Air-borne survey for locating mineral resources: A new venture of high promise for speedy mineral exploration in India

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THE development of the mineral-based industries of a country essentially depends upon the speed with which the exploration and exploitation of the mineral resources are carried out. Whereas the demand for non-ferrous metals like copper, lead and zinc by our industrial sector is growing rapidly, our efforts to find new resources in the country have not kept pace with the urgency of the situation. At present, the country has to lean heavily upon imports of these metals spending substantial amounts in foreign exchange. It has, therefore, become imperative to step up the pace of investigations to ensure that the tempo of industrialisation in the country is not seriously affected.

The major organisation in the country which is engaged in the immense task of prospecting for mineral resources is the Geological Survey of India (GSI), an institution with an outstanding record going back over a century. However, the GSI along with other Central and State Government organisations carrying out mineral investigations, have hitherto employed conventional methods of geological mapping and exploration.

In order, therefore, to speed up the pace of exploration and to take advantage of the latest scientific methods available outside India, it was considered essential to seek some foreign assistance. As a result of these efforts, the Project Operation Hardrock was drawn up in collaboration with the U. S. Agency for International Development (USAID).

The experience in other countries had already shown the efficacy and importance of aerial surveys. In a vast country like ours with large areas still to be surveyed carefully, the importance of such air-borne surveys needs no emphasis.

The advent of air-borne geophysical techniques has added new dimensions to the task of mineral exploration effectively helping in the acceleration of the exploration programme by localising target areas. Air-borne geophysical surveys provide the quickest and cheapest means of examining large areas to sift the most promising ore bearing ground from the less promising areas. The difficulties of terrain, inaccessibility, thick vegetation, swampy ground, etc. which impose serious limitations over ground surveys are obviated by air-borne surveys. A great deal of fundamental data of considerable value and significance to earth scientists can also be obtained through air-borne work. The success of this type of survey will revolutionise the entire philosophy of mineral exploration in our country and will open up possibilities of finding large ore bodies in a relatively short time.

Air-borne geophysical survey, over possible ore bearing terrain in the country, is an essential pre-requisite for an organised mineral exploration programme, not only as an aid for locating new deposits of base metals, but also for selecting the best among a large number of widely scattered prospects all over the country. In this context, past expericence has shown that even a preliminary ground appraisal of the potential of these scattered prospects, without a selective bias, is not only time consuming but most often without fruitful results. A programme of exploration based on old prospects had been pursued for over a decade by various agencies in this country, and is still being pursued by them, but the results achieved are not commensurate with the time and expenses involved. An air-borne geophysical survey adopting the latest techniques (INPUT Electromagnetic System) is, therefore, a desideratum to delimit specific areas for intensive ground work.

With the introduction of these modern and time-saving techniques, we now enter an era where it should be possible in the near future to reduce the survey cost by developing tools which will detect a higher percentage of ore bodies in a given area in much shorter time. Thus, the introduction of aerial survey techniques and on-the-job training being received by the Indian personnel, will certainly help us to achieve a real break-through in the mineral exploration programme in this country. This is one of the most important objectives and no efforts should be spared to achieve this end.

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Groundwater

Emphasis is also being paid to the search for groundwater utilising the air-borne electromagnetic data together with photogeological interpretation. Such studies are especially being accelerated in Andhra Pradesh in the first instance, to be carried out soon in Rajasthan and Bihar, in collaboration with the Exploratory Tube-Wells Organisation (ETO) of the Ministry of Food and Agriculture as well as the State geology departments who have shown considerable interest in pursuing this new line of investigation suggested to them.

The necessary interpreted electromagnetic (EM) and photogeological data are being provided to the State departments concerned and the ETO geologists who have already been given the opportunity to study all relevant data in this regard. The follow-up work on the ground including drilling will be carried out by geologists of these organisations in consulation with the geologists and geophysicists of Air-borne Mineral Surveys and Exploration. These studies are considered to be of topical importance in view of the severe drought conditions now prevailing in Andhra Pradesh and other areas already surveyed by Air-borne Mineral Surveys and Exploration from the air.

PHASE-I

Aerial survey

The first phase of the project comprised combined air-borne electromagnetic, magnetic and radiometric surveys over selected potential areas in Andhra Pradesh, Rajasthan and Bihar-Bengal. In this survey the the aircraft in which the sensitive instruments were mounted, essentially performed the functions of an air-borne geophysical laboratory which could be operated at a low average elevation of 70 metres from the ground, and visually navigated along flight lines marked at regular intervals of 1 km/½ km on airphoto mosaics prepared earlier. The sensitive instruments register a continuous recording of conductive, magnetic and radiometric responses, and any deviations from the general levels show up as anomalies. Thereafter, careful evaluation of these anomalies were made based on the available technical information, the geology and the known mineral occurrences of the areas over which the flying was carried out.

In the present project, provision was made for a total of 144 000 line kilometres of geophysical production flying to be completed in 10 months. The aerial survey which commenced in July, 1967, was completed on schedule in May, 1968, covering 144 465 45 line killometers as against the target of 144 000 line km.

Data processing

Data processing has involved two types of rationale. The first is based on the study of conductivity characteristics, and a theoretical basis/empirical formula has been evolved by the application of which the degree or strength of conductivity can be expressed in a comparative sense. By applying this formula, the innumerable anomalies shown up by aerial survey have been graded. This grading, purely based on theoretical considerations, has been further evaluated against the geological set up of the concerned areas and the associated magnetic anomalies observed. The resulting interpretation gave a comprehensive and purposeful grading of the anomalies into different groups. This formed the basis for allocation of priority for ground follow-up.

The second phase of the data processing has involved the transfer of these graded anomalies onto a geological map of the area concerned. Thus, the vital data, obtained as a result of the air-borne geophysical surveys, are translated into a series of geological overlays. These blue prints have been almost completed for the Andhra Pradesh area and have been finalised to a considerable extent in the case of Rajasthan and to a lesser extent for Bihar which was the last area to be geophysically flown. The remaining part of the evaluation is being continued and is expected to be completed shortly. Thus, the ground follow-up action is based on premises which are founded on sound geophysical and geological reasoning.

This important phase of data processing and interpretation on which depends the effectiveness of the ground follow-up surveys, has engaged the close attention of the members of the different field parties over a period of 5 months and each party has been individually responsible for the classification, evaluation of the geophysical anomalies onto the geological maps. This, however, is to be considered a working hypothesis meant to provide a basis for the pattern of ground follow-up, and therefore to be kept fairly flexible as changes in priority may become inevitable in the light of experience gathered in the course of actual ground follow-up action.

The blue prints for the different regions which have now emerged have involved a great deal of sustained thinking on assessment, interpretation and documentation of data. On an average, each anomaly overlay has 50 to 150 anomaly points and the total number of anomaly points in the 36 overlays for the three regions is of the order of about 6 000. Nearly 75% of these have been individually evaluated and the graded anomalies have been transferred to geological overlays.

Based on this evaluation the following may be the tentative order of targets involved in ground follow-up action.

(a)	Geological reconnaissance	...	3 000 anomaly points.
(b)	Ground electromagnetic and magnetic surveys coupled with geological plans by laying out grids	... ...	300 anomaly points
(c)	Induced polarisation surveys	...	40 points
(d)	Geochemical sampling	...	30 000 samples.

Phase II

Ground follow-up work

The second phase of the project involves ground follow-up work on selected anomalies in these areas. Initially, a rapid reconnaissance of the anomaly zones was made for selecting the more promising zones for further ground geophysical prospecting using magnetic, electromagnetic and the latest induced polarisation (IP) equipment, geological mapping, geochemical prospecting and photogeological interpretation. The sensitive IP equipment for locating base metal sulphide ore bodies is for the first time introduced in the country.

Phase III

Drilling and laboratory

The third phase of the project envisages exploratory drilling by using two small capacity rigs followed by detailed drilling over prospects considered promising. About 16 000 metres of drilling with four high capacity drills are planned. Three smaller drills will be used for initial probing. Necessary action with regard to procurement of the equipment-heavy drills, min-drills, trucks, pick-ups, etc. has already been initiated and these are expected to be delivered very shortly.

Besides, the regular chemical analyses, beneficiation and metallurgical tests will be carried out on ore samples. A modern, well-equipped laboratory is also being set up at Faridabad as part of this project to meet these essential requirements. Necessary accommodation for the laboratory has already been arranged at Faridabad. Most of the equipment for the laboratory have also arrived from the United States. Action with regard to organising the laboratory, i.e. provision of necessary fittings and furnishing, purchase of indigenous equipment i.e., chemicals, etc. is in progress.

Achievements

The progress achieved so far and the present position of work in the three selected areas are indicated below :

Andhra Pradesh

The areas selected for this project in Andhra Pradesh include parts of the districts of Guntur, Kurnool, Cuddapah and Nellore and cover about 30 500 sq. km. The air-borne geophysical survey was started in Andhra Pradesh on the 19th July 1967 and was completed on the 26th November 1967. A total of 32 660·6 line kilometres were flown to cover these areas comprising the following regions :

(i) East Cuddapah Basin	...	25 796·5 km
(ii) Gani-Kalava	...	692·0 km
(iii) Khamman	...	6 172·0 km

The flight line was spaced at 1 km in most of the areas and over some of the known occurrences such as Karempudi, Agnigundala, Varikunta, Zangamrajupalle and Kaluvaya, the flight line intervals were reduced to ½ km.

A comprehensive correlation of the conductive and magnetic anomalies was carried out with the known geological information and reported mineral occurrences. A large number of anomalies were found near the known mineral occurrences as at Karempudi, Peddagavalakonda, Varikunta, Zangamrajupalle, Nagasanipalle, Kaluvaya and Agnigundala. In addition, many significant anomalies were located away from these known mineral occurrences.

After a preliminary assessment of the anomalies, ground follow-up work was commenced in the northern part of the East Cuddapah Basin during March-May 1968. The initial examination of the anomalies corroborated by the field work which was commenced in the Guntur district, has shown that the following six anomaly zones may be taken up for detailed follow-up work and this is in progress :

1. Kakirala, S. E.
2. Gummanampadu
3. Papayapalem
4. Karempudi, S. E.
5. Oppicherlu
6. Guttikonda, N. E.

Other anomalies in the Guntur district, most of them in ground covered by cultivation, will be examined during this field season.

Critical evaluation of air-borne geophysical data of Gani-Kalava area with the magnetic contour and EM anomaly map correlated with geological information, was carried out. The aerial photographs of some parts of Cuddapah Basin were studied for delineating geological structures. The magnetic contour maps of the entire Cuddapah Basin are now ready.

Further ground work will commence soon after the return of the large party of geophysicists and geologists who are now in the Rajasthan area where they have been carrying out ground investigations and are receiving on-the-job training in the correct location of air-borne anomalies on the ground and the use of the latest IP equipment and the EM systems (recently received from USA) in probing selected anomaly zones.

Some radiometric anomalies have also been observed in the Kharmam area. Some of the wide persistent conductive anomalies may be related to ground water and close attention will also be paid to water resources studies in the course of our main investigation for base metals.

Rajasthan

The area selected under the project Operation Hardrock in Rajasthan included parts of Ajmer, Bhilwara, Bundi, Chittor, Jaipur, Jhunjhunu, Nagaur, Pali, Sikar, Tonk and Udaipur districts covering about 30 140 sq. km and was surveyed by flying 58 285·5 flight line kilometers out of a total of 144 465·5 km available for the whole project. The flights were carried out at intervals of ½ km. in most of the areas except in the Sembar lake area and South Ajmer where the spacing was 1 km. In addition, a few test flights were conducted over the Zawar mines area. The air-borne survey was started on the 4th December 1967 and completed on 7th April 1968.

The air-borne survey has shown very significant conductive and magnetic anomalies in the area. Some of the anomalies are over known mineralised zones as in Singhana, Khetri, Akwali, Kishorepura, Saladipura, Ajmer, Rajpura-Dariba and along strike extension of these zones. In addition, the isolated electromagnetic and magnetic anomalies in covered areas may lead to entirely new mineralized zones.

In addition to a comprehensive correlation of the anomalies with the known geological information, ground reconnaissance was carried out in Udaipur, Ajmer and Jhunjhunu districts. Ground electromagnetic and magnetic surveys were carrried out during the month of May 1968 over the anomalies South and East of Babai near Khetri. The presence of anomalies was confirmed by the ground survey and further work commenced in mid-August soon after the abatement monsoon.

Detailed ground geological, electromagnetic, magnetic and induced polarisation investigations were carried out according to programme over air-borne geophysical anomalies indicated in the Khetri Ajit sagar area (about 12 km east of Khetri copper mines) during August 1968. These have indicated significant ground electromagnetic, magnetic and induced polarisation anomalies and favourable geological indications in the area were examined.

It may be mentioned that sophisticated Induced Polarisation techniques are being deployed for the first time for base metal exploration in the country. This is one of the first zones which will be taken up early for initial drilling with the smaller drills, the supply of which is expected shortly. Till the end of November, three anomaly zones have been marked out for priority drilling.

Bihar-West Bengal

The air-borne geophysical survey over the selected areas in Bihar-West Bengal was started on 8th March 1968 and completed by the 14th of May 1968. The areas comprised two smaller zones referred to as Bihar North and Bihar South (including parts of West Bengal) occupying a total of 29 755 sq. km. The Bihar North area which is about 12 500 sq. km covers the eastern parts of the mica belt and includes the districts of Hazaribagh and Monghyr, Santhal Parganas and Bhagalpur. The Bihar South area covers about 17 445 sq. km and includes parts of the Singhbhum and Ranchi districts of Bihar and also parts of Midnapur, Purulia and Bankura districts of West Bengal. It covers the well known Singhbhum copper belt.

The flying in the Bihar-Bengal area involved 53 417·5 line kilometres.

Very significant conductive and magnetic anomalies have been noticed on the extension of the Singhbhum copper belt, and Jaldoga and Manoharpur in the western part of Bihar South area and in Midnapur, Purulia and Bankura districts of West Bengal. In Bihar North, the significant anomalies have been noted near Barragunda and other occurrences indicating possible strike extensions of these deposits. In addition, persistent radio-active anomalies have also been found in Bihar North and Bihar South.

A comprenensive study of the anomalies obtained in these areas in relation to the known geological information was carried out at the headquarters prior to commencing detailed ground follow-up work during this field season.

Expenditure

Cost-estimation

The execution of the Project Operation Hardrock involves an expenditure of Rs. 4·52 crores ; Rs. 1·9 crores represent the rupee component and the balance Rs. 2·62 crores the foreign exchange component. The USAID have given a loan of $ 3·5 million to cover the foreign exchange component.

Conclusions

Hardly any one has realised the magnitude of organisational work and logistics involved in building up a new department from "scratch" to execute this project and the concerted efforts called for which made it possible to complete the flying operations within a period of 10 months. The initial stages of organisation were the most challenging but we have succeeded in setting up a well-established department fully geared to execute effectively integrated aerial survey programmes of any magnitude.

The aerial survey commenced in July 1967 and we completed, on schedule, a total of nearly 100 000 sq. km within 10 months from the date of commencement of the first production flying. The data, obtained as a result of aerial survey, have already proved their great importance beyond any doubt both in their direct economic application as well as in gaining invaluable information of fundamental significance to students of earth sciences. We have also demonstrated beyond doubt, the effectiveness and speed with which air-borne geophysical survey can cover large and inaccessible areas with little difficulty as compared to conventional modes of ground surveys.

Thus the different phases of this integrated multiphase project is imparting invaluable experience and training to the Indian personnel associated with it. The knowledge and insight gained by them, especially in the operational aspects of aerial survey, the sophisticated air-borne instruments techniques, correlation and application of air-borne data to ground follow-up work, and the use of modern sophisticated geophysical and other equipment for ground surveys, would progressively raise their confidence level in organising and executing future air-borne surveys and ground follow-up work of this nature and magnitude.

The introduction of air-borne survey techniques and "on-the-job" training being received by the Indian personnel in the different phases of this integrated project, should help us to achieve in the near future a real break-through in the mineral exploration programme of the country.

APPENDIX

SOME OF THE SIGNIFICANT RESULTS

Some of the major anomaly zones based on analysis of air-borne data are located near the following places.

Andhra Pradesh

Taduvaya, Venkatayapalem, Karempudi, Kakirala, Gummanapadu, Vummadivaram, Nallakonda and Dhukonda, Markapur, Nayudapalle, Cumbum, Salakalavidu, Varikunta, Pamuru, Somalgregada, Zangamrajupalle, Vanipenta, Nagasanipalle, Rekalakunta, Vontimitta, Kaluvaya, Ramallakota, Venkatgiri, Kalava, Gani, Aswapuram, Banjar, Kotturu, Borgampad, Mailaram, Bethampudi, Thadkalpudi, Karepalli (Scint zone), Venkatayapalem, Khammam (Scint zone), Nialakondapalle (Scint zone), Bonakalu (E. M. and Scint zone).

Rajasthan

Singhana, Pacheri, Madan Kudan, Kharkhar, Kolihan, Ajit Sagar, Malwali, Babai, Akwali, Gurha, Udaipur Shekawati, Saladipura, Khandela, Kishangarh, Kayar (E. M. and Scint zone), Ajmer, Deonagari (Scint zone), Beawar, Barkhola (E. M. and Scint zone), Bali, Badner, Chainpura (E. M. and Scint), Kachola, Sawar, Umedpura, Jahazpura, Deopura, Pur, Bhilwara, Banera (E. M. and Scint), Karui, Betumi, Dariba Rajpura, Bargaon, Karera, Umarwas (Scint zone), Ghanerao (Scint zone), Deogarh (Scint), Todgarh (Scint), Sangawas (Scint) and Isarmand (Scint).

Bihar

Balarampur (E. M. and Scint), Sangira, Matkumbera, Kudada (E. M. and Scint), Puncha (E. M. and Scint), Gobarghus, Barabhum (E. M. and Scint), Daradih (Scint), Kunthi (E. M. and Scint), Poadiri, Paramdih, Kalimati (E. M. and Scint), Jaldega, Jaraikela, Barketunga (Scint), Tapkera (E. M. and Scint), Headi, Bandgaon (Scint), Nehalgara, Harbul (E. M. and Scint), Mosabani (E. M. and Scint), Tamajuri, Chandapathar, Phulkusma, Khatra (Scint), Baharagura, Jaduguda (Scint), Kunchla, Kuilapal (E. M. and Scint), Barhi, Naihet, Maunatani, Dandadih, Paradih, Bhogmari, Baraganda, Bairukhi, Deogarh and Tiur Pahar.

PHOTOGEOLOGY IN MINERAL EXPLORATION

In the search for ore deposits, photogeological studies can reveal fracture patterns, faults, fold patterns, unconformities, overlaps, etc. at a glance. Photogeological interpretation of rock types outline broad target areas of favourable parent and host rocks.

Major intrusive, anticlinal, domal and associated structures were readily interpreted in parts of Cuddapah, Rajasthan and Bihar-West Bengal areas where air-borne geophysical surveys have been conducted, based on drainage characteristics or topographic expression or strike and dip patterns. These are being checked on the ground. Certain E. M. and Magnetic anomalies reflecting the buried stream channels and alluvial deposits were eliminated by photogeological studies. Even buried domal structures, overlain by and thinly bedded flat lying sedimentary beds have been interpreted purely by drainage and tone studies of photopairs. Photogeological studies have been helpful in relating some of the air-borne scintillometer anomalies to buried alluvial deposits with radio-active minerals. In some areas devoid of outcrops, soil patterns or soil distributions coupled with tone changes and shape, the probable thickness of the soil cover and the probable sub-surface structures can be judged thereby aiding the geochemist for organising his programme of soil and rock sampling.

Photogeological interpretation for mineral exploration is being done, perhaps, for the first time in this country, by this Department and the results so far achieved could be used with great advantage by all field geologists in correlating or discarding the anomalies, with indications of probable structural and/or stratigraphic control of mineralisation in specified areas.

GROUND FOLLOW-UP

Andhra Pradesh

In Andhra Pradesh ground geological reconnaissance has been taken up near Potlagudem, Venkatayapalem, Erragondapalem, Kavalakunta, Vummadivaram, Siddayapalem and Markapur. Geophysical surveys—E. M. and magnetic—are being carried out near Gummanapadu and Kakirala. Geochemical reconnaissance by sampling stream gravels has been commenced in the Khammam area of Andhra Pradesh.

Bihar

After carrying out a geological reconnaissance of some of the anomaly zones in Bihar South area, the anomaly near Paramdih has been taken up for ground E. M. and Magnetic survey and geochemical sampling.

Rajasthan

Geological reconnaissance of significant air-borne geophysical anomalies obtained in the northern part of Rajasthan are in progress. Ground E. M. and magnetic surveys are in progress in Khetri-Ajit Sagar and areas east of Babai. Induced Polarisation Surveys have been carried out in Khetri-Ajit Sagar and are now in progress in the areas east of Babai.

DATA ON GENERAL GEOLOGY

Air-borne geophysical surveys are invaluable for bringing out major structural features and large scale aeromagnetic surveys have been flown in U.S.S.R. and North America for supplementing geological data prepared from ground observations. The present survey though planned primarily for prospecting for sulphide deposits has provided very valuable data for modifying and supplementing the known geology of the areas. Air-borne magnetic survey has brought the main structural features, folds, faults, domer, lithologic and stratigraphic continuities and discontinuties in all the three areas. Detailed studies supported by photo-geological interpretations are in progress.

The data so far obtained as a result of aerial survey, indicate considerable promise of locating new deposits. Several hundreds of anomalies of conductive zones have shown up in all the three areas which require careful ground investigation. The discovery of one or two major workable deposits of base metals would more than justify the entire investment on the project. It would help us in conserving foreign exchange and in overcoming our dependence on other countries for the vitally-needed metals.