CHAPTER V. MODERN PHILOSOPHY OF MINERAL EXPLORATION

Actuarial experts of a new type are needed to compile the necessary information and to appraise the risks in prospecting blind. We need to improve the art of comparing prospecting ventures in terms of the odds — just in one word, in terms of numbers.

— L.B. Slichter

It is an accepted fact that surface mineral deposits are fast vanishing all over the world. The good old days, when a prospector could, in his search for minerals, strike a 'bonanza' and make a fortune, are over. Now, minerals have to be searched in-ground, invisible to the naked eye. It has been aptly said that scientists engaged in the business of mineral exploration will have to look more and more for 'blind deposits'. This shift in the very nature of occurrence of mineral deposits calls for reorientation of outlook regarding their prospecting. Techniques and methods will have to be evolved and applied to locate the concealed deposits. Fortunately, a greater part of the earth crust remains to be examined for mineral occurrences. According to Nolan there seems to be a statistically sound relationship between the number and size of productive mining districts and the surface extent of geologically similar large

1 Slichter, L.B. — The need of a new philosophy of prospecting, Mining Engineering, June 1960.

areas. This approach also led him to conclude that many districts remain to be discovered, perhaps as many as ten times those now known. It also suggests that among these undiscovered districts, there will be the same relative number of major districts or "elephants" as has been found up to now.

The above mentioned situation has resulted in revolutionary changes in the methods and procedures of mineral exploration. Geophysical methods which were hitherto restricted to Petroleum exploration have now been extended to metals also. Geochemical techniques are being pressed into service for locating metallic deposits. Great strides have been made in geological mapping, study of metallogenic provinces, study of behaviour and habitat of various metals in the earth's crust, photogeology and the statistical approach to mineral exploration. A few of these new concepts have been described in some detail in the following paragraphs.

1. Geophysical techniques

Geophysics, as a science, is more than three centuries old, but as an exploration tool it is much younger. Its application in petroleum prospecting is well established, but in other mineral fields its utility is being slowly recognised and proved. Metalliferous deposits generally have complex structures which are difficult of interpretation from geophysical data. Moreover, structural controls of deposition are much less definite as compared to oil pools. These pools once located yield enormous dividends to prospecting companies. Deposits of other minerals are clearly at a disadvantage in this respect. During recent years, however, geophysical tools have proved valuable aids in prospecting for metallic deposits. As the word signifies, this
science embraces the study of the materials of which the earth is composed, its origin and age and its fields of forces. The knowledge thus gained when applied to the search for mineral deposits becomes the art of geophysical exploration.

The geophysical methods of exploration, although utilising techniques of high precision, nevertheless remain essentially qualitative, not quantitative. They detect discontinuities or changes in rock types or outline mineral bodies of certain characteristics capable of producing an 'anomaly'. An anomaly may be defined as a group of observed physical values of either higher or lower intensity than those in the surrounding area. The precise nature of the 'anomaly', the deposit, its extent and grade, however, will have to be established by drilling alone due to the incapability of geophysical tools to measure them quantitatively.

Magnetic methods

The compass and the magnet are the basic tools used in geophysical prospecting to detect the presence of magnetic forces. To trace buried formations with a compass there must be a great relative difference in the magnetic attraction of the rocks so that the difference in attraction is readily apparent. Small changes of 5° to 10° in the bearing of the line will indicate that there has been a change in the magnetic character of the underlying rock and very possibly there has been a change in the rock type. If very strong magnetic deflections are observed over a small area, the chances of local concentration of magnetite are great, but whether it is of grade or not can be ascertained only by sampling or drilling.
The dip needle and the magnetometers are more sensitive refinements of compass and magnet. The dip needle is most readily applicable to rapid reconnaissance investigations for magnetic anomalies. It is particularly applicable for locating iron formation, tracing faults in highly magnetic material, tracing dykes and igneous contacts and assisting in delimiting the scattered out-crops in general geological mapping.\(^1\)

**Magnetometer**

The ground magnetometer is used for prospecting ore bodies, and to outline geological lithology covered by over-burden. Magnetite and pyrrhotite could be detected directly by this instrument. Another type of deposit that may be discovered is one associated with a magnetic rock or magnetic alteration such as asbestos-bearing serpentine. It also renders valuable service in outlining geological structure and formations under the mantle of over-burden.

Magnetometer surveys in mining exploration are normally done on traverse lines, 400 feet apart with initial reconnaissance readings at 100-ft. intervals along the lines. Detail in interesting areas usually is on lines 100 or 200 ft. apart and with readings at 25 or 50-ft. intervals.\(^2\)

**Air-borne Magnetometer**

In comparison with ground magnetometer surveying, the air-borne magnetometer offers the following advantages.\(^3\)

---

(i) Almost any area is accessible, ground conditions being of little or no importance.

(ii) The rate of survey is much faster.

(iii) The cost is about one tenth per unit of profile.

(iv) Measurements are continuous, automatically recorded, and of high precision.

(v) Minor magnetic variations originating near the surface are reduced or eliminated. It follows that the airborne magnetometer responds to conditions over a greater area, according to the flying height; in other words, it gives less resolution than the ground magnetometer.

(vi) Areas surveyed are necessarily large, giving the advantages of broad interpretational techniques and concepts.

Various types of airborne magnetometers have been devised, operating on different principles. None are based upon the ground magnetometer principle in which a magnet system is delicately balanced against gravity. Most airborne magnetometers measure variations in the earth's total magnetic field. This is a fundamental and important distinction from ground instruments, which commonly measure the horizontal or vertical component only.

Aeromagnetic surveys produce the most useful reconnaissance information of a given area for the least cost of any type of exploration survey. In prospecting an unknown area of mineral deposit, an unqualified recommendation can be made that a reconnaissance type aero-magnetic survey be carried out to precede the start of main exploration programme.¹ At present there are

five basically different magnetometers being used, i.e. fluxgate, electron beam, proton free-precession, Overhauser and optical absorption beam magnetometers. Fluxgate type is usually considered good enough for production of standard one mile aeromagnetic maps. The most promising application of high senstivity magnetometers appears to be their use as magnetic gradiometers. For instance, at high magnetic latitudes, geological contacts are readily delineated by the zero contours of the first vertical derivative of the total intensity of the earth's magnetic field. Of interest in petroleum prospecting is the evidence that magnetic effects seem to be present in at least some sedimentary formations, and these give rise to 'fine-structure' in the recorded magnetic profiles. Thus the development of high-sensitivity magnetometers has given a 'new look' to aeromagnetic surveying techniques, and there is little doubt that even more will appear in the near future. There is a pronounced trend towards the digital recording of aeromagnetic survey data in order that the compilation of the final maps may be automated as much as possible. By recording in a digital format it should be possible to produce at very little additional cost maps other than the total intensity variety, such as the first and second derivative, running average and a number of other more exotic possibilities. Another interesting development is the successful completion of air-borne telemetering magnetometer system aptly named Telmag. This is a direct-reading proton free-precession magnetometer in which the proton signal is telemetered from the survey aircraft to the ground station. The method appears to have great potential use in mountainous terrain where use of light aircraft is preferred. It should be noted that remanent magnetism also produces anomalies on magnetic contour maps. An insitu susceptibility meter has been developed in Canada to measure remanent magnetism. A survey carried out in Canada in

certain areas showed that the major part of magnetic anomalies were due to remanent magnetism alone.

A typical procedure followed in aeromagnetic surveying is that parallel lines across the regional geological trend, are flown usually a quarter mile apart. Half and one mile spacing is permissible depending upon the requirements for detail of the survey. The flying height (ground clearance) for mineral surveys is 500 ft., or occasionally 1,000 ft, again depending upon the requirements of detail. After completing the survey lines, the aircraft flies widely-spaced, transverse tie-lines by means of which diurnal magnetic variations and instrument drift are reduced. A recording instrument on the ground may reduce or eliminate the need for tie-lines. The magnetic profiles are corrected according to the tie-lines or other control data.

Aeromagnetic surveys have two principal modes of application in mineral exploration which are given below.¹

a) The direct detection of economic mineral deposits

This is the less important application. Mineral deposits may or may not be appreciably magnetic. The majority of minerals are, in fact, non-magnetic.

Magnetic prospecting methods were developed originally to aid the search for magnetite, which is by far the most strongly magnetic of minerals. Other minerals cannot be put at par with

¹ Scott, H.S., The Airborne-magnetometer, Methods and case history in Mining Geophysics published by the General Committee, the Sixth Commonwealth Mining and Metallurgical Congress, 1957.
magnetite. Ilmenite is slightly magnetic, and it has the property of reverse magnetization which may aid in its detection. But magnetite being strongly magnetic, plays an important role as an indicator. Minerals associated with magnetite are also logically amenable to direct detection by magnetic means. For the same reasons, pyrrhotite which is an important constituent in copper and nickel sulphide ores, is a valuable guide to the location of these deposits.

Where the ore being sought is non-magnetic, as compared with its surroundings, magnetic surveying may still prove useful. This is a negative sort of application which relies heavily upon other local evidence for correct interpretation.

b) The interpretation of general geology

The airborne magnetometer has in a few short years established itself as the ideal complement to reconnaissance geological mapping. The magnetic properties of underlying rocks are continuously recorded over a large area in a short time. It is in this field that magnetic surveying plays an important role.

Gravitational method:

Modern gravimetric surveying consists of measuring minute variations in the pull of attraction between a small mass and the earth.

When the instrument detects a positive gravity anomaly, it means the presence of higher density material beneath the anomaly than that surrounding it. A negative anomaly, on the other hand, indicates lower density material beneath the anomaly. Gravity meters have been increasingly used in prospecting minerals.
since the Second World War, especially for near surface ore bodies. The method is also used as a follow up step to other geophysical techniques. It has become an invaluable aid in distinguishing massive sulphide bodies, electrically indicated, from graphite or sparsely mineralised zones.

In actual practice, if the requirement is to trace iron formation, stations could be spaced at 100 ft. intervals along lines 600 to 1000 ft. apart. To locate less extensive bodies, such as massive sulphide deposits, in an area of unknown rock types and geological conditions the survey may be conducted with stations at 50 ft. intervals along lines 200 ft. apart. To check conductors located by other geophysical methods, lines may be laid out across the interpreted conductor at right angles to the strike and extended 300 to 600 ft. on either side. Stations directly over the conducting zones should be at 25 ft. intervals, changing to 50 ft. intervals and eventually to 100 ft. intervals, as the survey extends outward from the conductor. The data collected is interpreted after making necessary corrections.

Radio-active method:

The discovery of numerous commercial deposits of uranium in recent years has been made possible by the development of portable instruments capable of measuring the radio activity. The Geiger and the Scintillation counters are the two instruments used for the purpose. Since this thesis is concerned with the deposits of other types, the application of nuclear radiation in prospecting has not been discussed in any detail. However, it may be mentioned that the common practice is that while other geophysical methods are used, provision is simultaneously made

1 Pemberton R., Gravitymeter Surveys, Methods and case history in Mining Geophysics, Sixth Commonwealth Mining and Metallurgical Congress, 1957.
for scintillation counters so that radio active minerals, if any, could also be detected side by side with the main work. The current project, i.e. operation hard rock which has been undertaken in India in collaboration with United States has got arrangements for scintillation survey also.

**Electrical methods**

Spontaneous polarisation or self-potential method is based on the principle of flow of natural currents (self-potential) in an ore-body. The currents are generated due to electro-chemical reaction between conductive minerals and electrolytes in the surrounding rocks. Most of the sulphides having metallic lustre are known to be metallic conductor of electricity with the exception of stibnite. The oxides are mostly non-conductive except for the manganese minerals, pyrolusite and psilomelane. Graphite is a good metallic conductor and anthracite coal owes its electrical activity to the sooty layers of conductive graphite material often inter-leaved with bright, shiny non-conductive portion. This material is absent from the lower orders of coal which, therefore, yield no currents.

The strength of the electrical potentials created depends on (i) the chemical nature of metallic and electrolyte conductors in contact with each other, (ii) the percentage of sulphide present, (iii) the vertical size of the deposit and (iv) the depth of overburden. Potentials naturally present in the ground are measured on a systematic grid of observation points. 1 The usual practice is to take readings at regularly spaced stations, along straight lines crossing the prevailing structural trends as nearly at right angles as is convenient. The stations may be at intervals

---

as small as 50 ft. to as great as 100 ft. depending upon the nature of the problem. The instrument used for measuring spontaneous polarisation potentials is the potentiometer-volt meter, sensitive to one millivolt. In this apparatus a measured current is drawn from some flashlight batteries and used to neutralise the ground current between two contacts with the earth, a 'Null Method' of measurement. By opposing the ground current with an equal and opposite current from the batteries no current is drawn from the ground.

Resistivity method

Resistivity is a measure of resistance a substance offers to the flow of electric current. Most rocks are insulators when dry, but the condition of dryness is seldom achieved by them as the pores contain water and other salts due to which they become conductors of electricity. Porous, fissured and fractured rocks have less resistivity.

The method has been widely applied in engineering and ground water geology.

Electromagnetic (Ground method)

The method is based on the inter-relation of the two fundamental physical phenomenon, electricity and magnetism.

Initially the method was based on passing a current through the ground via two metal stakes and measuring the resulting magnetic field at the surface. Subsequently sub-surface conductors were energised inductively rather than conductively. Modern electromagnetic surveys employ inductive energy sources. An
electrical field is established when a strong alternating current passes through a transmitting coil and, in turn, produces an alternating magnetic field about the coil. If there is a highly conductive mass near the coil the primary alternating magnetic fields induces electric currents in the conductive mass, which, in turn, produces another alternating magnetic field known as the secondary field. The secondary field distorts the primary magnetic field and it is the measurements of the disturbed primary field that are used in electromagnetic surveying.

Extraneous conductors are found in profusion which mislead the conclusion regarding anomaly. This necessitates some grading or sorting of these anomalies. The following qualitative 'grades' of conductors have been found on the basis of an electro-magnetic survey made in New Brunswick, Canada.¹

<table>
<thead>
<tr>
<th>Media</th>
<th>Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive sulphides—mostly pyrrhotite,</td>
<td>Excellent</td>
</tr>
<tr>
<td>graphitic shear zones, pyrrhotite stockworks.</td>
<td></td>
</tr>
<tr>
<td>Massive sulphides—mostly pyrite,</td>
<td>Good</td>
</tr>
<tr>
<td>graphitic shear zones, coarsely</td>
<td></td>
</tr>
<tr>
<td>disseminated pyrrhotite.</td>
<td></td>
</tr>
<tr>
<td>Pyrite stockworks — coarsely</td>
<td>Moderate</td>
</tr>
<tr>
<td>disseminated pyrite, highly carbonaceous</td>
<td></td>
</tr>
<tr>
<td>sediments, graphitic partings on shear</td>
<td></td>
</tr>
<tr>
<td>faces.</td>
<td></td>
</tr>
<tr>
<td>Carbonaceous sediments — disseminated pyrite,</td>
<td>Fair to poor</td>
</tr>
<tr>
<td>pyrrhotite, solution-filled faults and</td>
<td></td>
</tr>
<tr>
<td>shears, swamps, lakes, overburden.</td>
<td></td>
</tr>
</tbody>
</table>

Further sorting of the conductors is best done by employing secondary exploration procedures such as gravity surveys or geochemical surveys and diamond drilling, etc.

**Airborne Electromagnetic Surveying**

Airborne electromagnetic (AEM) prospecting is one of the newest geophysical techniques made available to the mining industry in 1950. Extensive application of this technique was made possible by late 1956.

AEM is intended to be a rapid reconnaissance survey technique for locating economic deposits of massive sulphide mineralisation within 100-200 ft. of the surface. Good conductors of electricity which respond to this technique are graphitic schists, carbonaceous sediments, fault and shear zones as well as the primary target, massive sulphide mineralization. The AEM equipment does not respond to changes in rock type and hence it is not useful as a mapping tool.

"The results of one survey over an area should not be expected to duplicate the results of a second survey over the same area unless the same instrument is flown at the same height, the same speed, and in the same direction along the same flight lines for both the surveys. AEM surveys have located many orebodies and at the same time in other areas these surveys have also missed some interesting sulphide bodies while detecting a host of extraneous conductors.

"Most AEM systems in operation today are based on the measurement of the mutual impedance between two coils as this impedance is affected by the presence of nearby naturally occurring
conductive bodies. When current \((I)\) flowing in the transmitting coil causes a voltage \((E)\) to appear across the receiving coil, the ratio \((\frac{E}{I})\) of the voltage in the receiving coil to the current in the transmitting coil is known as the mutual impedance between the two coils. If a conductive body is brought near the two coils, distributed currents \((I_0)\) will be caused to flow in it. These latter currents will cause a voltage \((E_0)\) to appear in the receiving coil. Then the total voltage appearing across the receiving coil will be \(E + E_0\), and the measured mutual impedance between the transmitting and receiving coils will be \(\frac{E + E_0}{I}\). It will thus be seen that a change in measured mutual impedance takes place when the coils are brought near the conductive body and this phenomenon is made use of in the exploration of mineral deposits.

**Seismic**

The Seismic refraction method is used to decipher sub-surface geology. It is based on variations in the elastic properties of the earth and the speed of transmission of elastic waves is measured, which varies with various rock types. In seismic refraction, an explosive charge is fired close to the ground. The resultant elastic waves transmitted through the ground are picked up by a number of geo-phones which are located in line with, and at known distances from, the shot point. The geo-phones transform the ground vibrations into electric impulses which are then conducted by cable to the recording equipment. The impulses are then amplified and recorded on photographic papers moving at high speed. The photographic paper records also the instant of start and a series of timing lines which enable the interval of time between the explosion and the arrival of elastic waves.

waves at each geo-phone to be determined accurately.

2. Geo-chemistry

The geo-chemical method of prospecting is based on measuring the trace content of some element or group of elements in naturally occurring material such as rock, soil, gossan, vegetation, stream sediments or water. The purpose is to discover a geo-chemical 'anomaly' or area where the chemical pattern indicates the presence of ore in the vicinity.

The elements are distributed in patterns that reflect both the abundance of the element in a moving material and the chemical equilibria characteristic of the local environment. These patterns are termed dispersion patterns. They are formed at depth by igneous and metamorphic processes (primary patterns) or at the earth's surface by the agents of weathering, erosion and surficial transportation (secondary patterns). In nature the latter phenomenon is most common. The secondary patterns are known as 'halo', 'fans' and 'trains'. A halo is a nearly equi-dimensional dispersion pattern enclosing or overlying the source material. A fan is a pattern spreading outward in one direction from a well defined source. A train is a linear dispersion pattern formed by movement along drainage channels.

**Geo-chemical anomaly**

The normal abundance of an element in any material where the equilibrium has not been disturbed is known as 'background values'. It is against these values that a contrast is recognised and geochemical anomalies established. One of the principal
problems, however, is to distinguish these anomalies from dispersion patterns of no economic significance. Factors that are helpful in solving such a problem are, (i) the range of non-significant variations in background, (ii) the threshold between non-significant and anomalous values, (iii) the contrast between anomalous and background values, and (iv) the homogeneity of the anomalous pattern.

Normally the geochemical data obtained in areas where the equilibrium has not been upset by the presence of a mineral deposit lie statistically within a well-defined range. The patterns of non-significant variations will fall within these background ranges. If they are not recognised, they may lead a scientist to wrong conclusions.

When an area is prospected by geo-chemical method, it is usually possible to select a certain limiting cut off or 'threshold' value below which the variations represent only normal background effects and above which they have significance in terms of possible ore. Such threshold values differ from area to area because it will depend on local geo-chemical factors. However, it is usually possible to select a threshold contour suitable for the area in question by careful appraisal of the geochemical data from that area.

Another criterion for significance of an anomaly is the geo-chemical relief or contrast between anomalies values and background values. It is expressed as a ratio either of maximum to threshold, maximum to background, or threshold to background, depending on which figure appears to be most significant. For example, in an area if the maximum to threshold ratio for one element is 100 and that for another is 10, then statistically the

The homogeneity or smoothness of a geo-chemical anomaly is important for spacing of sampling points. If there is wide variation, the samples have to be collected closely.

The following kinds of anomalies (primary) are important in prospecting.

(A) Geo-chemical/Metallogenic Provinces:

Certain minerals or metals possess a tendency to be confined or be abundant in particular regions. This fact led to the concept of metallogenic provinces. It is worthwhile to compile geo-chemical/metallogenic provinces so that a prospector can look for an element in an area in which the rock types are rich in it. Most authorities accept the general idea of such provinces but show much divergence in terminology, in application, and in explanation of their existence. Different writers have used different terms i.e. 'metallogenic', 'metallogenetic', 'metallographic', 'metalliferous', or 'minerogenetic'. There is wide range in the application of the term 'Province'. It may be used for vast divisions such as Precambrian shields or fairly small areas. It may be described in terms of one or two metals or all the metals it contains. Some writers consider only economic deposits, others include metals that occur even in trace amounts.

Several greatly different speculations have been advanced to explain the diversity in the distribution of metals or minerals.

Most are in one of the following categories: (1) that the distribution of elements in the original crust of the earth was sufficiently different to account for the present observations, (2) that certain elements may have become available in the deeper parts of the crust at certain times as a result of some process such as atomic transformation, and that relationship between such times and those of tectonic disturbances might exist, (3) that certain metals are associated with specific kinds of igneous rocks, such rocks being more abundant in certain regions than in others, (4) that the distribution of metals at and near the surface of a region is related to the geological history of the region, which determines such factors as suitable environment for sedimentary or igneous processes of concentration, tectonic features and depth of erosion.

It is a happy sign that some countries of the world such as U.S.S.R., Japan, Canada, U.S.A. and India have prepared metallogenic maps of their own. This has been done at the instance of the International Geological Congress and also the Economic Commission for Asia and Far East.

The concept of metallogeny and the purposes and preparation of metallogenic maps have been a subject of controversy, and the different suggestions can be broadly categorised into the following:

(a) Metallogenic maps prepared on a geological base containing other details like regional structural features, structure, depth and composition of ore bodies and host rock, potentials of ore bodies, genesis of the deposits and even delimitation of metallogenic epochs and provinces. Such maps have

1 Metallogenic - Minerogenetic map of India, 1963, Geological Survey of India.
been compiled for individual metals and sometimes as over-lays for super-imposition on a generalised base or in separate sheets corresponding to principal metallogenic epochs (e.g. metallogenic maps of Canada and Japan).

(b) Metallogenic maps on a generalised tectonic base showing genetic grouping of the principal mineral/ore deposits. Similar maps also depict the geotectonic position of the individual or group of deposits, linking them up with particular phases of magmatism corresponding to the different stages of tectonic evolution. The ultimate interpretation in such maps is contained in the delimitation of 'structural metallogenic' zones which are generalisation of the characterisation shown by different groups of deposits and the position and configuration of these zones are controlled by the characteristics of the tectonic divisions. Such maps have been compiled by the VSEGEI, Moscow.

Out of the above two, the latter one has been adopted by the Geological Survey of India for the preparation of a metallogenic map of India. The scale of the map already compiled by the Geological Survey of India is 1 : 2,000,000.

The following principal structural metallogenic zones have been recognised in India.1

Ancient Platform (Shield):

Dharwar System of Mysore and adjacent tracts of Southern India:

The metamorphites comprise a greywacke suite intimately mixed with metavolcanics and basic and ultrabasic rocks. These have been affected by three phases of acidic intrusions and granitisation together with an early and late basic phase. Charnockites are also associated with these. The earlier basic and ultrabasic rocks have been responsible for magmatic deposits of chromium, iron, etc., while the first phase of gneisses (champion gneiss) has caused a hydrothermal mineralisation namely of gold, copper, lead and zinc. Such hydrothermal mineralisations have also been caused by the later granites and gneisses (Peninsular gneisses and Clopet granite). The second phase of basic and ultrabasic rocks have also caused mineralisation of chromium and iron.

(a) Based on the above the following structural metallogenic zones are characterised by mineralisation of the initial stage of development of the mobile belt:-

Shimoga-Tumkur-Arsikere-Mysore-Salem zones - Cr, Fe.

(b) Structural – Metallogenic zones of the sedimentary metamorphic deposits considered as corresponding to the early stage of development of the mobile belts.

Sundur zone - Iron ores obtained from the banded quartzites occurring in a typical greywacke association.

(c) Zones of mineralisation of the intermediate - late - final stages of development of the mobile belt.

(i) Gadag – Chitaldrug – Mysore zone.
(ii) Bensimalai Hadbanata – Kowdali zone.
(iii) Raghmiri – E. Bangalore zone, and
(iv) Huttí - Chityala - Kolar - Mamandur - Konlhadu - Vellore - Tirupati zone - Au (As, Fe, Cu, Pb, W); Pb, (Ag, Zn, Cu, Fe).
(v) Garimemepenta - Nellore zone - Cu, Be, Nb, Ta, Y.

**Eastern Ghats belt of the Southern part of the Peninsular Shield:**

This principally comprises calcareous and aluminous metamorphites with various stages of granitisation and hybridisation. There are isolated areas of metamorphosed Flysch type of association with exogenic mineralisation of iron in banded hematite-quartzites which formed during the early stages of development of the mobile belt. These are represented by the following zones:

(i) Pipalgaon - Lohara - Asola - Dewalgaon - zone
(ii) Dhalli - Rajhara - Perrerkaroo zone, and
(iii) Bailadila - Kondpal - Parowada - Taki zone.

Endogenic deposits of manganese in Srikakulam - Kalahandi - Raigada zone are associated with metamorphosed and metasomatised calcareous sediments of the exterior areas. This phase may correspond to the intermediate stage of development of a mobile belt.

**Singbhum - Gangpur - Bijawar belt of eastern and east-central part of the Peninsular Shield:**

Iron ore series, Gangpur series, Bijawar series and equivalents represent the Archaean meta-sediments of several types. Deformed and folded belts of meta-sediments along with gneisses and granites of at least two generations (Chota Nagpur gneiss and Singbhum granite) cover a major part of the area and indicate the development of the interior portions of a mobile belt.
The important structural metallogenic zones are indicated below:-

(i) Cuttack-Keonjhar-Singhbhum-Dhalbhumi-Mayurbhanj zones -
    Cr (Fe, Ni, Co); Fe (V, Ti); Pb (Cr);

It is curved synform, containing metavolcanics and meta-
sediments of the flysch type, representing magmatism of the early
stage. Some ultrabasic rocks of Bonai are of a later phase and
penetrate the former zone.

(ii) Metallogenic zone of the sedimentary metamorphic deposits
    of iron and manganese considered to be corresponding probably to
    the early stage of development of the mobile belt are represented
    in (a) Singhbhum-Keonjhar zone and (b) Mayurbhanj-Sambalpur-
    Koraput-Sundergarh zones.

(iii) Zones of mineralisation of the intermediate - late -
    final stages of development of the mobile belts are represented in
    Benkakocha - Lawa - Kumar - Singhbhum copper belt - Sansel Pahardia
    Manoharpur - Beldih - Kulad zone Au, Cu, (Fe, Ni, U); Pb (Cu, Au,
    Fe, Zn); U, Th, Ca, (La, Pr, Rd, Sm, Be). Hydrothermal and
    pegmatitic mineralisation occurs in refolded synforms and dislocated
    antiforms of metamorphosed sediments of the greywacke suite and
    associated metavolcanics.

Sausar-Sakoli system of the
central part of the Peninsular shield:

Semi-greywacke suite and meta-volcanics are found in the
interior areas in the south, and quartz carbonate association in
the exterior areas in the north. There are subordinate gneisses
and granites of at least two generation: Endogenic mineralisation
is rare. Exogenic manganese and iron ore deposits are frequently
seen in the exterior and interior areas respectively.
Aravalli system of the north-western part of the Peninsular Shield:

This system essentially consists of metamorphosed flysch group of sediments with metavolcanics of the interior areas. These are affected by a phase of granitisation. Mineralisation of the early stage of development are rare, while acid magmatism of the intermediate - late stage has given rise to some pegmatitics and hydrothermal mineralisations. Structural metallogenic zones of mineralisation of the intermediate - final stages of development are (i) Rewara - Betumi-Pahari-Dariba zone - Pb, Zn and mica and (ii) Zewar - Debari-Rikhabdeo zone - Pb(Cu, Zn, Ag, Cd).

Cuddapah System:

This is developed in a crescent-shaped basin. Moderately metamorphosed quartz-slates occur in the east and comparatively undeformed associations are found in the West. Mineralisation of the earlier stage is not well developed, while hydrothermal mineralisation has been developed in two zones associated with granites, i.e. (i) Cuddapah zone - Pb, Zn (ii) Agnigundala - Belapalli zone - Cu (Fe); Pb, Zn, (Cu).

Delhi System:

This system shows basic volcanics of the earlier stage of development of the mobile belt and acidic magmatism of the late stage. Mineralisation of the late stage have given rise to (i) Singhana - Babai-Khetri Babai zone - Cu (Fe, As, Co); (ii) Arjari-Dariba-Bairat-Gudkishoridas-Jodhawas zone Cu (Fe, Ni, Co); Pb (Zn, Sb) and (iii) Kishengarh Ajitgarh - Taragarh - Ambamata zone - Pb (Cu, Ti), Cu. All these zones occupy highly contorted and refolded synforms flanked by granites and gneisses.
Areas of Vindhyan folding:

Metallogenic events are significantly rare in Vindhyan formations.

Areas of Himalaya-Naga-Lushai folding:

The principal zones of mineralisation are those of the late stage of development of the pre-Himalayan tectonic cycle that consolidated into the younger platform basement of the Himalaya. These zones occupy the axial parts of the regional folds, being associated with metamorphosed Palaeozoic and pre-Cambrian sediments. The various masses of gneisses or granites including subjacent bodies have caused these mineralisations. These zones show truncations and dislocations caused by the main Himalayan phase of overthrusting. The zones developed in the early stage of development of the Himalayan mobile belt occupy synclinoria and overthrust parts of the eugeosynclinal areas.

Platform Area:

The platform type cover along the fringe of the peninsular shield is not known to contain endogenic deposits of much significance. Exogenic iron and coal deposits are known.

Vast areas of laterite have given rise to important aluminium and iron deposits.

(B) Dispersion in aqueous fluids:

Most mineral deposits are formed due to chemical reaction within an aqueous solution and also with the wall rock, and
consequent deposition along certain vents or channels in the rocks. The anomalies in such types may assume areal pattern, leakage pattern and wall rock patterns. Areal patterns are helpful in reconnaissance exploration. Leakage halos are indicative of concealed ore-body. Wall rock patterns will indicate whether or not an ore-body is close to a drill hole or a cross-cut.

(C) Gaseous dispersion:

It's usefulness is restricted to petroleum, uranium and mercury deposits. In the case of petroleum, soil or soil air is sampled and analysed for traces of certain diagnostic hydrocarbon compounds.

The decay of certain radioactive elements results in the generation of noble gases such as radon and helium from uranium and thoron and helium from thorium. Analysis of stream and spring waters and soils for these gases can yield helpful clues to radioactive deposits.

Among the non-radio-active ore metal, mercury is the only one which has been studied in some detail in Russia. Vapour pressure in mercury minerals has been measured and related to gaseous dispersion of mercury from the primary deposits into the porous country rock.

Secondary dispersion:

The physical and chemical environments of the earth surface are entirely different from those prevailing at depth. Dispersion patterns formed by the agents of weathering, erosion and transportation, etc. are known as secondary dispersion. As pointed out
earlier these phenomena are more common in nature.

(a) Residual cover:

Weathering gives rise to three forms of products, i.e. residual primary minerals, secondary minerals formed at or very close to the site of weathering and soluble material removed from the local site of weathering by circulating waters. Study of dispersion patterns of metals in soil is an important method of geo-chemical prospecting.

Residual limonitic material left over after the migration of soluble products is known as "gossan". These gossans can lead downward to primary sulphide minerals. If the gossans have been dislodged from its original position, study of dispersion pattern of limonitic material can lead a prospector to the parent gossan mass and the hidden sulphide deposits beneath.

(b) Glacial action:

Movement of continental ice sheet is on a grand scale and glaciation acts as a forceful agent of transportation. Fan shaped pattern of glacial dispersion has been studied in detail in Scandinavia, etc.

(c) Animal activity:

Analysis\(^1\) of ant heaps for traces of ore metals has been attempted in Africa and Australia.

---

(d) **Underground water movement:**

Geo-chemical anomalies have been studied in detail in Russia and Japan in descending or laterally moving ground water, spring water and seepages, etc.

(e) **Vegetation:**

The metal contents of plants have proved useful guide in prospecting. Considerable work has been done on these aspects in Russia and such work is in progress in Canada. Beginning in 1945 Warren and co-workers at the University of British Columbia have been active both in research into the bio-chemistry of copper and zinc in Canadian flora, and in the application of plant sampling on a large scale as a prospecting method.

(f) **Streams and Rivers:**

Dispersion patterns are linear in character. They are also known as 'trains'. Study of heavy minerals is important.

3. **Photogeological methods**

Photogeology, in its proper perspective demands the application of accepted geologic principles to the study of aerial photography. It involves the recognition of rock types, delineation of individual beds and horizons to the greatest degree the photo will permit, measurements of attitudes by photogrammetric means, and

---

the cohesion of these into a consistent and compatible picture. The main factors involved in the analysis of a photograph are the following:

**Topography**: Variations in topography are easily recognised on a photograph and many useful facts can be inferred from the details of topography.

**Drainage**: A drainage system is an easily discernible feature on a photograph and is an important clue in the interpretation of photographs.

**Erosion**: Erosion characteristics are useful in identifying broad soil types and in determining geologic contacts, thickness of overburden and the rock type themselves.

**Tone**: Tone is influenced by the type of vegetation, drainage etc. Thus it may serve to delineate geologic and geomorphic units. Relative tones must be considered, because of slight differences in exposure and developing.

**Vegetation**: Vegetation can often be of help in determining soil types, by a physically and chemically influenced affinity or aversion to a rock or soil by a plant or tree.

The above aspects are looked for by the geologist, on the stereopair, in the study and identification of surface geological feature or landform and the nature of the rock or structure on which it is developed or which it characterises.

In the field, mapping of an area is done directly on aerial photographs covered with a thin film of acetate.
4. Exploration programme

Designing of a modern mineral exploration scheme would utilise one or several of the disciplines discussed above. For example, a complete exploration programme is generally tackled by a survey company in Canada in the following sequence.

1. Simultaneous flying of colour and black and white aerial photography of the area.

2. Geological interpretation of the aerial photography.

3. Field-checking and editing of the photogeological interpretation.

4. Combined airborne magnetometer and scintillometer geophysical survey of the area.

5. Geological interpretation of the airborne geophysical data.

6. Geochemical survey comprising the selection and analysis of selected alluvium rock chip and water samples.

7. Reconnaissance geologic mapping in areas selected from the history of the area, photo-interpretation, airborne geophysical data and geochemical data.

8. Reconnaissance ground geophysical surveys, including the use of ground magnetometers and Afmag equipment in areas selected from the results of steps 1 to 7.

1 Personal discussions with the officials of Hunting Survey Corporation Ltd., Toronto and Canadian Aero Service Ltd., Ottawa, Canada, 1963.
9. Detailed geological mapping at a scale of 1:5,000 in areas selected from the results of steps 1 to 8.

10. Diamond drilling on specific targets selected from the previous steps.

The combination of photogeology, airborne geophysics, geo-chemistry, geologic mapping and ground geophysics narrows the search and the subsequent drilling to the area of maximum commercial potential. However, it is only rarely that the commercial survey companies are asked to perform all the steps.

5. Expenditure on Exploration

A deviation from the definition adopted in this thesis for the terms 'Prospecting' and 'Exploration' will be necessary to examine the financial implications of an exploration programme. These two terms will have to be merged together to attain the objective in view. The best definition that might suit the purpose is that offered by Dewan: "The whole gamut of activities relating to the acquisition of knowledge essential for exploitation of mineral wealth constitutes mineral exploration. These activities can be conveniently divided into a number of stages such as regional reconnaissance surveys, detailed investigation of mineralised districts, preliminary appraisal of prospects and detailed exploratory and proving operations in selected prospects." Besides, it is

---

also necessary to pin-point the dividing line between 'exploration' and 'development' for the purposes of cost accounting. A practical criterion given by Preston\textsuperscript{1} appears to be adequate........"

Probably the most satisfactory theoretical standard here would be to include as exploration costs all expenses, other than purchase or long term leasing of mining sites, which are made in advance of management decision which establishes the size of the capital plant and the annual output of the mine. Once this decision is taken, then further activities can be thought of as the preparation of the site for operation at this rate, and thus constituting development rather than exploration."

Exploration activities in an operating mine directed to "develop a ton of reserves for every ton mined" are considered expenses of capital maintenance and not as cost of exploration.

Cost categories:

The following, then, will be the broad cost categories in a mineral exploration programme.

(1) Surveying and mapping (aerial and ground).
(2) Aerial photography.
(3) Interpretation of photographs.
(4) Geophysical (air and ground) and Geo-chemical survey.
(5) Detailed geological mapping on ground of a selected area on a large scale.
(6) Drilling.

\textsuperscript{1} Preston, Lee E, Exploration for non-ferrous metals, Resources for the future Inc., 1960.
GRAPH SHOWING VARIATION IN DRILLING COSTS WITH DEPTH AND NATURE OF FORMATIONS

COST PER METRE IN Rs.

DEPTH IN METRES

- VERY HARD FORMATION
- MEDIUM HARD FORMATION
- SOFT FORMATION
(7) Trenching: hand and machine.
(8) Test Pitting.
(9) Drifting and cross-cutting.
(10) Rehabilitation and preparatory work.
(11) Road Building.
(12) Trail Building.
(13) Surface cleaning.
(14) Sampling.
(15) Shaft sinking, raises and winzes (exploratory).
(16) Other work.
(17) Reports.

All the above categories may not be pertinent in a particular exploration programme. This will depend on the designing of the programme which, in turn, depends on geological and economic factors.

Cost figures in U.S.A. of most of the exploration methods are shown in tables XV and XVI. According to a latest estimates a combined magnetic and radio-activity airborne survey costs approximately U.S. $ 7 per linear kilometer. The maximum spacing of flight lines, for mineral investigation, is approximately one kilometer. Thus, the basic cost per 15,000 sq. km. is of the order of $ 6,000.

Electromagnetic induction methods require closer flight lines with a maximum interval of approximately half kilometer. The basic cost of a combined electromagnetic induction, magnetic, and radio-active airborne survey is of the order of $ 15,000 to $ 20,000 per 1,000 sq. kilometers.

These approximate costs apply to a survey of the general magnitude of 10,000 linear kilometers. To this must be added the costs of bringing the plane into the area and returning it to its home base. In areas of uncertain flying weather, a "stand by" charge is also made for the time the plane is grounded by bad weather.

The experience of the National Geophysical Research Institute indicates that magnetometric survey costs in India with complete indigenous facilities may come to about Rs. 30 to 40 per line mile for a minimum area of 10,000 sq. miles. The cost may increase to Rs. 60.00 per line mile with electromagnetic equipment (electromagnetic equipment is still to be developed in India).

Data regarding costs of various exploration methods are generally lacking in India. However, detail information on drilling costs with reference to Indian conditions have been compiled in tables XVII to XXXV in varying depths and geological formations. The data may have special significance as the amount of drilling usually governs the scale of operations and the time period involved. A usual method of estimating costs of specific exploration projects, in fact, is to estimate direct drilling costs plus 50 per cent.

Tables XXXVI to XXXIX give important data of man-power utilisation and expenditures in the Free World in geophysical activities both surveying and research. Table No. XXXVI indicates that on a man-month basis, an average of 664 professional and

1 Narayan, Hari, Need for Airborne Geophysical Survey in India, Oil Commentary Vol. VI, No.1, August 15, 1968.
2 Vernon Read, "Planning the Exploration Programme", Engineering and Mining Journal, CLVII (Mid-June, 1956).
technical persons were employed in mining geophysics in 1960, expenditure for geophysical exploration and research amounting to $10,974 million. The table also indicates that the United States utilised the most man-power with 2,010 men months (168 persons) followed by Europe, Japan, Canada and Latin America in that order. Table No.XXXVII shows that more man months were employed in geochemical exploration and research than any other methods. An average of 117 professional and technical persons were employed in the use of this method. It may be noted that government activity accounted for a large share of the geo-chemical data. Geo-chemical method was followed by resistivity and induced polariation techniques, seismic method, gravity, electro-magnetic, ground magnetic, aero-magnetic self-potential and radio-activity in that order. The aeromagnetic method with a relatively high expenditure per man month ranked first and accounted for an estimated outlay of $2,504 million. This was followed by geo-chemical, resistivity and seismic methods. It may also be mentioned that the number of man-months utilised by Government organisations accounted for 61.4% of the total Free World Man Power utilisation in 1960 but only 34.3% of the total expenditure. This is due to high employment of personnel in government departments and lower expenditure per man-month.

It may be of interest to mention that Canada which is supposed to have one of the most active exploration activities spends about 50 million Canadian dollars per annum on metal exploration, relating to capital expenditure alone. Contract drilling for testing metalliferrous deposits runs to approximately 5.5 million feet per annum. Similarly, Australia spends about $25 million (Australian $) per annum on mineral exploration other than petroleum and the drilling footage is reported to be 2.5 million

As per the report of the Planning Group on minerals in the Ministry of Steel, Mines and Metals, a sum of Rs. 450 million is estimated to be spent in India during the Fourth Five Year Plan on mineral exploration other than Petroleum, out of which about Rs. 350 million may be spent on geological, geophysical and drilling operations and the remainder on geo-chemistry, photogeology, exploratory mining, hydrology and marine geology, etc.

Optimum expenditure on Exploration:

The nature of exploration problems and the techniques adopted to solve them call for well-co-ordinated exploration programmes over larger areas to evolve hypotheses based on the study made in the area and to test them. This necessitates large exploration expenditure which is beyond the scope of a smaller company. Either the government itself or larger companies would be able to do the job. Large expenditure must be justified - the question of expenditure versus returns must be examined. It must at the same time be appreciated at the outset that exploration is a high risk enterprise and investment returns are difficult of prediction. Yet it is necessary to identify pertinent factors which will justify exploration expenditure and prevent wasteful expenditure of funds. Not much work appears to have been done in this field. However, Callaway¹ has made an attempt to express in the form of a formula determining permissible costs of exploration.

Callaway's Formula:

The cost of exploration varies directly as the anticipated value of the discovery and the probability of making the discovery. Mathematically,

\[ C = R N \]

where

- \( C \) = the maximum amount that can be spent economically on a given exploration project.
- \( R \) = the estimated probability success which is expressed as a fraction whose numerator is the number of discoveries and whose denominator is the total number of attempts to make a discovery.
- \( N \) = Discounted net value of the return.

Identification of Parameters \( R \) and \( N \)

**Probability success \( (R) \)**

The probability factor is usually judged on geologic considerations. It will be necessary to examine diligently all the work done in the area. If it is found that the district has been examined more thoroughly in the past and the factors governing ore localizations are known, \( R \) will increase say at 1/20. If it is a virgin area, or not much work is done in the area, \( R \) will have to be placed at say 1/500.

It appears pertinent to discuss first a few of the recent thoughts on probability of success in exploration ventures.

(a) Slichter\(^1\) compares prospecting for minerals with a gambling business and applies the law of Gamler’s Ruin,

---

Pr = e^{-NPs}

where
Pr = Probability of gamblers ruin.
Ps = Probability of success for a single venture.
N = number of ventures.

According to this theory the only sure way of avoiding risk of gambler's ruin is to have enough capital and the will to continue to play many times and thus ride out the inevitable runs of bad luck. For example, if the probability of success is one in 10 for each venture, there is 35% chance that 10 successive ventures will fail in a row. But if one has the capital to continue the play through a run of 100 failures, then the chance of the gambler's ruin is only 5 in 100,000. It follows from this that to prospect for minerals under such odds requires great confidence in the long term expectations of profit. For this reason, the prospecting agencies must have sound financial stability. Even the strongest may not have the necessary capital to prospect on an ideal scale. Joint ventures among the mining companies will be desirable for extending the available venture capital, or else the Government should take up the work, as is being done in India.

(b) Preston\(^1\) has examined exploration strategies vis-a-vis probability of success in somewhat greater detail. Some salient points of his discussions are given below.

**Exploration strategy in a single site**

The two extremes of exploration strategy may be characterised as (i) the practice of examining the most promising indicator first.

---

and, in the case of rejection, following with the examination of next most promising indicator, etc. and (ii) the practice of establishing a sampling programme for the area in question on the basis of a grid system, or some other system which the geology of the terrain suggests. An actual exploratory programme may represent a combination of these two approaches. Exploration strategy should not be random. It should be planned systematically and the operations should be divided into stages, and at each stage a kind of stock taking of the work done, vis-a-vis the objectives obtained, should be made. It may be necessary in certain cases to sample the entire area, in the first instance, either by geochemical methods or geophysical or detailed structural geology and then to arrive at conclusions regarding putting some drill holes for testing a hypothesis. In the initial work, as given above, it is not possible to determine the value of 'R' (probability of success) and 'N' (discounted net value of the return) but when the operation has progressed to a certain extent and some of the decisive tests have been performed, it would be possible to arrive at the value of 'R' and 'N'. This value will change with further exploration provided the results justify it.

**Exploration strategy with multiple sites**

It would also be necessary to examine exploration strategy involving a group of independent possible deposits spread over a large area. M. Allais and L.B. Slichter have done some work on this problem. The former, on the basis of statistics of mineral deposits in France, United States, N. Africa and other countries has evolved empirical estimates of 'R' in connection with a mineral

---

exploration programme in the Algerian Sahara. The resultant values of 'R' and the probable number of deposits per one million square kilometers is presented as follows:

<table>
<thead>
<tr>
<th>Hypothesis used.</th>
<th>Value of R</th>
<th>Number of Deposits of at least $2 million in Gross Value per One million sq. kilometres 95 per cent.</th>
<th>Estimate</th>
<th>Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Least favourable</td>
<td>1/1000</td>
<td>10</td>
<td>4-16</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>1/500</td>
<td>20</td>
<td>11-29</td>
<td></td>
</tr>
<tr>
<td>Most favourable</td>
<td>1/250</td>
<td>40</td>
<td>28-52</td>
<td></td>
</tr>
</tbody>
</table>

His most interesting observations concern the process of 'skimming' and the relationship of area explored to probability of successful outcome. The 'skimming' operation is defined as the selection of indicators found in the first phase of exploration to be analysed in the second phase. In other words, the less promising indicators are eliminated. One corollary that follows from the above is that if the operation is less selective, the number of indicators that will be required to be analysed are likely to increase which, in turn, may ensure that all existing deposits may be found. On the other hand, a less selective skimming will lower the ratio of deposits found to indicators analysed. The increase in the number of indicators will also increase the costs. For this reason the skimming operation requires a reduction in the number of indicators selected for examination by judicious application of geologic knowledge.

The second point high-lighted by Allais is the importance of the size of the exploration activity to its financial success. It has been concluded by him that the probability of financial success increases geometrically with the size of the exploration
venture. Equating geographical size with the amount of capital involved, and utilizing his median estimate of probable success and capital expenditures to estimate the parameter 'm', he calculates the probability of financial loss on the basis of the formula for ruin in gambling, i.e. \( P' = e^{-mx} \) where \( P' \) is the probability of ruin and 'X' is the capital expenditure. For values of X, given in billions of francs, the lower limits of the probability of the loss on the Sahara venture are calculated as follows:

<table>
<thead>
<tr>
<th>X</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>40</th>
<th>80</th>
<th>100</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>P'</td>
<td>0.98</td>
<td>0.95</td>
<td>0.91</td>
<td>0.81</td>
<td>0.72</td>
<td>0.65</td>
<td>0.42</td>
<td>0.18</td>
<td>0.12</td>
<td>0.04</td>
</tr>
</tbody>
</table>

He concludes that "mining exploration applied to the French Union as a whole practically would involve no risk of loss".

A somewhat similar analysis is developed by Silcheter in connection with exploration for hidden deposits of the Basin and Range Province based on Nolan's\(^1\) study. The basic pattern of both the studies is (i) initial assumption of the relative frequency and character of mineral deposits distributed over a certain area, and (ii) design of experiment based upon a large number of initial observations and a gradual culling of unpromising sites.

**The Insurance Principle of Exploration**

The studies of the above two scientists are largely arbitrary in nature and their quantitative results are not assured. But it is a fact that the direction has been more or less accepted

---

by the mining companies in developed countries. The most important conclusion from these studies is that there are important scale effects in exploration. It has been held that the chances of discovery are more in large scale multi-faceted exploration ventures. The argument based upon the 'law of large numbers' and frequently referred to in literature as the 'insurance principle' is that exploration activities are likely to be financially successful only if based upon large samples of potential mining sites. An analysis made in Canada of the properties of active mining companies listed in the Canadian Mines Hand Book in 1957 has shown that more than 11% of these properties had shown some evidence of becoming producing mines. This record of better than 11% success is very striking. It has been concluded on the basis of this study that effective skimming in initial selection of sites in new mining areas should raise the rate of success considerably, probably as high as 40%. It follows from this that the strategy of skimming is of importance in mineral exploration probability, but good skimming is based on knowledge, judgement and the most careful possible establishment of criteria upon which decisions are to be made. The availability of skilled knowledge will be more if the mining firms are big and financially sound. An individual or a small mining company may not be in a position to attract the requisite skill. The other important point is that if a large number of indicators are examined the chances of neglecting any indicator are eliminated. An individual or a small mining company may not afford to examine a large number of indicators.

Returns on exploration expenditures
(N of Callaway formula)

The tempo of exploration has to be judged in relation to the expected value of the mineral deposits. Value in this context
means the expected total revenue in excess of operating and capital costs for the life of the property, discounted to present value, which will depend on prices, costs, the value and time distribution of output, and the rate of discount employed. The length of delay between expenditure incurred and the beginning of the revenues has also to be considered. The period of deferment is important; a new deposit which has to be kept in reserve for longer period clearly has a different capital value for the same deposit for which production is to be obtained quickly.

**Time-Distribution of output**

Decision on optimum production rate of a mine hinges on the knowledge about the quantity and quality of the deposit and future pattern of prices, costs and technology. All these parameters are almost always imperfectly known and for this reason Hoover offered the strongest possible argument for the rapid exploitation of metal deposits. The problems arising will be large capital investment and amortization expense. Increased production may also result in reducing the market price. But a smaller profit margin on high production rate for a smaller number of periods may produce the same capital value as on low outputs with greater profit margins for a greater number of periods. Another point in favour of rapid exploitation is that the lower price and profit rates will inhibit the appearance of substitutes, encourage expansion of markets. The risk element will be eliminated.

**Price Cost Margin**

Valuation of the deposit which has to be mined in future will not depend on the past prices, but on anticipated future prices. But a study of the price-cost structure of metal mining in the past provides a basis for forecasting these relationships in
the future. It has been seen that a boom in the current prices have at times led to investments in exploration on a large scale, but the current price is certainly not enough to be applied for the valuation of a deposit to be mined in future years. Current prices, however, determine, to a great extent, the flow of funds from various sources in exploration activities. Damp prices diminish investments in exploration.

Discounting Prices

The discounting process is one by which the anticipated future revenues are reduced to present value. It is conditioned by two factors, i.e. time and risk. Risks are of two kinds, i.e. those which are functions of time and those which are independent of time. For example, the risk that the actual size and grade of an ore body will be something less than the present estimate is an absolute risk, irrespective of the time period considered. In contrast, the estimate that future price or cost will be within a certain range, + and -, of present prices or costs becomes increasingly uncertain as the time period in consideration is extended. The absolute risks involved in ascertaining the minimum size of the deposit are generally considered in the calculation of the 'amortization tonnage'. Generally, what is done is that the geological evidence available is evaluated and apparent operating profits and geological possibilities are calculated. If 2/3rds of operating profits will recoup the investments in 5 years or less and the geological possibilities are good, the property is considered effective, otherwise not. This formula amounts to return of 30% simple interest on invested capital for 5 years. Conservative cost, price and life estimates also compensate absolute risk to an extent. The risk elements which are thought to be functions of time are reflected in the discount rate or in other words, in the investors insistence upon a high minimum expected return from the investment.
Hoskold Formula

The present discounted value of a mineral deposit is calculated on the following considerations:

1. Life of the mine.
2. Rate of interest for the redemption of capital.
3. Rate of return on the investment.
4. Annual anticipated net value.

All the above elements are judged on the basis of experience and the data available. The life of a deposit, for example, will be governed by the data available regarding the mineable reserves. The rate of interest for the redemption of capital, which is also called the safe rate, has to be spread over the entire life of a mine. Argument in favour of this rate of interest in addition to risk rate is that a deposit is a depleting asset and the capital should be redeemed in addition to getting a profit. A 3% rate for safe interest has been applied by Hoskold. At times, this rate is increased to 4% by some mining firms. The risk rate is anybody's guess but generally it is held that a higher rate is essential considering the hazardous nature of the mining industry. Hoover, for example, has suggested a minimum rate of 7%. Others hold the view that this rate should be much more, as much as 16-17% rates have been suggested.

According to Hoskold\(^1\) the present value of a deposit can be calculated on the basis of the following formula:

\[
V = \frac{R}{\frac{r}{(1 + r)^T} + r'} \frac{1}{(1 + r)^T - 1}
\]

---

1 H.D. Hoskold, Engineers Valuing Assistant, Longmans Green, 1905.
where \( V \) = present value of the deposits.
\( R \) = annual net revenue
\( r \) = rate of interest on the sinking fund;
the 'safe' rate.
\( r' \) = rate of return on the investment;
the risk rate.
\( T \) = number of years of life of the mine.

The above formula has both its merits and demerits, but it is one which is handy because Hoskold has prepared comprehensive tables showing the discounted present value on various interest rates, but keeping the safe rate at 3%, over the varying life of a mine.

The Hoskold formula is not easily applicable to varying earning rate. Moreover, Hoskold applies a risk rate on the total original investment during the life of the property similar to that of a perpetuity. He visualised a sinking fund to be maintained during the life of the mine from which an investor will get his capital returned when the mine is depleted. Now-a-days, generally, the straight discount method is used within the industrial and financial sectors of business all over the world. This concept provides single interest on the unrecouped capital which should not be used to augment a sinking fund total. The annual capital write-off increments are such that they accumulate during the life of the mine to the total original investment without the assistance of interest. The most popular straight discount formula\(^1\) is given below:

\[
V_P = \frac{A \left( 1 + r' \right)^n - 1}{\left( 1 + r' \right)^n r'}
\]

where \( VP \) = Present value of the future earnings.
\( A \) = Annual earnings.
\( r' \) = Risk rate.
\( n \) = Life of the deposit.

The methods of valuation discussed above are elaborate in nature, and are applied before taking up the exploitation of a mineral deposit. Capital for mine development, surface facilities and transportation forms the major part of the fixed capital requirements. Exploration expenditures in relation to what has been stated above actually constitutes a small portion of the total investment. It is not really possible to estimate the actual value of undiscovered deposits. What is needed is to estimate that reserves having a value of more than a certain sum may be obtained.

6. Comments on exploration expenditures with reference to probability of success and valuation of anticipated reserves

The first and foremost point to stress is that exploration of metallic deposits, like petroleum exploration, is now a capital intense economic activity. In India, as elsewhere, hidden ore-bodies will have to be discovered after long series of trials involving considerable expenditure of funds. "Although a mining company may set aside specific sums to be spent in prospecting and exploration, no amount of budgeting will assure how much mineral will be found per dollar expended. In view of the uncertainties involved, no widely acceptable basis for estimating average cost has yet been devised." However, exploration expenditure has got to be an appropriate fraction of the potential prize of the target, a fraction which is determined by the odds judged to exist at the moment. But the assessment of the potential prize is the most

difficult question in the search for 'blind deposits'. In fact, in the hope of long term expectations, considerable funds may have to be spent to find ultimately that the project was not of any economic significance. The Irish bull 'Never stop until you have put another round' is often quoted, but Company after Company have gone broke, not knowing when to quit. The type of prospect known to the profession as 'teaser' can keep on consuming capital to the point where even if ore is finally discovered it does not pay a reasonable return on the large amount that is already invested.¹

A very specialised and experienced knowledge is necessary if the prediction regarding 'odds' and 'value' have to be of any significance in planning exploration programmes. To gain that knowledge and expertise intensive research is needed toward a better understanding of the origin and kinds of metallic deposits. The petroleum industry of the United States of America is probably the best example of the effectiveness of this approach. The vast increase in the oil reserves compared to what they were three decades ago, is attributed to industry supported research on the origin of oil and factors that control its migration and accumulation as well as development and application of more elaborate geological, geo-chemical and geophysical techniques in oil exploration. Now the petroleum geologist can predict and find oil and gas in environments that were poorly understood not too many years ago. It is true that odds are still very heavy in petroleum prospecting. In U.S.A. one out of nine wells show discovery of any kind, and one out of forty four contain reserves of one billion barrels or more. However, once an oil well is discovered, it pays good dividends to shareholders. Metal mining may not be as paying as that, yet the impact of research on the discovery of oil

pools should serve as good example, and research in the direction discussed above for metallic deposits should also be intensified. A good beginning has already been made in such and other related problems in certain industrially advanced countries such as U.S.A. and France. Barton has opened up the possibility of predicting the environments in which ore minerals may be deposited through his work on the equilibrium relations on these minerals. Similarly, Engel has studied variations in the ratio of isotopes of oxygen in some minerals associated with ore-deposits, and the possibility that such variations may reflect temperature gradients existing at the time of ore-deposition. Considerable work is needed in 'trace element' research; in the study of phases of trace occurrences and on factors causing local relative concentrations. Similarly, more knowledge is necessary regarding relationship between the tonnage of material containing a particular element and the grade of the element. The world's supply of any particular ore has been pictured as a cone, the height of which represents grade. Thus each conic section of equal height from the apex downwards is much larger in volume than the one above it. It might also be added that this representation calls for cones of different slopes for different minerals, but it seems safe to say that the available ore always approaches the inexhaustible when the grade falls low enough. Thus small improvements in mining or treating methods often can make available for profitable exploitation vast supplies of formerly submarginal material."

In addition to the above, statistical analysis of ore body occurrences, their size and values are of utmost importance if any


exploration programme is to bear fruit. On average, how many mines occur per unit of area of a mining belt and what is the chance that a unit of area will contain at least n mines where n is 0, 1, 2, 3, etc.? Such studies have become inevitable in the exploration of concealed deposits, and a good beginning has already been made in the study of such problems in U.S.A., Canada and France. For example, Allais and Blondell\(^1\) in the case of Algerian Sahara, find that the areal distribution of ore-bodies is well represented by the familiar Poisson distribution. Similarly, areal distribution of mines in Basin\(^2\) and Range area and the pre cambrian intrusive and sedimentary areas of Ontario has been studied in recent years. These areas were divided into squares of 1000 sq. km. each (185 in number) and the count of mines, square by square were recorded. The mean number of mines per 1000 sq. km. was found to be 0.43 in the Basin and Range areas and 0.80 in the Ontario area. Percentage distribution of units containing 'n' or more mines were established with the help of the counts made as well Poisson distribution law with the averages given above. One obvious conclusion of the tabulation was that large percentages of sub-areas contained less number of mines. For example in Ontario one or more mine was found in 43.78 per cent of the sub areas whereas six or more mines were found in 0.28% of the sub-areas. The two set of data, those obtained by counts and those calculated from Poisson formula, were then plotted graphically. It was observed that the straight lines representing the counts and indicating the exponential functions provided a better fit to the data than did the Poisson curves.

---


2 Nolan, T.B., "The Search for New Mining Districts", Economic Geology, 61 (November, 1959.)
"The exponential probability distribution has important implications. It implies that the chances that one or more additional mines exist in any unit is independent of the numbers that are already known to exist. There is no indication that a unit of this size has been appreciably depleted in potential undiscovered wealth because some two, three or four mines have already been found. The statistics indicates that the mines are there to be found and that the lack of discoveries is attributable to difficulties of discovery rather than absence of targets for discovery"\(^1\).

Similarly, based on statistical analysis it has been concluded that the rare big ore-bodies furnish the real rewards. It has been seen that the production of the 285 mining districts in Nolan's Basin and Range study follows closely the log normal distribution, and only 4% of the districts produced 80% of the wealth, and 16% of the districts accounted for 97% of the production. It has been concluded that one district in 1000 would produce over one billion dollar. Associated with the log normal distribution of ore bodies with respect to value, there is a similar log normal distribution in respect to their size and physical dimension. If direct information about sizes of the ore bodies is not obtainable, it is possible now to compute the size from the inference on values discussed above. Generally the assumption is $1.00 per cu.ft. irrespective to the kind of ore involved.

It is needless to emphasise that expert advice on spacing of flight patterns, interpretation of anomalies and spacing of drill holes will greatly improve expectations of finding ore-bodies against odds. A well laid out programme will eliminate

---

\(^1\) Slichter, L.B., The Need of a new Philosophy of Prospecting, Mining Engineering, June, 1960.
GRAPH SHOWING EXPENDITURE ON EXPLORATION WITH VARYING PROBABILITY FACTOR & CONSTANT DISCOUNTED NET VALUE OF PROSPECT AT Rs. 2,000,000,
odds at successive stages, and will determine the future course of action with reference to expenditure and the valuation of the target.

An attempt has been made in the graph facing this page to represent possible expenditures against varying odds but with constant value of prospect at Rs.2,000,000. Line OA represents the maximum limit of expenditure. When the expenditure crosses this limit, as for example, line aC, or turns negatively i.e. line aD, showing no increase in the probability factor, the project is to be given up. The curve aB represents successful exploration expenditure. At each successive stage the odds decrease and the expectation of finding target of the value of Rs.2,000,000 increases. It will be seen that with odds decreasing the proportion of the actual expenditure and the maximum worked out increases. It may, however, be mentioned that a particular exploration programme need not be strictly pursued through all the successive stages. The whole planning will depend on the circumstance prevailing at a particular moment. For example if it is determined at the very outset that the odds are one in ten to discover a deposit worth Rs.2,000,000 the expenditure in either proving or disproving the deposit should run in at Rs.100,000.

We have taken a hypothetical case when the assumed value is constant throughout. This seldom happens in practice. As the work progresses, both the 'odd' and the 'value' change in the light of new data available. It may not be difficult to cast exploration expenditure taking both the variables into consideration. For example, in the course of investigation, if a new lode is encountered and the value of of Rs.2,000,000 increases to 4,000,000 and the odds are reduced to one in five, then the expenditure of Rs.500,000 is not a bad bet.
7. The impact of Government's policy on exploration

The Industrial Policy Resolution of 1956 continues to govern industrial development in India. This policy provides for a flexible approach in the development of industries within the public, private and co-operative sectors. It is designed to accelerate the attainment of the objective of Government's economic policy i.e. creation of a socialistic pattern of society. According to the Resolution industries have been divided into three categories, having regard to the part which the State would play in each of them. All the industries the future development of which will be the exclusive responsibility of the State are listed in Schedule A. These include, interalia, iron and steel; coal and lignite; mineral oils; mining of iron ore; manganese ore, chrome ore, gypsum, sulphur, gold and diamond; mining and processing of copper, lead, zinc, tin, molybdenum and wolfram; atomic energy minerals. The second category consists of industries, which will be progressively state owned and in which the state will take the initiative in establishing new undertakings, but in which private enterprise will also be expected to supplement the effort of the state. This category, interalia, includes all the minerals except 'minor minerals' and also includes aluminium and other non-ferrous metals not included in Schedule A. The third category includes all the remaining industries, and their future development will, in general, be left to the initiative and enterprise of the private sector. It has been contended in the Resolution that the division of industries into separate categories does not imply that they are being placed in water-tight compartments. Inevitably, there will not only be an area of overlapping but also a great deal of dovetailing between industries in the private and public sectors.
In accordance with the above policy grant of mineral concessions for Schedule A minerals to private parties is restricted to those deposits which are not large enough for exploitation under public sector. In fact certain potential areas for these minerals have already been reserved for state exploitation. The fact of the situation is that these reserved areas have been lying untapped for a considerable length of time. It amounts to 'moth balling' them for future utilisation. This tendency is clearly against the principle of conservation. The resources of the private sector should be allowed to come into play at least in those areas where the Government does not have immediate plans of production, say, for another five years period.

The Policy of the Government undoubtedly would put severe limitations on exploration activities of the private sector. Government's role in mineral exploration field has got to be more pronounced.

8. Conclusions

1. Sophisticated methods of exploration such as photogeology, geophysics and geochemistry will have to be pressed into service in the exploration of blind deposits.

2. Exploration will increasingly become a capital intense economic activity. Patience will be required to test a large number of indicators, and narrow down the search for the target by a well laid down out "skimming" process. In Indian conditions direct Government's participation is inevitable. Apart from paucity of capital, lack of requisite technical expertise will be a limiting factor. Technical skill will be very much needed to
be developed. In the mean time inter-governmental assistance will hasten the search. The results of recently launched 'operation hard rock' in India with U.S. assistance should be watched with interest.

3. The primary importance of appraising the expectations of finding ore, and maximising the returns from prospecting, needs hardly any emphasise. To achieve these ends a better understanding of the origin and kinds of metallic deposits is needed. Extensive research in environments of deposition and nature of metals is the most important problem. Statistical analysis regarding expectations of discovery based on the distribution of ore bodies and their value, etc. will lead to significant conclusions and improve the art of prospecting blind.

4. According to the Industrial Policy of the Government of India, development of almost all the minerals is largely the responsibility of the state. The division of responsibility is not water tight and a fair amount of flexibility is provided, but the policy, as it stands today, puts severe limitations on exploration activities of the private sector. The State's role in this field, for this reason, has got to be more active and pronounced.
Table XV. Cost of Exploration in U.S.A.

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost (U.S. $)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aditng</td>
<td>26 per foot of which roughly one third is labour cost.</td>
<td></td>
</tr>
<tr>
<td>Shaft sinking</td>
<td>200 per foot with labour cost one third.</td>
<td></td>
</tr>
<tr>
<td>Drilling</td>
<td>0.50 per foot to 25 per foot*</td>
<td>up to 1,000 ft. depth</td>
</tr>
<tr>
<td>Churn drilling</td>
<td>2 per foot to 5 per foot</td>
<td>up to 1,000 ft. depth</td>
</tr>
<tr>
<td>Diamond drilling</td>
<td>2 per foot to 8 per foot</td>
<td></td>
</tr>
<tr>
<td>Geothermal (Ground)</td>
<td>100-150 per line mile</td>
<td></td>
</tr>
<tr>
<td>Magnetic (Air)</td>
<td>Contract work for 6-10 per line mile, but company costs may be as low as $1 per mile.</td>
<td></td>
</tr>
<tr>
<td>Magnetic (Ground)</td>
<td>Up to 150 per line mile. For a large reconnaissance utilizing various magnetic techniques cost may vary widely but $10 per acre is typical.</td>
<td></td>
</tr>
<tr>
<td>Seismic (Ground)</td>
<td>300 per day for ten observations</td>
<td></td>
</tr>
<tr>
<td>Gravitational (Ground)</td>
<td>10-50 per observations, up to 60 observations per day.</td>
<td></td>
</tr>
<tr>
<td>Geochemical</td>
<td>5 per observations about 20 observations per man day; 200-500 per sq. mile</td>
<td>One of the cheapest ground methods.</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>6-10 per line mile.</td>
<td>May be cheapest aerial method, but cost vary widely.</td>
</tr>
<tr>
<td>Electrical (Air)</td>
<td>10-20 line mile.</td>
<td></td>
</tr>
<tr>
<td>Electrical (Ground)</td>
<td>450 per day, up to 1,000 per sq. mile.</td>
<td></td>
</tr>
</tbody>
</table>


* A recent tabulation gives a range of $0.50-$10.00 per foot.
Table XVI. Representative Aerial Survey and Airborne Geophysics Cost Estimates for a Country 200,000 sq. miles in Area.

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost per sq. mile (U.S.$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Aerial photography of the whole area at scale 1:40,000.</td>
<td>5.00</td>
</tr>
<tr>
<td>2. Base map at 1&quot;=1 mile or 1:50,000 planimetry only including the establishment of some control.</td>
<td>4.00</td>
</tr>
<tr>
<td>3. Compilation of all known geology and photogeological interpretation of the whole area.</td>
<td>2.50</td>
</tr>
<tr>
<td>4. Field investigations to establish rock types together with subsequent report compilation and laboratory tests.</td>
<td>5.00</td>
</tr>
<tr>
<td>5. Airborne geophysical flying, including aeromagnetic and airborne scintillation contour and including interpretation of the results and compilation on to geological maps @ $25 per sq. mile, but since only 10% of the area is to be flown overall cost per sq. mile.</td>
<td>2.50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>19</strong></td>
</tr>
</tbody>
</table>

Table XVII. Rates for Diamond Core Drilling
(Size varying from NX to EX) per metre.

<table>
<thead>
<tr>
<th>Depths</th>
<th>Upto 150 m.</th>
<th>151 m. - 300 m.</th>
<th>301 m. - 450 m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock Formation</td>
<td>Rs.</td>
<td>Rs.</td>
<td>Rs.</td>
</tr>
<tr>
<td>Soft</td>
<td>110/-</td>
<td>140/-</td>
<td>215/-</td>
</tr>
<tr>
<td>Medium Hard</td>
<td>190/-</td>
<td>270/-</td>
<td>385/-</td>
</tr>
<tr>
<td>Very Hard</td>
<td>320/-</td>
<td>390/-</td>
<td>485/-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth</th>
<th>451 m. - 600 m.</th>
<th>601 m. - 800 m.</th>
<th>801 m.- 1000 m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock Formation</td>
<td>Rs.</td>
<td>Rs.</td>
<td>Rs.</td>
</tr>
<tr>
<td>Soft</td>
<td>290/-</td>
<td>620/-</td>
<td>810/-</td>
</tr>
<tr>
<td>Medium Hard</td>
<td>465/-</td>
<td>870/-</td>
<td>1025/-</td>
</tr>
<tr>
<td>Very Hard</td>
<td>625/-</td>
<td>1055/-</td>
<td>1270/-</td>
</tr>
</tbody>
</table>

Note: Accounts and Audit charges payable @ 1% on the amount billed for.

(Also see graph facing page 158).

Source: Geological Survey of India.
Table XVIII. Details of drilling costs for 150 metres depth in soft formations.

| A. | Capital cost of machinery | Rs. 60,000 | life 6 years. |
|    | Capital cost of accessories | Rs. 40,000 | life 2 years. |
|    | Working days per year | 300 |
|    | Depreciation of machinery | Rs. 10,000 | per annum (a) |
|    |                         | Rs. 33.33 per day |
|    | Depreciation of accessories | Rs. 20,000 |
|    |                         | Rs. 66.67(b) per day |
|    | Total Depreciation (a+b) | = Rs.100/- |
|    | Interest @ 5% on the cost of machinery: |
|    | Rs. \(\frac{60,000+50,000+40,000+30,000+20,000+10,000}{6}\) \(\frac{5}{100}\) \(\frac{1}{300}\) per day |
|    | = Rs.5.83 per day (c) |
|    | Interest @ 5% on the cost of accessories: |
|    | Rs. \(\frac{40,000+20,000}{2}\) \(\frac{5}{100}\) \(\frac{1}{300}\) per day=Rs.5.00 per day (d) |
|    | Total Interest (c+d) |
|    | = Rs.10.83 " (2) |
|    | Total of (1) and (2) |
|    | = Rs.110.83 " |

B. Wages:

| a) Average pay with allowances | = Rs.3,019.96 per month |
| b) Contingency (Labour etc.) | = Rs.1,250.00 " |
| c) Field allowance @ 20% of basic pay | = Rs. 407.00 " |
| d) Travelling allowance and Medical @ 29% of basic pay | = Rs. 590.51 " |
| Total wages (a+b+c+d) | Rs.5,267.47 per month |
|                         | Rs. 210.70 per day |

C. Fuel and Lubricants:

| Diesel charges | .. | .. | = Rs. 100.72 |
| Mobil Oil, etc. | .. | .. | = Rs. 20.00 |
| Total | | | Rs. 120.73 |
| Total charges | .. | .. | Rs. 120.73 per day |

contd..
D. Diamond bits, Reamer shell and T.C. bits:

Progress per day 6 metres in 2 shift

Diamond tools for 1 1/2 metres = Rs. 40.00
T.C. tools for 4 1/2 metres = Rs. 15.00
Total charges = Rs. 55.00 per day

E. Internal transport charges:

Total charges = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs
and purchases, renewals and sundries:

Total charges = Rs. 20.00 per day

I. Fixed charges (A) + (B) = Rs. 321.53
II. Running charges (C)+(D)+(E)+(F) = Rs. 291.73
III. Cost of non-operation 20% of II = Rs. 58.35
IV. Overhead 1% of II = Rs. 2.92

Grand total (I+II+III+IV) = Rs. 674.53

Average charges per metre = Rs. 112.42
Say = Rs. 110.00 per metre

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XIX. Details of drilling costs for 300 metres depth in soft formations.

A. Depreciation and Interest:
   As per Table XVIII
   = Rs. 110.83 per day

B. Wages:
   As per Table XVIII
   = Rs. 210.70

C. Fuel and Lubricants:
   As per Table XVIII
   = Rs. 120.73

D. Diamond bits, Reamer shells & T.C. bits:
   Progress per day 5 metres in two shifts Diamond tools for 1½ metres
   = Rs. 40.00
   T.C. tools for 3½ metres
   = Rs. 10.00
   Total charges
   = Rs. 50.00 per day

E. Internal transport charges:
   Total charges
   = Rs. 96.00 per day

F. Misc.: such as core boxes, petty repairs, purchases and renewals and sundries.
   Total charges
   = Rs. 40.00 per day

I. Fixed charges (A)+(B)
   = Rs. 321.53
II. Running charges (C)+(D)+(E)+(F)
   = Rs. 306.75
III. Cost of non-operation 20% of II
     = Rs. 61.35
IV. Overhead 1% of the II
     = Rs. 3.07

Grand total (I+II+III+IV) Rs. 692.68
Average charge per metre Rs. 138.54
Say = Rs. 140.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XX. Details of drilling costs for 450 metres in soft formations.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
<th>Life/Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost of machinery</td>
<td>Rs. 100,000.00</td>
<td>6 years</td>
</tr>
<tr>
<td>Capital cost of accessories</td>
<td>Rs. 75,000.00</td>
<td>2 years</td>
</tr>
<tr>
<td>Depreciation of machinery</td>
<td>Rs. 16,666.67</td>
<td>per annum</td>
</tr>
<tr>
<td></td>
<td>Rs. 55.56</td>
<td>per day</td>
</tr>
<tr>
<td>Depreciation of accessories</td>
<td>Rs. 37,500.00</td>
<td>per annum</td>
</tr>
<tr>
<td></td>
<td>Rs. 125.00</td>
<td>per day</td>
</tr>
<tr>
<td>Total depreciation (a+b)</td>
<td>Rs. 180.56</td>
<td>per day</td>
</tr>
<tr>
<td>Interest @ 5% on the cost of machinery:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rs. 9.72</td>
<td>per day</td>
</tr>
<tr>
<td>Interest @ 5% on the cost of accessories:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rs. 9.38</td>
<td>per day</td>
</tr>
<tr>
<td>Total interest (c+d)</td>
<td>Rs. 19.10</td>
<td>per day</td>
</tr>
<tr>
<td>Total of (1) &amp; (2)</td>
<td>Rs. 199.66</td>
<td>per day</td>
</tr>
</tbody>
</table>

B. Wages:

As per Table XVIII = Rs. 210.70 per day

C. Fuel and Lubricants:

Diesel charges = Rs. 130.20
Mobil Oil charges = Rs. 20.00

Total charges = Rs. 150.20 per day

D. Diamond bits, Reamer shells and T.C. bits:-

Progress per day 4 metres in two shifts.
Cost of diamond-tools for 2 metres.
@ Rs.30/- per metre = Rs. 60.00
Cost of T.C. Tools for 2 metres.
@ Rs.6/- per metre = Rs. 12.00

Total charges = Rs. 72.00 per day

contd..
E. Internal transport charges:

Total charges = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs, purchases, renewals and sundries.

Total charges = Rs. 50.00 per day

I. Fixed charges (A) + (B) = Rs. 410.36

II. Running charges (C+D+E+F) = Rs. 368.20

III. Cost of non-operation

20% of II = Rs. 73.64

IV. Overhead 1% of II = Rs. 3.69

Grand total (I+II+III+IV) Rs.855.89
Average charge per metre Rs.213.97
Say Rs.215.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXI. Details of drilling costs for 600 metres in soft formations.

A. Depreciation and Interest:
   As per Table XX = Rs. 199.66 per day

B. Wages: As per Table XX = Rs. 210.70 per day

C. Fuel and Lubricants:
   As per Table XX = Rs. 150.20 per day

D. Diamond bits, Reamer shells and T.C. bits:
   Progress per day 3 metres in two shifts -
   Diamond tools for 1½ metres @ Rs.50/- = Rs. 75.00
   T.C. tools for 1½ metres = Rs. 10.00
   = Rs. 85.00 per day

E. Internal transport charges:
   Total charges = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries.
   Total charges = Rs. 50.00 per day

I. Fixed charges (A+B) = Rs.410.36
II. Running charges (C+D+E+F) = Rs.381.20
III. Cost of non-operation
    20% of II = Rs. 76.24
IV. Overhead 1% of II = Rs. 3.81

Grand total (I+II+III+IV) = Rs.871.61

Average charges per metre = Rs.290.54
Say = Rs.290.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXII. Details of drilling costs for 800 metres depth in soft formations.

A. Capital cost of machinery = Rs. 180,000 Life 6 years.
   Capital cost of accessories = Rs. 120,000 Life 2 years.
   Depreciation of machinery = Rs. 30,000 per annum
                              100 per day (a)

   Depreciation of accessories = Rs. 60,000 per annum
                               200 per day (b)

   Total depreciation (a+b) = Rs. 300 per day (1)

Interest @ 5% on the cost of machinery

Rs. \((1,80,000+1,50,000+120,000+90,000+60,000+30,000)\times \frac{5}{100} \times \frac{1}{300}\)

= Rs. 17.50 per day (c)

Interest 5% on the cost of accessories:

Rs. \(\frac{1,20,000+60,000}{2}\) \times \frac{5}{100} \times \frac{1}{300}

= Rs. 15.00 per day (d)

Total of interest (c+d) = Rs. 32.50 per day (2)

Total of (1) and (2) = Rs. 332.50 per day

B. Wages:

= Rs. 234.56 per day

C. Fuel and Lubricants:

Disposal charges = Rs. 280.00
Mobil oil charges = Rs. 25.00

Total charges = Rs. 305.00 per day

D. Diamond bits, Reamer shells and T.C. bits - Progress per day 2 metres.
   Diamond tools @ Rs.50/-

   = Rs. 100.00 per day

E. Internal transport charges

Total charges

= Rs. 96.00 per day

contd...
F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries. = Rs. 80.00 per day

I. Fixed charges (A+B) ... = Rs. 567.06

II. Running charges (C+D+E+F) ... = Rs. 561.00

III. Cost of non-operation 20% of II. ... = Rs. 112.20

IV. Overhead 1% of II ... = Rs. 5.61

Grand total (I+II+III+IV) = Rs. 1245.87

Average charges per metre Say

= Rs. 622.94

= Rs. 620.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXIII. Details of drilling costs for 1000 metres depth in soft formations.

A. Depreciation and Interest:
   As per Table XXII = Rs. 332.50 per day

B. Wages: as per Table XXII = Rs. 234.56 per day

C. Fuel and Lubricants:
   As per Table XXII = Rs. 305.00 per day

D. Diamond bits, Reamer shells and T.C.bits -
   Progress per day 1½ metres
   Total charges = Rs. 75.00 per day

E. Internal transport charges
   Total charges = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries -
   Total charge = Rs. 60.00 per day

I. Fixed charges (A+B) = Rs. 567.06

II. Running charges (C+D+E+F) = Rs. 536.00

III. Cost of non-operation 20% of II = Rs. 107.20

IV. Overhead 1% of II = Rs. 5.36

Grand total (I+II+III+IV) = Rs. 1215.62

Average charge per metre = Rs. 810.40
   Say = Rs. 810.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXIV. Details of drilling costs for 150 metres depth in medium hard formations.

A. Depreciation and Interest:
   As per Table XVIII = Rs. 110.83 per day

B. Wages: As per Table XVIII = Rs. 210.70 "

C. Fuel and Lubricants:
   As per Table XVIII = Rs. 120.73 "

D. Diamond bits, Reamer shells and T.C. bits -
   Progress per day 4 metres in two shifts.
   Total charges per day = Rs. 120.00 "

E. Internal transport charges = Rs. 96.00 "

F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries -
   Total charges per day = Rs. 20.00 "

   I. Fixed charges (A+B) = Rs. 321.53
   II. Running charges per day (C+D+E+F) = Rs. 356.73
   III. Cost of non-operation 20% of II. = Rs. 71.35
   IV. Overhead 1% of II. = Rs. 3.57

   Grand total (I+II+III+IV) = Rs. 753.18

   Average charges per metre = Rs. 188.29
   Say = Rs. 190.00

Note: Account and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXV. Details of drilling costs for 300 metres depth in medium hard formations.

A. Depreciation and Interest:
   As per Table XVIII .. = Rs. 110.63 per day

B. Wages: As per Table XVIII .. = Rs. 210.70 "

C. Fuel and Lubricants:
   As per Table XVIII .. = Rs. 120.73 "

D. Diamond bits, Reamer shells and T.C. bits -
   Progress per day 3 metres in two shifts.
   Diamond tools @ Rs.50/- per metre
   Total charges .. = Rs. 150.00 "

E. Internal transport charges
   Total charges .. = Rs. 96.00 "

F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries.
   Total charges per day .. = Rs. 40.00 "

I. Fixed charges (A+B) .. = Rs. 321.53

II. Running charges per day (C+D+E+F) .. = Rs. 406.75

III. Cost of non-operation 20% of II. .. = Rs. 81.35

IV. Overhead 1% of II .. = Rs. 4.07

Grand total (I+II+III+IV) = Rs. 813.68

Average charge per metre = Rs. 271.23
Say = Rs. 270.00

Note: Accounts and audit charges @ 1% on the amount billed.
Source: Geological Survey of India.
Table XXVI. Details of drilling costs for 450 metres depth in medium hard formations.

A. Depreciation and Interest:
   As per Table XX = Rs. 199.66 per day

B. Wages: As per Table XVIII = Rs. 210.70 

C. Fuel and Lubricants:
   As per Table XX = Rs. 150.20 per day

D. Diamond bits, Reamer shells and T.C. bits:
   Progress per day 2 1/2 metres in two shifts -
   Total charges = Rs. 160.00 per day

E. Internal transport charges
   Total charges = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries.
   Total charges = Rs. 50.00 per day

I. Fixed charges (A+B) = Rs. 410.36
II. Running charges (C+D+E+F) = Rs. 456.20
III. Cost of non-operation 20% of II = Rs. 91.24
IV. Overhead 1% of II = Rs. 4.56

Grand total (I+II+III+IV) = Rs. 962.36

Average charges per metre Say = Rs. 385.94
                               = Rs. 385.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXVII. Details of drilling costs for 600 metres depth in medium hard formations.

A. Depreciation and Interest:
   As per Table XX. .. = Rs. 199.66 per day

B. Wages: As per Table XVIII .. = Rs. 210.70 per day

C. Fuel and Lubricants:
   As per Table XX. .. = Rs. 150.20 per day

D. Diamond bits, Reamer shells and T.C. bits:
   Progress per day 2 metres in two shifts.
   Total charges .. = Rs. 140.00 per day

E. Internal transport charges
   Total charges .. = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs and purchases and sundries.
   Total charges .. = Rs. 50.00 per day

   I. Fixed charges (A+B) .. = Rs. 410.36
   II. Running charges (C+D+E+F) .. = Rs. 436.20
   III. Cost of non-operation 20% of II. .. = Rs. 87.24
   IV. Overhead 1% of II. .. = Rs. 4.36

   Grand total (I+II+III+IV) = Rs. 938.16

   Average charge per metre = Rs. 469.08

   Say = Rs. 465.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXVIII. Details of drilling costs for 800 metres depth in medium hard formations.

A. Depreciation and Interest:
   As per Table XXII.               = Rs. 332.50 per day

B. Wages: As per Table XXII       = Rs. 234.56 Per day

C. Fuel and Lubricants:
   As per Table XXII.               = Rs. 305.00 per day

D. Diamond bits, Reamer shells and T.C. bits.
   Progress per day 1½ metres in two shifts.
   Diamond tools @ Rs.100/- per metre
   Total charges                   = Rs. 150.00 per day

E. Internal transport charges -
   Total charges                   = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries -
   Total charges                   = Rs. 60.00

I. Fixed charges (A+B)            = Rs. 567.06

II. Running charges per day (C+D+E+F)  = Rs. 611.00

III. Cost of non-operation
     20% of II                     = Rs. 122.20

IV. Overhead 1% of II.            = Rs. 6.11

Grand total (I+II+III+IV)         = Rs.1306.37

Average charges per metre Say    = Rs. 870.92
                               = Rs. 870.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXIX. Details of drilling costs for 1000 metres depth in medium hard formations.

A. Depreciation and Interest:
   As per Table XXII. ...... = Rs. 332.50 per day

B. Wages: As per Table XXII.
   ...... = Rs. 234.56 per day

C. Fuel and Lubricants:
   As per Table XXII.
   ...... = Rs. 305.00 per day

D. Diamond bits, Reamershells, and T.C. bits:
   Progress per day 1½ metre
   Diamond tools @ Rs.104/-
   Total charges ...... = Rs. 130.00 per day

E. Internal transport charges
   Total charges ...... = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries.
   Total charges ...... = Rs. 60.00 per day

I. Fixed charges (A+B) ...... = Rs. 567.06

II. Running charges per day
    (C+D+E+F) ...... = Rs. 591.00

III. Cost of non-operation 20% of II

IV. Overhead 1% of II.
   ...... = Rs. 5.91

   Grand total (I+II+III+IV) = Rs.1282.17
   Average charges per metre
   Say = Rs.1025.73

   Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXX. Details of drilling costs for 150 metres depth in very hard formations.

A. Depreciation and Interest:
   As per Table XVIII. .. = Rs. 110.63 per day

B. Wages: As per Table XVIII .. = Rs. 210.70 per day

C. Fuel and Lubricants:
   As per Table XVIII. .. = Rs. 120.73 per day

D. Diamond bits, Reamer shells and T.C. bits:
   Progress per day 2 1/2 metres in two shifts.
   Diamond tools @ Rs. 64/- per metre
   Total charges .. = Rs. 160.00 per day

E. Internal transport charges
   Total charges .. = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries.
   Total charges .. = Rs. 20.00 per day

I. Fixed charges (A+B) .. = Rs. 321.53

II. Running charges per day
    (C+D+E+F) .. = Rs. 396.73

III. Cost of non-operation 20% of II = Rs. 79.35

IV. Overhead 1% of II. .. = Rs. 3.97

Grand total (I+II+III+IV) = Rs. 801.58

Average charges per metre = Rs. 320.63
Say = Rs. 320.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXXI. Details of drilling costs for 300 metres depth in very hard formations.

A. Depreciation and Interest:
   As per Table XVIII. = Rs. 110.53 per day

B. Wages: As per Table XVIII. = Rs. 210.70 per day

C. Fuel and Lubricants:
   As per Table XVIII. = Rs. 120.73 per day

D. Diamond bits, Reamer shells, and T.C. bits:
   Progress per day 2 metres in two shifts.
   Diamond tools @ Rs.60/- per metre
   Total charges = Rs. 120.00 per day

E. Internal transport charges
   Total charges = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries.
   Total charges = Rs. 40.00 per day

I. Fixed charges (A+B) = Rs. 321.53

II. Running charges per day (C+D+E+F) = Rs. 367.73

III. Cost of non-operation 20% of II. = Rs. 75.35

IV. Overhead 1% of II. = Rs. 3.77

Grand total (I+II+III+IV) = Rs. 777.38

Average charges per metre Say = Rs. 388.69
                                   = Rs. 390.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXXII. Details of drilling costs for 450 metres depth in very hard formations.

A. Depreciation and Interest:
   As per Table XX. .. = Rs. 199.66 per day

B. Wages: As per Table XVIII. .. = Rs. 210.70 per day

C. Fuel and Lubricants:
   As per Table XX. .. = Rs. 150.20 per day

D. Diamond bits, Reamer shells, and T.C. bits -
   Progress per day 2 metres in two shifts.
   Diamond tools @ Rs.90/- per metre
   Total charges .. = Rs. 180.00 per day

E. Misc. such as core boxes, petty repairs and purchases, renewals and sundries.
   Total charges .. = Rs. 40.00 per day

I. Fixed charges (A+B) .. = Rs. 410.36

II. Running charges per day
   (C+D+E+F) .. = Rs. 466.20

III. Cost of non-operation 20% of II. = Rs. 93.24

IV. Overhead - 1% of II. .. = Rs. 4.66

Grand total (I+II+III+IV) = Rs. 974.46
Average charges per metre = Rs. 487.23
Say = Rs. 485.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXXIII. Details of drilling costs for 600 metres depth in very hard formations.

A. Depreciation and Interest:  
   As per Table XX.  
   = Rs. 199.66 per day

B. Wages: As per Table XVIII.  
   = Rs. 210.70 per day

C. Fuel and Lubricants:  
   As per Table XX.  
   = Rs. 150.20 per day

D. Diamond bits, Reamer shells, and T.C. bits.  
   Progress per day 2 metres in two shifts.  
   Diamond tools @ Rs. 100/- per metre  
   Total charges  
   = Rs. 150.00 per day

E. Internal transport charges  
   Total charges  
   = Rs. 96.00 per day

F. Misc. such as core boxes, petty repairs and purchases, renewals and sundries.  
   Total charges  
   = Rs. 40.00 per day

I. Fixed charges (A+B)  
   = Rs. 410.36

II. Running charges per day  
    (C+D+E+F)  
   = Rs. 435.20

III. Cost of non-operation 20% of II.  
   = Rs. 88.24

IV. Overhead - 1% of II.  
    = Rs. 4.36

Grand total (I+II+III+IV)  
    = Rs. 938.16

Average charges per metre  
    = Rs. 625.44

Say  
    = Rs. 625.00

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXXIV. Details of drilling costs for 800 metres depth in very hard formations.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Depreciation and Interest:</td>
<td>Rs. 332.50</td>
</tr>
<tr>
<td>As per Table XXII.</td>
<td></td>
</tr>
<tr>
<td>B. Wages: As per Table XXII.</td>
<td>Rs. 234.56</td>
</tr>
<tr>
<td>C. Fuel and Lubricants:</td>
<td>Rs. 305.00</td>
</tr>
<tr>
<td>As per Table XXII.</td>
<td></td>
</tr>
<tr>
<td>D. Diamond bits, Reamer shells, and T.C. bits.</td>
<td>Rs. 160.00</td>
</tr>
<tr>
<td>Progress per day 1/4 metres in two shifts.</td>
<td></td>
</tr>
<tr>
<td>Diamond tools at Rs.128/- per metre</td>
<td></td>
</tr>
<tr>
<td>Total charges</td>
<td></td>
</tr>
<tr>
<td>E. Internal transport charges</td>
<td>Rs. 96.00</td>
</tr>
<tr>
<td>Total charges</td>
<td></td>
</tr>
<tr>
<td>F. Misc. such as core boxes, petty repairs and purchases and sundries.</td>
<td>Rs. 60.00</td>
</tr>
<tr>
<td>Total charges</td>
<td></td>
</tr>
<tr>
<td>I. Fixed charges (A+B)</td>
<td>Rs. 567.06</td>
</tr>
<tr>
<td>II. Running charges per day (C+D+E+F)</td>
<td>Rs. 621.00</td>
</tr>
<tr>
<td>III. Cost of non-operation 20% of II</td>
<td>Rs. 124.20</td>
</tr>
<tr>
<td>IV. Overhead 1% of II</td>
<td>Rs. 6.21</td>
</tr>
<tr>
<td>Grand total (I+II+III+IV)</td>
<td>Rs.1318.47</td>
</tr>
<tr>
<td>Average charge per metre</td>
<td>Rs.1054.78</td>
</tr>
<tr>
<td>Say</td>
<td>Rs.1055.00</td>
</tr>
</tbody>
</table>

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXXV. Details of drilling costs for 1000 metres depth in very hard formations.

<table>
<thead>
<tr>
<th>Category</th>
<th>Per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Depreciation and Interest:</td>
<td>Rs. 332.50</td>
</tr>
<tr>
<td>As per Table XXII.</td>
<td></td>
</tr>
<tr>
<td>B. Wages: As per Table XXII.</td>
<td>Rs. 234.56</td>
</tr>
<tr>
<td>C. Fuel and Lubricants:</td>
<td>Rs. 305.00</td>
</tr>
<tr>
<td>As per Table XXII.</td>
<td></td>
</tr>
<tr>
<td>D. Diamond bits, Reamer shells and T.C.bits.</td>
<td>Rs. 120.00</td>
</tr>
<tr>
<td>Progress per day 1 metre</td>
<td></td>
</tr>
<tr>
<td>in two shifts.</td>
<td></td>
</tr>
<tr>
<td>Diamond tools @ Rs.120/- per metre</td>
<td></td>
</tr>
<tr>
<td>Total charges</td>
<td></td>
</tr>
<tr>
<td>E. Internal transport charges</td>
<td>Rs. 96.00</td>
</tr>
<tr>
<td>Total charges</td>
<td></td>
</tr>
<tr>
<td>F. Misc. such as core boxes, petty repairs</td>
<td>Rs. 60.00</td>
</tr>
<tr>
<td>and purchases, renewals and sundries.</td>
<td></td>
</tr>
<tr>
<td>Total charges</td>
<td></td>
</tr>
<tr>
<td>I. Fixed charges (A+B)</td>
<td>Rs. 567.06</td>
</tr>
<tr>
<td>II. Running charges per day</td>
<td>Rs. 581.00</td>
</tr>
<tr>
<td>(C+D+E+F)</td>
<td></td>
</tr>
<tr>
<td>III. Cost of non-operation 20% of II</td>
<td>Rs. 116.20</td>
</tr>
<tr>
<td>IV. Overhead 1% of II</td>
<td>Rs. 5.81</td>
</tr>
<tr>
<td>Grand total (I+II+III+IV)</td>
<td>Rs. 1270.07</td>
</tr>
<tr>
<td>Average charges per metre</td>
<td>Rs. 1270.07</td>
</tr>
<tr>
<td>Say</td>
<td>Rs. 1270.00</td>
</tr>
</tbody>
</table>

Note: Accounts and audit charges @ 1% on the amount billed.

Source: Geological Survey of India.
Table XXXVI. Free World Mining Geophysical Activities in 1960 by Geographical Areas.

<table>
<thead>
<tr>
<th>Geographical Areas</th>
<th>Manpower Utilization</th>
<th>Expenditures</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Man Months</td>
<td></td>
<td>Millions $ (U.S.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Govt.</td>
<td>Pvt.</td>
<td>Total</td>
<td>Govt.</td>
<td>Pvt.</td>
</tr>
<tr>
<td>United States</td>
<td>1,208</td>
<td>802</td>
<td>2,010</td>
<td>1.111</td>
<td>2,232</td>
</tr>
<tr>
<td>Europe</td>
<td>1,234</td>
<td>639</td>
<td>1,873</td>
<td>0.908</td>
<td>0.851</td>
</tr>
<tr>
<td>Japan</td>
<td>1,622</td>
<td>-</td>
<td>1,622</td>
<td>.747</td>
<td>-</td>
</tr>
<tr>
<td>Canada</td>
<td>455</td>
<td>700</td>
<td>1,155</td>
<td>.259</td>
<td>2.593</td>
</tr>
<tr>
<td>Africa</td>
<td>19</td>
<td>857</td>
<td>876</td>
<td>.023</td>
<td>1.249</td>
</tr>
<tr>
<td>Australia</td>
<td>349</td>
<td>18</td>
<td>367</td>
<td>.720</td>
<td>.072</td>
</tr>
<tr>
<td>Latin America</td>
<td>1</td>
<td>59</td>
<td>60</td>
<td>.001</td>
<td>.208</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>7,963</td>
<td>3.769</td>
<td>7.205</td>
</tr>
<tr>
<td></td>
<td>Per cent Total</td>
<td></td>
<td>100.0</td>
<td>34.3</td>
<td>65.7</td>
</tr>
</tbody>
</table>

Table XXXVII. Free World Mining Geophysical Activities in 1960 by Method Utilized.

<table>
<thead>
<tr>
<th></th>
<th>Manpower Utilization</th>
<th>Expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Man Months</td>
<td>Millions $ (U.S.)</td>
</tr>
<tr>
<td></td>
<td>Govt.</td>
<td>Pvt.</td>
</tr>
<tr>
<td>Geochemistry</td>
<td>1,066</td>
<td>340</td>
</tr>
<tr>
<td>Combined resistivity¹</td>
<td>631</td>
<td>703</td>
</tr>
<tr>
<td>Seismic</td>
<td>693</td>
<td>343</td>
</tr>
<tr>
<td>Gravity</td>
<td>557</td>
<td>279</td>
</tr>
<tr>
<td>Electromagnetic</td>
<td>352</td>
<td>425</td>
</tr>
<tr>
<td>Ground magnetic</td>
<td>311</td>
<td>460</td>
</tr>
<tr>
<td>Aeromagnetic</td>
<td>331</td>
<td>333</td>
</tr>
<tr>
<td>Self-potential</td>
<td>455</td>
<td>110</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>390</td>
<td>42</td>
</tr>
<tr>
<td>Other</td>
<td>102</td>
<td>40</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4,888</td>
<td>3,075</td>
</tr>
<tr>
<td>Research portion</td>
<td>2,817</td>
<td>342</td>
</tr>
</tbody>
</table>

Source: Geophysical activity in the Mining Industry - 1960, CMJ, March 1962, Vol.83, No.(1) Includes resistivity and induced polarization. Geophysical activity includes survey research. (2) Figures appear small, perhaps, due to inadequate coverage. (Please also see diagram facing Chapter V).
Table XXXVIII. Free World Mining Geophysical Activity-1960.

<table>
<thead>
<tr>
<th></th>
<th>Manpower Utilization</th>
<th>Expenditures</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Govt.</td>
<td>Pvt.</td>
<td>Total</td>
<td>Govt.</td>
<td>Pvt.</td>
<td>Total</td>
</tr>
<tr>
<td>Mining Surveys</td>
<td>2,071</td>
<td>2,733</td>
<td>4,804</td>
<td>2.268</td>
<td>6.753</td>
<td>9.021</td>
</tr>
<tr>
<td>Research</td>
<td>2,817</td>
<td>342</td>
<td>3,159</td>
<td>1.501</td>
<td>.452</td>
<td>1.953</td>
</tr>
<tr>
<td>Total</td>
<td>4,888</td>
<td>3,075</td>
<td>7,963</td>
<td>3.769</td>
<td>7.205</td>
<td>10.974</td>
</tr>
<tr>
<td>Per cent</td>
<td></td>
<td></td>
<td>39.7</td>
<td>39.8</td>
<td>6.3</td>
<td>17.8</td>
</tr>
<tr>
<td>Research</td>
<td>57.6</td>
<td>11.1</td>
<td>39.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table XXXIX. Free World Mining Geophysical Surveys-1960.

<table>
<thead>
<tr>
<th></th>
<th>Man power Utilization</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Govt.</td>
<td>Pvt.</td>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Mining Surveys</td>
<td>2,071</td>
<td>2,733</td>
<td>4,804</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contract Portion</td>
<td>54</td>
<td>1,424</td>
<td>1,478</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per cent contract</td>
<td>2.6</td>
<td>52.1</td>
<td>30.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>