COAL EXPLORATION AND MINING

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Keywords: Surface Geophysics, Drilling, Surface Mining, Underground Mining, Coal Exploration, Coal Mining, Air Borne Magnetic Surveys, Coal Reserves, Continuous mining, Conventional mining, Electrical resistivity, Electromagnetic methods, Field mapping, Gravity methods, In situ reserves, Longwall advancing, Longwall mining, Longwall retreating, Magnetic methods, Marketable reserves, Recoverable reserves, Room and pillar mining, Shortwall mining, Strip mining, Underground exploration, Literature Survey, Field Studies, Map Compilation, Seismic reflection, Coal Resource.

Contents

Summary

This article is primarily intended to introduce some general knowledge of coal exploration and mining. The first part of this article deals with the purposes and operative methods of coal exploration in terms of field studies, literature surveys, map compilation, surface geophysics, drilling for coal, and the collection and description of drill cores, after which the assessment of coal reserves is discussed. In the second part, two basic methods of extracting coal, i.e. surface mining and underground mining, are introduced. Firstly, two main methods—strip mining and open-pit mining—of surface mining are discussed. In underground mining, room and pillar, shortwall, and longwall mining methods are introduced. Finally, a brief prospect for coal exploration and mining is given.

With the wide range of subjects that have to be covered in an article of this type, the amount of detail that can be included on many aspects is greatly limited. As a complement to the text, therefore, the coal production of major coal producing countries in the world is given in the following table.

Country	**P.R. China**	**U.S.A.**	**Russia**	**Germany**	**Australia**	**South Africa**	**Poland**	**U.K.**	**India**
Year	1995	1994	1994	1993	1993	1993	1993	1993	1993
Coal Production (Mt)	1292.18*	935	271.3*	279.7	229.1	182.2	198.6	70.8	263.2

*Gross production

Table 1. Coal production (source: Energy Statistics)

1. Coal Exploration

The purpose of coal exploration is to determine the nature, location, and extent of the resources available in a particular situation, and delineate the features that may affect their economic extraction. A program of geological exploration for coal usually has one of two possible objectives: (a) to find an area from which a given amount of coal of a specific quality may be successfully recovered, or (b) to determine the amount and quality of coal that can be economically extracted from a given area.

Like other exploration activities, the evaluation of coal deposits involves the following operations:

- obtain legal title to explore the area
- evaluate the geologic information already available
- carry out surface exploration
- carry out subsurface exploration
- collect and analyze samples
- estimate the coal resources and the significance of geological factors in their extraction

- communicate the result to other members of the project team

1.1 Preparation for Field Studies

Geological exploration for coal is based very heavily on investigation carried out in the field. An efficient field study, however, depends on the preparation that precedes it, particularly in more remote areas where it may take some time, or considerable cost, to rectify any omissions.

1.2 Literature Survey

The first step in an exploration program is the gathering together of all available information pertinent to the area in question. This includes the study of published and unpublished scientific papers, geological maps, reports and theses, as well as topographic and cadastral maps, legal records, aerial photographs and satellite imagery. From such a study, the geologic framework of the area should be able to be assessed, as well as the topography, access, water supply, land ownership, and other factors that may govern the exploration program. The study should also indicate the type of base maps available for field studies and the need for any further ground surveying or photogrammetric mapping to allow fieldwork at the required scale.

1.3 Map Compilation

1.3.1 Base maps for coal exploration

In the course of the literature survey, it is necessary to compile items of geologic data onto an appropriate base map. The scale of the base map, and the features to be shown on it, depend on the size of the area under investigation and the degree of detail expected from that particular aspect of the study. A scale of 1:100 000 or 1:50 000 may be adequate for the preliminary appraisal of a large area, but a scale of around 1:10 000 is probably necessary for the geological work leading up to the planning of an actual mine development. If an operating mine is ultimately established, a plan will be drawn up at scale of around 1:2000,and the precision of mapping in the exploration program should bear in mind the subsequent need to plot boreholes and other features accurately on plans at such scale.

Maps published by government authorities may be suitable directly for use as a base in many exploration programs. In other cases, however, special maps will have to be prepared to suit the needs of the individual project. These may be compiled from existing maps or aerial photographs, or they may be based on additional, specially gathered ground and photogrammetric survey data.

The topographic data may also be processed to give a “digital terrain model” of the land surface. This can be of great value if computer-based methods are used for the assessment of coal reserves and planning of mine development, especially in open-cut mine situations.

1.3.2 Field mapping techniques

Geological mapping is a necessary starting point for the fieldwork of coal exploration. The principal objects of such a study are to determine the location, attitude, and extent of the coal-bearing strata, if not of the coal seams themselves, and the relation of these beds to other rock units in the area. Field mapping can also be used to reveal the nature and location of any igneous intrusions, faults, or other features that may affect seam continuity and mining conditions.

The techniques used in such a study depend on the nature of the area under investigation. Where the area has already been reliably mapped in detail, it may be sufficient to compile all existing data onto the base map, and use field work only to check on inconsistencies or points of detail. In other cases, however, a significant amount of outcrop mapping and aerial photograph interpretation may be necessary to gain an adequate understanding of the geological framework of coal occurrence.

Recognition and tracing of marker beds is an important component of a mapping program. Such markers may be beds of distinctive lithology, such as tuff, limestone, or flint clay horizons, or, alternatively, zones of unusual diagenesis or weathering characteristics. Palaeontological zones, derived from detailed study of bivalves, foraminifers, spores, pollens, or other organisms may also be useful in some cases. If these markers are concordant with the coal-bearing strata, their distribution and attitude may serve to correlate coal seams, elucidate facies patterns, and delineate the structural features of the area. This information can then be used to guide future surface and subsurface investigations.

Wherever possible, detailed stratigraphic section should be measured. Such sections may be obtained form cliff exposures, road cuttings, riverbanks, or creek beds, using aids such as tachometry and barometric leveling where required.

Outcrops of coal seam are subjected to the most intensive investigation. Detailed sections should be measured and if the coal is fresh, channel or strip samples may be taken. In area where the coal seams are mantled by a thick soil cover, it may be necessary to excavate pits, trenches, or costeans to provide surface exposures.

1.4 Surface Geophysics

Geophysical methods now play a critical role in many coalfield investigations .The techniques used at an early stage in the exploration program are normally those that give broad-scale information on a large area at relatively little cost. These include air-borne magnetometer investigations, regional gravity surveys and broad-scale seismic studies, used to delineate the sedimentary and structural framework of the area involved. They may be followed by ground magnetic, electrical resistivity and more detailed seismic investigations that give higher resolution of individual features, but at a significantly greater expense.

Together with the results of field mapping, the data from these techniques can be used to draw up the most appropriate drilling program to further test the value of the deposit.

Geophysical methods may also be used in conjunction with the down-hole logging methods. The initial drilling program is often followed by further use of surface geophysics, possibly based on techniques that give even higher resolution, to help solve particular problems or clarify ambiguities in the borehole data for reserves estimation and mine design.

1.4.1 Gravity Methods

Because a sedimentary sequence is usually less dense than its underlying basement rocks, gravity surveys are mostly used in coalfield exploration to provide data on the overall structure of the depositional basin involved. The results, in conjunction with field mapping and other information such as seismic or borehole data, can then be used to assess the most favorable areas within the region for further investigation.

A density contrast may also exist between the coal itself and the other sediments in the sequence. If the seam, or succession of seams is particularly thick and at relatively shallow depth, it may be possible to use gravity data from a closely spaced survey to map out its sub-surface distribution. With thin or particularly deep seams, however, anomalies of this type are usually too small to be detected.

1.4.2 Magnetic Methods

An airborne magnetic survey can be used in coalfield studies to map out the broad structural framework of a large exploration area. Such a survey depends on the existence of a contrast in magnetic properties between the basement rocks and the overlying sedimentary strata, and if all else is equal, the results will generally reflect variations in the depth to crystalline material. It will not detect coal, but if a sedimentary or tectonic model is applied to the sequence in question, it may assist in delineating those sectors likely to have significant coal accumulations at a reasonable depth.

Ground or vehicle-borne magnetic surveys are more commonly used for closer investigations in coalfield exploration. They may be used to provide further information on basement controlled geological structures, or to map out any bodies of mafic igneous materials, such as sills, dykes, and lava flows that occur within the area. The igneous bodies may act as markers for the sequence under investigation and help to delineate the outcrop pattern of the coal-bearing units, or they may act as intrusions that locally increase the rank of the coal and, in some circumstances, increase the value of the material. More commonly, however, igneous intrusions form barriers to mine development, and even render seams completely unworkable over large areas due to replacement and cinder formation.

Magnetic anomalies, usually of a smaller magnitude, may also be associated with the presence of fractured strata in joint zones and fault planes. The fractured rock may be preferentially mineralized by material of different susceptibility to surrounding strata, or else be leached of magnetic material, such as a ferruginous cement, by deeper weathering .In either event, they may show up as anomalies in detailed magnetic surveys. Like the igneous bodies, these structures can provide a barrier to mining, and their significance should be further evaluated as the program proceeds.

In some areas, ground magnetic techniques can be used for the delineation of burnt zones that may develop due to *in situ* combustion of coal seams in their outcrop area. The burned-out coal bed, as well as some of the surrounding non-coal strata, may become strongly magnetized during the cooling process, and produce a significant local anomaly. This can be used to trace the outcrop of such seams, even where they have been heavily obscured by soil, talus, or vegetation, and hence provide valuable data for field mapping studies. The technique can also be used to determine the extent of the burnt-out zone away from the outcrop, and assess the amount of otherwise mineable coal that has been destroyed in the combustion process.

Ground magnetic surveys for regional studies may be based on traverses along existing roads and other access routes in the area. For more detailed studies, however, especially over critical parts of colliery holdings, a surveyed system of intersecting traverse lines is necessary, with points of observation spaced 10–50 m apart.

1.4.3 Electrical Resistivity

The resistance of the rock strata to electric currents depends partly on the minerals involved and partly on the fluids present in the rock's pore spaces. Under laboratory conditions, sub-bituminous and bituminous coals are highly resistive. Shales, limestones and sandstones generally have lower resistivities, and such contrasts form the basis for the application of electrical resistivity techniques to coal exploration.

Resistivity techniques can be used on a regional scale or as part of a detailed investigation in a small area .The regional application may be used to delineate the position of coal-bearing formation, or other formation with distinctive resistivity characteristics. In the detailed study, however, the coal seam itself is normally the target.

1.4.4 Electromagnetic Methods

Electromagnetic methods of geophysical exploration are based on the production of a time-varying electromagnetic field by an alternating or pulsed electric current in a suitably laid out conductor at the ground surface or in the air above. As it builds up and collapses, this field generates a pattern of secondary currents in the subsurface strata due to the effects of electromagnetic induction.

The technique has the advantage over the electrical resistivity method that it does not require physical contact to be made with the ground surface. This avoids the risk of difficulties due to poor electrode contact or variable soil conditions, and may enable more rapid surveys to be carried out in some cases. Electromagnetic methods can be applied even when the near-surface layer is of very high resistivity, such as in arid lands or permafrost terrain.

The technique may also be used for evaluating subsurface geology in coalfield area. Both transient pulse methods and multi-frequency oscillation techniques have been used to assess factors such as depth to basement, coal-bearing rock units, or individual coal seams and to indicate the location of seam subcrops, faults, intrusions, and cinder-zones.

1.4.5 Seismic Reflection

Seismic reflection has proved to be vital to many coalfield investigations, where it is used both to delineate the broad structural features of a relatively large area and to map out individual small-scale structures, such as faults, splits, and washouts, that may disrupt mining operation.

For most studies, the energy pulse is derived by detonation of an explosive charge, but weight-dropping techniques or a vibratory tamper may be used as an alternative in some cases. Where the coal lies beneath a body of water, such as a lake, estuary or the sea, an air gun or an electric spaker device may be necessary.

Where high resolution is required, such as in studies to aid detailed colliery planning, it is also necessary to use only the high frequency or short wavelength components of the energy spectrum. Small charges (about 50g) of explosive materials represent the best energy source in these circumstances, but these suffer the disadvantage that the strength of the signal is relatively low compared to the level of ambient noise inherent in the seismic system. Special high frequency geophones and appropriate recording filters are used in this type of survey as well to enhance the signal desired.

With the techniques used in high resolution seismic surveys, faults with a throw of about 5m can be resolved in coal seams at depths of 800m, and faults with a throw of 4m at shallower depths have been detected.

1.5 Drilling for Coal

Further information on the depth, thickness, and quality of the coal at any point across the area, and of the strata with which the coal is associated, requires the effective use of exploratory drilling techniques.

Exploratory drilling may be directed towards the recovery of core samples of coal and non-coal strata for detailed lithologic description, analytical studies, and geotechnical testing, or towards recovery of broken fragments or “cuttings” of the materials penetrated. Core drilling is the only satisfactory means of obtaining representative samples of seams at depth for quality determination, but with the aid of geophysical logging techniques, the cuttings from non-cored holes can provide adequate geological data for many other purposes.

1.5.1 Non-core Drilling Techniques

The most widely-used method of non-core drilling in the coal industry is rotary drilling. In this technique, a string of metal drill rods is rotated axially, and a bit at the base of the string is forced downward, under controlled pressure, breaking up the ground and advancing the depth of the hole. Cuttings are swept away from the bit, and lifted to the surface either by means of pumped circulating water or by jets of compressed air.

Geological logging of non-core holes is mainly based on the cuttings obtained as the drill progresses. If water is used as the circulating medium, allowance must be made for the distance drilled in the time taken for them to reach the surface. The exact location of lithological contacts may be more clearly delineated from changes in the penetration rate or water flow conditions, as recorded in the driller's log. A series of geophysical logs may also be run in each hole, providing a wide range of additional data on the lithological sequence present.

1.5.2 Core Drilling

The most effective method of drilling for core recovery is the use of diamond drilling. In this technique, a hollow cylindrical drill bit impregnated with industrial diamonds is attached to a series of metal drill rods, and rotated under controlled downward pressure. A circle of rock is ground away, the cuttings removed by water flushing, and a cylindrical core remains in the hollow center of the drill string.

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Biographical Sketch

Lixun Kang is a mining engineering graduate of Shanxi Mining Institute, China. After a period in the coal industry, he joined the academic staff of Shanxi Mining Institute. In 1985, he gained a Master's degree from the University of Newcastle upon Tyne. In 1994 he was awarded his Ph.D. by China University of Mining and Technology for his research on roof caving at the end face and its control in Datong Coal Mining Area. At present, he is a Professor and the Principal of Mining Engineering College, Taiyuan University of Technology, China.