the MEC) must be well documented and accurately recorded and must be clearly marked on a map or with a GPS system. It costs on average $100 to collect one rock sample, so make sure it is properly recorded and archived. Each sample should be processed or analysed using reputable laboratories that observe international quality assurance systems (e.g. ISO 9000 etc).
- *Regional airborne geophysics* - typically aeromagnetic, electro-magnetic and rediometric surveys will be carried out by fixed wing aircraft or helicopter, particularly in remote areas. The type of data collected depends on the ground conditions and mineral sought. Similarly, the area to be surveyed depends on the commodity and style of mineralization.
- *Prospecting* - this is the oldest and least technologically advanced part of the MEC, but is arguably the most important. It is the physical on-the-ground search for mineralized rocks. Many of the world's great deposits have been discovered by prospectors, many of whom have been local people. Expert geologists will always engage a local prospector on their exploration team.

Reconnaissance Exploration - Satellite Imagery

The decision to purchase a satellite image depends on the type of exploration project and financial budget. Satellite images from the providing agencies cost from US$ 500 - 4,500 for each image, depending on size and scale. It may cost a further US$1000 -1,500 to process the image, but they provide a rapid and accurate means of evaluating a region for mineral potential. For example, satellite images can be an excellent tool for mapping alteration, structures, and general geology associated with mineral deposits without setting foot on the ground; however, in certain cases aerial