DISCOVER PROSPECTING

AN INTRODUCTORY PROSPECTING MANUAL

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# DISCOVER PROSPECTING
An Introductory Prospecting Manual

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PART 1: INTRODUCTION
INTRODUCTION

I) PURPOSE AND OBJECTIVE OF PROSPECTING COURSES

Basic prospecting courses have been delivered to the public across Ontario since 1894, when classes were first held in Marmora. The courses have been offered intermittently throughout the years and were continually revived by interest and demand from the general public and prospectors. The courses were initially taught by staff of the Ontario Bureau of Mines, later known as the Ontario Division of Mines and the Ontario Geological Survey, and staff of the Resident Geologist's and Mining Recorder's offices. The courses have been offered with the cooperation of other prospectors, mining industry personnel, universities, colleges and high schools.

The purpose and objective of the basic prospecting courses has been to encourage and promote mineral exploration by:
- encouraging more people to get involved in prospecting;
- to provide a better understanding of geology and mining and exploration activities in the student's local area;
- to provide students with the ability to recognize different rocks and minerals in the field and to recognize features which may indicate the presence of economic mineralization;
- and to educate the public about acquiring mining lands, the mineral exploration process and different aspects of the geosciences.

The courses provide enough basic, technical background for an individual to start prospecting and serve as a first step to more serious prospecting.

This Introductory Prospecting Manual is arranged into nine parts that can be divided into two halves. The first half of the manual consists of chapters on Minerals and Mineral Identification; Rocks; Tectonics and Mineral Deposits and covers the geological and theoretical aspects of prospecting. The second half of the manual consists of chapters on Acquiring Mining Lands; Prospecting Techniques: Planning and Research; Prospecting Techniques: The Search; and Exploration Techniques, and covers the technical and practical aspects of prospecting.

II) MINERAL EXPLORATION, PROSPECTING AND THE GEOSCIENCES

i) What is Mineral Exploration?

Mineral Exploration is the search for deposits of useful minerals, rocks or fossil fuels and establishes the nature of a known mineral deposit in preparation for development. Mineral exploration is stimulated by the demand for mineral and metal commodities.

Mineral exploration, like any other commercial venture, involves investment of money in the hope of future reward. It differs from industrial enterprises by the comparatively high risk of failure and the corresponding potentially high return (Horn 1989). No guarantee can be given on exploration expenditures, that's why venture capital for mineral exploration is only available as long as the potential rewards are great enough to balance the risks. Exploration funds are usually put up by profitable mining operations and the investing public. The funds are used to operate and sustain the exploration programs.

Exploring for an ore body is a process of selection which eliminates rocks that have the least probability of hosting ore and focusing on areas where the probability is greatest. The target area, during the initial stages of exploration, may be 1 to 10 km² or more in size, but decreases in size as the target is narrowed down during subsequent exploration. The end result is an ore body which may only be a few hundred square metres in area (Karvinen 1982). The chances of a prospect becoming a mine have been roughly estimated at 1000 to 1. Was it not for the methodical elimination of low probability areas and a disciplined approach to exploration, this figure would be much higher.

Specialized individuals are employed in exploration and include prospectors, geologists, geophysicists, geochemists, field
technicians, line cutters, pilots, assayers, lab technicians, surveyors, computer specialists, diamond drillers, expediters and engineers. All of these specialists, and others, are involved in the chain of data collecting and processing, evaluating, interpreting and reinterpreting.

A typical exploration program evolves from an initial **preliminary stage** that results in target acquisition; to the **advanced exploration stage** involving the testing, definition and delineation of a deposit; and finally to **deposit evaluation** and the **development stage**. The various stages of exploration are described below:

**Preliminary Stage** - Large areas are selected for reconnaissance during information research. The geology of the area is explored and prospected and details of the exploration targets are evaluated. Airborne geophysical surveys, regional geochemical and geological surveys may be conducted. If successful, this stage leads to the acquisition of land.

**Advanced Exploration Stage** - The exploration target is subjected to geological, geochemical and geophysical tests that are used to define the characteristic of the target. The dimensions, geometry and quality of the deposit are established by drilling programs. This provides information for early engineering and economic evaluation.

**Deposit Evaluation** - This is the transition stage between exploration and development. Close-spaced drill programs provide metallurgical, mining and environmental data which are required to complete engineering feasibility studies. Underground exploration and large scale bulk sampling may also be conducted during this stage.

**Development Stage** - This is the stage where a mine is developed and the facilities for the mine are constructed. Mine development may take one to two years to complete and up to eight years if difficulties are encountered.

The total time from the beginning of the exploration program to the completion of deposit evaluation range from six to fifteen years or more.

**Figure 1** is a chart which illustrates the various stages and components of the **Mining Sequence**. This sequence is a progression of events that begin at the "concept" stage of exploration and end at the closure of a mine. The first half of the sequence is comprised of the various stages of mineral exploration including prospecting in the very preliminary stage.

Mineral exploration has been described as the world’s biggest and best gambling business where the chips cost many thousands of dollars and where many millions or billions can be won. Nothing could be further from the truth. Although luck is an element in short-term exploration results, it has little to do with long-term success. Mineral exploration is fundamental to the growth and survival of a mining company; it is not a "game of chance" (Snow and McKenzie 1981).

Mineral exploration is more correctly compared to research and development. Exploration is to the mineral industry as research is to the pharmaceutical industry or high-tech industries such as computing and microelectronics. Research and development is a financial investment in experiments that may cost millions of dollars and where there is a high risk that any particular experiment will fail. It is methodical experimentation that results in new knowledge with practical applications, such as improved products, processes or services. Research and development activity only ceases after success is achieved, a discovery is made and approval is given to build production facilities. Mineral exploration is very similar to research and development. Each stage of mineral exploration is very costly experimentation aimed at achieving discovery and creating new production (Woodall 1989). The discovery of a mineral deposit represents a technical and geological success resulting in new knowledge with practical applications in further exploration.
Figure 1: The Mining Sequence

Modified from: Pearson, Hofman and Associates Ltd. 
Prospectors and Developers Association of Canada

Regional Survey
No claims
Field camps
Work includes:
- airborne geophysics
- geochemical surveys
- prospecting (hiking)
- other work
Mining Act and other acts apply
No new roads
Time accrued: approx. 1 year
Area: approx. 100,000 hectares

Land Acquisition
Claims staked
Field camps
Work includes:
- geological mapping
- surveys (no grids)
- prospecting (hiking)
- other work
Mining Act and other acts apply
No new roads
Time accrued: approx. 2 years
Area: approx. 10,000 hectares

Basic Exploration
Work permits not needed
Field camps
Work includes:
- same activities as during previous stage of exploration, but at a more detailed scale
- cut grids
Mining Act and other acts apply
No new roads
Time accrued: approx. 5 years
Area: approx. 1,000 hectares

Intermediate Exploration
Work Permits in "sensitive areas"
Field camps
Work includes:
- geophysical surveys (grids)
- limited stripping and trenching
- drilling
Mining Act and other acts apply
No new roads
Time accrued: approx. 10 years
Area: approx. 100 hectares

Advanced Exploration
Part VII of the Mining Act, and other acts apply
Work includes:
- drilling, bulk sampling, and trenching; may be underground work
Rehabilitation plan with financial assurance required
New roads likely
Time accrued: approx. 15 years
Area: approx. 100 hectares

Development/Production
Part VII of the Mining Act, and other acts apply
Work includes:
- active mining operations
Rehabilitation plan with financial assurance required
New roads likely
Formal provision for community concerns
Time accrued: approx. 20 years
Area: approx. 100 hectares

Closure/Rehabilitation
Part VII of the Mining Act, and other acts apply
Work includes:
- fulfillment of closure plan
- rehabilitation and monitoring
Roads likely
Time accrued: approx. 100 years
Area: approx. 100 hectares

Time
Sequence of Phases
ii) What is Prospecting?

**Prospecting** is the search for economically valuable deposits of minerals, rocks and mineral fuels. Mineral exploration is a broader term than prospecting in the sense that exploration goes beyond discovery. Although it is based on scientific principles, prospecting is an art or craft rather than a precise science and includes a large element of experience and some luck. Prospecting is part of the initial or preliminary stage of mineral exploration. It is the prospector that methodically and systematically searches the ground for minerals before other more sophisticated exploration tools and methods are used. Now that we have entered the 21st century, with technological advances creating more effective and efficient methods of discovering new ore bodies, prospecting remains an important aspect of the early stages of exploration and ore finding.

Most prospectors are self-taught and have studied the subject of prospecting on their own initiative. Lang (1970) stated that the consensus amongst thirty-four experienced prospectors, polled by Franc Joubin (a famous and successful prospector), was that it takes at least eight to ten months of practical experience in field prospecting and bush craft to be qualified as a prospector. There are no hard and fast methods for prospecting, much depends on the person, the metal or mineral sought and the nature of the area being investigated.

The prospector has made a tremendous contribution to the development of mineral resources in Ontario and Canada. Almost two-thirds of the mineral finds discovered before 1970 were first observed by a prospector. Between 1945 and 1965, 57% of the mines put into production in Canada were discovered by conventional prospecting (Lang 1970). Examples of discoveries made by prospectors in Ontario are: the gold deposits of Timmins, Kirkland Lake, Red Lake, Pickle Lake, Beardmore, Geraldton and Hemlo; the silver of Cobalt; the iron of Steep Rock; copper and zinc of Manitouwadge; uranium of the Blind River area; and the nickel of Sudbury and Shebandowan.

To be a prospector is to be part of a rich and successful tradition.

iii) The Role of the Prospector

The role and purpose of the prospector is to:
- find new mineral occurrences;
- rediscover, old and forgotten mineral occurrences;
- involve themselves in the early stages of exploration for a mineral occurrence by stripping, sampling, trenching and blasting;
- market, promote and sell mineral occurrences to mining companies for a profit and interest in the mineral properties.

Prospectors should be knowledgeable about the mining industry and require a good working knowledge of:
- geology and be able to make practical geological observations (i.e.: identifying a rock type, mineral or structure);
- the Mining Act, claim staking and other legislation;
- mineral exploration techniques and bush craft; geography and history of the area in which they are working;
- and negotiating mining agreements;

Prospectors must also have initiative, resourcefulness, amiability, patience, tenacity and realism. Prospectors enjoy working in the bush and breaking new ground. Successful prospectors have an overwhelming curiosity and desire to find an ore body, not just for financial gain, but just to do it. Many prospectors are part-time serious and do their prospecting on weekends, during vacations or after working hours. A few prospectors take up prospecting as a full-time occupation and may also contract their services to mining companies and other prospectors for claim staking, linecutting, blasting, geophysical surveys or prospecting.
The romantic image of a lonely prospector with beard, rumpled hat, suspenders, gold pan and trusty mule ambling through the bush has been replaced by the modern prospector armed with an arsenal of new technological inventions and geological knowledge.

Prospecting has changed because ore bodies with surface exposures are becoming increasingly difficult to find. The chances of discovering new deposits on pure observation alone are becoming less and less. Exploration has had to rely upon sophisticated geophysical, geological and geochemical methods to discover new mineral resources at greater depths.

New tools required to detect buried mineral deposits have been developed through advances and development in technology and geological reasoning. The disciplines of geology, geophysics and geochemistry have provided the prospector with techniques that take advantage of the unique characteristics of mineral deposits.

iv) The Geosciences

The geosciences include geology, geochemistry and geophysics and are used to study the Earth and explore for mineral deposits.

Geology is a science that covers a wide range of topics that are applied in various ways to many phases of the mining industry. The main branches of geology are:

Mineralogy - the study of minerals.

Petrology - the study of rocks.

Structural Geology - the study of physical forces and how they affect rocks and minerals in the Earth.

Engineering Geology - the study of rock and mineral materials and their stability during and after use in construction (i.e.: rock mechanics).

Physiography/Geomorphology - the study of landforms and the processes that form and shape them.

Hydrogeology - the study of the interaction between the Earth and water.

Environmental Geology - the study of geology and how it relates to the environment and human activities.

Glaciology - the study of glaciers.

Quaternary Geology - the study of the geology of the Earth through the last 2 million years and glacial features.

Historical Geology/Stratigraphy - study of the history of the Earth that is recorded in the layers of the Earth's crust.

Paleontology - the study of fossils.

Economic Geology - the study of mineral deposits and material that can be utilized profitably by man.

The role of the geologist is to observe, describe and interpret geological phenomenon. Geologists are involved in mineral exploration from its initial stages to development and mining. Most exploration geologists select and evaluate target areas; conduct geological mapping; supervise exploration programs; apply geological reasoning and theories to locate mineral deposits; interpret geophysical and geochemical data; compile geological data; and define the dimensions, geometry and quality of an ore deposit.

Geophysics is a branch of experimental physics that deals with the Earth. Geophysical equipment is used to search for poorly exposed or deeply buried ore bodies by detecting specific physical characteristics in the Earth's subsurface. Geophysicists interpret geophysical data and supervise geophysical surveys and the collection of data.

Geochemistry is the study of the distribution and migration of individual elements in the Earth's crust and includes the determination of
the relative and absolute abundances of elements in the Earth. Geochemistry is also used extensively in mineral exploration to assist in the detection of poorly exposed and deeply buried ore bodies.

III) THE ROLE OF THE ASSOCIATIONS

The role of the associations in exploration and mining is to provide a forum of representation in which individuals and companies can network, share information and lobby government in order to further the mutual interests of the members.

Ontario Prospectors Association (OPA)

The objectives of the Ontario Prospectors Association are to represent and further the interests of prospectors and the mineral exploration industry. Its mission is to enhance and promote the Ontario mineral exploration and development community to foster a healthy mining industry.

The OPA predicts its future membership of 3,000 to have Province wide representation as an effective advocate group on government, taxation, land access and environmental policies. It is an information source for the media designed to foster exploration and development awareness and connect buyers and sellers of properties. The OPA designs and promotes prospector development initiatives that support grassroots exploration.

The OPA is made up of individual associations located throughout Ontario, they are:

The Boreal Prospectors Association: [www.ontarioprospectors.com/boreal](http://www.ontariopropectors.com/boreal)

The Porcupine Prospectors and Developers Association: [www.porcupineprospectors.on.ca](http://www.porcupineprospectors.on.ca)

The Northern Prospectors Association:

The Sudbury Prospectors and Developers Association: [www.sudburyprospectors.ca](http://www.sudburyprospectors.ca)

The Sault and District Prospectors Association: [www.saultprospectors.ca](http://www.saultprospectors.ca)

The Northwestern Ontario Prospectors Association: [my.tbaytel.net/nwopa/index.htm](http://my.tbaytel.net/nwopa/index.htm)

Southern Ontario Prospectors Association: [www.southernprospectors.ca](http://www.southernprospectors.ca)

The official voice of the OPA is The Explorationist, a newsletter that is published 10 times a year.

For more information about the OPA visit their website: [http://www.ontarioprospectors.com/](http://www.ontariopropectors.com/)

Prospectors and Developers Association of Canada (PDAC)

The Prospectors and Developers Association of Canada (PDAC) is a national association representing the interests of the mineral exploration and development industry.

The work of the association is guided by the following mission statement:

The PDAC exists to protect and promote the interests of the Canadian mineral exploration sector and to ensure a robust mining industry in Canada. The PDAC will encourage the highest standards of technical, environmental, safety and social practices in Canada and internationally.

The association’s activities can be classified broadly under the following headings: advocacy, information, and networking.

For more information about the PDAC visit their website: [http://www.pdac.ca/index.html](http://www.pdac.ca/index.html)
Canadian Aboriginal Minerals Association

Canadian Aboriginal Minerals Association (CAMA) is an aboriginal, non-profit organization which seeks to increase the understanding of the minerals industry and aboriginal community’s respective interests in lands and resources. Through increasing this awareness, all parties will benefit.

CAMA acts as an instrument for the advancement of aboriginal community economic development, mineral resource management and environmental protection.

CAMA was formed out of the need expressed by aboriginal communities. Their priorities are the environment, employment and training, and economic development. Establishing relations with mineral companies to explore and develop mineral resources is seen as a way to achieve economic self-sufficiency.

For more information about CAMA visit their website: http://www.aboriginalminerals.com

Ontario Mining Association (OMA)

The Ontario Mining Association (OMA) was established in 1920 to represent the mining industry of the province. OMA’s forty-eight members are engaged in exploring, producing and processing mineral resources in an environmentally responsible manner. The majority of its members are operating mines in Northern Ontario and produce gold, nickel, copper and a variety of other metals and minerals. Several other operations are located in Southern Ontario and are involved in the production of salt, gypsum and other industrial minerals. Member companies provide direct employment for approximately 25,000 people across the province.

The OMA handles a broad range of responsibilities on behalf of its members. The three major functions of the OMA include, government relations, education and public communications. In this regard, the OMA: informs government of industry issues and the implications of government policy and legislation for the mining industry; notifies member companies of legislative, policy and regulatory matters affecting the mining industry; promotes the mining industry to the government and public; provides training and education services to its members and the public; and provides opportunities for members to exchange information and ideas on matters of common interest and concern.

For more information about the OMA visit their website: [http://www.oma.on.ca/index.html](http://www.oma.on.ca/index.html)

Canadian Institute of Mining, Metallurgy and Petroleum (CIM)

Founded in 1898, the Canadian Institute of Mining, Metallurgy and Petroleum is the leading technical society of professionals in the Canadian minerals, metals, materials and energy industries. With over 12,000 national members, CIM strives to be the association of choice for professionals in the minerals industries.

CIM has always maintained three main objectives, and will continue to focus on them. The objectives, the facilitation of exchange of knowledge and technology, fraternity, and the recognition of excellence, are what attract members to CIM. Through conferences, publications and awards, CIM members enjoy a sense of community within the Canadian mining, metals and energy industries, and are able to make contacts across the country and stay on top of the latest technological innovations shaping the industry.

For more information about the CIM visit their website: [http://www.cim.org](http://www.cim.org)
Geological Association of Canada (GAC)

The mission of the Geological Association of Canada is to facilitate the scientific well-being and professional development of its members, the learned discussion of geoscience in Canada, and the advancement, dissemination and wise use of geoscience in public, professional and academic life.

The vision of the GAC is a geoscience community, which is knowledgeable, professionally competent and respected, whose input and advice are relevant, widely sought and utilized, and whose vital contribution to the economic prosperity and social well being of the nation is widely acknowledged.

For more information about the GAC visit their website: www.gac.ca

Mineralogical Association of Canada

The Mineralogical Association of Canada (MAC) was formed in 1955 as a non-profit scientific organization to promote and advance the knowledge of mineralogy and the allied disciplines of crystallography, petrology, geochemistry and mineral deposits.

For more information about the MAC visit their website: http://www.mineralogicalassociation.ca

Canadian Association of Mining Equipment and Supplies for Export

Canadian Association of Mining Equipment and Supplies for Export (CAMESE) is a trade association made up of Canadian member companies offering products and services to the mining industry. It was established in 1981 for the purpose of assisting members in exporting their goods and services.

The association’s more than 250 corporate members across the country supply the entire mining industry spectrum including mineral exploration, mine development, mining, mineral processing, environmental monitoring, smelting and refining.

In brief, CAMESE provides its members with cost-effective, international marketing support that is complementary to their own marketing and selling efforts. It is also the only organization collectively representing suppliers in advocating for a strengthened mining industry in Canada.

For more information about CAMESE visit their website: http://www.camese.org

IV) THE ROLE OF THE MINISTRY OF NORTHERN DEVELOPMENT AND MINES: THE MINES AND MINERALS DIVISION

i) Introduction

The role of the Mines and Minerals Division of the Ministry of Northern Development and Mines (MNDM) is to create new wealth and benefits for residents of Ontario by stimulating environmentally and economically sustainable use of the province’s geology and mineral resources.

The Mines and Minerals Division works to generate new wealth and benefits for the residents of Ontario by providing basic geological information gathering and interpretation in support of Ontario’s exploration, mine development and mining sectors and the administration of Ontario’s Mining Act in a fair and consistent fashion. It collects, analyzes and publishes valuable information about the state of the mining and mineral industries, as well as specific information about the location and quality of mineral deposits. The field staff throughout the province provides consultative services to the industry through all phases of the mining sequence, and include resident geologists, mining recorders and mineral development officers (Figure 2).

The MNDM accomplishes this mandate by:

- Providing comprehensive and accessible
Figure 2: Ministry of Northern Development and Mines
Mines and Minerals Division
Resident Geologist Districts
information regarding Ontario's geological environment for mineral exploration and for land use planning and management purposes.

- Providing comprehensive information on Ontario's mineral resources sector.
- Facilitating mineral resource development.
- Promoting Ontario's mineral potential and supporting the marketing of mineral products, technological expertise and services.
- Advocating the value of discovering and developing Ontario's mineral resources.
- Providing an orderly and equitable process for the secure acquisition, maintenance and rehabilitation of mining lands through administering Ontario's Mining Act.

The Mines and Minerals Division is divided into two principal branches, each with a different purpose:

**Mineral Development and Lands Branch** is responsible for administering Ontario's Mining Act and facilitating mineral development and mine rehabilitation through two business units; the Mining Lands Section and the Mines Group.

**Mining Lands Section (MLS)** - provides orderly and equitable processes to ensure public access to Crown mineral rights for the exploration and potential future development of mining lands. The unit maintains an electronic registry of all provincial mining lands and performs all administrative functions related to the acquisition and maintenance of mining lands in Ontario. The MLS is located at the Division's head office at the Willet Green Miller Centre in Sudbury, with 4 Mining Lands Consultants located in Red Lake, Thunder Bay, Timmins and Kirkland Lake to deliver over-the-counter/advisory services. Operational procedures and services include geoscience approvals for assessment credit, administration of leased and patented mining land dispositions, the recording and administration of staked claims through the Provincial Mining Recorders Office and procedural policy development.

**Mines Group** encourages, promotes and facilitates the sustainable economic development of Ontario's mineral resources in an environmentally responsible manner, including the safe rehabilitation of mine sites. The unit is located at the Division's Willet Green Miller Centre in Sudbury, with Mineral Development Officers located in Thunder Bay and Timmins. Services provided include mineral development facilitation, industrial mineral commodity development, mining inspection & compliance, financial assurance, and abandoned mines inventory and rehabilitation.

**Ontario Geological Survey Branch (OGS)** is responsible for mapping, gathering and disseminating information and data on the province's geology and mineral resources, promoting and stimulating mineral exploration and development and assisting in the proper planning and management of the province's mineral and water resources. These operations are delivered through 5 business units listed below:

**Precambrian Geoscience Section (PGS)** is responsible for describing, characterizing and synthesizing the geology, tectonic history and metallogeny of the Shield areas in Ontario through bedrock mapping and geophysical and geochemical survey methods. The bedrock maps and reports produced by the Precambrian Geoscience Section provide the overall geoscience framework for the province. The PGS is located at the Division's Willet Green Miller Centre in Sudbury.

**Sedimentary Geoscience Section (SGS)** is responsible for mapping and the geochemical investigation of Ontario’s soil/surficial material and Paleozoic-age rocks within areas of high mineral potential to provide a framework for
mineral exploration and development. The section has four key programs: Surficial Geochemical Program, Surficial Mapping and Sampling, Industrial Mineral Assessment and Inventories, and recently Groundwater Mapping. Staff provide expert technical advice to clients, highlight the mineral potential of areas of the province, develop innovative exploration methodologies and transfer the information in the form of maps, reports and datasets. The geoscience data collected is also used for environmental and planning processes as well as protecting public health and safety. The SGS is located at the Willet Green Miller Centre in Sudbury.

Resident Geologist Program (RGP) is responsible for direct client services, including in-office/ in-field consultation/advisory services to mineral sector clients, providing access to geoscience information and materials such as drill core stored within the Ministry's drill core libraries, stimulating, promoting and monitoring mineral exploration and development, providing input into land use planning and management initiatives, and providing prospector training to First Nation communities. The RGP is delivered through a network of 10 district offices strategically located across the province.

Geoscience Laboratories (Geo Labs) is responsible for providing geochemical analytical and research services for the OGS, as well as reference material production and analytical methods development and mineralogy services. The OGS Geoscience Laboratories also provide specialized analytical services for the private sector, government and academic organizations, and Laurentian University earth science researchers through a partnership arrangement with the university. The Geoscience Laboratories is located at the Willet Green Miller Centre in Sudbury.

Information and Marketing Services (IMS) is located at the Willet Green Miller Centre in Sudbury, IMS is responsible for the national and international marketing of Ontario's competitive advantages that promote and foster mineral exploration and development. The business unit is responsible for the sales and distribution of OGS geoscience publications and digital data, maintaining the OGS geoscience library and the Division's Internet website, providing mineral sector statistics analysis and generating business development opportunities through GEOEnterprise.

Supporting both the Mineral Development and Lands Branch and the Ontario Geological Survey is Business Solution Services (BSS) that forms part of the Ministry's Information and Information Technology Branch. BSS helps develop and maintain computer applications for the electronic delivery of the Division's geoscience and mining lands information and geospatial data via the Internet.

V) IMPORTANCE OF EXPLORATION, MINING AND OUR MINERAL WEALTH

Mining organizations have been primary contributors to the natural resources base of Canada. The mining sector supplies the fundamental materials that form the basis of Canada's industrial structure and economic welfare.

Mining and mineral development in Ontario is older than the province itself. It was among the first pioneering industries to take hold and attract people, first creating mining camps that grew from small towns and communities to larger centers such as Timmins, Sudbury, Kirkland Lake, Cobalt and Red Lake. Today, successful mine operations are profitable businesses with equipment and techniques that rival any high-tech industry. Ontario's metals are used in a growing and diverse number of manufacturing processes. People and communities in Ontario continue to thrive because of our mining industry.

The mineral wealth of Ontario and Canada is part of everyone's life. Minerals and metals
mined in Ontario are used in a wide variety of products in all homes and workplaces and are used worldwide in applications as diverse as construction, transportation, medicine, defense, aerospace, communications and more. Mineral deposits are non-renewable resources; therefore, once a deposit is depleted a mine will close. Mine closure not only affects the economic well being of a mining community but also represents a reduction in Ontario's mineral production, tax revenue and overall wealth.

Canada's and Ontario's vast undiscovered resources contain enough high-quality ore deposits to support growing rates of mine production. The key lies in effective, efficient and environmentally sound exploration and mining. If Canada and Ontario are to remain as major mineral producers and maintain their economic well being, then ore deposits must be discovered and developed in the coming decades.
PART 2:

MINERALS
AND
MINERAL IDENTIFICATION
MINERALS AND MINERAL IDENTIFICATION

I) WHAT ARE MINERALS AND ROCKS?

Minerals are naturally occurring inorganic, crystalline solids. Every mineral occurs as a crystal with its own crystal structure and distinctive physical properties. The crystal structure of minerals distinguishes them from other naturally occurring solids. The physical properties of a mineral remain consistent throughout the entire mineral crystal. If a mineral crystal is broken in half the two pieces will have identical characteristics and properties.

Rocks are composed of various combinations and proportions of minerals. Rocks consist of various, small, “interlocking” or intergrown mineral grains and crystals, but may also be composed of various types of broken rock and mineral fragments that are cemented together. Rock types can be distinguished from each other by their mineral compositions, grain size and textures. However, rocks are mixtures of minerals and do not have the consistent physical properties that an individual mineral crystal would have. Therefore, the two halves of a broken rock will have different characteristics and features.

The following chapters of this manual will describe the various types of minerals and rocks and explain how to identify them. However, to fully understand the origin of minerals, rocks and the Earth, we must begin with a description of the building blocks of all matter: atoms.

II) ATOMS AND ELEMENTS

Atoms are the building blocks of all substances on Earth and in the universe. Atoms are distinct forms of matter that cannot be chemically separated into forms different from themselves. All that we see and touch is made of atoms whether it is a solid, liquid or gas.

An element is a material composed of only one kind of atom: gold is only composed of gold atoms and iron is only composed of iron atoms. There are 106 types of atoms and each atom comprises an element, therefore, there are 106 known elements. Each element has its own chemical symbol (Table 1), for example, Au is the symbol for gold and Fe is the symbol for iron. The chemical symbols are used to identify the elements in chemical formulas and on assay sheets.

Two kinds of elements are of interest to prospectors: metals and non-metals. The metallic elements are opaque; have a “metallic” appearance; and are conductors of heat and electricity. Non-metallic elements include gases, such as oxygen and hydrogen; and solid elements, such as carbon, sulphur and silicon, which do not have metallic properties. A few elements, such as arsenic and antimony, are known as semi-metals or metalloids because they possess both metallic and non-metallic properties (Lang 1970).

Several elements exist by themselves in nature in a “free” or “native” state, such as gold, silver, copper, platinum and carbon (graphite and diamond), but most are in various combinations of two or more elements. These mixtures or combinations of elements are naturally formed crystalline solids known as minerals.

Although there are 106 elements, chemical studies have shown that only 9 elements are found in such abundance that they comprise 99% by weight of the Earth’s crust as shown in Table 2.

The other 97 elements comprise about 1% by weight of the Earth’s crust. Few of the 9 elements listed in Table 2 occur in their free state but most combine with each other, or with the other 97 elements, to form minerals. Since the Earth’s crust is only composed of 9 elements, then the crust is actually composed of very few minerals. The list of elements in Table 2 does not include metals, such as gold, silver, copper and zinc, which we use in our day-to-day lives.
### TABLE 1: COMMON ELEMENTS AND THEIR CHEMICAL SYMBOLS

<table>
<thead>
<tr>
<th>Element Name</th>
<th>Symbol</th>
<th>Element Name</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>Al</td>
<td>Molybdenum</td>
<td>Mo</td>
</tr>
<tr>
<td>Antimony</td>
<td>Sb</td>
<td>Nickel</td>
<td>Ni</td>
</tr>
<tr>
<td>Arsenic</td>
<td>As</td>
<td>Niobium</td>
<td>Nb</td>
</tr>
<tr>
<td>Barium</td>
<td>Ba</td>
<td>Oxygen</td>
<td>O</td>
</tr>
<tr>
<td>Bismuth</td>
<td>Bi</td>
<td>Palladium</td>
<td>Pd</td>
</tr>
<tr>
<td>Boron</td>
<td>B</td>
<td>Platinum</td>
<td>Pt</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Cd</td>
<td>Potassium</td>
<td>K</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca</td>
<td>Silicon</td>
<td>Si</td>
</tr>
<tr>
<td>Carbon</td>
<td>C</td>
<td>Silver</td>
<td>Ag</td>
</tr>
<tr>
<td>Cesium</td>
<td>Cs</td>
<td>Sodium</td>
<td>Na</td>
</tr>
<tr>
<td>Chromium</td>
<td>Cr</td>
<td>Sulphur</td>
<td>S</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Co</td>
<td>Tantalum</td>
<td>Ta</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>Tellurium</td>
<td>Te</td>
</tr>
<tr>
<td>Fluorine</td>
<td>F</td>
<td>Thallium</td>
<td>Ti</td>
</tr>
<tr>
<td>Gold</td>
<td>Au</td>
<td>Thorium</td>
<td>Th</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>Tin</td>
<td>Sn</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>Titanium</td>
<td>Ti</td>
</tr>
<tr>
<td>Lead</td>
<td>Pb</td>
<td>Tungsten</td>
<td>W</td>
</tr>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>Uranium</td>
<td>U</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>Vanadium</td>
<td>V</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn</td>
<td>Yttrium</td>
<td>Y</td>
</tr>
<tr>
<td>Mercury</td>
<td>Hg</td>
<td>Zinc</td>
<td>Zn</td>
</tr>
</tbody>
</table>

### TABLE 2: ELEMENTS (IN ORDER OF ABUNDANCE) IN THE EARTH'S UPPER CRUST

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>% by weight</th>
<th>% by volume</th>
<th>% of atoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>O</td>
<td>46.60</td>
<td>94.07</td>
<td>62.1</td>
</tr>
<tr>
<td>Silicon</td>
<td>Si</td>
<td>27.72</td>
<td>0.88</td>
<td>22.0</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Al</td>
<td>8.13</td>
<td>0.47</td>
<td>6.5</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>5.00</td>
<td>0.34</td>
<td>1.8</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca</td>
<td>3.63</td>
<td>1.15</td>
<td>2.2</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>2.83</td>
<td>1.07</td>
<td>2.1</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>2.59</td>
<td>1.71</td>
<td>1.3</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>2.09</td>
<td>0.26</td>
<td>1.6</td>
</tr>
<tr>
<td>Titanium</td>
<td>Ti</td>
<td>0.44</td>
<td>0.04</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td><strong>99.03</strong></td>
<td><strong>99.99</strong></td>
<td><strong>99.80</strong></td>
</tr>
</tbody>
</table>
III) MINERALS

i) Introduction

Mineralogy is the science of minerals and is one of the main subdivisions of geology. Approximately 3000 minerals are known to exist and about 100 new minerals are discovered each year. There are about 100 common minerals that can be found almost everywhere on the Earth. The most common minerals are composed of the 9 most common elements in the Earth’s crust. Many minerals are so rare that they are only found in one location in the world and others can only be found in microscopic amounts. The following sections will describe how minerals are formed and discuss their crystal structures and chemical compositions.

ii) Mineral Formation

Minerals occur as crystals which are formed by complex chemical and crystallization reactions. The crystallization of a mineral begins during nucleation that is the formation of a nucleus or “seed” from which the mineral can enlarge and grow. The growth of the mineral will only proceed and continue if conditions, such as temperature and pressure, are favorable for growth. Minerals are formed in one of four ways:

1) By crystallization during cooling from molten rock. The minerals form like ice crystals in freezing water.

2) By crystallization and deposition from water as chemical precipitates. Salt and potash minerals, for example, are precipitated from water as the water evaporates (i.e.: salt flats). To demonstrate this process, suspend a string in a glass of very salty water and set the glass on a shelf. Some of the water will evaporate in a few days and will leave small salt crystals formed along the length of the string. Minerals also form from sublimation when mineral crystals grow by deposition directly from a vapour.

3) By the transformation or recrystallization of pre-existing rocks and minerals due to increased temperature and/or pressure. The original mineral constituents of a rock are broken down by intense heat and/or pressure, deep within the Earth, and new mineral crystals form and crystallize. This process is termed metamorphism and will be described in more detail in the “Rocks” section of this manual.

4) By organic processes due to the activity of animal and vegetable organisms. Minerals, such as aragonite in pearls and shells; calcite in coral; and apatite in teeth and bones; are formed organically.

iii) Crystal Structure

Every mineral occurs as a crystal and has a distinct structure. The atoms that form a mineral are organized in a regular and repeating 3-dimensional arrangement. The arrangement of the atoms is consistent throughout the crystal which is a basic characteristic of the crystal state. It is this crystal structure that distinguishes minerals from other naturally occurring solids (Figure 1).

Atoms of any given element are more compatible with some elements than with others. If two elements are strongly attracted to each other then the two types of atoms will cling together in a specific organized shape or building block, for example, a cube. Numerous small cubes will form when there are a significant number of these atoms near each other. The cubes also attract each other and arrange themselves in a very organized pattern to form a crystalline structure. If the pattern of the crystalline structure continues to repeat itself in all directions a mineral crystal will form.

The outward shape of a mineral crystal is determined by the arrangement or pattern of the internal crystalline structure of the mineral. For example, sodium (Na) and chlorine (Cl) atoms combine to form rock salt (halite) and organize themselves in a perfect cubic arrangement. This arrangement is reflected in the cube shape of salt crystals. This relationship between the arrangement of atoms and crystal shape is true for every
Figure 1: The Six Basic Crystal Systems That Form Minerals
mineral.

iv) Chemical Composition

A mineral has a definite chemical composition or a range of compositions within defined limits, which is expressed as a chemical formula. The chemical formula for common rock salt or halite is NaCl, in which one atom of sodium (Na) is combined with one atom of chlorine (Cl). Another example is pyrite or "fool's gold", FeS₂, in which one atom of iron (Fe) is combined with two atoms of sulphur (S). The small "2" in the chemical formula indicates that there are two sulphur atoms for every iron atom in the crystalline structure of pyrite.

Minerals may contain other elements even though they have specific chemical formulas and crystal forms. An atom can replace other atoms in the crystal structure of a mineral when: 1) it is similar in size; and 2) it has similar chemical properties with the atom it is replacing. Gold naturally combines with silver because silver atoms can replace gold atoms in the crystal structure of gold. Gold and silver form a solid-solution series in which mixtures of all ranges of composition, from pure gold to pure silver, can be formed (Hewitt 1972). A specimen of gold could contain a large amount of silver but it would still look like pure gold. Gold that contains over 20% silver is known as "electrum".

Sphalerite is a zinc sulphide mineral (ZnS) in which iron atoms may substitute or replace the zinc atoms in its crystal structure. The colour of sphalerite ranges from yellow, green, red, brown to jet-black and becomes darker with increasing iron content. Therefore, iron and zinc form a solid-solution series which ranges from an iron-poor form of sphalerite (yellow) to an iron-rich form of sphalerite (black). Sodium (Na) and calcium (Ca) form a solid-solution series in feldspar which ranges from sodium-rich feldspar (albite) to calcium-rich feldspar (anorthite). The sodium and calcium replace each other in the crystal structure of the feldspar.

IV) CLASSIFICATION OF MINERALS

Minerals are commonly classified and divided into groups according to their chemical compositions (Figure 2). Below is a list of some of the more common "chemical" mineral groups.

Native Elements - These are elements that commonly exist by themselves in nature, such as gold (Au), silver (Ag), copper (Cu), platinum (Pt) and carbon (C). Carbon exists in its native state as graphite or diamond.

Oxides - These are minerals composed of various elements combined with oxygen (O), such as hematite (Fe₂O₃), magnetite (Fe₂O₄), ilmenite (FeTiO₃), cassiterite (SnO₂) and quartz (SiO₂). Many of the iron oxides are metallic but some oxides, such as quartz, are non-metallic.

Sulphides - These are minerals composed of various elements combined with sulphur (S), such as pyrite (FeS₂), sphalerite (ZnS), galena (PbS), cinnabar (HgS), molybdenite (MoS), pyrrhotite (Fe₁₋ₓS), chalcopyrite (CuFeS₂) and arsenopyrite (Fe₃S₄). Sulphides are the largest group of metallic minerals.

Carbonates - These are non-metallic minerals composed of elements combined with carbon (C) and oxygen (O), such as calcite (CaCO₃), dolomite (CaMgCO₃), siderite (FeCO₃) and magnesite (MgCO₃).

Silicates - These are an important group of minerals composed of silica (SiO₂) combined with various elements to form the common, non-metallic, rock-forming minerals. Silicates are the most abundant minerals and combine in variable proportions to form almost all of the most common rock types. Figure 3 illustrates how various elements combine to form silicate minerals, which in turn combine to form a common rock type known as granite. Common silicate minerals are feldspar, micas, amphiboles, pyroxenes, olivines and garnets.

The mineral groups listed above include the majority of the most common minerals. There are other mineral groups, such as halides, borates, nitrates, chromates, sulphates, phosphates and tellurides, but most of these mineral groups are smaller and less common.
Figure 2: Chemical Classification of Common Mineral Groups

MINERALS

Native Elements
- Gold (Au)
- Silver (Ag)
- Copper (Cu)

Chemical Compounds
- Feldspar
- Magnetite
- Pyrrhotite
- Siderite
- Fluorite
- Gypsum
- Wolframite

Chemical Elements
- C
- S

Oxides
- Quartz (SiO₂)

Carbonates
- Siderite (Fe₂CO₃)

Sulphides
- Pyrite (FeS₂)
- Wolframite ((Fe, Mn)WO₄)

Silicates
- Halloysite
- Spodumene (LiAl(Si₂O₆))

Sulphates
- Barite (BaSO₄)

Fluorides
- CaF₂

Group
- Feldspar
- Fluorite
- Gypsum
Figure 3: Element and Mineral Composition of Granite

Elements

Minerals

Rock

Calcium $Ca$

Sodium $Na$

Oxygen $O$

Silicon $Si$

Potassium $K$

Aluminum $Al$

Plagioclase $(Ca_{x}Na_{1-x})AlSi_{3}O_{8}$

Quartz $SiO_{2}$

Microcline $KAlSi_{3}O_{8}$

Granite
Figure 2 summarizes the chemical nature of some of the larger mineral groups.

V) MINERAL PROPERTIES AND IDENTIFICATION

i) Introduction

The chemical composition and crystal structure of a mineral determines its physical properties. Minerals may be metallic or non-metallic; glossy or dull; light or heavy; hard or soft; coloured or colourless. Some minerals dissolve in water while others are unaffected by the strongest acids. Each mineral has its own distinctive properties and no two minerals are alike in every respect. The most characteristic physical mineral properties include: structure, crystal form (crystallinity), cleavage, fracture, hardness, colour, streak, lustre, specific gravity, diaphaneity and in some cases magnetism, fluorescence, radioactivity, taste, feel and smell.

One of the most important skills a prospector needs is the ability to identify minerals. The prospector does not need to recognize all 3000 of the known minerals, however, it is essential to be able to recognize the most common rock-forming and ore-forming minerals. Persistence, practice and careful observation are necessary for the successful identification of minerals. A prospector should become familiar with the most common and easily recognizable minerals, then try to identify the more difficult ones.

A prospector only needs a few simple pieces of equipment for mineral identification: a ten (x10) and/or sixteen (x16) power hand lens, a rock hammer, small magnet, penknife, streak plate, penny, small bottle of dilute hydrochloric (muriatic) acid and a good handbook on mineral identification. The most important tool of the prospector is the hand lens, which is essential when identifying minerals, since many mineral properties can only be determined visually. Minerals commonly occur as very small crystals which are difficult to identify with the naked eye. A hand lens magnifies the mineral and makes it easier to recognize. A prospector who works without a hand lens is working at about 50% efficiency.

ii) Mineral Properties

Many physical properties can be used to identify minerals, some of which are described below.

METALLIC/NON-METALLIC: One of the first things to do when identifying a mineral is to determine whether its appearance is metallic or non-metallic. A metallic mineral should appear like a piece of metal with a relatively shiny, hard, polished surface. Non-metallic minerals appear like a non-metallic substance, such as glass, wax, porcelain, stone, earth, resin, etc.

COLOUR: Colour is one of the first, obvious, recognizable characteristics of a mineral. A mineral will have a diagnostic colour if it has a fixed chemical composition and is free of impurities. Colour is an important feature of minerals, such as azurite (blue), malachite (green), galena (lead-grey) and chalcopyrite (yellow-green). Many minerals do not have a characteristic colour because the colour may depend on the type and amount of impurities in a mineral. A small amount of iron in a mineral, such as quartz or calcite, may produce a pink or red colour. Quartz can be smoky, pink to red, purple or green; or colourless; sphalerite can be yellow, green, honey-brown or jet-black. The true colour of a mineral may also be obscured by tarnishing which is a coating on the mineral caused by the exposure to weathering. Never use colour as the major identifying characteristic of a mineral.

STREAK: The streak of a mineral is the colour of the powder of the mineral and is always the same regardless of variations in the colour of the mineral. The streak may be determined by rubbing the mineral on a porcelain streak plate (unglazed porcelain such as the back of a piece of ceramic tile) or by scratching it with a penknife. The streak of a mineral may not be the same as its colour. Hematite, for example, has a characteristic brownish-red streak although the colour of the specimen may be silver, red, brown or black. Sphalerite almost always has a brown streak even if its colour is yellow, brown or black. Some
minerals have a streak that is the same as their colour, such as galena, which is lead-grey and has a lead-grey streak. Many minerals have colourless streaks, such as non-metallic or rock-forming minerals such as quartz, feldspar, scheelite and spodumene. Minerals harder than porcelain will scratch the plate and won't produce a streak.

LUSTRE: The terms "metallic" and "non-metallic" broadly describe the basic types of lustre that is the appearance of light reflected from the surface of a mineral to the eye. A variety of lustre's are listed below:
- metallic, like metal (chalcopyrite)
- resinous, like resin (sphalerite)
- vitreous, like porcelain (feldspar, spodumene)
- glassy, like glass (quartz)
- pearly, like mother of pearl (muscovite mica)
- adamantine, like diamond
- silky, greasy, dull, waxy

CRYSTAL FORM (CRYSTALLINITY): When a mineral is allowed to grow in an unrestricted open space it will develop natural crystal faces which produce a perfect geometric pattern. The shape of a crystal is a reflection of its internal atomic structure. The size and shape of mineral crystals can vary but the angle between crystal faces is constant and characteristic of a mineral. It should be noted that more than one mineral can have the same crystal form, for example, both galena and salt have cube forms; and many minerals can form more than one crystal shape as well. Some of the common minerals in which crystal form is diagnostic are: quartz (6-sided pyramid form); halite, pyrite, galena (cube form); garnet (10-sided crystal form); beryl (hexagonal crystal form); calcite (rhombohedral crystal form); fluorite (cube or octahedral form); hornblende, pyroxene, tourmaline (prismatic form).

STRUCTURE OR FORM: The term "structure" refers to the outward shape and form taken by the mineral (Figure 4). Structure may be described as:
- massive, a mass with no crystal faces (pyrrhotite)
- fibrous, composed of fibers, hair-like (asbestos)
- acicular, needle-like (tourmaline, arsenopyrite)
- micaceous, or platy (mica, which splits easily into thin plates)
- botryoidal, looks like a cluster of grapes (hematite)
- dendritic, tree or branch-like (native silver)
- earthy, looks like hard, dried clay (limonite)
- granular, composed of small grains like sugar (pyrite)
- powdery, flaky, radiating, concentric, or bladed

CLEAVAGE: The tendency of a mineral to split along smooth planes of weakness that have definite geometric relationships to one another is cleavage. A mineral will cleave or break along certain planes more easily than others because of their internal crystalline arrangement. The surface along which the break develops is called the cleavage plane and the orientation of the plane is the cleavage direction (Figure 5). Minerals can have several cleavage directions. Amphiboles have two cleavage directions at angles of about 120º and 60º. Pyroxenes and feldspars have two cleavage directions at 90º or at right angles. Rock salt has three cleavage directions also at right angles (Figure 5). Perfect, basal cleavage (mica) is easily recognized because it develops a smooth even surface in one cleavage direction. Cleavage planes may occur in a step-like manner (galena), but may be mistaken for a step-like fracture. If the specimen is rotated in front of a light the small, parallel, cleavage planes will reflect light in the same manner as a large, smooth, cleavage surface. An uneven fracture will not concentrate light in any particular direction (Figure 6). There may be some difficulty in distinguishing between a mineral's crystal surface and cleavage surface. Remember that a crystal face is an external characteristic of a mineral while the cleavage is internal. The cleavage can only be recognized by breaking the mineral and looking at the broken surface.

FRACTURE: If a mineral lacks cleavage it will fracture and break along irregular surfaces. The type of fracture may be diagnostic of a mineral, such as:
- conchoidal (quartz; looks like broken glass
Figure 4: Examples of Mineral Structure

- Granular
- Fibrous
- Botroidal
- Radiating (Globular)
- Platy
- Acicular
- Bladed
- Dendritic
- Colloform (Stalactite)
Cleavage in one direction: mica

Cleavage in two directions at right angles: feldspar

Cleavage in two directions not at right angles: amphibole

Cleavage in three directions at right angles: rock salt

Figure 5: Examples of Cleavage in Minerals
Reflected light from smooth cleavage.

Reflected light from stepped cleavage.

Reflected light from fracture.

Figure 6: Reflection of Light from Cleavage and Fracture Surfaces
HARDNESS: Hardness is the resistance of a mineral to being scratched, and is one of the most important diagnostic mineral properties. A scale known as Mohs’ Scale of Hardness was devised to measure mineral hardness. The scale ranges from 1 (softest) to 10 (hardest) and uses certain minerals as standards. The scale is also relative, for example, a mineral with a hardness of 4 will scratch any mineral with a hardness less than 4, but will be scratched by any mineral with a hardness greater than 4. The scale of hardness is listed below:

Moh’s Scale of Hardness
Diamond = 10 (hardest)
Corundum = 9
Topaz = 8
Quartz = 7
Feldspar = 6
Apatite = 5
Fluorite = 4
Calcite = 3
Gypsum = 2
Talc = 1 (softest)

Other common objects that can be used to determine hardness are: whetstone = 9.0; steel file = 6.5 to 7.0; glass = 5.5 to 6.0; knife blade = 5 (could be harder depending on the steel); copper penny = 3.0; and a fingernail = 2.5.

Always try to scratch a fresh, unweathered, crystal face of a mineral when testing its hardness. A deeply weathered surface of a mineral will be softer than the mineral's fresh surface. The hardness test can also be reversed, for example, if a knife won't scratch a mineral then try to scratch the knife with the mineral. Also be sure not to mistake a metal smear from a knife on a very hard mineral as a scratch. Always reverse the test if you are uncertain.

TENACITY: Tenacity is the resistance of a mineral to breaking. There are different types of tenacity, such as:
- brittle, mineral breaks easily into angular fragments (quartz)
- tough, mineral breaks with difficulty (pyrrhotite)
- malleable, mineral can be beaten into a thin sheet (native gold, silver or copper)
- sectile, mineral can be cut by a knife without powdering (native gold)
- flexible, mineral can be bent without breaking and it remains bent (selenite, gypsum)
- elastic, the mineral will bend but will regain its original shape when force is released (mica)
- pulverulent, mineral powders easily (limonite)

SPECIFIC GRAVITY OR HEAVINESS: Specific gravity is the ratio between the mass of a mineral and the mass of an equal volume of water. Specific gravity (S.G.) is one of the most constant physical properties of a mineral. A mineral's specific gravity can be determined by dividing its weight in air by the weight of an equal volume of water. You can estimate specific gravity quite accurately by lifting a mineral specimen in your hand and comparing it to other minerals. Most metallic minerals have high S.G.'s, for example, galena is 7.5 and pyrite is 5. Most rock-forming minerals such as quartz feldspar and calcite have low S.G.'s between 2.6 and 2.8.

MAGNETISM: This is the ability of a mineral to attract a magnet and is a physical property possessed by a few iron-bearing minerals, minerals such as magnetite (Fe₃O₄) and pyrrhotite (Fe₁₋ₓS) are very magnetic. Ilmenite (FeTiO₃) is similar in appearance to magnetite but is weakly magnetic. Hematite (Fe₂O₃) and limonite are non-magnetic. Non-magnetic minerals with magnetic impurities may be magnetic, but the magnetic response will vary in different areas on the mineral specimen.

DIAPHANEITY OR LIGHT PENETRATION: This is the measure of light, which passes through a mineral. The four types of diaphaneity are:
- transparent, light passes through a mineral and objects are visible when viewed through the mineral (quartz, calcite). Calcite may exhibit a characteristic known as double refraction, where an object viewed through a
A transparent piece of calcite appears doubled and gives a doubled or twinned image.
- **Translucent**, only light is transmitted through the mineral (mica). No images can be seen through the mineral.
- **Opaque**, no light is passed through the mineral (pyrite).
- **Iridescence**, light is reflected within the mineral (opal) that produces a variety of bright “twinkling” or “flickering” colours.

**Taste**: Minerals that dissolve in water can be tasted, such as halite (salt) or gypsum.

**Smell**: Some minerals have a particular smell, such as arsenopyrite, which gives off a garlic odour when freshly broken with a hammer. Minerals containing sulphur, such as chalcopyrite or pyrite, will give off a distinct sulphur odour (rotten egg smell) when struck by a hammer or powdered.

**Feel**: Some minerals have a distinctive feel such as talc (soapy), molybdenite and graphite (greasy), mica (smooth).

**Radioactivity**: Radioactive, unstable, elements such as uranium, barium, thorium and potassium emit rays and particles during their radioactive decay. The rays and particles can be detected with instruments, such as a Geiger counter or scintillometer, which detect the presence, amount and type of particles emitted from radioactive minerals, such as pitchblende or uraninite.

**Fluorescence**: Some minerals have the ability to “glow” or fluoresce in different colours under **ultraviolet (UV)** light. The minerals do not reflect the UV beam but absorb it. The ultraviolet light disturbs electrons that orbit the mineral's atoms. The electrons are displaced by the light and try to bounce back into their orbits. This disturbance releases electric and magnetic energy that is expressed as light. Most minerals stop glowing when the ultraviolet light is taken off them, however, some minerals continue to glow for seconds or hours, this property is called **phosphorescence**. The electrons in phosphorescent minerals take longer to get back into orbit; therefore, they emit light even after being exposed to ultraviolet light.

Fluorescent minerals are scheelite (fluoresces white blue), calcite (fluoresces red), fluorite (fluoresces blue). Phosphorescent minerals are sodalite and sometimes calcite.

**Reaction with acid**: Some minerals react with dilute (10%) hydrochloric acid that is commonly sold in hardware stores as muriatic acid. Acid is useful in detecting the presence of carbonate minerals, such as calcite, in a rock. Sprinkle a few drops of acid on a specimen and if the acid effervesces or fizzes (like adding vinegar to baking soda) the specimen contains a carbonate mineral. Some carbonate minerals, such as dolomite, may have to be scratched with a knife or powdered before they will react with acid.

**Mineral bloom**: Mineral "blooms" are colourful, earthy crusts or coatings on rocks that prospectors use to recognize the presence of such elements as copper, nickel and cobalt. Bright green (malachite) or sky-blue (azurite) carbonate coatings are common where copper minerals, such as native copper, chalcopyrite or bornite, have been weathered and exposed to moisture. Pale apple-green coatings (annabergite) commonly occur on weathered nickel minerals, such as niccolite. Bright, pink (erythrite), blooms occur on weathered cobalt minerals, such as cobaltite. A powdery, yellow stain (ferrimolybdenite) is an indicator of molybdenum mineralization. Several uranium-bearing minerals also exhibit various characteristic mineral blooms when they are weathered.

**Dimethylglyoxime ("Nickel Zap")**: This is a white, powdery, chemical used by prospectors to detect the presence of nickel in rocks and mineral specimens. Moisten a rock with a small amount of water or saliva and rub in a small amount of dimethyl. If the specimen contains nickel the white powder will turn pink. If the dimethyl becomes dark red or very bright pink then the specimen contains a high amount of nickel; pale pink indicates low nickel content. There are other chemical tests that can be used to detect elements such as zinc, tin, tungsten, magnesium and cobalt.
iii) Steps for Mineral Identification

Specific steps you can follow when attempting to identify minerals are listed below:

1) First determine if the mineral is metallic or non-metallic. Ask yourself, "Does the mineral appear like a piece of metal or like glass, stone, earth, resin, wax or some other non-metallic substance? Metallic minerals have relatively shiny, polished surfaces and are opaque.

2) Determine if the mineral is magnetic. If the mineral is magnetic then you have narrowed down the possibilities significantly since there are very few magnetic minerals.

3) Identify the mineral properties that can be determined visually, such as colour, lustre, structure, crystal form, cleavage, fracture and diaphaneity. Look for mineral blooms and scratch the surface of the mineral to check for tarnishing which may obscure the true colour of the mineral.

4) Determine the streak and hardness of the mineral. You can try to determine specific gravity if the mineral specimen is large enough to "weigh" in your hand.

5) Use your other senses to determine specific mineral properties such as feel, taste and smell.

6) Other tests for properties such as fluorescence, radioactivity and reaction to acid may also be useful in determining the identity of the mineral.

Remember that patience, careful observation and practice are needed to successfully identify minerals. Once you are familiar with the common minerals you should be able to recognize them easily. Complete descriptions of minerals can be obtained from numerous reference books on mineralogy and mineral identification that are available at bookstores and libraries.

VI) COMMON ROCK-FORMING MINERALS

The silicate groups of minerals combine in variable amounts to form almost all of the major rock types that make up the Earth's crust. The silicate minerals are composed of silica (SiO₂) and various other elements and have non-metallic properties. Carbonate group minerals may also combine with silicates to form rocks.

The silicates can be divided into two groups: light-coloured (white, pink, light grey, buff white, colourless, orange, yellow, light green, light blue or a pastel colour), felsic minerals such as quartz feldspar and muscovite mica; and dark-coloured (brown, black, dark green, dark grey or dark blue), mafic minerals such as amphibole, pyroxene, olivine and biotite mica. Light-coloured minerals impart a light colour to rocks while dark-coloured minerals impart a dark colour to rocks. The felsic silicate minerals, such as feldspar and muscovite mica, are mainly composed of silica, aluminum, calcium, sodium and potassium. Rocks containing abundant felsic minerals are called felsic rocks. A felsic rock is commonly light-coloured and rich in silica, with varying enrichments of aluminum, calcium, sodium and potassium.

The mafic silicate minerals such as amphibole, pyroxene, olivine and biotite mica contain large amounts of iron and magnesium. Rocks containing mafic minerals are known as mafic rocks. Mafic rocks are commonly dark-coloured and enriched in iron and magnesium.

Felsic and mafic minerals commonly occur together in the same rocks, but in variable proportions, this will be discussed in more detail in the section on "Rocks".

i) Light-Coloured Felsic Silicate Minerals

Quartz (SiO₂) - A very common mineral found in many rock types. Quartz has a hardness of 7, glassy or waxy lustre, conchoidal or uneven fracture and may form 6-sided crystals or granular and crystalline masses. Pure quartz is colourless and transparent but is commonly discoloured and opaque due to the presence of impurities. Quartz can be almost any colour. Quartz is the major mineral in many felsic rocks and is very common in veins.
Varieties of quartz include amethyst, chert, flint, opal, jasper, agate and chalcedony.

**Feldspar Group** - Feldspar comprise the most abundant mineral group in the Earth's crust. Feldspar has a hardness of 6, vitreous or porcelain lustre, two cleavage directions at right angles and may be pink, white, green, grey, orange or black.

The feldspars have two principal compositions:
- Potassium aluminum silicate, KA\(_2\)Si\(_3\)O\(_8\) which makes up orthoclase and microcline feldspars, also known as potash feldspars due to their high potassium (K) content.
- Sodium-calcium aluminum silicate (NaCa)AlSi\(_3\)O\(_8\), which makes up plagioclase (albite, anorthite) feldspars, also known as calcic or sodic feldspars due to their high calcium or sodium content.

**Mica Group** - Micas are common silicate minerals found in most rocks. Mica has a hardness of 3, a smooth, perfect cleavage in one direction and a pearly lustre. Mica breaks into very thin plates or sheets that are transparent or translucent. The three most common members of the mica group are listed below:
- **Muscovite mica** - A potassium- and aluminum-rich, silver-white or colourless mica. A fine-grained variety of muscovite is known as sericite.
- **Phlogopite mica** - A potassium- and magnesium-rich mica which is much like muscovite but amber or brownish in colour.
- **Biotite mica** - A black or brown mica described in the section on dark-coloured mafic, silicate minerals.

**Nepheline (NaAlSiO\(_4\))** - Nepheline is not a common rock-forming mineral and only occurs in rocks that are deficient in silica. Nepheline is never found with free quartz. Nepheline has a hardness of 5.5 to 6; good prismatic cleavage; a greasy to glassy lustre and is white, grey or pink. Nepheline weathers more readily than feldspars and is found in a rock type known as nepheline syenite.

**Amphibole Group** - Amphiboles have a hardness of 5 to 6, a glassy, non-metallic lustre and form long prismatic crystals. Amphiboles have two cleavage directions with angles at about 120° and 60°. The most common mineral of the amphibole group is hornblende that occurs in many rock types. Hornblende is rich in magnesium and iron and ranges in colour from dark green to black. The darker the hornblende the more iron it contains. Other common amphibole minerals are actinolite, tremolite and anthophyllite.

**Pyroxene Group** - Pyroxenes have a hardness of 5 or 6 and can be distinguished from amphibole by their poorer cleavage, with angles at 90° and shorter, thicker, prismatic crystals. Pyroxenes are commonly green but may vary from white to brown or black. The most common pyroxene is augite. Other pyroxenes are diopside, hypersthene, enstatite, wollastonite and spodumene.

**Biotite Mica** - Biotite is a dark-coloured, brown to black mica containing iron and magnesium.

**Olivine Group** - Olivine is commonly found in very mafic rocks and is an olive green to yellowish mineral that alters easily to brown or dark grey serpentinite. Olivine has a hardness of 6.5 to 7, a vitreous lustre, a conchoidal fracture and forms short, stubby, prismatic or rounded crystals.

**Chlorite Group** - Chlorite minerals are commonly dark green to black and have a vitreous or pearly lustre, a platy, micaceous cleavage and a hardness of 2 to 2.5. Chlorite is commonly found in metamorphosed, mafic, volcanic rocks.

**iii) Carbonates**

**Calcite (CaCO\(_3\))** is an important rock forming carbonate mineral composed of calcium, carbon and oxygen. Calcite is mainly found in sedimentary rocks but is also found in veins and along fractures in rocks. Other carbonate minerals found in rocks are dolomite, ankerite and siderite. Carbonate minerals have a hardness of 3 and are transparent to opaque with a pearly to vitreous lustre. Most
iv) Identifying Feldspar and Quartz

Feldspars are the most common, rock-forming, silicate minerals. The identification of some rock types depends on the ability of the prospector to identify the types of feldspar in a rock. Simply identifying a mineral as feldspar is usually sufficient, but if you wish to distinguish between the different types of feldspar, there are some physical properties that will help:

- **Striations** (closely spaced parallel lines) on the feldspar crystal indicate *plagioclase* (sodium feldspar); no striations indicates *orthoclase* or *microcline* (potassium or potash feldspar).
- To distinguish between the potash feldspars remember that *orthoclase* is commonly salmon-pink or brownish-pink and *microcline* is commonly pale whitish-green or apple green.

It is also difficult to distinguish between feldspar and quartz in fine-grained rocks. A few points to remember are:

- **Quartz** is grey, glassy and dull and does not commonly appear as well developed crystals.
- **Feldspar** has a porcelain lustre on fresh surfaces. Small, rectangular, lath-like crystals may be recognizable. Feldspars appear dull and powdery on weathered surfaces.
- If the crystals are large enough you can test them for hardness. Feldspar has a hardness of 6 and quartz has a hardness of 7.

VII) ECONOMIC MINERALS

Minerals commonly occur as constituents of rocks but may also occur in rare, naturally formed, concentrations known as mineral deposits. These deposits commonly consist of a various mineral and/or minerals containing valuable elements, that are extracted and used in our daily lives. The mineral deposits of Ontario have contributed great economic wealth to the province and Canada.

Many minerals must be broken down and processed to extract the useful elements in the mineral. Chalcopyrite (CuFeS₂) is a copper (Cu) mineral that also contains iron (Fe) and sulphur (S). Iron and sulphur must be separated from copper so that pure copper can be used for industrial purposes.

Metallic minerals are most commonly thought of as the main economic minerals sought after by the mining industry. However, there are many non-metallic minerals that are also extracted and used for a great variety of purposes. So many minerals have economic value today that it is easier to list the minerals and metals that we don’t use rather than list those that we do use. Many rocks also have economic value and are used as flagstone, facing on buildings, furniture, bathroom fixtures, street curbing, tile, etc. The list of uses can go on and on. The following sections describe only a few of the many metallic and non-metallic minerals that have economic value.

i) Metallic Minerals

Below is a list of the most common, metallic minerals. Not all of the minerals listed below are extracted for the valuable elements they contain, but many of them, such as pyrite or pyrrhotite, occur with economic metallic minerals, such as sphalerite, chalcopyrite and gold.

**Iron Minerals**

*Magnetite (Fe₃O₄)*: hardness 6; S.G. 5.2; commonly massive or granular in form; metallic lustre; iron-black; black streak; strongly magnetic.

*Magnetite (Fe₃O₄)*: hardness 5.5 to 6.5; S.G. 4.9 to 5.3; metallic to dull lustre; colour can be red, red-brown, black or metallic, steel-grey; red streak; can form platy crystals and botryoidal masses and is found as specularite in platy, silver-red, crystals.

**Limonite (FeO·OH·nH₂O)**: hardness 4 to 5.5; S.G. 2.7 to 4; found in earthy masses and may appear soft; brown, black, yellow; streak yellow-brown; dull, earthy lustre. Limonite is basically iron rust.
Ilmenite (FeTiO$_3$): hardness 5.5 to 6; S.G. 4.7; massive or crystalline form; metallic to sub-metallic lustre; iron-black; black to brownish-red streak; weakly magnetic.

Pyrite (FeS$_2$): hardness 6 to 6.5; S.G. 5; massive, fine, granular or cubic crystals; metallic lustre; pale brass-yellow; greenish or brownish black streak; brittle fracture. Pyrite is commonly referred to as “fools" gold" but is easily distinguished from gold by its hardness, crystal shape, colour and streak. Pyrite is commonly associated with gold and massive sulphide deposits.

Arsenopyrite (FeAsS): hardness 5.5 to 6; S.G. 5.9 to 6.2; metallic lustre; black streak; silvery-white; needle-like, stubby, crystals but also forms massive granular masses; garlic odour when freshly broken; commonly associated with gold. Arsenopyrite is also known as "mispickel".

Pyrrhotite (Fe$_{1-x}$S): hardness 4; S.G. 4.6; massive or granular form with irregular fracture; metallic lustre; bronze-yellow to brownish-red; tarnishes rapidly to dull brown or brass; greyish-black streak; commonly magnetic but may be non-magnetic. Commonly occurs with nickel and copper sulphides and sometimes gold.

Copper Minerals

Chalcopyrite (CuFeS$_2$): hardness 3.5 to 4; S.G. 4.2; generally massive form; metallic lustre; brassy to greenish-yellow; tarnishes easily; greenish-black streak; softer than pyrite but harder than gold.

Malachite/Azurite: copper carbonates; malachite is bright green, azurite is sky-blue; dull lustre; form in Earthy masses or crusts. Occur where copper ore minerals have been weathered.

Bornite (Cu$_5$FeS$_4$): hardness 3; S.G. 5.7; metallic lustre; fragile with poor cleavage; forms compact, granular masses; grey-black streak; reddish-brown or pinkish colour that tarnishes very quickly to an iridescent purple and blue film. Also known as "peacock ore".

Nickel Minerals

Pentlandite (Fe, Ni)$_9$S$_8$: hardness 3.5 to 4; S.G. 4.6 to 5; brittle; metallic lustre; yellow-bronze; bronze-brown streak; massive or mixed with other sulphides (usually pyrrhotite).

Niccotile (nickeline) (NiAs): hardness 5 to 5.5; S.G. 7.8; metallic lustre; pale copper-red to brownish-black streak; massive and brittle; may show pale green "nickel bloom" alteration (annabergite).

Lead Mineral

Galena (PbS): hardness 2.5; S.G. 7.6; excellent cubic cleavage; metallic lustre; colour and streak are lead-grey; forms in massive growths or as cubic crystals.

Zinc Mineral

Sphalerite (ZnS): hardness 3.5 to 4; S.G. 3.9 to 4.1; good cleavage; resinous lustre; variable colour from yellow to jet-black; streak is dark-brown. Black varieties of sphalerite are commonly known as "black jack". Sphalerite is also referred to as "zincblende".

Molybdenum Mineral

Molybdenite (MoS$_2$): hardness 1 to 1.5; S.G. 4.7; excellent cleavage; metallic lustre; greasy feel; silver to lead-grey; blue-grey streak; occurs in platy crystals and flakes. Commonly accompanied by a pale yellow powdery stain or bloom.

Cobalt Mineral

Cobaltite (CoAsS): hardness 5.5; S.G. 6.3; metallic lustre; silver-white; grey-black streak; may show pink "cobalt bloom" alteration (erythrite).

Native Elements

Gold (Au): hardness 2.5 to 3; very heavy with an S.G. of 19.3; occurs as irregular masses, flakes, scales, blobs or wires; malleable; golden-yellow colour and streak; soft and sectile; hackly fracture.
Silver (Ag): hardness 2.5 to 3; S.G. 10 to 12; forms irregular, wire-like masses, flakes, scales, plates or dendritic growths; malleable; metallic lustre; silver-grey colour and streak; tarnishes quickly to black.

Graphite (C): hardness 1 to 2; S.G. 2.2; marks paper with a black streak; metallic to dull lustre; black to steel-grey; greasy feel; forms tabular crystals or granular flaky masses. Graphite is also known as "plumbago".

ii) Non-Metallic Minerals

The following is a list of common, non-metallic minerals with economic value that are referred to as industrial minerals. Industrial minerals are any rock, mineral or other naturally occurring substance of economic value, excluding metallic minerals, mineral fuels and gemstones.

Gypsum (CaSO₄2H₂O): hardness of 2; S.G. 2.3; vitreous or silky lustre; forms clear, tabular crystals, and white to grey, granular, waxy-looking, compact masses or fibrous aggregates; white, grey, yellowish or brown.

Halite or Rock Salt (NaCl): hardness 2.5; S.G. 2.1; fragile with perfect cubic cleavage; transparent to translucent with vitreous lustre; forms large clear crystals or compact white, opaque, granular masses; salty taste; dissolves in water; colourless to white; yellow, red, brown.

Barite (BaSO₄): hardness 2.5 to 3.5; very heavy with S.G. of 4.5; prismatic cleavage; vitreous lustre; white; crystallizes into masses of tabular or bladed crystals; compact, granular, massive. Barite is an ore mineral of barium.

Talc (Mg₃Si₄O₁₀(OH)₂): hardness 1; S.G. 2.6; forms aggregates or compact, felted, light grey masses (soapstone); sectile; translucent with pearly lustre; greasy or soapy feel; white, greenish white, gray or brownish.

Calcite (CaCO₃): hardness 3; S.G. 2.7; rhombohedral cleavage; variable colour but commonly colourless; white or pale yellow; transparent with vitreous lustre; some varieties fluoresce red.

Silica or Quartz (SiO₂): hardness 7; S.G. 2.6; no cleavage but good conchoidal fracture; transparent to translucent with vitreous or glassy lustre; forms granular or crystalline masses or clear 6-sided crystals; variable colour from colourless and white to purple (amethyst), pink, red, green, yellow or black.

Dolomite (CaMg(CO₃)₂): hardness 3.5 to 4; S.G. 2.8; fragile; rhombohedral cleavage; transparent to translucent with vitreous or pearly lustre; forms in aggregates of crystals; commonly colourless, white, pink or yellowish.

Spodumene (LiAl(SiO₃)₂): hardness 6.5 to 7; S.G. 3.1; long prismatic crystals; uneven splintery fracture; brittle; vitreous lustre; greenish-white, gray, yellow-green; white streak. Spodumene is a member of the pyroxene group of silicates and is an ore mineral of lithium (Li).

Lepidolite: hardness 2.5 to 4; S.G. 2.8; basal, micaceous cleavage; pearly lustre; lilac to purple. Lepidolite is a member of the mica group of silicates and is an ore mineral of lithium (Li).

Fluorite (CaF₂): hardness 4; S.G. 3.2; cubic crystals; brittle; vitreous lustre; variable colour but commonly purple or green; fluoresces blue. Fluorite is an ore mineral of fluorine (F).

Scheelite (CaWO₄): hardness 4.5 to 5; S.G. 5.9 to 6.1; vitreous lustre; non-metallic; yellow, brown, white or pink; white streak; fluoresces white-blue. Scheelite is an oxide and is an ore mineral of tungsten (W).
iii) Additional Information on Metallic Minerals

a) Identifying Gold

One of the most common problems a new prospector faces is identifying gold and being able to distinguish between gold and other yellow-coloured minerals (i.e. pyrite or fool's gold). Tiny yellow flakes of muscovite mica or bronze flakes of biotite mica can also be mistaken for gold, but the flaky, basal cleavage of the mica will commonly give it away. Mica flakes will also float on water in a gold pan, while flakes of gold will sink (but not always). The properties of gold and metallic sulphide minerals commonly mistaken for gold are presented below:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Colour</th>
<th>Form</th>
<th>Streak</th>
<th>Hardness</th>
<th>S.G.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>gold-yellow</td>
<td>wires, flakes and masses</td>
<td>gold-yellow</td>
<td>soft (2.5 to 3)</td>
<td>19.3</td>
</tr>
<tr>
<td>Pyrite</td>
<td>pale brass-yellow</td>
<td>granular, cubic crystals</td>
<td>black</td>
<td>6 to 6.5</td>
<td>5</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>brassy to greenish-yellow</td>
<td>massive</td>
<td>greenish-black</td>
<td>3.5 to 4</td>
<td>4.2</td>
</tr>
</tbody>
</table>

The colour of gold is very distinct and is commonly more yellow than jewellery gold. Gold does not tarnish and it can be cut with a knife (sectile) without breaking or powdering. Small flakes of gold are very reflective.

b) Properties of Common Sulphide Minerals

Below are the key properties of the most common, metallic, sulphide minerals. Many of these minerals occur together in massive sulphide deposits and there may be some difficulty in distinguishing one from the other.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Colour</th>
<th>Streak</th>
<th>Hardness</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrite</td>
<td>pale brass-yellow</td>
<td>black</td>
<td>6 to 6.5</td>
<td>cubic crystals</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>brassy to greenish-yellow</td>
<td>greenish-black</td>
<td>3.5 to 4</td>
<td>commonly massive</td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td>bronze-yellow</td>
<td>black</td>
<td>3.5 to 4.5</td>
<td>commonly massive and magnetic</td>
</tr>
<tr>
<td>Arsenopyrite</td>
<td>silvery-white</td>
<td>black</td>
<td>5.5 to 6</td>
<td>stubby, needle-like crystals; garlic odor</td>
</tr>
<tr>
<td>Sphalerite</td>
<td>yellow, brown to black</td>
<td>brown to pale yellow</td>
<td>3.5 to 4</td>
<td>resinous lustre</td>
</tr>
<tr>
<td>Galena</td>
<td>lead-grey</td>
<td>lead-grey</td>
<td>2.5</td>
<td>bright metallic lustre, cubic cleavage; heavy</td>
</tr>
</tbody>
</table>
PART 3:

ROCKS
ROCKS

I) INTRODUCTION

Atoms or elements combine to form minerals and minerals combine to form rocks. Most rocks are composed of varying combinations and proportions of non-metallic, rock forming, minerals.

Rocks consist of a mixture of one or more minerals in the form of small grains and crystals, or they may consist of rock and mineral fragments that are cemented together. Therefore, rocks are distinguished from each other by physical properties that are different from the properties used to identify minerals. The properties used to identify rocks are:

1) The mineral composition of a rock or the composition and relative proportion of rock fragments and minerals in a rock.

2) The coarseness or fineness of the grain or texture of a rock.

3) The arrangement of mineral crystals in a rock, for example, in parallel directions; in parallel bands; or in a granular mass without noticeable arrangement.

Rocks host all economic mineral deposits, many of which are only associated with specific rock types. In some cases, the rocks themselves have economic value, as in deposits of dimension or decorative stone. Therefore, it is essential for the prospector to be able to recognize and identify rocks. The identification of a rock depends on the prospector's ability to identify minerals and various characteristic textures of specific rock types. A knowledge of rocks enables prospectors to read and understand geological maps and reports and allows them to make their own maps. The following chapters describe the formation and characteristics of the three major classifications of rocks and explains how to identify them.

II) CLASSIFICATION OF ROCKS

Rocks are classified according to their origin, mineral content and texture and are divided into three main groups based on how they are formed. The three rock groups are igneous, sedimentary and metamorphic rocks and are defined and described in the following sections:

I) Igneous Rocks

Igneous rocks are formed by the cooling and crystallization of molten, liquid rock known as magma. Magmas originate deep in the Earth where temperatures and pressures are extremely high. If the magma cools and crystallizes beneath the Earth's surface then the resulting rock is termed intrusive or plutonic. A rock is referred to as extrusive or volcanic if the magma is ejected from a volcano and pours out as a lava on the Earth's surface where it cools and crystallizes.

Igneous rocks dominantly composed of light-coloured felsic, silicate minerals such as quartz, feldspar and muscovite mica, are known as felsic rocks. The felsic minerals dominantly consist of elements such as silicon (Si), aluminum (Al), sodium (Na), calcium (Ca) and potassium (K); therefore, felsic rocks are also rich in these elements. Felsic igneous rocks commonly contain abundant silica. Igneous rocks composed of dark-coloured, mafic, silicate minerals, such as amphibole, pyroxene, biotite mica and olivine, are known as mafic rocks. The mafic minerals contain large amounts of iron (Fe) and magnesium (Mg); therefore, mafic rocks are also rich in these elements. Mafic igneous rocks are generally lacking in silica (quartz).

Most igneous rocks have a crystalline texture consisting of tightly intergrown or "interlocking" mineral crystals. The texture of igneous rocks can range from very large, coarse-grained, mineral crystals to a very fine-grained texture. Some rocks are so fine-grained that it is impossible to identify individual mineral crystals in hand specimens. Mineral crystals in fine-grained igneous rocks are less than 1 mm in size; mineral crystals in medium-grained igneous rocks range in size from 1 mm to 5 mm; and coarse-grained igneous rocks contain mineral crystals that are greater than 5 mm in size.
The size of mineral crystals in igneous rocks is dependent on the length of time it has taken the magma to cool from a liquid to solid state. Intrusive igneous rocks are commonly medium to coarse grained because the rock cools slowly inside the Earth, allowing large mineral crystals an opportunity to form before the magma completely solidifies. Extrusive or volcanic rocks are generally fine-grained because they cool and harden soon after they are extruded onto the Earth's surface. In this case, the liquid magma cools quickly so that mineral crystals have very little time to grow. The magma may also cool instantly and form volcanic glass that contains no mineral crystals.

ii) Sedimentary Rocks

Sedimentary rocks are extremely variable and differ significantly in texture, colour and composition. There are two types of sedimentary rocks: clastic and chemical sedimentary rocks.

Clastic sedimentary rocks are formed by the consolidation of loose rock fragments or clasts and mineral material collectively known as sediment that may accumulate together in layers. This loose sediment is produced by the weathering and erosion of pre-existing rocks by wind, water, heat and ice. The sediment is transported by running water, wind, gravity and glaciers and deposited in topographic depressions or low areas that are commonly filled with water, such as lakes, rivers, oceans and bogs. Mud on the bottom of a lake, sand on a beach, or a gravel bed are examples of unconsolidated sediments deposited in water. After the loose sediments are deposited they are compacted. The compaction process occurs when the weight of overlying sediment compacts the material below it and reduces the amount of open space between fragments. Compaction also "squeezes" out water from the spaces between the fragments and "dries" the sediments out. Finally, the sediments are cemented together to form solid rock. The individual fragments in the sediments are cemented together by dissolved minerals that precipitate out of the water as it is driven off. The precipitated minerals, such as calcite, act like a cement and bond the fragments together. This entire process of compaction and cementation is known as lithification. Most sedimentary material that is deposited in water accumulates in layers. This layering is preserved in sedimentary rocks and is known as bedding. Bedding is commonly horizontal when it is first formed, but becomes tilted, folded or distorted by deformation of the sediments before and/or after they are hardened into rocks.

The bulk of most clastic sedimentary rocks is composed of quartz, calcite, clay and mineral and rock fragments. Clastic sedimentary rocks are mixtures of different sizes of rock and mineral fragments. The largest of the fragments are commonly known as clasts. Finer material that fills spaces between the clasts is known as a matrix. The matrix and clasts are bonded together by the cement that fills tiny cavities between the rock and mineral fragments.

Chemical sedimentary rocks or precipitates are formed by chemical precipitation of minerals from water. Fresh or salt water contains a considerable amount of dissolved minerals. The amount of a mineral that can be dissolved in a given volume of water depends on numerous variables which include temperature, pressure and the amount of other minerals in solution. A change or fluctuation in these conditions may cause the water to lose its ability to keep minerals dissolved. When this change occurs the minerals will "come out of solution" and form crystals. This chemical process is known as precipitation. The mineral crystals settle to the bottom of the body of water and form "chemical" sediments that are eventually compacted and hardened into rock. Water contains abundant, dissolved calcium carbonate (calcite) which commonly precipitates from water and forms limestone. Other examples of chemical sediments are: salt and potash deposits, iron formation and chert. Some chemical sediments can form organically from the accumulation of shells or skeletons of small animals. Many sea animals extract dissolved minerals, such as calcite or silica, from water to form their shells. When
the animals die their shells accumulate to form deposits rich in silica or calcite.

iii) Metamorphic Rocks

Metamorphic rocks are sedimentary, igneous or other metamorphic rocks that have been changed by heat, pressure and/or the chemical action of fluids and gases.

The word *metamorphism* means "change of form", for example, a caterpillar changes or metamorphoses to a butterfly. In rocks, metamorphism causes a change in the constitution of a rock to a more compact and highly crystalline form. An older, pre-existing rock is buried deep in the Earth's crust where it is affected by intense pressure and temperature which increase with depth. There are also hot solutions of dissolved minerals flowing through the rock as it is heated and pressurized. These processes cause new minerals to form in a rock and commonly change its texture and appearance. Most metamorphosed rocks become coarser-grained. Minerals in the rocks may also be segregated into layers. Time is also important in the formation of metamorphic rocks. The longer a rock is exposed to intense heat and pressure the more metamorphosed it will become. It can take millions of years to metamorphose a rock.

Metamorphic rocks may be described as "high-grade" or "low-grade" depending on the degree or intensity of metamorphism. The greater the pressure and/or temperature which affects a rock the higher the metamorphic grade will be. A number of metamorphic minerals, such as garnet, sillimanite and staurolite, form at specific temperatures and pressures, therefore, the presence of such minerals in a metamorphic rock can assist in determining the degree of metamorphism that affected the rock.

III) THE ROCK CYCLE

Igneous, sedimentary and metamorphic rocks are related to one another through the rock cycle (Figure 1). All rocks that form the Earth's crust undergo a slow, continual process of recycling and renewal over a very long period of time. The Earth's crust is in a constant dynamic state and is constantly changing through several geological processes.

Almost all rocks are exposed to the process of erosion and weathering by wind, water, heat and ice. The process of erosion breaks down solid rock into loose particles that are transported and deposited in thick accumulations which are compacted and cemented into sedimentary rocks. The erosion process can reduce high mountain ranges to flat or rolling plains over many millions of years.

Sedimentary rocks may be buried to great depths in the Earth's crust as more material is deposited over them. At these great depths the rocks are changed by intense heat, pressure and chemical solutions into metamorphic rocks. At even greater depths, the rocks are melted and form molten, liquid rock or magma which may cool and crystallize to form igneous rocks. The "new" rocks are eventually exposed to erosion and the cycle started again. The cycle may be interrupted and follow different paths but the constant renewal of older rocks is inevitable. Figure 1 illustrates the rock cycle and the different paths it can follow.

IV) IGNEOUS ROCKS

i) Terms for Plutonic (Intrusive) Rocks

Liquid magma is injected or intruded into pre-existing rocks where it hardens into rock. Specific names are given to these irregular masses or *intrusions* of igneous rock depending on their shape and size. Some of the most common names are listed below and are depicted in Figure 2.

**Batholith** - This is an igneous intrusion which has an exposed surface area of more than 100 square kilometres (Faulkner 1986). Many batholiths are believed to be funnel-shaped in cross-section and have an irregular, circular shape in plan view. Examples of batholiths are the large intrusive bodies of granite at the margins of greenstone belts. **Pluton** is another term for a large igneous intrusion.
Figure 1: The Rock Cycle
Figure 2: Types of Igneous Intrusions
Stock - An intrusion with an exposed surface area less than 100 square kilometres (Faulkner 1986). Stocks have an irregular, rounded or oval shape in plan-view and may be long and cylindrical in cross-section.

Plug - A small, circular or oval-shaped, pipe-like intrusion formed in the "neck" or central vent of a volcano.

Dike - A tabular, sheet or slab-like intrusive body that cuts across the bedding or layering of the rocks it has intruded.

Sill - A tabular, sheet or slab-like body, which is parallel to the layering of the rocks, it has intruded. Sills and dikes are commonly intruded along weaknesses, such as fractures and faults, in pre-existing rocks.

ii) Identification of Plutonic (Intrusive) Rocks

The identification of igneous intrusive rocks is largely dependent on their mineral content. The amount of quartz; the type and amount of feldspar; and the quantity of dark-coloured, mafic minerals are criteria that can be used when identifying intrusive rocks. Determining the type of feldspar (i.e.: orthoclase vs. plagioclase) in a rock assists in further classifying and identifying an intrusive rock, but it is something prospectors don't really have to concern themselves with. However, a prospector should attempt to visually determine the amount of quartz in a rock. A rock with abundant quartz is probably felsic. A rock with very little visible quartz may be mafic. A prospector should also be able to determine the mafic mineral content of a rock to distinguish between mafic and felsic rock types.

The colour of igneous intrusive rocks is dependent on the proportion of light minerals to dark minerals; therefore, the colour of a rock commonly reflects its mineral composition. A felsic rock which contains few mafic minerals is commonly buff-white, light grey or pink. A mafic rock containing abundant mafic minerals is dark grey, green or black.

The following criteria apply when determining whether a rock is mafic or felsic:

- **felsic** rocks contain less than 15% mafic minerals and are light-coloured.
- **intermediate** rocks contain between 15% and 35% mafic minerals and are medium grey or green in overall colour.
- **mafic** rocks contain greater than 35% mafic minerals and are dark grey to very dark grey or green.

Rocks known as ultramafic are commonly composed of only mafic minerals and are very dark grey, brown, black or green. Figure 3 is a comparison chart that can be used to assist you in estimating percentages of mafic minerals in a rock.

The hardness of igneous intrusive rocks also assists in their identification. Mafic rocks are relatively soft, easy to scratch and break easily when struck with a rock hammer. Ultramafic rocks are generally very soft and may contain talc or asbestos minerals. Felsic rocks are quartz-rich and are very hard; difficult to scratch; and very difficult to break with a hammer.

The specific gravity of igneous rocks can be used to distinguish mafic rocks from felsic rocks. Mafic rocks contain abundant iron and magnesium and have a higher specific gravity than felsic rocks that contain light elements such as aluminum and silicon. Specific gravity can be estimated by holding a hand-sized specimen of each rock type and comparing their weights. Mafic rocks are heavier than felsic rocks.

The texture of igneous rocks only varies with respect to grain size. An intrusive igneous rock has not been subjected to metamorphic processes; therefore, it has a consistent, even texture with none of the mineral alignments or segregations that result from metamorphism. Igneous rocks have a distinctive, massive, crystalline texture where different mineral crystals have grown together and appear to "interlock" with each other. Igneous rocks which are part of large intrusive bodies, such as batholiths, plutons and stocks are generally medium- to coarse-grained. Fine-grained
Figure 3: Comparison Chart for Estimating Mineral Percentages
(from A.G.I. Data Sheets, 1982)
intrusive rocks occur in smaller intrusive bodies, such as plugs, dikes or sills, where the liquid magma has cooled and solidified very quickly. Table 1 is a simplified system of classification that can be used to identify some of the more common igneous rocks by colour, grain size and quartz content.

A prospector should be able to identify the most common intrusive rock types and igneous textures and be able to distinguish between mafic and felsic intrusive rocks. Definitions and descriptions of the most common intrusive rocks are listed below.

**Granite** - This is the most common, intrusive, felsic rock which forms large batholiths, smaller plutons and stocks. It is composed of mostly potash feldspar (orthoclase) with abundant, easily visible quartz and minor mica and/or hornblende (amphibole). Granites are commonly medium- to coarse-grained and pale pink, pale grey, white or pale pinkish-brown. A prospector should be able to recognize granite, but doesn't have to know all the different types of granites which are based on relative proportions of quartz, orthoclase and plagioclase feldspar.

**Diorite** - This is a common, medium- to coarse-grained, grey or greenish, intrusive rock. It contains about half dark and half light minerals with little or no quartz. It consists of plagioclase feldspar, hornblende and biotite mica.

**Granodiorite or quartz diorites** are members of the diorite family of rocks and are igneous rocks that have a composition between granite and diorite.

**Syenite** - Resembles granite but contains mainly potash feldspar (orthoclase) with very little or no quartz. Syenite may contain hornblende or biotite mica. Syenite is commonly medium- to coarse-grained, pale brown to pinkish brown, orange or red. Syenite is part of a group of rocks, known as **alkalic igneous rocks**, that are typically rich in potash feldspar and depleted in silica.

**Carbonatite** - This is an unusual type of igneous rock which consists of carbonate minerals, such as calcite, ankerite and dolomite. It is soft (hardness of 3), light-coloured and forms roughly circular intrusions. Carbonatites are relatively rare and commonly associated with alkalic igneous rocks, such as syenite.

**Gabbro** - This is one of the most common, mafic, intrusive rocks. It is medium- to coarse-grained, dark grey to very dark greyish-green and contains very little or no quartz. It is mainly composed of pyroxene and plagioclase feldspar with minor biotite mica, olivine, magnetite, ilmenite or pyrrhotite. Some gabbros can be weakly to moderately magnetic.

**Diabase** - Diabase appears much like gabbro but is commonly fine- to medium-grained and dark grey or green. It is essentially composed of plagioclase feldspar and pyroxene. Plagioclase occurs as randomly oriented, lath-shaped crystals. Diabase is very massive, hard and commonly magnetic. It weathers to a distinctive orange-brown on rounded, "hump-like" outcrop surfaces and commonly occurs in large dikes or sills.

**Ultramafic Rocks** - These rocks are composed of mafic minerals and are less common than most intrusive rocks. Ultramafic rocks are commonly medium- to coarse-grained and dark green or brown. Some common ultramafic rocks are: **dunite** composed of 90% olivine; **peridotite** composed of abundant olivine and minor pyroxene and **pyroxenite** composed almost entirely of pyroxene. Ultramafic rocks are commonly very soft and easily altered to talc, serpentinite, soapstone and asbestos minerals.

**Porphyry** - A porphyry is any igneous rock that contains large mineral crystals, called **phenocrysts**, embedded in a very fine-grained **groundmass** or **matrix**. The large mineral crystals appear to “float” in the groundmass. This feature is known as a **porphyritic texture**. The phenocrysts can consist of any mineral, such as feldspar, quartz, hornblende, pyroxene, etc. Therefore, “quartz-feldspar porphyry” is an igneous rock containing quartz and feldspar phenocrysts.
### Table 1: Simplified Classification for Igneous Rocks

<table>
<thead>
<tr>
<th>Origin and Texture</th>
<th>Composition</th>
<th>Felsic</th>
<th>Intermediate</th>
<th>Mafic</th>
<th>Ultramafic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plutonic (Intrusive)</td>
<td>Coarse-grained</td>
<td>Granite</td>
<td>Diorite</td>
<td>Gabbro</td>
<td>Peridotite</td>
</tr>
<tr>
<td>Volcanic (Extrusive)</td>
<td>Fine-grained</td>
<td>Rhyolite</td>
<td>Andesite</td>
<td>Basalt</td>
<td>Olivine Basalt</td>
</tr>
</tbody>
</table>

- **<15%** INCREASING DARK MAFIC MINERALS **>90%**
- **INCREASING LIGHT FELSIC MINERALS AND QUARTZ**
**Pegmatite**- Pegmatites are extremely coarse-grained intrusive rocks where all the minerals in the rock consist of very large crystals. Mineral crystals are generally greater than 1 cm in size, but may range up to 1 m or more. Pegmatites can be mafic, felsic or alkalic and commonly occur as dikes or sills. The felsic varieties are composed of quartz, feldspar and mica and are pink to white. Mafic varieties contain feldspar, mica, pyroxene and/or amphibole and are grey or green. Pegmatites are known to host economic rare element minerals.

**Felsite**- A Felsite is a very fine-grained, felsic, intrusive rock. It is so fine-grained that individual mineral crystals are difficult to identify with a hand lens. Felsite commonly occurs in narrow dikes and sills.

**iii) Terms for Volcanic (Extrusive) Rocks**

**Extrusive** rocks are formed from liquid magma which is poured out on the Earth's surface as flat sheets known as lava flows. Extrusive rocks can also form thick accumulations of ash and rock fragments called pyroclastics.

**a) Mafic Volcanic Rocks**

Mafic magmas are iron- and magnesium-rich; have a low viscosity; and behave like a very runny liquid. The mafic magma pours from the volcano in large, thin, lava flows which may cover hundreds of square kilometers. The flows accumulate in layers, with each successive eruption and may form sequences that are several kilometers thick. The mafic magma and gases escape from the volcano easily and result in relatively peaceful eruptions. Mafic volcanism presently occurs on the Hawaiian Islands which are a group of dormant and active volcanoes.

The most common mafic volcanic rock is basalt, which comprises the majority of volcanic rocks in Ontario's greenstone belts. Basalt is the extrusive equivalent of a gabbro which is an intrusive igneous rock. Therefore, basalt and gabbro are composed of the same minerals: pyroxene and plagioclase feldspar with minor biotite mica and very little or no quartz. Basalt is a fine-grained, very dark grey or greenish-grey rock, which commonly forms lava flows. Below are some descriptions of common structures found in basalts.

**Pillows**- Pillows are structures formed in mafic lava flows which have been extruded under water. Pillows are discontinuous, pillow-shaped masses that range in size from a few centimetres to several metres. Pillows are separated from each other by thin, dark rims or selvages that may be a few centimetres wide. Pillows are close fitting with very few spaces between them. The concave rim of one pillow matches or fits the convex rim of another pillow (Figure 4).

Pillows are formed as a mafic lava which is commonly extruded underwater. The lava forms large tubes and irregular masses and lumps. The surfaces of these lumps cools instantly into glass which forms the rims or selvages around the pillows. The pillows have solid glassy rims but are semi-molten in the middle, therefore, the pillows on top of a lava flow sag over the pillows at the bottom of the flow (Figure 5).

In outcrops, pillows appear as close-fitting, irregular shapes with dark green or black rims (selvages). Grain size in a pillow decreases from the centre to the rim, because the centre cooled more slowly that the outside part of the pillow. Gas holes (vesicles) commonly occur along the rims of the pillows.

**Vesicles and Amygdules**- Gas escapes from a cooling lava as it is extruded onto the Earth's surface. The escaping gas forms bubbles and gas holes in the molten rock. When the lava hardens to rock it is left with round or irregular-shaped gas holes called vesicles. If the vesicles are subsequently filled with secondary minerals such as calcite or quartz, then they are known as amygdules.

**Porphyritic basalts**- Porphyritic basalt exhibits a porphyritic texture similar to that in intrusive igneous rocks. The basalts contain large, white feldspar crystals (phenocrysts) which appear to "float" in the fine-grained rock.
Figure 4: Features of Mafic Pillow Structures

Figure 5: Form of a Pillowed Mafic Lava Flow
Ultramafic rocks may also form lava flows that are relatively rare compared to basalts. Ultramafic lava flows are referred to as komatitites and may contain all of the features found in basalts. A distinctive but rare feature found in komatitites is spinifex texture formed by long, bladed olivine crystals that radiate in a characteristic fan-like appearance. Ultramafic rocks are darker coloured than basalts; they are very soft; and are easily altered to talc, serpentine or soapstone.

b) Felsic Volcanic Rocks

Felsic magmas are silica- or quartz-rich; have a very high viscosity; and behave like a very thick liquid. The magma forms small, thick, lumpy, lava flows which cover a relatively small area. The most familiar felsic volcanic rock is rhyolite which is the extrusive equivalent of granite. Rhyolite is composed of feldspar and quartz and is extremely fine-grained and glassy with little or no crystalline texture. Rhyolite is extremely hard and may be buff white, pink, grey or pale green. A common feature found in rhyolite flows is flow banding which appears as long, irregular, wavy streaks or bands in the rock. Flow banding is caused by movement of the felsic lava flow as it cooled. Other features such as vesicles may also occur in rhyolites. Pillow structures are not commonly found in felsic flows due to the fact that most felsic magmas are too viscous or thick to form pillows.

Other extrusive rock types which are intermediate in composition between a felsic rhyolite and a mafic basalt are dacite and andesite. Dacite is the extrusive equivalent of a granodiorite and is a fine-grained and medium grey. Andesite is the extrusive equivalent of a diorite and is the plagioclase feldspar-rich rock containing minor biotite. Andesite is also fine-grained and medium grey or green.

Pyroclastic rocks are formed by the explosive fragmentation deposition and accumulation of volcanic rock fragments. The word "pyroclastic" is derived from Latin and means "fire" (pyro-) "rock" (clastic). Pyroclastic rocks form when magma and gases escape forcefully from a volcano and produce violent eruptions which eject rock fragments and ash for thousands of metres or kilometers from the volcanic vent. Recent examples of such events are: the eruption of Mt. St. Helens in Washington in 1980 and the eruption of Mt. Pinatubo in the Philippines in 1991. Violent eruptions commonly occur from volcanoes that eject felsic, silica-rich magma. The felsic magma is very thick and tends to solidify near the surface, forming domes and plugs that seal off channels and fissures through which the magma rises. This blocking prevents the escape of gases and magma and turns the volcano into a giant pressure cooker. An eruption results when the surrounding rock is no longer able to hold the pressure of the expanding magma. Rock fragments and ash are ejected into the air and fall to earth to form thick accumulations of pyroclastic rocks or tuffs. Huge, blocky or angular fragments accumulate near the volcanic vent while smaller fragments and ash accumulate further away from the vent.

Pyroclastic rocks are classified according to the shape, size and composition of the rock fragments. A rock fragment greater than 64 mm in size is called a block if it is angular in shape or a bomb if it is has a rounded shape. Fragments which range in size from 2 mm to 64 mm are called lapilli; fragments less than 2 mm in size are called ash. The term tuff is used to describe fine-grained, pyroclastic rocks dominantly composed of ash-sized rock fragments. A lapilli tuff is a pyroclastic rock composed dominantly of rock fragments ranging in size between 2 mm and 64 mm. A pyroclastic breccia and tuff breccia are pyroclastic rock types containing abundant, coarse, rock fragments greater than 64 mm in size. The term "breccia" applies to rocks which mainly consist of angular rock fragments.

These are only a few of the terms prospectors will encounter when reading geological maps and reports. The terminology for pyroclastic rocks alone can be very overwhelming and confusing. A prospector doesn’t need to know all the terms but should be familiar with terms that apply to coarse-grained and fine-grained pyroclastic rocks.
A problem with some pyroclastic rocks is that they can be confused with sedimentary rocks, especially if the pyroclastic rocks have been deposited in water. Pyroclastic rocks exhibit many features found in sedimentary rocks, for example, they are composed of rock and mineral fragments that are compacted together. They consist of rock clasts embedded in a fine-grained matrix and they may contain layering or bedding. This problem is discussed further in the section on sedimentary rocks.

iv) Identification of Volcanic (Extrusive) Rocks

The same criteria used to identify igneous intrusive rocks can be used to identify igneous extrusive or volcanic rocks. Almost all volcanic rocks are fine-grained; therefore, it is difficult to identify the minerals which compose the rock. Such criteria as the colour of the rock, hardness, and specific gravity, assist in determining if the rock is mafic (basalt), intermediate (dacite or andesite) or felsic (rhyolite) in composition. Table 1 is a simplified system of classification that can be used to identify common volcanic igneous rocks. Below is a list of field criteria that can be used to distinguish between felsic and mafic volcanic rocks:

1) The presence of grains of quartz suggests that the rock is felsic in composition.

2) Felsic volcanics are lighter in colour than mafic volcanic rocks. However, very dark or black rhyolites do exist, as well as pale green or white basalts. A small amount of dark green chlorite minerals can significantly darken the colour of a felsic rock.

3) Felsic volcanic rocks are very hard and may have a conchoidal fracture. Mafic volcanics are softer than felsic volcanic rocks and break easily when struck with a hammer.

4) Felsic volcanic rocks have a lower specific gravity or density than mafic volcanic rocks.

5) Felsic volcanic rocks may have a high pitch ring when hit with a hammer.

6) Felsic volcanic rocks weather to sharp angular blocks. Mafic rocks weather to rounded edges.

7) Pyroclastic rocks are more likely to be felsic or intermediate in composition.

8) Pillowed volcanics are more likely to be mafic in composition.

Some questions to ask yourself when you are identifying igneous rocks are:

1) What is the overall grain size of the rock? An intrusive rock is commonly medium to coarse-grained and has a crystalline texture, while extrusive rocks are fine-grained and may not have a crystalline texture.

2) What is the overall colour of the rock? What is the mafic mineral content and quartz content? A light-coloured rock containing free, visible quartz and few, mafic (dark) minerals is probably felsic in composition. A dark-coloured rock containing little or no quartz and abundant mafic minerals is probably mafic.

3) How hard is the rock? How heavy is the rock? A very hard rock may be felsic and a heavy rock may be mafic.

4) What does the weathered surface of the outcrop look like? After you have studied the rock specimen, have a complete look at the outcrop for any surface features that may help you identify the rock. For example, if you recognize pillow structures then you’re probably looking at mafic volcanic rocks.

V) SEDIMENTARY ROCKS

i) Clastic Sedimentary Rocks

The majority of clastic sedimentary rocks are relatively easy to identify. They are composed of rock fragments or clasts set in a fine-grained matrix and bonded together by cement. Rock and mineral particles in sedimentary rocks commonly show evidence of wear and rounding and are cemented together. Sedimentary rocks do not have a crystalline texture like igneous rocks and are...
not massive or consistent in texture.

**Clastic sedimentary rocks** are formed from loose sediments deposited in water and commonly display sedimentary structures associated with water lain sediments. These structures are formed as the sediments are deposited and are preserved when the sediments are hardened into rocks. Some of the most common sedimentary structures are described below.

**Bedding** - This feature has been discussed previously. Bedding is formed as layers of sediments are accumulated on top of each other. Bedding is caused by changes in the settling of particles in water; by changes in the type and amount of sediment that is deposited; and by differences in colour of the sediments.

**Cross-bedding** - These are fine laminations that occur at an angle to the bedding.

**Graded Bedding** - This results from the sorting of material in individual beds with coarse sediment at the base of the bed and fine material at the top.

**Ripple Marks** - Ripple marks are preserved on the tops of beds that are buried by other sediments.

**Mud Cracks** - Bedding surfaces of shaly sedimentary rocks may have mud crack patterns that were formed when the clay was drying on an exposed mud flat.

**Flame Structures and Ball-and-Pillow Structures** - These structures are formed when beds of sediments are deformed into adjacent layers. Flame-like structures are formed when material is squeezed upwards into overlying beds of sediments. Ball-and-pillow structures occur when rounded masses of sediment sag down into underlying layers.

One of the easiest methods of recognizing the different clastic sedimentary rocks is by determining the size of the rock and mineral fragments in the rocks. A **fine-grained** sedimentary rock is composed of particles that are too small to identify with the unaided eye and are less than 1/16 mm in size (silt size). A **medium-grained** sedimentary rock contains particles that are 1/16 mm to 2 mm in size (sand size). **Coarse-grained** sedimentary rocks contain particles greater than 2 mm in size and are easily seen with the unaided eye. A **coarse-grained gravel** contains particles between 19 mm and 76 mm in size (Bates and Jackson 1987). There are various other size ranges for coarse-grained sands and silts as well. **Table 2** illustrates a simple classification scheme for clastic sedimentary rocks. Below are descriptions of the common clastic sedimentary rocks classified according to grain size.

**Conglomerate** - The coarsest grained sedimentary rock is conglomerate, which is formed by the cementing together of a mixture of various types of rounded rock fragments. Conglomerate is gravel cemented into a rock. Rock fragments in a conglomerate range in size from sand-size particles to boulders therefore they are poorly sorted. Conglomerates may have very thick beds or no bedding at all. The coarse material that forms conglomerate is commonly transported and deposited by fast moving water or ice that can move heavy material very quickly.

**Sandstone** - Fairly pure sand composed almost entirely of cemented quartz grains forms sandstone that is also referred to as arenite. Most sandstones are hard and well bedded. Rounded grains of quartz: should be visible with or without a hand lens. Sandstones are generally grey to white or brown but impurities can give a wide variety of colours, such as pink, red, yellow or green. A sandstone that is rich in feldspar, rather than quartz, is known as an **arkose**.

**Greywacke** - A "dirty" or "muddy" sandstone containing large amounts of other minerals besides quartz, such as feldspar, mica, amphibole or pyroxene. A greywacke also contains abundant sand-sized rock fragments. Greywacke is grey, green or brown and may be massive and poorly bedded although bedding is commonly present. Greywacke contains poorly sorted sand-sized mineral and rock fragments in a very fine-grained, muddy, matrix.
Table 2: Simplified Classification for Clastic Sedimentary Rocks

<table>
<thead>
<tr>
<th>Texture</th>
<th>Composition</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>COARSE GRAINED (over 2mm)</td>
<td>Rounded fragments of any rock type</td>
<td>CONGLOMERATE</td>
</tr>
<tr>
<td></td>
<td>Angular fragments of any rock type</td>
<td>BRECCIA</td>
</tr>
<tr>
<td>MEDIUM GRAINED (1/16 mm to 2 mm)</td>
<td>Quartz grains</td>
<td>SANDSTONE (ARENITE)</td>
</tr>
<tr>
<td></td>
<td>Quartz with at least 25% feldspar grains</td>
<td>ARKOSE</td>
</tr>
<tr>
<td></td>
<td>Quartz, rock fragments and abundant clay</td>
<td>GRAYWACKE</td>
</tr>
<tr>
<td>FINE GRAINED (1/256 mm to 1/16 mm)</td>
<td>Quartz and clay</td>
<td>SHALE</td>
</tr>
<tr>
<td>VERY FINE GRAINED (less than 1/256 mm)</td>
<td>Quartz and clay</td>
<td>SILTSTONE</td>
</tr>
</tbody>
</table>
Shale- When very fine-grained sediments, such as mud or clay, are hardened into rock they form shale. Shale is very thinly bedded, soft, brittle and may be black, brown, red, grey or green. Shale commonly breaks into small plates that can be broken between two fingers. The mineral grains in shale are clay-sized and generally too small to be identified with the naked eye or hand lens. Siltstone is a fine-grained shale.

ii) Chemical Sedimentary Rocks

Chemical sedimentary rocks consist of minerals, such as salt, gypsum, calcite, dolomite, silica and iron which precipitate out of water. The water in which they are deposited is very calm and undisturbed; therefore, the minerals accumulate in very fine layers and laminations at the bottom of a body of water.

Chemical sedimentary rocks are relatively easy to identify. They are composed of only one or two minerals and may be very thinly bedded or laminated. Chemical sedimentary rocks, such as iron formation, can form in long, continuous layers that can be followed for a length of several hundred metres or several kilometres. Below are descriptions of the most common chemical sedimentary rocks.

Limestone—Limestone is composed almost entirely of calcite with some impurities. Limestone can be scratched easily with a knife (hardness of 3) and fizzes or effervesces freely with dilute hydrochloric acid. Limestones are white, buff white, grey or brown. Limestone weatheres into rough, knobby, outcrop surfaces that will stained rusty-orange if the calcite contains iron impurities. Limestone that contains fossils is referred to as fossiliferous limestone, coquina or chalk. Banded calcite is known as travertine.

Dolomite (Dolostone)—Dolomite is a rock that has the same name as the main mineral in the rock. Dolomite is very similar to limestone but can be distinguished with an acid test. Dolomites do not fizz in acid as much as limestone and may only fizz if scratched or powdered. Dolomite may be coarser grained than limestone and is more massive and thickly bedded. Dolomite is white, grey or buff white and may weather to orange-brown with rough outcrop surfaces.

Chert—Chert is composed of extremely fine-grained silica (quartz) which is commonly dull-grey or grey-brown, but may also have a highly variable colour. Chert is very hard with a conchoidal fracture and is dull and resinous in appearance. Chert forms relatively thin beds that are finely laminated.

Iron Formation (Ironstone)—Iron formation is dominantly composed of iron minerals and quartz. The quartz occurs as thin layers of chert or jasper (red chert) which alternate with layers of iron minerals. The iron minerals in an iron formation may consist of iron oxides (magnetite, hematite), iron carbonate (siderite) or iron sulphides (pyrite, pyrrhotite). Iron formation may be extremely magnetic.

iii) Identification of Sedimentary Rocks

The first thing to do when identifying sedimentary rocks is to distinguish between clastic and chemical sedimentary rocks. A sedimentary rock is clastic if it is composed of rock and mineral fragments that are cemented together. The fragments should also show evidence of wear and rounding. The clastic sedimentary rock can be further classified by determining its grain size.

If the rock is fine-grained, then attempt to identify it on the basis of composition. If the rock is dominantly composed of only one mineral then it is probably a chemical sedimentary rock. Try to determine if the chemical sediment is composed of salt, gypsum, calcite, dolomite, and quartz or iron minerals.

Shale and siltstone are very fine-grained, clastic sedimentary rocks that appear as if they are composed of only one mineral. Shale and siltstone are composed of mud or clay hardened into rock and that is exactly what they look like.

It may be difficult to distinguish volcanic
pyroclastic rocks from clastic sedimentary rocks because both types are composed of rock fragments. Pyroclastic rocks may be deposited in water and can display features commonly associated with sedimentary rocks. Below is a list of general criteria that can help a prospector distinguish between the two rock types:

1) Most pyroclastic rocks contain angular fragments that show few signs of wear or rounding.

2) Pyroclastic rocks are composed of volcanic rock fragments that tend to be felsic or intermediate in composition. Clastic sedimentary rocks contain a mixture of rock fragments with a great variety of compositions consisting of intrusive igneous rocks, volcanic rock types, metamorphic rock types and fragments of other sedimentary rocks.

3) Clastic sedimentary rocks are generally well bedded while pyroclastic rocks commonly have poorly developed bedding.

VI) METAMORPHIC ROCKS

Metamorphic rocks are sedimentary, igneous or other metamorphic rocks that have been changed by heat, pressure and chemical reactions with fluids and gases. The texture and composition of the original rock are changed during metamorphism. The effects of metamorphism can form new crystalline structures in a rock; cause the formation of new minerals; and produce a coarsening of texture and layering of minerals. Recrystallization of a rock may also produce a dense, coarse-grained, crystalline or massive texture with no layering or mineral segregation.

Metamorphism also causes recrystallization and mineral layering that results from flattening and segregation of the minerals. This layering or preferred orientation of minerals is called foliation. The development of a foliation begins microscopically as mineral crystals grow and align themselves in layers. As metamorphism continues the minerals grow larger and segregate into distinct bands. The coarseness of the foliation or layering can vary. A rock with a well-developed foliation breaks easily along the foliation into flat slabs. A very well foliated rock is termed schist and a rock with well developed mineral banding is termed gneiss.

The mineralogy of the original rock changes during metamorphism so that "new" minerals are formed in the rock. Some new minerals will form coarse-grained, well developed crystals, while the rest of the rock remains fine-grained. These new large mineral crystals are termed porphyroblasts. Porphyroblasts commonly grow over pre-existing textures, such as layering, that were in the rock before it was metamorphosed. Garnet is a common metamorphic mineral that forms as porphyroblasts in iron-rich, sedimentary and volcanic rocks.

i) Types of Metamorphic Rocks

Massive, recrystallized metamorphic rocks are classified according to their compositions. Other metamorphic rock types are classified according to the degree of foliation in the rock. Below is a list of some massive, recrystallized, metamorphic rock types that are classified according to their compositions.

Quartzite- A metamorphosed sandstone with original quartz grains that are interlocking or intergrown due to recrystallization under heat and pressure. Quartzites are very hard, massive and no longer contain rounded sand grains. Quartzite is pale grey, or white; coloured bands or layers may indicate original bedding.

Marble- Marble is grey to white, recrystallized limestone or dolomite. It consists of medium- to coarse-grained interlocking calcite crystals and fizzes in dilute hydrochloric acid. Any bedding in the original limestone is destroyed by recrystallization of the calcite.

Amphibolite- An amphibolite is a metamorphosed, recrystallized mafic rock that is dominantly composed of amphibole minerals such as hornblende. The rock is hard, green to black, medium- to coarse-grained and dominantly consists of intergrown amphibole crystals.
**Hornfels** - A hornfels is formed when rocks are metamorphosed by intense heat in a zone of low pressure. This process is called contact metamorphism because it occurs near the margins or contacts of large igneous intrusions. When fine-grained sedimentary and/or volcanic rocks are metamorphosed to hornfels they become very hard fine-grained, massive, grey to very dark grey and may be variably magnetic. Hornfels is unusually tough and gives a sharp ring when struck with a hammer. Hornfels also has a splintery fracture and may contain sulphide minerals, such as pyrite or pyrrhotite.

Other metamorphosed rock types are classified according to the degree of foliation in the rock. The rock name is commonly derived from the term which describes the type of foliation. These rock types are listed below.

**Slate** - Slate is a very fine-grained (microscopic grains), hard rock derived from the metamorphism of clay or shale by intense heat and/or pressure. Slate is commonly black but may be grey, red or green. Slate has a well-developed foliation termed slaty cleavage and breaks into thin slabs or sheets with smooth, dull, surfaces. The rock breaks into slabs along the cleavage which is at an angle to the original bedding. Bedding may be visible as faint bands or layers.

**Phyllite** - Almost all mineral grains in a phyllite are microscopic. Cleavage surfaces have a bright "sheen" caused by reflections from platy or linear minerals, such as mica or amphibole. The cleavage surface is commonly corrugated with smooth ridges.

**Schist** - A fine-grained (mineral grains can be seen without a hand lens), metamorphosed rock composed of flaky, platy, highly cleavable minerals, such as mica, which are aligned in roughly parallel layers. This alignment of minerals defines a well-developed foliation known as a schistosity. A schist will break into irregular, thick slabs with rougher surfaces than slate. Schist has no specific composition and is named after a conspicuous mineral in the rock, such as mica schist or chlorite schist.

**Gneiss** - A gneiss is a medium-grained, highly metamorphosed rock that is colour banded and composed of light and dark layers of minerals. All of the light-coloured, granular minerals such as quartz and feldspar segregate together into the light-coloured layers. The dark-coloured, schistose, linear or platy minerals, such as biotite mica, amphibole and pyroxene segregate into the dark layers. The coloured mineral layering in a gneiss is commonly wavy and discontinuous. This characteristic layering defines a coarse foliation which is known as a gneissosity. A gneiss may fracture and break unevenly due to the coarseness of the foliation. A gneiss does not have a specific composition and may be named after a conspicuous mineral in the rock, such as hornblende gneiss or biotite gneiss.

**Migmatite** - A gneissic rock containing discontinuous banding with injected layers of granitic rock.

**ii) Identification of Metamorphic Rocks**

The best way to identify metamorphic rocks is to try and determine their composition, their grain size and the type of foliation they exhibit. **Table 3** illustrates a simple chart you can use to assist in identifying metamorphosed rocks. Below is a list of criteria that can be used to identify a metamorphic rock and to distinguish between different metamorphic rock types:

1) Determine if the rock contains porphyroblastic minerals, such as garnet, that appear to have grown in the rock.

2) Determine if the rock exhibits characteristic textures found in metamorphic rocks. Is the rock massive and recrystallized or does it have a foliation such as slaty cleavage, schistosity or gneissosity?

3) Test how easily the rock breaks along its foliation. If it has an uneven fracture it may be a massive, recrystallized rock. If it has mineral layering and an uneven fracture it may be a gneiss. If it breaks into regular slabs it may be a schist or slate.
### Table 3: Simplified Classification for Metamorphic Rocks

#### I. FOLIATED

<table>
<thead>
<tr>
<th>Texture</th>
<th>Composition</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-layered Very Fine Grained Chlorite</td>
<td></td>
<td>SLATE</td>
</tr>
<tr>
<td>Non-layered Fine Grained Mica</td>
<td></td>
<td>PHYLLITE</td>
</tr>
<tr>
<td>Non-layered Coarse Grained Quartz</td>
<td></td>
<td>SCHIST</td>
</tr>
<tr>
<td>Layered Coarse Grained Feldspar Amphiboles Pyroxene</td>
<td></td>
<td>GNEISS</td>
</tr>
</tbody>
</table>

#### II. NONFOLIATED/MASSIVE

<table>
<thead>
<tr>
<th>Texture</th>
<th>Composition</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Grained Silicate Minerals Iron Oxides and some Sulphides</td>
<td></td>
<td>HORNFELS</td>
</tr>
<tr>
<td>Fine to Coarse Grained Amphibole</td>
<td></td>
<td>AMPHIBOLITE</td>
</tr>
<tr>
<td>Fine to Coarse Grained Quartz</td>
<td></td>
<td>QUARTZITE</td>
</tr>
<tr>
<td>Fine to Coarse Grained Calcite or Dolomite</td>
<td></td>
<td>MARBLE</td>
</tr>
</tbody>
</table>
4) Determine the grain size in the rock. Schists, slates, phyllites and hornfels are commonly fine-grained to very fine-grained, while amphibolite and gneiss are medium- to coarse-grained.

If the rock is medium-grained; contains mineral layering; and breaks irregularly; then it may be a gneiss. If the rock is fine-grained with visible minerals that are not layered; and breaks easily along foliation planes with rough surfaces; then it is probably a schist. If the rock is very fine-grained; and breaks easily along foliation planes with smooth, dull surfaces; then it may be a slate.

Recrystallized rocks, such as marble and quartzite, can be identified by their composition since they are composed of only one mineral. Marble, quartzite, amphibolite and hornfels can also be recognized by their massive recrystallized texture, lack of foliation and uneven fracture.

VII) TIPS FOR IDENTIFYING ROCKS

A good way to familiarize yourself with rocks in your area is to obtain a geological map of the area.

A geological map identifies different rock types and outlines their surficial extent. A prospector can use the map to locate and check different rock types and become familiar with their appearance and features. Try to recognize a rock as igneous, sedimentary or metamorphic and identify the features that make them different. Learn the minerals you would expect to find in the different rock groups. Collect samples of different rock types in your area and study them until you know them. Bring samples of rocks that you are unsure of to the Resident Geologist’s office for identification.

Remember to carefully inspect the hand specimen of a rock with a hand lens and have a complete look at the outcrop surface that the hand specimen came from. Try to identify any surficial features on the rock surface that may help you identify the rock. Making careful observations and descriptions of a rock is more important than coming up with the correct rock name.

Be consistent in your observations and descriptions of rocks. Give the same name to rocks that share similar features, compositions and distinguishing characteristics. Try to consistently recognize a specific rock type in the field every time you see it.
PART 4:

TECTONICS
TECTONICS

I) GEOLOGICAL TIME

Sedimentary and igneous rocks that underlie an area occur in the order of their ages of deposition or intrusion and form a geological succession. Older rocks are situated at the bottom of the succession because they were deposited first and younger rocks are located at the top because they were deposited last.

The documentation of geological successions in various parts of the world has led to the development of a geological time scale (Figure 1). The study of fossils and various methods of age-dating have allowed geologists to divide geologic time into definite intervals or time periods of great duration, beginning when the Earth was first formed to the present day. Each time period is marked by a specific, significant event, such as the appearance of fishes; the appearance and extinction of dinosaurs; and the first appearance of mammals.

The first and oldest time interval is the Precambrian which lasted more than five-sixths or 88% of the entire span of geological time (Figure 1 and 2). The Precambrian started at least 4.6 billion years ago, when the Earth first formed and ended 570 million years ago. The Precambrian encompasses a time when much of the Earth's crust was developed.

Precambrian time is divided into two eons: the older Early Precambrian or Archean Eon (4.5 to 2.5 billion years) and the younger Late Precambrian or Proterozoic Eon (2.5 billion years to 570 million years) (Figure 1). Precambrian rocks occupy more than two-thirds of the surface area of Ontario and have had a complex history of igneous intrusion, volcanism, sedimentation, mountain building, faulting, burial, uplift, weathering, erosion and metamorphism. The majority of Ontario's metallic mineral deposits were formed during Precambrian time.

The period of time that started 570 million years ago, when the Precambrian ended, is called the Phanerozoic Eon. The Phanerozoic Eon encompasses the last 12% of geologic time (Figure 1 and 2). Extensive sedimentation occurred during the Phanerozoic Eon, as well as the development of life forms from simple algae to dinosaurs and mammals. During the Phanerozoic, dinosaurs evolved and became extinct; several periods of glaciation occurred; mammals and modern plants developed; and man appeared about 2 million years ago (Figure 2).

Man has been on the Earth for a relatively insignificant amount of time. If you think of geological time represented by the face of a clock and watched it from noon (beginning of time) until midnight (present day) then man would not appear until a half second before midnight. Figure 2 illustrates this example and also demonstrates the relative duration of Precambrian and Phanerozoic time.

II) THE PRECAMBRIAN: THE CANADIAN SHIELD

The Canadian Shield encompasses about half of Canada and is composed of rocks that are Precambrian in age. The Canadian Shield wraps around Hudson Bay and encompasses almost all of Ontario, Quebec most of the Northwest Territories and some of the Arctic Islands (Figure 3). The Shield also extends into the United States where it covers a large area south of Lake Superior. The Shield region consists of rugged, rocky, terrain that forms the foundation of Ontario. The Shield is one of the largest and greatest sources of metals in Canada. The world-class mineral resources of the Shield have made a major contribution to Canada and Ontario's economic wealth.

i) Structural Provinces

The Canadian Shield consists of plutonic, volcanic and sedimentary rocks which were formed at various times during the Precambrian. Volcanism, for example, was very active during the Late Precambrian or Archean Eon and extensive sedimentation and igneous intrusion occurred during the
### Figure 1: Simplified Geological Time Scale (after Lang 1970)

<table>
<thead>
<tr>
<th>Eon</th>
<th>Era</th>
<th>Period</th>
<th>Characteristic life</th>
<th>Total estimated time in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Precambrian</td>
<td>Archean</td>
<td></td>
<td></td>
<td>3,000,000,000 or more</td>
</tr>
<tr>
<td>Late Precambrian</td>
<td>Proterozoic</td>
<td></td>
<td></td>
<td>1,640,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hadrynian</td>
<td>Primitive Invertebrates and Algae</td>
<td>880,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heilikan</td>
<td></td>
<td>570,000,000</td>
</tr>
<tr>
<td>Phanerozoic</td>
<td></td>
<td>Aphebian</td>
<td></td>
<td>2,390,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ordovician Cambrian</td>
<td>Higher Invertebrates</td>
<td>1,500,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Devonian Silurian</td>
<td>Fishes</td>
<td>65,000,000</td>
</tr>
<tr>
<td>Mesozic</td>
<td></td>
<td>Permian Carboniferous</td>
<td>Amphibians</td>
<td>225,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cretaceous</td>
<td>Reptiles</td>
<td>3,000,000,000</td>
</tr>
<tr>
<td>Cenozoic</td>
<td>Tertiary</td>
<td>Recent Pleistocene</td>
<td>Man</td>
<td>1,640,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pliocene Miocene</td>
<td>Mammals and Modern Plants</td>
<td>880,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oligocene Eocene Paleocene</td>
<td></td>
<td>570,000,000</td>
</tr>
</tbody>
</table>

### Figure 2: Geological Time Compared to the Face of a Clock
Figure 3: Extent of the Canadian Shield (after Lang 1970)
Early Precambrian or Proterozoic Eon. The rocks of the Shield were deformed by large-scale crustal movements during intervals of mountain building (orogeny) which occurred at different times and places and resulted in extensive folding, faulting and metamorphism. The Canadian Shield has been divided into seven large areas called structural provinces. These are: Bear, Churchill, Grenville, Nain, Slave, Southern and Superior. Each structural province was affected by mountain building processes at different times and can be distinguished from each other by broad differences in rock types, structural trends and types of folding. Boundaries between the structural provinces occur where one structural trend is terminated by different structural trends. The Ontario part of the Canadian Shield includes portions of three structural provinces: the Superior Province, the Southern Province and the Grenville Province (Figure 4).

a) Superior Province

The Superior Province (Figure 4) is the largest assemblage of Archean Eon (Early Precambrian) rocks in the world, comprising 23% of the Earth's exposed Archean crust. The Ontario part of the Superior Province covers 565 000 km² (Thurston 1991).

The Superior Province evolved during long periods of volcanic activity and sedimentation that occurred throughout the Archean Eon. Between about 2730 and 2550 million years ago, the volcanic and sedimentary rocks were folded, faulted and metamorphosed and intruded by large granite batholiths during a period of mountain building known as the Kenoran Orogeny. The Superior Province became a stable region after this period of deformation and has remained stable to the present day except for minor earth movements and intrusions of diabase dikes and sills. A long period of erosion subsequently leveled the land, upon which relatively flat-lying sedimentary rocks of the Southern Province was deposited (Hewitt 1972).

More than half the area of the Superior Province is composed of large, granitic, batholiths surrounded by numerous, small, greenstone belts. Greenstone belts are long, kilometre-scale belts consisting of volcanic rocks with lesser amounts of sedimentary rocks. The volcanic rocks are commonly altered by metamorphism, to chlorite, and other green minerals, which give them their name "greenstones". Greenstone belts are the primary source of metals in the Superior Province. Greenstone belts, on a typical geological map of Ontario, appear as relatively small, green areas "floating" amongst large areas of pink and red which represent granitic rocks.

The Superior Province is subdivided into several, linear east trending, fault-bounded regions termed sub provinces (Figure 4). Each sub province consists of several greenstone belts and has its own distinctive rock types, structures, ages, metamorphic conditions and mineral deposits (Thurston 1991). The twelve sub provinces in the Superior Province are: the Sachigo, Winisk, Berens River, Uchi, English River, Bird River, Winnipeg River, Wabigoon, Quetico, Wawa, Abitibi and Opatica sub provinces (Figure 4).

The greenstone belts within the sub provinces of the Superior Province are major sources of gold, copper, zinc, iron, and numerous other mineral commodities. Large, complex regions such as the Abitibi and Uchi sub provinces have produced great quantities of gold from the Porcupine and Red Lake gold camps, respectively. The Abitibi Subprovince also hosts numerous and very large copper- and zinc-rich base metal deposits such as the Kidd Creek Mine near Timmins. The Wawa Subprovince hosts the immense gold deposits at Hemlo on the north shore of Lake Superior. These are only a few examples of the major metal-producing areas within the Superior Province.

b) Southern Province

The Southern Province (Figure 4) is a region of the Canadian Shield dominantly consisting of Proterozoic Eon (Late Precambrian) sedimentary, plutonic and volcanic rocks which overlie and intrude older Archean rocks of the Superior Province. The Southern
Figure 4: The Structural Provinces in Ontario

(from Geology of Ontario, Special Volume 4, Part 1, OGS)
Province underlies much of Lake Superior and encompasses a region situated along the northwest shore of Lake Superior, including the Nipigon area. The Southern Province also encompasses an area north of Lake Huron, known as the Penokean Fold Belt which extends in an arc from Lake Huron into the Cobalt area (Figure 4).

The rocks of the Southern Province consist of thick sequences of flat-lying or slightly tilted sandstones, shales and conglomerate. These sedimentary rocks have an approximate maximum thickness of about 10 km. The sedimentary rocks are known as the Huronian Supergroup in the Cobalt and Elliot Lake regions. Sedimentary and volcanic rocks in the Thunder Bay and Nipigon areas are known as the Animikie, Osler and Sibley groups. The Osler group consists of mafic and felsic volcanic rocks exposed along the north and northwest shores of Lake Superior.

The rocks of the Southern Province were folded, faulted and metamorphosed several times. Large diabase sills and dikes intruded the sedimentary rocks about 2150 million years ago. The eastern part of the Southern Province, in the Cobalt and Elliot Lake regions was affected by the Penokean Orogeny about 1800 million years ago which formed the Penokean Fold Belt north of Lake Huron. The large, nickel and copper bearing Sudbury Structure was emplaced about 1700 million years ago and minor periods of igneous intrusion continued sporadically about 1000 million years ago. A major fissure or rift occurred in the crust of the Canadian Shield about 1100 million years ago. This major structure is situated beneath Lake Superior and is referred to as the Midcontinent Rift.

The rocks of the Southern Province are major sources of silver, cobalt, nickel, copper, uranium, iron, amethyst, agates and decorative and dimension stone. The Cobalt area has produced enormous amounts of cobalt and silver from outstanding silver ores within sedimentary rocks of the Huronian Supergroup. Silver has been produced from numerous small mines in the Thunder Bay area. The Thunder Bay area is also well known to mineral collectors for its amethyst mines and agate collecting localities along the shores of Lake Superior. Sedimentary rocks at Elliot Lake have been the major source of Ontario’s uranium; and mafic, igneous, intrusive rocks of the famous Sudbury Structure host enormous, rich, nickel-copper-platinum deposits. The United States portion of the Southern Province hosts large, rich, copper deposits in northern Michigan and immense iron deposits in Michigan, Wisconsin and Minnesota.

c) Grenville Province

The Grenville Province (Figure 4) comprises about 1 000 000 km² of igneous and metamorphic Proterozoic Eon rocks which are about 1 billion years old and form the youngest part of the Canadian Shield. The Ontario portion of the Grenville Province encompasses about 70 000 km² and lies southeast of Sudbury where it extends to the St. Lawrence River (Thurston 1991).

The Grenville Province consists of highly deformed and high-grade metamorphic gneisses and schists intruded by abundant felsic to mafic igneous rocks which include pegmatites and syenites. Many of the igneous rocks are also metamorphosed. Sedimentary rocks, such as sandstone, limestone and carbonate-rich shale and siltstone have been metamorphosed to quartzites and marbles, respectively.

The northern boundary of the Grenville Province is referred to as the Grenville Front Tectonic Zone which forms a wide, northeast-trending belt that extends from Georgian Bay of Lake Huron to the Ontario-Quebec provincial boundary and continues to the east coast of Canada (Figure 4). Rocks of the Grenville Province consist of altered and faulted, highly deformed gneisses that have been compressed and thrust up against the relatively rigid Southern and Superior provinces. The Grenville Front represents the northwest boundary of these thrust-up rocks. The rest of the Grenville Province is subdivided into the Central Gneiss Belt and Central Metasedimentary Belt by the intensity or grade of metamorphism displayed by the rocks. The Central Gneiss belt consists of
highly metamorphosed gneisses of both igneous and sedimentary origin; the Central Metasedimentary Belt consists of less metamorphosed gneisses, sediments and volcanic rocks. The Central Metasedimentary Belt is separated from the Central Gneiss Belt by a northeast-trending boundary or "tectonic" zone (Figure 4) consisting of highly deformed gneisses and rare igneous rocks, such as nepheline syenite and uranium-bearing pegmatites. All of the rocks of the Grenville Province were intruded at several different times by a wide variety of igneous rock types.

About 1200 to 1000 million years ago the rocks of the Grenville Province were subjected to mountain building and high-grade metamorphism during the Grenville Orogeny. This metamorphism caused extensive partial melting and plastic deformation of the rocks. Metamorphism was followed by faulting and rifting accompanied by the intrusion of alkaline igneous rocks.

The Grenville Province is known for its pegmatitic and metamorphosed mineral deposits including: various industrial minerals, dimension stone, iron, lead, zinc, silver and uranium. The Bancroft area, in the Grenville Province, is famous as a mineral collecting locality. Graphite is mined in the Huntsville area. Numerous deposits of silica, limestone, talc, dolomite, calcite, marble, nepheline syenite, gemstones, flagstone, dimension stone and decorative stone are scattered throughout the southeastern part of Ontario. Gold deposits have also been found in the Grenville Province; in fact, the first gold discovery in Ontario was made at Madoc in 1866.

III) THE PHANEROZOIC EON

The Phanerozoic Eon encompasses a time which included long periods of extensive sedimentation and the development of life forms from simple creatures to dinosaurs and mammals. Several periods of glaciation occurred during the Phanerozoic Eon. Phanerozoic sedimentary rocks have filled large depressions or "basins" in the northern and southern portions of Ontario and cover about 220,000 km² of the province. A large region south of Hudson Bay is covered with thick Phanerozoic sedimentary rocks which were deposited in the Hudson Bay and Moose River basins (Figure 4). Phanerozoic rocks occur in a relatively small area northeast of Lake Ontario along the St. Lawrence River; and in an area that extends between Lake Huron, Lake Erie and Lake Ontario (Figure 4).

These thick sequences of Phanerozoic sediments were deposited when large areas of land were flooded by inland seas. The land was affected by episodes of uplift and sinking (subsidence) which affected the level of the seas and rates of sedimentation. The majority of these sedimentary rocks consist of clastic sediments, such as shale, sandstone and conglomerate; carbonates, such as dolostone and limestone; and evaporites, such as gypsum and salt. Many of these sediments also contain fossils of creatures and plants which thrived during the Phanerozoic.

Phanerozoic sedimentary rocks are the source of all Ontario's salt and gypsum production and almost all of the clay, shale, crushed stone, lime, cement, sand and gravel and some dimension stone. Phanerozoic sediments also host oil and gas deposits, such as those located north of Lake Erie.

The Quaternary time period encompasses the last 1.8 million years of the Phanerozoic Eon up to the present day. The Quaternary period was dominated by several intervals of continental glaciation which deposited loose, unconsolidated sediments across the landscape in various distinctive land forms.

The glaciers were systems of flowing ice, up to 3.5 km thick, which moved out from a zone of accumulation and spread over the entire landscape. The glaciers originated in cold, polar regions where there was sufficient snowfall to build up and maintain a thick, roughly circular or elliptical body of ice. The ice flowed out of the zone of accumulation in all directions and moved rapidly into low areas where it formed irregular, lobe-shaped margins. The weight of the ice depressed the Earth's crust so that the surrounding land sloped towards the glacier. This produced large lakes along the ice margins.
A number of significant landforms resulted from geological processes operating at the margins of continental glaciers due to the evaporation and melting of the ice. Sediment carried by the glaciers was deposited along the ice margins or was reworked by melting water and deposited as outwash. The sediment deposited at the ice margins followed the lobe-shaped outline of the glaciers and formed various types of moraines. Lakes, which formed in the depressions along the ice margins, received sediment from melt water running from the glaciers. The sediments accumulated as deltas or were deposited over the lake bottom. Melt water from the glacier also flowed through tunnels beneath the ice and formed rivers and streams which deposited sand and gravel.

When the glacier receded, the ridges of moraines were left at the former position of the ice margins and sandy, silty and clayey tills were left at the site of former lakes. Long, sinuous ridges known as eskers were formed by sediment deposited in ice tunnels beneath the glaciers. The activity of man and recent erosional processes continue to rework and redeposit these loose, glacial sediments.

Ontario’s Quaternary sand and gravel deposits have been a major source of building aggregates worth several hundred million dollars each year. Sediments deposited in glacial lakes have also formed the rich agricultural lands of southern Ontario. The disadvantage of these glacial deposits is that they have covered Precambrian rocks with thick overburden which hampers mineral exploration.

IV) PLATE TECTONICS AND GREENSTONE BELTS

i) Introduction

The Earth is in a continual state of change and is constantly reshaped by a dynamic system of geological processes. The majority of these processes, such as volcanism, igneous intrusion and mountain building are driven by the interior heat of the Earth. The Earth is segregated into layers of heavy and light elements from its inner core to its surface. The inner core of the Earth is composed of very dense hot, heavy, molten, iron and nickel enclosed in a 2800 km-thick layer of rock termed the mantle (Figure 5). The upper part of the mantle, which underlies the Earth’s outer crust, is known as the asthenosphere (Figure 5) and is approximately 200 km thick. The outer crust of the Earth is a light, cool, rigid shell known as the lithosphere (Figure 5) which is about 80 km thick. The lithosphere is dominantly composed of light elements, such as oxygen, aluminum and silicon.

The lithosphere is broken into several large, cool, rigid slabs known as tectonic plates. These plates consist of two types: oceanic and continental. The oceanic plates consist of thin accumulations of mafic volcanic rocks and sediments located below oceans and seas. The continental plates are large areas of thicker crust consisting of a felsic, plutonic base overlain by recent sediments.

Scientists have discovered that the changes in density and temperature, from the Earth's inner core to its outer shell cause instability and movement within the rocks of the Earth. It is now known that the tectonic plates of the Earth's crust are sliding and colliding with each other in very slow motion on top of the asthenosphere (Figure 6). The asthenosphere is hot, weak and capable of viscous flow known as convection. Convection occurs as hot material in the mantle rises, cools near the Earth's surface, and sinks again toward the Earth's interior (Figure 6). This circular motion provides a mechanism for the tectonic plates to glide on top of the mantle. The plates move at a speed ranging from 1 to 10 cm per year. Over billions of years these small movements can amount to very large distances. This theory of moving plates is called plate tectonics.

ii) Plate Tectonics

Several different geological processes occur at tectonic plate boundaries depending on whether the plates are colliding with each
Figure 5: Cross-section of the Earth

- **Oceanic Crust**
- **Continental Crust**
- **Lithosphere**
- **Asthenosphere**
- **Upper Mantle**
- **Lower Mantle**
- **Outer Core**
- **Inner Core**

Distances:
- 70 km
- 250 km
- 700 km
- 2900 km
- 5000 km
- 6371 km

**Composition:***
- **Solid**
- **Liquid/Solid**
- **Solid**
- **Liquid**
- **Solid**
other or separating and sliding away from each other. Separation of tectonic plates occurs when the lithosphere is rifted. A rift (Figure 6) is a long, narrow, trough which marks a zone along which the entire thickness of the lithosphere has ruptured and is forced apart due to extension. These rifts are called divergent boundaries (Figure 6). The Mid-Atlantic Ridge is a very large rift, situated below the Atlantic Ocean, that extends from Iceland to Antarctica. Mafic lavas pour out on the ocean along the rift as older crust spreads away from it.

As a result of this spreading motion, the oceanic plates slowly move under the edges of large continental plates at convergent boundaries (Figure 6), where the ocean's crust is consumed in the Earth's interior as one plate slides under another. The oceanic plate descends below the edge of the continent and melts into large bodies of magma which feed volcanoes on the Earth's surface. This process, called subduction, causes earthquakes and volcanic activity to occur along the edges of the continental plates. Convergent boundaries also produce mountain ranges, such as the Canadian Rockies and Himalayas, when one plate is thrust over the edge of another plate during a process called obduction. A transform boundary is another type of collisional boundary that occurs where plates slide past each other, but crust is neither produced nor destroyed. Immense stress builds up at these boundaries as the plates grind against each other. Relief of this stress occurs during sudden movements or earthquakes, along linear structures known as faults, which are located near the plate boundaries.

These processes are very active today and explain the mountain ranges and intense earthquake and volcanic activity along the west coasts of North and South America and the east coast of Japan. These are areas where oceanic plates are subducted and consumed below the edge of continental plates.

The movement of these lithospheric plates has occurred since the Earth first formed and is responsible for many of the topographical features on the surface of the Earth today. The large mountain ranges of the Himalayas resulted from a collision between two tectonic plates as they glided across the Earth's surface and squeezed oceanic crust and thick accumulations of sediments between them. This explains why fossils of sea animals, and rocks that are known to be deposited underwater, are found at the top of mountains. The province of Newfoundland was once part of the British Isles until they were separated by spreading along the Mid-Atlantic Ridge. The continent of Antarctica was located at the Earth's equator and was covered by thick tropical jungles. This explains the coal deposits, found below the ice of Antarctica, which formed from the remains of tropical plants.

Many mineral deposits are formed where tectonic plates collide and spread apart. The large copper, gold and molybdenum deposits, found along the west coasts of North and South America, were formed during volcanic activity related to subduction. Large deposits of copper and zinc are presently accumulating on the ocean floor, in areas of active volcanism, along the coasts of Japan, New Guinea, British Columbia and California.

iii) Evolution of Greenstone Belts

Geologists have unraveled the past by observing the present. The study of active volcanoes and other geological processes, as they occur today, have assisted geologists in interpreting how rocks were formed billions of years ago. Understanding the geological processes and environments that formed greenstone belts and other rocks of the Canadian Shield, assists in understanding how, when and where specific types of economic mineral deposits were formed.

Below is a list of five steps which explain the development of a typical Archean greenstone belt. Each step corresponds with the numbers on the illustrations in Figure 7.

1) The first step in the development of a greenstone belt is the opening of a small ocean during the rifting of an ancient
Figure 6: Mechanisms of Plate Tectonics

Divergent Boundary

Convergent Boundary

Volcanoes and Mountains

Mid-Oceanic Ridge

Divergent Boundary

Continental Plate

Islands

Oceanic Plate

Volcanic

and Volcanoes

Lithosphere

Asthenosphere

Subduction Zone
Figure 7: Evolution of an Archean Greenstone Belt
(after Blackburn 1980)

1. Rift
2. Ancient Lithospheric Crust
3. Mid-Ocean Ridge Volcano
4. Sediments
5. Granite Stock
6. Subduction Zone
7. Mafic Volcanic Rocks
8. Granite Batholiths
9. Greenstone Belts (Volcanic and Sedimentary Rocks)

see text for explanation
lithospheric crust. The opening of the rift caused widespread extrusion of large thickness of pillowed, oceanic basalts. As new crust was formed the older crust was pushed away from the rift (divergent boundary).

2) The oceanic plate, furthest from the rift, began to slide below the edges of small continental plates (convergent boundaries). At the same time, however, the continental plates were also sliding together. The subduction of the oceanic plate initiated the development of volcanoes along the edges of the continents. The majority of rocks extruded from these volcanoes were felsic in composition. Large, granitic, batholithic intrusions of magma fed the volcanoes along the convergent boundaries. The batholiths were composed of less dense felsic magma which rose upward in the crust.

3) Sedimentary rocks were deposited around the volcanoes and above the subduction zones, at the end of volcanism, as the rocks began to erode away. Rifting ceased and the ocean closed as the continental plates continued to slide together.

4) Oceanic crust was squeezed between the two colliding plates. The oceanic rocks were thrust on top of the continental plates to form high mountain ranges. Granitic batholiths continued to rise upward intruding the rocks during this period of mountain building. The volcanic and sedimentary rocks were compressed, folded and faulted.

5) Final intrusion of granitic batholiths and other igneous rocks and subsequent metamorphism, erosion and glaciation resulted in the greenstone belts as we see them on present day maps: narrow belts of volcanic and sedimentary rocks squeezed between large granitic batholiths.

All of the steps listed above would have occurred during the Early Precambrian or Archean Eon when the Canadian Shield was formed and became stable. Subsequent erosion of the Shield resulted in large amounts of sediments that formed Proterozoic and Phanerozoic sedimentary rocks.

V) DEFORMATION AND STRUCTURE OF ROCKS

Introduction

Structural geology is the study of the Earth’s physical forces and the structures developed in rocks by these forces.

The crust of the Earth is constantly subjected to forces of compression and extension. When rocks are compressed they are squeezed, flattened, crushed and folded together. When rocks are subjected to extensional forces they are stretched and pulled apart. These forces cause deformation of rocks in the form of cracks, large-scale down-warping and up-warping, and folding on smaller scales.

Stress is used to describe the magnitude of physical force acting on a body of rock. Stress refers to pressure and is the measure of force per unit area affecting a rock (i.e.: 1 kg per square centimetre). Stress is caused by increases in weight exerted on the Earth’s crust as sediments are accumulated. A reduction in pressure or stress occurs where there is a lessening in weight due to the effects of erosion. Strain is the shape change or deformation of a body of rock that is caused by stress. Strain results in a change in form or a change in volume of a rock. Rocks attempt to accommodate stress by readjusting and changing their internal structure, for example, by stretching, flattening and bending minerals and realigning minerals and rocks fragments. Fracturing occurs when stress can no longer be accommodated.

Rocks have three basic responses to stress:

1) Elastic Response - Rocks deform when stress is applied but return to their undeformed state when stress is released (stretching an elastic band).

2) Plastic Response (or Ductile) - Rocks deform when stress is applied but when stress is released, the rock remains permanently deformed (molding wet clay).
3) Failure - Rocks yield to stress by breaking or fracturing (like snapping a cracker).

Many mineral deposits are related to and controlled by structures in rocks. Therefore, it is important for prospectors to know how to recognize various structures in the field and on maps. The most important structures that prospectors should be familiar with are fractures, faults and folds.

ii) Fracturing and Faulting

Rocks can yield to stress by fracturing. Hard, competent, felsic rocks such as granite, rhyolite and chert-magnetite iron formation are brittle and crack and fracture easily when stress is applied. Softer, less competent, mafic or ultramafic rocks, such as basalt or peridotite, are ductile and resist fracturing. Ductile rocks yield to stress by bending, stretching and squeezing into new shapes. Therefore, ductile mafic rocks can absorb or accommodate more stress than a brittle, felsic rock.

The simplest structures produced by stress in rocks are joints, which are long, even fractures where no displacement or movement has occurred. Joints range in length from a few metres to several hundred metres and always occur in groups or sets. Joints may be parallel to each other or intersect in distinct geometric patterns, such as diamond or criss-crossing patterns. A tension fracture or gash is a fracture along which the walls of the fracture have been pulled apart. Tension fractures are open, gash-like or lens-shaped fractures that have relatively short lengths and may be filled with secondary minerals, such as quartz or calcite.

Continued stress on a fractured rock may cause the rock on one side of a fracture to move relative to the other side. This type of movement, which occurs parallel to the fracture surface, produces a fault. Movement can also occur along surfaces of natural weakness in rocks, such as sedimentary bedding, pillow rims and rock contacts. A rock contact is the boundary between different rock types and is a natural surface of weakness between the rocks. Movement is most likely to occur along this surface when stress is applied.

The movement along a fault grinds and pulverizes rock into powder or "rock flour" and forms a clay-like deposit of crushed rock termed fault gouge. Fault gouge may be a few centimetres to several metres thick. Rock within a fault, may also be broken and crushed into sharp, angular, fragments forming a fault breccia or brecciated zone between the walls of the fault. Movement along a fault may also result in the development of a shear zone where the walls of the fault are separated by a tabular zone of rock consisting of variable thickness of sliced, sheared and schistose rock. Sheared rock is crushed and brecciated along numerous parallel fractures and commonly breaks into thin slabs and loose pieces when struck with a hammer. Shear zones may have very long lengths and may range in width from a few metres to several hundred metres. Boudinage (sausage structure) is commonly found in very strongly deformed and sheared rocks. Boudinage occurs when features such as an igneous dike, a sedimentary layer or a quartz vein is stretched, thinned and pulled apart at regular intervals forming small bodies resembling sausages (Figure 8).

Movement along a fault takes place on a surface called the fault plane (Figure 8). The direction of the fault plane is its strike (Figure 9). Strike is the trend or direction of any linear geological feature, such as a fault plane, sedimentary bedding, a quartz vein, foliation or a dike, that can be measured with a compass and expressed as a compass bearing. The strike can be measured by simply aligning the compass in the direction of the geologic feature and reading the compass bearing. Dip is the angle that a tilted structural surface, such as a fault plane, makes with the horizontal. The dip direction is measured at right angles to the strike direction of a linear structure. If a fault has a northerly strike then the dip direction will be to the east or west. The dip angle can be estimated visually or measured with a compass equipped with a dip needle or clinometer. An edge of the compass is set against the dipping surface and the dip
Figure 8: Anatomy of a Fault

- **Fault Breccia**
- **Shear Zone**
- **Boudinaged Dike or Vein in Shear Zone**

Figure 9: Strike and Dip

- **Strike**
- **Dip**
needle on the compass is allowed to come to rest. The dip needle will point to the dip angle indicated on the face of the compass. Figure 9 illustrates strike and dip.

Fault planes are commonly vertical but many are also inclined. If the fault plane is inclined, then the upper surface of the fault plane is called the **hanging wall**; and the lower surface of the fault plane is the **foot wall** (Figure 8). Vertical as well as horizontal movement can occur along the fault plane between the foot wall and the hanging wall. If the hanging wall has moved downward with respect to the foot wall then the fault is a **normal fault** (Figure 10); if the hanging wall has moved upwards then the fault is a **reverse or thrust** fault (Figure 10).

Horizontal movement along a fault is referred to as right-handed (dextral) or left-handed (sinistral), depending on the direction of the movement. For example, if an observer is standing on a faulted quartz vein, looks across the fault and finds that the corresponding part of the vein is to the right, then the fault is a right-handed or dextral fault (Figure 11). The opposite is true for a left-handed or sinistral fault (Figure 11).

Below are more terms commonly used to describe faults:

**Slickensides** - A term applied to the grooving, scratching and polishing of rock on both sides of a fault plane during movement.

**Fault Scarp** - A cliff formed by fault movement.

**Fault Block** - A mass of rock bounded on its sides by faults.

**Fault Zone** - Faults are rarely single clean fractures. They commonly consist of a zone, which is hundreds to thousands of metres wide, composed of interlaced smaller faults, breccia and shearing. A fault zone may also be referred to as a **deformation zone**.

**Strike Slip** - The amount or component of movement along the fault plane parallel to its strike.

**Dip Slip** - The amount or component of movement along the fault plane parallel with the direction of dip. It should be noted that strike slip, dip slip or both types of slip can occur along a fault plane.

**Mylonite** - Fine-grained, laminated rock formed by extreme milling or crushing and brecciation of rocks during movement on faults.

**iii) Folding**

The word **fold** describes the shape of any non-planar or curved surface resulting from deformation. Rocks can yield to stress by buckling into folds which can range in size from very tiny, microscopic folds to very large troughs and arches that are kilometres wide.

The **hinge** (Figure 12) of a fold is the point of maximum curvature or bending in a folded surface and may also be referred to as the **fold nose** or **fold closure**. An imaginary line along the hinge or middle of the fold is the **hinge line** or **fold axis** (Figure 12). The orientation of the hinge line is expressed by its **plunge** and **direction of plunge** (Figure 12). The plunge is the angle between the hinge line or fold axis and a horizontal plane. The direction of plunge of the hinge line is the trend of the line, which is measured looking down the plunge. The sides of a fold are referred to as the limbs (Figure 12). The limbs of a fold "meet" at the hinge or fold closure. The "tightness" of folding refers to the angle between the two fold limbs (Figure 13). Therefore, the smaller the angle between the fold limbs the tighter the fold will be. Rocks are commonly found in tilted positions because they are on the limbs of a fold. Rocks that were originally deposited in layers on a flat, horizontal surface may be rotated by folding into an inclined or vertical position. The majority of rocks in Archean greenstone belts have been tilted into vertical or subvertical positions due to tight folding.

A fold, with limbs that converge upward into an arch is referred to as an **antiform** (Figure 14). A fold, with limbs that converge
Figure 10: Normal and Reverse Faults

Normal Fault
- Hanging wall
- Foot wall

Reverse Fault
- Hanging wall
- Foot wall

Figure 11: Left-handed (Sinistral) and Right-handed (Dextral) Faults

RIGHT-HANDED (DEXTRAL) FAULT
- Faulted Dike
- Strike of Fault
- Observer looks in this direction

LEFT-HANDED (SINISTRAL) FAULT
- Faulted Dike
- Strike of Fault
- Observer looks in this direction
Figure 12: Anatomy of a Fold

Axial Plane

Fold Axis

Fold Closure (hinge, nose)

Fold Limb

Plunging Fold (inclined fold axis)

Axial Plane

Angle of Plunge

Axis

Horizontal
Figure 13: Tightness of a Fold

Figure 14: Anticlines and Synclines

Figure 15: S- and Z- drag folds
downward into a trough is referred to as a synform (Figure 14). Anticlines are arched folds in which the oldest rocks are in the core of the fold (Figure 14). Synclines are trough-like folds in which the youngest rocks are in the core of the fold (Figure 14). An anticline is represented on a map by two arrows pointing away from the middle of the fold. The map symbol for a syncline is two small arrows pointing toward the middle of the fold.

Other types of folds are Z-shaped and S-shaped drag folds. They are formed when rocks are stretched and dragged against the walls of a fault during displacement. The Z-folds are found near faults that exhibit right-hand or dextral movement. S-folds are found in the vicinity of faults that exhibit left-hand or sinistral movement (Figure 15). Several other structures that are related to folding are: tension fractures which commonly develop along the limbs of folds; and open spaces or dilations which occur at fold noses or closures.

iv) Recognizing Faults and Deformation Zones

Faults are distinctive features that may be recognized on topographic maps, air photographs and in the field. Faults and other related structural features can be very large, with widths ranging from several metres to several hundred metres; and lengths ranging from several hundred metres to several hundred kilometres. Below is a list of features that may indicate the presence of faults on air photographs and topographic maps:

- Straight, linear, topographic features, such as long, straight streams and rivers; long, narrow lakes; straight, regular shorelines on lakes; long cliffs and rock ridges.

- Abrupt changes in topography, such as streams and rivers that abruptly change direction; ridges or hills that end abruptly at low areas such as swamps or lakes.

Faults may be recognized in the field as long, low depressions or as rock escarpments and cliffs. Other indications of faulting are: offset rocks units and layering; S-shaped or Z-shaped drag folds; and sheared rock, fault gouge, fault breccia, slickensides and intense fracturing. Faults are represented on geological maps by different types and thickness of line symbols. Faults may be referred to in reports and on maps as 1) defined; 2) approximate; and 3) inferred. An inferred fault lacks field evidence; an approximate fault is known to occur but its exact location is unknown; a defined fault is directly observable in the field.

Deformation in rocks can be recognized by several distinctive features. Pillow structures in mafic volcanic rocks are generally round in shape when they are unreformed. However, when pillows are strained they appear elliptical, flattened and stretched. Rock fragments in sedimentary and pyroclastic rocks can be stretched and flattened into long ribbon-like features when they are strained. Strong tensional deformation results in boudinaged or pulled-apart quartz veins, dikes or layering.

A deformation zone consists of a wide area of rocks affected by faulting and having a common structural trend or direction. Therefore, deformation zones have very specific strike directions. In general, rocks become progressively more deformed or strained towards the centre of a deformation zone. Undeformed rocks, which occur on both sides of the deformation zone, are relatively unfractured and show few signs of strain. Fracturing begins to increase at the outer margins of a deformation zone. Pillow structures may show signs of flattening or stretching and rock units may be dislocated and offset near the centre of the zone. In the main part of the deformation zone the rocks will be intensely deformed, sheared and schistose; there may be drag-folding; abundant quartz veining; stained (rusty) and discoloured rocks; and boudinage structures. These features assist a prospector in recognizing deformation and allow him to outline the length and width of a deformation zone.

All of the rocks in a deformation zone may not be deformed and there may be large areas of relatively undeformed rocks within the zone.
Many deformation zones consist of several individual, shear zones which are separated by various thickness of undeformed rocks. Deformation zones may also consist of narrow faults enveloped by a wider area of intensely fractured rocks.

VI) HOW TO READ A GEOLOGICAL MAP

Geological maps (Figure 16) depict observed and inferred information on the types of rocks exposed in an area and underlying it. A geological map uses colour shading, patterns and symbols to indicate the distribution and characteristics of various rock types in an area.

A typical geological map includes geographic features such as rivers, lakes, roads, buildings, etc. Patented mining claims and township boundaries are also indicated. Maps are drawn at a specific map scale, such as 1 cm = 400 m. The scale tells you how the distance that you measure on the map corresponds to distances on the ground.

Types of rocks and their distribution are shown using different colours. An enclosed dashed line is commonly used to indicate the limit of exposed outcrop. Dark shades of colours within the dashed lines indicate that the rock is exposed and the rock type is known. Areas around the outcrops, where there are no exposed rocks, are coloured with a pastel shade of the same colour used for the outcrops. This lighter shade of colour indicates that the geology is inferred, in other words, it is not 100% certain whether the rocks exposed in outcrops also underlie the area. Rock contacts are depicted by thin lines which separate different coloured areas on the map.

The colours that represent various rock types have remained relatively consistent on most geological maps of Ontario. Below is a list of the common colours and the rocks they may represent:

- **dark green** - mafic volcanic rocks, i.e.: basalt
- **pale green** - intermediate volcanic rocks i.e.: dacite
- **yellow** - felsic volcanic rocks i.e.: rhyolite
- **brown or grey** - sedimentary rocks i.e.: conglomerate, shale
- **blue** - mafic intrusive rocks i.e.: gabbro
- **purple** - ultramafic rocks i.e.: peridotite
- **orange** - diabase, a mafic intrusive rock
- **various shades of pink and red** - granitic igneous rocks and various metamorphic rocks

Rock formations are listed in a legend (Figure 17), which is arranged to show rocks in order of their ages. Therefore, the oldest rocks are at the bottom of the legend and the youngest rocks are at the top. Rock types are also commonly represented by numbers, with the oldest rocks numbered "1" and younger rocks numbered upwards from "1".

Structural features, such as faults, shear zones, various foliations, bedding, pillows, folds, etc. are indicated by specific symbols and lines on the map face (Figure 18). Definitions of the symbols are listed in the margins of the map. Mineral occurrences and mines are also indicated by various symbols (Figure 18). All the symbols on geological maps of Ontario are used consistently.

Geological maps are relatively easy to use as long as you read and use the legend on the map and familiarize yourself with the various map symbols and colours.
Figure 16: Example of a Geological Map

- **Topographic features**
- **Rock type identifier**
- **Small outcrop**
- **Foliation symbol**
- **Bedding symbol**
- **Extent of outcrop**
- **Mineral occurrences**
- **Inferred Contact between rock types**
- **Diamond drill holes**
Figure 17: Example of a Geological Map Legend

LEGEND

CENOZOIC

PLEISTOCENE AND RECENT
Sand, gravel, clay

UNCONFORMITY

PRECAMBRIAN

ARCHEAN

FELIC IGNEOUS AND METAMORPHIC ROCKS

GRANITIC ROCKS

Youngest Rocks

5 Undifferentiated granitic rocks.
5a Biotite-and (or) hornblende-quartz-feldspar gneiss, augen gneiss, migmatite, granite gneiss, hybrid granite gneiss, amphibolite gneiss.
5b Granite, granodiorite, quartz monzonite, quartz diorite, porphyritic granite and quartz monzonite, pegmatite, quartz porphyry, feldspar porphyry.

INTRUSIVE CONTACT

MAFIC AND ULtramafic igneous rocks

4 Undifferentiated.
4a Gabbro, metabasalt, mafic gabbro.
4b Peridotite, serpentinite.

INTRUSIVE CONTACT

METASEDMENTS

3 Undifferentiated.
3a Conglomerate, arkose, greywacke, siltstone, argillite, shale, and derived schists.
3b Metasediments with some metavolcanics.
3c Paragneiss, lit-par-lit gneiss.

Iron formation.

METAVOLCANICS

FELIC TO INTERMEDIATE METAVOLCANICS

2 Undifferentiated.
2a Rhyolitic and dacitic tuff, agglomerate and flows.
2b Tuff with some metasediments.

Iron formation.

MAFIC METAVOLCANICS

1 Undifferentiated.
1a Massive lava, pillow lava, tuff, agglomerate, amphibolite, and derived schists and gneisses.
1b Metavolcanics with some metasediments.

Iron formation.

Oldest Rocks
Figure 18: Map Symbols for a Geological Map

SYMBOLS

- Glacial strie.
- Small bedrock outcrop.
- Area of bedrock outcrop.
- Bedding, top unknown; (inclined, vertical).
- Bedding, top (arrow) from grain gradation; (inclined, vertical, overturned).
- Lava flow; top (arrow) from pillows shape and packing.
- Schistosity; (horizontal, inclined, vertical).
- Foliation; (horizontal, inclined, vertical).
- Lineation with plunge.
- Geological boundary, observed.
- Geological boundary, position interpreted.
- Geological boundary, deduced from geophysics.
- Fault; (observed, assumed). Spot indicates down throw side, arrows indicate horizontal movement.
- Lineament.
- Drag folds with plunge.
- Anticline, syncline, with plunge.
- Drill hole; (vertical, inclined).
- Drill hole; (projected vertically, projected up dip).
- Vein, vein network. Width in inches.
- Shaft; depth in feet.
- Test pit or trench.
- Magnetic attraction.
- Swamp.
- Tract, portage, winter road.
- Township boundary, with mileposts, approximate position only.
- Property boundary, approximate position only.
- Claim line, approximate position only.
- Approximate position of former mining property. 1. Bohns, J. D. S.
  4. Stuabach, Wm. M.
PART 5:

MINERAL DEPOSITS
MINERAL DEPOSITS

I) INTRODUCTION

The purpose of prospecting is to search for mineral deposits that have a chance of being commercially valuable. Prospectors should have some understanding of the processes that concentrate minerals and should be familiar with the rock types, minerals, structures and alterations associated with specific types of mineral deposits.

An ore deposit is a concentration of one or more minerals that have economic value and can be extracted and sold at a profit. Metallic minerals are most commonly thought of as the main economic minerals that form profitable ore deposits. However, many varieties of non-metallic minerals, such as quartz, gypsum, salt and talc; and rocks, such as granite, limestone, sandstone, marble, shale and nepheline syenite are extracted for a great variety of uses. Mineral fuels, such as oil, natural gas and coal and deposits of sand, gravel and gemstones are also considered to be ore deposits.

Below are some terms that apply to mineral deposits:

Base Metal - Common metals such as copper, lead, zinc and nickel. Base metals are chemically active (i.e.: they oxidize when exposed to oxygen and hydrogen) and they are the principal metal of an alloy (i.e.: copper in brass).

Precious Metal - A general term for gold, silver or any platinum group elements.

Precious Stone - A gemstone that owing to its beauty, rarity, durability and hardness, has very high commercial value. Examples include diamond, ruby, emerald and sapphire.

Noble Metal - Any metal with a high economic value or one that is superior in certain desired properties, such as gold, silver or platinum.

Industrial Mineral – Any rock, mineral or other naturally occurring substance of economic value, excluding metallic ores, mineral fuels and gemstones.

Ore Minerals – Minerals that contain valuable metals that are to be extracted, for example, chalcoprite is an ore mineral of copper; sphalerite is an ore mineral of zinc; and spodumene is an ore mineral of lithium.

Gangue or Waste Mineral - Minerals that occur with ore minerals but which have relatively no economic value, i.e.: pyrite, pyrrhotite, and arsenopyrite.

Host Rock or Wall Rock - These terms refer to rock types that contain and enclose ore minerals.

Grade or Tenor - The relative quantity or the percentage of element or ore mineral content in a mineral deposit.

Assay/Analysis - assays or analysis refer to several types of lab procedures and tests used to determine the grade and quality of a given mineral or element in a rock.

Showing - A small surface exposure of ore minerals with no sampling or analyses.

Occurrence - A showing that has been sampled and analyzed and which may or may not be trenched and stripped.

Prospect - An occurrence that has been sampled, trenched or stripped but may or may not be diamond drilled.

Developed Prospect - A prospect that has been sampled, assayed, trenched and stripped with extensive diamond drilling and underground development.

Mine - A producer (underground or open pit) of a mineral commodity.

Quarry - Open mine workings developed for the extraction of some types of industrial minerals and stone.
Disseminated Ore - Ore minerals are scattered in a random or uniform manner throughout a rock.

Semi massive Ore - Ore minerals form small, discontinuous concentrations that are separated by waste rock.

Massive Ore - A large concentration of ore minerals in one place. A massive concentration commonly contains greater than 60% ore minerals.

Vein - A mineral filling of a fault or fracture in a rock. Minerals are deposited in a fracture by solutions which move through the Earth’s crust from some nearby source.

Syngenetic - A syngenetic mineral deposit is formed at the same time as the enclosing rock. Both the rock and mineral deposit are formed by essentially the same geological processes.

Epigenetic - An epigenetic mineral deposit is formed after the formation of the enclosing rocks.

Alteration - Alteration commonly occurs in host rocks which enclose mineral deposits. The host rocks are changed chemically and mineralogically during mineral concentrating processes that involve hot solutions and vapors.

II) WHAT CONSTITUTES ORE?

The total amount of elements in the Earth has remained constant throughout geological time. The elements found in ore deposits and rocks around the world have remained within the Earth for its entire history. However, mineral concentrations that are economically valuable are relatively rare and generally difficult to find. Many elements and minerals that are valuable are rare compared to the large amount of common, rock forming, elements and minerals present in the Earth’s crust. You may remember that 9 out of 106 elements comprise 99% by weight of the Earth's crust therefore; the other 97 elements comprise only 1% by weight of the crust (see Table 2 in "Minerals and Mineral Identification"). For example, the Earth’s crust contains 46.6 weight % oxygen but only 0.0000004 weight % gold. Let's assume that the minimum percent of gold for commercial extraction is 0.0012 weight % or 0.35 ounce Au per ton. Based on that assumption, gold must be concentrated 3000 times (0.0000004 weight % x 3000 = 0.0012 weight %) its average occurrence in the Earth’s crust to have any significant economic value (Hewitt 1972). This example should help to illustrate that most elements and minerals must be significantly concentrated by special processes acting in the Earth before they become large, valuable deposits.

Many factors, specific to various types of mineral deposits, can adversely or favourably affect the quality and value of a deposit. Quality is adversely affected if valuable elements in a deposit are difficult to extract from their minerals during milling processes. Difficulties in extracting an element from a mineral may result in a complicated and expensive milling process with poor recovery of the element. Impurities can also adversely affect the colour, purity, quality and value of various industrial minerals, such as quartz, nepheline syenite, limestone and marble. Abundant fracturing, unattractive variations in colour and flaws or variations in texture, adversely affect the quality of dimension and decorative stone. Therefore, concentrations of minerals must be of adequate quality before they are valuable. Mineral concentrations or deposits are not considered to be "ore" unless they can be extracted and sold at a profit. Normally, if the costs of bringing a mineral deposit to production are greater than the determined value of the deposit then a mine will not be developed. The concentration and quality of minerals are important in determining the economic viability of a mineral deposit, but there are many other factors that determine if a concentration of minerals can be extracted profitably. Some of the factors that must be considered are listed below.

1) Demand: Is there a strong and consistent market demand for the mineral?

2) Size and Grade: Is the deposit large enough and rich enough to mine? How long
will it be before the mining company receives a return on its investment?

3) **Commodity Price**: Is the mineral valuable enough to mine at a profit?

4) **Transportation and Access**: How expensive will it be to transport the mineral commodity to market? Do roads or railroads have to be built to the mine site?

5) **Capitalization and Construction Costs**: How much will it cost to construct a mine and mill and bring the deposit into production?

6) **Mining and Milling (Operating) Costs**: How much will it cost to operate the mine and mill the commodity? Will the commodity be difficult and expensive to mill?

7) **Infrastructure**: How expensive is electricity costs, water costs, and cost of housing? What is the availability of a trained work force? Are there nearby sources of water and electricity?

8) **Environmental Costs**: How much will environmental assessments, monitoring and environmental equipment cost?

9) **Closure Plans**: What is the amount of money that must be put up front for the closure and rehabilitation of the mine?

10) **Market Conditions**: How will factors, such as taxation rates, free trade and competition from foreign countries affects the costs of operation?

11) **Miscellaneous Expenditures**: What are the costs of financial payments to land and mining claim holders; financial agreements with native groups, etc.

12) **Corporate Policy**: Is the deposit too small for the company? Are production decisions influenced by inter-company politics and pressure applied by executives?

13) Changes in government legislation, technology, laws and social influences are all factors that influence profitability of a deposit and production decisions. The factors that are listed above are continually changing therefore, what constitutes ore varies according to place and time. A decision to develop a mineral deposit means that expected financial returns will outweigh the costs and risks involved. A decision not to mine is made when costs and risks are considered to be too great in relation to possible returns. A hold decision means that it is too close to decide (Snow and McKenzie 1981).

Almost any mineral or rock is valuable if there is a demand for it; therefore, demand is a major influence on the value of a mineral deposit. Demand for minerals initiates mineral exploration by prospectors and mining companies. However, a downturn in demand can negatively affect the mining industry and mineral exploration. For example, if the automobile industry has a downturn in sales due to low demand for cars, there will be a subsequent decrease in demand for the metals used in the construction of the cars.

Decreases in demand reduce the market value of metals, such as zinc and lead, which also reduces the profits of mining companies and the value of their zinc and lead deposits.

In the case of many industrial minerals, a demand for the mineral or rock may result after it is discovered rather than before. A good example of this is decorative stone. A prospector may discover a rock with an attractive colour and texture that looks good as a decorative stone. However, the prospector may have to convince potential consumers and developers that the stone is attractive and aggressively create a demand and market for the stone. After a period of time demand may decline and the stone will lose its value in favour of other varieties of stone.

All ore deposits are non-renewable resources that are limited in size. Some deposits are enormous and others are small but all of them are eventually mined out. Therefore, new mineral deposits must be found as producing mines are depleted, to meet the continual demand for metals, minerals, rocks and mineral fuels.
III) PROCESSES OF MINERAL CONCENTRATION

Many ore elements ascend toward the Earth’s surface in magmas or hot solutions and vapours associated with magmas. Depending on the type of geological environment or other substances encountered during the ascent, the ore elements either become concentrated into mineable minerals or remain dispersed amongst rocks. Minerals are also concentrated from pre-existing rocks by weathering, residual concentration or secondary enrichment or by sedimentary and metamorphic processes. Therefore, mineral deposits are formed by a variety of mineral concentrating processes that occur under specific conditions in the Earth's crust. Most mineral deposits are concentrated by combinations of the following processes: i) evaporation and precipitation; ii) sublimation; iii) magmatic segregation and concentration; iv) hydrothermal processes; v) metamorphic recrystallization; vi) residual concentration and secondary enrichment; and vii) sedimentation.

i) Evaporation and Precipitation

Evaporation and precipitation are the most common processes of mineral formation that occur in waters (solutions) containing large amounts of dissolved minerals. The amount of a mineral that can be dissolved in a given volume of water depends on temperature and the amount of other minerals in solution. A change or fluctuation in these conditions, caused by evaporation, may cause the water to lose its ability to keep minerals dissolved. As bodies of saline water evaporate, especially in arid or desert conditions, the concentration of salt in the water increases. Eventually, a critical saturation limit is reached and the salt begins to precipitate out of the water, forming salt crystals. If the conditions that cause evaporation are sustained for a long period of time and the site of crystal growth and accumulation is kept undisturbed, large deposits of mineral crystals may form. Minerals other than salt may form by the same processes in seawater, groundwater and hot spring water.

ii) Sublimation

Sublimation is a minor process in the formation of mineral deposits and occurs when mineral crystals are formed and concentrated by deposition directly from a vapour. Vapours originating from deeply buried, molten magmas escape into open fractures where they cool and successively precipitate minerals along the walls of the fractures.

iii) Magmatic Segregation and Concentration

Minerals form, separate and concentrate in certain parts of a cooling and crystallizing magma by magmatic segregation and concentration that result from a combination of factors involving sulphur content, crystallization, gravity settling and liquid immiscibility. Encountering sulphur is a major factor in determining a metal’s form within a magma. In an ordinary magma, metallic elements join with the rock-forming silicate minerals in trace concentrations dispersed throughout the magma. As the magma cools, it forms igneous rocks with no economic concentration of metal ores. However, if the magma contains sulphur, the metals in the magma join with the sulphur to form metallic sulphide minerals. Provided the magma has a high enough sulphur and metal content, the resultant sulphide minerals may form an economic mineral deposit or orebody.

Solid mineral crystals separate from a cooling magma as they reach their individual freezing points. Therefore, various rock-forming, silicate and metallic minerals may crystallize or freeze sooner than others during the cooling of the magma. Sulphide and oxide minerals tend to crystallize while the magma remains partially molten. These metallic minerals are distinct from common, rock-forming, silicate minerals because of their high metal content and high specific gravity. Therefore, they settle by gravity toward the base of the magma body. A particular mineral or minerals may accumulate into layers; irregular semi massive patches; massive bodies near the base of the magma; or as disseminations scattered throughout the magma (Figure 1).
Figure 1: Types of Ore Deposits formed by Magmatic Segregation

- **Massive Cu-Ni sulphides at the base of a mafic intrusion**
- **Chromite layers in a layered intrusion**
- **Small pods of sulphides at the base of an intrusion**
- **Disseminated sulphides in an intrusion**
- **Simplified formation of pegmatite dykes**
- **Pegmatite dykes and sills**

Residual vapours and liquids escaping into fractures.

Granitic Intrusion

Cooling Granitic Intrusion
Another process of magmatic segregation is **liquid immiscibility** which occurs when magma separates into two or more liquid phases that are physically separated from each other by gravity or other processes. This process is similar to mixing oil and water. Oil will not mix with water and rises to the top of the water. The liquids in a magma are commonly sulphide- and silicate-rich and react like oil and water. The sulphide-rich liquid is more dense than the silicate-rich liquid and settles out from the rest of the magma. The sulphide-rich liquid crystallizes into concentrated accumulations of metallic, sulphide ore minerals.

Late-stage magmatic segregation and concentration occurs during the final cooling stages of a magma. Leftover accumulations of magma, liquid, vapour and gas residues are segregated as the majority of the magma solidifies. This residual material may crystallize as part of the magma or may be injected along fractures in nearby country rocks to form intrusive dikes and sills. This late-stage segregation commonly forms pegmatites (Figure I).

### iv) Hydrothermal Processes

Hydrothermal mineral deposits are formed from hot solutions and vapours derived from a wide variety of sources in the Earth’s crust. Essentials for the development of hydrothermal deposits are:

1) available mineralizing solutions capable of dissolving and transporting minerals;
2) available openings in rocks through which solutions are channeled;
3) available sites for the deposition of minerals;
4) chemical reactions with wall rocks and fluctuations in temperature and pressure that result in mineral deposition; and
5) sufficient concentrations of deposited minerals to constitute deposits.

The term "**hydrothermal**" means "**hot water**". Hydrothermal solutions originate from the dehydration of rocks during compaction and metamorphism; and from cooling, igneous intrusions. The water (seawater, groundwater, rainwater) may also originate on the Earth's surface but percolates downwards into the crust where it is heated and circulated. These fluids are highly mobile and chemically reactive, making them excellent solvents for metals and minerals. Open fractures and porous rocks allow the passage and circulation of these solutions. Vigorous chemical reactions occur between the fluids and minerals in rocks that are exposed along the walls of the fractures. These chemical reactions change the composition of the rocks and the fluids. When the composition of the hot solutions is changed their ability to transport dissolved elements quickly diminishes and metals and minerals are precipitated and deposited in the open fractures. Mineral fillings in open fractures or **veins** are typical hydrothermal mineral deposits.

Hot vapours form minerals in open fractures by sublimation where minerals are deposited directly from vapours along the walls of the fractures. This process is partially responsible for the formation of mineral crystals in **vugs**, which are open spaces or cavities in rocks that are filled or lined with beautiful crystals of a variety of minerals.

### v) Metamorphic Recrystallization

Minerals are formed and concentrated by recrystallization due to increases in temperature and pressure during metamorphism. Recrystallization results in the formation of new minerals in a rock. The new minerals are commonly larger than the original minerals and may differ in composition and/or structure. Secondary recrystallization occurs when minerals grow very large by consuming neighbouring mineral grains. Recrystallization may also cause changes in texture and mineral segregation when specific types of minerals separate into discrete layers.

### vi) Residual Concentration and Secondary Enrichment

Minerals in rocks that are exposed to the atmosphere decompose, disintegrate and dissolve as they react with groundwater, rainwater, oxygen and hydrogen in the atmosphere to form mineral deposits by
residual concentration and secondary enrichment processes. Residual concentrations of metals and minerals are formed by the weathering or leaching (removal) of other undesired minerals and metals in a rock. The concentration is due to a decrease in volume caused almost entirely by surficial chemical weathering. The mineral residues may continue to accumulate until their purity and volume make them valuable. The requirements for residual concentration are: 1) rocks that contain valuable minerals that are insoluble are combined with soluble undesired gangue minerals; 2) climatic conditions that favour chemical decay; 3) outcrop relief that is relatively flat so that mineral residues are not washed away and; 4) stability of the Earth's crust must be maintained so that the deposits are not destroyed by erosion. For example, a limestone formation containing iron oxide minerals will slowly be dissolved leaving insoluble iron oxide as residue. If the limestone continues to decompose a larger deposit of concentrated iron minerals will form (Bateman 1950).

Many elements and minerals are leached away from exposed rocks by weathering and the downward migration of water to form mineral deposits by secondary enrichments. The rocks are oxidized by the leaching solutions down to the groundwater table or to a depth where oxidation cannot take place. The leaching solutions concentrate the metals below the weathered mantle of material on the exposed rock surface. This process forms secondary enrichments of oxidized metals and may form new minerals from other decomposed minerals. Secondary enrichment also concentrates, enriches and redistributes minerals in pre-existing mineral deposits that are exposed to weathering processes.

Mineral deposits formed by residual concentration and secondary enrichment are not common on the Canadian Shield due to glaciation which has removed the majority of weathered zones from exposed rocks. Weathering of rocks is well developed in regions that have hot climates with long rainy seasons.

vii) Sedimentation
Simple sedimentary mineral deposits are accumulations of a mineral deposited by sedimentary processes amongst sedimentary rocks. The formation of a sedimentary deposit involves: 1) an adequate source of minerals; 2) the gathering and concentration of the minerals in solution or by other processes; 3) the transportation of minerals to the site of accumulation; and 4) the deposition of minerals in a sedimentary basin. The minerals in sedimentary rocks are derived from the erosion of pre-existing rocks and/or mineral-rich solutions produced during volcanic activity. The minerals are carried in water either in solution or as small grains and deposited by precipitation, evaporation or mechanical concentration.

Mechanical concentration is a dynamic process which concentrates specific types of minerals as a result of weathering and movement of water. Concentration begins as minerals and rock particles are released from rocks by weathering. Sorting occurs when sedimentary particles or minerals having some particular characteristic, such as similarity of size, shape or specific gravity, are selected and separated from associated particles by wave or stream action of water. The sorted minerals are deposited and concentrated when water velocity in streams slow down in river bends and pools and allow mineral particles to settle from the water. The minerals are also "trapped" in crevasses on the stream bed or on the downstream side of obstructions in stream and river beds. Mechanical concentration forms placer-type mineral deposits which are concentrations of valuable minerals in loose, unconsolidated sediments, such as sand and gravel.

IV) IMPORTANT ASSOCIATIONS
The majority of mineral deposits are associated with specific types of rocks and minerals. Most of the mineral deposit and rock associations that occur in Ontario are described below:
i) Mineral Concentrations in Igneous Rocks

Certain types of mineral deposits are formed far below the Earth's surface by the simple crystallization of intrusive igneous bodies such as batholiths, stocks, sills and dikes. These deposits are crystallized directly from magmas during magmatic segregation and concentration processes.

a) Mafic and Ultramafic Associations

Iron-nickel-copper sulphide deposits, platinum and chromium deposits are characteristically associated with mafic and ultramafic igneous rocks.

The iron-nickel-copper sulphide deposits consist of massive, semi massive and disseminated pyrrhotite, pentlandite (nickel sulphide) and chalcopyrite (copper sulphide); and contain variable amounts of cobalt, platinum group elements, gold and silver. The deposits generally occur at the base of irregular gabbro intrusions, but may be found in ultramafic intrusive lenses or extrusive flows. The sulphides may also be concentrated in shear zones, and faults within the intrusions or may occur as veins or lenses in country rocks adjacent to the intrusions. Examples of significant iron-nickel-copper sulphide deposits in Ontario are: the complex and enormous deposits at Sudbury; the Shebandowan and Great Lakes Nickel deposits near Thunder Bay; and the Gordon Lake Mine at Rex-Werner lakes north of Kenora.

Chromium and platinum deposits occur in layered, sill-like or funnel-shaped, mafic to ultramafic intrusions. The layering consists of different rock types formed when various minerals are concentrated and segregated into layers as the intrusion crystallizes. The intrusions consist of layers of ultramafic rocks at the base with more felsic, granitic layers at the top. Individual layers may be a few centimetres to hundreds of metres thick. The chromium and/or platinum mineralization is commonly concentrated in ultramafic, peridotite layers that are rich in olivine. The deposits form tabular, parallel layers with remarkable lateral continuity. Chromite forms semi massive or massive chromitite seams that contain no sulphide minerals. Platinum group elements are also associated with sulphide minerals (pyrrhotite, chalcopyrite, pentlandite) that comprise less than 5% of the rock. Chromium deposits may also occur as intensely deformed pods or lenses of mineralization in highly deformed and altered ultramafic rocks. The ultramafic rocks are commonly serpentinized, sheared and faulted.

Chromium deposits are known to occur in intrusions at Puddy, Obonga and Shebandowan lakes and in the Crystal Lake Gabbro near Thunder Bay; in the Big Trout Lake layered intrusion north of Pickle Lake in Northwestern Ontario; and in the Rex-Werner lakes area north of Kenora.

Platinum is produced at Sudbury and occurs in the Lac Des Iles Intrusion north of Thunder Bay; in the Big Trout Lake Intrusion; and in the Rex-Werner lakes area. Platinum is found in very low or anomalous amounts in many ultramafic intrusions throughout Ontario.

b) Felsic Associations

Iron (magnetite, hematite), tin (cassiterite), iron-titanium-vanadium (ilmenite, titaniferous magnetite) and zirconium (zircon) deposits are formed by magmatic segregation in felsic igneous rocks, such as granites, anorthosites and related rock types. These deposits consist of semi-massive, massive or disseminated minerals in lenses, veins and layers similar to the copper-nickel, chromite and platinum deposits in mafic and ultramafic rocks. Titaniferous magnetite deposits occur near Bad Vermillion Lake at Fort Frances in Northwestern Ontario; and at Mattawa and Millbridge in Southeastern Ontario. No economic tin or zirconium deposits have been found in Ontario.

Carbonatites are unusual, small, roughly circular intrusions composed of carbonate minerals, such as calcite, dolomite and ankerite. Carbonatite intrusions are associated with silica-depleted, alkali-rich rocks, such as syenite. Carbonatites are relatively rare rock types that have attracted attention because they host deposits of
niobium, uranium, thorium, copper, zirconium, phosphorous and rare earth elements, such as lanthanum, yttrium and neodymium. The mineral deposits occur as lenses or layers within the carbonatite intrusions. These types of deposits are relatively rare in Ontario although carbonatite intrusions are widely scattered throughout the province, especially in Southeastern Ontario and north of Lake Superior.

**Pegmatites** are intrusive, very coarse-grained rock types that are formed as a result of late-stage magmatic segregation from a larger intrusive body of magma. Pegmatites are associated with granitic rocks composed mainly of feldspar, quartz and mica with a wide variety of accessory minerals that may host rare elements. Pegmatites may also be alkalic and silica-depleted or mafic in composition. Bodies of pegmatite occur as intrusive dike- or sill-like masses that occur in groups or clusters in igneous and/or metamorphic rocks.

Pegmatites are valuable because their coarse mineral crystals allow them to be a source of common minerals such as feldspar, mica and quartz. They may also contain economic amounts of minerals containing rare elements, such as beryllium (beryl), lithium (spodumene), cesium (pollucite), tantalum (tantalite) and metals, such as molybdenum (molybdnite) and tin (cassiterite). These minerals and elements are generally minor constituents of pegmatites and only exceptional occurrences become mineable deposits.

Granitic and syenitic pegmatites were sources of uranium (uraninite, uranothorite) at the Bicroft, Faraday, Greyhawk and Canadian Dyno mines at Bancroft. These are the only pegmatite deposits in Canada that have produced uranium. Feldspar was produced from pegmatites in the Kingston and Bancroft areas and phlogopite mica was mined from pegmatites at Kingston, at the Eau Claire deposit near Mattawa and the Purdy Mine near North Bay. Pegmatites at River Valley near North Bay and at Verona, north of Kingston, have produced small amounts of silica. Lithium-cesium-beryllium-tantalum-bearing pegmatites occur near Dryden and lithium-bearing pegmatites occur in the Favourable Lake area in Northwestern Ontario. A small amount of beryllium was extracted from pegmatite dikes in Lyndoch Township near Quadeville, Ontario.

**Porphyry copper** and **copper-molybdenum** deposits are enormous mineral concentrations that can consist of 1.5 to 3 billion tonnes of low grade copper, molybdenum and gold ores associated with felsic igneous intrusions. The mineralization is widely distributed and deposited by hydrothermal solutions which originate from the intrusions as they cool and solidify. The hydrothermal solutions circulate through extensively and intensely fractured country rocks and in fracture systems within the intrusions themselves. The solutions deposit widely disseminated copper and molybdenum sulphides throughout the host rocks. The mineralization is accompanied by wall rock alteration such as sericitization and potassic alteration (see "Mineral Concentrations in Veins" in this manual) which is formed by chemical reactions between the country rocks and the mineralizing hydrothermal solutions.

These types of deposits are found in British Columbia and the western United States but are not common in Ontario. Small uneconomic porphyry copper-molybdenum deposits occur at Setting Net Lake and Mink Lake north of Red Lake; Lateral Lake north of Dryden; Moss Lake West of Thunder Bay; and in the Pearl Lake porphyry intrusion at the McIntyre Mine at Timmins. A small porphyry molybdenite deposit at High Lake, west of Kenora, produced a small amount of molybdenum in the 1960’s.

c) **Igneous Rocks as Ores**

Igneous rocks themselves can also form economic deposits as a result of the crystallization of bodies of magma. **Dimension and decorative stone** is extracted from various types of felsic and mafic igneous intrusions at quarries located across Ontario. The rocks must be relatively unfractured; have an attractive, consistent, colour and texture; and should not contain
minerals that decay during weathering. Igneous intrusions of nepheline syenite are mined for nepheline and feldspar at Nephton north of Peterborough. Small quantities of corundum have been produced from nepheline syenite quarries in Ontario. Sodalite is quarried from nepheline gneisses at the Princess Mine in the York River area near Bancroft. Sodalite is formed by the alteration of nepheline in igneous rocks, such as nepheline syenite and nepheline pegmatite. Sodalite is commonly used for jewellery and lapidary work.

d) Kimberlite, Heterolithic Breccia and Lamprophyres - Diamond

Kimberlite

The most common rock type associated with the occurrence of diamonds is kimberlite. Kimberlite is a rare and unusual rock that displays an inequigranular texture and a unique suite of minerals. Kimberlite contains medium- to coarse-grained mineral crystals (macrocrysts and megacrysts) set in a fine-grained ground mass with numerous angular fragments of country rock. Kimberlite resembles concrete and is green, grey or dark brown in colour. The most common minerals in kimberlite are rounded grains of ilmenite, pyrope garnet, olivine, clinopyroxene, phlogopite, enstatite and chromite. Olivine is the most common mineral, while diamond is exceedingly rare. Ilmenite crystals in kimberlite are weakly magnetic and look like small shards of steel grey metal, garnets are deep red to lilac in colour while clinopyroxene (chrome diopside) is usually bright green. Phlogopite mica is dark green to chocolate coloured and exhibits cleavage, so the crystals will often present flat faces to view. Olivine looks like broken pieces of pale to dark green glass and when present, diamonds are colourless with a brilliant lustre and have well preserved crystal faces. If you are lucky enough to find a diamond, try scratching it. You won't!

Of all the kimberlites discovered to date, fewer than 1% carry enough diamonds to be mineable, so the chances of even seeing a diamond in kimberlite are exceedingly rare. Kimberlite is an ultramafic rock related to lamprophyre. Similarities between these rock types have often caused confusion and incorrect identification. For example, kimberlite has been referred to as mica-rich or biotite rich lamprophyre in diamond-drill logs and in older geologic literature. Another common description for kimberlite is 'pebble lamprophyre'; a descriptive term previously used to describe the presence of rock fragments and macrocrysts in the rock.

Unfortunately, kimberlite cannot be positively identified based on visual inspection alone. Specific mineral chemical compositions are required before a rock can be correctly classed as kimberlite. Therefore, microprobe analysis of individual mineral grains to determine their chemical composition is necessary to properly identify kimberlite. Nonetheless, the recognition of the essential minerals that constitute kimberlite is an important step in their discovery. A prospector can quickly learn to identify kimberlite indicator minerals in the field, thereby reducing the chance of misidentifying kimberlite before completing costly laboratory analysis.

Kimberlites form as small gas-rich volcanic eruptions and typically occur as circular pipe-shaped bodies or as dikes and sills. When preserved, the near surface components (crater facies) of the kimberlite will exhibit volcanic features including tuffaceous kimberlite and air-fall bedding of kimberlite ash. Country rock fragments are numerous and large but decrease in size and quantity with depth. In the lower parts of the kimberlite (hypabyssal facies), both volcanic and intrusive aspects of kimberlite occur, such that country rock fragments and kimberlite magma are thoroughly mixed. Fragments (xenoliths) of country rock often exhibit reaction rims that appear partly melted as a result of high heat and chemical interaction with the kimberlite magma. The lower most (diatreme facies) kimberlite occurs as narrow dikes and sills with fewer and smaller xenoliths of country rock.
**Heterolithic Breccia and Lamprophyres**

A second bedrock source of diamonds was discovered in 1995 in the Wawa area. These rocks were originally mapped as intermediate **heterolithic breccias** and tuffs intruded by **lamprophyre** dikes. Older geological maps referred to them as spherulitic greenstones or lamprophyre. The rocks are characterized by fragments of Archean-aged rock and mantle xenoliths supported by a fine-grained groundmass. The mantle xenoliths are the most visually distinctive feature of these rock types. The xenoliths are characterized by talc or carbonate cores and spectacular radiating crystals of amphibole. Visual inspection of these breccias also isn’t enough to establish whether they are likely to contain diamonds. Microprobe analysis of individual mineral grains is required to confirm their chemistry.

Recent geological investigations have also subdivided these “breccias” into three distinctive facies. The pyroclastic facies contain breccia, lapilli and ash sized fragments. Angular fragments of country rock, some hypabyssal fragments and rare mantle xenoliths characterize this facies. The subvolcanic or intrusive facies are the most variable in appearance. The fragment composition is variable ranging from >99% Archean rock fragments to roughly equal proportions of Archean rock fragments, mantle xenoliths and crustal fragments. The hypabyssal facies originally identified as lamprophyre, hosts variable concentrations (<25%) of sub-rounded to rounded mantle xenoliths as well as minor proportions (<10%) of gneiss or trondhjemite fragments.

Because this type of diamond occurrence is found in rocks that are much older than kimberlites, and because much of Ontario is composed of rocks that are similar in age to those in the Wawa area, the potential for discovery of this type of diamond occurrence may be relatively higher than kimberlite. Since the Wawa discovery, diamonds have been recovered from similar-looking rocks in the Cobalt area. The economic potential of this type of diamond occurrence has yet to be established.

The Wawa type diamond occurrences most closely resemble debris flows that erupted from a volcanic source.

**ii) Mineral Concentrations in Sedimentary Rocks**

Sedimentary mineral deposits are accumulations of minerals concentrated amongst sedimentary rocks and deposited by sedimentary processes. Most sedimentary mineral deposits are sedimentary rocks that have economic value such as sandstone, limestone, dolomite and iron formation.

**a) Sedimentary Mineral Deposits**

**Iron deposits** consist of fine, regularly banded, alternating iron-rich and quartz-rich (chert) layers enclosed within sedimentary and volcanic rocks of Precambrian age. The deposits are very long, flat lenses that can be up to 160 km long and 45 m to 600 m thick and contain billions of tonnes of ore. Iron deposits are concentrated near regional sedimentary-volcanic rock contacts or are localized within regional fault troughs or basins in dominantly volcanic rock sequences. The iron minerals in iron deposits may consist of iron oxides (magnetite, hematite) interlayered with chert layers; iron carbonate (siderite) interlayered with chert and pyrite layers; or iron sulphides (pyrite, pyrrhotite) alternating with chert-rich layers. The deposits occur amongst sedimentary rocks such as black shale, chert, greywacke, conglomerate, dolomite, limestone and felsic, mafic and ultramafic flows and pyroclastic rocks. The majority of iron deposits were formed by the precipitation of dissolved iron from large bodies of quiet, undisturbed, oxygenated and/or deoxygenated (stagnant) water.

Iron deposits occur at the Helen Mine at Wawa; the Sherman Mine at Temagami; and the Griffith Mine at Ear Falls. Many other developed and undeveloped iron deposits occur throughout Ontario.

The Steep Rock Mine at Atikokan is another type of iron deposit consisting of residual masses of iron oxides (hematite, limonite, goethite) formed by weathering residual concentration and secondary enrichment
processes. The action of deeply circulating ground water in fractured and permeable parts of a pre-existing iron deposit oxidized, enriched and concentrated the iron and leached away other minerals in the deposit.

**Salt and gypsum deposits** consist of regularly banded, thick accumulations of evaporite minerals, such as halite, gypsum, anhydrite and sylvite enclosed within shale limestone and dolomite. The salt and gypsum deposits were formed during the Silurian time period in the early Phanerozoic Eon. The ores form thick (up to 200 m), continuous, sedimentary beds, lenses or salt domes. The deposits may consist of 90% to 100% salt or gypsum and contain tens of millions to greater than 1 billion tonnes of ore. Salt and gypsum deposits were formed in arid hot regions during the evaporation of water from shallow, saline bays or inland seas that did not have outgoing drainage. The evaporation initiated the chemical precipitation of minerals, such as calcite, halite and gypsum, which formed successive accumulations of rock salt and gypsum beds.

Salt is mined from the Salina Formation in Southern Ontario at Windsor and Godrich. Salt brine wells produce salt at Sarnia and Amherstburg. Gypsum is mined at Hagersville, Caledonia and Drumbo.

**Limestone deposits** consist of thick, continuous sedimentary beds formed by the chemical precipitation of calcium carbonate (calcite) in inland seas or bays; by deposition of calcium carbonate shells and organisms (biochemical precipitation); or by the accumulation of limestone eroded from pre-existing limestone beds.

**Dolomite deposits** are formed by chemical precipitation from water, but are also formed when underground fluids circulate through limestones and add large amounts of magnesium to the rocks. The magnesium combines with calcite in the limestone to form dolomite. Dolomite deposits consist of irregular, discontinuous lenses or continuous sedimentary beds.

Limestone and dolomite are used for cement, lime, crushed stone, decorative and dimension stone and mineral fillers. **Magnesium** was produced from a dolomite deposit at Haley, Ontario near Renfrew and was Canada's only magnesium producer. Limestone and dolomite are quarried across Northeastern and Southern Ontario at Cornwall, Sault Ste. Marie, Ingersoll, Amherstberg, Guelph, Owen Sound and numerous other locations.

**Placers** are concentrations of metallic minerals or gems in unconsolidated sand or gravel that are formed by the processes of weathering, erosion and mechanical sorting and concentration.

**Paleoplacers** are ancient placer deposits preserved in sedimentary rocks. The minerals that form placers are commonly heavy, hard and resistant to chemical decomposition or solution, such as gold, platinum, cassiterite (tin), ilmenite, magnetite and gemstones.

Several requirements are necessary for the formation of placers: 1) there must be a suitable supply of mineral in the rocks; 2) weathering must have gone on for a very long time; and 3) conditions must be favourable for concentration and deposition. The last requirement demands a region of hills or mountains to give streams enough velocity to separate the lighter minerals from the heavy minerals.

Many placers have been destroyed by erosion and glaciation which explains why large placer deposits have not been found on the Canadian Shield. Although the Canadian Shield contains many gold deposits which may have been eroded into placers, glaciers probably scraped the placer deposits away. Some minor amounts of gold and other minerals are reported to have been panned in gravel, pits and stream beds in various locations across Ontario.

**The uranium deposits** of the Blind River-Elliot Lake region are paleplacer deposits. The uranium occurs in distinctive, pyrite-bearing, quartz-pebble conglomerates. The conglomerates were deposited by streams and rivers in ancient valleys and depressions.
The deposits are 2 m to 10 m thick and consist of detrital uranium minerals, such as uraninite, brannerite and monazite, associated with up to 15% pyrite. The uranium and pyrite were weathered and eroded from igneous intrusive rocks and deposited and buried quickly by fast moving water. The uranium may have been redistributed and concentrated by hot solutions flowing through the rocks long after deposition.

Sand and gravel deposits were formed by erosional and sedimentary processes during glaciation. These deposits are excavated across Ontario. Iron ore was extracted from sand and gravel pits at Atikokan. The iron-rich gravels were eroded from the nearby iron deposit at the Steep Rock iron mine during glaciation.

Sedimentary rocks, such as conglomerate, sandstone and shale, can also form economic ore deposits. These rocks are quarried across Northeastern and Southern Ontario for decorative and dimension stone, flagstone, brick, tile, etc. Pure sandstone and quartzite are quarried to produce silica for filler, sandblasting and glass making at Killarney. Jasper-bearing conglomerate at Bruce Mines was quarried for ornamental stone. Certain factors such as attractiveness, colour, texture and purity affect the value and quality of these rocks. Sandstone must be very white and pure if it is to be used as a source for silica.

b) Stratabound Mineral and Fuel Deposits

Stratabound deposits occur in specific horizons within sedimentary rocks and show preferences for certain sedimentary rock types. Mineralization can occur in layers or within specific rock types as pore-space and breccia fillings and cave and solution-cavity fillings. These deposits occur in sedimentary rocks but are not formed by sedimentary processes. They are commonly formed during compaction and chemical alteration of the sediments after they have been deposited and buried.

Oil and natural gas are not minerals because they lack crystal structure and are hydrocarbons formed from organic matter. However, they will be briefly discussed because they occur as stratabound deposits in sedimentary rocks.

Oil and natural gas are mineral fuels found in early Phanerozoic Eon sedimentary rocks (Cambrian, Ordovician, Silurian, Devonian) in Southern Ontario. These deposits initially began as bacteria and organic material which accumulated in shaley and sandy sediments along shallow seashores. The sediments were subsequently buried, compacted and subjected to a slow increase in temperature and pressure that reduced the organic material to gas and oil globules. Upon compaction, oil, gas and water was squeezed from the rocks and migrated up dip along suitable structures (fractures, faults) to a variety of reservoirs, such as structural traps and permeable rock units and reefs, where the oil and gas were concentrated.

Permeable rocks are like sponges and contain abundant interconnected pore spaces that allow the slow passage of liquids and gases. The oil and gas collected in permeable sandstone and dolomite situated within domes and troughs of large folds; and in permeable "reefs" which are masses of organic skeletal material, such as corals. All of these traps are enclosed by less permeable rocks that prevent the oil and gas from escaping from their reservoirs.

Oil and gas deposits are presently exploited in Southern Ontario at Innerkip, Gobles, Petrolia, and Oil Springs and along the shores of Lake Erie and Lake Ontario.

Stratabound lead-zinc deposits hosted by carbonate-rich sedimentary rocks occur in Ontario but are generally small with little economic value. The deposits consist of sphalerite (zinc sulphide) and galena (lead sulphide) mineralization hosted by brecciated limestone and dolomite in Phanerozoic Eon sedimentary rocks.

Stratabound lead-zinc deposits formed in a similar way to oil and gas. The zinc and lead mineralization precipitated from solutions (brines) that were "squeezed" from shaly
sediments compacted beneath overlying sediments. The brines migrated into structural traps and permeable rocks (dolomite, limestone) and precipitated lead and zinc sulphide minerals in open spaces and fractures.

Uneconomic stratabound lead-zinc mineralization occurs in carbonate-rich Phanerozoic sedimentary rocks in sections of the Niagara Escarpment in Southern Ontario.

iii) Mineral Concentrations in Volcanic Rocks

Mineral concentrations in volcanic rocks are formed by the discharge of hot, hydrothermal solutions onto the seafloor. Metal-rich, sulphide minerals precipitate from the solutions and accumulate amongst volcanic and sedimentary rocks. These deposits form disseminated, semi-massive and massive, lens-shaped bodies of volcanogenic massive sulphides (VMS) which are a major source of copper, zinc, lead, silver, gold and minor amounts of tin, cadmium, antimony and bismuth. The typical economic deposit consists of several individual massive sulphide lenses that contain 1 to 10 million tonnes of ore grading 2% to 10% combined Cu, Zn and Pb. The largest deposits contain in excess of 100 million tonnes of ore. Deposits tend to occur in clustres and individual deposits occur within a single, specific sequence of rocks.

Massive sulphide deposits form in areas of underwater volcanic activity where seawater is drawn down through fractures in volcanic rocks and heated by cooling igneous intrusions beneath the seafloor. The heated seawater circulates through fractures and reacts with the rocks, leaching out metallic elements. Continued heating causes the solutions to circulate upwards along fractures. The solutions eventually pour out into the sea where metallic sulphide minerals precipitate from the solutions on or near the seafloor (Figure 2).

The form of the massive sulphide deposits range from steep-sided cones to flat, tabular, sheets that accumulate in deep water on the flanks of felsic volcanoes or in topographic depressions (Figure 3). The most common metallic mineral in a massive sulphide lens is pyrite accompanied by pyrrhotite, chalcopyrite, sphalerite and galena. Chalcopyrite content decreases upward and outward from the base of the massive sulphide lens. A thinly bedded unit of iron-rich chert commonly overlies a sulphide deposit and may extend laterally away from the deposit. In some cases, the massive sulphides are spatially associated with magnetite-hematite and pyrite-pyrrhotite iron deposits (Figure 4).

Volcanogenic massive sulphides can be divided into two types: 1) a Zn-Pb-Cu type associated with intermediate to felsic volcanic flows, felsic quartz-and quartz-feldspar porphyries, felsic pyroclastic rocks and fine-grained sedimentary rocks; and 2) a Cu-Zn type associated with mafic, volcanic flows and fine-grained sedimentary rocks (Lydon 1984). Deposits of the Cu-Zn type occur where the rocks below the deposit consist of mafic volcanic rocks or their direct sedimentary derivatives, whereas deposits of the Zn-Pb-Cu type occur where the rocks below the deposit consist of felsic volcanic rocks or fine-grained, shaly sedimentary rocks.

Massive sulphide deposits are commonly underlain by a wide and extensive alteration zone (Figure 4) found in rocks that lie below the ore body (footwall rocks). Hot solutions that deposited the sulphides on the seafloor circulated through the rocks and chemically changed them by adding or removing elements during vigorous chemical reactions that occurred between the rocks and the solutions. Most footwall rocks beneath a massive sulphide lens are enriched in magnesium (Mg), iron (Fe), silicon (Si), potassium (K), copper (Cu) and zinc (Zn) and depleted in sodium (Na) and calcium (Ca). The altered rocks contain large amounts of minerals that would not normally occur in unaltered rocks, such as chlorite, sericite, biotite, talc, quartz, iron carbonate and disseminated sulphides. If the altered rocks are metamorphosed they may contain unusual concentrations and assemblages of very coarse-grained minerals, such as
Figure 2: Formation of Volcanogenic Massive Sulphide (VMS) Deposits

Heated water leaches elements from the rocks

HOT MAGMA

Figure 3: Common Forms of VMS Deposits

A. Conical Deposit

B. Tabular Deposit
Figure 4: Common Characteristics of a VMS Deposit
(after Lydon 1984)

- Massive Sulphide Lens
  - sharp contact with overlying rocks (hanging wall)
  - iron-rich chert (chert +/- pyrite +/- jasper)
  - gradational contact with footwall rocks
  - sericite-chlorite alteration with py+/- sp+/- gn
  - chlorite alteration with cpy+/- py+/- po

- HYDROTHERMAL ALTERATION ZONE
  - alteration exhibits sharp contact with overlying rocks (hanging wall)
  - alteration exhibits gradational contact with footwall rocks
  - sp+/- gn+/- py
  - py+/- sp+/- gn
  - cpy+/- py+/- po

- Iron-rich chert (chert +/- pyrite +/- jasper)

- chlorite alteration with cpy+/- py+/- po

- sericite-chlorite alteration with py+/- sp+/- gn

- cpy = chalcopyrite
- gn = galena
- po = pyrrhotite
- py = pyrite
- sp = sphalerite
anthophyllite, kyanite, cordierite, sillimanite, staurolite, garnet, biotite and sericite. The occurrence of such minerals serves as guides to exploration for volcanogenic massive sulphide deposits.

Volcanogenic massive sulphide deposits occur across Ontario and are mined at the Kidd Creek Mine at Timmins; the Winston Lake Mine near Schreiber; and the Geco Mine at Manitouwadge. Past producers are the South Bay Mine near Red Lake; the Mattabi and Lyon Lake mines near Ignace; and the Temagami Mine at Temagami Lake.

iv) Mineral Concentrations in Veins

Veins are formed by the circulation of hydrothermal solutions through openings in rocks. Chemical reactions between the solutions and the rock and/or reductions of temperature and pressure results in the deposition of minerals from the solutions into the open spaces. A typical vein is a mineral deposit which has filled an open fissure solidly from wall to wall. Veins usually have sharply defined boundaries but there may be a complete gradation from the vein into the surrounding wall rocks. The shape and physical character of a vein depends upon the type of fissure it has filled, such as an opening formed by structural deformation, or an original opening in the rock. Veins may be any size and form; they can be found in any rock type; and they may be composed of only one type of mineral or extensive assemblages of over thirty minerals. The majority of veins are dominantly composed of quartz and/or carbonate minerals with a wide variety of accessory minerals. Some of the commodities that have been produced from veins are gold, silver, silicon, white quartz, amethyst, copper, lead, zinc, cobalt, antimony, bismuth, barium, molybdenum, tin and fluorine. Gold has been mined from various gold-bearing quartz vein systems across Ontario in locations such as Red Lake, Pickle Lake, Beardmore, Geraldton, Kirkland Lake and Timmins. The gold deposits at Timmins, Kirkland Lake and Red Lake are famous world class ore bodies that have produced gold for many years. The Dome Mine in Timmins, for example, has produced gold for over 90 years. The rich and famous silver-cobalt-nickel arsenide ores of the Cobalt region were extracted from vein systems as well as the silver-argentite-calcite-fluorite ores of the Thunder Bay area.

Tungsten was extracted from gold-bearing quartz veins containing scheelite at the Hollinger Mine in Timmins; lead was produced from quartz- and/or calcite, fluorite, barite veins at the Kingdon Mine near Galetta, at the Hollandia Mine north of Madoc, at the Jardun Mine near Sault Ste. Marie and the Frontenac Mine north of Kingston; lead, zinc, silver and gold were produced from quartz veins at the Berens River Mine at Favourable Lake; copper was produced from quartz-chalcopyrite veins at the Bruce Mine on the north shore of Lake Huron; and fluorite and barium were produced from barite-calcite-fluorite veins near Madoc and Cardiff. White quartz and amethyst (purple quartz) are extracted from veins near Dryden and Thunder Bay, respectively.

a) Types of Veins

Below are descriptions of some of the most common types of vein systems also depicted in Figure 5:

Composite, Crack and Seal or Ribbon Veins: These veins consist of narrow layers of vein minerals separated by thin dark seams of smeared, altered wall rock that are arranged parallel to the walls of the vein. This parallel "layering" represents successive periods of fracturing, reopening and movement along wall rock/vein contacts and successive emplacement of vein material. This type of vein is commonly found in shear zones.
Figure 5: Various Types of Veins

A. Crack and Seal Vein
B. Chambered Vein
C. Lenticular Vein
D. Sheeted Vein
E. Gash Veins
F. Linked Veins
G. Ladder Veins
H. Saddle Reef Veins
I. Vein Stockwork
J. Replacement Vein
Fissure Veins: A simple fissure vein occupies a single fissure whose walls are relatively straight and parallel. More complex fissure veins are:
- **chambered or breccia veins** where the walls of the vein are irregular and brecciated.
- **dilation or lenticular veins** which are lenses in schistose rocks (shear zones). They may also occur as *en echelon* lenses.
- **sheeted veins** are a group of closely spaced distinct, parallel veins in fractures separated by layers of wall rock. If individual fractures are linked by diagonal veinlets a **linked vein** is formed (Bateman 1950).

Gash Veins: These veins commonly form in sets of *en echelon* or subparallel veins generally occupying a set of tension gashes or fractures. These veins tend to be lens-shaped with limited strike lengths.

Ladder Veins: These are a series of regularly spaced horizontal veins which extend parallel to each other from wall to wall of a dike or other vein. The veins resemble the rungs of a ladder.

Saddle Vein or Saddle Reef: If a thick stack of writing paper is sharply arched and folded, openings will form between the sheets at the hinge of the arch. Similar openings are formed when alternating layers of brittle and ductile rocks are tightly folded (Bateman 1950). These openings are filled with small, vein-like, bodies formed in the core or crest of an anticlinal fold. The vein is also anticlinal in form with its concave surface facing downwards and resembles the cross-section of a saddle. Saddle veins may occur in vertical sets occupying the hinge zone of an anticlinal fold.

Replacement Vein: Replacement veins are formed when country rock is progressively replaced or substituted by vein material. The formation of a replacement vein does not involve mechanical fracturing.

Stockwork: These are large-scale systems of interlacing networks of small veinlets. The individual veinlets rarely exceed a few centimetres in width or a few metres in length and are spaced a few centimetres to a few metres apart.

b) Structural Affiliations of Mineralized Veins

Veins represent mineral fillings of open spaces in rocks. Therefore, they are very closely associated with strongly deformed rocks. Most veins occur in very structurally complicated deformation zones and tectonic breaks that provide an abundance of open spaces for vein development. Veins may be associated with small-scale faults, shear zones, folds structures and fracture systems or large deep-seated fracture and fault systems developed during regional earth movements. Open spaces in rocks also include features not associated with structural deformation, such as vesicles, bedding planes, cooling cracks, hollow lava tubes and naturally permeable rock types.

The composition of rocks localize deformation zones and specific types of structures. Felsic rocks, iron formation and small igneous intrusions commonly host fracture systems and brecciated zones. Mafic and ultramafic rocks host shear and fracture zones. Rock contacts between different rock types are also the site of deformation due to the contrast in composition between the rocks.

Vein systems are usually tabular, sub-vertical, structures. The thickness of a vein system is commonly measured in metres and its strike and dip dimensions measured in tens or hundreds of metres. The economically valuable part of the vein may be considerably smaller than the vein itself because the majority of veins are not evenly mineralized. The vein system may also be part of a larger structure consisting of a system of separate shear zones each hosting their own vein systems.

For example, the gold mines in Kirkland Lake are located along a continuous vein-bearing shear zone system that has a strike length of 5 km, a width of 450 m and extends for a vertical depth of at least 2 km (Roberts 1987).
Below is a list of the structures formed in rocks that host mineral filling deposited by hydrothermal fluids (Bateman 1950).

**Vesicles or gas holes:** These are openings produced by expanding gases and vapours as they escape from mafic lava flows. Vesicles are known to host quartz and/or carbonate fillings known as agates and amygdules as well as various sulphide minerals and native copper. Other original openings in volcanic rocks, such as hollow lava tubes, spaces between pillows and volcanic breccia pipes may be filled with vein minerals.

**Cooling Cracks:** These are regularly spaced joints, parallel platy partings or irregular cracks formed as a result of contraction in cooling igneous rocks.

**Bedding Planes:** These are features in sedimentary rocks which permit the intrusion of hydrothermal fluids which may result in the replacement of wall rocks by vein minerals.

**Fractures and Fissures:** These are continuous tabular openings in rocks with considerable lengths and depths. They are formed by tensional, torsional and compressive forces and may or may not be accompanied by faulting. They provide long continuous channelways for fluids.

**Shear and Fault Zones:** Shear zones consist of numerous closely spaced, relatively parallel, discontinuous fractures formed by rupture and crushing resulting largely from faulting. The narrow sheet-like openings provide channelways for solutions.

**Vein systems** can occur in the central part of shear zones within larger regional shears and faults; in **fault splays** which are secondary structures that branch off from the main fault; and at the intersections of two or more faults or fissures. Minerals can be deposited as pervasive disseminations in highly sheared rocks (i.e.: the Madsen gold mine at Red Lake) without the formation of veins.

**Folding:** Veins occur in dilational zones related to folding such as tension gashes and fractures along the hinge of folds; pitches (inclined) and flats (horizontal) which are openings formed by the parting of sedimentary beds due to gentle folding or slumping; and openings at the hinges or noses of tightly folded anticlines.

**Breccias:** Breccias are formed by the crushing of brittle rock due to folding, faulting, intrusion or other tectonic forces. The openings between the angular fragments provide space for circulation of solutions, cavity filling and replacement. The amethyst deposits near Thunder Bay are formed in this manner.

**Solution Openings and Collapse Breccias:** Solution openings are caves and enlarged joints or fractures in soluble rocks which supply channelways and open spaces for cavity fillings. The collapse of rock overlying these openings forms collapse breccias.

**Porous and Permeable Rocks:** A porous rock contains open spaces between individual mineral grains. A permeable rock is a porous rock in which the open spaces are interconnected. A permeable rock will allow the passage of fluid whereas a rock that is porous impedes fluid flow. Many sedimentary rocks, pyroclastic volcanic rocks and altered wall rocks are porous and permeable due to abundant interconnected pore spaces between mineral grains. Hydrothermal fluids circulating through these permeable rocks deposit abundant vein minerals throughout the pore spaces which partially replaces the original rock and evenly distributes mineralization. Structural deformation generally increases the permeability of a rock through fracturing, faulting and folding.

c) **Rock Associations of Mineralized Veins**

Hydrothermal mineral deposits, such as veins, can occur in any host rock, but there are specific types of rocks that influence ore deposition more than others.

The physical properties of rocks determine how they will respond to deformation. Some rocks fracture more easily than others. Many rock types contain original, natural open spaces, such as vesicles, bedding planes,
cooling cracks, etc. Certain rock types are naturally very porous and permeable, such as sandstone, and contain abundant interconnected pore spaces that permit fluid circulation.

The chemical composition of rocks causes hydrothermal fluids to precipitate and deposit vein minerals; these rocks are known as chemical traps. The minerals precipitate as the solutions chemically react with specific minerals and elements in the trap rocks. Carbonate-rich rocks such as limestones, dolomite or large carbonate veins, are good chemical trap rocks and are the common host rocks for skarn deposits. Carbonate rocks are also good hosts because they are soluble and dissolve in hydrothermal solutions permitting solution openings. Iron-rich rocks such as magnetite-rich iron deposits, gabbros and mafic volcanic rocks are good hosts for gold-bearing veins. The sulphur in the hydrothermal solutions reacts with the iron in the rocks to form iron sulphide minerals, such as pyrite. This process stimulates the precipitation of gold, which commonly coats or "plates" the pyrite crystals. Ultramafic, magnesium-rich rocks and carbon-rich, graphitic rocks are also good chemical traps for vein minerals such as gold-bearing veins.

Other rock types, such as intermediate to felsic, igneous intrusive rocks, are also closely related to vein deposits. These intrusive rocks may have been sources for hydrothermal fluids that escaped from the intrusions as they cooled and transported minerals and elements into open fractures. This may explain why many vein deposits are spatially associated with intrusive igneous rocks. Many gold vein deposits, for example, occur at or near the margins of felsic intrusions and silver vein deposits are closely related to intrusions of diabase.

d) Wall Rock Alteration of Mineralized Veins

Vigorous chemical reactions occur between hydrothermal fluids and wall rocks as the fluids circulate through open spaces. These chemical reactions promote the precipitation of minerals from the solutions and change the mineralogical and chemical composition of the wall rocks. The chemical reactions commonly remove and/or add elements to the rocks resulting in the destruction of pre-existing minerals and the formation of new minerals. This effect is called wall rock alteration, which accompanies all mineral deposits formed by hydrothermal fluids. Wall rock alteration is readily visible to the eye and commonly results in discolouration of the rocks and the growth of new minerals. It can also change the physical properties of rocks and make them harder or softer. In a simple fissure vein the alteration extends parallel to the walls of the fissure and forms an alteration halo around the vein. The halo is relatively uniform in width but can vary according to the size of the vein, or the intensity/amount of fluid movement. If the veins are closely spaced, the alteration halo of one vein may merge with the halos of other veins. The alteration may also be very extensive and widespread affecting a large area of rocks. The type, extent and intensity of the alteration depends upon the chemical composition of the wall rocks and solutions; temperature and pressure of the mineralizing solutions; the amount of solutions involved; and the size of the open spaces. Rocks that are easily altered, such as mafic and ultramafic rocks, will exhibit intense and extensive alteration. The reverse is true for less chemically reactive rocks, such as felsic, silica-rich rocks. Large structural systems that allowed the passage of enormous quantities of solutions will host extensive vein systems with widespread alteration.

Many vein systems are relatively small and difficult to locate, therefore, recognizing wall rock alteration is important. The alteration that surrounds a vein system may be much more extensive and widespread than the smaller vein system. Therefore, recognition of rock alteration may lead a prospector to the mineralized veins.

Wall rock alteration is not only associated with veins, but occurs with any mineral deposits formed by the circulation of hydrothermal fluids in rocks. Below are descriptions of the more common types of wall rock alteration.
Carbonatization: This involves the formation of carbonate minerals (calcite, ankerite, dolomite) in the wall rocks. This alteration "bleaches" or discolours the rock and gives it a distinctive orange-brown appearance on weathered surfaces and a pale grey or buff colour on fresh surfaces. Small crystals or "rhombs" of carbonate can sometimes be seen in the rocks. Carbonatization is most well developed in intermediate to mafic and ultramafic rocks.

Chloritization: This is the formation of abundant dark green chlorite in wall rocks due to enrichments in magnesium (Mg). Chloritized rocks are soft, dark green and schistose. Chloritization is associated with carbonatization and is usually well developed in mafic rocks. It can also occur in very felsic rocks such as rhyolite.

Albitization: This is the formation of albite feldspar in wall rocks due to enrichments in sodium (Na). Albitized rocks are mottled white to grey and may contain small laths of secondary feldspar.

Epidotization: This is caused by the pervasive enrichment of epidote in wall rocks. Epidotized rocks are pale apple green and can be extremely hard with conchoidal fractures. Epidotization is most prominently developed in intermediate to mafic rocks.

Potassic Alteration: This type of alteration is caused by the enrichment of potassium (K) in wall rocks. Minerals that contain high amounts of potassium such as biotite mica, sericite mica and potash feldspar are abundant in potassium-enriched rocks. Rocks containing abundant, fine-grained, biotite may be schistose with a shiny, purple-brown tinge on weathered surfaces. Sericite is very fine-grained, muscovite mica, which is very white and shiny giving the altered rock a platy, schistose texture. Rocks enriched in potash feldspar are commonly pink or pink-orange and may contain laths of feldspar.

Sericitization: As mentioned above, sericitization is a result of potassium enrichment forming sericite mica. Sericite is commonly accompanied by quartz and pyrite. If the sericite is enriched in chromium it becomes a bright emerald green and is known as fuchsite or mariposite. Sericitization commonly occurs in felsic and sedimentary rocks while green sericite forms in mafic, ultramafic and felsic rocks. Green sericite is commonly associated with carbonate.

Silicification: This alteration occurs when there is a major enrichment of silica (SiO₂) in the wall rocks. Silicified wall rocks are very quartz-rich; have a cherty, porcelain or dull lustre; and are very hard with a conchoidal fracture. Silicification can occur in any rock type.

Sulphidation: This alteration consists of the development of iron sulphides (pyrite, arsenopyrite) in wall rocks due to the addition of sulphur to the iron-rich rocks. The sulphur combines with iron released during the decomposition of iron-rich minerals and forms iron sulphides. Sulphidation commonly occurs in iron-rich, mafic rocks and iron formation.

Many other types of alteration can occur, such as tourmalinization (development of tourmaline due to enrichments in boron); dolomitization (addition of magnesium to limestone forms dolomite); garnetization (abundant garnet developed in an altered rock). Enrichments of aluminum in rocks commonly form assemblages of aluminum silicate minerals, such as andalusite, sillimanite and kyanite. Other minerals such as biotite, cordierite, chloritoid staurolite and anthophyllite may be formed by the metamorphism of altered rocks with enrichments of aluminum, iron and magnesium.

v) Mineral Concentrations in Metamorphic Rocks

Metamorphic processes alter pre-existing rocks, form new minerals and concentrate minerals by increased heat, pressure and invading solutions. Valuable mineral deposits are concentrated in rocks by the process of recrystallization and reconstitution of rock-forming minerals during metamorphism. Metamorphic processes can also modify the
form and arrangement of pre-existing mineral concentrations, such as massive sulphide deposits or iron formation. Metamorphic processes and mineral deposits can be subdivided in two principal types:

**Contact Metamorphism/Metasomatism:** This type of metamorphism is localized at the contacts of intrusive bodies of igneous rocks. It develops when a pre-existing host rock is metamorphosed primarily by increased temperature and chemically changed and/or replaced by migrating hydrothermal fluids, vapours and gases.

**Regional Metamorphism:** This type of metamorphism is developed over hundreds of square kilometres and is associated with burial and folding of rocks.

**a) Contact Metamorphic/Metasomatic Mineral Deposits**

These types of deposits are commonly known as *skarns* and are associated with large plutonic intrusions. Host rocks for the deposits must be highly reactive and relatively soluble to trap hydrothermal solutions, vapours and gases escaping from the intrusions. The best host rocks therefore, are carbonate-rich rocks, such as dolomite and limestone, which are reactive and soluble.

As solutions and gases invade the carbonate-rich host rocks the carbonate is dissolved, making way for the deposition of new minerals derived from the igneous intrusion or formed by the reaction of the solutions with the host rocks. Impure carbonate combines with silica to form a variety of calc-silicate minerals such as diopside, pyroxene, epidote and garnet. The form of the deposits is defined by the intrusive rock contact. Mineralization "fingers" out into the host rocks from the intrusion. Some mineralization may also occur in brecciated or fractured portions of the intrusion.

Gangue minerals in skarn deposits consist of quartz veins, fluorite, topaz, tourmaline, talc, apatite, sodalite and various calc-silicates. Metallic minerals generally consist of magnetite, hematite, pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, galena and molybdenite.

Numerous skarn-type deposits occur throughout the Ontario part of the Grenville Province and host a wide variety of mineral and metal commodities. *Molybdenum* was mined from pyroxenite skarns at the Hunt and Spain mines near Renfrew. The deposits consist of syenite dikes intruding limestones, which contain pyrite, pyrrhotite and molybdenite. *Iron* was mined from numerous skarns in the Madoc-Marmora region. The Coe Iron Mine near Madoc was an iron skarn deposit that also produced copper and was later known as the Eldorado Copper Mine. *Talc* was mined from skarnified limestones at the Henderson and Conley mines near Madoc. Small amounts of apatite were produced from skarns near Kingston. Numerous small skarns composed of metamorphosed impure limestone and dolomites host zinc, lead and iron throughout the Ontario part of the Grenville Province. Most of these deposits occur in the Ottawa Valley where a few deposits produced small amounts of zinc and lead.

**b) Regional Metamorphic Mineral Deposits**

Regional metamorphism develops over a wide range of both temperature and pressure and commonly affects sedimentary and mafic volcanic rocks. Increasing pressure and temperature changes the mineral assemblages and physical structure of the rocks producing slates, schists and gneisses. Regional metamorphism can affect whole rock units resulting in very large mineral deposits.

Mineral deposits formed by regional metamorphism are generally non-metallic and encompass a wide range of minerals and rocks. *Slates, schists, marbles and quartzite* are regionally metamorphosed rocks that are quarried in Southern and Southeastern Ontario for a wide variety of purposes.

**Asbestos, talc and soapstone** deposits are formed by the regional metamorphism and deformation of ultramafic and mafic rocks. Soapstone deposits can be found in various
locations across Ontario and asbestos was mined at the Munro Mine at Matheson. **Garnet** was mined from the River Valley property northwest of North Bay; and abundant **kyanite** occurrences are found throughout the Sudbury and Mattawa areas. **Graphite** disseminated amongst gneissic rocks is mined near Huntsville.
PART 6:

ACQUIRING MINING LANDS
ACQUIRING MINING LANDS

I) INTRODUCTION

The Mining Lands Section of the Ministry of Northern Development and Mines manages the Mining Act through which the public can obtain mining lands and mining rights in Ontario. At the end of this section “Acquiring Mining Lands” there is a list of Ministry of Northern Development and Mines Offices that you can contact:

- to help you obtain required Mining Act forms
- where you can pay required fees
- to give you advice about staking and requirements of the Mining Act

There you will also find the internet address for the Mining Lands Section web site.

II) HOW TO OBTAIN MINING LANDS/MINING RIGHTS

Anyone who is 18 years of age or older can prospect and stake a mining claim on land that is open for staking or buy an existing mining claim, lease, license of occupation or patented mining land. You must contact the existing mining landholder if you are interested in purchasing their mining land. You can hire a licensed claim staker to stake on your behalf.

A prospector will always be cautious that he or she does not trespass on private property nor risk losing a promising showing to a competitor. Be aware of the “status” of the land on which you will work and attempt to secure some form of exclusive rights to explore. To explain the term “land status” there are three broad categories to be aware of:

1) Crown land
2) private surface rights/Crown mining rights
3) private property

III) CROWN LAND

Crown land is land that is owned by the Province of Ontario.

Mining claim maps, show Crown land and Crown mining rights that are open for staking. The Provincial Recording Office of the Ministry of Northern Development and Mines keeps the claim maps up to date. (See the Contact List.)

Some reasons why land might not be open for staking is that the land could:

- already be staked, leased or owned
- be a Reserve as provided by the Indian Lands Act
- a Provincial or Federal park

The staff in the Provincial Recording Office or Mining Lands Consultants Offices can help you interpret the claim map that you are interested in.

There is far more Crown land in Northern Ontario than there is private property. However, do not assume that no one owns land in remote areas. Be sure to check the mining claim map before you begin prospecting and staking. The claim map does not show every detail so you may discover buildings or other improvements on the land when you are staking. Always be cautious when you find that others are using the land and carry out your activities so that conflict may be avoided.

In addition, you should be aware of policies established by Ministry of Natural Resources under the Public Lands Act for Crown land. These policies may influence your mineral exploration and development activities by, for example, limiting the creation of new access routes or prohibiting the development of new quarries. Policies for Crown Land are available on-line at:

http://crownlanduseatlas.mnr.gov.on.ca/
is possible that timber rights do not belong to the landowner. Also it is possible that an owner holds title to "surface rights" but not to "mining rights". Sometimes there may be 2 owners for the same land: one owning the surface rights and someone else owning the mining rights.

Where the surface rights are private property but the mining rights are owned by the Crown then the land might be open to staking and prospecting subject to conditions as specified in the Ontario Mining Act. Of course one of the chief conditions is that the prospector holds a valid prospector's license. Another condition is that the prospector is legally responsible to compensate a surface rights owner for any damage.

Mining claim maps show where the surface rights are owned and the mining rights are open for staking. The maps are not guaranteed to be correct, therefore, it is advisable to conduct title searches at the Land Registry Office for the area where the land is located. Terminology such as "surface rights patent" or "patented for surface rights only" often are used in describing private land that does not include the rights to the minerals. In some situations the Mining Act requires that you have consent of the surface rights owner before you prospect or stake.

In all cases where there are private surface rights the first time you prospect/explore you must give notice to the surface rights owner. If you don't give them notice, then under the Mining Act you can try to get written permission from the surface rights owner after you explore but you are taking a chance that they will cooperate. To give the notice to the surface rights owner you must use the Ministry's prescribed form. It might be in your best interest to adopt a policy of always communicating with landowners before you enter on the land.

You can contact the Provincial Recording Office if you have any questions concerning prospecting, staking, forms, or fees.

V) PRIVATE PROPERTY

Mining claim maps show where the land is privately owned. Land ownership records are administered under the Registry Act or Land Titles Act by the Land Registrar for that particular area (Ontario Ministry of Government Services). Additional information may be available from the municipality (if one exists) or the local Tax Assessment Office (Ontario Ministry of Finance).

If the mining rights are privately owned you must deal with the owner if you are interested in the mineral potential of that property.

In Southern Ontario most of the land is private property. However claim staking and mineral exploration do occur in some areas where the mining rights are held by the Crown, especially in southeastern Ontario. In some such areas, the surface rights are privately held, while in others they are held by the Crown.

VI) MINING CLAIMS

Anyone prospecting, staking and recording mining claims in Ontario must have a valid prospector's license issued by the Provincial Recording Office. You do not need a license to hold a mining claim in your name.

It is critical that the staker knows and follows the Claim Staking Regulation because anyone can "dispute" your claim and challenge your rights if you have not staked the claim properly.

To apply for a prospector's license you must be at least 18 years of age. The application fee is $25.50. The license is valid for 5 years and is renewable. You can obtain the application form from one of the offices listed in the Contact List or from the Mining Lands Section web site.

After staking a mining claim it is necessary to "record" the claim at the Provincial Recording Office within 31 days after completing staking. You must use a prescribed form called an Application to Record Staked Mining Claim(s).
If the claim is not recorded within 31 days it is not a legal claim. A recording fee must be paid when filing the application. The application includes a sketch of the staking and a statement certifying that all the information in the application is true.

The “anniversary date” of the claim is the date on which the Provincial recording office receives your acceptable application to record. There are deadlines, which will then fall on the anniversary date in future years. In order to keep a recorded mining claim in good standing, the holder of a mining claim must perform and file prospecting or exploration work which the Mining Act calls “assessment work”. There are prescribed forms, which must be used.

Deadlines to file assessment work are specified in the Assessment Work Regulation. The deadlines usually fall on the anniversary date each year. Become familiar with the Assessment Work Regulation. See the Contact List for whom to contact for any questions concerning work deadlines, assessment work forms, technical reports or the types of assessment work recognized by the Mining Act. Failure to meet the Assessment Work Regulation requirements results in an automatic forfeiture (loss) of the claim and the land is once again open for staking at 8:00 A.M. standard time the day after a notice of reopening is posted in the Provincial Recording Office.

A claim holder may keep the right to the mining claim by performing and filing assessment work every year or assigning assessment work credits from contiguous mining land. If you are not familiar with assigning credits it is important that you discuss this with staff of the Provincial Recording Office or Geoscience Assessment Office. (See Contact List).

A mining claim only gives the right to explore that claim. Minerals cannot be removed from the claim until a lease is issued. The holder of a claim may choose to apply for a 21-year lease at any time after recording and Ministry approval of the first unit of assessment work.

**VII) LEASES**

Before a lease can be issued the land must be surveyed (in unsurveyed territory) by an Ontario Land Surveyor at the expense of the claim holder. Also there is an application fee of $75.00 plus $4,400.00 minus the value of assessment work recorded. If you consider the formula you will quickly realize that the cost of the lease application is reduced as you file increasing amounts of assessment work before applying for a lease.

When the lease is issued, it is registered at the Land Registry Office. The lease must be used for mining purposes only or the Minister can declare the lease forfeited back to the Crown. The lessee must pay a lease rent of $3.00/hectare each year.

A leaseholder enjoys the exclusive right to explore and mine during a 21-year term. There is no yearly requirement to report work after the lease is issued. When the lease is expiring it can be renewed for another 21 years if the lessee can prove to the Minister that exploration or mining occurred on the lease.

**VIII) MINING CLAIM MAPS**

The Provincial Recording Office updates the claim maps daily. They can be bought through the Ministry’s Publications Office or can be printed from the Mining Lands Section web site. If you are not familiar with the symbols on the map call the Provincial Recording Office or a Mining Lands Consultant. (See the Contact List).

**IX) LEGAL OPTIONS FOR EXTRACTING INDUSTRIAL MINERALS (INCLUDING STONE) ON CROWN LAND**

On Crown land either the Aggregate Resources Act or the Mining Act, can be used to obtain permission to start surface mining of non-metallic minerals. The Mining Act applies
to surface mining of non-metallic minerals excluding natural gas, petroleum and aggregate as defined in the Aggregate Act. There are currently 20 industrial minerals that are exempted under the Aggregate Act and are subject to the Mining Act. Thus, on Crown land industrial materials may be extracted:

- by obtaining an Aggregate Permit under the Aggregate Resources Act from the Ministry of Natural Resources. This choice grants the limited right to remove aggregate, but does not give land ownership. Its advantage is that approval is sometimes faster. Royalty fees and a rehabilitation levy must be paid. Conditions that specify site procedures and rehabilitation requirements will be written into the permit.

  OR

- by staking a mining claim, recording it with the Provincial Recording Office and bringing the claim to lease under the Mining Act. A leaseholder can mine industrial minerals once mine closure requirements of the Mining Act and other pertinent environmental and safety legislation are met. The definitions in the Mining Act indicate that sand, gravel and peat are not a mineral, therefore, when one stakes a mining claim those materials are not included in the rights of the claim holder. For sand and gravel on Crown land apply to the Ontario Ministry of Natural Resources for an Aggregate Permit under the Aggregate Resources Act.

MNR is the Crown's steward for lands and surface rights. The ministry's mandate is to administer, protect and conserve public lands; its domain includes land, water, trees, fish, animals and certain minerals. When a permit to extract is requested, MNR officers will consider all of the interests on Crown land and could refuse the permit application.

For additional information on the Aggregate Resources Act contact the nearest Ministry of Natural Resources office. You can access the Aggregate Resources Act and its regulation on the government’s e-law web site http://www.e-laws.gov.on.ca.

XI) CONTACT AND RESOURCE LIST FOR SERVICES UNDER THE MINING ACT

On the Mining Lands Section web site http://www.mndm.gov.on.ca/mndm/mines/land/s/default_e.asp you will find:

- Mining Act policies
- Forms
- Fees
- mining claim maps
- mining claims information per mining claim
- information about the Provincial Recording Office and how to contact staff
- information about assessment work
- a staking guide
- a link to the Mining Act and its regulations

You can also access the Mining Act and its regulations directly on the internet at http://www.e-laws.gov.on.ca.

Services are also provided at a number of MNDM offices across the province. Locations, and the services provided are available at: http://www.mndm.gov.on.ca/MNDM/MINES/L
Contact information for several offices is also listed below.

PROVINCIAL RECORDING OFFICE (and Sudbury Mining Division)

Phone:  (705) 670-5742
Toll free:  1-888-415-9845
Fax:    (705) 670-5681
Toll free Fax:  1-877-670-1444

Address:  933 Ramsey Lake Road, 3rd Floor, Sudbury, Ontario, P3E 6B5

For questions about assessment work call: 1-888-415-9845.

MINING LANDS CONSULTANTS

Thunder Bay Mining Division
435 James St. South, Suite B003
Thunder Bay, ON P7E 6E3

Phone: (807) 475-1311
Fax: (807) 475-1124

Porcupine Mining Division
Porcupine Mining Lands Consultant's Office
E Wing, Ontario Government Complex,
P.O. Bag 3060, Hwy 101 East,
South Porcupine, ON P0N 1H0

Phone: (705) 235-1600
Fax: (705) 235-1610

Larder Lake Mining Division
Larder Lake Mining Lands Consultant's Office
10 Government Rd. East
Kirkland Lake, ON P2N 1A8
Telephone: (705) 568-4521
Fax: (705) 568-4524

PARTIAL SERVICES

Southwestern Ontario
Resident Geologist Program
Macdonald Block, Room M2-17, 900 Bay St.,
Toronto, ON M7A 1C3

Phone: (416) 314-3800
Fax: (416) 314-379

Southern Ontario - Tweed
Resident Geologist Program
126 Old Troy Road, Bag Service 43
Tweed, ON K0K 3J0

Phone: (613) 478-3161
Fax: (613) 478-2873

Government Information Centres

There are several Service Ontario Government Information Centres (GICs), which offer partial Mining Act services. Both the number of GIC offices offering these services and the types of services are increasing so it is best to contact the nearest GIC to see if they offer Mining Act services and what services they do provide.

ORDERING CLAIM MAPS

To order claim maps contact:

Publication Sales
933 Ramsey Lake Rd., Level A3
Sudbury, Ontario P3E 6B5
Tel: 1-888-415-9845 (toll-free inside Canada and the United States)
Tel: (705) 670-5691 (local calls)
Fax: (705) 670-5770
E-mail: pubsales@ndm.gov.on.ca

or visit the Mining Lands Section web site
http://www.mndm.gov.on.ca/mndm/mines/land
s/default_e.asp

XII) MINING AGREEMENTS

i) Introduction

It is very expensive to explore and develop a
mineral property. Therefore, most prospectors enter into a mining or exploration agreement with another party (mining company, syndicate, and individual) whereby the other party agrees to: 1) develop the property to and beyond the point of production; or 2) finance the prospector's exploration ventures. Entering into agreements accompanied by long legal documents is an aspect of the mining business for which many prospectors are not prepared. It may be considered to be a waste of effort to negotiate the terms of an agreement on an occurrence that will probably never become a mine. However, no one can predict what property will develop into a producing mine, therefore, all mining agreements must be negotiated and settled assuming that every property may become a mine.

Prospectors require some knowledge of mining agreements and money raising and property selling techniques so that they can be effective at selling and optioning their mineral occurrences. A prospector should seek advice from a lawyer who is familiar with mining law before signing any mining agreements. Prospectors should know and understand the general rules of the mining business so that their demands and proposals are reasonable with regard to the value of their project and/or property.

Most exploration agreements create a partnership where both parties: 1) have an interest in the property; 2) are interested in seeing the property explored; and 3) will profit from production. During the negotiation of property agreements, everybody is enthusiastic about the property and in the eagerness to get the deal signed some important details may get overlooked or not given enough thought. A few months later, perhaps after the first few drill holes have failed to intersect interesting mineralization, both parties begin to take a long hard look at the agreement. At that time the prospector will be thankful to have received the advice of a lawyer when the deal was negotiated (Scott 1984).

Efforts to sell or option the property should be directed at mining companies who will be interested in the property. Many companies may restrict the type of commodity they are looking for and others may be totally unfamiliar with the area where you are working. Therefore, approach companies who have local or regional field offices with geologists who are familiar with the area and who are able to visit your property; be sure they are interested in the mineral or metal commodity you have found; and determine whether they are financially able to make work commitments and option agreements. Check into the background of the company to determine: how long they've been in business; what their assets are; the value of their shares; what other properties they own and so on.

A prospector should have an organized and well-planned property report to submit to a mining company. The property should be well exposed with sample locations clearly marked on the outcrops so that company representatives can make a proper evaluation. The prospector should also have an outline of some reasonable proposed terms of agreement that can be discussed and negotiated with the mining company. Always give some thought to what you want from a mining agreement and make sure you know what your property is worth.

A prospector can use some of the following criteria to assist him in determining the value of a property:

- The technical merits of a property are a prime consideration in determining the worth of a property. A good showing in a geologically favourable environment will bring a higher price than speculative claims staked in a relatively unknown area (Walker 1984).

- A prospector's expenditures on the property also affect its value. A prospector who has completed extensive work on a property should receive better terms in an agreement than a person who has staked on speculation. However, a mining company will not expect to assume a proportionate share of the cost of prior work, which has been badly directed and is of little or no value (Walker 1984).
- Competition affects the value of a prospector's claims. A very good offer will be required to obtain a property in the vicinity of an important new discovery or producing mine (Walker 1984).

ii) Property Examinations

A property examination by a company will usually consist of one visit by one or two geologists. They will examine outcrops and mineralization and they will expect to take samples for analysis. The geologist will also verify any statements you have made about the property. Do not allow the geologist to conduct geophysical tests; detail map your property; take channel samples; or take a very large sack of soil samples for geochemical tests. You want your property examined to create a favourable impression but you should not allow it to be explored until after a deal is signed. Remember to ask lots of questions so you can assess the experience and ability of the geologist and the attitude of the company (Faulkner 1986). Do not expect to get an immediate yes or no response about making a deal. The company will have to wait for assay results and do some research. Ask when you can expect a decision and if you haven't heard by the stated time, contact them. The company should provide you with the results of any sampling they conducted on your property whether they option your claims or not.

After negotiations are concluded, but before a deal is signed, the prospector and the mining company may sign a letter of intent. The letter will state that both parties will sign a deal, containing the terms agreed to during the negotiations, on or before an agreed date. This provides the prospector and company with some protection while the fine details of the formal agreement are worked out. There may be no problems with a letter of intent but it should be scrutinized to ensure that it is not an agreement. If it is signed, the company will delay replacing it with another document and may use the general and incomplete language of the "letter" to get away with liberties and abuses. Most importantly, there may be very little a prospector can do about it. Beware of any language in a letter of intent that may suggest it is an agreement such as "this agreement is binding" or "if you accept the terms of this agreement" or if the letter has no deadline date for replacement by a formal agreement.

There are two general types of mining agreements: 1) Agreement of Disposition and 2) Financial Agreements. The following sections describe these mining agreements and discuss points to consider when negotiating terms of agreement.

iii) Agreements of Disposition

Disposition agreements are made when a prospector has full legal title to the mining property and enters into an agreement with a mining company where the company can obtain complete ownership of a percentage of the property. The two types of disposition agreements are: i) the outright sale of the property and ii) an option agreement.

a) Sale of a Property

If a property is sold for cash or shares then nothing more is required other than a transfer or Bill of Sale from the prospector to the purchaser. In addition to a Bill of Sale, an agreement for sale will be negotiated to specify in more detail the terms of payment and to commit the prospector to certain warranties of title (Lau 1982). The prospector relinquishes all title and interest in the mining claims on the date of the transaction.

b) Option Agreements

In an option agreement the prospector grants to another party the right to acquire an interest in the property. The optionee (mining company) can earn its interest by:

- making payments to the prospector (cash, shares or both)
- conducting work on the property; and
- promising to pay the prospector a percentage of the revenue from the resulting mine, if there is one.
In most agreements the prospector negotiates a deal which:

- provides for immediate reimbursement of the prospector's out of pocket expenses
- provides progressive cash payments known as option payments (i.e.: a prospector receives $1000 after the first year of the agreement; $2000 after the second year; $5000 after the third year; and so on)
- guarantees exploration work commitments;
- provides a royalty based on the mineral production from the property, if there is any.

Option agreements can be variable and complex, therefore, it is essential that the prospector obtain the services of a lawyer when negotiating and settling the agreement. Most option agreements are negotiated for 3 to 5 year periods. After each year the mining company can terminate the agreement, if it decides that the property does not merit further exploration or development, and only after making the option payment for the previous year. If the mining company has fulfilled its obligations to the agreement then it may acquire full title to the mining claims.

Some mining companies have "Standard Forms" for option deals where a geologist or other official has the authority to fill in blanks with your name, details of your property, and so on, as well as to write out a cheque for any cash up-front. You are offered a completed package with no negotiations, hassles, delays or uncertainties. A standard form from a major company should be one that has gained some acceptance among prospectors and you may accept it even though it does not offer all the terms you want. However, always have a lawyer examine the documents before you sign them.

The following are some terms a prospector should try to get in an option agreement:

1) Sufficient cash should be paid to the prospector to cover costs of acquisition and to provide the prospector with a profit. Try to get as much cash up front as possible, rather than seeking attractive later provisions, because very few option agreements get beyond the first or second year. A prospector should seek enough money to: recover prospecting and staking costs on the property; costs of any work done since staking; legal fees; and anything extra you can get (Faulkner 1986). The cash should be paid when the agreement is signed. Junior companies may wish to issue shares to the prospector in lieu of cash, which usually provides a satisfactory front-end payment while allowing a prospector to retain a worthwhile interest in the property (Scott 1984).

2) The agreement should ensure that the company performs work of increasing value on the property for the duration of the option agreement. Exploration work should be conducted and data submitted for assessment credits to keep the property in good standing. Enough work should be performed to keep the mining claims in good standing for at least one full field season after the termination of the agreement. This allows the prospector time to re-option the property. There should also be an increase in the periodic cash payments made to the prospector. The agreement should state that the option would terminate on or before a prescribed date if an option payment were not met by the company. The mining company may also insert a stipulation into the agreement that requires the prospector to notify the company when an option payment is due.

3) The company should provide reports to the prospector on a periodic basis (i.e. every 6 months) to provide information on the progress of the work on the property. The agreement should state that copies of all maps and other data would be delivered to the prospector at the termination of the option agreement. This information should be kept confidential by both parties for the duration of the agreement.

4) The prospector should negotiate a retained interest or **royalty payments** which are periodic payments paid by the mining company if the property is brought into
production. It should be noted that by the time a property reaches production the prospector usually has no further right or title in the property, therefore, royalty payment is simply a contract obligation covered by the option agreement. The common types of royalty payments are:

**Gross Proceeds Royalty** - a prospector receives a percentage of the gross value of the mined ore.

**Tonnage Royalty (Product Payment Royalty)** - a prospector receives a fixed amount of cash for each ton of ore that is mined and processed through the mill.

**Net Smelter Return Royalty (N.S.R.)** - a prospector receives a percentage (1% to 4%) of the gross value of the ore after deduction of charges (i.e.: mining costs, mill treatment costs, refining and smelting costs, transportation costs) for preparing and transporting the ore to the smelter or any other buyers. N.S.R. is the most common form of royalty payment and is paid to the prospector regardless of the profitability of the mine.

**Net Proceeds Royalty (Net Profit Interest)** - a prospector receives a percentage of the N.S.R. after the deduction of other expenses including: operating costs, labour costs and pre-production expenses. Net proceeds are a percentage of what the mining company considers to be the net profit from the ore. The problem is to define what "legitimate expenses" will be deducted from the net smelter return. If the expenses are not outlined in great detail in the agreement a prospector could discover that all types of expenses are being deducted from profits leaving very little net smelter return for the prospector to share in. In the majority of situations the net profits interest will be to the advantage of the company and the net smelter return will be to the advantage of the prospector (Faulkner 1986).

**Interest dilution** could occur when there is a reduction in a prospector's interest in a property due to such things as: the sale of more units of a syndicate; or the issuance of more shares in a company (if your interest is in shares). The signing of a second deal involving a property can also dilute a prospector's interest. For example, let's assume that a prospector's retained interest in a property, at the end of an option agreement, is 5% of any profits the company makes from the property when they put it in production. The company may have to enter a deal with another company to acquire finances for development of the property, retaining only a 10% interest for themselves. As a result of this deal, the prospector's interest is reduced from 5% to 5% of the 10% or only 0.5% (Faulkner 1986). Your agreement should state that any new operator of the mine or new partner in the interest of the mine will honour royalty payments in the event of a sellout or formation of a new company.

5) Additional claims staked by the mining company within a specified distance from the property, should be considered part of the property covered by the agreement.

6) Upon termination of the agreement the mining company is given a specified period of time to remove equipment and supplies from the property. After this date, the prospector becomes the owner of the items.

7) That all work done on the property by the mining company is conducted in accordance to applicable laws and legislation. The company should be responsible for all reclamation work required during the period of the agreement. You do not want to have to clear up a mess left by the company to satisfy the Ministry of the Environment, Natural Resources or any regulations under Section IX of the Mining Act.

8) A prospector should receive specified advance royalty payments if the mining company refuses or delays bringing the property into production for reasons other than the property's own merits. Major companies with several operating mines may be in no hurry to start up another one. Therefore, a production decision may be made on your property but with no start-up date set and with no money coming in for a very long time. Advance royalties discourage companies from...
"sitting on" your property and provide you with income before production starts. If advance royalties are paid the company usually deducts them from royalties due when production starts. The company may also offer to buy-out your royalties as an alternative to advance royalties (Faulkner 1986).

Prospectors should also be aware that they have certain obligations under agreements. These obligations are the representations and warranties of the prospector as to the title of the mining property. If the warranties are breached the mining company can terminate the agreement and sue the prospector for damages suffered as a result of the breach. Therefore, at the date of signing the agreement, the prospector must ensure that:

- the prospector is the legal, beneficial and recorded owner of the mining claims;
- the mining claims are in good standing;
- the mining claims are free of liens and charges;
- the prospector has the right to enter an option agreement (i.e.: the prospector may be part of other partnerships that require approval before an agreement can be signed);
- all other parties with an interest in the property are identified and aware of the agreement;
- the mining company may insist on the right to abandon and restake claims (i.e.: if the claims are improperly recorded or staked) and to reduce the size of the claim block to a more manageable size on written notice to the prospector;
- the mining company would have an exclusive right to explore and develop the property for the duration of the option agreement;
- upon signing of the agreement, the mining company can acquire an interest in the property;
- upon completion of the agreement the mining company would acquire full title to the property;
- valid transfers should be delivered by the prospector to the mining company or to a third party (escrow agent) at the start of the agreement. Upon completion of the agreement the mining company would retain the transfers, or upon termination of the agreement, the transfers would return to the prospector.

Another term of agreement that is part of some option deals is the right of first refusal. The mining company would have the first opportunity to purchase the prospector's interest in the property if the prospector chooses to sell. The mining company would have the right to veto the sale of all or part of the prospector's interest in the property to parties the company deems unacceptable. This ensures that the mining company does not end up with an unacceptable working partner. The mining company may also buy-out the prospector's retained interest from production (royalty payment) if the prospector chooses to sell it. The mining company may also wish to retain an interest in the property after termination of the option agreement: this clause is rare and should be avoided by the prospector because it may make it difficult to re-option the property. A company that wants to make a deal with you would also have to negotiate with any third party that holds a retained interest. This complicates agreements and reduces your chances of getting another deal.

**iv) Financial Agreements**

Financial agreements are made so that a prospector is financially backed by an individual or group (partner, mining syndicate, mining company) to explore in a specific area and/or for a specific commodity. The prospector is supplied with a cash advance or is compensated for expenses. Any discoveries made and staked by the prospector become the property of the financial backers. The prospector is compensated financially or acquires an interest in the mining claims. The interest the prospector acquires can be as follows:

**Undivided Interest** - a prospector obtains
complete ownership in a percentage of the mining claim. Sale of the claim requires the prospector's consent.

**Participating Interest** - a prospector must contribute financially to any development of the mining claim in order to maintain a percentage of interest in the claim. Failure to contribute would dilute the prospector's interest. This type of interest should be avoided unless you have direct control over all spending. Others who have participating interests may run up bills and if they go bankrupt or disappear you'll end up paying a portion of all their debts. You may also be required to provide funds for any exploration or mining in proportion to your participating interest. (Faulkner 1986).

**Carried Interest** - a prospector retains an undiluted interest throughout the development of the claim without having to contribute financially. The prospector's interest is not usually in the ownership of the claims but in proceeds from production.

**Vendor's Interest** - a prospector is entitled only to a percentage of the proceeds (cash, shares) from the sale of the claims.

The two common financial agreements prospectors are likely to enter into are: i) Syndicate Agreements; and ii) Grubstake Agreements.

**a) Syndicate Agreements**

A mining syndicate has a certain capitalization that is divided into units which the prospector or organizer of the syndicate can sell. In return for money, the prospector undertakes to prospect and stake anything that is found in a specified area. Purchasers of units acquire a proportionate interest in the mining claims according to the terms of the syndicate agreement.

Participants in a syndicate are usually protected by the fact that their liability in a lawsuit is limited to the total assets of the syndicate. Therefore, there is no personal liability in the shareholders or participants. Most syndicates are formed for a limited purpose and for a limited period of time. In other words, they are created and last for a specific venture. Syndicate agreements may be subject to possible securities regulations.

**b) Grubstake Agreements**

This is the most common and well known financial agreement prospectors can involve themselves in. A grubstaker is an individual or group who provides financial backing to prospectors who are searching for or developing mineral properties. The relationship of a grubstaker to a prospector is similar to that of an owner to a contractor, an employer to an employee or a partner to a partner. Any discovery made by the prospector entitles the grubstaker to a majority interest, while the prospector retains a smaller percentage of interest in the discovery.

**c) Terms for Financial Agreements**

All financial agreements, whether a syndicate or grubstake agreement, should have the following terms:
- clearly specify the purpose of the agreement;
- specify an expiry date for the agreement;
- if a prospector's activities are limited to a specific area or property, then the limits of the area should be defined as accurately as possible;
- if a specific commodity or commodities are being prospected, then they should be clearly stated;
- the interests of the prospector and the financial backers in the event of a discovery should be clearly defined;
- persons who are authorized to deal with other outside parties should be identified.

**INCOME TAX**

Prospectors are subject to the same general rules as other taxpayers in determining their employment or self-employed income. As a prospector, you are allowed to claim Canadian Exploration Expenses (CEE) incurred in your
search for minerals. The Income Tax Act allows an expense to be claimed to the extent that it was made or incurred by an individual for the purpose of producing income from a business or property. Therefore, an expense directly relating to your prospecting activities may be claimed, provided you maintain accurate and organized records to prove that the expenses claimed were in fact incurred. Expenses must be supported by receipts and they must relate directly to the prospecting being done. The total must be reduced by any personal use included in your expenses, such as personal use of a truck. The value of labour you perform yourself cannot be claimed as an expense. A prospector may also be entitled to a share of CEE incurred by a partnership (syndicate) of which the prospector is a partner.

Certain assets you purchase cannot be totally deducted as an expense. Instead, you may claim a depreciation deduction known as capital cost allowance, which represents a portion of the value of the asset. You may claim capital cost allowance on tools, equipment and machinery that qualify for various rates of amortization. These deductions will be allowed only when the equipment is used solely for prospecting as opposed to personal or some other non-prospecting use.

A prospector should always consult with a tax advisor to determine what expenses are eligible for deductions. It is advisable to do this before initiating a prospecting program.
PART 7:

PROSPECTING TECHNIQUES:

PLANNING AND RESEARCH
PROSPECTING TECHNIQUES: PLANNING AND RESEARCH

I) DECIDING WHAT TO PROSPECT

Once you have decided to start prospecting, your next step is to set an objective or goal and decide what to prospect. Prospectors explore for mineral and metal commodities that are presently in demand. They may search for several types of minerals in a particular area, but are always alert for any unexpected mineral occurrences they may find while prospecting or other activities such as hunting, fishing, hiking, working and so on.

Price and demand for minerals are variable and a commodity that is popular now may be unpopular in six months time. Therefore, a prospector must stay informed on up-to-date metal prices; trends in demand for different mineral and metal commodities; new discoveries; current trends and activities in the mineral industry; and future prospecting possibilities for particular metals and minerals. Those commodities that are or will be in demand should be placed high on any prospector’s search list. The best way for a prospector to obtain this information is to read one or more mining newspapers or magazines, such as The Northern Miner, Canadian Mining Journal or the CIM Bulletin on a regular basis.

Some metals and minerals go through low and high cycles of interest and demand. It may be easier to prospect for a mineral that is experiencing a period of reduced demand because other prospectors and mining companies aren’t competing for it. Staked occurrences and prospects of the mineral may come open for staking due to the lack of interest. A disadvantage of searching for a mineral in low demand is that it will be difficult to interest mining companies in your discoveries (Lang 1970).

Once you have chosen one or several mineral commodities as your main objective, it is advisable to learn as much about them as possible, such as mode of occurrence, demand and uses. Learn what the size, grade and quality of a deposit of the mineral must be to make it economically valuable. Make sure that the mineral occurs in your local area: research where and how it occurs; and determine the rock and mineral associations related to the occurrences. Familiarize yourself with the geology of some of the main areas or mines where the mineral has been found or is produced. Learn the geological environments, regions or belts that are recognized as being favourable for hosting the mineral. All of this information can be obtained from the Resident Geologist’s office and public libraries.

It is not necessary to have only one particular mineral in mind as a goal for prospecting, since many areas host a variety of commodities. Always keep three or four commodities at the top of your search list. Keep an open mind and investigate anything that looks interesting.

II) DECIDING WHERE TO PROSPECT

Most prospectors explore for minerals in the area where they live or work, but they must still decide where they are going to concentrate their efforts. Most active prospectors focus their attention on the following types of areas:

1) An area for which the government has released reports, maps, geochemical or geophysical surveys aimed at stimulating exploration.

2) Areas that host known deposits that have increased in demand and value.

3) Areas containing occurrences of minerals that have received publicity on rising future demand.

4) Areas where there have been recent mineral discoveries or staking activity.

5) Areas with low exploration activity where research suggests a higher mineral potential than previously thought.

6) Areas with intense to moderate exploration activity or where mines have been developed.
7) Areas where the geological setting is favourable for the mineral commodity the prospector is looking for and which contain known occurrences or prospects of the commodity.

8) Areas where a particular metal or mineral has not been found or reported, but where geological conditions are reasonably similar to other localities containing important deposits.

9) Areas with new roads that provide and improve access in previously inaccessible areas. The building of new roads provides new and fresh rock exposures to prospect.

There are specific factors, however, that may constrain the choice of an area, such as:

Availability of Crown Land for Staking: The suitability of an area for prospecting largely depends on the availability of open ground and the degree of difficulty in acquiring mineral and surface rights. An area that contains important new discoveries and/or producing mines is generally very active and heavily staked with an abundance of patented and leased mining claims. Although these types of areas have high mineral potential, it is very difficult for the prospector to acquire ground. Areas where older occurrences, prospects and past producers are located are less popular and promising ground may be available for staking.

Prospectors should also be aware that mineral exploration is not allowed or restricted on land within: provincial parks; nature reserves; tree nurseries; First Nation Reserves; and areas that are sensitive habitats to specific types of wildlife. All of these situations restrict the availability of land for exploration and constrain the choice of an area. Land status, whether Crown or private, can be verified at appropriate Mining Recorder's offices. Ownerships of private land may be determined at Land Registry offices. Areas designated under the Aggregate Resources Act are shown on maps available from Ministry of Natural Resources Aggregate and Petroleum Resources Branch.

Accessibility: An area with good road and water access is relatively easy to reach; requires less expenditure on travel, supplies and mineral exploration; and is generally better covered by maps and reports. It is easier to get representatives of mining companies to visit your discovery in an accessible area. The disadvantage of good access is that the area is generally heavily prospected and may be heavily staked.

An area with poor accessibility may not be well prospected and it may be less active. Therefore, the prospector has an opportunity to make new discoveries with very little competition from other prospectors or mining companies. However, poor access requires more expenditures on travel, supplies and mineral exploration. A discovery in a remote area must have exceptional quality and good grade and size potential to interest a mining company.

Personal Considerations: A prospector should think about personal preferences and considerations, such as finances, experience and time, when deciding where to prospect.

A prospector's finances commonly influence the selection of an area. Exploration activities and ability to travel to remote areas is restricted by a lack of finances.

A prospector's time is also a consideration. Many people cannot afford to spend long periods of time in the bush and may only be able to prospect on weekends. A retired person, on the other hand, may have plenty of time to prospect and enjoy the bush.

A prospector's experience and familiarity with the bush is also a consideration. A person who lacks bush experience or is uneasy in the bush may prefer to work in accessible areas. Other prospectors relish bush life and may prefer remote regions. Prospectors may also prefer to explore areas where they have lived, worked, fished, hunted or trapped because they are more at home and familiar with that region.

Once an area of interest has been chosen, maps and reports must be selected for more detailed information. Geological, geochemical
and geophysical maps and reports, as well as topographic maps, claim maps, road maps and air photographs should be compiled and studied to familiarize yourself with the area and to acquire more detailed information.

III) GATHERING INFORMATION

A systematic information search is the next step in planning a prospecting program. A prospector’s research should begin in the Mining Recorder and Resident Geologist’s offices or on the MNDM website.

i) Mining Recorder’s Office

Prospectors can obtain claim maps for areas they’re planning to explore in the appropriate Mining Recorder’s office. A claim map indicates mining claim locations and provides information on land status. A prospector may also acquire information regarding land use restrictions and conflicts with other land use activities, such as timber cutting operations or aggregate permits. Prospectors can purchase a prospectors license, claim tags and government maps and reports at the Mining Recorder’s office and obtain all the forms necessary to record and transfer claims and submit assessment work. Most importantly, a prospector can obtain sound advice on any aspect of the Mining Act.

A prospector requiring information regarding the Aggregate Resources Act or Work Permits should consult the Ministry of Natural Resources who administers the Aggregate Resources Act and is responsible for the issuance of work permits.

ii) Resident Geologist’s Office

The Resident Geologist’s office provides a wealth of information regarding geology, mining and mineral exploration activities in their respective districts. The Resident and Staff geologists know the geology of their districts very well and will provide sound advice and assistance regarding mineral exploration. Below is a description of the many information sources and services available to the prospector, mining industry personnel and general public from Resident Geologist’s offices.

a) National Topographic System (N.T.S.)

Before describing the information sources available in the Resident Geologist offices it is necessary to describe the index system used to organize the information. Most Resident Geologist offices use the National Topographic System to index and organize assessment files, information files, maps, reports, air photographs and various other data. The N.T.S. is used to specify the location of any map area in Canada by means of a number and letter combination. The scales of maps are also related to the system so that a N.T.S. reference will provide you with the location of a map area and the map scale to expect (Faulkner 1986) (Figure 1).

Canada is divided into rectangles along lines of latitude and longitude. The rectangles are numbered so that the number increases by “tens” from east to west and by “ones” from south to north. Ontario is covered by rectangles that are numbered 30, 31, 32, 40, 41, 42, 43, 52, 53 and 54 (Figure 1). Maps in this sequence are published at a scale of 1:1 000 000 (Faulkner 1986). Each rectangle is subdivided into sixteen smaller rectangles that are each given a letter for example, 52A, 52B, 52C (Figure 1). Maps in this sequence are published at a scale of 1:250 000.

Each of the smaller rectangles is further subdivided into sixteen even smaller rectangles, which are given a second number, for example, 52A/1, 52A/2, 52A/3 (Figure 1). Maps in this sequence are published at a map scale of 1:50 000.

The smallest rectangles are subdivided further into northeast, northwest, southeast and southwest quadrants, for example, 52A/1NE, 52A/1NW, 52A/1SE, 52A/1SW (Figure 1). Maps in this sequence are published at a scale of 1:15 840. Ontario claim maps are included in this sequence but are published at a scale of 1:31 680. Regions that are subdivided into townships have claim maps that are also subdivided according to
Figure 1: The National Topographic System (N.T.S.)

Scale 1:31 680
This map is 52A/16N

Scale 1:250 000
This map is 52P/8

Scale 1:250 000
This map is 53L
townships.

b) Assessment File Library

The assessment files are available for free public use and are comprised of geological, geophysical and geochemical surveys, assay data, diamond drill logs and a wealth of other information that has been filed for assessment work credits by mining and exploration companies and individuals since 1941. Each Resident Geologist's office has a complete assessment file library for their own district. The assessment files are indexed according to N.T.S. reference numbers, which corresponds to claim map areas. Assessment files may also be indexed according to townships in surveyed and subdivided areas of Ontario.

The assessment files are commonly cross-referenced to an assessment work overlay that consists of a mylar overlay sheet attached to a claim map. Areas where assessment work has been conducted are indicated as blocked-out sections on the mylar overlay sheet. The areas are numbered and cross-referenced to their corresponding files in the assessment library. A list which accompanies the overlay indicates: 1) who did the assessment work; 2) the date the work was done; and 3) the type of work completed. Many offices have digitized these index maps and the process is ongoing.

The assessment filing system may differ in some offices, therefore, asks someone in the Resident Geologist's office to explain their system to you.

c) Information Library

The information libraries in most of the Resident Geologist's offices contain the following information that can be used during your information search.

Provincial Government Reports and Maps: These are various types of geoscience publications, released to the public by the Ontario government, that cover a wide range of topics regarding geology and mineral exploration. Most offices are only able to keep maps and reports that refer specifically to their districts, however, many offices maintain complete collections of annual and geological reports. There are microfiche copies of all reports and maps and each office has publication indexes. The various types of reports and maps are described in detail in the "Publications" section of this manual.

Federal G.S.C. Reports and Maps: These are geoscience publications released by the Geological Survey of Canada that refer to the Resident Geologist's District. These maps and reports may cover a wide range of topics, such as Quaternary geology, geochemical and geophysical surveys, bedrock geology and special studies.

Mineral Deposit Files: This is a system of files, indexed according to N.T.S., that summarize all known data on location, development, ownership, geology, ore minerals, reserves, production and references for all known mineral occurrences, prospects and mines. These files are updated periodically.

Historical Files: These are files containing historical information on numerous mineral deposits in the Resident Geologist's District. They consist of a variety of clippings from old newspapers and other historical information sources for many mineral deposits. The historical files contain valuable information on mineral properties, such as descriptions of locations and access, production data, assay values and exploration information that cannot be found in other publications. These files are indexed according to N.T.S. or by township and organized alphabetically by property or company name.

Newspaper Clipping Files: These files are collections of recent newspaper clippings, which refer to various mineral deposits in the Resident Geologist's District. The files may be organized alphabetically by the name of the mineral property or by the name of the company that has worked on the property.

Thesis Library: This is a collection of unpublished university theses (BSc. MSc and PhD) completed in the Resident Geologist's
District. Thesis work is usually very specific, academic and scientific.

**Reference Library**: This is a collection of articles and scientific papers from geological magazines and journals that cover a wide range of geoscience topics. The Reference Library contains articles on mineral deposits, mineral potential and other aspects of geology related specifically to the Resident Geologist’s District. Current mining newspapers and magazines, such as the Canadian Mining Journal, The Northern Miner and The CIM Bulletin are also available for viewing at most offices.

**Quaternary Geology Library**: Some Resident Geologist’s offices have a library of Quaternary geology maps, reports, articles and papers that provide information on the surficial, glacial geology in their districts.

**Canadian Mines Handbooks**: Most Resident Geologist’s offices have a complete collection of Canadian Mines Handbooks. These handbooks list all of the mining and exploration companies working in Canada. The handbooks provide a wealth of information on each company, such as a company’s head office address; names of company executives and directors; a list of the company’s properties and holdings; and profit and loss statements. The handbooks also contain information on specific mineral properties and ore reserves.

**Mineral Deposit Inventory (MDI)**: The Mineral Deposit Inventory or MDI is a computerized geoscience database established in the early 1970’s. The MDI database is an overview of mineral deposits across Ontario and is comprised of two parts: 1) a digital index of about 20,000 records on mineral deposits; and 2) hard copy, paper files containing information on mineral occurrences and deposits in Ontario. The paper files are available in each Resident Geologist’s office. The MDI files are continuously updated and reviewed and new records added as required. The MDI database emphasizes deposit names; location of the deposit; size of the deposit (i.e.: occurrence, prospect, producer); minerals; commodities; and references to information in government reports and maps, assessment files and newspapers.

**d) Other Information**

Below is a list of other information available for use or viewing in a Resident Geologist’s office.

**Air Photographs**: Provincial and Federal air photographs are available in most offices. Provincial air photographs are also available for viewing in local M.N.R. offices. Resident Geologist’s offices may also have large photomosaics and landsat photographs for their districts.

**Bathymetric Maps**: Maps that depict lake bottom contours. These maps may not be available at every office.

**Field Trip Guidebooks**: Published guidebooks for geological field trips given within the Resident Geologist’s District during various geological conferences.

**Microscopes and Other Equipment**: Many offices have binocular, optical and reflecting microscopes that can be used to study rock samples, thin sections and polished sections. Some offices have ultraviolet lamps to check fluorescence; scintillometers to check radioactivity; portable rock saws; geophysical equipment; wajax pumps; rock drills; and other equipment a prospector may use.

**Mine Plans**: Many offices have mine plans from closed and operating mines in their districts.

**Ontario Geological Survey Field Notes**: Some offices may have the original field notes and air photographs used during geological mapping surveys conducted by the Ontario Geological Survey. Some of these notes consist of detailed outcrop descriptions that may be useful to the prospector.

**Other Geological Publications**: Offices may have libraries of various types of special papers and publications released by the Geological Association of Canada (GAC), Canadian Institute of Mining (CIM) and many
other organizations.

**Road Maps**- Maps of roads, such as logging roads, are available at most offices as well as information on road conditions, such as washouts, etc.

**Rock and Mineral Collections**- Collections of rocks and minerals from the Resident Geologist's District, and elsewhere, are displayed at each office. Many offices have specific collections of rocks and minerals from various occurrences, prospects and mines in their district.

**Topographic Maps**- Offices have complete collections of all topographic maps for their districts at various scales (i.e.: 1:20 000; 1:50 000; 1:100 000, etc.)

**Videos**- Government produced videos (VHS), such as "Hidden Heritage"; "Full Circle"; "100 Years of Discovery" and four videos on the Mining Act are available for viewing at Resident Geologist's offices. Some offices may also have videos produced by other organizations.

**iii) Publications**

A large amount of geoscience information is published each year by the Ministry of Northern Development and Mines. Reports and maps can be viewed at the John B. Gammon Geoscience Library, Willet Green Miller Centre, Sudbury; the Mines and Minerals Information Centre (MMIC) library, Toronto; and at the Regional Mines and Minerals office(s) responsible for the area covered by the publication. All regional Mines and Minerals offices are over-the-counter sales outlets for publications that report on work performed in their region. All Mines and Minerals publications are available for sale at the Publication Sales office located in the Willet Green Miller Centre in Sudbury. The Publication Sales office also handles all telephone, mail and fax orders. Tel: 1-888-415-9845 (toll-free inside Canada and the United States); Tel: (705) 670-5691 (local calls); Fax: (705) 670-5770; E-mail: pubsales.ndm@ontario.ca.

Prospectors can keep abreast of the information by obtaining a free **Publications Release Notice**, which is an advance notice of forthcoming publications issued six times a year. You can be placed on an email distribution list for these notices by simply sending an email to pubsales.ndm@ontario.ca. Releases notices are posted 2 weeks prior to the release at the following website: [http://www.mndm.gov.on.ca/mndm/mines/ims/pub/release_e.asp](http://www.mndm.gov.on.ca/mndm/mines/ims/pub/release_e.asp).

**Miscellaneous Paper 77** entitled "Index to Published Reports and Maps" is a complete index of all geoscience publications released by the Ontario government. This publication is updated by supplements published every few years. There are also numerous map indexes available for most reports and maps.

Below are descriptions of the majority of publications released to the public.

a) Maps

**Final Maps (2000 Series)**: Final maps are detailed, coloured, bedrock geology maps produced at various scales, which result from geological mapping surveys conducted across the province by the Ontario Geological Survey (formerly Ontario Division of Mines). These maps commonly accompany Reports and some Studies. This map series includes a variety of coloured geological compilation maps that cover large areas of the province. There are also map compilations of mineral deposits, geophysical, geological, and structural data. All Final Maps are produced in the 2000 Series.

Old bedrock geology maps published before 1959 are not part of the 2000 Series and are described with "Annual Reports" in this manual.

**Geophysical-Geochemical Maps (80 000 Series)**: The geophysical maps in this series are the result of airborne magnetic and electromagnetic surveys flown over areas with high mineral potential. The geophysical data is presented on a series of maps at a scale of 1:20 000. Aircraft flight lines are superimposed over a green map face, which
is an airphoto mosaic of the area that was flown. A second set of maps at a scale of 1:31 680 accompanies the green maps and present electromagnetic data superimposed on flight lines and a brown or grey airphoto mosaic. The geochemical maps provide information on various geochemical surveys including backhoe till sampling and sonic drill hole data. The majority of these maps refer to areas in Northeastern, Southeastern and Southern Ontario.

The majority of Geophysical-Geochemical Maps are produced in the 80 000 Series Maps introduced in 1979. These maps were released in the P. Number Map Series prior to the 80 000 Series. Uncoloured airborne magnetic maps and radioactivity maps, released in the 1950’s may still be available for viewing in Resident Geologist’ offices.

Geological Data Inventory Folios (GDIF): Geological Data Inventory Folios provide a map-based index of assessment files and all other geoscience data in the area of coverage. The folios provide index and data maps at a scale of 1:31 680 and include summaries of drill hole data; geophysical and geochemical data; accurate locations of all known mineral properties; summaries of assessment work; and references.

Northern Ontario Engineering Geological Terrain Study (NOEGTS) Maps (5000 Series): These reports and maps include detailed descriptions of engineering geology and surficial terrain studies of specific areas. Most coloured maps are accompanied by a User's Manual and a report. The maps provide information on glacial deposits and the type of overburden in an area. All NOEGTS maps are published in the 5000 Series Maps.

Preliminary Maps (P. Number Series Maps): This series includes monochrome and coloured maps on a variety of geoscience subjects such as Precambrian bedrock geology, drift thickness, geochemical, geophysical and geochronological data, mineral deposits, petroleum resources, Quaternary geology, Paleozoic geology, pit and quarry status and structural geology. To expedite the release of maps in this series, Preliminary Maps have not gone through a technical edit. Preliminary Maps may be followed by more fully edited Final Maps.

b) Reports

Aggregate Resource Inventory Papers (ARIP): These are reports on the nature and extent of aggregate resources within a specific area and are accompanied by coloured or uncoloured maps illustrating areas of high extraction potential for planning purposes.

Annual Reports. (AR): These reports were published annually between 1891 and 1959 and are comprehensive volumes that include: most final geological reports and coloured maps completed during the year; reports by Mines Inspectors on mines in Ontario; and statistical reviews of the mineral industry in the province. Annual reports and maps can be purchased separately but some of them are now out- of- print. Final maps published before 1959 are not part of the Final Maps (2000 Series) and are numbered by the year they were published. After 1959, the Annual Reports were followed by a separate report series for geological and statistical reports.

General Index Volumes: These consist of nine volumes, that list references by subject and report numbers for all reports of the Ontario Geological Survey. These indexes will provide the first specific map and report references covering the area or subject being investigated. For example, looking up names and topics, such as Vermilion River, Dog Lake, drag folds, uranium or copper, provide specific references to the maps and reports in which these subjects are mentioned. The references that appear to be of interest can be consulted for the required information.

Guidebooks (GB): Guidebooks, formerly Geological Guidebooks, are interesting, informative and colorful guides to the geology, physiography and scenery of specific areas in Ontario. Guidebooks emphasize geological features that can be observed along main highways in the province.

Industrial Mineral Background Papers (IMBP): These were formerly Industrial
Discover Prospecting

Mineral Reports. They cover a wide variety of subjects related to industrial minerals and provide the background information needed by government agencies and aggregate industry companies in order to make economically viable decisions.

Mineral Deposit Circular (MDC): These publications were formerly known as Mineral Resource Circulars (MRC) and are comprehensive inventory and geological characterization studies of specific types of mineral deposits, commodities and resources, mainly on an Ontario-wide or regional basis.

Miscellaneous Paper (MP): Miscellaneous Papers may cover any geoscience subject. They were formerly known as Preliminary Reports and Study Series Reports. Miscellaneous Papers are prepared for prompt public release and have included up until recently, annual publications, such as the Report of Activities of the Resident Geologists, Summary of Field Work and Other Activities of the Ontario Geological Survey and Geoscience Research Grant Program described below. Report of Activities and Summary of Field Work and Other Activities are not published as Open File Reports (see below).

The Report of Activities of the Resident Geologists is released each year in early spring and summarizes mining activities and mineral exploration work completed by individuals and companies in each Resident Geologist's District. The report is written by the staff of the Resident Geologist's office and includes recommendations for exploration, descriptions of various mineral properties and descriptions of projects conducted by the staff.

The Summary of Field Work and Other Activities of the Ontario Geological Survey is released each year in mid-December and includes brief summaries of field mapping projects, mineral deposits studies, etc., conducted by staff of the Ontario Geological Survey. New information of economic importance, such as the location of new mineral showings or descriptions of favourable geological and/or structural conditions for mineral exploration is published in this report.

The Geoscience Research Grant Program, no longer active, was published each mid-December and consisted of summaries of scientific research work funded by the Ontario Geoscience Research Grants Program. This work was commonly conducted by staff and students of various universities for research on geologically related projects.

Mineral Policy Background Paper (MPBP): This report series covers a variety of subjects each related to the background information needed by government agencies and companies to make in-depth economic decisions on metallic mineral matters.

Open File Report (OFR): This series of reports is used to release information on field work and other research activities as soon as possible and without the delay required by editing and map preparation. Many of the open files are edited at a later date and published in one of the final Report Series.

Oil and Gas Paper (OGP): These reports include information on the exploration, drilling and production of oil and gas in Ontario. These reports have replaced the Papers-Oil and Gas Series, which were discontinued in 1979.


Reports: The Report Series, formerly referred to as Geological or Geoscience Reports, are fully edited reports and describe the results of detailed geological surveys and are accompanied by one or more coloured maps. The Report Series also includes synoptic studies, stratigraphic studies and detailed geophysical reports.

Special Volumes: The Special Volume Series was first issued in 1984 and is designed to publish comprehensive compilations on major
topics of broad interest to the geoscience community. The Special Volume series includes the flagship publication "Geology of Ontario", Volumes 1 and 2.

**Study:** The Study Series reports on new information or concepts of scientific merit not covered by other series publications. The content of this series varies but mainly covers larger areas than covered by the Report Series or discusses a specific subject.

c) Other Publications

**Miscellaneous Release—Data (MRD):** The MRD series allows for the release of digital data (usually geochemical in nature) that may or may not have been previously released in "analog" form in a report or map format. The files generally contain tables of data that can be manipulated by the user. Information that may be too impractical to include in an Open File Report (e.g., comprehensive set of field photos, extensive tables) are also release in this series. The data are generally released in CD-ROM format, and are sold separately from any associated publications.

**Geophysical Data Sets (GDS):** Geophysical Data Sets are used to release geophysical data. Contents may include profile and grid data, geotiffs, vector data, keating anomalies, and documentation. The series is released on CD-ROM or DVD-ROM.

**Groundwater Resources Studies (GRS):** The Groundwater Resources Study series seeks to better the understanding of Ontario’s groundwater resources through the collection, evaluation and distribution of geoscience data. The main objective of the series is to provide accurate information on a range of groundwater-related themes, including local-to watershed-scale aquifer characterization and delineation; geologic controls and influences on groundwater quantity and quality; and methods development. Products of the groundwater program include geoscience reports, data sets and protocols for information collection and handling.

iv) Drill Core Libraries (Ontario Drill Core Storage Program)

The purpose of the Ontario Drill Core Storage Program is to preserve and archive drill core obtained from mineral exploration programs. The Ministry offers significant assistance to the mining and exploration industry by storing drill core and making the related data available to the public. This information can be useful to prospectors as well as mineral industry personnel.

Core libraries are located in Kirkland Lake, Tweed, Sault Ste. Marie, Thunder Bay and Kenora. Each drill core library is under the direction of a Resident or District Geologist. The Resident Geologist or District Geologist should be consulted to make arrangements for viewing core.

Testing of cores and cuttings is permitted, provided that the results of any analytical work and the pulps of all samples are deposited with the program for safekeeping and public use. Arrangements may also be made for thin sections to be prepared at the user's expense, on the condition that the thin sections are also filed with the program. Microscopes for the examination of thin sections are available.

Each drill core library features a computerized system for indexing to provide rapid access to relevant information. Drill holes are catalogued by location, length, the company which provided the sample and assay data, if any. A catalogue of drill cores, updated on a regular basis, is available for use. Maps indicating drill hole locations are also available.

v) MNDM Internet Services

The purpose of the Ministry of Northern Development and Mines and Minerals Website is to provide secondary support to the Division as it works to focus on the provision of basic geological information gathering and interpretation in support of Ontario’s exploration, mine development and mining sectors and the administration of Ontario’s Mining Act in a fair and consistent fashion.

The Website provides a one-stop destination for a wide variety of information on services,
product and program listings and up-to-date information on Ontario’s mineral exploration and development. Also found within the site are web-based service delivery applications such as Claimaps, MCI (Mining Claims Information) and ERMES, (Earth Resources and Mineral Exploration website)

The MMD website located at [http://www.mndm.gov.on.ca/MNDM/MINES/default_e.asp](http://www.mndm.gov.on.ca/MNDM/MINES/default_e.asp) contains over 3000 pages and averages about 45000 visits per month.

The website is structured in a manner similar to the organizational structure of the Mines and Minerals Division itself. A sitemap highlighting program areas and key web entry points and can be found at [http://www.mndm.gov.on.ca/mndm/sitemap_e.asp#mines](http://www.mndm.gov.on.ca/mndm/sitemap_e.asp#mines).

**Mines & Minerals Site Map**

**Contact Us**
- Telephone Directory
- Mines and Minerals Offices & Publications
- Sales Offices
- Resident Geologist Program- Contact List
- Mining Lands Offices

**Mining Lands**
- Mining Claim Maps
- Mining Claims Information Abstracts & Reports
- Bulletin Board
- Mining Act Forms
- Mining Land Policies
- Assessment Work
- Land Tenure/Dispositions
- Land Withdrawals & Reopenings
- Brochures & Guides
- Ontario’s Living Legacy
- Mining Act and Regulations
- Provincial Recording Office

**Information and Marketing Services**
- MMD News Releases
- ERMES
- Publication Services
  - Release Notices
  - Errata
  - Ordering Publications

- Digital Data Catalogue & Data Licensing
- OGS Annual Reports
- Geoscience Library
- Investment & Marketing
  - Investment and Development Publications
  - Marketing Events
- Mining Facts
  - Ontario Mine Location Map
  - Statistical Bulletins and Directories
  - Historical Mining Image Archive
- Amethyst-Ontario's Mineral Emblem

**GeologyOntario**

GeologyOntario was officially launched in early 2007 as the Ministry of Northern Development and Mines new internet-based data discovery portal. It provides electronic access to all Ontario Geological Survey publications and assessment reports. GeologyOntario brings more than 85,000 reports, two million pages, 150,000 maps and hundreds of digital products together in a format that can be easily accessed and analyzed.

GeologyOntario uses a database management system in combination with a geographic information system map viewer to provide multiple search options of database records, geospatial information, and portable document format (PDF) image data from MNDM’s provincial geoscience databases. The map viewer can be used to link to and display other on-line map services, including Claimaps land tenure, and to generate multi-thematic maps at select scales. Data can also be queried through a full-text search option that searches on specific text strings within PDF documents.

Geoscience data currently available for search and download through GeologyOntario resides in the following six databases:

**Assessment File Database (AFRI)** - Assessment files are the technical results from exploration programs carried out on Crown Land in the Province of Ontario. The AFRI database currently houses 75,000 assessment files (150 Gigabytes of image data representing over two million document pages and maps) from the 1940s to the present and grows by approximately 1200 files per year.
Ontario Drill Hole Database (ODH) – This database contains surface and underground drilling data compiled from assessment files for which drilling credits have been claimed. Approximately 126,000 percussion, overburden, sonic, and surface and underground diamond drill holes are currently indexed.

Ontario Geological Survey Publications (PUB) – The PUB database contains a record of all reports, maps, books, and the more recent digital data sets, published by the Ontario Geological Survey. The database contains 18,000 records which represents approximately 3500 unique books, 10,000 maps and 500 digital data sets.

Mineral Deposit Inventory (MDI) - The Mineral Deposit Inventory provides an overview of mineral occurrences in the province of Ontario, presently contains more than 19,000 records, and is continually being updated and expanded.

Lithogeochemical Database (LGC) - Data in the Lithogeochemical (LGC) database are derived from rock samples collected by Ontario Geological Survey staff during field projects dating from the 1970s to the early 1990s. The database contains analysis (major oxides and trace elements) for approximately 31,500 rock samples.

Abandoned Mines Information System (AMIS) - A database of site assessments of the 6000 abandoned mine sites in Ontario.

Ontario Geological Survey
- ERMES
- Resident Geologist Program
- OGS Publications and Digital Data Information
- Geophysical Atlas of Ontario
- OGS Annual Reports
  - Summary of Field Work
  - Report of Activities
- Current Fieldwork Projects
  - OGS Posters
  - Sedimentary Geoscience
- Precambrian Geoscience
- Regulations for Geoscientists
- Summer Student Field Work Information
- Generalized Geology and Selected Mineral Deposit Map of Ontario

Mineral Development and Mine Rehabilitation
- Advanced Exploration and New Mine Development
- Mine Rehabilitation
- Financial Assurance
- Part VII Forms
- Part VII Legislation and Regulation
- Abandoned Mines Rehabilitation Program
- Industrial Minerals and Dimension Stone
- Ontario Dimension Stone Producers and Processors Directory
- Certification of a Remote Mine

Geoscience Laboratories (Geo Labs)
The Geo Labs website contains a “Schedule of Fees and Services”:
www.mndm.gov.on.ca/mndm/ mines/labs

Further information about analyses and services provided by the Geo Labs can be obtained by contacting the Data and Client Services Coordinator:
Tel. (705) 670-5637
Toll Free: 1-866-GEO LABS (1-866-436-5227)
Fax. (705) 670-3047

Main entry points which follow the layout of the sitemap are as follows:

1) Mining Lands section
http://www.mndm.gov.on.ca/MNDM/MINES/LANDS/Default_e.asp
which is mandated to provide orderly and equitable processes that ensure public access to crown mineral rights for the exploration and potential development of mining lands has extensive information available via the website. The information is updated nightly and includes:

• MCI (Mining Claims on Internet), a registry of mining claims in Ontario at
http://www.mci.mndm.gov.on.ca/claims/clm_in
tr.cfm
This registry can be searched by claim
number or by recorded claim holder. Reports
of active and cancelled/posted mining claims
can be created.

• CLAIMMaps, a database of claim maps in
Ontario at
http://www.mndm.gov.on.ca/mndm/mines/land
s/claimap3/default_e.asp
Maps can be found by entering a township or
area name, by “g-plan” number or by zooming
in to geographical areas starting with the map
of Ontario. The maps show active mining
claims; lands open to staking, lands withdrawn
from staking, leases, patents and other land
dispositions. The maps can be downloaded as
.png or .bmp images at no charge.

• Lands Withdrawn and Reopened to staking. A
list of lands withdrawn and reopened to
staking is available.

• Forms required for filing transactions. Most
forms required for filing transactions on mining
claims can be downloaded in a number of
formats.

• Other useful information on the website:
Brochures, including the Staking Guide and
the summaries of the staking and assessment
work regulations. A Bulletin Board outlining
recent decisions of the Mining Recorders and
Mining and Lands Commissioner can also be
found within this section.

2) Mines Group Section
http://www.mndm.gov.on.ca/mndm/mines/mg/
default_e.asp
whose role is to encourage, promote and
facilitate the sustained economic development
of Ontario’s mineral resources in
environmentally responsible manner. As well,
the Group administers Part VII of the Mining
Act which deals principally with the
rehabilitation of mines and mining lands in the
province of Ontario. The Mines Group
Website is divided into the following areas that
includes a summary of their contents as well
as the appropriate staff members to contact.

Advanced Exploration and New Mine
Development
• Definition of advanced exploration,
permitting requirements, application
instructions for bulk sampling, Notice of
Project Status and Notice of Material Change
forms and links to the wording of the current
legislation.

Mine Rehabilitation
• Overview of recent changes to Part VII of the
Mining Act and Regulations thereunder and
the abandoned mines databases and reports;
Notice of Project Status and Notice of Material
Change forms; and examples of rehabilitated
mine sites across the province.
• Overview of the Abandoned Mines
Rehabilitation Program including news
releases on the program, tables of
rehabilitated sites, locations of these sites and
photos of several such sites.

Financial Assurance
• A summary of the acceptable forms of
financial assurance under Part VII of the
Mining Act, templates of some of these forms,
a summary of the corporate financial test,
links to the wording in the legislation and to a
site that lists approved firms that may issue
surety bonds.

Industrial Minerals and Dimension Stone
• Overview of role of Commodities Office, list
of previous publications on industrial minerals
dimension stone, a link to the Ontario
Dimension Stone Producers and Processors
Directory web site.

Ontario Dimension Stone Producers and
Processors Directory
http://www.mndm.gov.on.ca/mndm/mines/mg/
dimstone/default_e.asp
• overview of the Ontario Dimension industry
including a brief description of the various
types of dimension stone produced in the
province, a listing of Ontario stone producers
by stone type, an alphabetical listing of
Ontario stone producers and an alphabetical
listing of Ontario stone processors. The first
two lists include photos of some of the stone
types.
3. The Ontario Geological Survey

http://www.mndm.gov.on.ca/mndm/mines/ogs/Default_e.asp consists of the following units:

- Precambrian and Sedimentary Geoscience Sections based out of Sudbury are responsible primarily for the collection, interpretation and dissemination of geological, geochemical and geophysical data. The website lists current field projects, Open House posters available for viewing and downloading, Drill Core Online search and discovery application, geophysical atlas of Ontario and links to downloading the OGS Report of Activities and Summary of Field work reports.

- Resident Geologist Program
  http://www.mndm.gov.on.ca/mndm/mines/resgeol/default_e.asp
  provides comprehensive geoscience information, publications, library and advisory services to the public through a network of offices strategically located throughout the province. The website is defined by links to the 11 offices in 10 Districts across Ontario.

- Information and Marketing Services
  http://www.mndm.gov.on.ca/mndm/mines/ims/Default_e.asp
  produces and disseminates all digital and paper products of the Ontario Geological Survey and collects and disseminates statistical data on Ontario's mineral development sector. It also administers all trade and investment activities of the Mines and Minerals Division and plays a key role in promoting mineral development opportunities in Ontario. The website contains links to marketing and exploration statistics, historical mining image archive, publication and digital data release notices and catalogues, investment and marketing events and facts, MMD Geoscience Library and a report on Amethyst-Ontario's Mineral Emblem.

- Geo Labs
  http://www.mndm.gov.on.ca/mndm/mines/labs/default_e.asp is a full-service inorganic chemistry facility. It offers a wide range of services to the exploration, mining, environmental, industrial and research industries. The primary focus is on research grade analysis for the academic and government geological survey markets.

The Mines and Minerals Website is also complimented by pages listing:

- contact and personal listing for Ministry staff
  http://www.mndm.gov.on.ca/mndm/mines/call/default_e.asp

- MMD related news releases,
  http://www.mndm.gov.on.ca/MNDM/pub/newrel/Default_e.asp?

- links pages to Mining related companies, prospectors and organizations operating in Ontario
  http://www.mndm.gov.on.ca/mndm/mines/links/default_e.asp

vi) Other Services

Staff of the Resident Geologist's offices provide many other services to the prospector, some of these are:
- a Regional Resident or District geologist will visit your property on request to advise and assist you in your exploration program.
- staff of the Resident Geologist's office can assist with mineral and rock identification.
- the Regional Resident and District geologists act as liaisons between the prospector and mining companies and refer prospectors to companies who may be interested in their properties or vice versa.
- Resident Geologist's offices take part in annual Ontario Prospectors Association sanctioned symposia, held at various locations across Ontario. Prospectors are encouraged to attend these functions because they are an excellent place to meet mining industry personnel and staff of the various Resident Geologist's offices. New geological information is presented in poster displays and oral presentations delivered by staff of the Ontario Geological Survey, mining company personnel, prospectors and staff from other ministries and other branches of the Ministry of Northern Development and Mines.
Various assays, analyses, mineral testing and mineral identification can be conducted by the MNDM Geoscience Laboratories. The MNDM Geoscience Data Centre can supply computerized rock analysis data for samples collected by the staff of the Ontario Geological Survey during mapping programs and other studies conducted throughout Ontario. The MNDM Mines Library has a wealth of geoscience information available for use.

IV PERMITS REQUIRED FOR PROSPECTING ACTIVITIES

Mineral exploration encompasses a broad variety of activities that are constantly changing as new technology and techniques are applied to the search for mineral resources. Many of these activities are governed by legislation and often require permits or notification before the exploration begins. Because of the variety and complexity of possible activities and future changes in legislation it is not practical or possible to list all of the legislation and permitting that may apply to all exploration activities.

The following is a list of some of the Provincial and Federal Acts that prospectors should be familiar with and related permits that prospectors may require before undertaking exploration activities. This list is not extensive or complete and the prospector is advised to consider that any activities undertaken may require permits or be governed by legislation; for example this list does not include: vehicle licensing, driver licensing, road access permits, transportation and storage of dangerous goods or requirements for firearms. It is good practice to inquire with all related ministries and departments about applicable permits and legislation. Be aware that requirements may vary from region to region and may change over time.

Ontario Mining Act (MNDM)

Prospectors license is required to stake mining claims in Ontario.

Section 52 permission for bulk sample (for testing only) on unpatented (staked) claims. Required if sample is greater than 10 tonnes but less than 1000 tonnes but for precious or semi-precious stones permission is required for a bulk sample of greater than 50 kg.

Where surface rights are held by a third party, notification to surface rights holder is required before exploration work begins.

Be aware that many exploration activities such as development of new mine workings, modification of existing mine workings, disturbance of rehabilitation areas, bulk sampling and overburden stripping can trigger Advanced Exploration provisions (Part VII) of the Act. Advanced Exploration activities require a certified closure plan and the proponent must include financial assurance to the Ministry to cover the closure costs.

DEFINITION OF ADVANCED EXPLORATION:

“advanced exploration” means the excavation of an exploratory shaft, adit or decline, the extraction of material in excess of the prescribed quantity whether the extraction involves the disturbance or movement of prescribed material located above or below the surface of the ground, the installation of a mill for test purposes or any other prescribed work.

Types of Work under the Regulations:

1. Exploration carried out underground involving the construction of new mine workings or expanding the dimensions of existing mine workings.

2. Exploration involving the reopening of underground mine workings by the removal of fixed or permanently fastened caps or bulkheads, or involving the excavation of backfilled shafts, raises, adits or portals.

3. Exploration that may alter, destroy, remove or impair any rehabilitation work made in accordance with Part VII of the Act, or a filed closure plan.
4. Excavation of material in excess of 1000 tonnes.

5. Surface stripping of any mining lands of an area in excess of 10,000 square metres; or volume in excess of 10,000 cubic metres.

6. Surface stripping on any mining lands of an area in excess of 2,500 square metres or volume in excess of 2,500 cubic metres, if any of the activity occurs less than 100 metres from a body of water.

Contact: MNDM Mining Lands and Mineral Development Officer

Public Lands Act (MNR)

Work Permits: On Crown land, a work permit is required for construction of a building (not tents), construction and upgrading of roads and installation of water crossings, pipes and culverts. Environmental Guidelines for Access Roads and Water Crossings, 1988 is available at:

MNR must be contacted if you need to remove or alter a beaver dam.

Contact information for MNR District offices is available at:
http://www.mnr.gov.on.ca/MNR/csb/message/mnroffices.html

Crown Land Camping: Ministry of Natural Resources instituted a policy in 2002 limited free use of Crown land for camping to 21 days a year in any one location, or as otherwise posted in areas extensively used by the transient public (e.g. public access points).

Prospectors can, however, apply to the MNR District Office for approval to camp beyond 21 days on Crown land outside of an unpatented mining claim in support of their prospecting activities. In addition, claimholders can camp on their unpatented mining claims for an unlimited time while doing exploration, in accordance with subsection 50(2) of the Mining Act.

Should a claimholder wish to construct or place a structure on their unpatented mining claim within the area of the shoreline reserve where the surface rights have been reserved to the Crown, however, they must obtain land use occupational authority from Ministry of Natural Resources.

Lakes and Rivers Improvement Act (MNR)

Work permit required on Municipal or private land to
- construct or make improvements to a dam
- construct a water crossing draining an area >5 sq. km
- channelize a stream/river that may harmfully alter fish habitat or impede the movement of fish.
- any installation that may result in damming/diverting of water

Contact information for MNR District offices is available at:
http://www.mnr.gov.on.ca/MNR/csb/message/mnroffices.html

Fisheries Act (Federal – DFO)

Recommend contact with DFO before any work that may impact on fish or fish habitat

DFO will be involved in reviewing work in or near water e.g. a water crossing, to ensure there is no deleterious effect on fish habitat. MNR will require their sign-off as part of MNR approval process.

Contact: Regional DFO Office

Forest Fires Prevention Act (FFPA - MNR)

Fire permits are required during the fire season for certain activities such as burning of brush if specific conditions are not met, or for any fire in a restricted fire zone. The FFPA also has requirements to have certain fire fighting equipment on hand at a work site.

Contact: District MNR Office
Crown Forest Sustainability Act (MNR)

Forest Resource License (FRL) is required for cutting of crown owned trees during road construction (under a work permit). Some other activities, including stripping, may require an FRL.

Contact: Mineral Development Officer and District MNR Office

Environmental Protection Act & Ontario Water Resources Act (MOE)

Permit to Take Water if >50,000 litres/day and Certificate of Approval to discharge may apply depending on the characteristics of the water being discharged.

Diamond drilling guidelines for off / on shore drilling are available.

Contact: District MOE Office

Occupational Health & Safety Act (MOL)

Common Core training is required for diamond drill operators.
All drilling operations require prior notification to MOL.

Contact: District MOL Office

Public Transportation and Highway Improvement Act (MTO)

Entrance permit required from the Ministry of Transportation (or local municipality) for any road or trail that provides access from, across or to a highway right-of-way.

Encroachment permit for activities on MTO highway right-of-way

Contact: Local Corridor Management Officer for MTO

Gas Handling and Storage Equipment (TSSA)

Must use approved equipment and certified installer (no permits required).

The Health Protection & Promotion Act (MOH)

Notice must be provided for establishing a Camp for more than 5 people.

Contact: Local Health Unit

Navigable Waters Act (Transport Canada)

Approval for any “work … built or placed in, on, over, under, through or across any navigable water”

Contact: Regional Transport Canada Office

Explosives Act (Federal)

Explosives Purchase and Possession permit required.

Contact: Vendor

V) ONTARIO EXPLORATION CORPORATION (OEC)

The Ontario Exploration Corporation (OEC) was initiated to provide financial assistance in the search for new grassroots exploration targets in Ontario. It provides financial assistance to those qualified individuals carrying out prospecting and exploration activities on either their own properties or Crown land.

The OEC Board of Directors sets the amount of funding on a year by year basis. There is a limit of one funding per applicant per year and one funding per project per year. If your application and exploration proposal are accepted, fifty per cent of the funds will be paid in advance, upon the designation of a proposed project described by the Application of Funding Form.

The balance of the funds will be paid after review and acceptance of your final report on the program. Incomplete reporting of your prospecting project may result in the denial of the second portion of the funds.
To qualify for OEC funding you must:

- hold a valid Ontario Prospector’s License;

- have a prospecting project within Ontario on ground that you have a legal right to prospect (i.e. staked, leased or patented claims in which you hold an ownership interest in the mining rights);

- have a right to enter into a Purchase Agreement with OEC surrendering an NSR;

- have a prospecting target that includes rocks containing metallic or non-metallic minerals but excludes sand, gravel and crushed stone;

- provide satisfactory evidence of having sound knowledge of mineral prospecting techniques through experience or training; and

- clearly identify your proposed prospecting area on a current claim map submitted with your application.

The various Application Forms for the OEC funds are attached to a guidebook that provides many more details on how to apply, eligible expenditures, final submissions, etc. OEC applications/guidebooks can be obtained from the Ontario Prospectors Association or from the local MNDM Resident Geologist Office. The Resident Geologist may be able to assist with project planning and the preparation of the Funding Application and Final Submission.
PART 8:}

PROSPECTING TECHNIQUES:
THE SEARCH
PROSPECTING TECHNIQUES: THE SEARCH

I) SAFETY AND NAVIGATION

A prospector spends a substantial amount of time in the wilderness. This time should be spent productively, comfortably and safely. However, without knowledge of the risks you face in your working environment and without careful planning to reduce or eliminate those risks, your time in the bush can result not only in discomfort and lack of accomplishment, but also in serious or even fatal injury (Umpherson, Bennett and Webb 1991).

Prospectors should always be well equipped and prepared and know how to use their equipment and materials. The Ministry of Northern Development and Mines, with cooperation from the Mines Accident Prevention Association of Ontario, have released a free brochure entitled, “Bush Safety in Mineral Exploration” (Educational Series No.2). This publication summarizes safety and first aid procedures and survival techniques that apply specifically to mineral exploration activities in the bush. Anyone who plans to start prospecting is urged to read the brochure and any other publications they can find regarding bush safety and survival and take some first aid and/or bush survival courses.

i) Equipment and Clothing

Whether it’s for several hours or several weeks, there are certain items, which no one should be without when entering the bush. Your backpack, or pockets should contain:
- a compass (with mirror), and topographic map or airphotos. Try to find out anything you can about unfamiliar territory;
- a pocket knife (preferably an army-style survival knife);
- a lighter or wooden matches in a sealed pill bottle or film canister to keep them dry, and a candle;
- insect repellent;
- a whistle and small mirror (it can reflect a signal that can be seen up to 30 km away);
- a roll of electrical tape or duct tape;
- some safety pins;
- a couple of large, orange garbage bags, which can be turned into a highly visible tarp with the help of the electrical tape, or used as emergency rainwear;
- a small first aid kit and space blanket.

All these items should fit into a pocket of your backpack. If you are entering a remote area or are going to be away for more than a day or two, you should also include:

- a small flashlight;
- a small bottle of water decontamination tablets;
- about 6 metres (20 feet) of thin nylon cord;
- a small sharpening stone;
- extra clothes and rain gear;
- a nylon tarp;
- some bungee cords (they stretch easily and can be used to attach other items to your pack);
- additional food-high energy foods like chocolate, granola bars, trail mix, raisins, dehydrated soups, bouillon cubes, salt;
- a large metal cup and pan;
- 12 metres (40 feet) of heavy-test fishing line, hooks and 6 metres (20 feet) of snare wire;
- a small axe.

No matter how long you plan to be in the bush, it is extremely important to include an emergency first aid kit. It should contain:
- a first aid manual;
- more than the necessary amount of any prescribed medication in case of a prolonged stay;
- several rolls of one-inch and two-inch wide gauze bandage;
- sterile gauze dressings, about three inches square for larger cuts;
- adhesive tape, self-adhesive bandages and antiseptic;
- triangular bandages;
- aspirin or other painkillers (optional).

Wrap these items in a separate waterproof bag with a tight seal and put it in an accessible part of your pack.

The following is a list of equipment and tools that are essential to prospectors every time they are in the field.

- Compass (with a dip needle or clinometer and mirror)
- Maps (geographical, geological, claim maps)
- Notebook, pencil, pen, felt marker
- Geological hammer (sledge, crack, pick)
- Chisel (hardened tip)
- Safety glasses
- Rock sample bags
- Hand lens
- Packsack
- First aid kit
- Flagging tape
- Toilet paper

The following list consists of equipment and tools that can be very useful to a prospector. It is recommended that this gear be accessible to the prospector in the field.
- Grubhoe (Mattock head)
- Shovel
- Small broom
- Hip chain/tape measure
- Penknife
- Pocket magnet
- Streak plate
- Scratch plate
- Diluted hydrochloric acid (muriatic acid) in a leak-proof plastic bottle
- Gold pan
- Mineral identification handbook
- Tent and sleeping bag (light and portable)
- Cookery set (propane stove, pots and pans, plates, cups, utensils, etc.)
- Axe and file

Remember to carry all the necessary tools and materials you may need to conduct maintenance or repairs on equipment such as boat motors, chain saws, rock saws, pluggers, etc.

Another important aspect of working in the bush is having the proper clothing. Clothing should provide comfort and protection and should be adaptable to changing weather and terrain conditions. "Layering" of clothing is recommended for better adaptability to changing temperatures.

**Pants and shirt:** - durable and quick-drying.
- polyester/cotton work shirts and pants recommended.
- shirts should be long-sleeved.
- layering of shirts to adapt to changing temperatures (i.e.: T-shirt, light work-shirt and heavier woolen shirt or sweater)
- woolen pants and underwear in colder weather.

**Footgear:** should be durable and waterproof.
- should afford ankle support and a good grip.
- leather or rubber boots (or a combination) are most common.
- hiking boots are also common.
- steel toes and shanks are recommended.

**Coat:** The type of coat is dependent on such factors as season temperature and weather conditions. A coat should be windproof, breathable and water resistant. It is recommended that a lightweight, compact set of rain gear also be carried with you.

**Socks:** Woolen socks are recommended because they tend to retain warmth even when wet. More than one set is usually required.

**Gloves/Mitts:** Sturdy leather, work gloves are recommended for prospecting work.

**Headgear:** A cap or sun hat is recommended. It will shield your eyes from the sun, protect from sunburn and help keep branches and debris out of your hair and eyes.

**Vest:** A cruiser or engineer's vest is highly recommended. A vest allows you to conveniently store a lot of your field gear (notebook, pencils, sample bags, compass, hand lens, etc.).

**ii) Compasses**

A compass is an instrument that consists of a
magnetized needle which points consistently towards the north magnetic pole. The compass is used primarily for navigation but is also used for measuring the strike and dip of geological features.

A compass should have the following features:
- It must be adjustable for magnetic declination so that all directions are related to true north.
- It must have some means of "damping" or slowing down the vibrations and movements of the compass needle. This is usually accomplished if the needle is immersed in a liquid-filled capsule.
- You must be able to aim the compass at the target while being able to see the compass needle. This is accomplished by a small mirror attached to the compass.
- It should have a clinometer or dip needle for measuring dip angles.
- It should be graduated to 360 degrees.

There are many types of compasses to choose from but the most commonly used instruments are the Brunton and Silva compasses. The Brunton compass is elaborate in design and generally more accurate but can be difficult and tedious to use. The Silva compass is less expensive, easy to use and has built-in scales and a transparent base so that they can be used to measure distances and directions directly on a map (Faulkner 1986). Always remember to read and understand the instructions that are included with the compass you own! Treat your compass with care and keep metallic objects and magnetic metals such as rock hammers and magnets away from the compass at all times or your compass needle may become permanently damaged. If the compass is in a liquid-filled capsule it may become sluggish in very cold weather, therefore, keep the compass in a warm inside pocket between readings.

A compass bearing is a direction normally given relative to true north. It is common for approximate bearings to be specified as north, south, northeast, and so on. However, for accurate measurements, the bearing directions are given as angles measured from the true north. The circle of a compass is divided into 360 units called degrees (360°) that are measured in a clockwise direction from true north. Therefore, north is 0° east is 90°, south is 180° and west is 270° (Figure 1). A direction between north and east would have a bearing between 0° and 90°. When taking a compass bearing, keep the compass away from any metal objects such as your rock hammer or belt buckle, which may deflect the compass needle from the bearing.

One end of a compass needle points to the north magnetic pole and is referred to as "north seeking". Presently, the north magnetic pole is located in the Canadian Arctic Islands about 1500 km from the north geographic pole. Since the north magnetic and geographic poles are not coincident, a compass does not generally point to the true north. The angle of correction is called the magnetic declination or variation. A compass must be adjusted to correct for magnetic declination so that compass bearings are made with respect to true or geographic north. The magnetic declination is variable from place to place and it also changes slowly with time because the magnetic pole is continually drifting. For example, let's assume that the magnetic declination in an area is 10 degrees 15 minutes east in 1970 and the annual change is 5 minutes westerly. This means that in 25 years the declination will have decreased by 125 minutes or about 2 degrees (1 degree = 60 minutes). Therefore, in 1995 the declination would be 8 degrees 10 minutes east. These changes can significantly affect your compass bearings and readings. The value of the magnetic declination can be obtained from topographic maps for a given area.

A compass may be adversely affected by a magnetic attraction or M.A. in the local region you're prospecting. The M.A. could be a magnetic iron formation or other magnetic rock type, such as diabase or gabbro, or man-made objects such as hydro lines or railroad tracks. A local magnetic attraction will pull the compass needle away from the magnetic north direction either gradually or abruptly. Most geological maps indicate the presence of M.A.s in an area and warn a prospector of possible compass problems. Be careful when
Figure 1: Face of a Compass
compassing in areas that have abundant magnetic rock types and closely watch the compass needle.

If you find yourself in a situation where you have lost or broken your compass or the compass cannot be depended upon due to strong magnetic attractions, there are some alternative methods of determining directions described below.

**Watch Method:** Hold a watch flat in your hand. Turn the watch until the hour hand points directly at the sun. Between the hours of 6 a.m. and 6 p.m. (Standard Time) a line from the centre of the watch that divides the small angle between the hour hand and 12 o'clock, will point south (Figure 2). Between 6 p.m. and 6 a.m. divide the large angle to find south. **Remember to use the hour hand of the watch.** Also remember that if it is Daylight Saving Time you'll have to deduct an hour from the position of the hour hand.

If you have a digital watch you can draw the hour and minute hand on paper or on the ground to locate north and south.

**Shadow Stick Method:** Another method of finding north is to place a long stick in the ground to obtain a shadow. As the sun progresses across the sky, mark the end of the shadow of the stick at intervals of 15 minutes or more. Draw a straight line along the marks: the direction of the line will indicate east and west because the sun moves in an east to west direction. North will be at a right angle to this line **(Figure 3).**

**Other Methods:** An obvious method of direction finding is watching the sun. During the spring, summer and fall the sun rises in the east and sets in the west. During the winter months the sun rises in a southeast direction and sets in a southwest direction.

When navigating through the bush look for unmistakable, distinguishing landmarks that you may recognize if you are lost. Remember to stay alert while navigating in the bush. It's the surest way of moving in a straight line and reaching your destination.

**Maps**

The use of air photographs and topographic maps at home and in the field can assist prospectors in planning and executing their exploration programs. Air photographs are commonly black and white photographs of the ground, taken from aircraft and are available in a variety of scales. Provincial air photographs are produced at a scale of 1 inch to a quarter mile while federal air photographs are at a scale of 1 inch to 1 mile. All air photographs are numbered sequentially according to aircraft flight lines and index maps for the photos indicate aircraft flight lines and photograph numbers. Index maps and air photographs are available for viewing at your local Resident Geologist's office or in the appropriate District Office of the Ministry of Natural Resources. Provincial air photographs can be purchased from the Natural Resources Information Centre (MNR) in Toronto, while federal air photographs can be purchased from the National Air Photo Library, Energy, Mines and Resources Canada in Ottawa. All air photographs can be enlarged to various scales at extra cost.

There is a 2/3 overlap between each air photograph along the same flight line and a 1/3 overlap between photographs on neighboring flight lines. Therefore, any point on the ground will appear on at least two photographs. Any ground in the area of overlap between two photographs can be viewed in three-dimensional relief by viewing one photograph with the left eye and the other with the right eye. The 3-D effect is best achieved with the aid of a **stereoscope.** This makes it easier to identify topographic details that do not appear on maps (Faulkner 1986). Even if you don't use the stereoscope, air photographs can be useful in determining outcrop locations and providing other detailed topographic information.

Topographic maps **(Figure 4)** serve as a base for other types of maps, such as claim maps and geological maps. A topographic map depicts the topography or physical features of an area with contour lines and symbols. The most commonly used topographic maps are at a scale of 1:50 000 (1 cm equals 0.5 km) but topographic maps are also published at
Figure 2: The Watch Method

Figure 3: Shadow Stick Method
other scales such as 1:250,000 and 1:500,000. The sides of a topographic map are true north lines with north at the top of the map. A pattern of grid lines on the topographic map are part of the Universal Transverse Mercator Grid (UTM Grid). This grid system is useful in determining the accurate location of specific points on the map. The grid squares are 1 square km on the 1:50,000 and 1:100,000 scale maps and grid lines are numbered sequentially. Points on a map can be located accurately by using the grid lines for reference, which is easier than using latitudes and longitudes. Notes in the margin of every topographic map explain how to use the UTM grid (Faulkner 1986). The notes on a topographic map also indicate the magnetic declination of the area, map scale, map area location and definitions for all map symbols.

Contours are the most important features of a topographic map. A contour line joins points of equal elevation; therefore, the ground anywhere along a contour line is the same height above sea level. Most contour lines are numerically labeled according to their elevations (Figure 4). A 100 m contour line shows where the ground is exactly 100 m above sea level. For example, if the sea flooded the land and rose exactly 100 m, the new shoreline would be located exactly along the 100 m contour line (Faulkner 1986).

Not all contour lines on a map are numerically labeled and you may have to count up or down from a nearby labeled line to determine elevation. To do this you need to know the contour interval, which is indicated in the map margin. If the contour interval is 50 m, then contours are drawn on the map for every 50 m increase in height above sea level such as 50, 100, 150, 200, 250 m and so on (Faulkner 1986). Topographic maps also have metres to feet conversion scales for elevations in the map margin.

Topographic maps can be purchased from the Canada Map Office in Ottawa or from local dealers, such as outfitting stores or tackle shops. The Natural Resources Information Centre sells Ontario Basic Mapping Series topographic maps at scales of 1:10,000 or 1:20,000. These maps are more detailed than regular topographic maps but map coverage is presently limited in various parts of Ontario.

iv) Navigating with Global Positioning Systems

The use of GPS units can make your claim staking and prospecting more efficient.

The Global Positioning System consists of a constellation of satellites that are constantly orbiting the earth emitting a continuous stream of time-coded radio data. This data includes specific codes that enable a GPS receiver to determine its position on the face of the earth. Think of it as a very high tech way of using triangulation to determine your position, but instead of using sight lines and bearings, the GPS uses time-coded radio waves.

The Global Positioning System can provide relative and absolute locations in three dimensions and many other functions depending on the model. Most GPS can be set to provide data in imperial, metric or nautical units and can provide coordinates in a variety of datum (UTM, lat-long, etc) that can be directly related to maps such as topographic maps and claim maps etc.

It is critical to the functioning of the GPS receiver that it receives a strong signal and has a good lock on at least four satellites. There are certain conditions that will degrade the GPS signals. These can be heavy tree cover, high hills and low valleys, or any condition where you do not have a clear view of the sky.

The accuracy of the GPS depends on a variety of factors but typically varies from 5 to 25 metres for most units under good conditions. Elevation measurements tend to be less accurate than two-dimensional surface coordinates. WAAS technology is available with some GPS and this can improve the accuracy of the data.

If you have a downloadable GPS, you can connect the unit to a computer and download all your data to construct a map including claim posts and lines, sample locations and sample numbers, roads and trails, traverse
routes, stripped zones and trenches and any other features that you have mapped in.

Remember that GPS are electronic devices and are subject to failure through malfunction, breakage or running out of batteries. You should always carry a map and compass with you and frequently check your location on a map to be certain you know your location should the GPS stop working properly.

**Claim Staking with GPS**

When you need to stake a claim one of the best resources to use is the Claim Map site on the MNDM website (http://www.mndm.gov.on.ca/mndm/mines/lands/claimap3/). One thing you have to absolutely remember is to set your GPS to the same Datum as the map you will be working with. If you are working from the MNDM Claim Map site that would be NAD 83 plus the UTM zone you will be in.

Get on the Claim Map site and locate where you wish to stake a claim. Once you have zeroed in on your area, you can pick off the coordinates of your planned posts. Record these carefully in your notebook and then enter them into your GPS unit as waypoints. If you are staking more than a one unit claim, collect all the coordinate values for each of your posts for each claim. Don’t forget to pick and download the line post locations as well.

If the Claim Map site is not available, coordinates can be measured directly from a claim map or topographic map but remember to check the map datum.

For this exercise we will stake a single unit claim and we will call the number one post ‘Waypoint 1’, the number two post ‘Waypoint 2’, the number three post ‘Waypoint 3’, and the number four post ‘Waypoint 4’. We will assume that you have established your number one post. Once that is done, call up WAYPOINT 2 on your GPS screen and set up the GPS to navigate to Waypoint 2. If this is done correctly you should see a bearing figure, a heading figure, and a distance figure. This will vary with what screens you have visible on your GPS. You should at this stage set your compass to the bearing figure.

Start walking towards the number two post location, keeping the bearing and the heading figures the same; when the distance screen reads ZERO, you are at the position where you will locate the number two post. Alternatively, use your compass with the initial bearing (if you are going from the number one post to the number two post this will be 180 degrees or south) and check your GPS every now and then to determine the distance you have traveled and the remaining distance to the number two post location. If you wander off line, the GPS should indicate this. You can always get a new bearing to the post location by doing another “Navigate to Waypoint 2” and resetting the compass.

Establish the number two post and then set the GPS to navigate to the Number three post or Waypoint 3. Repeat this for the Waypoint 3 to Waypoint 4 leg and for the Waypoint 4 to Waypoint 1 leg. You have completed your claim.

Note that you may not always be able to establish your posts in the exact location that you have planned. They should be fairly close, however. For this reason you must also record a Waypoint file for the actual post location after you have established each post. This data will come in handy when drawing your claim sketch in order to record the claim. If you have a waypoint averaging GPS, set the GPS on the post and let it collect data for a while (five minutes or so). You will see the accuracy figure of the GPS start to stabilize somewhere near ten meters or less (with WAAS enabled GPS).

Even though your waypoints are saved in the GPS, be sure to keep a record of each waypoint in your notebook as well.

**Prospecting with GPS**

Thanks to GPS, there is an alternative to pace-and-compass traversing. Say that you want to go out and prospect the claim you have just staked. Before you enter the bush, get a waypoint reading on your initial location (this may be your boat, truck, camp, etc). Record the waypoint number in your notes or rename the waypoint.
Start your prospecting traverse. At every sample site, number your sample and record the location of the sample site as a waypoint. You can name the waypoints the same number as the sample number. Even though you have a good GPS location for the sample, always mark the spot with flagging tape and write the sample number on the flagging tape. Continue this pattern for the rest of the day.

The GPS can also map roads and stripped areas. To map a road the use of an external antenna is recommended. Simply drive the road with the GPS on and it will record the location of the road in its memory and display the track on the screen. If you need to map in the extent of your stripped zone, simply turn on the GPS and slowly walk around the stripped area and the GPS will map out the size and shape of the stripping.

Here are some important internet websites that can provide additional information:

- General GPS Information
  - http://gpsinformation.net/ (highly recommended)
  - http://gpscity.com/canada
  - http://www.garmin.com/
  - http://www.lowrance.com/
  - http://www.colorado.edu/geography/gcraft/not es/gps/gps_f.html
  - http://www.trimble.com/
  - http://www.cansel.ca/
  - http://www.leica-gps.com

- Mapping software
  - http://www.qvn-canada.com/
  - http://www.oziexplorer.com/
  - http://www.fugawi.com

An Internet search will reveal many more GPS information sites.

**v) Survival and Common Sense**

Careful planning and common sense are key ingredients to successful prospecting projects in the bush. Factors to be considered in preparing and outfitting yourself include your destination, the season, method of transportation, and the number of people with you and duration of the trip. Don't forget to let someone know where you are going; when you expect to reach your destination; when you intend to return; and what your route will be. This information makes it easier for someone who has to look for you if you become lost (Umpherson, Bennett and Webb 1991). Getting lost in the bush can be an uncomfortable and frightening experience that may result in panic. It is essential that you remain calm; assess your resources; form a plan and follow it. The best thing to do is to remain where you are.

Your priorities should be to: 1) attend to any injuries you may have; 2) seek or construct a shelter; 3) conserve and create warmth; 4) find water; 5) rest to conserve energy; and 6) find food. Sit down and orient yourself by using your map and compass; look for familiar landmarks; estimate the amount of sunlight left; set up a camp if daylight is fading; get a fire started; have something to eat and drink and get some sleep. Each activity in your plan should be assessed according to whether it conserves and/or adds to your energy, or uses it up. Building a shelter to stay warm is energy well spent due to its long term value. However, wandering the woods looking for food may use more energy than what is gained from any food that is found (Umpherson, Bennett and Webb 1991).

More information regarding bush survival can be obtained from the "Bush Safety in Mineral Exploration" brochure and many other books, manuals and courses concerning bush survival.

**II) THE SEARCH**

**i) Introduction**

Prospecting in the field should begin with a careful examination of air photographs, topographic maps, geological maps and road maps. Plan where you are going to go; how you're going to get there; and how you're going to get back. Ensure that you are properly equipped and have a valid Prospector's License, claim tags, a recent claim map of the area and a copy of the Mining Act regulations.
Become familiar with the rocks and mineral occurrences in the area you’re going to prospect. Examine outcrops and compare them with geological maps and descriptions in geological reports. Investigate favourable rock types, structures or contact zones and cover the local area systematically and thoroughly.

Patient, detailed, systematic searching is the key to successful prospecting. Go at your own pace and be alert to anything in the rocks that appears unusual or interesting. Be observant, and record your observations in a notebook or diary. Carefully and accurately record the location and description of any samples you take. Your description of a bedrock outcrop should include:
- location of the outcrop;
- description of any features in the rocks such as pillow structures or bedding;
- strike and dips of any veins or structures in the rocks and their size;
- grain size of the rock;
- colour of weathered and fresh rock surfaces;
- descriptions of any unusual colouring or staining;
- descriptions of minerals observed in the rocks; and the rock type.

ii) Systematic Coverage and Traversing

A region can be systematically prospected in three ways: 1) traveling from outcrop to outcrop; 2) following topographic features such as rivers, lakes, hills, ridges and valleys; and 3) traversing a straight line (compass bearing) from one point to another.

Traversing is an efficient method of systematic coverage and can be accomplished by planning a series of closely spaced traverse lines (Figure 5).

To plan a traverse:

1) Draw a line on a map joining your chosen starting point with your chosen point of destination.

2) Measure the distance of the line using the scale of the map.

3) Measure the direction of the line (relative to true north) with a compass or protractor to obtain a compass bearing for the line.

Points to consider when planning a traverse are:

1) Traverse lines should be perpendicular to the strike or trend of rocks in the area.

2) Traverse lines should start and finish at easily identifiable geographical features, such as lakes, rivers, roads, swamps or ridges.

3) Avoid long traverses. A 1 or 2 km traverse line is long enough in bush conditions.

4) Traverse lines should systematically crisscross an area at equal line spacings. The distance at which you space the lines will affect the detail of your search. Closely spaced lines provide more detail than more widely spaced lines.

5) Traverse lines should be planned so that they intersect the maximum amount of outcrop. Plan the traverse to avoid difficult ground such as swamps, bogs, wide river or stream crossings, steep slopes, etc.

In the field, at the start of the traverse, ensure that your compass is adjusted to the proper magnetic declination and set the compass bearing in the required direction of travel. Follow the procedures for your particular make of compass in the instructions for the compass. Hold the compass at arm’s length away from you and turn your body until you have aligned yourself in the direction of travel. Sight the compass at an easily recognizable landmark, such as a tree, in the path of your direction of travel and walk toward it. When you reach the landmark, repeat the procedure until you arrive at your destination at the end of the traverse. It is easy to deviate from your direction of travel in thick bush, windfall, or difficult terrain, therefore, make more frequent sightings on landmarks.

It is important to know how far you have traveled on a traverse in the bush. The simplest method is pacing which is based on counting the number of double strides taken in covering the ground.
Figure 5: Some Examples of Prospecting Traverses
You count one pace every time your left foot touches the ground. Keep count of your paces by clicking a tally counter. The distance covered by each double stride (pace) depends on the person and the type of terrain. Each person should measure the length of their pace: most people have a pace between 1.5 and 1.8 m (5 to 6 feet). To calculate the distance you have traveled, simply multiply the number of paces by the length of your pace (100 paces x 6 feet (or 1.8 m) = 600 feet). Your pace will vary in rough terrain: paces become shorter walking uphill and longer walking downhill; and there will be pacing difficulties when stumbling through windfall and tag alder swamps. Pacing along your direction of travel will allow you to plot the location of interesting discoveries with relative accuracy and will assist you in locating your position on a map or air photograph.

During your traverse remember to carefully check every exposure of rock. Peel back moss and thin overburden to expose as much rock as possible. Check fresh rock exposures under uprooted trees and inspect frost heaved boulders.

iii) Visual Indicators of Mineralization

There are several visual indicators of mineralization that prospectors watch for during their search, these are listed and described below:

1) Presence of obvious and unusually pure mineral concentrations. Concentrations of metallic minerals, especially sulphides, should always be inspected and sampled.

2) Striking colours (very white, very orange, very green etc.) and abrupt colour changes in and on rocks.

3) Attractive colours and textures in a rock or a rock with unusual purity.

4) Ore mineral stains on rocks (gossans) produced by chemical weathering of minerals such as:
   - orange, brown or yellow - due to iron-rich sulphide minerals.
   - blue or green - due to malachite and azurite on copper minerals.
   - pink - due to erythrite staining on cobalt minerals.
   - pale green - due to annabergite staining on nickel minerals.
   - yellow - due to staining from molybdenite or uranium minerals.
   - black - due to weathering of manganese minerals; weathering of some copper minerals and silver mineralization.

5) Check all veins and thoroughly expose them. You may discover a very narrow vein that becomes much wider along strike. A vein can vary in thickness from 1 cm to several metres wide. If you discover a barren, unmineralized vein be sure to check it along strike: a barren vein may contain mineralized sections.

6) Inspect all pegmatite dikes and any other very coarse-grained rocks. A pegmatite that contains both biotite and muscovite may carry other more exotic minerals.

7) Check all shear zones fractures, faults, breccia zones and areas of deformation. Remember to prospect along the strike of a shear zone or other linear structure. A barren structure may be mineralized or host veins elsewhere along its strike.

8) Check all rock contacts, especially at the margins of felsic intrusive rocks, where deformation, veining and mineralization, may be concentrated.

9) Check rocks that appear to have weathered recessively or rocks that stick out and resist weathering.

10) Check boulders for mineralization especially frost-heaved boulders that have been pushed up through overburden by frost action. Frost-heaved boulders are angular and may have broken off from bedrock outcrops immediately below the overburden.

11) Check all road and railroad rock cuts. Always be sure to inspect rock cuts and exposures along new roads.

12) Check for signs of previous prospecting such as old, filled-in pits, trenches and rock
13) Be aware of various rock and mineral associations.

14) Look for wall rock alteration near structures or igneous intrusions such as orange staining due to carbonatization; abundant concentrations of sericite mica, epidote, chlorite, albite, biotite; pink potassic alteration; silica enrichment; and concentrations of metamorphic minerals, etc.

iv) Rock and Mineral Associations

a) Rock Associations

The "Mineral Deposits" section of this manual described many mineral concentrations that are associated with specific rock types due to various geological factors. Even vein-type deposits are associated with structures in some specific rock types that act as chemical "traps" for mineralization.

Prospectors should be aware of these associations when working in the field. Below is a listing of some general rock associations with mineral or metal concentrations.

Mafic and ultramafic igneous intrusive rocks (gabbro norite, peridotite): Copper-nickel sulphides (chalcopyrite, pentlandite); iron sulphides (pyrrhotite); magnetite, soapstone, talc, asbestos; chromite and platinum in layered intrusions.

Felsic igneous intrusive rocks (granite, granodiorite): Molybdenite, chalcopyrite, gold and silver in porphyry intrusions; iron, copper, lead, zinc associated with skarns; vein-hosted deposits near contacts of intrusions; ilmenite, sodalite, nepheline, silica, feldspar, corundum, monazite, zircon, uranium, cassiterite (tin), scheelite (tungsten); dimension and decorative stone.

Pegmatites: Feldspar, mica, silica, uranium, rare earth elements.

Carbonatites: Rare earth elements, vermiculite, phosphates.

Intermediate to felsic igneous volcanic rocks (pyroclastics, flows, felsic quartz and quartz-feldspar porphyries): copper-zinc-lead sulphides (chalcopyrite, sphalerite, galena) with iron sulphides (pyrite, pyrrhotite) in volcanogenic massive sulphide (VMS) deposits.

Sedimentary Rocks: iron, salt, gypsum, petroleum (oil and gas), talc, marble, limestone, dolomite, quartzite (silica), uranium, gemstones, platinum and gold in placers and paleoplacers; various sedimentary rocks are used for decorative and dimension stone.

Kimberlite, Heterolithic Breccia and Lamprophyres: diamond

Veins: quartz, calcite, fluorite, barite; native copper, gold, silver; various iron sulphides; various sulphide minerals of copper, zinc, lead, silver, cobalt; telluride minerals; arsenide minerals, and so on.

b) Mineral Associations

Some metals and minerals occur together in deposits due to chemical and geological factors. The presence of certain minerals in a rock may indicate the possible presence of more valuable minerals or metals. For example, pyrrhotite in a gabbro or peridotite may indicate the presence of nickel. Gold and silver mineralization may accompany such minerals as pyrite, chalcopyrite, arsenopyrite, galena or tetrahedrite in a quartz vein. Mineral associations are important to recognize in the field because they may lead a prospector to economic mineralization. Some of the common mineral associations are listed below:

1) Nickel with pyrrhotite.

2) Silver with galena and galena-sphalerite mineralization, tetrahedrite, argentite and nickel and cobalt-arsenide sulphide minerals. Silver is also found with calcite, fluorite and quartz.

3) Gold with pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, pyrrhotite and tetrahedrite. The gold is rarely visible and may
be locked up within the crystal structures of these minerals. Gold is also found with quartz, carbonate, chlorite and tourmaline.

4) Sphalerite, chalcopyrite and galena with pyrite and pyrrhotite.

5) Copper sulphides with molybdenite or vice versa.

III) EXPOSING DISCOVERIES

Once a prospector has discovered and staked a showing of mineralization the next step is to prepare the showing for inspection. It is important that the showing is carefully prepared for evaluation and display. The preparation work involves relatively low cost development that can be credited as assessment work and allows a preliminary evaluation of the showing. The prospector should do as much as possible in two dimensions to expose the mineralization. This work enables a prospector to sample the showing effectively and write a knowledgeable and factual report on the property. Geologists who are responsible for recommending properties for option usually have more properties offered to them than they can possibly devote the time and expense to visit. Consequently, they will select those that are accessible and the most effectively exposed and sampled.

The importance of carefully planning your work cannot be overemphasized. Mining industry personnel commonly find that a prospector has not done enough work such as stripping or sampling and that their trip to the property has been a waste of time; however, they also find that a prospector has conducted too much misdirected work such as extensive or unnecessary blasting (Lang 1972). Therefore, carefully planning your exploration program and reassessing it on a regular basis is extremely important in conducting an effective, efficient and low cost program.

ii) Stripping

Once the paper work is out of the way a prospector can finally begin to initiate the exploration program. The first thing to do is to determine the width and length of the mineralized zone by stripping your discovery. Stripping involves the removal of overburden from the bedrock surface by manual or mechanical means. Some prospectors use mechanical stripping as a means of prospecting which is not recommended unless overburden is very deep.

There are several advantages to stripping your discovery:

1) Stripping results in better exposure of the rocks and assists in determining the size and extent of the mineralized zone.

2) Stripping cleans off the rocks for detailed sampling. Sampling must be representative of variations within the mineralized zone and wall rocks therefore exposure must be complete.

3) Stripping may result in the discovery of more mineralization.

4) Stripping exposes more bedrock surfaces providing a better geological understanding of the mineralized zone.

5) Stripping helps to attract interest because your property is "exposed for display".

Various factors that affect stripping are:

1) The type and depth of overburden: thick overburden composed of clay or large boulders may be difficult to remove and require the use of heavy equipment. Shallow overburden, a few centimetres thick, can be easily removed with a pick and shovel.

2) The amount of stripping will depend on the type of mineralization. Erratic, discontinuous mineralization requires close visual inspection and careful, detailed sampling for which continuous exposure is necessary. Widespread, disseminated mineralization may require stripping very large areas. A zone that is continuous and well developed may only need to be stripped at various locations along its strike length. Wall rocks on either side of
the mineralized zone should be exposed because mineralization may extend from the main zone into the surrounding country rock.

The following is a list of steps to follow when stripping:

1) Conduct a reconnaissance of the area you're planning to strip. This will help you determine the size of the area to be stripped; where stripping can be done to best advantage; and if stripping can be conducted at all. Determine the type and depth of overburden by digging through it to bedrock or by probing it with a steel sounding bar, pipe or post-hole auger. Surficial geology maps provide information on overburden thickness and type. If diamond drilling has been conducted on or near your property refer to the drill logs in the assessment file library to check casing depth (overburden depth) in the holes. Use flagging tape or bright spray paint on nearby trees to mark out the area you're planning to strip. This type of planning will help you to effectively and efficiently strip the area; maximize outcrop exposure; and minimize operating costs.

2) Prospectors equipped with a grub hoe, pick, shovel, axe, chainsaw, hammer and water pump can effectively expose a small mineral showing manually. If you must strip a large area or if the overburden is very deep, then you should use a bulldozer or backhoe. A bulldozer is commonly used for stripping large areas and is capable of working on steep hillsides; in rough and rocky areas; and in timbered areas. However, bulldozing does have disadvantages such as: loose material may level and become compacted under the wide blade; material may spill over the blade; bulldozed embankments may give way and collapse; and if a bulldozer must "climb out" of an excavation it will have to move a lot of material to build a ramp. A backhoe works efficiently in relatively flat areas and does not move as much dirt as a bulldozer. A backhoe digs clean trenches with exposures that are generally better preserved than in a dozer cut. A backhoe is most effective in areas of deep overburden. Small-sized backhoe units are truck, tractor or skidder mounted and more portable and maneuverable than a large bulldozer. Remember that all large trees should be cut down and neatly stacked prior to stripping to avoid unsightly tangled messes of trees and forest fire hazards.

3) It is advisable to be present during the excavation, if you're not operating the equipment yourself, to supervise the work; inspect boulders and bedrock as they are stripped and to change the stripping plan if necessary. The stripping plan may need to be changed if more mineralization is exposed; if the mineralized zone terminates quickly; and if overburden becomes very deep or difficult to remove.

4) The full width of the mineralized zone and as much of the strike length as possible should be exposed.

5) Clean-up the outcrops by sweeping them off and hosing them down with a water pump to remove loose dirt, root and moss. A strong jet of water from a high pressure pump is very effective at removing debris. It is essential that the outcrop is washed and swept clean to allow close visual inspection of all details prior to sampling and geological mapping.

6) Remember to complete just enough stripping to adequately evaluate and sample the zone. It is usually not necessary to expose areas that are thousands of square feet in size. Stripped areas the size of football fields tend to be overkill.

7) If overburden is very deep (in excess of 1.5 m) you may be able to excavate long, deep trenches with a backhoe to try and reach bedrock and expose sections of the mineralized zone rather than strip a large area. The trenching should be conducted at 7.5 m to 15 m (25 to 50 feet) intervals perpendicular to the strike of the mineralized zone. If the mineralized zone is very wide small pits can be spaced at intervals across the zone rather than digging a very long trench. The trenches and pits can also be used to sample the overburden during geochemical surveys.

8) The mineralized zone should be constantly reappraised as stripping or backhoe trenching proceeds. There is no reason to continue the work if the zone is too small or has poor
mineral content.

Be aware that stripping can trigger advanced exploration as defined by the Mining Act. See section describing permitting.

iii) Trenching and Blasting

Deeply weathered and stained rocks commonly need to be blasted and trenched to obtain a fresh rock surface for sampling and mapping. Blasting is also conducted when it is necessary to remove tree stumps and large boulders from the work area. Blasting should only be conducted if it is absolutely necessary and with plenty of forethought and careful planning. If not done properly, it can result in the destruction of the showing and valuable geological information. If too many explosives are used it is actually possible to blow the whole showing away with nothing left but widely scattered rock rubble. Improper blasting can also result in a very rough, fractured and irregular outcrop surface that will prevent effective sampling. Blasting can be an effective prospecting tool when it is well planned and done properly with the proper explosives for the required job. You should always be aware of the injuries and damages that can result if responsible or irresponsible people incorrectly follow procedures while they are using or handling explosives.

Rock trenches are blasted across the width of a mineralized zone perpendicular to its strike. Most trenches are 0.9 m to 1.5 m deep, 1.2 m to 1.8 m wide and 1.8 m to 3 m long, but their size generally depends on the size of the mineralized zone and the depth of weathered rock. Test pits are blasted along the strike or across the width of a mineralized zone and are smaller than trenches. Blasting can also be conducted on the surface of the outcrop for the purpose of fracturing the rocks and obtaining a fresh surface.

Describing all the various blasting procedures and regulations is beyond the scope of this manual, however, published information can be obtained from licensed vendors of explosives; the Explosives Division, Energy, Mines and Resources Canada; Ontario Ministry of Labour; and the Ontario Provincial Police or R.C.M.P. You should be familiar with all Acts and Regulations regarding the use, transportation and storage of explosives. If you do not wish to work with explosives you can always hire another prospector or person familiar with blasting procedures to do the work for you.

a) Rock Drilling

Rock drills or "pluggers" are used to drill holes in rocks for the purpose of blasting. Pluggers are popular amongst prospectors because their small size and relatively light weight makes them easy to use and transport through the bush. Special frames are available for backpacking rock drills.

The drill steel that is commonly used is 7/8-inch hexagon with attached chisel bits and numerous specially designed detachable, tapered, drive-on or threaded bits for a variety of uses. The drill steel comes in variable lengths starting with 40 cm long starter steel (for "starting" a hole) and ranging up to lengths of 6.4 m. The bits are tungsten carbide and come in diameter sizes ranging between 27 mm and 40 mm, which allow free access for 2.5 cm diameter explosives. Most rock drills have a maximum drilling angle above horizontal of 45° and can drill to a maximum depth of 6 m. Bits should be sharpened on a regular basis to maintain effective drilling.

Prior to starting the drill, examine the area to be drilled and determine the direction in which you intend to throw the rock during the blast. Depending on the natural slope of the bedrock in an area, it may be necessary to drill longer or shorter holes on the first row or on any number of rows of holes, so that all holes end at the same general depth. The spacing of holes depends on the depth to be drilled, the rock type and the amount and angle of fracturing in the rock. The number of holes is dependent on the amount of rock you plan to excavate. It is important for beginners to get tips from someone experienced in rock drilling regarding the depth, spacing and arrangement of the holes.

Make sure to follow the fire prevention guidelines and regulations for power saws when using a rock drill. Do not refuel the drill
when hot and move away from the refueling site before starting the engine. The noise level of the drill requires ear protection; safety glasses are necessary; and in some cases full face shields could be necessary. Safety boots are required because of the potential for foot injuries from breaking drill steel or dropping the machine on your foot. A dust mask is required if the rock you are drilling produces large amounts of dust. Do not operate the drill within a building or in a deep trench where fresh air flow may be restricted. Always stop the engine when changing drill steel and be aware that the cylinder and lower part of the drill become very hot after a few minutes use. Always read and understand the manufacturer's instructions before using a rock drill.

b) Explosives and Blasting

Three words should always be kept in mind when handling or working with explosives: safety, safety, safety! There are three components you must have to achieve an explosive blast: the explosive, the fuse and the detonator. When a blasting cap (detonator) is attached to a fuse and inserted into a stick of dynamite (explosive) the unit is known as a primer. Several varieties of explosives are available to the prospector and each type has a range of grade strengths and explosive velocities. For example, "B" Forcite Gelatin Dynamite has grade strengths ranging from 30% to 90% where the velocity of the dynamite ranges from 14,000 feet per second for 30% to 23,000 feet per second for 90% strength. A strength ranging between 40% and 75% is probably adequate for most prospecting work. Some explosives do not store as well as others under extreme temperature changes and some explosives are superior to others when blasting wet holes.

Safety Fuse is a medium through which flame is conveyed at a uniform rate. It consists of a core of black powder wrapped in textiles and waterproof materials to protect the powder from abrasion oil and moisture, which can disrupt the burning time of the fuse. A disruption in the burning time can cause the dynamite to misfire. Burning time of the fuse is 120 seconds per yard or 40 seconds per foot, therefore, 3 feet of fuse allows less than two minutes for lighting a round. There is an allowable variation of 10% in burning speed, therefore, a liberal trim of the fuse is recommended allowing an extra half-inch of fuse per foot. Never use fuse shorter than 3 feet! Safety fuse can be purchased in rolls of various lengths without blasting caps attached or it can be purchased in lengths ranging from 3 feet to 14 feet with a blasting cap attached at the factory.

Blasting caps initiate an explosion and are used in conjunction with a safety fuse for the firing of explosives. Blasting caps are small 1/4-inch diameter and 1 3/8 inch long cylinders made of aluminum that are closed at one end and loaded with a charge pressed into the base. The charge is ignited when the safety fuse has burned to its end, which is situated inside the blasting cap. The explosion of the charge in the blasting cap sets off the dynamite.

There are a wide variety of electric blasting caps available but they are not widely used by prospectors. They differ from regular blasting caps because they are ignited with an electrical charge.

Fuses are lit by three methods: the spitter and hot-wire lighter and the igniter cord and connector. These are commonly used to ignite more than one charge of dynamite and eliminate fumbling with matches while attempting to light a single fuse or several fuses. The spitter is a length of fuse with notches in it, the notches cut the powder train in the fuse and are spaced an inch to 2 inches apart. The spitter is attached to the row of safety fuses and ignited. As the fire travels along the spitter, flame blows out of each notch and ignites the safety fuses in the round. The hot-wire lighter is a piece of wire coated with a hot-burning compound that is ignited with a match. The hot-wire lighter is inserted in the split end of the safety fuse and ignites the safety fuse as it burns through the split end. The burning time of spitters and hot-wire lighters are variable and may not be reliable if they are exposed to moisture, oil, gas or grease; therefore, they should be destroyed immediately if they have been exposed to those substances.
Igniter cord is also a hot-burning wire that is attached to fuses with an igniter cord connector. The connectors are the same size as blasting caps but are made of copper. They contain an ignition charge in the base, through which a slot has been cut leaving enough metal to provide a hinge that can be pressed together with your thumb after threading the igniter cord through it. When the igniter cord burns to the connector, it sets off the charge in the connector igniting the safety fuse. There are two types of igniter cord: Type A which is green in colour with a burning rate of 8 seconds per foot, and Type B which is red in colour and burns at a rate of 16 seconds per foot. Each type is supplied in 100-foot rolls or in packages containing 33 1/3 feet. Both types are marked at 1-foot intervals to assist in determining the length of the cord you are using for a hook-up.

Primacord or B-Line is a detonating cord with a highly explosive core that detonates at 20,350 feet per second. The use of primacord is recommended when you wish to fire several shots at the same time and replaces the use of safety fuses and caps in each hole to be blasted. The primacord is inserted through a stick of dynamite and attached to another length of primacord, which is detonated with a blasting cap attached to a safety fuse. The primacord and dynamite fire at about the same time.

Other equipment needed for preparing a primer are: a powder punch which is a rounded, pointed piece of copper 1/4 inch in diameter and 6 inches long used for piercing holes through a stick of dynamite; loading sticks which are rounded wood or plastic units in a variety of lengths and sizes used for tamping dynamite in drill holes; and a cap crimper used for attaching blasting caps and igniter cord conductors to safety fuse. Steel or any other material that may spark should never be used to punch holes in dynamite or tamp dynamite in drill holes. Possible sparks from steel or other sparking materials could detonate the dynamite.

To prepare a primer for a blast begin by cutting a piece of safety fuse (never shorter than 3 feet) with the "cutting slot" on the cap crimper. Carefully and gently insert (without twisting) one cut end of the fuse into the blasting cap and seat it properly into the bottom of the cap. Using the crimping groove of the cap crimper, place it over the top end of the cap, about 1/8 inch down from the top of the cup and press the handles firmly together, move down another 1/8 inch and repeat the procedure. This "double crimp" ensures that the fuse will remain water proof for a considerable length of time. Next, carefully open the paper fold at one end of a stick of dynamite and make a hole 2 1/2 to 3 inches deep in one end of the stick with the powder punch (made from non-sparking material). Insert the fuse and cap in this hole and draw the paper closely around the fuse and tie it tightly with a string. Great care must be taken to properly place the end of the fuse into the bottom of the blasting cap and to avoid kinking the safety fuse. Both of these can result in a misfire.

Before loading the drill holes clean them out and make sure there are no obstructions in the hole. All drill holes should be of sufficient size to admit the free insertion, to the bottom of the hole of a stick or cartridge of explosive without ramming, pounding or pressure. Care must be taken to ensure that the cap is not pulled out of the dynamite. Sticks of dynamite on top of the primer are tapped in firmly but not pounded and great care should be taken to avoid damaging or kinking the fuse. Do not use any metallic tool or rod to tamp the dynamite in the hole. It is not good practice to load the hole for more than two-thirds of its length. Earth, old pieces of cloth and sand can be pressed firmly into the collar of the hole on top of the explosive to maximize breaking forces of the explosive.

If a number of holes are to be fired (called a "round" of holes) they are arranged so that the holes fire in a regular order. This is necessary for three reasons: 1) the holes are drilled so that the first breaks a certain amount of ground in order to give the next an opportunity to break more ground; 2) to prevent cut offs or misfires of subsequent blasts; 3) so that a count can be kept of the number of shots. "Rotation firing" is accomplished by trimming the various fuses to different lengths. After the holes have been
loaded (with fuses of equal lengths) a piece is cut from the fuse in the hole to be fired first. The length that is cut off will depend on the number of holes in the round. This piece of fuse is used to adjust the length of fuse for the number two hole, which must be at least 2 inches longer. The rest of the holes are treated in a similar manner. When this has been done the ends of the fuses are split longitudinally for about half an inch with a sharp knife. The fuses are then lit in the order in which they are to go off (Lang 1970).

**Mud-cap blasting** is the method used when rocks are to be broken without drilling a hole. A place on a rock surface, preferably a small hollow, is selected and a charge composed of three or four sticks of dynamite and a primer is placed on the rock. The dynamite is covered with mud or clay and detonated as in the case of a drilled hole. A prospector can also use plastic explosives for this purpose. The explosive is encased in a 1 kg pillow package. The explosive is removed from the package and gently shaped into a cone shape on the rock surface. A blasting cap and fuse is inserted into the cone and fired. The effect of mud-cap blasting is not as great as it is with a drilled hole but saves on the time and expense of rock drilling and provides a fresh, broken surface for sampling.

**Every precaution must be taken to ensure that all approaches to the blast site are carefully guarded.** Your place of refuge should be far enough from the blast site to ensure that you are not hit by flying rock. Immediately after the fuse is lit, warning must be given by shouting "fire" several times. When firing a round of holes always count the number of shots exploding to ensure that no shot explosion is missing. If the firing has been done with safety fuses no person should be permitted to leave their place of refuge from the blast and return to the scene of a blast within the number of minutes that is equal to twice the number of feet in the longest fuse used during the blast. This time should be calculated from the time when the last shot is heard.

No discussion of blasting or blasting methods is complete without speaking of the treatment of misfires. If the rules and precautions for blasting are adhered to, very little trouble should be experienced from this cause. However, if a misfire does occur, no one should be allowed to return to the scene of the blast until at least thirty minutes has elapsed. After that time the holes can be examined. If it is found that for some reason the charge has not exploded, no attempt should be made to remove the old charge; it should be fired without undue delay by means of a fresh primer in the hole on top of it. Another precaution against misfires: never cut fuse until ready to use it (Lang 1970).

This manual is not designed to be procedure manual for blasting. This section was written as an introduction to blasting, therefore, anyone not familiar with blasting procedures should read appropriate manuals and regulations regarding the use, handling, transportation and storage of explosives. If you know someone familiar with blasting procedures then have them demonstrate the proper procedures to you or receive instructions from vendors of explosives. You can never be too careful when using explosives.

**c) Mucking**

Mucking is a mining term used to describe the removal of waste rock from a blasted site. Once you have successively blasted an outcrop, mucking is necessary to clean the broken rock from the trench or pit. Carefully remove broken rock pieces and try to separate the mineralized rock from unmineralized waste rock. Freshly blasted pieces of rock can be extremely angular and sharp and are capable of slicing leather, therefore, always wear good gloves and steel-toed boots while working in the trench. Sweep out the trench and wash it down with buckets of water or a hose. Try to plan some type of drainage from the trench so that it does not fill up with water.

**IV) SAMPLING TECHNIQUES**

**i) Introduction**

Sampling is defined as the process of taking a small part of a mineralized body so that the value and consistency of the parts are
representative of the whole body. One of the most important skills of prospecting is to take rock samples that are sufficiently representative of a mineralized zone.

Mineralization is seldom uniform or consistent in a deposit. Gold, silver or other very valuable minerals commonly occur erratically throughout a mineralized zone. The irregularity of these minerals makes them easy to miss when collecting samples and can result in a low analysis. However, a small quantity of the mineral can also make a sample analysis very high. Therefore, sampling a mineralized zone must be done properly.

The following general rules of sampling should be followed for most sampling techniques:

1) Try to collect fresh rock samples. Weathered rusty rock may be enriched or depleted in minerals and may not be representative of the mineralized zone.

2) When sampling a rock with hard and soft spots a prospector should take care not to collect more soft material in favour of the harder material. The sample should include all materials in the vein in their proportionate amounts.

3) Care should be taken to keep foreign material out of the sample.

4) Samples should be taken at regular intervals along the strike of the mineralized zone. These samples should include the entire width of the zone. If the zone is narrow, such as a vein, it may be necessary to sample the "minimum mining width (1 m to 1.2 m)" which is the combined vein and waste rock material that must be removed for mining (1 to 1.2 m).

5) The location, sample number, amount of sample, length of sample, type of sample and description of the sample should be carefully documented in a notebook and map. The importance of this point cannot be overemphasized. Many individuals have taken samples and received favourable assays but forget where the sample came from because they did not describe the sample or carefully document the sample location. Be sure to write the sample number on a durable piece of paper or cardboard and place it in a tough, plastic or canvas sample bag. Mark the sample number on the bag with waterproof ink. Note all the sample information in a notebook and immediately mark the sample location on a map or sketch. Check the samples at the end of each day for proper labeling; examine the sample for significant minerals; and make note of the minerals and their percentages in the sample. Determine what elements you want analyzed and write lab tests to be performed on the tags in the bag, on the bag and in a notebook. Seal each bag with a twist tie or wire, pack the samples carefully and ship to the lab with a covering letter explaining what analyses you want to have performed, including a complete list of the sample numbers.

6) Make sure to contact several assay labs to compare costs and to inquire about their lab services and sampling techniques.

There are numerous methods for sampling a mineralized zone based on the detail of the sampling that is required. The sampling techniques described below are most commonly used.

ii) Grab Sampling

Grab samples are usually collected during the first preliminary evaluation of a mineral showing. The samples may or may not be representative of the mineralized zone. Grab sampling involves picking out a hand- or fist-sized piece of material from the showing. A person taking a grab sample should indicate if it is representative of the mineralization present (representative grab) or if it has been selected to highlight a particular feature of the mineralization (selective grab). Often a person will high grade a mineralized zone during initial sampling and pick out the best looking mineralization in order to get an idea of the highest grade that can be expected from the mineralized zone. Taking a composite sample of the showing, by combining several representative grabs, will produce a more representative analysis.
iii) Chip Sampling

Chip Sampling is an inexpensive preliminary sampling technique. Rock chips are knocked off at intervals of a few centimeters along a line across the estimated true width of the mineralized zone. The rock chips can also be taken continuously across the zone. A hammer, chisel and pick are used to chip the rock and the sample is collected on a plastic sheet, in a bag, or in a box. The sample is meant to be representative so if a large piece of rock is broken off, it is split, and an average piece is included with the sample. The chip sample provides a representative analysis over a specified width and is commonly repeated at regular intervals along the strike length of the mineralized zone.

iv) Channel Sampling

Channel sampling is one of the best methods for obtaining representative material from a mineralized zone. It should be conducted after grab and/or chip sampling has indicated that the showing is favourably mineralized. Channel sampling is time consuming and expensive and is used to obtain more detailed assay/analysis information. The samples are taken from a "channel" at least 5 cm wide and 5 cm deep, which is cut at right angles to the strike of the mineralized zone. The channel is cut with a portable rock saw (mortar saw) and the material between the saw cuts is removed with a hammer and chisel. Channel samples are collected at regular intervals along the strike length of the mineralized zone.

The rock saw used for channel sampling is about the size of a chain saw and can be equipped with inexpensive mortar-cutting saw blades (30.5 cm in diameter) or expensive diamond-impregnated blades which cut easier, faster and last longer. The blade must be kept wet at all times to cool the blade and reduce rock dust. A small water-filled fire extinguisher or other water container can be attached to the saw with a rubber hose. The hose is attached to the side of the saw near the blade, so that water can trickle on the blade as it rotates. The container of water must be kept above the level of the saw so that the water can flow downwards by gravity feed.

There are seven steps that you should follow when channel sampling, some of the steps also apply to chip sampling. These steps are listed below:

1) Clear the outcrop surface thoroughly with a broom, brush and water.

2) Mark the sample intervals across the width of the mineralized zone with paint, felt marker, or crayon. Mark the lines that you will follow with the rock saw and keep the lines at an even width.

3) Cut along the lines on the rock surface with the rock saw. Let the saw blade "pull" the saw forward do not push the saw or the blade may bind and break or "burn". Make sure to keep the blade wet. Wear safety glasses, hearing protection, steel-toed boots and a mask if there is excessive dust. Make sure that the depth of the saw blade and width of the channel are kept as constant as possible.

4) Chip out the sample across the entire width of the vein, take care to catch the cut material on a sheet of plastic, canvas or cloth. Great care must be taken to see that the sample is not contaminated from fine material from previous sampling, therefore, clean the plastic or use another sheet when collecting the next sample. Wear gloves and safety glasses to protect yourself from flying rock chips.

5) The width and depth of the channel should be held as constant as possible when chiseling out the sample.

6) A kilogram or more of rock material is usually obtained for each linear metre of channel. Individual samples should never exceed 1.5 metres of channel length. Separate continuous samples should be taken if mineralization is more than 1.5 metres wide. A few centimetres of the wall rock at each side of the mineralized zone should be included in the sample in case it contains valuable mineralization. Separate channel samples of wall rock should be taken adjacent to the mineralized samples to ensure that all significant mineralization has been sampled.

7) Separate channel samples are usually
taken along strike of the mineralized zone at even intervals, depending on the size of the showing; the regularity of mineral distribution (the more irregular the more closer spaced the samples should be); and the time and money available for sampling.

8) The samples should be planned and collected without favouring mineralized sections within the zone.

v) Panel Sampling

Panel samples are taken the same way as chip or channel samples but cover larger surface areas. They are taken from areas 0.5 m to several metres square in an attempt to obtain a more representative sample. Lines may be drawn on the outcrop surface in the form of a grid and alternate squares may then be sampled (Lang 1970).

vi) Bulk Sampling

Bulk samples are taken to: 1) provide a more representative estimate of the grade of a deposit; 2) to determine whether the deposit can be treated economically; and 3) to determine the best method of treatment and the percentage of recovery that can be expected. Many industrial minerals must be bulk sampled to determine quality and purity such as limestone, quartzite and dimension stone. Most bulk samples are removed when a deposit of substantial grade and size is outlined by other exploration techniques.

A bulk sample may range from a few hundred kilograms to several tonnes in weight and is commonly blasted from pits or trenches at the surface or from underground workings or obtained from drill chips or core. The rock pieces in a very large sample are commonly reduced in size by a portable crusher to make the sample more manageable. If the material is taken from more than one trench or location within the mineralized zone then it should be kept separate for comparison of the grade and quality in different parts of the deposit. The samples can be combined later for treatment tests.

If the transportation of a bulk sample is a problem and you cannot ship the entire sample for treatment, it is possible to reduce the sample into a smaller representative sample by "coning and quartering". This process involves shoveling the whole bulk sample into a cone-shaped pile. The top of the pile is flattened by spreading the material as evenly as possible into a pile whose height is one-tenth its diameter. Two opposite quarters of the pile are shoveled into a new pile and it is quartered in the same way. This process is repeated until a convenient sample size is obtained. Equipment such as sample towers can also be used for splitting and reducing bulk samples.

A prospector should be aware that the extraction of material in excess of 500 tonnes is considered to be advanced exploration. As such, you will be required to give notice of the project to the appropriate regional MNDM office. The Director of Rehabilitation may require public notice, a closure plan or both. The decision of whether you must undertake any of the above procedures will be made within a 30-day waiting period. If you have not been contacted during the 30-day period, you may proceed with your bulk sampling project, provided you have secured all other necessary approvals or permits.

vii) Panning

When most people think about prospecting, they think of panning. Panning is an integral part of prospecting lore but it is a dying art. Prospectors generally only use panning when they are prospecting for placer gold deposits in loose sediments but very few prospectors use it when prospecting for gold deposits in "hard rock" terrains.

Panning can be a very effective and low cost method of testing gold discoveries in the field. Some points you should know about panning and the panning method are listed below:

- A pan should be a sheet iron pan, 10 to 16 inches in diameter, 2 to 2 1/2 inches deep with sides sloping at 035°-040°, and should weigh 1 1/2 to 2 lbs. If the pan is dirty, greasy or too highly polished it will not retain fine-grained gold or other valuable metals. Durable plastic pans are also available.
- Grind and powder rock samples with a steel
mortar and pestle. If the sample contains sulphide minerals, burn the sulphur off by placing the sample in a tin can and roasting it on a wood stove, propane hot plate or over a fire for 4 to 5 hours. A butane torch can also be used to roast the sample and is much hotter and faster. The roasting frees any gold that might be trapped within sulphide minerals. Don’t breath the fumes produced by roasting and always roast in a ventilated area. Be very careful with samples containing arsenopyrite: roasting releases arsenic from arsenopyrite, which will be present in the fumes. Arsenic is poisonous and should not be inhaled.

- Place the crushed and roasted sample in the pan.
- The pan is alternately shaken (side to side) and gently rotated under water, then raised to the surface at an angle so that the lighter material is spilled off and washed away.
- This process is repeated until only heavy mineral grains remain in the pan. These are commonly composed of magnetite, pyrite, hematite, and other heavy minerals, as well as any gold that may be present.
- If a little water is added and the pan is gently rotated the gold will be separated to form a "tail" behind the other heavy minerals. Small flakes or grains of gold are called "colours".
- Examine the heavy minerals with a hand lens to definitely identify the gold.
- Don’t totally rely on panning to evaluate a vein or gossan zone, send some samples in to an assay laboratory for testing.
- The beginner should constantly practice the panning techniques with sand mixed with iron filings and become proficient at separating the iron filings from the sand.

When prospectors discover a promising gossan zone or vein in the field they can immediately test it by panning. Simply obtain a sample from the mineralized zone, powder the sample with a steel mortar and pestle and pan the sample in a nearby body of water. If gold is obtained in the pan you know immediately that you have a promising discovery and you can spend more time working on it or staking it. Without the use of panning you would take a sample; travel home; send the sample for assay; and wait a few days or longer for the results. If the results were favourable you would have to travel back to your discovery to do more work. This process is not as effective or efficient as panning in the field. Collecting samples, roasting and panning them at home is also efficient and eliminates the need to assay a large number of samples and reduces sampling and assaying costs. Samples that are panned and barren of gold can be ignored. Panned samples that contain gold can be sent to the lab for more accurate assaying. A skilled "panner" can pan a sample and visually estimate what the assay will be to an accuracy of 1 ppm Au.

Panning is not only used to pan gold but is useful for the detection of any heavy and resistant minerals such as: platinum, gemstones, cassiterite (tin) and so on.

V) TESTING DISCOVERIES

i) Introduction

A knowledge of the various tests that can be performed on samples is important to prospectors. A prospector should know which tests can be used to evaluate various commodities; the detection limits of the tests; and their costs.

A test that determines the chemical composition or relative quantity or percentage of an element or mineral in a rock sample is an assay or analysis. Various analytical procedures are used to test: the quantities of various precious metals, base metals and rare elements; talc content in soapstone; calcite to dolomite ratios in limestone; moisture content in soils; purity of silica and limestone and so on. Tests for industrial minerals are used to determine physical properties, such as specifications, sizes and colour. Tests include determinations of compressive strength and modules of rupture for building stone; grain or flake size of silica and graphite; whiteness of limestone, talc, gypsum, nepheline syenite, barite and silica; specific gravity of minerals (metallic and non-metallic) and other essential qualities and properties of the minerals.

The only analytical procedures described in this manual are the most common techniques used to determine relative quantities of elements or minerals in a rock sample.
ii) Units of Concentration and Methods of Reporting Analytical Data

Conventional units of concentration are based on weight. Thus, if a rock sample weighing 100 grams (g) contains 1 g of sulphur, the concentration of sulphur in the sample is said to be 1 part per hundred or 1 percent.

The chemical elements that make up a rock are classified according to their natural crustal abundances. Major elements are those occurring with a concentration greater than 1%; minor elements occur with a concentration range between 0.1 - 1.0%; trace elements occur in the range 0.0001 - 0.1%; and ultra-trace elements occur at less than 0.0001%.

To simplify the presentation of concentration data three units of concentration are commonly used. Elements occurring at "major" and "minor" levels of concentration are reported as percent (%); elements occurring at "trace" levels are reported as parts per million (ppm); and elements occurring at "ultra-trace" levels are reported as parts per billion (ppb). Parts per million (ppm) and grams per metric ton (g/T) are equivalent. 1% is equivalent to 10 000 ppm; 1 ppm is equivalent to 1000 ppb. Table 1 gives examples of assay data for gold, silver and base metals.

Assayers have traditionally used troy ounces per short ton (oz/ton) to express gold and silver assay data. That the unit has remained popular is perhaps due to the ease with which one can imagine "an ounce of gold" and a "ton of ore". One troy ounce is equivalent of 31.1034768 g and one short ton is equivalent to 907.18474 kg. This means that there are 29 167 ounces in a ton. 1 oz/ton is the same as 1 part per 29 167; this is equivalent to 34.286 parts per million.

Low gold assay values are occasionally quoted in pennyweights (dwt) per ton; there are 20 dwt in 1 troy ounce. Conversions between dwt/ton, oz/ton, and % involve complicated conversion factors (see page 175 "Conversion Factors" in this manual). Conversions between ppb, ppm and % are simple decimal conversions. Consequently the decimal conversions scale is preferred.

iii) Analytical Techniques

Below are brief descriptions of the most common quantitative analytical procedures. It should be noted that all rock samples that are analyzed using these techniques are crushed to 1/4-inch fragments and about 200 g of the sample is then pulverized to fine powder.

**Fire Assay:** Used mainly with gold. A specific weight of powdered sample is mixed with a flux and a known amount of lead compound. The mixture is heated to high temperatures and any gold in the sample is concentrated into a lead button, which is weighed. Anything over the known amount of lead is gold. The detection limit for this technique is about 0.3 ppm.

**Atomic Absorption:** The powdered sample is dissolved in acid and the resulting liquid is burned in a gas flame. Various elements colour the flame differently. By comparing this colour to standards of known composition the concentration of elements in the sample can be determined. The method is good for base metals but there can be problems with gold. The detection limit is 0.002 ppm.

**Fire Assay/Atomic Absorption:** These techniques are combined by some labs. A lead button is produced by fire assay and then assayed by atomic absorption. This combined method is good for gold assays and has a detection limit of about 2 ppb.

**X-Ray Fluorescence:** A powdered sample is fused at high heat to form a pellet. The pellet is exposed to x-rays, which causes different elements to fluoresce. The colour of the light indicates the elements present and the intensity of the light indicates the amount.

**Neutron Activation:** A sample is exposed to radiation from a nuclear reactor. The way in which the sample loses the "induced" radiation indicates the type of elements present; and the amount of radiation indicates the amount of elements present. This is a very accurate and precise method.
<table>
<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>GOLD Au (ppb)</th>
<th>COPPER Cu (ppm)</th>
<th>ZINC Zn (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTA-90-50</td>
<td>15</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JP-90-115</td>
<td>35</td>
<td>690</td>
<td>153</td>
</tr>
<tr>
<td>JP-90-116</td>
<td>6220</td>
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<td>1.1%</td>
</tr>
<tr>
<td>JP-90-117</td>
<td>&lt;2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JP-90-118</td>
<td>11</td>
<td>380</td>
<td>42</td>
</tr>
<tr>
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<td>880</td>
<td>3.1%</td>
<td>420</td>
</tr>
<tr>
<td>JP-90-121</td>
<td>70</td>
<td>915</td>
<td>137</td>
</tr>
<tr>
<td>JP-90-122</td>
<td>2050</td>
<td>500</td>
<td>165</td>
</tr>
<tr>
<td>JP-90-123</td>
<td>410</td>
<td>1%</td>
<td>87</td>
</tr>
<tr>
<td>JP-90-124</td>
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<td>98</td>
</tr>
<tr>
<td>JP-90-125</td>
<td>385</td>
<td>9500</td>
<td>80</td>
</tr>
<tr>
<td>JP-90-126</td>
<td>&lt;2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JP-90-127</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JP-90-128</td>
<td>12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JP-90-129</td>
<td>3170 ppm</td>
<td>3.05%</td>
<td>180</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>GOLD OZ. PER TON</th>
<th>GOLD VALUE PER TON</th>
<th>SILVER OZ. PER TON</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.74</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>trace</td>
<td>trace</td>
<td></td>
</tr>
<tr>
<td>Aa3</td>
<td>nil</td>
<td>nil</td>
<td></td>
</tr>
<tr>
<td>A4</td>
<td>0.70</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>nil</td>
<td>nil</td>
<td>Lead - .03%</td>
</tr>
<tr>
<td>C#1</td>
<td>0.56</td>
<td>0.28</td>
<td>Copper - trace</td>
</tr>
<tr>
<td>C#2</td>
<td>0.02</td>
<td>0.08</td>
<td>Copper - 0.05%</td>
</tr>
<tr>
<td>C#3</td>
<td>nil</td>
<td>trace</td>
<td>Copper - trace</td>
</tr>
</tbody>
</table>

Table 1: Examples of Assay Data for Various Elements
ICP-MS (Induced Coupled Plasma-Mass Spectrometry): The sample is dissolved in an acid solution and subjected to extreme heat to produce plasma. The individual elements in the plasma are directly measured by a mass spectrometer. The ICP-MS method has detection capabilities in the parts per trillion (ppt) range.

VI) Prospecting Techniques for Diamonds

Prospecting for diamonds is quite different from other target commodities and deserves a separate discussion of the methods currently employed. Although utilizing common exploration techniques, diamond exploration exploits the unique mineralogy of kimberlite indicator minerals and distinct geophysical characteristics to identify targets.

Once an area is selected for prospecting, the prospector should focus attention on existing gravel pits and glacial deposits such as eskers and kames where kimberlite boulders may be found. Due to their mineral composition, kimberlites often retain water after rainstorms, making them easier to detect by their wet appearance. If kimberlite boulders are discovered, look "up-ice" or upstream to try to determine where the kimberlite originated. This will help to focus the area for more thorough prospecting for bedrock sources of kimberlite.

Kimberlite is a soft rock and weathers readily, has a distinct mineralogy and is fairly easy to recognize in the field, notwithstanding the precise analysis necessary to confirm the classification. Careful observations of rock outcrops in favourable areas may reward the prospector with a kimberlite discovery.

Geophysical Surveying (Airborne and ground)

Most kimberlites commonly exhibit isolated circular or ovoid magnetic anomalies (typically 100-500 metres in diameter) that contrast with the country rocks they intrude. The magnetic signature may be positive or negative, depending on the magnetic contrast with country rock and the mineralogy and magnetic susceptibility of the rocks. However, not all kimberlites have a geophysical expression while others have very subtle geophysical signatures. Magnetic surveys may be useful in detecting kimberlites but they will not establish whether the pipe is diamondiferous. That requires actual mineralogical sampling.

Electromagnetic (EM) and Very Low Frequency (VLF)-EM surveys measure the electrical resistivity of the material at or near the Earth's surface. Such surveys work well for kimberlite pipes containing well-developed, weathered, conductive, clay altered upper horizons. In addition, there needs to be good contrast between the kimberlite and the surrounding material in order to aid detection.

Gravity surveys also are useful in delineating the size and shape of a kimberlite pipe, especially where the density of the kimberlite is significantly different than the country rock.

Due to the physical and mineralogical character of the host rocks, geophysical techniques have not yet proven successful in detecting Wawa-type diamond occurrences.

Surface Sampling

Surface sampling includes a variety of sampling media. Most commonly, glacial till, stream sediments and bedrock grab samples are collected as the primary sampling media. The principle behind the sampling is to look for and define dispersion patterns for anomalous chemical elements of mineral grains. Sometimes, these dispersion "trains" can be traced back to the kimberlite source. This technique requires knowledge of the geological history of the region, including any glacial or alluvial activity that may have occurred since the deposition or emplacement of the kimberlite pipe. Since the late 1990's, the Ontario Geological Survey has assisted prospectors by conducting regional till and stream sediment sampling programs in areas of the province that are considered to have good diamond exploration potential.

The most widely used method of surface sampling is heavy mineral concentration for kimberlite indicator minerals (KIM). A suite of
resistant heavy minerals associated with kimberlite include pyrope garnet, chromite, ilmenite, chrome diopside, picro-ilmenite and diamond. Samples of glacial till, stream sediment or bedrock are collected and processed in order to concentrate these mineral grains. The number, type and appearance of each of these grains is recorded for each sample. Once plotted, dispersion trains may become apparent suggesting areas for detailed exploration efforts.

Diamond is the only KIM that has consistently been found in association with the Wawa type diamond occurrences. Processing of grab samples from outcrop ranging in size from <10 kg to >10 tonnes has consistently produced gem quality diamonds. There are also reports of six alluvial diamonds recovered within 20 km of the Wawa bedrock diamond occurrences; these range in size from 0.25 carats to 1.92 carats.

Numerous alluvial diamonds have been found and reported elsewhere in the province, their distribution is likely the result of glacial dispersion of diamonds eroded from bedrock sources.

**VII) REPORT WRITING**

Mining companies receive hundreds of property submissions every year that can vary in quality from a bag of rocks to a full feasibility study. Unfortunately, the presentation of many submissions is poor and difficult to review and evaluate. If you want to effectively market your property and interest a mining company then you must submit an organized and informative report in a clear and neat manner. Below is a list of essential points that should be in a report.

1) The report should be brief and to the point. Most properties can be described in five to ten pages with three or four maps. If there is a large amount of data available on a property a summary of the information will suffice. The rest of the data will be requested if the company is interested.

2) Accurately describe the location of the property, including N.T.S. reference, township or district. Locate the general area (i.e. 72 km north of Kenora) accompanied by a more detailed location description (i.e.: southeast shore of Seagull Island in Jackfish Lake). Describe the access or means of reaching the property. The report should include a map showing the location of the property, claim boundaries, trails and roads into the property. From a properly prepared report and map a person should be able to reach the property and find the showings without a guide.

3) Describe ownership and history of the property; provide the names of other owners; include information such as date of staking and past and present assessment work. Include an up-to-date claim map with records (abstracts) of claims staked.

4) The geological information about the property is most important and is usually the section most poorly presented. The report should summarize past (by previous owners) and present exploration on the property. If it is an old property that has had some previous production the history of the property should be described completely.

5) State the type of work and the cost of work you have conducted on the property.

6) Describe the main features of the local geology which may be taken from geological reports and maps or described from personal observations if reports or maps are unavailable. Include a copy of a published geological map and/or report if available.

7) Describe the number of mineralized zones present; their type (i.e. pegmatite, quartz vein, shear zone); the length, width and strike of the zones; and state the number of strippings, pits or trenches. Include sketch plans of the property indicating the location of all drill holes, trenches and stripped areas.

8) Include all relevant assay data with sketches indicating the sample locations. Indicate the type of samples taken and their widths. Copies of assay reports from the lab should be attached.

9) Sign and date the report and provide your
address and phone number.

10) Do not include detailed data on nearby mines or adjoining properties unless it is specifically relevant.

The following is a list of "chapters" or "headings" that should be included in the report.

1) Title of the Report (include your name, address and phone number on the cover page of the report).
2) Purpose of the Exploration Program.
3) Location and Access (with location maps).
4) Claim Status (with claim map and abstracts).
5) Previous Exploration History.
6) Work Performed.
7) Results of Work (describe rock types and showings; include assay data and sketches).
8) Appendix (includes copies of relevant information from assessment files, assay lab sheets and so on).
9) Accompanying Maps and Reports (include air photographs, topographic maps, government publications, and so on).

The proper preparation of reports is important not only for submissions to mining companies but also for Applications for OEC funding and OEC Final Submissions. Always maintain a detailed diary of your field work and a library of information on your properties. Staff of the Resident Geologist's office can assist you in the preparation of your reports and can help you decide what information to include.

VI) SUMMARY OF STEPS FOR PROSPECTING

The following is a list, which summarizes the general prospecting procedures. Remember to take advantage of the services offered by the Resident Geologist's office: the staff can assist and advise you with all aspects of your exploration program.

1) Research the commodity and area you're interested in prospecting. Visit the Mining Recorder's office to acquire information on the land status of the area you're interested in. Make sure you have an up-to-date prospecting license. Be systematic: conduct an assessment file search, research government reports, files and maps. Keep good organized records and personal files.

2) Collect grab samples from your property or area of interest. Label the samples with numbers and locate them on a map. Ship the samples to an assay lab with clear and specific assay instructions.

3) Contact the Resident Geologist and approach him with samples from the property or area of interest. A government geologist will conduct property visits and provide limited free analytical services.

4) Plan your exploration program carefully and logically.

5) If assay results are encouraging, the mineralized showing should be stripped and sampled systematically and thoroughly. Attempt to "trace out" the mineralized zone to determine its extent on surface. Trench the showing if necessary. Do as much surface work as possible in two dimensions to expose the mineralized zone. Apply for a Work Permit before you can work on your property.

6) Make a rough sketch and/or take photographs of the geology of the occurrence and immediate area. The sketch should include the locations of stripped and trenched areas and sample locations. Make sure enough claims cover the mineralized zone and set up a good access route into the property, i.e. cut a trail.

7) Approach mining companies working in the area with your property submission including analyses, sketches, copies of old data (i.e. information from assessment files or government reports), rock specimens and so on. Approach companies with local field offices, since they are familiar with the area and can usually get a geologist to the property quickly.

8) In dealing with companies be aware that most have a minimum requirement for grade and tonnage and often restrict the commodity they are exploring for.

9) It doesn't hurt to approach several
companies. It is surprising how many are receptive to making property visits with thoughts of optioning.

10) Talk to the geologists at the Resident Geologist's office in your area. They know the companies, the geologists to contact and the geology of their area. Also keep a library of reports and maps of your area of interest and a number of good reference books.

VIII) CONVERSION FACTORS AND USEFUL NUMBERS FOR ANALITICAL DATA

1 short ton = 2000 lbs.
1 long ton = 2240 lbs.
1 metric ton (tonne) = 2204 lbs.
1 ounce (troy)/ton (short) = 34.3 ppm
= 34,300 ppb
= 34.3 grams/tonne (metric ton)
= 20 pennyweight

1% = 10 000 ppm
1 ppm = 1000 ppb = 1 gram/tonne = 0.029 ounce/ton

Conversion from SI to Imperial

<table>
<thead>
<tr>
<th>SI Unit</th>
<th>Multiplied by</th>
<th>Gives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 g/t (short)</td>
<td>0.291666</td>
<td>ounce (troy)/ton</td>
</tr>
<tr>
<td>1 g/t (short)</td>
<td>0.58333333</td>
<td>pennyweights/ton</td>
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Conversion from Imperial to SI

<table>
<thead>
<tr>
<th>Imperial Unit</th>
<th>Multiplied by</th>
<th>Gives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ounce (troy)/ton (short)</td>
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<td>grams/tonne</td>
</tr>
<tr>
<td>1 pennyweight/ton (short)</td>
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</tr>
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<td>ounce (troy)/ton (short)</td>
<td>34.3</td>
<td>ppm</td>
</tr>
<tr>
<td>ounce (troy)/ton (short)</td>
<td>34,300</td>
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PART 9:

EXPLORATION TECHNIQUES
EXPLORATION TECHNIQUES

I) INTRODUCTION

Mineral exploration work, other than prospecting, stripping, trenching and sampling consists of various geophysical, geochemical and geological surveys and drilling methods. These surveys are generally expensive and require technical expertise for the collection and interpretation of data. The surveys are conducted to detect specific physical characteristics of a mineral deposit and to provide information that is used to: 1) assess the mineral potential of an area; 2) outline the extent of mineralized zones on surface and below ground; 3) detect mineralization not exposed on surface; and 4) determine whether it is warranted to spend more money on more advanced exploration. The results from the various surveys are most effective when they are combined with each other to produce the "best fit" of all the characteristics, which may indicate the presence of a particular mineral deposit.

The following chapter describes the various types of surveys and techniques used in mineral exploration.

II) ESTABLISHING A GRID

One of the first things that must be done before detailed survey work begins is to establish an exploration grid over the area of interest so that: 1) an area can be surveyed with accurate horizontal ground control; 2) survey data and mineral occurrences can be accurately located with respect to the grid; and 3) the size and extent of the mineral occurrence can be determined.

A grid consists of evenly spaced, cut lines that intersect at right angles. The lines are accurately located using compass bearings and survey transits and are measured and picketed at specific intervals along their lengths (Figure 1). Any point on the grid can be located by using the grid coordinates for that point. Grid lines are cut using axes, chainsaws and machetes. Traces are blazed along the lines and underbrush is cut out with a machete. Well cut lines can be located after 10 years even with new tree and shrub growth, but a poorly cut line can be lost after one year.

The baseline is the main control line for the entire grid. All other lines are cut and measured from the baseline. The baseline is established parallel to the strike of rocks in the area of interest (Figure 1). For example, if a mineral occurrence is hosted by rocks that trend 090º then the baseline is oriented in the same direction. If a mineral occurrence is located in a structure, such as a shear zone, then the baseline should be oriented parallel to the trend of the structure. The baseline must be cut and located accurately and is usually surveyed with a transit. The line should be cut out to a width of 2.5 to 3 m so that it is easy to sight down the line.

Cross-lines are established along the length of the baseline and are oriented perpendicular to the baseline and to the strike of the rocks or structures in the area (Figure 1). Cross-lines are cut at evenly spaced intervals determined by the width and length of the mineralized zone and by the amount of detail required. Cross-lines are commonly spaced at 30 to 250 m intervals along the baseline. The cross-lines are cut from the baseline and extend as far as necessary to cover the area. The cross-lines should be well blazed; cut out to a width of 1.5 to 2 m; and kept as straight as possible.

Tie-lines are relatively short grid lines that are cut at various intervals along the grid for control of the cross-lines (Figure 1). Tie-lines are commonly oriented parallel to the baseline.

After the grid is cut the lines are chained and picketed. Pickets are 1.5 to 1.8 m long poles that are sharpened and erected at measured intervals along the grid lines. A chain is a 50 m to 100 m long cable that is marked off at 1 m or 1-foot intervals and is used to "chain" or measure a grid. The chain is carried between two people as they walk along a grid line. The person at the front of the chain cuts the pickets while the other follows behind and marks the chainage and grid coordinates on the pickets. The lines are picketed at 25 to 100...
The inscription on the picket always has two coordinates: Crossline No. 3+00 W and Station No. 2+00 S.
metre intervals depending on the detail that is required. Each picket must be marked with its appropriate grid coordinate. A carpenter's pencil should be used to mark the picket because it is durable and long lasting. Felt markers fade quickly and cannot be seen after 6 months or a year.

All lines must be chained from the baseline. Chaining that is done from the end of the cross-line to the baseline is called back-chaining and results in major errors in the chainage along the lines of the grid. Results of survey work conducted on the grid will be inaccurately located on the grid base map if the chainage errors are not detected during or prior to the survey work.

A GPS can be used to great effect to ensure that the grid lines are not deviating significantly from the intended location and that chaining is correct. Many GPS units demonstrate an accuracy of just a few metres and can be set to display actual grid coordinates making them an invaluable tool.

If a baseline is cut in an east-west direction then all of the cross-lines will be cut in north-south directions. The cross-line at the middle of the baseline is numbered Line 0+00. Cross-lines west of Line 0+00 are numbered L1W, 0+00; L2W, 0+00; L3W, 0+00 on the baseline, while lines east of Line 0+00 are numbered L1E, 0+00; L2E, 0+00; L3E, 0+00. If each cross-line has been picketed at 25 m intervals then pickets north of the baseline on L1W will be numbered as follows: L1W, 0+25N (25 m north of the baseline on Line 1 West); L1W, 0+50N; L1W, 0+75N; L1W, 1+00N; L1W, 1+25N; and so on. Pickets on Line 1W that are south of the baseline are numbered L1W, 0+25S; L1W, 0+50S; L1W, 0+75S and so on. Figure 1 illustrates the manner in which the lines and pickets are numbered.

A base map of the grid is drafted to scale with all of the grid lines and grid coordinates indicated on the map. Survey data is plotted and interpreted on the grid base map as the various surveys are completed. Drill holes are planned and accurately located based on the grid coordinates and the location of survey data on the grid.

### III) GEOPHYSICAL SURVEYS

#### i) Introduction

Geophysics is a branch of experimental physics concerned with the forces and properties belonging to the Earth and their resulting effects. Since the Earth consists of rocks and minerals, many geophysical properties are also observed in hand samples of rocks and minerals. Phenomena such as gravity, conductivity, radioactivity and magnetism are geophysical properties shared by both hand specimens and large scale Earth features. The value of these properties is that they are not confined within the dimensions of the mineral or rock mass from which they originate. Geophysical properties extend beyond the location of a mineral deposit and may express themselves over an area much larger than the size of the deposit by causing abnormal variations in one or several geophysical properties. The chances of discovering a mineral deposit are enhanced because of the enlarged area of geophysical expression. Even a deeply buried deposit may be detected at the Earth's surface through the measurement of geophysical properties.

Modern geophysical prospecting techniques have the function of 1) directly finding mineral deposits because of some detectable physical characteristics; and 2) detecting various rock types and assisting in the interpretation of geological maps. Magnetic and electromagnetic surveys are used to "map" the characteristic magnetic and conductive responses of specific rock types, which can be extended under areas of poor exposure and heavy overburden. The development of computer technology and data processing software has greatly advanced the development, efficiency and effectiveness of geophysical equipment and surveys and has aided in the interpretation of geophysical data. Many modern geophysical instruments are small, lightweight and very easy to use. Geophysical data can be manipulated and presented in a variety of ways using different types of computer software programs.

The exploration objective of a geophysical survey is to detect and map the distribution of various geophysical responses of materials at
the Earth’s surface and to as great a depth as possible.

Geophysical surveys map the distribution of conductive material (electromagnetic surveys); magnetic material (magnetic surveys); naturally occurring radiation (radiometric surveys); mass within the Earth (gravity surveys); and detect velocity and density variations in the subsurface (seismic surveys). Geophysical surveys detect anomalies, which are measured, abnormal, variations from the expected or normal. Geophysical anomalies are geological features, distinguished by geophysical means, which are different from the general surroundings. These anomalies are of interest to mining companies and prospectors because they may indicate the presence of an economic concentration of minerals.

Geophysical surveys are conducted on the ground and from the air. Airborne geophysical surveys are conducted with geophysical equipment mounted on airplanes and helicopters. These types of surveys are useful for reconnaissance exploration and are capable of collecting data over very large areas. The results of airborne surveys assist in the selection of areas with high mineral potential. Ground geophysical surveys are commonly used to follow-up results from airborne surveys. Ground surveys provide more detailed and accurate information and accurately locate geophysical anomalies on the ground.

There are a great variety of geophysical equipment, techniques and methods used in the search for mineral deposits, however, this manual will only describe magnetic and electromagnetic techniques in detail. The descriptions of the techniques are not intended to give directions for carrying out surveys or for interpreting results. The purpose is to supply enough information to enable the readers to gain some background as to how and where the methods can be applied, the significance of the results and how data is assessed.

ii) Magnetic Methods

The Earth’s magnetic field can be envisaged as numerous "lines of force" which converge at the north and south magnetic poles. The "north-seeking" end of a compass needle aligns itself with these lines of force and points towards the north magnetic pole. The Earth’s magnetic field is not uniform and is "distorted" by variations in the magnetite content of rocks. Strong magnetic properties are only possessed by certain materials such as iron, nickel and some special alloys. The magnetic properties of rocks are due to the presence of magnetite and other magnetic iron oxides; all other minerals make a minor contribution except for pyrrhotite in some areas. Magnetite is a mineral that responds more readily to the Earth's magnetic field than other minerals and becomes spontaneously magnetized. The Earth's magnetic field "induces" magnetism in grains of magnetite. If the Earth’s magnetic field were removed the magnetite grains would no longer be magnetic. The physical property of a mineral or rock, which measures its ability to acquire induced magnetism, is called its magnetic susceptibility. Natural concentrations of minerals exhibit varying magnetic susceptibilities. Minerals with high susceptibilities are: magnetite, ilmenite, pyrrhotite and manganese minerals. Minerals with low susceptibilities are: pyrite, hematite, sphalerite and galena.

The Earth’s magnetic field lines are distorted by concentrations of minerals with high magnetic susceptibilities. The field lines are "pulled in" toward a concentration of magnetic minerals, which translates in an increase in the strength of the field. Such variations in the magnetic field are known as magnetic anomalies. It is this anomalous behaviour of the Earth’s magnetic field above some mineral deposits and rock types that makes the physical property of magnetism useful in mineral exploration.

In the past, magnetic anomalies or variations in the Earth's magnetic field were measured by using a compass or similar piece of equipment known as a dip needle. By moving along survey lines and recording changes in the position of the magnetized
needle, distortions of the magnetic field could be detected. A more sophisticated tool, which is used today, is the magnetometer. These are very sensitive instruments that map small variations in the Earth's magnetic field. The instruments basically measure the magnetite content of rocks and the magnetite contrast between rocks. Magnetometers measure the Earth's magnetic field in units called gammas where: 1 gamma = 1 nanotesla; 100 000 gammas = 1 oersted; and 1 nanotesla = $10^{-9}$ teslas.

There are two types of magnetometers that have been used for magnetic surveys; these are the flux-gate and proton precession magnetometer. The proton precession magnetometer is more widely used in exploration because it is a hundred times more sensitive that the flux-gate type, which is now virtually obsolete. Readings on the p.p. magnetometer are displayed digitally while the flux-gate instrument uses a meter. Ground magnetometer surveys are conducted using an exploration grid for control. A number of precautions must be taken to ensure that the magnetic data that is collected during the ground survey is accurate and reliable, these are:

1) Operators shall ensure that they are "iron sterile" and free of magnetic items that could adversely affect the quality of readings such as loose change in pockets; wristwatches; steel toed boots; steel belt buckles; compasses in shirt pockets; magnets; hand lenses; rings; penknives and so on.

2) The operator should be alert for interference from magnetic sources such as railway tracks, iron survey or fence stakes, abandoned automobiles, farm machinery, drill pipe or casing, bridges, culverts, iron-rich boulders and so on.

3) Measurements should be taken at 12.5 m intervals on grid lines 50 to 100 m apart for adequate detail.

4) When recording readings take the best out of three and look for repeatability. Record the time the reading was taken, grid line coordinates and topographic features at the location.

Corrections must be made to the magnetic data once it is collected. The strength of the Earth's magnetic field varies naturally from day to day as well as varying through a daily or "diurnal" cycle. Solar activity can also distort the field with magnetic "storms" that cause the magnetic field to fluctuate wildly and cause inaccurate measurements. Therefore, magnetic surveys should be discontinued during magnetic "storms". The other natural variations in the magnetic field can be corrected with the use of a base station magnetometer. This magnetometer is kept at a fixed position on or adjacent to the exploration grid. The base station continually takes magnetic field strength readings. By remaining stationary, the only factors that can cause deviations in the base station readings are the natural daily variations in the magnetic field. If a change occurs at the base station then it is assumed that the same amount of change will occur everywhere else on the grid.

A printed readout of the magnetic field strength with the corresponding time of each reading is supplied by the base station. While performing the survey, the operators must also record the time at which each of the grid readings are taken with watches synchronized with the base station clock. If changes are observed at the base station then the readings taken at corresponding times on the grid must be adjusted. The correction is usually a simple addition or subtraction of amounts dictated by the changes recorded at the base station.

If a base station magnetometer is unavailable then measurements are taken by the operator at specific points along the baseline of a grid every hour or so during the survey. These measurements are taken throughout the day and from day to day. Returning to a specific point on a grid to take a reading every hour is tedious work that slows down the survey, but is necessary for accurate data.

Ground magnetic data is plotted on a scale map of the exploration grid. Each reading is plotted at the grid coordinates where it was recorded (Figure 2). The data is then
Figure 2: Presentation of Ground Magnetic Data

Magnetic data plotted on a grid map.

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Contoured magnetic data (contour interval is 200 gammas).
contoured at a chosen contour interval based on the lowest and highest magnetometer readings (Figure 2). A contoured magnetic map displays the variations in magnetic data in the same way a topographic map displays variations in relief. A contour is a line connecting points of equal value; therefore, the values could represent elevation in metres or magnetic field strength in gammas. If magnetic data is to be contoured at intervals of 200 gammas then a contour line is drawn for each 200 gamma change in the readings. Since contour lines join points of equal value they can never intersect or cross each other. The shape and extent of a magnetic anomaly is made apparent by contouring (Figure 2) which creates a visual representation of the data that can be used effectively during interpretation.

Airborne magnetometer surveys consist of a series of closely spaced, parallel flight lines, which are flown by survey aircraft at right angles to the geological strike of rocks in the survey area. The output of data from the magnetometer is processed by a computer in the plane and recorded digitally on magnetic tape. The terrain clearance of the aircraft is maintained at a constant height and recorded using a radar altimeter. The flight paths are monitored by navigational equipment and photographed by a 35 mm camera mounted on the plane. The flight line spacing of the survey is about twice the distance of the aircraft above the surface. Most aeromagnetic surveys use a flight line spacing of 400 m or less and a survey altitude of 100 or 150 m.

Aeromagnetic data is compiled and presented on a variety of map scales and in a great variety of ways. Typical aeromagnetic maps have flight line information shown with magnetic contours superimposed over them. The magnetic contours and flight lines are presented in different colours. Airphotograph mosaics or topographic map information appears as subdued backgrounds on the aeromagnetic maps so that the anomalies can be located with respect to geographic features for ground follow-up purposes.

Colour plotters are used to produce colour contoured or shaded magnetic maps. The typical colour contour scheme utilizes the spectrum of white light with red representing high magnetic values and blue representing low magnetic values. Another method of presenting the data is the simulated shaded-relief maps. A computer simulates shading from the sun on the magnetic data, which is presented in relief. For example, the computer may simulate shading from the sun if it were shining from the north, therefore, "shadows" would occur on the south face of the magnetic highs and lows. The computer can produce these maps with the sun shining from any variety of directions or angles. These maps emphasize low amplitude linear features in the magnetic maps that are not easily seen on contour or coloured maps and emphasize or bring out very subtle features of the rock structure. These maps are stunning in appearance and very useful in the interpretation of data.

iii) Electromagnetic Methods

The exploration objective of electromagnetic (EM) geophysical surveys is to map the distribution of conductive materials at surface and to as great a depth as possible. Rock conductivity is a combination of the conductivity of the rock and the conductivity of pore fluids in the rocks. Most common geological sources of conductive electromagnetic responses are massive and disseminated sulphide mineralization (i.e.: pyrrhotite, chalcopyrite, pyrite, but not sphalerite); graphitic bodies; alteration products (i.e.: serpentinized ultramafic rocks); saturated clays, organic material and saline solutions. Careful interpretation of the electromagnetic data is necessary to single out suitable targets from conductive responses with no economic potential.

Traditionally, electromagnetic systems have been used to detect anomalously high conductivity, however, in recent years the surveys have begun to measure a wide range of conductivities in order to map rock types and geological structures. Electromagnetic methods are also used for overburden mapping, archaeology, engineering and waste management. There are a great variety of electromagnetic
methods with their own specific features and utilization. The type of electromagnetic method that is used depends on the particular application it is to be used for.

Electromagnetic methods are based on the principal that when a current of electricity is passed through a wire, a magnetic field of force is created in the vicinity of the wire. Early workers first thought that an electrical current had to be passed directly through the ground to cause currents to flow within subsurface conductors. However, it was discovered that an alternating electrical current (AC) flowing in a loop of wire suspended above the surface of the Earth would cause currents to flow in buried conductive deposits. This process is called "induction" and the steps in the process are:

1) The alternating current flowing in the wire loop (transmitter) creates an alternating magnetic field or primary magnetic field in the vicinity of the loop (Figure 3).

2) The primary magnetic field will cause currents to flow in any subsurface conductor.

3) Induced currents flowing in the conductor will create a secondary magnetic field (Figure 3) that distorts the primary magnetic field. This secondary field is measured by a "search coil" in a receiver. The "search coil" is connected to a sensitive meter, which measures voltage. The actual measurements that are taken include the amplitude of the secondary field and the phase difference between the transmitted (primary) and received (secondary) fields.

4) The secondary field is absent unless a conductor of electricity exists below the surface.

The secondary field produced by a conductor can be experienced when driving under hydro transmission lines while listening to the car radio. The fuzzy static or interference heard is the secondary magnetic field around the hydro lines interacting with the radio (a receiver) and distorting incoming radio waves. It is this secondary field around conductive mineral concentrations that the EM receiver detects. A conductor can be buried hundreds of metres below the surface and still "express" itself via its secondary magnetic field, which extends to the surface.

The majority of electromagnetic systems consist of a power source to generate an electrical current, a transmitter to create a primary magnetic field and a receiver to measure the secondary magnetic field created by the conductor. Horizontal or lateral changes in conductivity are measured by moving the electromagnetic system from place to place, however, to achieve depth information at each location the system must induce currents to flow in the ground at various depths. This is accomplished in two ways: 1) keeping the receiver and transmitter at a fixed distance apart and changing the frequencies of the primary electrical current; or 2) keeping the frequency fixed and changing the distance or geometry between the receiver and the transmitter. A large separation between the transmitter and receiver results generally in better depth penetration. Low frequencies from the transmitter detect areas of high conductivity, such as massive sulphide deposits; and penetrate conductive overburden effectively. High frequencies detect areas of low conductivity, such as disseminated sulphides; and are used for geological mapping and gold exploration.

The ability of an EM system to detect nearby conductors depends upon: 1) the strength of the primary field that is transmitted 2) how well the primary field can be distinguished from the secondary field and 3) the sensitivity of the receiver. The ability of the EM system to provide information about the geometry and depth of the target depends upon the geometry and separation of the transmitter and the receiver.

As stated previously, the primary field from a transmitter is distorted by the secondary field from a nearby conductor. The receiver in an EM system measures the direction and intensity of this secondary field. The receiver consists of a "search coil" connected either to a voltmeter or audio device. The intensity of the secondary field cutting the "search coil" is indicated by the reading on the
Figure 3: Electromagnetic Induction in the Earth
voltmeter or by the loudness of the signal emitted from the audio. The secondary field is parallel to the search coil when the coil is rotated into a position where it is not cut by the secondary field (the search coil is parallel to the secondary field). In these positions, no voltage is induced in the search coil and no signal is heard in the audio (Figure 4). When the search coil is tilted in either direction away from the position of minimum voltage a signal is heard in the audio.

The angle between the secondary field and the horizontal at any point is referred to as the **dip-angle**, and its determination is the fundamental measurement in the search for conductors. A typical dip-angle profile is depicted in Figure 5 where dip-angles are plotted along a traverse over a body of massive sulphides. Over barren ground the dip-angles are almost zero. The approach to the conductor is marked by increasing dip-angles, which decrease to zero directly above the conductor, this is known as the **crossover**. The dip-angles increase, but in the opposite sense, away from the conductor. Finally far from the conductor, they reduce to zero again (Lang 1970).

The mining industry uses several different types of EM methods, each with its own particular capabilities and limitations. The most widely known methods are **VLF** (Very Low Frequency), **Vertical Loop EM** (VLEM) and **Horizontal Loop EM** (HLEM). VLF-EM is an inexpensive; preliminary geophysical exploration tool used to locate conductors caused by massive and disseminated sulphide minerals, faults or shear zones, conductive rock types and irregularities in overburden. VLF-EM instruments are light weight, small, easy to use and require only one operator. Horizontal and Vertical Loop-EM is effective in detecting massive sulphide bodies. The system is more cumbersome to use than a VLF system and requires two operators. The operator with the receiver is attached by a cable of variable length to the second operator with the transmitter coil.

Another type of ground EM survey is **Pulse E.M.** (PEM). The PEM survey uses a large loop of wire (up to 1 square kilometre) connected to a generator as a transmitter and is capable of detecting very deep anomalies. Borehole PEM is used to measure conductivity in drill holes and is effective in detecting massive sulphide bodies.

Certain precautions should be taken when operating EM instruments to ensure the collection of reliable and accurate data. Most of these are outlined in operation manuals that accompany the instruments.

Ground EM surveys are conducted by moving the receiver and transmitter along grid lines and recording changes in the conductivity of the Earth at various locations. Data is plotted on a scale map of the exploration grid. Each instrument reading is plotted at the grid coordinate where the reading was measured. The readings along each grid line are connected to form profiles from which the axis of anomalies can be interpreted. VLF-EM data can also be contoured to supply information on the trend of the anomalies, which may reflect structures or specific geological units.

Airborne electromagnetic surveys are conducted in generally the same way as aeromagnetic surveys and are almost always flown at the same time from the same plane. Airborne EM data is presented differently from magnetic data, but is commonly superimposed over magnetic contours on the same maps.

Airborne EM maps indicate the location of the peaks of conductive anomalies and the interpreted conductive zones. Symbols (black circles) show the position of the anomaly peak and indicate the number of channels or frequencies the anomaly was detected on. An anomaly designation letter beside each circle indicates which anomaly it is on the flight line. Solid lines between the circles indicate a definite anomaly axis. A dashed line implies tentative line-to-line correlation and/or uncertainties in location. Where the axis of a conductive area is not obvious the area may be outlined.
Figure 4: Illustration of the Electromagnetic Method

Search coil parallel to secondary field (minimum voltage)

Ground Surface

Secondary Field

Conductor

(after Lang 1970)

Figure 5: Dip Angle Profile over a Conductive Body

Dip Angle Profile

Cross-over Dip Angle = 0

Ground Surface

Country Rock

Conductive Body

(after Lang 1970)
iv) Other Geophysical Methods

Below are brief descriptions of other types of geophysical methods used in mineral exploration.

**Self Potential Method:** A concentration of metallic minerals may spontaneously acquire a natural electrical polarity, that is, one end of the mineral body becomes electrically positive while the other end becomes negative. Therefore, the mineral body acts as a weak, natural, electric battery whose voltage is measurable in millivolts. A self potential survey detects this weak voltage generated by the mineral body. This survey is not widely used but can detect massive sulphide bodies, graphitic bodies, manganese oxide minerals and anthracite coal deposits.

**Resistivity Method:** When an electrical current is applied across a material a current is caused to flow through the material. The ratio between the current and the voltage that is required to apply the electrical current across a material is referred to as the "resistivity" of the material. Resistivity is a measure of the resistance offered by a material to the flow of an electrical current and is measured in ohms/centimetre or ohms/metre.

Most rocks, when perfectly dry, are excellent resistors. However, most rocks contain pore spaces filled with water, which conduct electricity. The greater the porosity of a rock, the more water it can contain and the lower will be its resistivity. Resistivity surveys can be useful in distinguishing one rock type from another by differences in resistivity, which indicates a general difference in porosity and water content. There are a number of substances, such as graphite, metallic sulphide minerals and a few metallic oxides, that can conduct electricity even when they are perfectly dry. These minerals are much better conductors than barren rocks and can be distinguished from rocks by their decreased resistivity.

**Induced Polarization (I.P.) Method:** This type of survey measures the chargeability and resistivity of a mineral body. A current is passed through the ground between two electrodes placed at the surface. As current passes through a mineral body the forces that oppose the current establish positive and negative poles at the boundaries between metallic mineral grains and water in pore spaces between the grains. Therefore, an overvoltage is applied to drive the current across these barriers in the mineral body. When the current is turned off, the overvoltage decays with time. Therefore, there is a brief storage of energy in the mineral body that can be measured after the current is turned off. Induced polarization surveys are useful in detecting bodies of disseminated sulphides and have been used widely in gold exploration. However, I.P. surveys also detect sericite, graphite, serpentine and chlorite, which may react in the same manner as sulphide minerals.

**Gravity Method:** The gravity method measures very small variations in the pull or attraction (gravitational force) between a small mass and the Earth. Any subsurface material that has a higher density than the surrounding rocks will exert an extra gravitational pull that will add to the Earth's normal force of gravity. If a large mass of very dense material, such as a massive sulphide body; is surrounded by rock of lesser density, then the force of gravity directly over the sulphide body will be greater than it will be to one side due to the excess mass of the sulphide body. A gravity meter measures the vertical component (downward pull) of this extra or anomalous force. Therefore, a positive gravity anomaly (an area of greater gravitational force) indicates material of higher density beneath the anomaly than that surrounding it. A negative anomaly indicates material of lower density.

**Radiometric Method:** Radiometric surveys measure naturally occurring radiation to determine the presence of radioactive minerals, such as uranium, thorium and potassium, in geological environments. The primary use is to directly locate economic deposits of uranium. It is also useful for mapping out rock types and detecting alteration haloes (potassium alteration) around some mineral deposits. Instruments such as geiger counters and scintillometers
measure the energy released during the process of radioactive decay. The geiger counter is now virtually obsolete and has been replaced by the more efficient and sensitive scintillometer. As an atom of uranium decays it emits alpha and beta particles and gamma rays, which are detected by the scintillometer. The operator can select which particles and rays are to be detected.

Seismic Method: Seismic surveys use artificially generated acoustic disturbances to investigate the Earth in search of mineral deposits. The method detects velocity and density variations in the subsurface and is used to map structure and stratigraphy in sedimentary rocks. Its main use is in petroleum, coal, potash and uranium exploration. It is also used to detect depth of overburden cover and map buried bedrock topography.

The seismic method is conducted by creating small artificial shock waves, which are generated at a specific point by detonating a charge of explosives in a shallow drill hole or by dropping heavy weights from specific heights. The speed of the shock waves is measured by sensitive "listening" devices known as geophones which are placed at various locations near the origin of the shock waves. The speed of the shock waves fluctuates as they travel through materials with variable densities in the Earth's subsurface. The time it takes the shock waves to reflect from various points between rock units of different densities is measured. Important structural information is obtained from these surveys, which assists in the location of mineral deposits.

IV) GEOLOGICAL SURVEYS

i) Introduction

A geological survey simply involves mapping the geology covered by an exploration grid and locating and identifying rock types, structures, alteration and mineralization. The composition and distribution of rocks and the deformation patterns and age relationships between the various rock units are determined by mapping. A sequence of geological events can be interpreted from this information. The geologist can extrapolate observed geological features through adjacent areas of overburden and to some depth within the Earth.

Mining companies may conduct geological surveys first before other surveys, so that they obtain an immediate understanding of the geology on the grid. Companies may also conduct the geological survey after geophysical and/or geochemical surveys are completed. If interesting results are obtained from the other surveys, the geologist can search for signs of those results on surface while mapping the geology.

ii) Types of Surveys

a) Reconnaissance Mapping

This type of geological survey is done to quickly obtain geological information across a large region. It is usually conducted during the preliminary assessment of a region's mineral and geological potential. Long, widely spaced traverses are conducted across the area to detect broad structural features and favourable geological environments for mineralization. Some reconnaissance surveys may also be conducted with helicopters to cover larger areas. Grab samples are taken from interesting rock types for analysis. Information is plotted along the traverse line on an air photograph. This type of survey is similar to prospecting.

b) Grid Mapping

Geological mapping on a grid is conducted by simply walking along the grid lines and mapping the geology. The rock outcrops and various geological features are carefully located according to the grid coordinates. The geologist also walks between the grid lines to map in outcrops. Each rock outcrop is carefully described and important geological features are measured and noted. The information is plotted on a map of the grid.

c) Mapping Showings and Trenches

Detailed mapping of trenches and stripped showings may be conducted to obtain
detailed geological information from an occurrence. This type of mapping assists in a detailed understanding of the alteration types and structural features associated with mineralization. Sample locations are carefully mapped and favourable assay data from the samples are correlated with specific geological features. This type of mapping may assist in determining information such as: the amount and type of sulphides associated with economic mineralization; the type of structures associated with mineralization at the occurrence and so on.

This mapping is conducted by establishing a small grid (cross-lines spaced every 1 to 10 m apart) or baseline across the occurrence and mapping the geology with respect to the grid.

V) GEOCHEMICAL SURVEYS

i) Introduction

Geochemistry involves application of the fundamental principles of chemistry to studies of naturally occurring earth materials and the geological environment in which they occur. Applied to exploration, it is a tool that can be used in the search for mineral deposits.

Very small amounts or "traces" of one or more elements in a mineral deposit are commonly dispersed in the vicinity of the deposit. The elements are spread through the rocks, soils, water and plants, which occur in the vicinity of the deposit, by simple weathering, leaching and groundwater action. Elements may also be concentrated in the bodies of animals, which live in the vicinity of a mineral deposit.

Modern exploration geochemistry involves the sampling and chemical analysis of a variety of materials from rocks, soils, soil gases, vegetation, waters and stream and lake sediments. These surveys attempt to detect dispersions of elements (mainly metals) that occur in above average amounts and are considered to be anomalies. Geochemical anomalies tend to occur over a larger area than the deposit itself, thus enlarging the exploration target. However, the strength of the geochemical anomaly bears little relation to the richness or size of the deposit.

Most elements occur in very small amounts in rocks, water, soils and plants. The amounts that are normally present are called background levels. The background level for different elements differs from element to element and region to region. The upper limit of the normal background determined for an area is called the threshold. Amounts two or more times greater than the threshold are called anomalies. An anomaly indicated by analyses to average about twice the background is usually referred to as a "first-order" anomaly (Lang 1970). Therefore, if the background level of copper in soils is 10 ppm then the threshold level would be 50 ppm copper and an anomaly would be about 150 ppm copper.

Many mineral deposits are surrounded by a zone or halo of rock containing small amounts of some or all of the elements in the deposit itself. These types of zones are termed primary haloes (Figure 6) because they were formed in the enclosing rocks of a mineral deposit at about the same time the deposit was formed.

Zones of wall rock alteration have been discussed in the section on Mineral Deposits in this manual. No sharp distinction can be made between wall rock alteration and primary dispersion haloes. However, wall rock alteration is generally noticeable visually, while the features of primary halo may only be detectable by the analysis of elements present in trace amounts. Dispersion haloes are generally more extensive in size than most wall rock alteration haloes (Lang 1970).

Secondary haloes (Figure 6) are formed by the dispersion of one or more elements by weathering which includes soil-forming processes and the underground circulation of water. Weathering processes mobilize and re-deposit elements from a mineral deposit or primary halo in to surficial material or other environments. Secondary haloes may be formed in the soil by: 1) the wearing down of rocks and their contained mineral deposits; 2) frost action and glaciation; 3) elements absorbed from soils by plants; and 4) they may form in soil through which water has passed after circulating through a mineral deposit or primary halo (Lang 1970).
Figure 6: Geochemical Patterns near a Mineral Deposit

(from Bradshaw, Clews and Walker 1969)

Examples of Indicator and Pathfinder Elements

<table>
<thead>
<tr>
<th>Ore Association</th>
<th>Indicators</th>
<th>Pathfinders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porphyry copper</td>
<td>Cu, Mo</td>
<td>Zn, Mn, Au, Rb, Re, Tl, Te</td>
</tr>
<tr>
<td>Sulfide ore complexes</td>
<td>Zn, Cu, Ag, Au</td>
<td>Hg, As, S (as SO₃), Sb, Se, Cd</td>
</tr>
<tr>
<td>Precious metal veins</td>
<td>Au, Ag</td>
<td>As, Sb, Te, Mn, Hg, I, F, Bi, Co</td>
</tr>
<tr>
<td>Skarn deposits</td>
<td>Mo, Zn, Cu</td>
<td>B</td>
</tr>
<tr>
<td>Uranium (sandstone)</td>
<td>U</td>
<td>Se, Mo, V, Rn, He</td>
</tr>
<tr>
<td>Uranium (vein)</td>
<td>U</td>
<td>Cu, Bi, As, Co, Mo, Ni</td>
</tr>
<tr>
<td>Ultramafic orebodies</td>
<td>Pt, Cr, Ni</td>
<td>Cu, Co, Pd</td>
</tr>
<tr>
<td>Fluorspar veins</td>
<td>F</td>
<td>Y, Zn, Rb, Hg</td>
</tr>
</tbody>
</table>
Samples of material are analyzed for the metals being sought and for "pathfinder elements" which are easier to detect than the other economic elements in the deposit. Pathfinder elements are defined as those which because of some particular property or properties, provide anomalies or haloes more readily usable than the sought-after element with which they are associated (Lang 1970). A good pathfinder element has a much lower background than the sought-after element and provides a more conspicuous anomaly. Pathfinder elements are also more mobile during weathering and are more easily concentrated in soils and plant life than other elements. Some pathfinder elements and the mineral deposits they are used to detect are: mercury which is used to detect silver, lead, zinc and copper deposits; arsenic is used to detect cobalt and gold deposits; silver is used to detect silver-bearing gold ores; molybdenum is used to detect porphyry copper deposits; and antimony is used to detect silver-gold deposits.

Geochemical surveys may not be successful in outlining dispersion haloes because the mineral deposit may not have a recognizable halo. There are also no guarantees that an anomaly, even if it exists, will be detectable. Therefore, to optimize the probability of success, it is important that a geochemical survey be planned to cover the area of search with an adequate amount of sampling and that individual samples are representative of the material being sampled (Horn 1989).

It is important to understand the glacial history of the survey area especially if soils or glacial tills are sampled. Material in the overburden may have been transported from another location by glaciers and may not be representative of the local area. As a result, secondary dispersion haloes may not be well developed in the overburden. Therefore, a study of the overburden in the area of search is essential before initiating a geochemical survey. It may be determined after examining the nature of the overburden, that a geochemical survey would not be effective in detecting a mineral deposit.

After the samples are collected and analyzed the data is plotted on a scale map of the exploration grid. The analysis values are plotted at the grid coordinates where the sample was collected. Results obtained from streams or lakes are commonly plotted on maps where the samples were collected. The data is contoured as with some geophysical data, to obtain a visual representation of the shape and size of the geochemical anomalies. Different colours or symbols may be used on maps to indicate different elements; and ranges in the quantity of an element may be represented by different sizes of dots or other symbols. The lab data is commonly subjected to a number of statistical studies to determine background levels, standard deviation and so on. The results of geochemical surveys cannot be interpreted by statistical studies or plotting of data alone: topographic, geological and glacial features of the study area must be considered as well (Lang 1970).

ii) Types of Surveys

The following are brief descriptions of some of the different types of geochemical surveys conducted during mineral exploration.

Lithogeochemical Sampling: This type of survey is conducted by methodically collecting samples of bedrock to detect primary dispersion haloes. The surveys are effective in detecting subtle alteration patterns associated with volcanogenic massive sulphide deposits. The main advantages of this survey are: 1) geochemical patterns may be related directly to the mineral deposit; 2) the samples can be taken during geological mapping and previously stored samples or drill core can be tested; and 3) bedrock is not easily contaminated. A disadvantage is that the surveys are confined to areas with good bedrock exposures.

Soil Sampling: The sampling of soil, till and overburden is useful in outlining regional dispersion patterns of elements and for localized exploration. The term "soil-sampling" includes all forms of residual and transported overburden. Residual soils are formed by the weathering of rocks in place while transported soils have been moved by water, glaciers or
wind. Residual soils are more representative of the underlying bedrock, however transported soils may contain elements from a distant source. Glacial soils, for example, may be too mixed and far removed to be useful.

Soils are generally divided into three **horizons**, a few centimetres to a few metres thick, which may or may not all be present at a particular location.

The sequence of soil horizons is known as the **soil-profile (Figure 7)**. The horizons from lowest to highest are:

**C-Horizon**: This horizon represents the underlying bedrock and consists of grains of rock and a minimum amount of organic matter. The C-horizon may rest directly on bedrock, or one or more layers of overburden (glacial till) may lie between the C-horizon and bedrock.

**B-Horizon**: This horizon consists of material from the C-horizon that has been modified by weathering. The B-horizon may also contain clay minerals, iron and organic material.

**A-Horizon**: This is the uppermost horizon and contains material composed of decomposed plants and microorganisms. It is commonly referred to as **humus**.

The C-horizon is preferable for geochemical sampling, if it is available or can be reached, because it directly represents the bedrock. The A-horizon is also good for sampling because it is generally enriched by elements derived from the remains of plants that absorbed the elements from deeper soils.

Soil samples are obtained by: digging pits, trenches, or cuts in banks, manually or with a backhoe; using hand augers, post hole augers and crow-bars; and by rotary overburden drills. A rock drill or “plugger” can also be used to drive drill rods through very deep overburden to bedrock. A hollow tube at the end of the rods collects material from soil at the bedrock surface.

**Stream and Lake Sediment Sampling**: This type of sampling involves collecting samples of sediment from the bottom of lakes and streams for reconnaissance and regional surveys or more local detailed surveys. The metals in dispersion haloes and mineral deposits eventually enter streams and lakes and settle amongst clay and silt at the bottom of various bodies of water. If anomalies are detected in stream or lake sediments then the drainage pattern in the search area is carefully studied and the anomalies are traced back along the drainage systems to the source of the metals. The presence of anomalously high metallic elements in lake or stream sediments may indicate the presence of a mineral deposit in the general location of the bodies of water.

**Water Sampling Surveys**: The main use of water sampling methods is to attempt to outline regional patterns of metal distribution. Samples of groundwater are collected from wells, drill holes and springs. The groundwaters may contain traces of metals leached from mineral deposits as the water flowed through fractures and pores in the rock. Groundwaters are collected in lakes, swamps, streams and bogs where the metals may also be detected in the waters.

**Biogeochemical (Vegetation) Sampling**: Plants absorb chemical elements from soils. Some of the elements are necessary for the health of the plant and others are stored in the bark, leaves and twigs of the plant. Plant roots absorb water, in which elements are dissolved from soil. The elements are subsequently dispersed through the plant. Plant material collected during biogeochemical surveys may consist of: plant remains such as peat in bogs; ground vegetation such as moss, lichen, herbs and shrubs; the bark, leaves, needles, sap and twigs from shrubs and young trees; and parts of large, mature trees. Many species of plants are not affected by the abnormal amounts of an element in the soil, but others preferentially accumulate elements such as: balsam fir which accumulates traces of zinc, copper and molybdenum; labrador tea, jackpine, tamarack and blade spruce that accumulate traces of copper and zinc; wild mint and willows that accumulate copper; and cat-tails which are known to accumulate traces of gold. Biogeochemical surveys are useful in detecting fairly local dispersion patterns of elements.
Figure 7: A Simplified Soil Profile (modified after Nevill 1963)
Other surveys, particularly for radioactive minerals such as uranium, are used to detect radon gas and alpha and beta particles emitted from decaying radioactive elements. These particles and gases escape from radioactive mineral deposits, through rocks and soils and into the atmosphere. The surveys are conducted by setting out small, simple instruments along the grid lines in a search area. The instruments are left on the grid for a few days and measure the amount of radon gas or particles escaping from the soils. The instruments are collected and "read" and the results are plotted and contoured to locate the position of anomalies. Carbon dioxide (\(\text{CO}_2\)) and sulphur dioxide (\(\text{SO}_2\)) soil gases can also be detected to evaluate the subsurface potential for structurally controlled sulphide bodies.

**VI) DRILLING**

**i) Introduction**

Geophysical and geochemical surveys are effective at detecting various anomalies and defining their characteristics, shape and size. However, these surveys cannot determine the source of any of the observed anomalous values. The only method of determining the rock and mineral composition of the cause of an anomaly is to obtain a sample from the source of the anomaly. This is achieved by taking bedrock samples at depth during exploratory drilling. The principle of drilling for samples involves a drill stem, powered at the surface, that penetrates the overburden and rocks of the target area. Samples in the form of rock chips or core are recovered for lab analysis and geological inspection.

Drilling is the last stage of "grassroots" or preliminary exploration and it is the most expensive. The major expense occurs in mobilizing equipment into remote areas and preparing the drill site. Roads may be built and helicopters chartered, months of planning completed and a camp established before drilling to determine the size and grade of an anomaly can be conducted. Therefore, it is very important to drill the best possible targets (anomalies) so that the maximum amount of information can be obtained at minimum cost.

Once all the surveys have been completed and the results have been interpreted, the best possible targets are selected to be drilled. Geologists decide where the holes are to be drilled and use all the information acquired during geological, geochemical and geophysical surveys to select the targets. The geologist must logically justify the reasons for drilling each hole.

Drill targets are areas where the odds of intersecting economic mineralization are the best. A hole is planned so that it intersects the area where mineralization is believed to exist and results in a good geological cross-section. The holes may be drilled vertically or at various angles and directions, depending on the strike and dip of the target. In any case, all holes are drilled perpendicular to the dip of the zone being tested (Figure 8). Mining companies hire drilling contractors to conduct the drilling. The contractor supplies drillers, drills and any other equipment that is required to get the job done.

The position of drill hole collars are accurately located with respect to coordinates on the exploration grid and may be surveyed in. The elevation of drill hole collars above sea level is also determined. Before drilling begins, the drill is leveled to ensure that the hole is started at the proper angle. The drilling is conducted at even, widely spaced intervals along the strike of the mineralized zone. If encouraging results are obtained, other holes are drilled between the completed holes, to provide more detailed information. The final spacing depends on the irregularity and size of the deposit and the amount of detail required. Widely spaced holes may be used to test for a large massive sulphide deposit, but more closely spaced holes may be required to test smaller, irregular deposits such as gold-bearing vein systems.

Core samples are placed in a core box and labeled. The label indicates the hole number and the footage or meterage of the core in the box. A geologist logs the core and describes rock types, structures, alteration and mineralization observed in the core samples. The core is sampled by splitting it in half with
Figure 8: Generalized Drill Setups (inclined, vertical, horizontal)
a core splitter. One half of the core is sent to a lab for analysis while the other half remains in the core box. The core boxes are usually stored in core racks where they can be referred to if further information is required. If rock chip samples are retrieved, the chips are inspected by a geologist and described. A portion of the chips are sent for analysis while the rest are stored for reference.

The data from the hole is plotted to scale on a drill hole cross-section where results can be interpreted and correlated with other holes and data. A small compass device is inserted in a drill hole at various intervals during the drilling to measure the angle and direction of the hole. This information is used to determine where the hole went under the ground and to plot accurate cross-sections.

Drilling is used during advanced exploration to outline mineralized zones in detail. The drilling is conducted systematically along grid lines and at closely spaced intervals. Drilling is also conducted during underground mining to explore for mineralization and test known mineralized zones.

ii) Types of Drilling

There are several types of drilling methods used in exploration which are described below:

Diamond Drilling: Diamond drilling is one of the most versatile and widely used drilling methods used to retrieve core samples of rock. The main parts of a diamond drill are the bit, reaming shell, core barrel, drill rods and power unit. The bit is a ring shaped piece of metal that is impregnated with diamonds and used as a cutting tool. Above the bit is a cylindrical reaming shell, which also contains diamonds, which trims the hole to a constant size. The bit is rotated at speed, under controlled pressure, by means of hollow steel drill rods through which water is pumped to cool the bit and remove rock cuttings. The circulating water raises the cuttings and sludge to surface outside of the drill rods. As the bit is rotated and advanced, the core of rock passes upward through the centre of the bit into a hollow tube known as a core barrel, which is attached to the end of the drill rods. The core barrel and each drill rod is usually 10 feet long. When 10 feet of core has been drilled, the core barrel is withdrawn from the hole, the core is removed and an additional length of drill rod is attached to advance the hole. This operation is repeated until the hole is drilled to its desired length.

In the past, all of the drill rods had to be pulled out of the hole to retrieve the drill core, which was a slow and tedious process. Today, drills are installed with a wire line which is a steel cable connected to a core tube housed within the core barrel. The wire line is used to pull the core tube and core out of the hole without pulling the drill rods. This is a faster and much more efficient method of retrieving the core.

Diamond coring bits can cut core with diameters ranging in size from 47/64 inches (18.7 mm) to 5 31/32 inches (151.6 mm). Drill core sizes vary with the type of machine that is used and the purpose of the test.

Light drills known as x-ray or Winkie drills, weigh about 200 lbs and are used for drilling short holes (about 45 m) in remote locations. These types of drills are commonly used by prospectors and produce "x-ray" core that is 5/8 or 3/4 inches in diameter. The drills can also be modified to produce 7/8 inch (EX) or 29/32 inch (EXT) core (Lang 1970). Other types of light diamond drills can be dismantled for backpacking.

Rotary Drilling: These drills produce chips and cuttings of rock instead of core. The drill holes must be vertical or close to vertical so that cuttings can be effectively circulated to the surface. Various geophysical instruments and logging devices are lowered down the relatively large holes produced by rotary drilling. The instruments measure various properties and characteristics of rocks along the length of the hole. Rotary drilling is only suitable for testing flat-lying mineral deposits.

Reverse Circulation Drilling: This drilling method is used in glacial overburden. The method uses a large tri-cone bit and dual tube drill pipe. The drilling fluid or air (or a combination of both) are pumped down between the dual tubing and returned up the inner tube, bringing cuttings from the bit to the
Sonic Drilling: This method of drilling is used to test unconsolidated, loose sediments in overburden, such as soils and glacial till, and produces an undisturbed core of the unconsolidated material. Sonic drill holes must be kept very close to vertical for the efficient retrieval of core. A sonic vibration device pushes the drill rods into the ground to obtain core.

VII) SUMMARY

If a checkerboard was covered with sand and one square on the board represented an orebody, it would be virtually impossible to exactly pinpoint that square once the board was covered. That is the problem that faces mining companies during mineral exploration. Most of Ontario has been glaciated and is covered with thick deposits of clay, sand and swamps. Therefore, the task of finding an unexposed mineral deposit requires patient, detailed and methodical "detective" work.

The geophysical, geochemical and geological surveys described in this section are constantly updated and improved to provide more efficient and effective methods of detection. Although exploration is increasingly disciplined, methodical and scientific, the one thing it can never be is static. Development and uses of many types of new technology has been assured through competition between companies, contractors, research organizations and individuals (Vozoff 1989). Improved methods of exploration that assist in the detection of very deeply buried mineral deposits are essential for the continuance of successful exploration in Ontario.

In years to come remote-sensing methods from satellites in space may be more widely used for mineral exploration. The development of super-conductors may revolutionize some types of geophysical equipment. Methods and instruments based on the use of optical reflectance and photoluminescence phenomena are being used to provide another type of survey method for exploration. Geophysical equipment is being combined so that an operator can conduct up to four different surveys during a single traverse. Global positioning systems, which use a network of eighteen transmitting satellites, are being used for the accurate location of survey data. Analytical lab techniques are being improved to detect elements to values of parts per trillion. The collection, presentation and interpretation of data is becoming more efficient and effective due to advances made in computer hardware and software (Seigal 1989). All of these technological advances will enhance and improve present day surveys and increase the effectiveness of mineral exploration.
REFERENCES


SUGGESTED READING


Smith, P. 1986. Harvest from the Rock: A History of Mining in Ontario; Macmillan of Canada, 201
Toronto, 346p.


Notes: There are numerous other publications on a wide variety of topic regarding prospecting, bush survival, mineral deposits, exploration and mining, that can be obtained at public libraries, the MNDM Mines Library and the Resident Geologist offices.