Chapter 3

Exploration Geology

Chapter Outline

One discovery out of 100 or even 1000 attempts will pay back the entire efforts.

—Author.

3.1. DEFINITION

Exploration is a complete sequence of activities. It ranges between searching for a new prospect (Reconnaissance) and evaluation of the property for economic mining (Feasibility study). It also includes augmentation of additional ore reserves in the mine and whole of the mining district. There are various exploration techniques being followed over the centuries. Exploration is conducted by one or a combination of many of the techniques. It all depends on the availability of infrastructures, funds with the state agencies and private players, size and complexity of the deposit, price of the minerals, government policy and good will. The programs are carried out by multidisciplinary data generation in a sequential manner. In addition to technical inputs, the activities encompass collection of information about the infrastructure around the area, such as accessibility (road, rail, nearest rail head, airport and sea port), average rainfall, and availability of potable and industrial water, power grid and supply system, local community, living condition, health care, security, forest and environment. The information about agencies from Federal and State/Regional/Provincial Government and Public Sector and Private Sector (PS) including multinational companies (MNCs) engaged with any mineral exploration program in the area will be useful.

3.2. REGIONAL PLANNING AND ORGANIZATION

The regional planning for all mineral resource development for the nation as a whole is carried out in the form of Five-Year Plan program. A multidisciplinary expert group selected from Federal Administrative Services, Planning Commission, Technocrats, Economists and Statisticians from Public and Private institutions collect information about past trend of consumption-supply, import-export and strategic importance of various mineral commodities. The information is projected for futuristic demand and optimum resource generation on the principle of scientific and sustainable use for each mineral (refer Figs 1.1 and 1.2). The activities are identified and responsibilities are earmarked to respective organizations/institutions along with allocation of funds and budgeting. The government continues routine monitoring, reconciliation and corrective

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measures at appropriate stage. The key implementing organizations are:

3.2.1. Bureau of Mines

The prime role of the Bureau of Mines (BM) is to create and maintain an up-to-date onshore and offshore mineral database, promote scientific development, encourage sustainable conservation and protect environment in mineral industries. BM is responsible for approval of mining plan and regulatory inspecting authority for mining and environment management plans to ensure maximum use of in-situ mineral resource at minimal adverse impact on environment. BM publishes "Mineral Year Book" every year highlighting the total mineral-related statistics and disseminates free online service as well as in printed form at cost. The various institutions are Department of Mines and Petroleum (DMP), Australia, Bureau of Mines, Canada, Bureau of Mines, Chile, Indian Bureau of Mines (IBM) and United States Bureau of Mines (USBM).

DMP, Australia, ensures a stronger focus on the resources sector, maintaining a mining and petroleum regulatory role incorporating the resources safety and responsibilities. DMP processes and provides an efficient and timely approval of mining title, which is essential for guaranteeing the sustainability of the resources sector and the future prosperity of the States/Region/Province.

The Mining sector in Chile is the major support of national economy. Copper export alone contributes ~40% to the government exchequer.

IBM, established in 1948, is a multidisciplinary national organization with headquarter at Nagpur and several regional/district offices. It is responsible for the mineral policy planning, conservation and mining research. IBM is the custodian of total mineral statistics for the Government of India. The functions of IBM include promoting conservation of mineral resources by way of inspection of mines, geological studies, scrutiny and approval of mining plans and schemes, conducting environmental audits, evolving technologies for mineral beneficiation, preparation of feasibility reports for mining and beneficiation projects, preparation of mineral maps and National Mineral Inventory of minerals resources, providing technical consultancy services to mineral industry, and maintains data bank for mines and minerals, and preparing of technical and statistical publications. IBM compiles and publishes "Mineral Year Book" every year covering statistics of total exploration, geological reports, mine production, export and import, price trend and related matters of all minerals. IBM maintains database of entire RP, PL and MLs in the country and available on price. IBM has six technical divisions with its headquarters at Nagpur supported by a Modern Mineral Processing Laboratory and Pilot Plant. IBM has 3 Zonal Offices, 12 Regional Offices and 2 Subregional Offices, 2 Regional Ore Dressing Laboratories and Pilot Plants spread over the country located at Ajmer, Bangalore, Bhubaneswar, Kolkata, Chennai, Dehradun, Goa, Guwahati, Hyderabad, Jabalpur, Nagpur, Nellore, Ranchi, and Udaipur.

USBM was established in 1910 as primary government agency with a mission to conduct scientific research to enhance the mineral resources, safety, health care and environment impact, and disseminate information on mining, processing, extraction, use and sustainable conservation of minerals. Since inception, USBM was viewed as the nodal point for the new and emerging science and technology in the mineral sector, both nationally and internationally. The government closed the BM during 1995−1996 and merged certain functions to other interrelated federal agencies. Mineral Year Book of USBM is the pioneering effort by collection, analysis, and dissemination of information about mining and processing of more than 100 mineral commodities across the Nation and in more than 185 countries around the world.

3.2.2. Geological Survey

The Geological Survey (GS) is the national geo-scientific and academic institution responsible for specialized multithematic mapping of the entire country to develop basic research in earth science and to target new mineral discoveries that includes water and energy resources to meet the demands of growing population. The other functions are assessment of earth science-related environmental impacts and geological hazards like landslide, earthquake, flood, coastal zone instability and desertification. It creates and updates geo-scientific database, reports and maps for dissemination to the government departments, user agencies and individuals free or at cost as the case may be. There are several national geological institutions, namely Geological Survey of Australia (GSA), Geological Survey of Canada (GSC), Geological Survey of India (GSI), United States Geological Survey (USGS), and National Service of Geology and Mining (NSG & M), Chile.

The Geological Survey of Western Australia (GSWA) is a division within the DMP. Since 1880, the function of GSWA is to collect and synthesize information on the State's geology, exploration, and mineral and petroleum resources. GSWA publishes reports, maps, and state-of-the-art database documenting all information to enable building blocks to design exploration programs. Reports, maps and Geographical Information System (GIS) information on the geology, geophysics, geochemistry, geochronology, mineral exploration, resources as well as reports of Exploration Company can be downloaded free of charge from WAMEX system. Mineral deposit and mine information is available from MINEDEX. The department is critical in government decision making, particularly on economic and land use issues. Every State or Region in Australia functions in a way suitable to that State or Region or Province.

The GSC established in 1842. It is a part of the Earth Science Sector of Natural Resources Canada. The GSC is the premier agency for geo-scientific information and research, with world-class expertise focusing on geosciences surveys, sustainable development of Canada's resources, environmental protection and technology innovation.

GSI, established in 1851, is an all India national organization with Central Headquarter at Kolkata and six Regional Offices, several operational wings in each region and six training institutes. The Regional Offices are spread over at Kolkata (Eastern Region and Coal Wing), Shillong (Northeastern Region), Hyderabad (Southern Region), Lucknow (Northern Region), Jaipur (Western Region) and Nagpur (Central Region). The headquarter of AMSE Wing is located at Hyderabad with five Zonal Offices at Hyderabad, Nagpur, Ranchi, Shillong and Jaipur. GSI is premier institution in the country imparting state-of-the-art training in different disciplines of earth science. The headquarter of training institute is at Hyderabad and conducts various training programs through its six centers located at Hyderabad (Andhra Pradesh), Lucknow (Uttar Pradesh), Zawar (Rajasthan), Ranchi (Jharkhand), Raipur (Chhattisgarh), and Chitradurga (Karnataka). The Institute has specialized divisions such as Photo Geology and Remote Sensing, Geophysics and the Center for Geo-information Management Training, located at Hyderabad.

The main functions and responsibilities of GSI is preparing and updating geological, geophysical and geochemical maps, exploration and assessment of mineral and energy resources of the country and its offshore areas, systematically developing and maintaining national drill core libraries, conducting research in earth sciences and promoting application of the new knowledge for effecting management of the earth system and its resources. It also works on promoting understanding of geological knowledge to reduce risk to life and property from geological hazards to enhance quality of life. The other function is creating and maintaining earth science databases and acting as the national repository of earth science data generated by various organizations and disseminating these in public domain for developmental, educational and societal needs. It maintains national geological monuments, museums and parks. GSI participates in international collaborative scientific projects and developing data sharing net works with other countries. The maps and reports are available from central and regional offices to everybody at cost.

Survey of India (SOI) was established in 1767 with its headquarter at Dehradun, Uttarakhand. The principal responsibilities of the SOI are geodetic control (horizontal and vertical) and geodetic and geophysical survey, topographical control, surveys and mapping within India, mapping and production of geographical maps and aeronautical charts, surveys for developmental projects. The organization prepares topo-sheets at 1:250,000, 1:50,000, 1:25,000 scales for the entire country. The survey sheets that are not of strategic importance (restricted) can be purchased by anybody from the SOI offices located at all the state capitals. The restricted topo-sheets can be obtained by the special permission of authorized Central and State Administrative Officials and/or the Ministry of Defense.

Mineral Exploration Corporation Limited (MECL) was established in 1972 as an autonomous Public Sector Company to bridge the gap between the initial discovery of a prospect and its eventual exploitation. MECL conducts geo-scientific services like survey, geology, geophysics, detailed exploration, mine development, metallurgical tests and feasibility reports for mine planning and allied activities for major minerals. The institution works on promotional as well as payment basis in India and abroad.

The USGS was established in 1879 as a scientific agency of the government. USGS headquarter is at Reston, Virginia, with major offices at Lakewood, Colorado (Denver Federal Center) and Menlo Park, California. The primary mission was to study of landscape, topographic mapping, natural resources, earthquake and volcanic hazards, geomagnetism program and related matter. USGS has prepared Geological Quadrangle (GQ) Maps, Geophysical Investigations (GP) Maps, Hydrologic Investigations Atlas (HIA), Land Use and Land Cover (L) Map, Mineral Investigations Resource (MR) Maps, etc. The organization has four major science disciplines comprising of biology, geography, geology and hydrology. The USGS is a fact-finding research organization with no regulatory responsibility.

3.2.3. State/Regional Department of Mines and Geology

State/Regional/Provincial Department of Mines and Geology (DMG) is responsible for limited mineral exploration, granting of RP, LAPL, PL and ML with the approval/consent of Federal Government, and the inspection and collection of royalty from various mining units.

3.2.4. Public Sectors Undertakings

In the mineral sector, there are many government-owned companies (GOCs), state-owned companies, state enterprise, publicly owned companies [Public Sector Undertakings (PSU)] with legal entity created by the government whose primary focus is to explore, operate and expand mineral properties in the country. GOCs can be fully or partially owned by the government. The major shares of these companies are held by the government with limited share by the individual public. The GOCs are Aerosonde Ltd (Australian Platinum Mines), Alkeno Exploration.

Since independence, the government of India focused on development of essential minerals through PSU such as: Coal India Limited (CIL, 1951), Orissa Mining Corporation Limited (OMCL, 1956), a State and Federal joint sector company, Oil and Natural Gas Commission (ONGC, 1960), a Fortune Global 500 company, Bharat Gold Mines Ltd (BGML, 1972), National Mineral Development Corporation (NMDC, 1958), Manganese Ore India Limited (MOIL, 1962), Bharat Aluminum Company Ltd (BALCO, 1965), now a part of Vedanta Resources, Hindustan Zinc Ltd (HZL, 1966), now a part Vedanta Resource plc, Hindustan Copper Ltd (HCL, 1967), National Aluminum Company Ltd (NALCO, 1981). These PSUs are formed for exploration mining and to promote the growth of specific minerals even in the remote areas and economic development of the tribal community. Most of these PSU have exploration wing to carry out own requirements. Exploration and sampling are continuous activities for mine planning, grade control and reconciliation.

3.2.5. Private Sectors

Mining industry site covering exploration through to mining, processing and transport of minerals are privately owned or PS activity in countries like: Osisko Mining, Argentina, Red Back Mining in Canada, Australia, Europe, United States, Latin America, Anglo American plc, Anglo Platinum, De Beers, Exxaro Resources Ltd, Gold Fields, Harmony Gold, Impala Platinum, JFPI Corporation, Kumba Resources, Rio Tinto and Wesizwe Platinum in South Africa and Equinox, Meteopex, Mopani Copper, Konkola Copper, Zambia Consolidated Copper Mines, First Quantum Minerals, Venturex Resources Ltd, and Vale, Zambia. The other international exploration companies are CSR Ltd, Forteseue Metals Group, Rio Tinto Group, Santos, Zinifex Ltd, Goldstream mining NL, IMX Resources Inc., Australia, Cameco Uranium, Goldcorp, Exeter resource Corporation (2002), Canada, Codelco Mining Corporation (1976), and Capstone Mining Corporation, Chile. The major Indian PS exploration and mining companies are: ACC Ltd, ADI Gold Mining Pty Ltd, Binani Zinc Ltd, Birla Corporation Ltd, BHP Billiton, De Beers India Pvt Ltd, ESSAR Mineral Resources Ltd, Ferro Alloys Corp Ltd, Rio Tinto India Pvt Ltd, Sesa Goa Ltd, Tata Steel Ltd and Vedanta Resources plc. The companies are permitted to explore and mine nonrestricted minerals. The PS are equipped with technical personnel and machineries to conduct exploration and evaluation of mineral deposits in on going mining as well as in virgin areas.

3.2.6. Multinational Limited Companies

The concept of open market policy gave way to radical opportunity to Multinational Limited Companies (MLC) or MNC worldwide. Any MNC registered in the country, individually or as Joint Venture partner, is allowed to explore and mine all nonstrategic minerals with 100% FDI. The participation of MNC in mineral sector has far-reaching effects and benefits to the receiving country by way of readily available specialized experienced skilled technocrats and most advance technology. The MNCs working all over the world are Anglo American plc, BHP Billiton, De Beers Private Ltd, Freeport-McMoRan Copper and Gold Inc., Rio Tinto Group, etc.

3.3. SURFACE GUIDE

Most of the mineral deposits portray surface signature like favorable stratigraphy and host rocks, weathering effects of metallic and nonmetallic mineralization, presence of earlier mining and smelting remnants, shear zone, lineaments, etc., that can be identified by experienced eyes. If the features are recorded properly during geological traverses in the field followed by exploration, a new deposit may be discovered.

3.3.1. Favorable Stratigraphy and Host Rocks

The existence and identification of favorable stratigraphy and complimentary host rocks are the essential prerequisites to initiate any exploration program for a specific mineral or group of minerals. Geological maps are available from GS or BM or Department of Mines. This can be downloaded free of cost or purchased at small price. The layered ultramafic-mafic assemblage of Archean-Proterozoic age is the most suitable target for chromium-nickel-platinum-copper and gold association (Bushveld chromium-platinum in South Africa and Sudbury nickel-platinum in Canada, Stillwater nickel-copper-platinum in United States, The Great Dyke platinum-chromium in Zimbabwe, and Sukinda-Nausahi chromium in India).

3.3.2. Weathering

Weathering and leaching of near-surface metallic deposits is an indicator of probable existence of mineral deposit down depth. This has been described in detail at Chapter 4.5.2.4 and (Figs 4.4–4.9). Presence of gossans above Broken Hill zinc-lead-silver deposit in Australia, Adi Nefas, zinc-copper-gold-silver deposit Madagascar, Rajpura-Dariba zinc-lead-silver deposit and Khetri copper deposit in India are good examples of base metal deposits.

3.3.3. Ancient Mining and Smelting

Ancient mining and smelting has been reported and radiocarbon dated of woods in the Indus valley (3000 BC for gold mining), along Lake Superior, North America

(3000 years Before Christ (BC) for copper mining), Egypt (2613 and 2494 BC for Cu mining), India (3000 BC for copper, 1400 BC for iron, 1000−100 BC for zinc-lead-silver mining) and Spain (25 AD for gold mining). One can find ancient mine debris around open pits with wooden wall supports, entry system to shallow and greater depth for underground mining, abandoned underground gallery with wooden ladder and platform, in situ potholes rock grinder at surface for ore dressing, smelting furnaces, enormous heaps of slag and retorts reused for wall making, ruined places of worship and deserted township in and around the ancient mine-smelting sites. These evidences easily suggest existence of rich ore deposits and guide for modern-day exploration for depth and strike continuity in the region.

The remnants of ancient mines play significant role in mineral exploration. Once the mineralization was located at the surface based on the presence of gossans or fresh mineralized veins, the ancient miners excavated the area as open pit mine with wall supports wherever required as observed in case of East Lode of Rajpura-Dariba mine. The miners follow the downward extension along dip and pitch of narrow ore shoot making vertical or inclined entry system (Fig. 3.1). The excavations are generally carried out by fire setting and sudden cooling by water.

The entry system can be of multiple in nature in case of large exposed orebody and particularly extends over great depth (Fig. 3.2).

The miners develop huge stopes and underground chambers within rich part of the mineralization. They have demonstrated competent skill of engineering by making arching of the pillars, use of wooden ladders and platforms, wooden launders for underground drainage, timber support to prevent roof collapse and clay lamps for mine illumination (Fig. 3.3).

The presence of small pits on the surface nearby the smelting sites and vast heaps of crushed debris near the mine opening indicate that the zinc ore was crushed, richer portion handpicked and later ground, before smelting. At Rajpura-Dariba, north of East Lode in the hard calc-silicate outcrops, potholes of 30 cm in diameter and 60−70 cm deep with rounded bottoms are observed (Fig. 3.4).

The ancient zinc smelting process was resolved through distillation and condensation technology (pyrometallurgy) of zinc ore using moderately refractory clay retorts. Archaeometallurgical excavation at Zawar discovered intact ancient zinc distillation furnaces containing their full spent charge of 36 retorts (Fig. 3.5). Each furnace is 60 cm

FIGURE 3.1 Ancient entry system to underground mine at shallow depth of orebody without any plunge during the 3rd and 2nd millennium BC at Khetri copper belt, Rajasthan, India.

FIGURE 3.2 Ancient entry system to underground mine at greater depth with orebody plunge to northeast at Rajpura-Dariba copper-zinc-lead-silver mine, India.

FIGURE 3.3 Ancient underground mining in rich zinc orebody at a depth of 172 m from surface. The arching of stope chamber evidenced high engineering skill. The wooden ladder (left) and platform (right) are still at abandon work site. Radiocarbon age dating indicates 3000 years from now at Rajpura-Dariba Mine, India.

FIGURE 3.4 Ancient potholes at surface used for crushing, grinding and concentration of rich zinc ore are still preserved at Rajpura-Dariba mine, India.

in height and divided in two parts, a lower condensing chamber, separated by perforated plate from the upper main furnace of distillation chamber. The smelting was carried out at 1100−1200 °C for 4−6 h. This site is recognized and preserved by the American Society of Metals as International Zinc Smelting Heritage in 1988.

A complete retort is cylindrical in shape, tappers at one end (Fig. 3.6) and fitted with an extended cylindrical hollow tube for channeling distilled hot zinc vapor from the retorts at upper chamber and condensed at the lower cooling chamber. The condensed zinc metal is dropped at collecting pot.

The exhausted retorts are either dumped or reused for making walls of hutments for the mining community (Fig. 3.7) in the township.

There are ample evidences of antique mining and smelting history as seen at the old deserted ruined Industrial Township in the valley area of Zawar Mine, India. The presence of abandoned mine entry system in the surrounding hills, clay and sand covered intact smelting furnaces, part of broken down residential walls, and Hindu

FIGURE 3.5 Ancient smelting furnace unearthed with 6 × 6 numbers of retorts placed in an inverted position for distillation of zinc by heating and condensation process at Zawar mine, during 2180 ± 35 years from today, India.

FIGURE 3.6 Ancient cylindrical distillation clay retorts from the smelting site at Zawar mine area, India.

temples (Fig. 3.8) of thirteenth century AD in the center of the ancient zinc smelting site. Some of the historical monuments are maintained by Indian Archeology Department.

3.3.4. Shear

Shear zones is the result of huge volume of rock deformation due to intense stress in the region, typically in the zones of subduction at depths down to few kilometers. It may occur at the edges of tectonic blocks, forming discontinuities that mark a distinct structure. Shear zones often host orebodies as a result of syngenetic or epigenetic hydrothermal flow through orogenic belts. The rocks are commonly metasomatized, and often display some retrograde metamorphism assemblage. An intense fractured or shear zone is a favorable structure to trap mineralization. The Hyde-Macraes shear zone, New Zealand, is a low-angle thrust system in which gold-bearing quartz veins have been deposited. Copper sulfide vein-type mineralization associated with migmatization in the southeastern part of the Singhbhum shear zone, Jharkhand, India, is an example of shear-controlled copper-uranium mineralization.

FIGURE 3.7 Ancient smelting retorts reused for walls for living shelter in the mining township at Zawar, India.

FIGURE 3.8 Ancient Hindu temple of thirteenth century AD in the center of the ancient deserted zinc smelting site at Zawar Mine area, India (Credit: Prof Martin Hale, The Netherlands).

3.3.5. Lineament

In general, mineral deposits occur in groups and follow a linear pattern along fold axis, shear zone and basement fracture traps. The linear alignment can be traced in the regional map of Aravalli Mountain, India, and McArthur-Mt Isa Province, Australia. Lineament mapping of different terrains using Remote Sensing Imageries is capable to guide ground water flow. Analysis of surface lineament with the help of Geoinformatics became significant in oil and gas exploration as at Sabatayn mature basin in Yemen. A satellite image Enhanced Thematic Mapper-based analysis was conducted for extracting surface and subsurface lineaments overlaying the seismic, magnetic and gravity data.

3.4. TOPOGRAPHIC SURVEY

An accurate topographic map is essential for long-term and short-term purposes of any type of projects. This is more relevant during all stages of mineral exploration, mine development, mining and related activities. The simplest way of topographic surveying is carried out by a tape and a compass with low level of accuracy. The accurate topographic surveys are carried out using Electronic Total Stations (ETS) to capture three-dimensional (3D) observation data (x, y, z) on site. The data is processed using commercial software to generate Digital Terrain Model (DTM). The DTM is capable to produce contours, volumes, sections and 3D wireframe view and plots.

An accurate topographic map (topo-sheets) in 1:250,000 or 1:50,000 scales, marked with reference survey station or triangulation points, contours and all other land-related features is easily available on cost from the National Survey departments. Topo-sheets can also be downloaded internationally from US Army Mapping Service in Universal Transverse Mercator (UTM) system at nominal price. The sheets are base maps and significantly useful for geological mapping, sampling and borehole locations. In the advance stages of exploration and detail mine planning, highest accuracy is maintained in topographic surveys (1:5000, 1:1000 scales) by using Leica total station and Leica global positioning system (GPS) equipments. The underground mine survey is routinely cross-checked by closing the survey from and to the known surface station.

3.5. GEOLOGICAL MAPPING

The first work in mineral exploration is the preparation of a high-quality geological map. The precision and scale of map depends on the stages of exploration, technical infrastructure and finance available for the program. A geological map is a record of geological facts such as occurrence of rocks in space and their contacts, weathering effects such as leaching or gossan, and structure in their correct space relations. There are sharp distinctions between observations and interpretations. The inferences are confirmed by opening through pits and trenches. It can also be authenticated by subsurface information as obtained from drill holes and mine workings. The map must have a scale, direction and index describing various features shown on it.

3.5.1. Surface Map

Surface maps are prepared by taking traverses on the surface at various intervals and plotting the records like rock types and all other observations including strike, dip, plunge, etc. The government agencies prepared maps of the entire country on a regional as well as district scale for future planning purposes. The maps are becoming précised and meaningful with the advent of facilities like Remote Sensing Technology.

3.5.1.1. Regional Scale

Regional scale mapping starts with the study and interpretation of geological features from satellite imageries, aerial photographs. These base maps along with topo-sheets at 1:250,000 or 1:50,000 scales are used for selection of boundaries for Reconnaissance License. The regional survey is based on widely spaced traverse and cross-verification of broad geological contacts, shear zones and weathering features. The map represents an overall regional

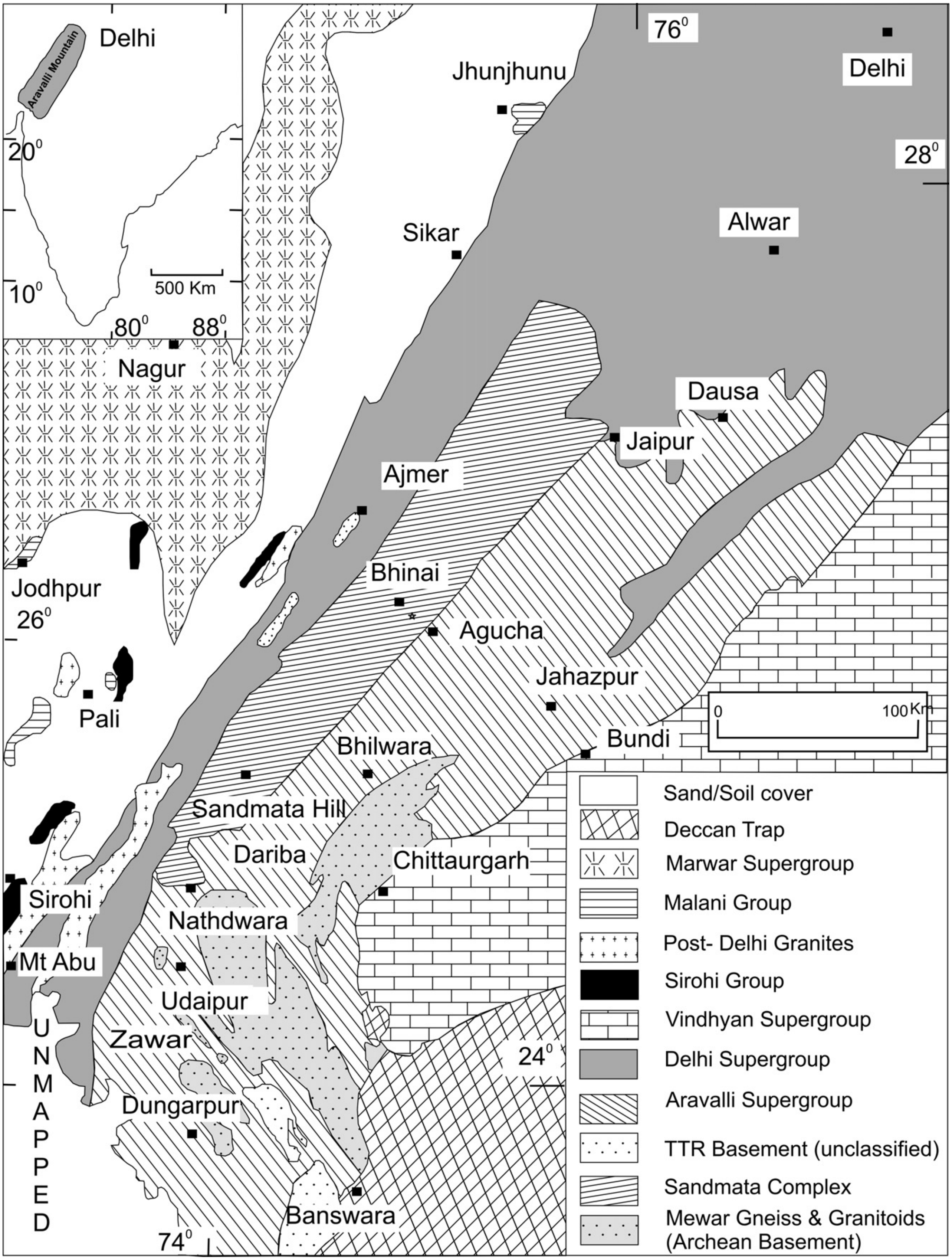

FIGURE 3.9 Regional geological map of the Aravalli Mountain showing major tectonostratigraphic units. BGC/MGC stands for Banded Gneissic Complex/Mewar Gneissic Complex, respectively showing location of mineral deposits (Credit: Prof. AB Roy).

picture including geomorphology, drainage pattern and major structures. Regional scale maps are not for representing precise specific features. Soil, grab and chip samples of rocks and weathered profiles are collected at this stage. The purpose is to provide a base map for further detail study from search of economic minerals, design of roads, dam and other infrastructures (Fig. 3.9).

3.5.1.2. District/Belt Scale

The district/belt map represents a part of the regional map having a cluster of mineral deposits. The features are recorded with close space traverses and rock sampling. The scale of map may be in 1:25,000 and 1:10,000 scale using theodolite and GPS survey instrument. The geological map is linked with topography. The map will be useful for selection of Prospecting Lease boundary and to formulate exploration program. The map makes an assessment of right stratigraphy, accurate lithology, detail structures, surface show of mineralization and analysis of ancient history of mining and smelting (Fig. 3.10).

3.5.1.3. Deposit Scale

The deposit map contains maximum detail information and is more focused at large scale like 1:5000 to 1:1000 with triangulation station benchmarks. The area is under Prospecting or Mining License. The map helps to design the drilling program to delineate the mineral or orebody (Fig. 3.11). The map stands for detail surface geological features, extent of deposit, location of trenches, pits and boreholes. The map helps to draw sections along and across the elongation of mineralization.

3.5.2. Underground Mapping

The surface geology related to lithology, structure and mineralization can be correlated for down-depth continuity with subsurface features as the mine progresses through service and stope development. The walls and back of mine entry system like adit, incline, raises, winzes and shafts, and level development in the form of drives and crosscut

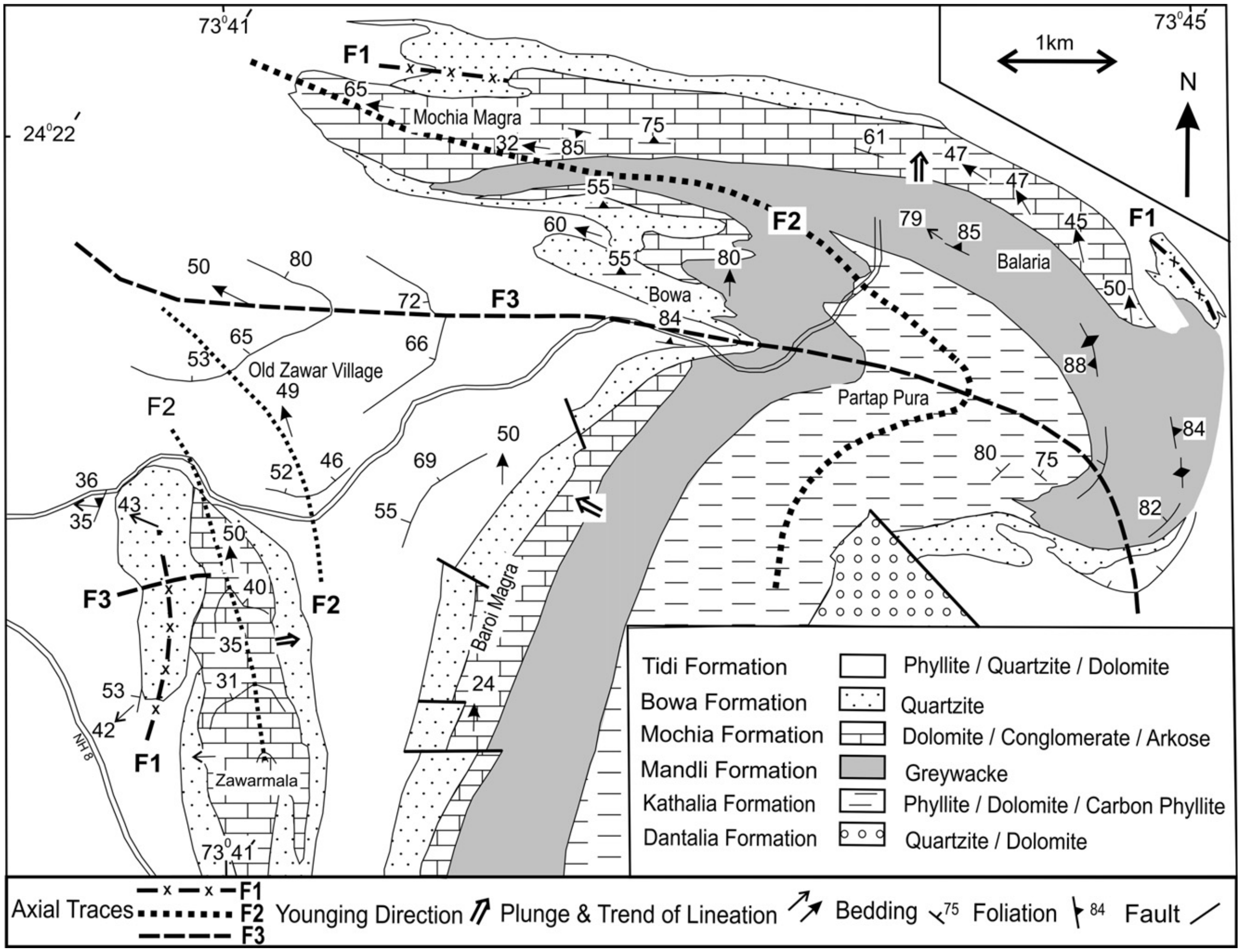

FIGURE 3.10 Surface map of Zawar Group of deposits showing all mining blocks, namely Balaria, Mochia Magra, Baroi, and Zawarmala, India (Credit: Prof. AB Roy).

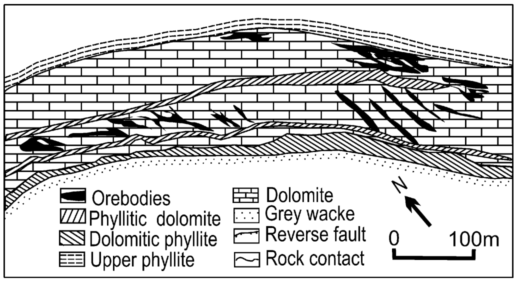

FIGURE 3.11 Surface geological maps showing strata-bound en echelon orebodies of Balaria zinc-lead-silver deposit, Rajasthan, India.

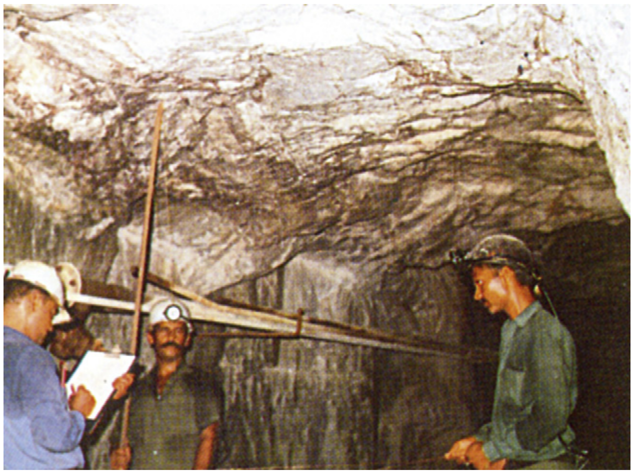

FIGURE 3.12 Scan line underground mapping of crosscut at Balaria mine, India.

are mapped (Fig. 3.12) carefully in very large scale such as 1:200 or 1:50.

In all underground workings, survey stations are marked in the roof of the working maintaining the line of sight to guide the successive development. The surface is cleaned by high-pressure water jet or compressed air. Cloth tape is stretched between two survey stations. Pocket metallic tape is used for taking off-set of working profile, rock contacts, foliation, bedding, joints, fractures, shears, void fills and mineralization (Fig. 3.13). The information is plotted on graph sheets in the underground and later transferred to master plan in the office. These maps help in drawing rocks and orebody contacts with confidence, planning of underground drill holes and finally stope design.

3.6. STRATIGRAPHIC CORRELATION

The geological maps of regional, basin and deposit scale can be analyzed and correlated to establish a comparative statement of the lithological succession with metallogeny of the region (Figs 3.14 and 3.15). This helps to generalize the ore-hosting horizon for future search in the in-between blocks and extension on either side.

3.7. EXPLORATION ACTIVITY

The geological exploration can be divided in to three broad groups, namely regional scale, district scale and deposit scale. The overall activities can be identified as:

3.7.1. Regional Scale

- Survey of existing literature, examination of aerial photographs, satellite imageries, acquisition of geophysical data, if any, and geological maps of prospective region, understanding the stratigraphic setting and structural architecture, synthesis of all available data and concepts and submission of RP. The resource at this stage is of preliminary nature.
- The work plan includes preparation of organization plan, exploration scheme with fund allocation and budgeting and time schedule to achieve specific objective (refer Table 1.1).
- The task encompasses aerial geophysical and broad geochemical survey, ground check, wide space soil and rock chip sample collection, pitting trenching, few scout drilling to establish existence of mineralization and demarcation of priority and ranking of targets.
- Investment decision for next phase.

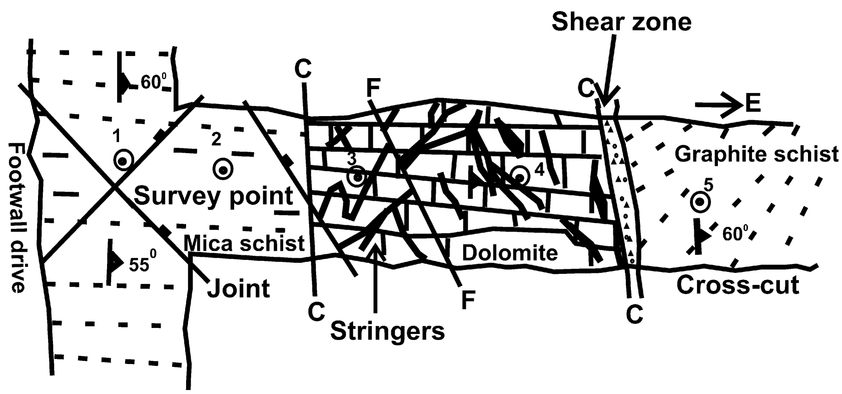

FIGURE 3.13 A typical underground map of development working showing survey stations (points and circle), rock contacts (C-C), structures and mineralized stringers (black) in dolomite host rock at Balaria mine, India.

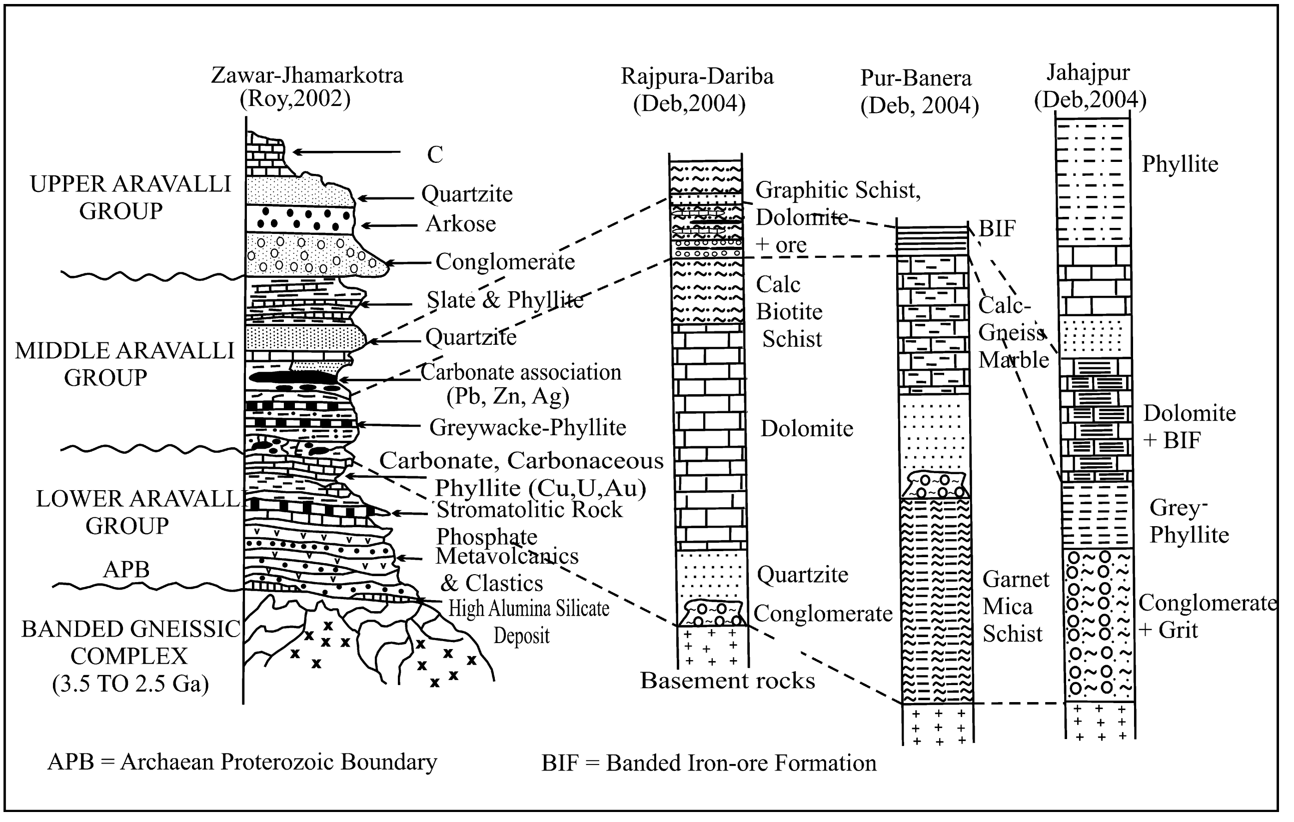

FIGURE 3.14 Lithostratigraphic correlations of Aravalli Province hosting rock phosphate, copper-uranium-gold and zinc-lead-silver mineralization from lower to higher horizons (Source: Haldar, 2007) [33].

3.7.2. District Scale

- Submission of Prospecting Lease, designing the exploration scheme with respect to work component, technology, type of exploration method, time and fund requirement (refer Table 1.2).
- Geological mapping of the target areas, recognition of surface signatures like presence of weathering and alterations, identification of host rock, structural settings and control.
- Ground geophysics and geochemistry, pitting, trenching, data synthesis and interpretation for reinforcing the drill targets (refer Fig. 4.2). Drilling continues to delineate proved, probable ore reserves and possible resources.
- Baseline environment plan.
- Investment decision and next phase.

3.7.3. Local Scale

- Detail geological mapping of host rock and structure controlling the mineralization, close-spaced surface directional drilling (refer Figs 15.2 and 15.7) to compute reserve with high confidence, pitting, trenching and entry to subsurface for level development, underground drilling for precise ore boundary, reserve of higher category, metallurgical test work and environmental baseline reports.
- Scoping study, Pre-feasibility study and Feasibility study.
- Submission of ML application along with Environment Management Plan.
- Ore production, mineral processing, extraction of metal or salable commodity.
- Cash inflow-out flow (Fig. 13.3).

3.7.4. Exploration Components

The various exploration components that can be summarized as:

- Sampling: soil, pitting, trenching, grab, chip, channel, directional drilling, sample reduction, check studies, tests of Quality Control and Quality Assurance that has been elaborated at Chapter 7.
- Optimization of drilling.
- Preparation of cross-section, longitudinal vertical section, level plan, 3D orebody modeling, estimation and categorization of reserves and resources (Chapter 8).
- Environment Management Plan.
- Sustainable development in mining (Chapter 14).

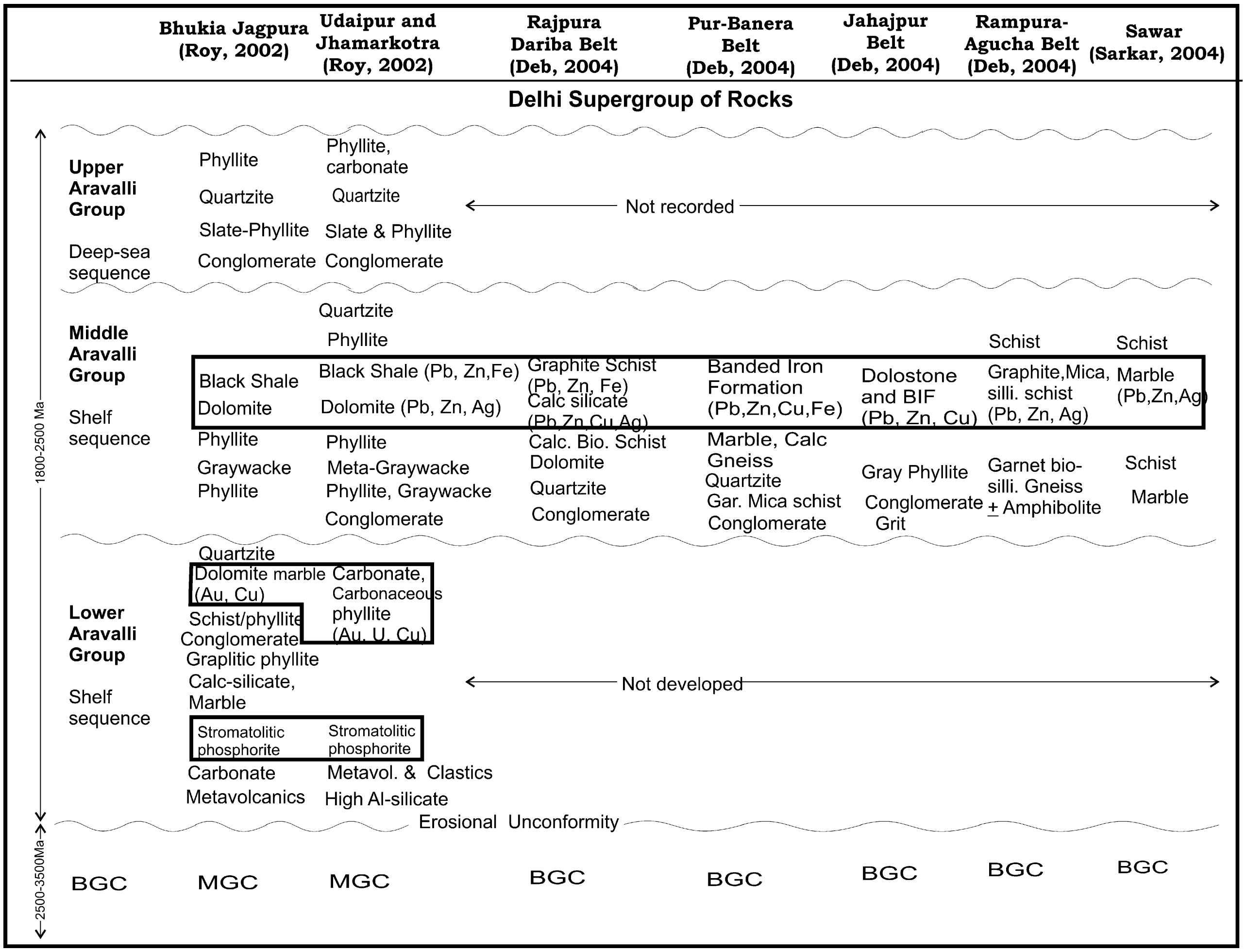

FIGURE 3.15 Lithostratigraphic correlations and comparative statement of the Aravalli rocks hosting rock phosphate, copper-uranium-gold and zinc-lead-silver mineralization (Source: Haldar, 2007) [33].

3.8. EXPLORATION OF COAL AND COAL BED METHANE

Coal is stratified carbonized remains of plant material transformed over millions of years. It is formed, first, by heavy growth of vegetable matter followed by accumulation and in situ burial under sediments. The next process is the transformation to coal by chemical and thermal alteration of organic debris. Coalification can also happen by drifting of the plant material to distance lakes or any water body and submersion under sediments. Plant materials tend to alter progressively through peat-lignite-subbituminous-bituminous and anthracite coal during the transformation process. Water, carbon dioxide, nitrogen and methane gas are produced along with coal in this process.

Coal bed methane (CBM) is a clean burning fuel for domestic and industrial uses. Its extraction reduces explosion hazards in underground coal mines. These gases are part of the coal seam at different percentages. It occurs as free gas in the fractures or absorbed into the micro pore surfaces in the matrix of the coal beds. The amount of methane held in coal seam depends on the age, moisture content and depth of the coal seam. The excess gas migrates into the surrounding rock strata and sand reservoirs that may overlie the deeply buried seams. The gas is being tapped and sold in commercial quantities using recent suitable technology. It is identified as a cleaner natural gas (CNG) form of energy than traditional coal and petroleum.

The exploration for coal and CBM includes geological mapping, study of geological setting of coal basins, remote sensing, surface geophysical inputs, core and noncore drilling technology, digital down-the-hole logging, use of GPS and microcomputers. Remote sensing data can identify the major lineaments, faults and other tectonic setup useful to explore coal-bearing area. High-resolution seismic survey can define the basin configuration, its tectonic style, thickness of coal-bearing formation, lateral continuity and approximate depth of different coal seams.

The design and procedure for core and noncore drilling program for coal seam must be performed on a sequential approach by successively narrowing the drilling interval along the elongation of expected coal seam. Down-hole geophysical logging will be helpful in proving the continuity of seam in strike and dip directions. The use of bentonite drill mud is substituted by high-density polymer foams to facilitate removal of cuttings and stabilize side-wall of drill hole, thereby allowing ready conversion of drill holes to monitoring wells. The core recovery in and around the coal seam should be achieved over 85% by using split tube core barrels. Samples of drill cuttings are taken at regular intervals for analysis. Formal core descriptions are made and the core is frequently photographed by digital cameras that are then appended to computerized drilling reports.

The operational aspects must achieve the aims of maintaining wells and prevent formational damage in case of CBM exploration. Excessive pressure of gas/water induces disproportionate disruption within the formation and imposes primary concern for drilling in the presence of high permeability. It often results in loss of circulation fluid, damage of coal formation and finally sloughing of holes. Another major problem during drilling could be the excessive water flow. Escape of large quantities of water from the coal seam generally obstructs drilling with pressure. The rigs, commonly employed, are portable, self-propelled and hydraulically-driven.

The total recoverable coal reserves in the world as on end 2006 stand at 9,09,000 million tonnes (Mt). This is shared by United States (2,47,000 Mt, 27%), Russia (1,57,000 Mt, 17%), China (1,15,000 Mt, 12.6%), India (92,000 Mt, 10%) and Australia (78,000 Mt, 8.6%). The world coal production during 2009 was 6940 Mt. The major coal producing countries during the same year were China (3050 Mt, 46%), United States (973 Mt, 16%), India (558 Mt, 8%), Australia (409 Mt, 6%) and European Union (537 Mt, 7.7%).

FURTHER READING

Haldar (2007) [33] and Banerjee et al. (1997) [2] on mineral exploration practices will be a good reading. A brief reference of coal in India is available from Deshmukh (1998) [21, 22].