

Australian Standard[®]

**Guide to the technical evaluation
of higher rank coal deposits**

This Australian Standard was prepared by Committee MN/1, Coal and Coke. It was approved on behalf of the Council of Standards Australia on 9 March 1993 and published on 14 June 1993.

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Australian Chamber of Commerce and Industry
Australian Coal Association
Australian Coal Industry Research Laboratories
Australian Coal Preparation Society
Australian Institute of Energy
Australian Mining Industry Council
Bureau of Steel Manufacturers of Australia
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STANDARDS AUSTRALIA

RECONFIRMATION
OF
AS 2519—1993
Guide to the technical evaluation of higher rank coal deposits

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Technical Committee MN-001 has reviewed the content of this publication and in accordance with Standards Australia procedures for reconfirmation, it has been determined that the publication is still valid and does not require change.

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NOTES

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PREFACE

This Standard was prepared by the Standards Australia Subcommittee on Coal Mining and Geology, under the supervision of the Committee on Coal and Coke and the direction of the Multitechnics Standards Policy Board, to supersede AS 2519—1982, *Guide to the evaluation of hard coal deposits using borehole techniques*. It has been prepared as a guide to the technical evaluation of higher rank coal deposits using borehole techniques, and was written to meet a longstanding need for a uniformity of approach to the evaluation of higher rank coal bore cores.

The guide is based on papers presented at the Symposium on Coal Borehole Evaluation (Brisbane 1977) conducted by the Australasian Institute of Mining and Metallurgy. It also incorporates relevant details from AS 2617, *Guide for the taking of samples from hard coal seams in situ*.

No single set of procedures will satisfy the varied objectives of all exploration drilling programs. This guide merely describes the options, together with sufficient explanation for readers to select the procedures appropriate to their needs. A bibliography of selected texts to allow for more detailed study is given in Appendix A.

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FOREWORD

The exploration of a coal prospect has to be carried out in a series of well-defined stages and should involve the combined efforts of a team comprising geologists, mining and coal preparation engineers, chemists and technologists. It is equally essential that those involved in management, marketing and finance have a fundamental understanding of the procedures involved.

In the initial exploration stages, techniques other than the drilling of bore cores may be used. These may include the appraisal of existing data, field mapping, the use of geophysical surveys and the lithological and instrumental logging of non-cored boreholes.

Small-diameter bore core samples of coal are subsequently taken and analysed to provide information on coal quality, to assist in the geological correlation of seams and the calculation of the amount of resources available for exploitation. Mechanical tests are carried out on certain cores to provide mining engineering data.

Large-diameter bore core samples of the proposed seam working section are pretreated, to produce the expected run-of-plant size distribution, then tested and analysed to predict the yield and quality of likely products and to generate coal preparation design data. These data are then used in the mine plan to calculate commercial reserves. Samples may also be prepared for bench-scale coke oven, or power station, performance tests.

In the final exploration stages, bulk samples are extracted from the seam to enable pilot-scale trials to be carried out and to provide large samples for evaluation by potential purchasers.

Exploration may continue, ahead of mining, for the life of the mine.

The major aim of this Standard is to provide guidelines for the laboratory testing of coal samples recovered by drilling.

Sections that cover exploration stages, other geological techniques and drilling methods are included to provide an understanding of the position and importance of sample testing in a coal exploration program.

STANDARDS AUSTRALIA

Australian Standard

Guide to the technical evaluation of higher rank coal deposits

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE This Standard sets out recommended practices for the technical evaluation of a higher rank coal deposit, principally using borehole techniques.

It defines the various stages that comprise an exploration project, describes drilling equipment and methods, and makes specific recommendations concerning procedures that should be adopted in the logging, testing and analysis of a bore core.

This Standard recommends procedures for the technical evaluation of a coal deposit within the context of the entire exploration program. It provides a reference framework that will promote—

- (a) greater appreciation, within an exploration team, of the individual needs of its members; and
- (b) a uniformity of approach, from team to team, to the technology of coal exploration.

A bibliography of reference texts appropriate to the various clauses of the Standard is given in Appendix A.

1.2 REFERENCED DOCUMENTS The documents referred to in this Standard are listed in Appendix A.

1.3 DEFINITIONS For the purpose of this Standard, the definitions in AS 2418 apply.

SECTION 2 STAGES OF PROSPECT EVALUATION

2.1 GENERAL In order that optimal use is made of available exploration technology, the exploration program should be planned and executed in a series of coordinated *stages*, each stage being based on the accumulated results of previous work.

Use should be made of geological and geophysical survey techniques in the early stages to provide an overall picture of the deposit and indicate target areas for subsequent structural drilling. The drilling of boreholes, during all stages, provides *core* or *chip* samples for testing and analysis and a *hole* for *in situ* evaluation of coal and non-coal properties using a variety of down-hole instrumental logging techniques.

It is most important that, at each exploration stage, the *optimum* amount of information be obtained and recorded from each borehole drilled, to avoid the expense and delay involved in redrilling and retesting.

The evaluation of a prospect does not necessarily terminate with the commencement of mining but may proceed throughout the entire life of the mine.

The aim of the evaluation should be to provide sufficient information to determine the commercial viability of the deposit. Specific areas of uncertainty should be highlighted and the appropriate economic sensitivity analysis carried out.

For there to be a complete interdisciplinary understanding of the objectives of the evaluation and interpretation of the results, the program must be supervised by a *team* comprising geologists, mining and coal preparation engineers, coal chemists, coal technologists and marketers. Personnel having management accountancy backgrounds should also be actively involved in the technical evaluation process, to ensure that there is complete understanding within the team of both the technical and the commercial aspects of the project.

2.2 PRE-EXPLORATION STAGE

2.2.1 General Once the presence of coal in an area has been established or reasonably inferred, a *research* stage is undertaken, during which the pre-existing data base is collated and evaluated to determine the feasibility of proceeding with the exploration using drilling and geophysical survey techniques. It may form the basis of a detailed tender for an area of land offered by the Government from a state reserve.

2.2.2 Objectives The aim of the pre-exploration stage is to make *reliable assumptions* as to the likely number, depth, extent, quality and technical potential of coal seams within the prospect.

2.2.3 Method During the pre-exploration stage, a study is made of existing—

- (a) topographical and cadastral (land subdivision) maps;
- (b) geological maps and reports;
- (c) aerial/satellite photographs;
- (d) aerial geophysical maps and photogeological studies;
- (e) local knowledge;
- (f) exploration reports;
- (g) water bore records;
- (h) drillhole records and geophysical reports;
- (i) seam and other outcrops;

- (j) environmental aspects;
- (k) land title survey; and
- (l) availability of essential services needed for mining extraction.

In the case of further interest in the prospect, the existing information should be supplemented by carrying out geological reconnaissance mapping, using the existing studies and surveys, to prepare a preliminary geological map and cross-sections. These may then be used to define the extent of the area to be explored and to select drilling targets. An exploration program can then be designed and costed for presentation to management.

Future environmental requirements should be considered and planned for at this stage.

2.3 EXPLORATION STAGE 1—REGIONAL ASSESSMENT

2.3.1 General During the first stage, it is essential to obtain a clear picture of the geology of the deposit, so that possible mining sections of known coal quality can be defined. To this end, the broad geological structure and the distribution of seams and coal ranks, grades and types are conjointly examined.

Initially, use is made of geological mapping and geophysical techniques to determine the regional stratigraphy and structure. Photogeology and other imaging techniques may also be employed at this stage to help locate the position of scout drillholes.

This stage of the exploration usually involves the drilling of a number of boreholes on a widely-spaced drill pattern at convenient locations based on existing studies and geological reconnaissance. The boreholes will be fully cored, or interspersed with rotary chip holes and geophysical logs, depending on the nature of the coal prospect.

The core of one or two boreholes, depending on the extent of the area of prospect, may be geomechanically tested to determine the strata properties over a minimum 30 m of roof and 5 m of floor of each potentially economic seam. A correlation may be developed between strata strength and geophysical logs (i.e. sonic logs), enabling an overview of the strength of the surrounding strata to be made. The properties of surrounding strata make the evaluation of likely mining methods possible.

Stage 1 is completed when potential coal seams have been positively located and defined. Decisions are then made as to the utilization potential of the coal prior to proceeding to Stage 2 or terminating the drilling.

2.3.2 Objectives Exploration Stage 1 is carried out to determine the correlation and lateral continuity of the coal seams and strata, and the likely mining methods and utilization potential for various possible end uses.

2.3.3 Methods

2.3.3.1 Geological structure Topographical and geological base maps should be prepared, using geological mapping and existing data.

If coal seams outcrop, the area should be mapped in detail in an attempt to establish subcrop lines for the seams. Prominent marker beds, such as sandstone units, should be traced to assist in the correlation of seams across the area. Geomorphological changes due to variations in lithology may assist mapping, particularly if outcrop is poor. Attention should be given to any faults, folds or intrusions (e.g. dykes) which may need to be investigated in more detail using other techniques. The geological map should be revised regularly as further information becomes available from drilling and geophysics.

Surface geophysical techniques may be employed, for example seismic refraction or ground electrical resistivity (especially for shallow seams), seismic reflection (especially for deep seams), magnetic and ‘gravity’ surveys.

These techniques share the common advantage over drilling of being relatively fast and inexpensive and, because many more data-recording points are used, a more continuous picture of the seam and its discontinuities may be obtained. These techniques do not replace drilling; they are complementary.

Unless elaborate and therefore costly methods are adopted, seismic survey suffers loss of accuracy where used at depths shallower than 300 m, or in ground having a deep and variable degree of seismic and physical weathering. In such conditions, the signal-to-noise ratio and use of filters may prevent the interpretation of faults having throws of less than 10 m to 15 m.

High-resolution techniques give improved accuracy, at increased cost, and therefore are used in the later stages.

Resistivity methods are sometimes effective for exploring shallow coal deposits; they can locate seam subcrops and fault dislocations. Aquifers and *in situ* coking may also be identified, but resistivity methods may overstate the dislocations by confusing them with other ground conditions which cause similar lineations in the apparent resistivity contour plans.

Available regional or semi-regional aeromagnetic data may be useful for delineating basins, by defining basement structure and identifying basin margins or basalt cover which could limit the areal extent of coal measures or the application of open-cut methods. Airborne and satellite multispectral images provide interpretations of regional structures and their locations, and a method of extrapolating structural conditions from better-known adjacent areas.

The construction of a depositional model may assist in predicting seam behaviour, and in anticipating significant variations in seam, roof and floor properties. It may also assist in the prediction of fault locations which are commonly localized by competent sedimentary bodies.

2.3.3.2 Seam properties Boreholes should be drilled to define resources to ‘indicated’ status.

NOTE: The Australian Code for reporting identified coal resources and reserves is presented in Appendix B.

Cores, where taken, will be of small-diameter (generally HQ (63.5 mm nominal core diameter minimum)), and will be tested on a ‘ply-by-ply’ basis, as described in Clause 6.2. This enables the geologist to detect lateral and vertical changes in quality and to correlate seams.

A composite sample, representative of the combined sections which compose the preferred mining section, should be analysed in detail to quantify the other properties of the chosen product, according to market requirements.

To enable the accurate subdivision of the seams into plies, comprehensive use should be made of geophysical logging and, where possible, of non-destructive laboratory test methods. The information so derived (e.g. X-ray radiograph, lithotype log) will also greatly assist the geologist in establishing seam correlations.

In Exploration Stage 1, it is possible that not all holes will be cored. Initial seam assessment may be carried out instead by one or more of a variety of down-hole instrumental logging techniques, such as calliper, density, natural gamma-ray, spontaneous potential (SP), apparent resistivity, neutron-neutron and sonic logs. Coal quality may be inferred, if a suitable correlation can be demonstrated between the log parameters and coal quality variation in core from adjacent drill holes.

2.4 EXPLORATION STAGE 2—RESOURCE EVALUATION

2.4.1 General The geological structure was delineated, and seams were correlated, in the previous stage. Information obtained on the quality and quantity of resources, as well as possible mining and preparation methods, was, however, indicative only. In Exploration Stage 2, the information has to be raised to higher confidence levels, to provide the basis for assessment of mining methods and costs, and of potential markets. Some preliminary testing and analysis should be carried out for spontaneous heating and combustion, outbursting and gas emission.

2.4.2 Objectives The aim of Exploration Stage 2 is to make a confident, conservative assessment of coal resources, coal quality, mining conditions and (for potential surface mines) overburden quantities, for preliminary mine and production planning and market surveys.

2.4.3 Method In Exploration Stage 2, the level of confidence in information and conclusions acquired in previous stages should be raised. Exploration in this stage involves drilling a greater number of cored boreholes. Boreholes may have devices installed, e.g. geophones for subsequent in-seam seismic surveys.

Some geophysical logs and ‘ply-by-ply’ testing may be required to complete or confirm seam correlations. By this stage, however, possible mining sections will be well-defined, and most seams will be tested on a ‘working section’ basis.

Engineering tests should be carried out on the potential roof and floor rocks from certain indicative cores, to enable mechanical properties such as compressive and tensile strengths to be determined. Similar tests may be carried out on the coal core, while still including it in subsequent working section tests and analyses.

The analyses obtained on the working sections, which will have usually been first prepared by float-and-sink separation in an organic liquid, will provide the coal technologist and marketer with more extensive information on the potentially saleable product. In addition, the increased intensity of drilling will enable the calculation of the resources to a higher status (at least ‘indicated’ for underground and ‘measured’ for open-cut potential mines). Although minimum drillhole spacings are defined for each resources category, it is accepted that the greater the variation in seam thickness and coal quality and the more complex the structure of the area, the closer is the drilling pattern required.

2.5 EXPLORATION STAGE 3—MINE PLANNING

2.5.1 General This is the *design stage*, during which exploration is aimed at providing detailed data for the design of the mine layout, the preparation plant, and the market or utilization specification. Care should be taken not to sterilize coal when designing the layout of surface facilities.

In this stage, the structural disturbances need to be well-defined, especially where longwall extraction, for which delays are very costly, is planned. It may be necessary to drill additional holes to the target seam and to make extensive geophysical surveys (e.g. seismic surveys) so that mine workings can be laid out to reduce the effects of faults and dykes.

Whereas the requirements of previous stages could be met by testing and analysis of a core broken to an arbitrary top size under laboratory conditions, it is essential that all test work in this stage be carried out on a core sample which has been first broken to produce a size distribution similar to that of the anticipated run-of-mine coal. Furthermore, for the generation of suitable coal preparation plant design parameters, the core should undergo degradation in water to duplicate the breakdown of coal and shales that would occur during a washing process. This latter consideration applies particularly to soft coals (i.e. high Hardgrove grindability index) and to seams containing soft stone bands.

Large-diameter cores (say 150 mm or 200 mm) are most suitable, since they provide enough coal for pretreatment in water by standard methods and also for a synthetic ‘product’ sample to be prepared for small-scale coke oven blend tests or combustion rig tests.

If earlier testing has indicated gas emission, coal outburst or spontaneous heating and combustion, additional testing is necessary to try to quantify the extent of the problem.

For open-cut mines, detailed chip drilling is needed to define accurately the coal seam oxidation limits.

In this stage, environmental monitoring should be implemented, so that all specific requirements of the environmental impact study (EIS), e.g. dust, noise, water quality, are covered.

2.5.2 Objectives During this stage, the objective is to derive all extra information, and to confirm existing data required for detailed drafting of mine plans, preparation plant design and market specifications. In particular, structural delineation of the seam is critical to the planning of an underground mine.

2.5.3 Method Where seams are to be mined by underground means, usual practice is that a pattern of holes be drilled immediately adjacent to the proposed mine entry site. Core from these holes is tested in detail to confirm the mechanical properties, washability and product quality of the coal to be mined in the first period, as well as to confirm the structural interpretation, particularly in the region of the entry site.

For near-surface seams, closely-spaced drilling along traverse lines or on a grid will assist in the preparation of detailed seam profiles. Hole spacing should be adequate to define seam variability and seam gradient, and to delineate faults. As seam location is the only objective of drilling these structural holes, the holes need not be cored, but should be geophysically logged to prove the seam position.

At this stage, further geophysical surveys may considerably reduce the amount of drilling necessary to locate faults and dykes.

For better design of the support of underground workings, the borehole measurement of ground stress may be considered, followed by computer simulation of stress distribution around these workings. Where the preferred method of extraction is by longwall, the caving properties of the rocks above the seam are of great importance in the design of the equipment and in the evaluation of surface subsidence.

Where surface mining is to be carried out, the drilling of roof or overburden cores is necessary to complete and confirm accumulated data on such properties as rippability, breakdown in water, mechanical strength, friability, expansion in water, permeability, cutting characteristics, water inflow, blasting characteristics and factors likely to influence high wall and spoil pile stabilities. Chip drilling, or some other suitable technique such as resistivity or down-hole logging, needs to be carried out to define accurately the limits of coal seam oxidation for low-wall definition. The chip drilling should be carried out in traverses across the strike of the inferred oxidation line. Coal chips should be collected at half-metre intervals throughout the thickness of the seam, and tested for oxidation as described in Clause 7.4.

The selection of sites for drilling larger-diameter cores will be based on results obtained from the small-diameter cores, to provide samples most representative of the range of quality which will result from future production. The increased top particle size of the broken core will enable a comprehensive test program to be carried out, using the principles of pretreatment, to provide preparation plant design data on a number of possible combinations of washing processes. A simulated washed product can be prepared from the pretreated relative density fractions and fine coal concentrate. This ‘washed coal’ should be as representative as possible of the clean coal expected from the preparation plant and should be of sufficient mass to enable—

- (a) for coking coal detailed coke oven blend studies and coke strength tests; and
- (b) for fuel coal fly-ash precipitability or other tests.

2.6 EXPLORATION STAGE 4—BULK SAMPLING OR TRIAL MINING

2.6.1 General During the final exploration (or immediate pre-mining) stage, it is necessary to obtain a greater mass of coal from the seam than is possible from a single bore core. For example, tonnage quantities may be required for trial—

- (a) processing through a full-scale or pilot-scale preparation plant;
- (b) combustion through a power station or pilot testing facility to determine grinding, burning and fly-ash collection characteristics;
- (c) coking, using either a pilot or production coke oven; and
- (d) shipment of prepared samples to prospective users.

Much valuable data can be obtained by the mining or drilling and blasting engineer during the bulk sampling stage.

2.6.2 Objective The aim of this stage is to obtain a representative sample of the coal for large-scale testing and evaluation.

2.6.3 Method The method of taking the sample will depend on the location of the seams, their number, depth, dip and the proposed mining method. For near-surface deposits, it may be economical to obtain the required mass by aggregating a number of large-diameter cores. The drill sites may be either concentrated at one location to represent the seam at a point, or spaced over an area to represent the average properties of the seam. Generally, however, the sample will be taken by trench, box cut, adit or drift. In all cases, the bulk sampling exercise will provide the colliery engineer and geologist with invaluable first-hand information on the geomechanical properties of the overburden or roof rocks, and of the coal seam itself. The nature and amount of in-seam and above-seam water flows, and seam gas emission, can also be measured.

2.7 ONGOING EVALUATION DURING MINING The evaluation of a coal deposit does not cease when mining commences. Throughout the working life of the mine, by a variety of techniques, more detailed and selective data on seam, roof and floor properties are obtained in advance and at the point of mining. These techniques include drilling, geophysics, mapping and sampling.

SECTION 3 GEOPHYSICAL SURVEYS

3.1 GENERAL A number of geophysical techniques are used for geophysical surveying. These include surface surveys, airborne surveys and underground surveys.

3.2 SURFACE SURVEYS Surface geophysical techniques such as seismic, resistivity and magnetic surveys are relatively fast and cheap, and should be considered for inclusion in an exploration program where geological conditions permit. If successful, they provide a broad picture of the seam, and may highlight areas for subsequent structural drilling.

These techniques have limitations, and are best considered as complementary to drilling. Consultation with specialist companies that provide these services will give a full picture of the costs, benefits and limitations of a geophysical survey.

Examples of some techniques available are as follows:

- (a) Surface resistivity measurements—to trace boundaries of shallow oxidized coal, concealed igneous rocks and near-surface faults.
- (b) Magnetic profiling—to indicate some aspects of igneous rock occurrences, e.g. to locate dykes.
- (c) Seismic velocity measurements of near-surface rocks—to predict rippability.
- (d) Seismic reflection methods—to assess broad structural trends and locate faults.

3.3 AIRBORNE SURVEYS

3.3.1 Aeromagnetics Aeromagnetic surveys map the distribution of magnetic materials and, as such, can identify many aspects of the geology. In coalfields, particular success has been achieved because—

- (a) dykes and sills are usually magnetic, and may be identified by aeromagnetic techniques;
- (b) other igneous bodies, e.g. granitic intrusions, can usually be mapped;
- (c) in areas of basalt cover, magnetic methods may easily locate windows in the basalt;
- (d) regional structural information can be obtained, and this can then be usefully related to the more detailed structure; and
- (e) an indication of basin thickness can often be inferred from the data.

3.3.2 Aeroradiometrics Aeroradiometrics is usually conducted in conjunction with aeromagnetic surveys. Most of the radiometric signal reaching the aircraft is derived from the top 0.5 m of the ground. This reduces the technique's effectiveness to areas of very limited overburden or to areas having residual soils. However, in suitable areas, aeroradiometrics yields a substantial amount of geological information which is useful in determining the overall geological picture. Recent imaging techniques have facilitated the interpretation of these data.

3.3.3 Electrometrics Electrometrics is of value in identifying near-surface faults and the boundaries of shallow coal.

3.3.4 Parameters When planning aeromagnetic and aeroradiometric surveys, many parameters need to be set and included in a contract. The more important of these are—

- (a) flight-line separation;
- (b) flight-line direction;
- (c) detector height;

- (d) magnetometer sampling rate;
- (e) spectrometer sampling rate; and
- (f) tie-line separation.

3.4 UNDERGROUND SURVEYS

3.4.1 In-seam seismic surveys In-seam seismic (ISS) surveys are commonly used for mapping structural features ahead of mine workings and within blocked-out areas.

Three methods are used, as follows:

- (a) *ISS reflection*—for exploration ahead of workings for geological structures or old workings.
- (b) *ISS transmission*—for workings to workings, borehole to borehole, or workings to borehole exploration of structural features or old workings.
- (c) *ISS tomography*—for exploration for structural or stress features within coal blocks surrounded by mine workings.

3.4.2 Radio-imaging method The radio-imaging method is used for identifying structure and lithology within blocks of coal surrounded by mine workings.

SECTION 4 DRILLING

4.1 GENERAL Current drilling practice involves the use of various types of rigs, equipment and methods in the evaluation of coal deposits.

The success of a drilling program is largely dependent on well-maintained, up-to-date equipment, competent operators and, where contractors are used, good relations between the client and the drilling contractor. A comprehensive specification for exploratory drilling is essential to ensure this.

NOTE: Aspects of the drilling contract are discussed in Appendix C.

4.2 THE DRILL RIG

4.2.1 General The choice of rig depends on the nature of the available access, the maximum target depth, and the type of drilling required. The rig may be truck-mounted, with multi-wheel drive vehicles being used to obtain satisfactory traction in areas having locally steep track grades or poor track foundation materials. Where greater depth is required, it may also be skid-mounted on jacks.

4.2.2 Diamond drill Diamond drilling units may come as specialist core-drilling rigs—trailer-, skid- or truck-mounted—or as top head drive hydraulic rigs. Modern diamond rigs are fitted with hydraulic heads, automatic chucks and hydraulic rod and casing breakout equipment.

4.2.3 Rotary rig For non-core drilling and conventional non-wireline drilling to depths of approximately 400 m, the mobility and speed of drilling of rotary rigs puts them at a significant economic advantage over the conventional diamond drill rig. Rotary rigs are eminently suitable for open hole work, e.g. ‘scout’ drilling.

4.2.4 Top-drive hydraulic rig The top-drive hydraulic rig is a popular choice for coalfield drilling. It has the ability to vary rod speed and is thus suitable for both rotary chip and hammer drilling, as well as core drilling. The rig can also be used for angle drilling, and many are fitted with complex mobile drilling tables and slide-mounted masts. The rig has its drill head located in the mast and the length of the stroke and size of the drill rod or casing being handled are limited only by mast length and design. All operations on the drill are hydraulically driven; thus the control may be conveniently situated for easy operator control.

4.3 NON-CORE DRILLING

4.3.1 Soft superficial formations Most soft superficial formations are readily drilled using blade bits. These bits are either of unitary construction or have replaceable blades with tungsten carbide tips or inserts, and are of variable shape and profile to suit the formation conditions. Because of their high penetration rate, relatively low cost and ease of maintenance, blade bits provide the most economical means of non-core drilling, particularly where high velocity air circulation is used. They also produce coarser cuttings which are more readily identifiable geologically than cuttings produced with roller bits.

4.3.2 Hard formations In order of increasing hardness of formation, the following bits can be used:

- (a) *Roller bits*, which are of unitary construction with various cutter designs, mainly with tricone rollers having tungsten carbide teeth of varying shape. These bits require considerable pressure to operate effectively. Roller bits are relatively expensive and have a limited life owing to failure of roller bearings and cutting teeth wear.

- (b) *Polycrystalline diamond (PCD) bits*, which are rotary bits with cutters or posts faced with synthetic diamonds. These bits offer longer life in hard formations than do roller bits, but they need to be used with water or mud circulation. The bits are of high initial cost, but the cutters can be refurbished several times.
- (c) *Rotary percussion down-hole hammers*, which are preferred for the hardest formations. Drilling may be limited by depth and water inflows where such hammers are used with coal exploration rigs, and roller bits may be required with water circulation under these conditions.

Although the initial cost of hammers is relatively high, long life and ease of maintenance make them more economical than roller bits.

4.3.3 Air circulation The use of air as the circulating fluid is desirable geologically, as it enables more accurate recording of depth of formation changes, and enables the ground water environment to be more easily observed.

Also, penetration rates are appreciably higher using air circulation rather than water circulation for lubrication. However, a high-capacity and high-pressure (e.g. 400 L/s, 2.5 MPa) source of compressed air is needed to enable this technique to be applied as deeply as possible, or in holes where cuttings return is impeded by pervious zones or by water inflow (which may otherwise require water circulation to achieve progress). Cuttings return in deep holes can be assisted by water injection, or by use of foam.

4.3.4 Water circulation Water circulation is more inconvenient because of the need to provide water, by either tanker transport or pipeline, to the drill site. Where water circulation is essential, the information obtained from drill cuttings may be inaccurate or misleading, unless the holes are geophysically logged.

4.4 CORE DRILLING

4.4.1 Borehole size The selection of the borehole size is influenced by the quantity of recovered core required, the interpretation of geological data, and a number of other factors (particularly economic).

The cost of cored holes increases with the size of the cores and the depth of the hole. The mass (in kilograms) of coal recovered from cores is approximately $d^2/900$ per metre, where d is the diameter of the core, in millimetres.

As the core diameter decreases, there is an increased tendency for fracture of the core (due to high stress) and for core losses to increase, especially in soft and friable strata.

The effects of core loss and fracture are significant in interpreting geological data, from both a stratigraphic and a strength view point. Generally, the larger the core size the better the recovery, particularly in soft formations. Large-diameter core also reduces the effect of surface erosion of the bright coal bands.

4.4.2 Barrels A conventional core barrel with a triple tube system, comprising core barrel with stationary inner tube and removable splits, ensures maximum recovery under all conditions.

However, continuous coring at all depths and coring deep measures is now carried out with wireline equipment which enables continuous coring without removal of the drill stem.

The wireline method comprises an outer barrel and bit assembly attached to special drill rods, an inner barrel assembly attached to the wireline through a swivel, and an overshot assembly which is lowered through the rods to unlock and retrieve the inner assembly.

The triple-tube system is invariably used with either wireline or conventional drilling systems.

The wireline method has the disadvantage of producing a slightly smaller core diameter for the same hole size than a conventional core barrel.

The core and hole sizes vary with the individual types of barrels supplied by equipment manufacturers.

Table 4.1 indicates examples of the sizes of barrels that are commonly used for coal.

TABLE 4.1
BARRELS COMMONLY USED FOR COAL

Type	Size			
<i>Wireline barrel (triple tube)</i>	<i>NQ</i>	<i>HQ</i>	<i>PQ</i>	
Core diameter, mm	45	61	83	
Hole diameter, mm	76	96	123	
<i>Conventional core barrel (triple tube)</i>	<i>NMLC</i>	<i>HMLC</i>	<i>'4-inch'</i>	<i>'6-inch'</i>
Core diameter, mm	53	63	102	150
Hole diameter, mm	76	100	165	210

Wireline barrels and some conventional barrels incorporate bottom-discharge waterways for drilling fluid circulation, pressure valves to indicate core blockage, improved core lifters to minimize core loss through dropped core, and a pressure line to extrude the inner split tube and core.

Larger-diameter conventional barrels, to cut cores of diameter greater than 150 mm, are also available.

4.4.3 Rods The rod diameter should be as large as possible in relation to the barrel being used, and this relationship becomes increasingly important as depth of the hole increases.

Rods should be straight, to reduce vibration and wear and to assist in core recovery.

4.4.4 Bits For continuous coring using wireline methods, step-faced, bottom-discharge diamond bits are used. Side-discharge bits, and bits set with polycrystalline diamonds, can also be used. All of these bits require water as the drilling fluid, to enable satisfactory cooling and lubrication of the bit.

Tungsten carbide bits, however, are generally satisfactory for coring in softer formations and, unlike the diamond bit, can be used with air as the circulating fluid.

4.4.5 Orientated core To obtain orientated core, various instruments have been developed for use with standard wireline or conventional barrels.

The orientated core is used to determine strata dip, stress and paleocurrent directions. Structural petrofabric analyses and petrographic analyses may be made on thin sections of the core.

4.5 DRILLING FLUIDS AND ADDITIVES Drilling fluid additives are sometimes necessary to prevent fluid loss, improve penetration rates, assist in the smooth running of the drill stem and reduce down-hole tool wear. Polymer-based drilling additives have replaced bentonites and soluble oils for most water-based drilling operations. The polymers can be used in small quantities, produce a thinner and stronger wall cake, and control rod vibrations more effectively than bentonites and soluble oils. Coal core used for chemical analysis is not contaminated by the polymer-based additives.

Fillers such as Portland cement, flaked cellulose and treated shredded paper are sometimes required to overcome loss of circulation in badly fractured formations.

4.6 CASING AND COMPLETION OF HOLES Casing is often necessary to retain the unstable upper sections in holes where the strata are likely to cave. Steel or polyvinyl chloride (PVC) casing can be used. PVC casing is preferred for shallow holes, or where high strength is not required. However, it lacks wear resistance and rigidity, and is difficult to handle in the hole.

Oversize drill rods with shoe bits are commonly used; high tensile steel casing is preferred for deep holes, and is generally retrieved if a suitable mud is used in the drilling.

All completed holes (except those drilled in open-cut prospects) are cement-plugged from the bottom to at least 30 m above the highest potentially workable coal seam, to prevent ingress of water into any subsequent underground workings. Tests should be conducted on the formation water to determine whether it adversely affects the setting characteristics of the cement. Geophones and piezometers are commonly cemented in the hole at time of completion. A cement pad and marker are placed over the completed hole.

4.7 DIFFICULT DRILLING Difficult drilling conditions are sometimes imposed by non-cohesive superficial deposits, irregularly weathered, fractured and blocky volcanic rocks, soft, friable overburden and some coarse-grained sedimentary rocks.

Non-cohesive sands and silts may require casing to solid rock to ensure that coring operations can be successfully completed without the jamming of the core barrel in the hole. Loose deposits of boulders may prevent the penetration of casing.

In the above instances, a reverse-circulation technique may be appropriate. This involves the use of a dual-tube drill pipe, whereby the circulating fluid passes down the outside and returns up the inside. The walls of the hole are thus not subjected to the scouring action of the circulating medium and, as the hole is virtually fully cased, the risk of the hole caving in is reduced and an uncontaminated sample is produced.

In some highly stressed coal seams, the coal seam sometimes squeezes onto the barrel behind the bit. As circulation is cut off, the pump pressure rises, increasing the effect of closure, which either jams the barrel in the hole or blows the rod upwards against the hydraulic down-feed of the rig. This is sometimes overcome by coring with a truncated triangular-shaped, oversize bit on a standard NMLC core barrel, or with the use of an oversize reamer, if practicable.

4.8 SURVEY OF THE HOLE All holes should be accurately located by survey and their positions recorded on plans.

In deep bores and those penetrating steeply inclined strata, the hole may deviate from vertical, giving misleading information on depths and dips. Borehole inclination measurements should be made in these situations.

SECTION 5 DRILLING SITE FUNCTIONS

5.1 GENERAL At the drilling site, it is essential that standard procedures be established for recording drilling data and for the geological logging and sampling of drill cuttings or cores. Boreholes should be named in a consistent way, e.g. the company name (or abbreviation), a locality name, a code for the type of hole (e.g. DDH for diamond drill holes) and the hole number.

Recorded observations and measurements of gas flows, loss of circulation and water flows are also of value.

Wireline geophysical techniques may be applied down the hole to provide supplementary information on the coal seams and rock formations.

It is important to observe and record the maximum amount of data at the drilling site, as it may not be until after mining has commenced that the full importance of seemingly trivial detail will become apparent.

The site should be restored, as nearly as possible, to its original condition.

5.2 DRILLING THE HOLE When the borehole is being drilled, the following important information should be recorded:

(a) *Drilling data*

- (i) Hole number.
- (ii) Date of drilling and seam coring.
- (iii) Hole location, ISG coordinates, elevation.
- (iv) Depth intervals of various types of drilling (i.e. of blade, bits, hammer or core drilling).
- (v) Drilling penetration rates and bit usage.
- (vi) Type of core barrel and core bit.
- (vii) Type of circulation fluid, and depths and degree of loss of circulation during drilling.
- (viii) Hole, bit and core diameters.
- (ix) Details of hole casing and stand pipe.
- (x) Core recovery and reasons for core losses.

(b) *Rock formation cuttings*

- (i) Rock type.
- (ii) Composition.
- (iii) Depth to top and base of units.
- (iv) Colour.
- (v) Grain size and sorting.
- (vi) Occurrence and type of fossils.
- (vii) Occurrence and type of minerals.

(c) *Coal seam cuttings*

- (i) Depth to top and base.
- (ii) Coal lithotypes.

- (iii) Stone bands.
- (iv) Degree of oxidation, e.g. oxidized (sooty), partly oxidized (hard coal but iron-stained), or visually unoxidized.
- (d) *Hydrogeological data*
 - (i) Depth to top and base of aquifers (with detectable make of water).
 - (ii) Measured rate of inflow, e.g. air-lift pumping and V-notch weir, or container filling time.
 - (iii) Fluctuation of water levels, e.g. sub-artesian or artesian.
 - (iv) Water quality comments, such as turbidity, smell, taste, salinity; major inflows should be sampled.
 - (v) Standing water level after stabilization (generally 48 h after drilling).

NOTES:

- 1 Significant water flows should be reported to the appropriate regulatory authorities.
- 2 Any significant water flows can be measured by V-notch weir measurement, which should be conducted at the conclusion of drilling in any wet holes.

- (e) *Geotechnical data*
 - (i) Degree of weathering.
 - (ii) Estimated strength, based on chip hardness and penetration rate.
 - (iii) Unusual mechanical properties of chips, e.g. soft and puggy, firm or hard clay.

5.3 LOGGING, FIELD TESTING AND REMOVAL OF CORE

5.3.1 General The prerequisites for accurate sampling and logging of drill cores are disturbance-free retrieval from the core barrel, and secure storage and packaging of cores in the interval between drilling and testing.

Core should be drilled using a split inner tube barrel to deliver the core in an undisturbed condition.

Where a drilling contract includes a guaranteed core recovery, any core loss should be assessed and endorsed on-site with the drilling contractor.

Core is normally stored in steel or aluminium boxes. For core that is to be stored for some time, steel boxes having lids are recommended. The core should be placed in the boxes in a consistent way. A driller's block, showing the depth at the end of the drilling run, the length drilled in the run, and the length recovered, should be placed at the end of the core from each run.

Blocks should also be placed at the top and bottom of the core stored in each box, to indicate the arrangement of the core in the box and the depth interval stored in the box. The box should be clearly labelled on the end and inside the lid, with the borehole name, box number and the core depth interval contained in the box. When coal or other core is removed for sampling, wooden blocks indicating the amount of sample removed, the purpose of the sampling and the name of the sample should be placed in the space.

Full core boxes are heavy, and care should be taken that they are not stacked in a dangerous manner or against government safety regulations. Care is also needed to avoid back or other injuries in lifting and moving boxes.

5.3.2 Core logging

5.3.2.1 Rock strata Coal measures commonly exhibit marked changes in rock type, composition and texture which, to some degree, reflect variations in mechanical properties and the relative strengths of the roof and the floor in underground or surface mines.

Descriptive logs of rock cores should use accepted geological terminology. The description of sedimentary rocks should be based on grain size, colour, grain composition, grain fabric and stratification patterns, and cementation.

The mechanical properties of core should be described, including weathering and alteration, estimated intact strength, spacing and surface features of discontinuities, such as joints, faults, slickensides, fractures and bedding planes and weak beds that could be susceptible to breakdown.

Photographs of the drill core also provide a useful record of the rock strata, and may be of value as an appendix to the lithological log.

5.3.2.2 Coal seams Accurate lithotype logging is not possible on a machined, wet and muddy coal core surface. Detailed lithotype logging therefore should be carried out on split core in the laboratory, as described in Clause 6.1.4.

In cases where the hole has been drilled using air circulation, lithotype logging is often carried out at the drilling site. Such logging should be confirmed and refined in the laboratory as stated above. Valuable details on the coal seam should be recorded in the field, preferably while the core is still in the split tube. These include—

- (a) coal lithotype;
- (b) depths of marker or stone bands;
- (c) location and amount of core loss;
- (d) approximate dip of seam;
- (e) cinder zones;
- (f) loose partings;
- (g) slickensided surfaces, joints, fractures, fault zones;
- (h) seam thickness; and
- (i) minerals present and their mode of occurrence.

The washed core and immediate roof and floor plies should be photographed (in the split tube or later in the core box) in colour, preferably using a colour reference card for colour control and a scale rule.

5.3.3 Field tests Qualitative physical field tests on cores are numerous; the range adopted in practice is chosen to suit particular engineering objectives.

Examples of simple tests available for use on either coal seams or adjacent strata are as follows:

- (a) Knife blade tests on weak, non-brittle rocks.
- (b) Impact strength index (ISI) test for relative strengths of coal.
- (c) Water reaction test on sedimentary rocks liable to immediate breakdown when moistened.
- (d) Accelerated weathering test on rocks containing incipient parting planes, clay or similar minerals liable to swelling, fretting or disintegration.
- (e) Moisture adsorption tests, as a guide to clay mineral composition.
- (f) Point load strength evaluation, offering a guide to the relative strengths of the strata or coal. This test can be conducted at the drill site or in the laboratory (see Clause 6.3.3).
- (g) Strain relaxation tests, using strain gauges attached to the core immediately after retrieval.

- (h) On-site hydraulic fracturing test to establish the magnitude and orientation of maximum and minimum horizontal stress components. This requires a test interval of uniform intact rock as long as the test tool (currently 3 m), and core samples of the test interval.
- (i) Borehole photography or television viewing, utilized for specific targets above standing water level.

5.3.4 Core removal The core should be carefully removed into tubes or boxes. One method of removal into tubes is by—

- (a) placing a PVC (or aluminium) half tube over the core exposed in the bottom split of the barrel inner tube;
- (b) carefully inverting the PVC tube and replacing the barrel tube with another PVC half tube;
- (c) carefully binding the PVC tubing and plugging both ends; and
- (d) where coals are of low rank or samples are required for geotechnical testing, either sealing the tube by encasing the bound tube in clear polyethylene tubing, before inserting in the core box, or sealing the core in clear plastic film and coating with wax.

5.4 DOWN-HOLE GEOPHYSICAL WIRELINE LOGGING

5.4.1 General Down-hole geophysical logging records various physical properties of strata in a borehole, either directly, or by recording the response of the strata to various physical stimuli. In certain cases, important chemical properties may be inferred from the physical properties recorded. Data may be reported in analog (chart record) or digital form.

Logging equipment comprises a control/recording unit connected to a down-hole tool (sonde) by a wireline cable attached to a winch which lowers and retrieves the sonde in the borehole. Control of the sonde operation and retrieval of data are effected through a signal wire located in the core of the wireline cable.

Geophysical logging has long been recognized in the petroleum exploration industry as an essential complement to a drilling program. In more recent times, slim-hole explorers, in particular those in the coal exploration field, have come to realize the similar benefits to their own drilling programs, to the extent that the majority of coal exploration companies now log all boreholes drilled. This increase in demand for slim-hole logging has been accompanied by increasingly complex down-hole equipment and data processing software being developed by logging contractors.

Geophysical logs allow accurate definition of lithological boundaries which can only be estimated from chip cuttings. They can indicate formation changes not identified from chips and, most importantly, in the case of holes where sample return is contaminated or otherwise inadequate, they allow accurate interpretation of lithologies continuously throughout the borehole. In such cases, geophysical logging provides maximum information from a borehole which would otherwise be worthless. In addition, various logs can provide other information such as porosity, comparative and quantitative rock strengths, friable/fracture/fault zones, water inflow zones, strata dip and azimuth, coal quality, as well as other properties that are not normally available from chip logging alone.

Figures 5.1 to 5.4 illustrate interpretations of lithologies typically encountered in sedimentary sequences, using the most appropriate combinations of logs for the various samples.

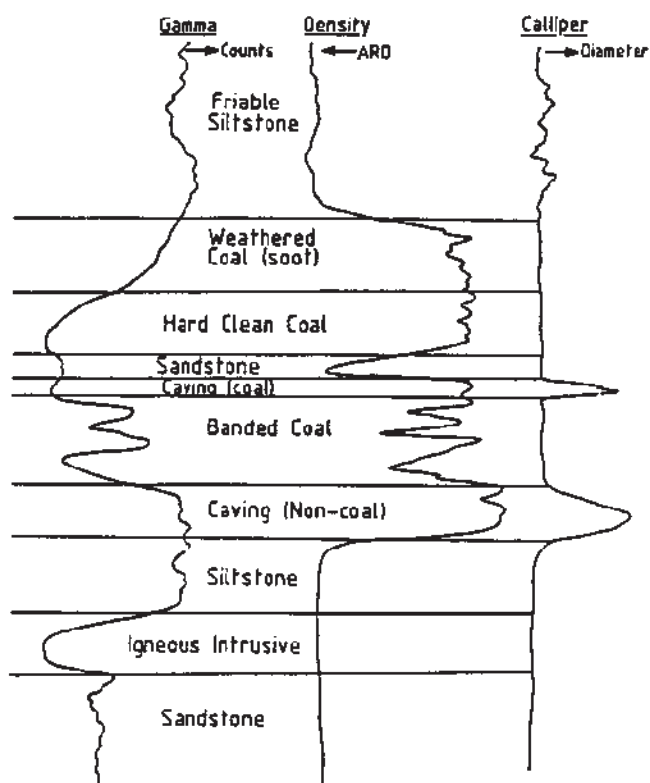


FIGURE 5.1 COAL INTERPRETATION

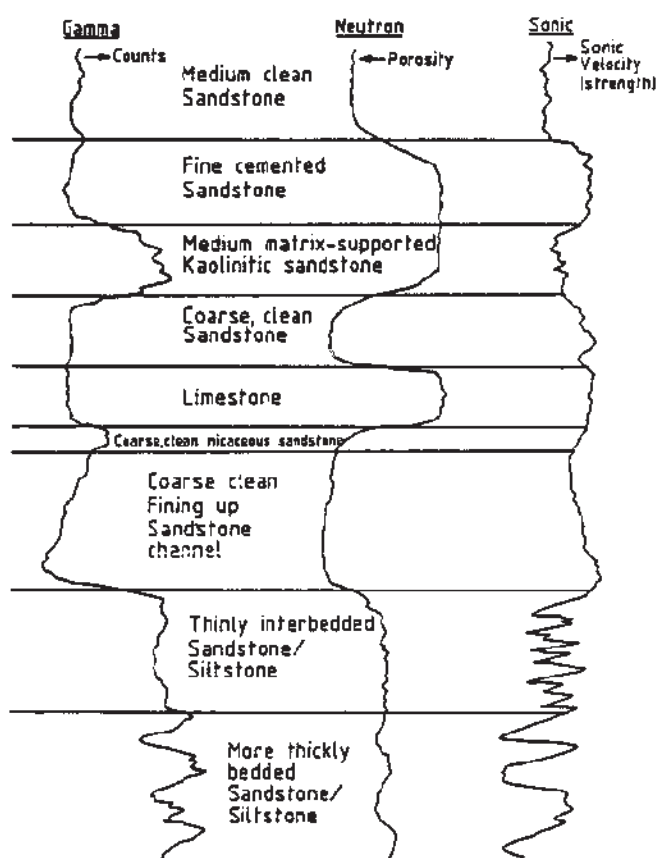


FIGURE 5.2 SANDSTONE SEQUENCE INTERPRETATION

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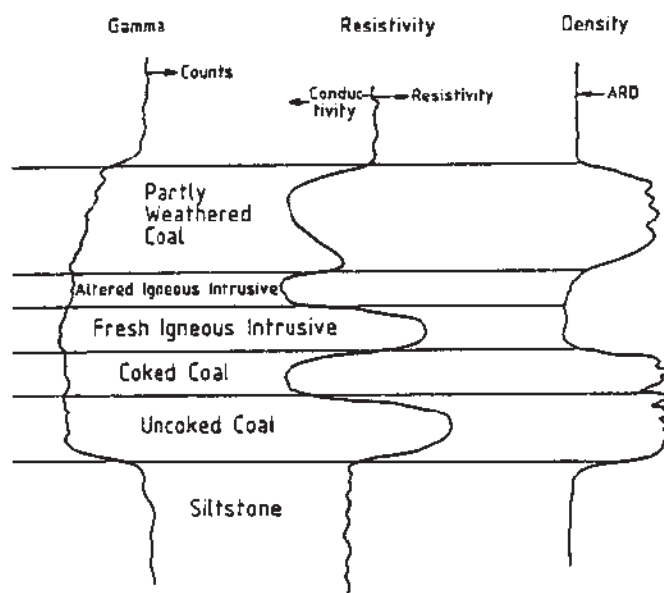


FIGURE 5.3 INTRUDED COAL INTERPRETATION

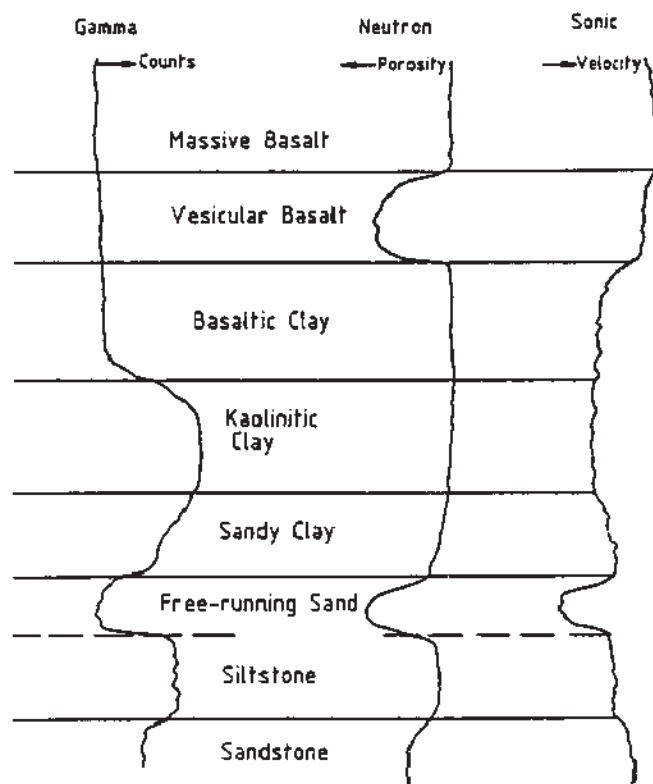


FIGURE 5.4 TERTIARY SEQUENCE INTERPRETATION

5.4.2 Types of geophysical logs The most commonly run logs are as follows:

- (a) *Nuclear logs*, consisting of—
 - (i) gamma-gamma density;
 - (ii) natural gamma; and
 - (iii) neutron-neutron.
- (b) *Electric logs*, consisting of—
 - (i) single-point resistivity;
 - (ii) focussed electric; and
 - (iii) dipmeter (using micro-resistivity).
- (c) *Direct physical readings*, consisting of—
 - (i) sonic velocity logs;
 - (ii) calliper logs; and
 - (iii) temperature logs.

5.4.3 Nuclear logging

5.4.3.1 Gamma-gamma density logging In the gamma-gamma density log, the density sonde comprises a radioactive source (caesium-137) which emits high-energy gamma rays into the strata. Two gamma detectors, usually spaced at 150 mm and 480 mm from the source, measure the radiation returned after collision with electrons of the strata. The two logs resulting are referred to as short-spaced or bed resolution density (BRD) and long-spaced density (LSD), respectively. To function effectively, the gamma-ray source must be in contact with, and directed towards, the wall of the borehole. This may be achieved by the use of bow-springs on the sonde but, more usually, a calliper arm is set opposite the source window, serving the dual purposes of providing a log of hole irregularities and maintaining maximum contact between source and borehole wall.

It is essential that density logs always be interpreted in conjunction with the calliper log, as caving of the borehole wall provides a volume of low-density fluid between the source and strata, resulting in an artificially low density being recorded (see Figure 5.1). The short-spaced density is more susceptible in this regard, due to its shorter area of influence and consequent shallower penetration. The long-spaced density is minimally affected, except in the worst instances of strata caving and, as such, is regarded as a reliable stratigraphic indicator. The BRD log is more sensitive and, in favourable hole conditions, is an accurate indicator of stone banding within coal seams.

Known correlation factors allow presentation of logs as apparent bulk density of strata. Logs are usually presented for the full borehole at 'normal' scale of 1:200 or 1:100. Logs through coal seams are normally replayed and presented at a larger scale, usually 1:20. The BRD in combination with the gamma log is presented as 'seam thickness log', whereas the LSD/gamma logs are presented as 'coal quality log'. As the name implies, the coal quality log may be processed to provide quantitative estimates of ash percentage and density over various defined seam horizons. Provided that sufficient bore core analytical data are available for reliable correlation, it may be possible for the explorer to minimize the costly coring and analysis components of a drilling program.

Density logs are universally regarded as the best coal/non-coal stratigraphic indicators, since the bulk densities of all non-coal strata in coal basins are very similar and much higher than coal. Non-coal lithotypes cannot generally be differentiated.

5.4.3.2 Natural gamma logging In natural gamma logs, the natural gamma sonde encloses a sodium iodide (NaI) scintillation crystal which measures the gamma radiation emitted by radioisotopes occurring naturally in the strata. The principal source of radioactivity in coal measure sediments is the potassium-40 isotope, although thorium and

uranium also occur in trace amounts. Therefore, fine-grained, clay-rich rocks exhibit a relatively high gamma count, whereas coarser, more siliceous strata and, in particular, coal have very low counts. This makes the natural gamma log an excellent tool for lithological definition. The natural gamma log normally provides definition of seam roof/floor to an accuracy of 10 cm. It is also a good indicator of sandstone grainsize, and gradational fining/coarsening can usually be identified. The natural gamma log has the additional advantages of being unaffected by hole caving, recording equally well in dry or fluid-filled holes and not requiring an artificial radioactive source, thereby avoiding handling problems and regulatory requirements. It also provides a log of acceptable quality when run inside drill rods or steel casing. With these advantages, the natural gamma log is an ideal all-purpose log which is suitable for running a compact portable logging unit using company personnel with minimal training. This practice enables immediate facilities for correlation of strata in areas of limited data or steeply dipping formations, as well as highlighting geophysical anomalies which may be checked while fresh drill cuttings are available. In addition, depths for ensuing coring at the chip hole site for target seams/strata may be accurately defined.

The natural gamma log does have several limitations, as outlined below, but these can generally be overcome by assessment in conjunction with no more than one other geophysical log. The limitations are as follows:

- (a) Coal seams cannot be accurately defined if the immediate roof or floor is composed of a similarly low gamma material such as coarse or cemented sandstone or limestone. Density logs are referred to in such cases.
- (b) Gamma count increases with coal oxidation, so that weathered seams are generally indistinguishable from adjacent strata. Density or resistivity logs are used in this case (see Figure 5.1).
- (c) Typical material intruding into coal seams, e.g. dolerite, exhibits similar gamma counts to coal. Density logs as well as sonic, neutron and, generally, resistivity will accurately define intrusive horizons (see Figure 5.3).
- (d) Differentiation of discrete lithological units in sandstone sequences may be masked or exaggerated by the presence or absence of kaolinitic clay minerals in the sandstone matrix. Proportion and mineralogy of matrix are also not generally apparent from drill cuttings. Likewise, an abundance of mica in sandstones tends to increase gamma count. Neutron logs are excellent indicators of porosity and, therefore, of tightness in sandstones, as are sonic logs, which are also good indicators of stronger cemented zones (see Figure 5.2).
- (e) Thinly interbedded sequences tend to exhibit little gamma variation, owing to the 'averaging' effect of the relatively insensitive sonde. Sonic logs are often the best indicators of thin interbedding (see Figure 5.2) with high-resolution neutron likely to produce similar results.

Together, the gamma and density/calliper logs may provide all the coal and non-coal lithological information required in certain drilling programs. In recognition of this fact, the commercial logging service companies have developed the coal combination sonde (CCS), which provides gamma, long and short-spaced density, as well as calliper logs in a single logging run. This sonde obviously improves the cost efficiency of a geophysical logging program. One minor aberration of this configuration is that, in dry sections of the borehole only, the natural gamma detector tends to record some of the scattered radiation generated by the density log source. The resultant increase in background gamma count is usually consistent, but care should be exercised in inferring lithological changes on the basis of gamma only at the standing water level.

5.4.3.3 Neutron-neutron logging In neutron-neutron logs, the neutron sonde comprises a radioactive source, providing a continuous output of high-energy neutrons and a detector to record the neutrons reflected, the remainder of the output having been absorbed by the

strata. As hydrogen has the major influence on the nuclear deflection, the neutron log depicts the water content of the strata, which by inference correlates with porosity below the borehole water level. The neutron log parallels the gamma log, and is therefore a useful stratigraphic indicator in its own right, but neutron and gamma logs should be considered together to optimize interpretation of a basic sandstone sequence. Neutron logs also show a contrast between sandstone and limestone, which may be indistinguishable in gamma logs (see Figure 5.2).

5.4.4 Electric logging

5.4.4.1 General Electric logs measure the relative resistivity/conductivity of the strata on application of an electric current. They are good stratigraphic indicators, subject to the nature of the strata being investigated. Fresh coal of bituminous rank and above is clearly defined, being a strong electrical resistor. Conversely, weathered coal becomes relatively conductive, thereby providing accurate oxidation limits if the seam roof is defined by density log.

5.4.4.2 Single-point resistivity logging A unique attribute of the resistivity log is its ability to define coked coal, which is also strongly conductive relative to unaltered coal (see Figure 5.3). It is possible that coking may be detected also by neutron or sonic logs in high-temperature coking of lower rank coal, where the coke tends to be more porous.

5.4.4.3 Focussed electric logging In recent times, the most widely used electric sonde is the focussed electric sonde, which has shields to direct the current laterally into the strata, resulting in greater sensitivity of readings. This log has largely superseded the less precise, single-point resistivity (SPR) sonde.

5.4.4.4 Dipmeter logging The dipmeter provides dip and dip azimuth of down-hole strata. It is discussed here, as results are obtained by processing of electrical data. The sonde consists of three or four micro-resistivity pads, set equidistant from each other and mounted on sprung calliper arms to maintain constant contact with the wall of the borehole. The sonde is orientated relative to true north and lowered into the borehole. Computer processing of the three or four highly sensitive resistivity logs matches similar log profiles if possible. In the case of dipping strata, the matching profiles will be at different depths. Using those different depths and knowing the borehole diameter and orientation of each pad, dip and strike are calculated by a complex mathematical equation.

The precision of the logs produced by the dipmeter indicates that micro-resistivity may provide the most sensitive log for small-scale lithological definition, such as identifying stone partings in seams. However, the process requires absolute smoothness of hole walls as well as stable fluid conditions, and it is not widely used at this time.

5.4.5 Direct physical reading techniques

5.4.5.1 Sonic velocity logging The sonic log measures the transit time for an emitted acoustic pulse between the sonde's source and its two or four receivers. Stronger, more competent strata exhibit shorter transit times (greater sonic velocity) than weaker strata. Good correlation between the sonic velocity (expressed in microseconds per foot) and measured rock strength has been established and unconfined compressive strength (UCS) may be estimated from the sonic velocities recorded. Sonic logs are being increasingly used, for the principal purposes of fracture/fault location, rippability, and for optimizing charging/stemming in blast design.

Sonic logs have been reported as being good coal and lithological indicators and this is true in many cases, particularly in defining interbedded silt/sand sequences. However, weaker zones may be due to open jointing, fracture or fault zones rather than lithological changes. The definition of such features is a benefit of sonic logging, but can be reliably inferred only in conjunction with better lithological logs, such as gamma logs. Coal seams are also difficult to define in many instances by sonic logs alone, with coal exhibiting similar velocities to the weak clay-rich rocks that frequently occur in seam roofs and floors.

5.4.5.2 Calliper logging The calliper log measures borehole diameter and can therefore define caved zones and friable/fractured horizons. It will also accurately define casing depths and locate any parted casing joints. It is also of value in confirming depths of cored intervals which may be of value in estimating core loss.

The single calliper tool comprises three or four arms, opposed at 120° or 90°, which are opened down-hole and sprung to maintain contact with the borehole walls as the tool is raised in the hole. However, as described previously, the calliper device more frequently comprises a single arm opposite the radioactive source window and on the density and CCS sondes. This configuration saves an additional logging run, but the single-arm calliper log may be less accurate, as caving of hole walls may not necessarily be symmetrical.

5.4.5.3 Temperature logging Temperature logs, which can record spot temperatures or temperature gradients, are rarely used in coal exploration. They may indicate *in situ* coal seam heating or water inflows, should these data be necessary.

Down-hole logging equipment may also be used for other functions such as borehole deviation surveys, *in situ* stress measurement, pressure testing or sidewall coring.

5.5 GAS EMISSION TESTING

5.5.1 Pressure testing In-seam gas pressure can be determined with the aid of a borehole, inflatable packing device, pressure gauge and a length of pressure line. The packing device is equipped with one pressure line to allow inflation and pressure tapping, which enables the pressure build-up behind the packer to be sensed by means of the pressure line connected to the pressure gauge. The inflatable section of the packing device is of sufficient length to form an effective seal against the surface of the hole.

If an excessive amount of water is present in the hole, it is removed prior to taking any pressure measurements. Care has to be taken to ensure that seam gas pressure, and not hydrostatic water pressure, is measured.

There are technical problems associated with the determination of seam gas pressure, due to such factors as variations in coal permeability, leakage past seals, difference between pore pressure and virgin seam pressure.

5.5.2 Seam gas analysis All coal seams cored in an underground mining prospect should have their seam gas content and composition determined. The method for this determination is given in AS 3980.

Seam gas is present in coal seams in the form of adsorbed and absorbed gas. Part of the gas is attached to the surfaces of the coal, and is liberated as the coal surfaces are exposed. The remainder is weakly attached to the micropore surface of the coal, and is liberated at a slower rate.

When a core of coal is removed from a seam and the pressure is reduced below the *in situ* pressure, there is some loss of both absorbed and adsorbed gas.

The method involves the sampling of the coal core in a special canister at the drill site. The rate of gas release is measured on site for one hour, and extrapolated back to time zero to determine the lost gas. The sealed canister containing the coal core can then be transferred to a laboratory and the gas allowed to desorb freely to practical completion.

The volume of desorbed gas is measured, and recorded as 'measurable gas'. The coal core is removed from the canister, weighed, subsampled and crushed to fine powder for the residual gas content to be determined. The sum of the 'lost gas', 'measurable gas' and the 'residual gas', divided by the mass of the coal sample, determines the seam gas content, expressed in cubic metres per tonne or cubic metres per cubic metre of coal.

Desorbed gas, either diluted by air or undiluted, should be collected for analysis and the composition expressed on an 'air-free' basis. Seam gases consist of methane and other hydrocarbons, with carbon dioxide, nitrogen and small amounts of carbon monoxide and hydrogen.

The analysis of the seam gas, together with the estimated *in situ* volume and pressure, assists the mining engineer in determining the most likely underground mining methods and pit layout, taking into account the probable ventilation requirements and the likelihood of seam outbursts or gas ignitions. It also gives an initial indication of the requirement for gas pre-drainage and potential for use.

5.6 DATA RECORDING Various computer systems are available for the storage, processing and retrieval of the large amounts of data obtained from coal exploration and mine development drilling.

In the field, the geologist enters the lithologic data on a specially set-out coding sheet (see Figure 8.5), using abbreviations in appropriate columns, for subsequent transcription by a keypunch into the computer. Alternatively, the data can be entered directly into a field-portable computer unit at the drill site, and transferred directly to the project's main database.

5.7 HANDLING THE CORE

5.7.1 General The coal core may be subdivided in the field, or sent to the laboratory for detailed logging and sampling, depending on which stage the exploration or development drilling program has reached.

Non-coal core, particularly roofs and floors of important coal seams, is commonly retained for such purposes as geotechnical testing, or for later reference.

5.7.2 Field subdivision Where the sampling intervals can be identified with certainty at the drilling site, precluding the need for non-destructive evaluation in the laboratory, subdivision of the core can be carried out in the field. Packaging in an airtight and non-corrodible container, properly identified inside and outside, secures the sample for delivery to the laboratory.

One advantage of field subdivision is that the core can be transported to the laboratory without loss of moisture. This can allow seam moistures to be determined in the lower rank bituminous and sub-bituminous coals.

5.7.3 Packaging for laboratory subdivision Particularly in the first stages of exploration, it is desirable, and sometimes essential, to transport the core to a laboratory in an undisturbed condition for detailed logging and testing. If the coal core has to be packaged in sections, division should be made at stone bands or at an obvious change in lithology.

When removed from the barrel and transferred to a protective container, it is essential that the core be securely packaged for transportation to the laboratory with minimum delay and disturbance to the core. X-ray radiography will be assisted by the marking of the cleat direction on the container, prior to despatch to the laboratory.

5.7.4 Packaging of non-coal core Non-coal core is usually packed in partitioned core boxes.

The top and bottom depths of each core run, and the length of core recovered from the run, should be identified using marked wooden blocks, or similar labels, placed in the appropriate partitions in the core boxes. Likewise, similar labels should be used to identify intervals of core removed for analysis or testing.

Each box should be labelled at least to identify the borehole and the core interval stored in the box.

SECTION 6 LABORATORY TESTING AND ANALYSIS

6.1 NON-DESTRUCTIVE TESTS

6.1.1 General Non-destructive tests are those tests that are conducted without disturbing or changing the core in any way. Some tests which disturb the core may also fall into this category, provided that the core can be reassembled afterwards into the ‘as-received’ condition.

The five tests described in this Clause are X-ray radiography, lithotype logging, lump-sample relative density determinations by immersion and gamma-ray attenuation, and ash estimation by portable XRF analysis. Information derived from these tests can greatly assist the geologist in establishing or confirming seam correlations and in subdividing the core (see Clause 6.2). The tests are usually applied to small-diameter cores, but may be applied to large cores.

6.1.2 X-ray radiography Where test facilities are readily available, X-ray radiography should always be the first of the non-destructive tests carried out. Testing in the ‘as-received’ condition ensures that the X-ray record most closely reflects the ‘*in situ*’ ply configuration of the seam.

In this procedure, the coal core is moved at a uniform speed through a collimated beam of X-rays, with the residual radiation which has passed through the core being recorded on X-ray sensitive film immediately below it; the X-ray absorption is a function of the density of the material through which it passes, modified slightly by atomic number. Pure coal has little X-ray absorption; hence low-ash sections in the core are registered as a dark image on the developed X-ray film. Stone bands completely stop radiation of the intensity used in this procedure, and thus register as a clear image.

With boxed core, handling is facilitated by lining the compartments with thick plastic film, which can be lapped over and taped so that the core can be lifted straight onto the carriage of the radiography unit. Where core is packed in tubes as described in Clause 5.3.4, it can be radiographed while still in the tube. Clear plastic tubes are preferred. Opaque plastic or aluminium tubes can be used, but will not give as clear an image because of their additional X-ray absorption.

A static procedure, such as that used for medical or weld examination purposes, can be used, but does not usually produce as clear an image as the collimated beam technique.

The X-ray radiograph offers numerous benefits, including the following:

- (a) A detailed and permanent, full-size, objective record of the mineral matter distribution of the seam is produced without the core having been disturbed.
- (b) Pyrite, siderite and calcite stand out clearly.
- (c) Because film density decreases with the percentage of mineral matter, it gives a semi-quantitative estimate of the amount of ash (in other words a qualitative assessment can be made of the mineral matter distribution throughout the seam). This correlates well with the ash percentage as analysed.
- (d) Dull, low-mineral content coals are readily distinguishable from carbonaceous shale.
- (e) The presence of vitrain bands can often be inferred from the occurrence of calcite in the cleats. Cleat calcite is indicated by white traces on the film perpendicular to the bedding plane.
- (f) The coal preparation engineer can make an immediate judgment on the degree of difficulty of preparing the coal. For example, the mineral matter in a coal ply could be present as—

- (i) evenly dispersed nodular siderite;
- (ii) finely interbanded coal and non-coal;
- (iii) uniformly high inherent mineral matter; or
- (iv) distinct bands of coal and non-coal.

Even though an ash determination on all the above plies may yield the same result, the plies in each case would vary considerably in terms of their ease of preparation.

6.1.3 Relative density of lump sample Lengths of core of uniform character (lithotypes or combinations of lithotypes) are weighed in air and in water. The lump relative density is determined by dividing the mass in air by the loss in mass on weighing in water (see AS 1038.21.2). The selection of core sections for the test is facilitated by referring to the X-ray radiograph. It is also permissible to do a trial lump relative density test on fragments of core, which afterwards should be carefully replaced.

The test is a measure of the relative density of the length of the core, and includes any voids that may be present in the core. The results are, therefore, lower in value than the true density of the coal matter and slightly lower than the relative density determined on the crushed coal analysis sample (see Clause 6.7.3.1).

Lump relative density test results are essential where preparing sections for analysis by making composites of ply samples in the correct proportions by mass, and also for determining the volumetric core recovery obtained by the drillers.

As an exploration program develops, it will be possible to establish a general relationship between lump relative density and ash values of plies for each seam. It may be useful, where correlating a seam from bore to bore, to compare graphical profiles of lump relative densities or estimated ash values for each seam section.

6.1.4 Lithotype logging Lithotype logging involves accurately recording the length and description of the various rock types and coal types present in the core.

Rock lithotypes include all of the rocks that may be encountered in coal seams—predominantly lutites, such as shale, siltstone, and mudstone—but may sometimes include sandstones and intrusive igneous rocks. It is important to describe the mechanical and compositional nature of the stone beds as completely as possible, as these observations may help in identifying marker beds which can be used in seam correlation or may assist the coal preparation engineer when considering analytical requirements and processing implications.

Coal lithotypes are macroscopically recognizable coal varieties that are discerned by the geologist on the basis of relative brightness using the standard brightness categories listed in Table 6.1 (see AS 2916). This visual categorization basically reflects the microscopic content of the maceral vitrinite (see AS 2856).

Before detailed logging is commenced, it is recommended that the core be carefully measured and the position or depths of several easily recognized lithotype units within the seam be established. This will help minimize core expansion and loss of relativity of units due to removal and splitting of core for detailed logging.

TABLE 6.1
STANDARD COAL BRIGHTNESS CATEGORIES

Brightness designation	Coal description
BR	Bright (greater than 90%)
BB	Bright with dull bands (60% to 90% bright)
BD	Interbanded dull and bright (40% to 60% bright)
DB	Mainly dull with frequent bright bands (10% to 40% bright)
DM	Dull with minor bright bands (1% to 10% bright)
DD	Dull (less than 1% bright)

6.1.5 Gamma-ray attenuation tests A borehole core analyser has been developed for the production logging of the density and ash values of freshly retrieved coal drill cores in the field or laboratory. The core analyser, known by the acronym CORAN, is based on gamma-ray attenuation, and has been designed as a portable instrument. The basic analyser consists of a high-energy and low-energy gamma-ray source, a NaI (Tl) gamma-ray detector and associated electronics. The borehole core is placed in the path of a well-collimated gamma-ray beam from the sources, and the detector measures the attenuation of the gamma rays.

The attenuation experienced by the high-energy gamma rays is a measure of the density of the borehole core section. The ash value is derived from the attenuation experienced by both the high-energy and low-energy gamma rays.

The instrument is automated with the aid of a microcomputer. Laboratory and field measurements on borehole cores have shown that density and ash values can be measured to within 0.015 g/cm³ and 1 percent ash, respectively.

6.1.6 Portable XRF analysis Portable XRF analysers can be used for the rapid (non-destructive) measurement of ash and certain elements in coal. Ash determination is based upon measurement of backscattered electromagnetic radiation from a sample of coal. The intensity of the backscatter varies inversely with ash value, and is also influenced by the constituent elements and their concentrations. Interferences are minimized by selection of a specific radiation source for particular elements (notably iron, calcium and titanium).

Accuracy of the determination varies with the concentration of interfering elements and ash level. Trials on one particular unit have achieved 1.0 percent (absolute) on one coal seam only and accuracies ranged between 1 percent and 5 percent (absolute) on three other seams, in the broad range of 10 percent to 80 percent ash.

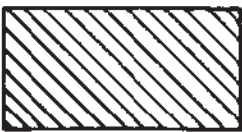
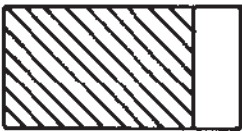
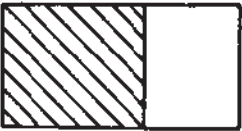
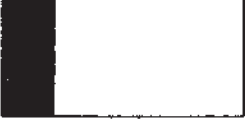
6.1.7 Colour photography Colour photography of all sampled coal seams is a recommended practice. If carried out properly, the photographs can serve many useful purposes after the coal is destroyed by analysis. Situations where colour photography may be useful include the checking of sample intervals and non-coal content if analysis is uncharacteristic of the sampled interval, identification of previously unrecognized marker beds for correlation purposes, and providing a visual representation of the coal seams for prospective purchasers of coal prospects.

Photography of coal core should be carried out both before the core is disturbed and after logging and sample division. All depths and sample intervals should be clearly marked with chalk or white metal markers, and the seam and sample intervals should be recorded on a separate blackboard in chalk and included in the photograph. It is a good idea to mark each lithotype boundary on the core or on the edge of the core box with chalk, so that, if necessary, the units can be matched against the log at a later time. An appropriate scale such as a builder's white ruler should be included in the photograph.

Photography is best done indoors with appropriate flood lighting and filters to give realistic colour reproduction. Prints and negatives should then be catalogued for subsequent retrieval. Good quality photographs can be enlarged to natural scale if necessary. A core photography book should be kept and each photograph logged into the book with all relevant details, including film and exposure numbers, bore number, seam name, interval photographed and date.

6.2 SUBDIVISION

6.2.1 General Subdivision involves dividing coal cores into samples of comparable, equivalent, correlatable intervals for the purpose of assessing vertical and lateral variations in coal quality of a seam.

Symbol No.	Symbol		Abb.	Description
	Shading system	Line system		
1			BR	COAL—bright (greater than 90% bright)
2			BB	COAL—bright with dull bands (over 60% and up to and including 90% bright)
3			BD	COAL—interbanded dull and bright (over 40% and up to and including 60% bright)
4			DB	COAL—dull with common bright bands (over 10% and up to and including 40% bright)
5			DM	COAL—dull with minor bright bands (over 1% and up to and including 10% bright)
6			DD	COAL—dull (up to and including 1% bright)
7			CE	COAL—sapropelic undifferentiated

(a) Symbols to illustrate abundance of dull and bright lithotypes

FIGURE 6.1 (in part) SYMBOLS USED FOR THE REPRESENTATION OF COAL SEAM CHARACTERISTICS

Symbol No.	Symbol		Abb.	Description
	Shading system	Line system		
8			PA	Pale brown to yellow. Wood present, but uncommon
9			LT	Light brown. Medium to low wood content
10			ML	Medium brown to light brown. High to low wood content; often well preserved
11			MD	Dark brown to medium brown. High to medium wood content; often large pieces
12			DK	Black brown to dark brown. High wood content; often small fragments

(b) Symbols to illustrate variations in colour and texture

FIGURE 6.1 (in part) SYMBOLS USED FOR THE REPRESENTATION OF COAL SEAM CHARACTERISTICS