GEOTECHNICAL FIELD OPERATIONS

Geotechnical field operations are best conducted during and in association with exploration and resource assessment drilling. The purpose of this work is to characterise the rock mass and its structural features for the purposes of determining the engineering behaviour of the rock mass and to locate major structural defects. The associated data analysis provides a concise suite of results consistent with mine design and numerical modelling input.

The field work includes detailed core logging. It may also advantageously incorporate:

- Borehole geophysics
- Stress measurements
- Groundwater fluid measurements

It should also be accompanied by rock strength measurements, which may be conducted in part in the field or otherwise in the laboratory.

Sigra provides the experienced field personnel with the capability to conduct the standard exploration drilling supervision and analysis in conjunction with the geotechnical aspects essential to mine design and specific mining related problems.

Core Logging for Geotechnical Purposes

This is split into three stages of logging: the first to capture lithological information, the second to capture the orientation of structural orientation and the third for examination of structural features and determination of rock strength.

Lithological Logging

The first pass of core logging is to obtain information on the core lithology. This stage of logging is preferably conducted with the core still in one of the inner splits of a triple tube core barrel. If a triple tube barrel is not being used the core is reassembled immediately on its extraction from the inner tube to an alternative split. It is accompanied by the photography of the core in 1 m intervals.

Lithological logging is undertaken according to local requirements and with compatibility with the geological data base in use. One the prime purposes of this stage of logging is the management of depths and the location of zones of core loss.

Structural Feature Orientation Logging

Where the core is not excessively fractured, Sigra measures three points on each structural feature while it is in the split. This enables the dip and relative dip direction to be calculated.

These features are normally finally oriented by comparison with Acoustic Televiewer (ATV) images rather than by use of core orientation systems.

Examination of Structural Features and Assessment of Rock Strength

This third stage of core logging involves opening the core to examine any jointing and its infill, and to separate natural from drilling or handling induced breakage. The strength of the rock is also assessed. Any lithological information that could not be gained from the first stage of logging, while the core was still in the split, is added.

The core is then packed into 1 m length core trays with depth markers and re-photographed. Core may then be removed for mechanical testing and the removed sections marked.

Core Photography

Core photography is an important part of geotechnical analysis to provide a permanent record of core condition at the time of recovery. Colour photographs can show details and characteristics that cannot be easily recorded or conveyed on borehole logs.

Core is photographed in the split immediately after retrieval. The core is placed in the core box. Zones of core loss are marked and depths are marked at the end of each row of core. The core is then re-photographed.

Geophysical Logging

Sigra uses geophysical logging (by a third party) to determine lithological units in open holes and confirm logged depths in cored holes. The standard suite of logs for lithological purposes includes:

- Calliper (or three arm calliper) to determine borehole wall deterioration and its effect on other log records;
- Density provides a method of determination of the carbonaceous content in coal bearing sediments. Various logs are usually provided, including bed resolution to determine contacts and compensated logs for coal density determination;
- Natural gamma logs provide a non-spectral record of the natural radioactive differences between different rock units;
- Sonic logs provide relative strength of rock units at different depths;
- Focussed electric (FE, resistivity) logs measure the resistance to current flow in the borehole wall. It is common to plot the short and long spaced FE data logarithmically in opposing directions. This gives a picture of contrasted response in different rock units. This log also has the potential to give information on fluid flow into the hole under specific conditions.

Logs that provide specific quantitative geotechnical information should also be utilised. These include:

- Acoustic Televiewer (ATV) gives an image of the return of a sonic pulse from the borehole wall both in amplitude and travel time. Because the image is oriented, the direction of the major principal stress can be determined from borehole wall breakout, and the orientation and intensity of natural discontinuities can also be determined using specialised software. This log requires a water filled borehole.
- Optical Televiewer (OTV) provides an oriented optical image of the borehole wall and is analysed as for the ATV. This log can be run in an open hole or through clear water.
- Full Wave Form Sonic (FWS) records the time taken for acoustic pulses from a number of source – receiver arrays (usually four) to travel through the borehole wall and return as the sonde is raised through the borehole fluid. The time taken for the returned signals are combined to provide an image of the separate components (Stonely or tube wave, the compressive wave and the shear wave). With a knowledge of these components, dynamic elastic properties of the strata can be computed using fundamental equations. The dynamic UCS can also be derived from the compressive wave slowness by empirical correlation. The FWS log requires a fluid filled borehole.

Rock Stress Measurement

Sigra can undertake rock stress measurement in five ways. These are:

IST-2D overcoring

This overcoring technique is used with HQ or PQ sized wireline coring. When used in conjunction with suitable core testing for elastic parameters it provides information on the stress field perpendicular to the borehole. The technique is suitable for near vertical holes. It is quick to perform, requiring approximately one hour interruption to coring for holes up to 100 m depth and a six hour interruption for 1000 m holes. A tool for use in boreholes of any orientation is in development.

IST-3D overcoring

This involves overcoring a glue-in cell. It is available for HQ coring only. It is suitable for use in any orientation hole and depths up to 1000 m. When used in conjunction with suitable core testing for elastic parameters it provides information on the full stress tensor. The test cycle is normally a full 24 hour process per test.

Hydrofracture

This involves the hydrofracture of an intact borehole wall using straddle packers. The minimum stress is determined by the closure pressure of the fracture. The major stress can only be determined if the stress acting in the axis of the hole is greater than the transverse stress. The analysis can be complex, especially where the borehole is not aligned with a principal stress direction. Sigra operates this test in HQ sized core holes using HRQ drill pipe with its proprietary sealing system. Alternatively, depending on location, Sigra may supply high pressure tubing for hydrofracture testing.

Hydrojacking

This is a variant of hydrofracture that is used to open pre-existing fractures and measure the normal stress to the fracture by examining the pressure decline for fracture closure pressure. Sigra operates this test in HQ sized core holes using HRQ drill pipe with its proprietary sealing system. Alternatively, depending on location, Sigra may supply high pressure tubing for hydrojacking.

Borehole breakout analysis

Utilising information from Acoustic Televiewers, or in some cases Optical Televiewers, Sigra can examine the hole wall record for breakout, or in some cases tensile cracking. These measurements may be used to gain information on the principal direction of stresses and the ratio of stress at the borehole wall to rock strength. This method of stress assessment can be used anywhere where breakout occurs in the hole. The method does not delay field operations.

Core ovality measurement

Sigra measures the ovality of core with its own precision device which rotates the core and measures its diameter in multiple locations to better than one micron. From this measurement, and the use of suitable core elastic property measurement, it is possible to determine the difference between the major and minor stresses acting perpendicular to the core. The measurement can also be used with estimated parameters to obtain information on the variation of the stress difference along the length of core. The method is quick and easy to use and does not delay field operations. It can be used on core from 45 to 83 mm diameter.

Ground Fluids

Sigra measures ground fluid behaviour and installs permanent ground fluid pressure monitoring systems. It uses a variant of drill stem testing (DST) adapted from oilfield practice for permeability measurement, as it offers significant advantages over methods normally used in groundwater. Sigra also measures directional permeability and storage behaviour by various interference techniques including pulsed tests. Sigra has a variety of techniques for measuring gas in rock.

Drill Stem Testing (DST)

Sigra measures the permeability of rock primarily by the use of the DST test. This provides information on fluid pressure, permeability and near well bore losses. The system is normally used as a production test to avoid injecting borehole fluids into the rock. The system provides infinitely superior results to packer testing and is much quicker and more economical to use than conventional pumping tests. A variant of the test uses a closed chamber to retrieve sample fluid.

The standard system is designed to be operated in conjunction with HQ coring. Other systems are available on request.

Pulsed Testing

This is an interference test that can be conducted from one hole to another to provide information on directional permeability and storage parameters. It offers significant advantages in separating inhomogeneity from anisotropy of fluid behaviour. In its standard form it involves conducting a DST test in the formation of interest in one hole. A pressure sensing system is then left in the hole and another is drilled and DST tested. This provides two mean permeabilities plus a directional permeability. The system can be extended to test more holes.

Gas Content Testing

Sigra offers four options to determine the gas content of rock. These are:

Core desorption – suitable for carbonaceous rock with adsorbed gas.

Simple chip desorption – used with open hole drilling. It is suitable for carbonaceous rock with adsorbed gas.

Gas content while drilling – This is a system designed to measure all gas contained in rock including that in pore space. It is designed to be used with open hole drilling and requires some level of adaption to the drilling equipment.

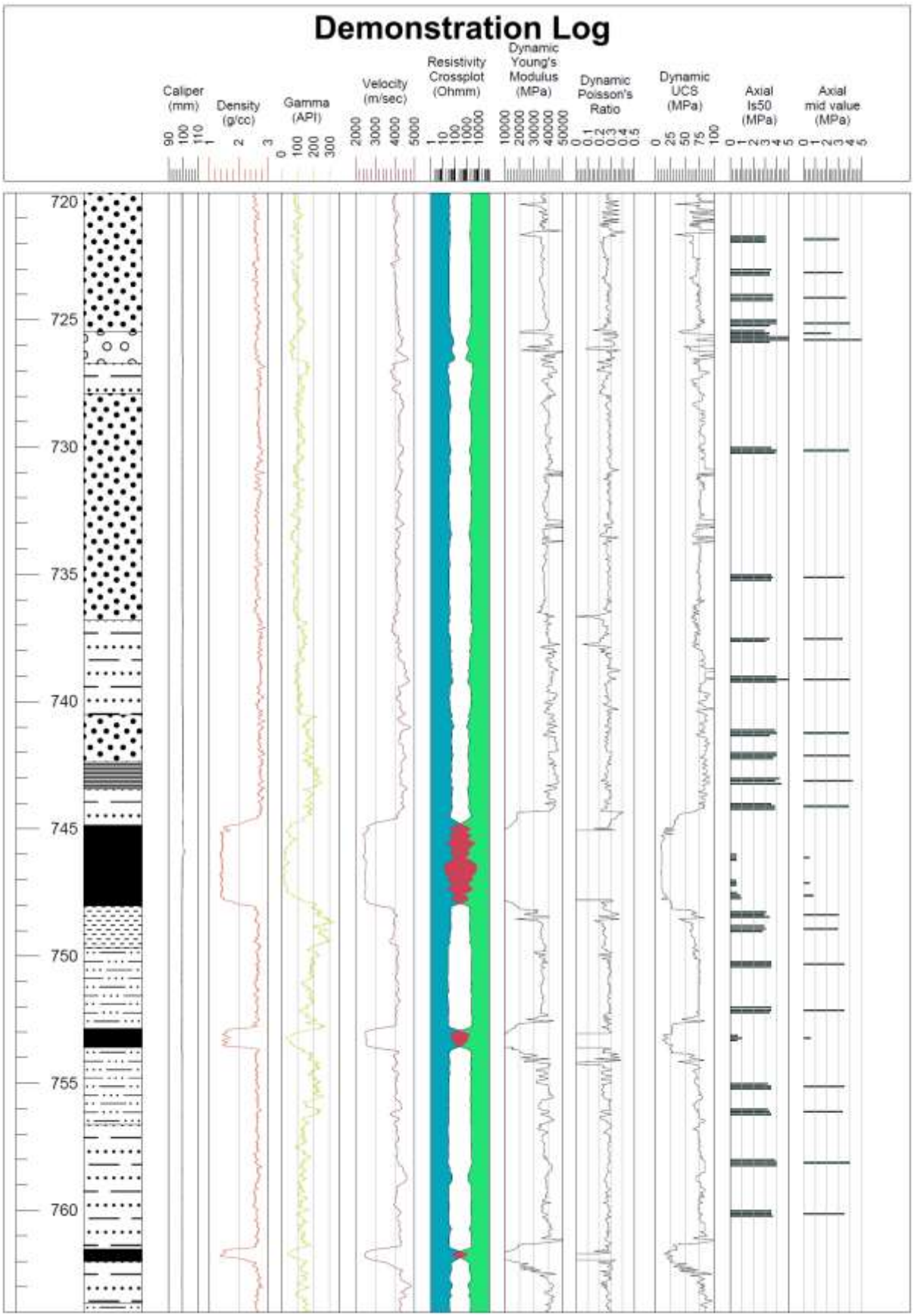
Gas capture core barrel – This is a modified HQ coring system designed to collect all gas held within core within the inner barrel.

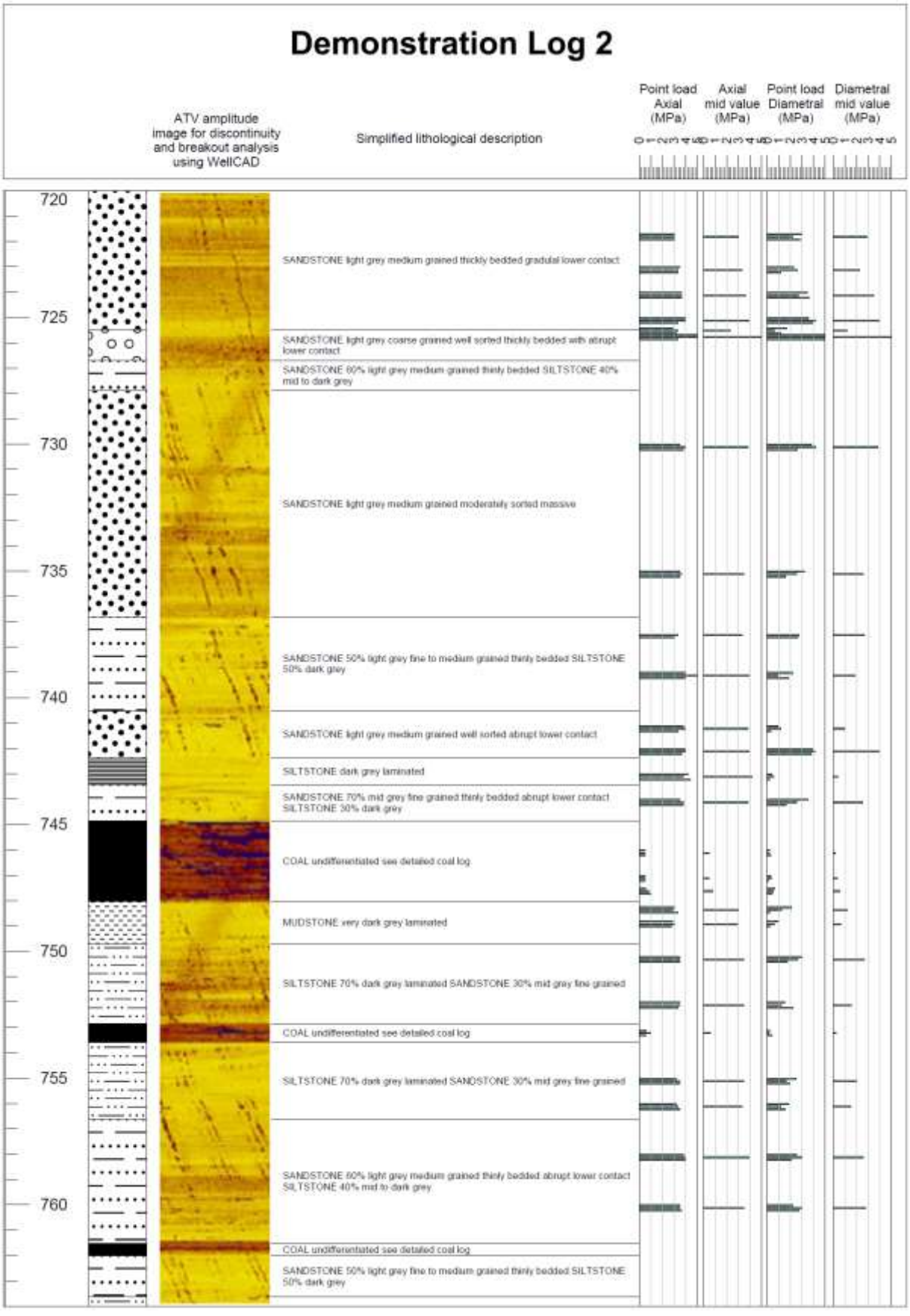
Pressure Monitoring (Piezometers)

Sigra installs permanent fluid pressure monitoring systems that include:

Conventional piezometers
Piezometers installed by cement (grout) displacement
Packer systems

Sigra can supply global remote monitoring systems to acquire data from these installations.


Demonstration Log
Caliper (mm)
90 100 110
Density (g/cc)
1 2 3
Gamma (API)
0 100 200 300
Velocity (m/sec)
2000 3000 4000 5000
Resistivity Crossplot (Ohmm)
1 10 100 1000 10000
Dynamic Young's Modulus (MPa)
10000 20000 30000 40000 50000
Dynamic Poisson's Ratio
0 0.1 0.2 0.3 0.4 0.5
Dynamic UCS (MPa)
0 25 50 75 100
Axial Is50 (MPa)
0 1 2 3 4 5
Axial mid value (MPa)
0 1 2 3 4 5
720
725
730
735
740
745
750
755
760


Demonstration Log 2
ATV amplitude image for discontinuity and breakout analysis using WellCAD
Simplified lithological description
Point load Axial (MPa)
Axial mid value (MPa)
Point load Diametral (MPa)
Diametral mid value (MPa)
720
725
730
735
740
745
750
755
760
SANDSTONE light grey medium grained thickly bedded gradual lower contact
SANDSTONE light grey coarse grained well sorted thickly bedded with abrupt lower contact
SANDSTONE 60% light grey medium grained thinly bedded SILTSTONE 40% mid to dark grey
SANDSTONE light grey medium grained moderately sorted massive
SANDSTONE 50% light grey fine to medium grained thinly bedded SILTSTONE 50% dark grey
SANDSTONE light grey medium grained well sorted abrupt lower contact
SILTSTONE dark grey laminated
SANDSTONE 70% mid grey fine grained thinly bedded abrupt lower contact SILTSTONE 30% dark grey
COAL undifferentiated see detailed coal log
MUDSTONE very dark grey laminated
SILTSTONE 70% dark grey laminated SANDSTONE 30% mid grey fine grained
COAL undifferentiated see detailed coal log
SILTSTONE 70% dark grey laminated SANDSTONE 30% mid grey fine grained
SANDSTONE 60% light grey medium grained thinly bedded abrupt lower contact SILTSTONE 40% mid to dark grey
COAL undifferentiated see detailed coal log
SANDSTONE 50% light grey fine to medium grained thinly bedded SILTSTONE 50% dark grey