COAL EXPLORATION AND MINING GEOLOGY

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Keywords: Coal, geology, exploration, mining, resources, reserves, geophysical methods, drilling, borehole logging, deposit evaluation, quality assessment, environmental impacts

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Summary

Coal exploration involves finding new coal deposits. It also involves evaluating new or existing deposits to determine the quantity and quality of the coal contained within them, and to identify any geological factors that may affect the recovery and use of the coal concerned.

A variety of geological techniques is used in coal exploration is including field mapping, interpretation of air photos and satellite images, and airborne and ground geophysical surveys such as gravity, magnetic and seismic studies. Detailed information on coal seam thickness, quality and structure, as well as on the mechanical properties of the rocks associated with the coal deposit and the distribution and quality of the groundwater, are obtained mainly by exploration drilling programs, supplemented by down-hole geophysical logging and comprehensive analysis and testing of core samples. Geological information from these different sources is integrated using computer database and modeling systems. The results are used to develop a three-dimensional understanding of the deposit as a basis for mine planning, to evaluate the in-situ, recoverable and marketable coal resources, and to help assess the impact on the environment of any proposed mining activity.

Geological studies continue as the mine develops and becomes operational, shifting progressively from deposit evaluation to monitoring the geological conditions encountered as the coal is extracted for use. Coal mining geology activities include delineating in more detail any geological features that may affect the mine layout, such as individual faults and igneous intrusions, as well as monitoring any variations in the seam that may impact on the quality of the coal produced. They are also concerned with identifying geological factors affecting the stability and safety of open-cut and underground mine openings, and with the relation of geological features, such as soil and groundwater properties, to the environmental impact of the mining operation.

1. Introduction

Coal is a vital component of the world's energy resources, and one that is expected to fill a significant role in meeting our energy needs well into the foreseeable future. Geological science and associated technology are used to find and evaluate the coal resources that will be used to meet these needs, a process referred to as coal exploration, and to assist in designing and operating effective systems for coal mining (coal mining geology), preparation and utilization tasks.

The overall process of coal exploration and mining involves six separate but interdependent and overlapping components:

- **Exploration:** the identification and geological assessment of a new coal-bearing area;

- **Mine Design:** the design and economic evaluation of the most appropriate mining operation to make use of the coal in that area;

- **Coal Marketing:** the procuring of markets or development of facilities to use the coal that will come from the mine over its working life;

- **Mine Development:** the acquisition, construction and commissioning of the plant and facilities required by the mine design;

- **Mine Operation:** the day-to-day running of the mine to maintain regular coal production;

- **Decommissioning:** the dismantling of mining operations, once the mineable resource is exhausted, and the return of the land to other forms of use.

None of these is independent of any other, and the geology of the deposit is significant to all of them. The geological features of the deposit, for example, determine the type of mine that will be established (e.g. open-cut or underground), the location of any shafts, preparation plant etc., and the optimum layout of the mine workings. The quality of the coal and the degree to which the coal quality varies throughout the deposit, combined with the method of working and the day-to-day extraction schedule, determine the properties of the mine product to be processed, marketed and used. A combination of the geological features also determines the impact of the mine upon the existing environment, including a number of important interactions with the groundwater system. Similar geological factors need to be taken into account when the mine is ultimately closed, to ensure the safety and wellbeing of subsequent land users and the people in the surrounding region.

The exploration phase is aimed at proving the technical, economic and environmental feasibility of a new mining operation. Some exploration activities may continue, alongside inputs from other disciplines, into the operation and decommissioning stages of the project. The application of geological studies to the actual mining process, sometimes referred to separately as coal mining geology, follows on after the mine begins operation. Coal mining geology embraces a number of special skills and techniques, but is otherwise essentially a continuation of exploration activities into the production phase of the project.

2. Objectives of Coal Exploration Programs

As indicated above, coal exploration is the first part of a continuous process, that if successful leads to the establishment of a new coal mine or the extension of an existing mine into a previously unexplored area. The object of coal exploration is to determine the nature, location and extent of coal resources in a particular situation, such as a coal mining lease or a coal-bearing sedimentary basin, and to identify the geological factors that may affect its economic, safe and environmentally-acceptable mining and use.

Depending on the context, the immediate aim of a coal exploration program may be to find an area containing a given mass of coal meeting a given set of extraction and quality guidelines. Alternatively, the program may be required to determine the quantity and quality of coal that may be extracted from a given area, and to identify the geological and environmental factors that may affect mining and use of the identified coal resources. Most programs ultimately become investigations of the latter type.

Coal exploration programs typically involve the following components:

- Obtain legal title to explore the area;
- Evaluate the geological information already available, and compile suitable base maps for further exploration;
- Carry out surface exploration (mapping, geophysics etc) and gather environmental baseline data;
- Carry out subsurface exploration (drilling and related activities);
- Collect, analyze and test coal and other rock samples;
- Compile information; evaluate coal resources and mining factors;
- Communicate results to other members of the project team.

Lower-cost techniques, such as literature survey and geologic mapping, are ideally carried out before more costly methods such as drilling. It is also desirable to evaluate the whole of the area in general terms before concentrating the exploration activity on particular parts of the deposit.

3. Background Studies for Coal Exploration

3.1 Exploration Titles

Broad-scale regional assessments based on literature survey, interpretations of air photos or satellite imagery, and perhaps regional field mapping, may not require a formal title, claim or license to permit them to be carried out. Indeed, such studies are often used to identify areas for which exploration titles should be sought. Most other exploration activity, however, usually requires some sort of legal agreement with the owners of the resource, such as an exploration license from the relevant government, before significant geological fieldwork can be carried out.

Exploration titles generally place requirements on the holder to respect the rights of owners or occupiers of the land surface. Even after an exploration title is granted, individual negotiations may be required to provide access for exploration activities such as drilling, and to establish the level of any compensation for disruption to surface activities by the exploration process.

Especially in undeveloped areas, activities associated with exploration, including provision of access tracks, clearing of ground, sampling of outcrops and operation of drilling equipment, should also be conducted in such a way as to provide minimal impact on the existing environment of the site. Minimizing the environmental impact of the investigation may in fact be a formal requirement of the exploration title involved.

3.2 Evaluation of Existing Data

Geological maps, reports, theses, papers and other technical data relevant to the area should be gathered and reviewed as part of the literature survey for the exploration project, as well as lists of previous title holders, existing well logs, seam analyses and production histories. Explorers should also maintain an on-going familiarity with research and development in coal geology and exploration technology, as well as in coal mining, analysis and utilization. These might provide opportunities to improve the exploration, marketing and feasibility studies for the project.

Base maps of the area are required from a very early stage of an exploration project, for compilation of the various geological data. The scale of these maps depends on the size of the area and the scope of the exploration project, but ultimately points such as borehole locations, fault lines, igneous intrusions and other features will need to be plotted accurately on mine plans at a scale of around 1:2,000. Even if base maps at a smaller scale (e.g. 1:10,000) are used in the initial stages of the program, surveying of boreholes, seismic lines and other sites should be precise enough to allow plotting at the larger scale when mining is under way.

Special topographic maps may need to be compiled for the project. These may be based on existing or specially flown aerial photographs, and are typically compiled in digital form. Survey control for such maps requires the establishment of accurately positioned ground stations.

The ground stations should ideally be marked in such a way that they are visible on the aerial photographs. They should also be located at points that will not be disturbed as coal extraction proceeds, such as on the up-dip side of outcropping coal seams, so that they can be retained for survey control throughout the life of the mining operation.

4. Surface Geological Studies

4.1 Geological Mapping

Geological mapping, section measurement and interpretation of air photos or remote-sensing imagery provide the essential framework for geological studies in all but totally concealed coalfield areas.

Coal seams themselves may be the targets of such mapping, but the work can be equally useful if non-coal beds, such as key sandstone, limestone or tuff horizons, can be traced as markers to delineate the structure and distribution of the coal-bearing sequence. Igneous intrusions that may alter or replace the coal, and faults that may displace the seam and affect mining, should also be noted as part of the geological mapping process.

Seam outcrops may be excavated and sampled. Although weathering and oxidation can affect a number of important coal properties, macroscopic studies and micropetrographic analysis may still be useful, even with weathered materials, as a guide to other coal properties.

Trenches, shafts or box-cuts may be excavated to provide access below the soil or surficial sediment cover. Such excavations are more commonly introduced at a later stage of the project, however, to provide exposure of critical structures, geotechnical data on roof or overburden materials, and bulk samples of coal for pilot-scale preparation or utilization tests.

4.2 Surface Geophysics

Gravity and magnetic surveys at various scales can be used to outline basement trends and hence give information on the overall structure and distribution of the coal-bearing sequence [Figure 1]. Magnetic studies may also be useful in delineating igneous bodies, such as dykes intruding the sequence, or igneous markers such as lava flows. Joint zones and even burnt-out coal seams have also been delineated, in favorable circumstances, by detailed use of magnetic methods.

Electrical resistivity and electromagnetic methods may also be of use in some areas for coal exploration, either to trace particular markers or locate coal seam outcrops and hence delineate the overall geological structure.

Seismic reflection techniques can also be used at various stages of coal exploration projects, either to provide information on the geological structure of the area as a whole, to guide the subsequent drilling program, or to delineate particular geological features that may affect the coal mining operation.

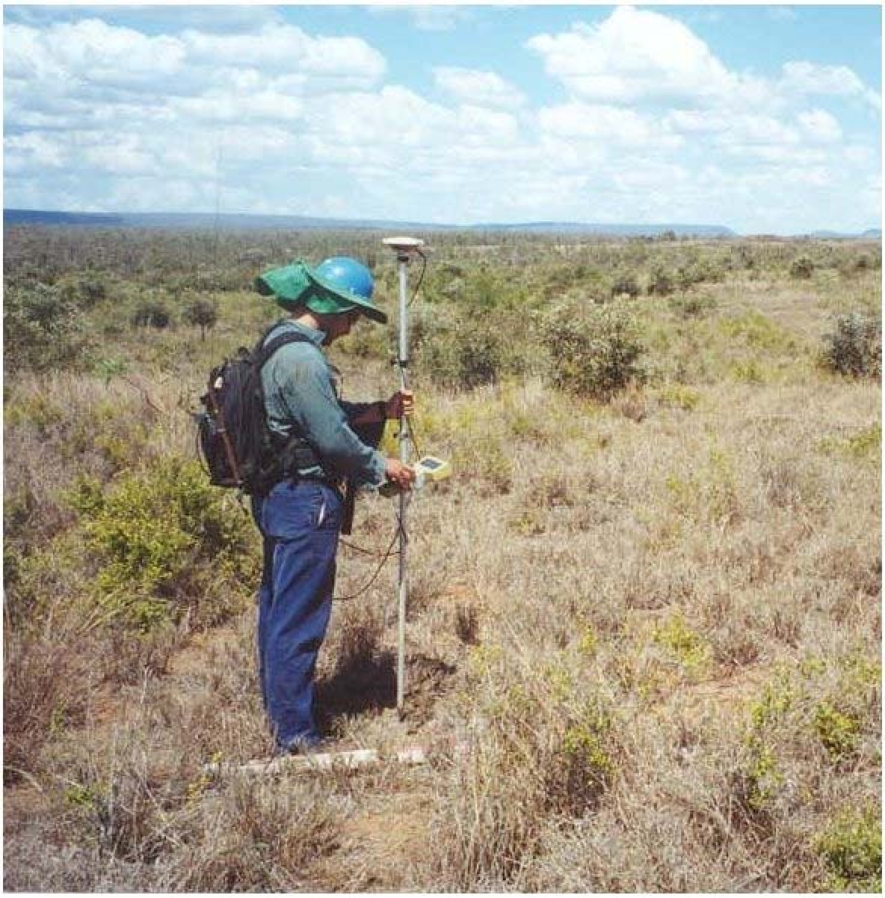

Figure 1: Gathering ground magnetic data as part of a coal exploration program

In contrast to petroleum geology, where relatively large-scale geological features are investigated at substantial depths, coal exploration is concerned with structures (e.g. faults) of less than 10 m in height and less than 1 km in depth. Such features give rise to very short two-way travel times (less than one second) for the reflected seismic signal, and may require special high-resolution techniques for detailed evaluation. Three-dimensional seismic surveys, where data from a closely spaced grid of traverses across the area are processed by computer to give a three-dimensional interpretation, may also be of value in resolving structural features.

4.3 Environmental Baseline Data

Major coal mining projects usually require a formal environmental impact study as part of the mining approval process. Such studies require information on the environmental conditions such as flora and fauna, noise and dust levels, soil types, land use, water flows and quality already prevailing at the mine site, in order that the anticipated impacts of the proposed mine can be objectively assessed.

A program to gather the necessary data on these factors should be initiated at an early stage of the exploration project, before the area is disturbed to a significant extent by land clearing, road construction, seismic exploration and drilling activities. The geological aspects mostly involve an extension of other mapping activities, although some specialist components, such as groundwater studies, flora and fauna surveys, land use evaluations and archeological assessments, may also need to be included in the environmental program.

5. Drilling Programs

Drilling for coal exploration programs may involve either core or non-core drilling. Core drilling is the only satisfactory means of obtaining representative samples, either of coal seams for thickness and quality assessment or of non-coal rocks for geotechnical tests. Non-core drilling, however, supported by down-hole geophysical logs, can give useful information on thickness and depth of coal and other beds for use in structural and stratigraphic studies.

Although regular grid patterns of boreholes are commonly employed, the location and depth of holes in the drilling program should also be based, especially in the early stages of the program, on the results of surface studies such as field mapping and geophysical investigations.

5.1 Drilling Techniques

Non-cored exploration boreholes are mainly drilled by rotary methods. A blade bit may be used for shallow holes in soft strata, but a roller bit is usually preferred for harder beds. Air flushing brings the cuttings to the surface more rapidly than water circulation, and allows a better estimate of the depth from which individual materials were derived. Water flushing is preferred, however, in built-up areas (to avoid dust), or where groundwater inflow to the hole is expected to be significant.

Core drilling is mainly carried out with diamond bits and water circulation, although tungsten carbide bits and air flushing may also be used. A triple tube core barrel is preferred for coal seams and other soft or friable strata, recovering the core in a split metal tube that allows it to be exposed for inspection with a minimum of disturbance.

Cores of between 45 and 85 mm in diameter are typically taken for coal exploration programs. Larger diameter cores, 150 mm and 200 mm, may also be taken for bulk sampling and pilot-scale coal preparation tests. Keyhole samplers, where a large-diameter hole is scooped out by a special expanding head at the bottom of a relatively small-diameter hole, may also be used to gather bulk samples of subsurface coal seams.

Excessive amounts of core loss in a particular hole may necessitate wedging off and re-drilling the relevant interval. Techniques also exist to obtain oriented cores, such as might be needed for structural or geomechanical analysis. Down-hole scanners may be used in some cases, to gather information on fractures and other features in the walls of the hole to assist lithologic logging and geotechnical assessment.

Measurement of water flows at different levels, and in some cases measurement of gas flow rates, may also be involved. Coal cores in some programs may be placed in sealed canisters, immediately on recovery at the ground surface, to measure and sample the gas adsorbed in the subsurface seam.

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Biographical Sketch

Colin Ward, coal geologist and sedimentologist, is Associate Professor and Head of the School of Geology at the University of New South Wales, Sydney, Australia. He obtained his BSc in Applied Geology from the University of New South Wales in 1967, and his PhD in Geology from the same university in 1971. He was Lecturer and Senior Lecturer in Geology at the New South Wales Institute of Technology (now University of Technology, Sydney) from 1971 to 1984, before returning to UNSW and progressing to his present appointment. Colin has also spent periods of Study Leave with the Illinois State Geological Survey (1975), the University of Kentucky (1980), CSIRO Division of Energy Technology and the University of Sheffield (1998). He has also worked on coal exploration and mining projects in Malaysia and Thailand, as well as in different parts of Australia. His research interests are focussed on coal geology, including mineral matter in coal, coal maceral chemistry, and the application of geology to coal exploration and mining.