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Successes and Future Challenges For Longwall Mining in Structured Ground

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SUCCESSES AND FUTURE CHALLENGES FOR LONGWALL MINING IN STRUCTURED GROUND

BY I STONE

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ABSTRACT: The experiences from the recent 3 years at Springvale Mine have highlighted once again the importance of understanding the geological structure at a mine site. Springvale Mine previously had a history of difficult roof conditions, although not clearly linked to geological structure. From mid 1998 a series of complex strike slip fault structures were encountered, one set running with and along the commencement of the 404 Panel gateroads. The unexpected faulting, its critical location, and unknown extent had a serious impact on panel development and business performance. Even the most carefully constructed business plan and budget is quickly damaged by an unwelcome geological surprise.

INTRODUCTION

The experiences contained in this paper are focussed on Springvale Mine. In doing so the uniqueness of the Springvale site is stressed. Particular geological interpretations, methods used, geotechnical analysis and roof support systems that have been used with success at Springvale may not be appropriate elsewhere. Each mine has its own "geological grain" and geotechnical character. Before dismissing the Springvale methods as site specific, they are worth checking for a broader application at other mine sites.

Geological structure at Springvale impacted in a number of ways:

- physical weakening of the strata caused by fracturing
- changes to the stress direction and an increased stress magnitude
- dramatically increased strata support requirements for both development and longwall roadways
- different mining systems to support the ground
- required radical changes to the panel layout to keep the panel moving forward

This paper is not intended to provide a description of the Springvale geology. Rather it attempts to look at the nature of the issues encountered with geological faulting and the types of approaches taken to plan for mining future fault zones. Springvale mines the basal 3m of the combined Lithgow – Lidsdale seams at a depth of 260m – 380m.

FOUR PRINCIPLES FOR SUCCESS IN STRUCTURED GROUND AT SPRINGVALE

To the extent which it is possible an attempt is made to encapsulate 4 principles used at Springvale which might be transferable to other sites. In any case the Springvale experience will be explained within those 4 categories as they were the areas within which work concentrated.

1. Reliable geological structural model for the mine site. To be comfortable that the types of faults, their most likely orientation, continuity, frequency and the mining impact, for both development and longwall, is understood to, say an 80% reliability.
2. Reliable geotechnical understanding of typical mining conditions. The ability of a mine site to extend a geotechnical understanding to variable fault affected conditions will depend on knowing zone locations.
3. Appropriate strata control hardware or methods to support both development and longwall extraction.
4. Efficient strata control installation systems, which include equipment, systems, manning and specialist teams.

Three other strategies important to success were:

- allowing the site personnel to have responsibility and authority for their area of work. Success would depend on developing skills to understand and "own" the problem. In 1997 Springvale corporate management, in the midst of a number of unresolved geotechnical based issues, gathered together a group of some 20+ industry experts to comment or recommend. You will not be surprised to learn that no unity of thought emerged. The subsequent operational strata control methods were ultimately unsustainable. A consequence of this process was the very limited control or ownership of solutions by site personnel.

- a clear understanding of the business risk associated with geological structure. Budgets and mine plans need to be developed with realistic time and cost allowances. For example, de-rate advance rates using historical information.

- focus on returning balance to the development progress of Mains Panel and the Gateroad Panel. The lack of appropriate Mains development did not allow access for the required inspection, and exploration for future mine and business planning (not to mention the level of inventory required to cope with any future poor mining conditions)

STRUCTURAL GEOLOGY

Background

At the time of unexpectedly mining into a complex N – S strike slip fault zone in mid 1998 it was difficult to forecast fault location because:

- the structural model of the western coalfield, based essentially on lineament zones, following rigorous work by John Shepherd and associates, (and to some undefined extent on the presence of swilleys) did not fit. From Springvale's viewpoint the lineament model was not mine site specific to the extent it provided the likelihood of fault location, intensity, type and extent. It was a zone, of variable width, which contained "slackey rolls" – seemingly a catchall term for very soft faulted ground including complex thrust structures.
- Springvale had not intersected any previous significant faulting, and in particular none which was associated with high horizontal stresses – providing extreme mining conditions.
- It was likely that these structures have very little displacement (< 1m and typically less than 0.3m)

Springvale's working roof is approximately 4m of coal with inter-bedded claystone units. Within this unit:

- faulting can fracture the coal into fine "sugar coal" which has no inherent strength; and
- faults use the claystone to extend laterally.

Fig. 1 shows, as example, the location of the main N – S fault zone at the start of the 404 Panel. The development of 404 panel was delayed by approximately 3 months because of the unexpected fault zone and its difficult mining conditions. To progress the panel and meet production contract commitments, some key roadways were driven around the faulting. Roadways were driven into both longwall blocks 404 and 405, with obvious longer term cost consequences.

Initially some inseam drilling was used to navigate roadways around the immediate structure zone. The continuity of the structure northward remained uncertain with the existing information base.

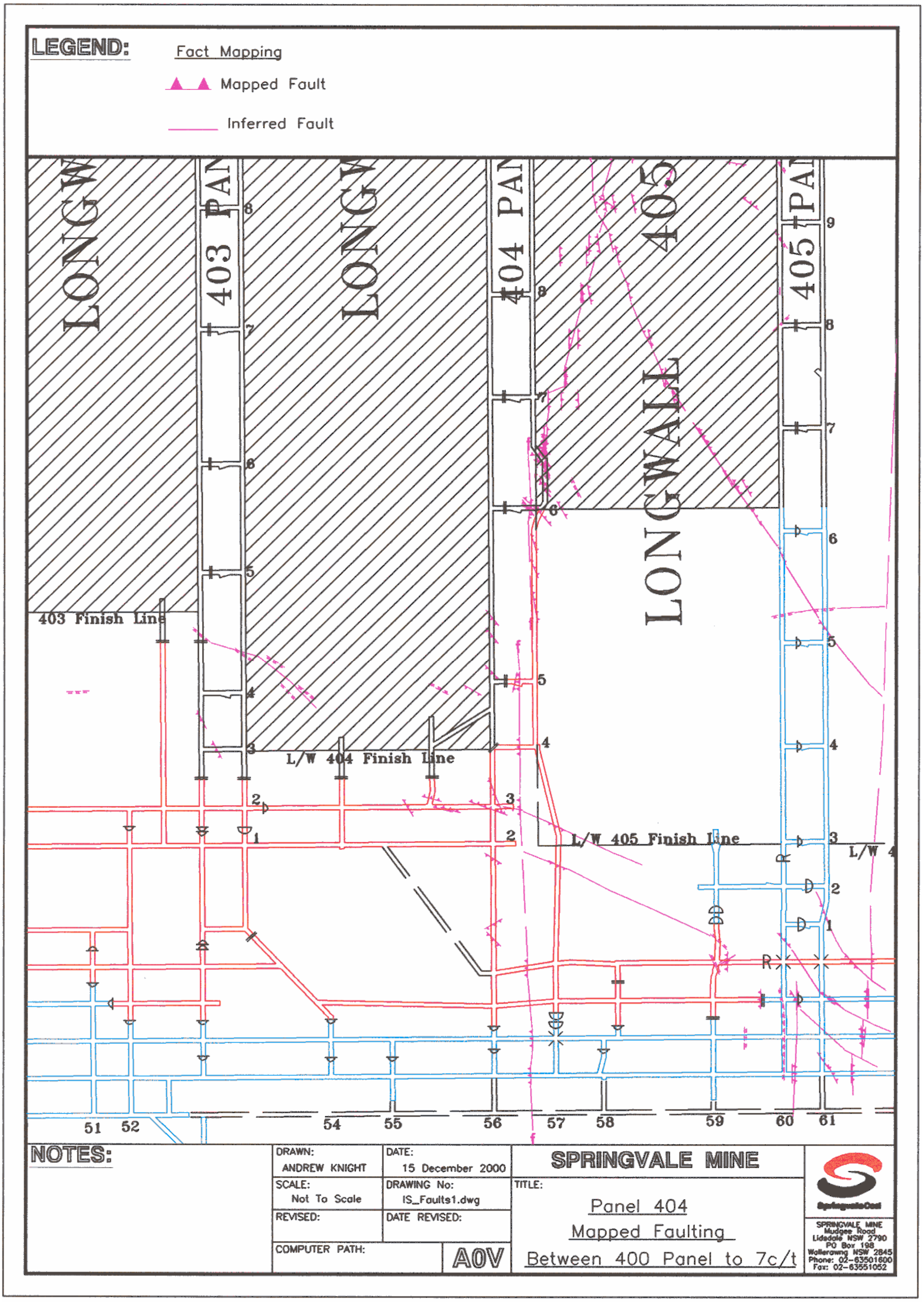

Fig. 1 Faults mapped in the 404 and 405 Panel area

Geological Model

An alternative structural model was developed with assistance from SRK who bought a high level of structural geology skills and a fresh interpretative approach. The Springvale structural geology framework was considered with respect to its place in the broader framework of southeastern NSW. Looking successively at the different scales of regional, district and ultimately mine site gave SRK a likely tectonic model in which to interpret Springvale.

For the detailed mine site focus SRK used an existing set of aeromagnetic data which had been flown as a collaborative exercise between mines in the Western Coalfield. Aeromagnetic data proved effective at Springvale because:

- the Lithgow seam was stratigraphically within 100m above the older basement rocks of the folded and deformed Lachlan Foldbelt.
- The structural grain of the older basement rocks appears to be related to structures within the Lithgow Seam.
- Aeromagnetics effectively picks up the basement structures.

The revised Springvale structural model was based essentially, but not entirely, on the following basement trends

- importance of the N – S trending structural grain of the basement;
- recognition of a set of regional NW - SE structural zones.

Both of these structural trends have been found in Springvale mine (Fig. 2). In addition the structural interpretation provided a hierarchy of severity of the different faults – with areas adjacent to the intersection of the N – S and the NW – SE zones considered to provide the most severe conditions (e.g. in Mains Panel just inbye 405 Panel).

Impact of the Geological Model

The revised geological model has proved to be invaluable to the development of robust mine plans and preferred layout of gateroads to avoid structure. It was able to provide a level of confidence to operations staff and mine owners of the fault zone locations, and that unexpected structures were unlikely. The presence or absence of structures projected by the model are proving to be of the order of 80%+ accurate (Fig. 2).

Some consequences of the model are:

- exploration using in seam drilling to confirm structures is routine;
- the level of detail in the Springvale structural model is remarkably high. Some zones with little faulting, and little development effect, provide noticeably poorer longwall (LW)extraction conditions;
- significant structures are recognised in the mine plan by appropriate de-rating of development or LW extraction rates;
- appropriate roof support can be planned ahead;
- the severity of different structural zone directions vary;
- the intersection of N-S with NW – SE zones has so far produced the worst conditions;
- some projected zones (NW-SE) show little faulting but have higher stress;
- by observation, stress fields around fault zones may increase in magnitude and rotate from E-W to N-S;
- detailed mapping of structures and mining conditions to confirm and refine the severity of differently oriented zones, including their intersection, is ongoing. This includes the status/impact of the long recognised surface lineaments.

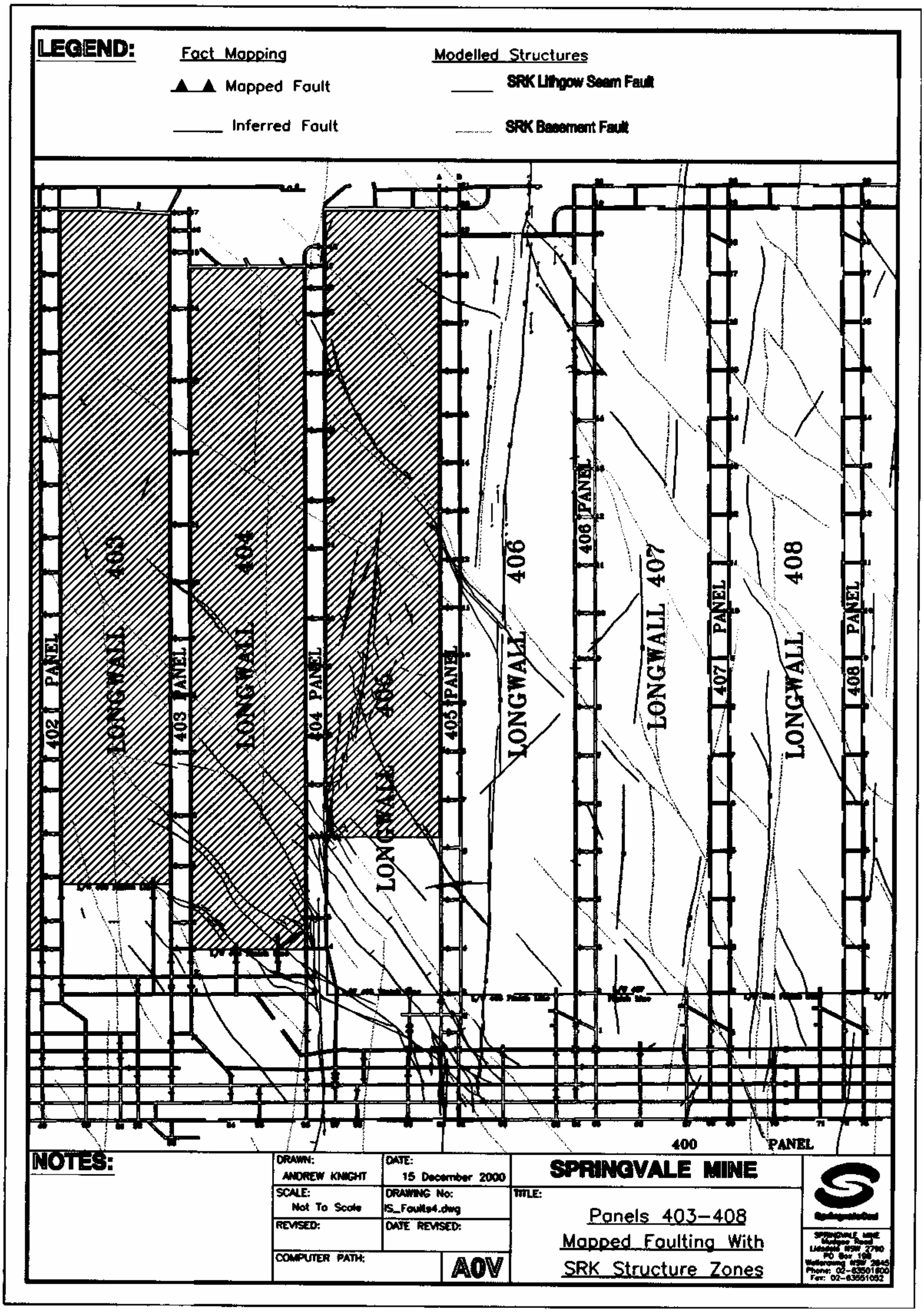

Fig. 2 Projected and mapped structure zones

GEOTECHNICAL UNDERSTANDING

Springvale had a history of poor roof conditions, for example, difficult sections of gateroad during LW extraction, and time dependent development roadway failure .

In response a considerable body of geotechnical work accumulated, which identified the mechanism of roof failure in typical Springvale conditions. These issues included:

- relatively weak ribs which allowed rib failure to increase the roof span and failure to propagate above the installed support;
- the location of the Mains beneath a series of "valleys" which caused a relative increase in the usually E-W trending stress field and poorer NS roadways. The development strata conditions under the deeper plateau areas (320 to 380m) were typically stable;
- a dominantly E-W stress field which was magnified on the MG corner of the retreating longwall. Areas toward the end of the LW were notoriously difficult, the maingate was heavier approaching cutthroughs and certain maingate areas had very significant floor heave;
- various technical assessments identified the part played by the presence of softer wet clay bands within the roof bolting horizon.

The resultant was a record of very heavy LW maingate, areas of poor tailagtes and isolated roof falls on development. One outbye fall in the development panel stopped the panel for a period of 3 months. In addition the NS roadways in the Mains deteriorated over time; many became unusable due to falls, extensive passive support was installed in others.

Valley Effects

Analysis of roof monitoring data by Strata Engineering clearly linked the onset of the "valley" stress effects in N-S roadways to time dependent failure of the particular strata at the 4 to 6m in the roof. Installation of secondary support within 4 weeks of mining would normally prevent an acceleration of roof displacement.

Longwall Gateroads

The reasons for poorer stress induced maingate conditions near the end of the longwall block were understood. Unexpected maingate roof falls elsewhere where not understood. Before the event it was not visually possible to differentiate these fall areas from normal gateroad conditions.

Consequently the LW403 the gateroad was extensively supported with a range of secondary tendon types. The tendons were installed in parallel with development. This approach was driven by:

- lack of geotechnical understanding of the issue;
- need to secure the business from unexpected production loss.

The ability of site personnel to target the maingate areas at most risk of roof failure was linked to the development of the structural model. For example, the N-W trending structure zones, which may have had little or no expression during development, usually became areas of higher roof displacements. In addition acceleration of roof displacement would occur much further ahead of the face than the usual 10 to 20m, (Fig. 3). While not yet fully understood the structure zone is likely to have a higher stress which mobilises during longwall extraction.

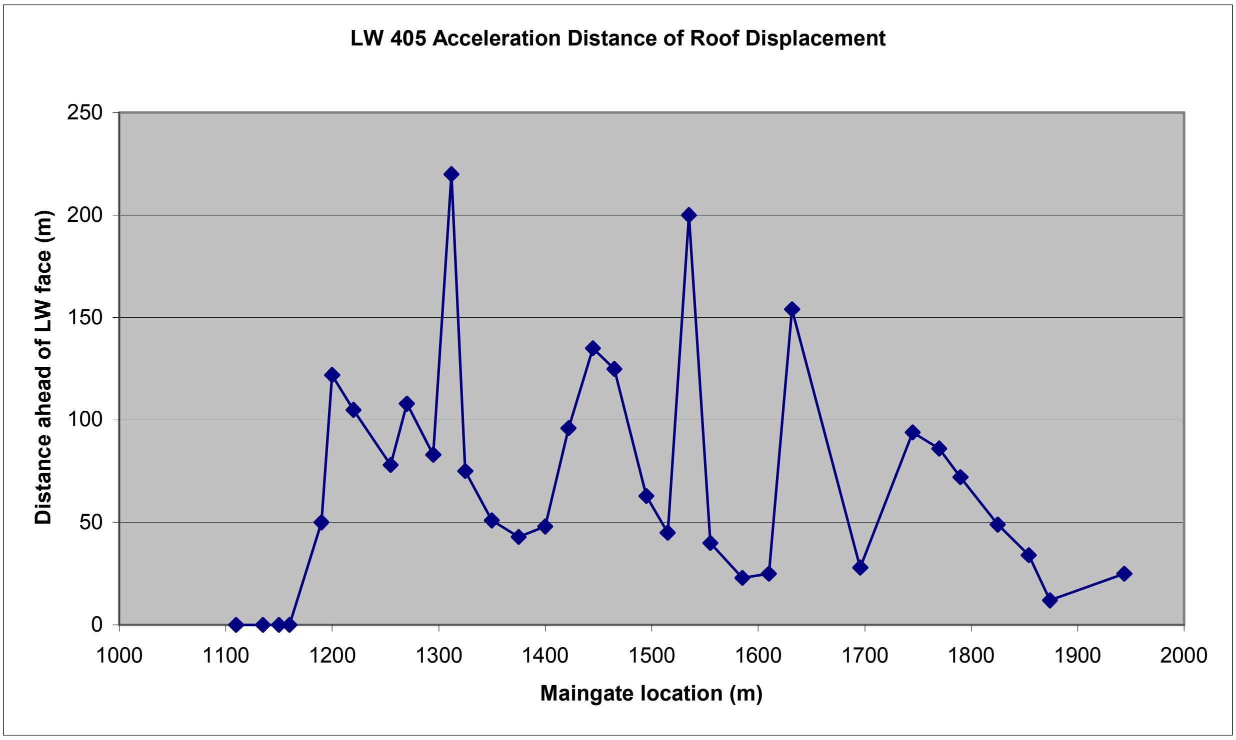

Fig. 3 LW 405 Acceleration Distance of Roof Displacement

Understanding the Fault Zones

Geotechnical understanding of the more variable fault zones is based on grouping the conditions into four types. The weaker ground around faults includes the seam, its clay bands and the floor strata. Higher stress levels can be relieved on many horizons.

Fault Characteristic	Geotechnical Characteristic
Structured ground with minor faults	Common, not necessarily near severe fault zones, usually have little impact but are bolted with long tendons. Usually associated with increased stress in MG in vicinity of LW face. Secondary support here necessary
Increased stress	Usually in the vicinity (<100m) from more severe faulting, usually where 2 fault zones intersect. Stress often rotated to N-S, and causes guttering on development. Essential to bolt with long tendons at time of mining.
Fault zone (no stress)	Are generally stable with a routine amount of bolting, and have soft roof only at the fault zone.
Fault Zone with high stress	Very severe mining conditions. Recommend spiling and arches. Have used cable bolts, square steel sets and PUR etc without stabilising.

Monitoring and the SMP

Fundamental to the development of any consistent geotechnical understanding is the availability of good data. At Springvale monitoring was used to both understand the changing geological conditions and act as a warning of unstable roadways. Extensive use of extensometers and tell – tales at all intersections and along key or at risk roadways was routine. Up to 80 monitoring points might be active at any time, including outbye stations.

A systematic collection of data was supervised by Technical staff who also had developed a comprehensive data management and warning package. Roadway sites which had exceeded predetermined levels of roof movement were listed for inspection, resupport or further close monitoring.

The monitoring was part of a Strata Management Plan which had monitoring, inspection and remedial work as its core. It was managed by a system of clear documentation and authority. A monthly Strata Management Plan meeting was important to maintain the link between the needs of the Operations employees and the direction of the Technical employees.

DEVELOP STRATA SUPPORT HARDWARE

Background

If so much was known of the geotechnical behaviour why then did the mine have so many roof support issues? The answer to this was the understanding probably developed quicker than the appropriate support systems. Ideally Springvale needed a secondary support system which could be pre-tensioned and fully grouted. Installation would need to be within weeks of development, or sooner in poorer ground. Installation processes which could be at least partly in parallel with the continuous miner would reduce the impact on development rate.

Springvale over time have tried just about all types of secondary support systems available to the industry. Initially the fully grouted truss and cable bolt systems had mixed success as they were probably placed too late to provide the expected results. Consequently passive support was extensively used in outbye roadways.

Analysis of the roof behaviour in "valley" conditions required early placement of secondary support for the long term support of north – south roadways. Therefore the mining cycle also included a secondary bolting phase in the valley areas. Different point anchored tendon truss systems were used to improve the mining and secondary support cycle time. This point anchor design was flawed for the conditions but it was a step toward placing long tendons within 2 –4 weeks after mining.

In the period mid 1997 to mid 1998 significant trialling of new systems was achieved. The value of pre-tensioned long tendons placed soon after mining was recognised from monitoring data. Valley north – south roadways and areas of higher stress were targeted. Various single long tendon support designs were used during the same period because of the different capability and design of the secondary bolting rigs. These tendons were all essentially point anchored, except for the 8m tendons - largely encapsulated by 2 or 3 slow and extra extra slow set resin anchors.

Different bolting rigs would likely be installing different tendon supports, which made supplying bolting hardware, resin anchors and the different sized bits more complex than desirable.

Probably the most useful improvement was during this period was developed by a continuous miner crew who discarded the nut on the flexibolts for the barrel and wedge. This allowed superior pretension to be installed at the face and reduced the range of tendons and accessories.

By mid 1998 Springvale had available an assortment of long tendons and bolting rigs. In essence long tendons installed at the face were 4m to 6m long point anchored. The more fully encapsulated (resin cartridge) 8m tendons were completed at a later stage by a mobile bolting rig.

Support of Structured Ground

Mining into the main fault structure of 404 Panel used the secondary support systems described above. The higher stress zone adjacent to the fault saw up to 4 or 5 phases of support. The initial continuous miner support patterns were supplemented by 8m tendon support placed by bolting rigs in the mining cycle. In some sections bolting was repeated, and in time, areas had steel square sets placed. Additional or alternative work such as fully grouted cable bolts/trusses, PUR injection and rib fill were used in some sections of roadway. Monitoring showed continuous roof movement over many months.

This was a very inefficient process, with mining rates in faulted zones less than 1m/shift.

Mining along the main north south fault zone in 404 panel was very slow. A pattern emerged of the CM mining for up to 10m with long tendon installation and/or steel square sets installed within 5m of the face. The decision to install sets was not made in some sections until it was obvious that the tendon support was inadequate. All of this work was made more difficult by a very soft floor.

The effect of the mining in the fault stress areas was not only a series mining support process but was compounded by the repeated efforts to stabilise the strata.

Improvements to Support of Structured Ground

For Springvale to improve development in structured ground two aspects were addressed:
- installation of pre-tensioned long tendons at the face, for more effective longer term support, and those tendons to be fully grouted;
- mining across complex strike slip fault structures affected by higher stress levels.

Post Grouted Tendons

Springvale developed and improved a pre-tensioned, post grouted tendon for installation at the face by the CM crews. They are normally placed:
- within 50m of projected structure zones;
- in north south "valley" roadways which are subject to higher stress;
- in special roadways, such as those driven higher in the seam for overcasts.

The 8m post grout bolt is installed and pre-tensioned to approximately 10 t at the face by spinning the bolt into a single resin cartridge and locking off with a barrel and wedge. The bolt is a normal Jennmar Superstrand which is bulbed at the inbye end. At a later time the bolt is fully grouted by specialist crews using a nil slump grout developed with MBT, which is pumped by grout tube to the inbye end of the bolt and down the hole to the collar. Campaign grouting routinely achieves above 40 bolts per 8 hr shift.

The post grout bolt allows long tendon support to be placed at the face where the effects of pretension gives the best result, and where the grouting can be done off the mining cycle. The improvement in development rates, in roadways where 8m tendons are needed within weeks of mining, has been of the order of 35% to 65%. For example, installation of 2 x 8m bolts per 2m to support N – S "Valley" roadways improved development rates from 4.4m to 7.3m/shift.

Patterns of post grout bolts installed maybe 2 per 2m to 4 per 1m. A typical cycle time for the installation of a row of post grout bolts is 16min. The post grouting of bolts is normally left from 1 to 4 weeks in typical higher stress areas. In the few intense stress structure areas it has been necessary to post grout within 10 to 20m of roadway advance.

Spiling and Arches

Mining across the most highly deformed and stressed structures does not have a simple answer. Springvale in being able to identify the location of these zones will be able to move the gateroad location if necessary. The mains roadways still will intersect fault zones.

The strong N – S structure zone intersecting the Main Panel outbye of 406 panel (Fig. 1) was initially mined with normal bolting systems. Those methods could not control formation of large cavities forming across the roadway (up to 5m high and 2m deep), in the crushed coal at the fault zone. A system of spiling and setting arches was implemented to regain control of ground conditions using a planned and organised process.

Spiling is a technique that had its origins from driving solid bars into fallen ground so the bar action provides a protective canopy. In recent times this crude technique has been improved with rails replaced by drill steels. The use of spiling in fallen ground has been extended by its application to solids.

Spiles were drilled into the solids ahead of the face and across the fault structure at approximately 300mm centres. Their purpose being to contain the extremely friable material as the face was advanced. This worked extremely well. A set of 18m long spiles, in an arch pattern, were drilled in 4-5 days. Drilling conditions played a role in timing. Important features for success were spile alignment, self drilling spiles drilled into place, reinforcing and grouting the spiles.

Arch sets were used in response to the failure of square sets used in combination with spiling on an adjacent roadway. The stress acting on the soft ground was not able to be contained by the square sets, although successfully mined using spiles.

Four piece arches , for ease of installation by Springvale crews, were designed by Connell Wagner based on their civil engineering experience and expertise. The mains travel road contains 49 arch sets at 750mm spacing. Key features were; 3 rounds of spiling and arches, use of shuttering and ribfill with CMT grout (at 8 to 10 Mpa strength) to stabilise and support the arch legs, and attention to packing the arch segment. Long tendons were installed prior to setting the arches.

This work was completed off cycle, initially by two selected Springvale crews. In the longer term it was thought using specific Springvale crews would be better than the issues of mobilisation and installation of large roadheaders. The process was refined on site, and severe fault zones intersected in the future can be handled in a controlled manner by experienced crews.

APPROPRIATE INSTALLATION SYSTEMS

One area in which geotechnical consultants could take a greater role in is working to match the best geotechnical solution with the appropriate mining cycle systems. The constraints on equipment at any site may limit the short term geotechnical options. Longer term goals should not be lost by either the mine site or the advising consultants.

Springvale were fortunate in being allowed to acquire a variety of bolting rigs to allow installation of long tendons (e.g. cable bolts, spinbolts, trusses, megabolts). The capability of each rig to install different types of tendons, in different diameter holes was in itself a difficult operation.

Development mining with secondary bolting in a series process did not satisfy the real geotechnical and mining cycle needs. In other words, maximise face installation of essential secondary support and minimise work done in series with the development process.

Implementing the use of post grouted bolts, installed from the CM during roadway development has simplified the following areas:

- pre-tensioned long tendons are set at the face
- subsequent grouting is done in parallel with development, except in the most severe conditions.
- CM's do not require bolting rigs with the more complex through the chuck motors
- The range of drill bit sizes used reduces to 3 (from 7)

The use of specialist teams of contractors has proven to be very effective at Springvale as they develop efficiencies by focussing on one task. The main areas of their work has often been related to the presence of structure zones.

For example

1. A specialist weekend crew to post grout the long tendons. They have an effective rate of 40 bolts per 8 hr shift.
2. Bolting crews who install long tendons in the maingate ahead of the retreating longwall. The ongoing task is focussed at the maingate stress notch approaching the longwall take-off. Importantly they are used to add supplementary support to identified structure zones which cross the maingate and usually have heavier conditions.

3. Project crews to prepare the special purpose roadways prior to longwall extraction. For example, the roads specifically driven into longwall blocks to avoid faulting. Such work involves removal of steel sets and replacement with cuttable cans, rib filling and pumping sections of roadways.

SUMMARY OF SUCCESSES

Springvale Mine have experienced a range of difficult mining conditions associated with geological structure zones and roof falls. A series of methods have been developed to lessen the impact of faulting on the business.

- A geological structure model has been developed which has been directly responsible for highlighting the zones, particularly in the longwall maingate where roof falls are most likely.
- There have been no substantial roof falls in production areas since the development of the geological model and associated roof support measures.
- The geological structural model for Springvale was developed by placing Springvale into a regional structural context. This recognised the most likely origins and orientations of the structures in the mine. It also provided exploration targets for in seam drilling.
- Springvale has developed a risk ranking of the different structure types and associated mining rates which are fundamental in building the production schedule. Be aware that geological models always need to be upgraded and their blinkered acceptance is unwise.
- Analysis of roof monitoring and observation data has shown that the installation of pre-tensioned fully grouted tendons as soon as possible after mining improves the long term roof conditions.
- The development of the 8m long Post Grout Tendon at Springvale, which could be installed and pre-tensioned during development, has improved development rates by up to 65% in areas which need such support.
- Severe mining conditions such as crossing highly stressed fault zones, were mined in a planned and controlled manner using spiling and arching methods.
- Strata control issues which are significant enough to pose a business risk were best resolved at Springvale by developing a committed Technical team with responsibility and authority for the task.

FUTURE CHALLENGES

The most obvious challenge for mining into structured ground is to know the geology, in particular:

- Where the fault is located;
- The intensity of the fault zone;
- The mining rates through the zone;
- The support intensity and effectiveness.

This work starts with the ability of the geological personnel to provide a level of data for assessment. Experience would show that the geotechnical solutions are usually satisfactory if the necessary data is available. Any mine site that does not have a clear picture of the geological structure and its variability will have to rely on luck to always meet its business plan without the impact of unscheduled delays.

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