GEOLOGY, GROUND CONTROL, AND MINE PLANNING AT BOWIE RESOURCES, PAONIA, CO

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ABSTRACT

Bowie Resources maintains one of the most pro-active ground control programs in the U.S. mining industry today. Its guiding philosophy is that everyone in the organization, from the miners at the face all the way through the top management, are involved in ground control. Some of the unique elements of the Bowie ground control program include:

- Roof bolt operators log the stratigraphy of test holes in nearly every cut. These "lith-graphs" are used by section foremen to determine the need for additional roof support, and they are entered into the geologic data base for use in geologic modeling and mapping.
- Underground core drilling is conducted to obtain data for CMRR and stability maps.
- Weekly "Quality" meetings, involving mine management and technical staff, are held to ensure that ground control information is integrated into production operations.

The paper will describe the program in detail, discussing the involvement of roof bolters, section foremen, surveyors, technical staff, and production managers. It will also show how the program has contributed to the mine planning process. Case histories of successful ground control interventions will be discussed.

INTRODUCTION

Bowie Resources operates the Bowie No. 2 longwall mine, located near Paonia, CO. The mine employs approximately 160 people and produced 4.1 million tons of clean coal in 2005.

Mining has been conducted on the Bowie property for many years. The Bowie No. 1 Mine (formerly the Orchard Valley Mine) was a room-and-pillar mine that was active in the Upper B seam during the 1980's and early 1990's. The Bowie No. 2 Mine opened in 1996 and initially worked the D seam. Bowie first employed longwall mining at the No. 2 Mine in 1999. D seam mining was completed in 2005, and the longwall was relocated to the No. 3 portal in the Upper B seam, approximately 300 ft below the D seam (figure 1). A typical stratigraphic column is shown in figure 2.

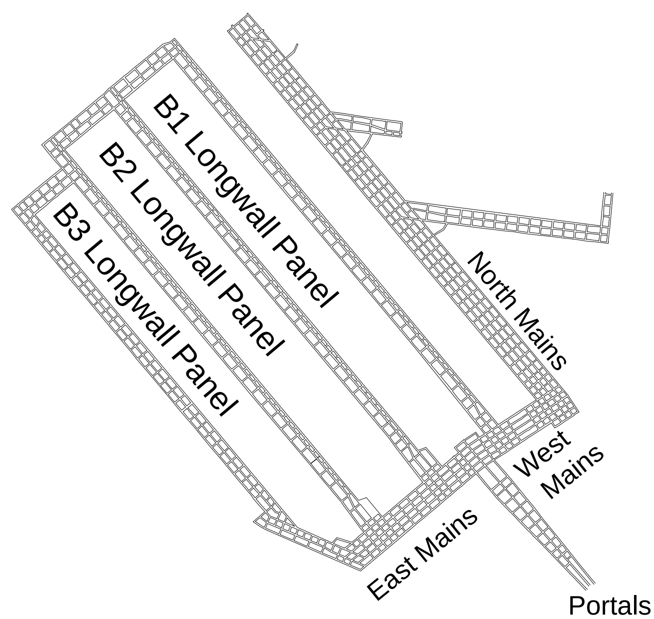


Figure 1. Bowie No. 2 Mine, Upper B Seam workings, first longwall district.

The Bowie property has presented a number of ground control challenges. The depth of cover increases rapidly, from 0 at the outcrop to more than 2,000 ft. Access to the coal can be difficult due to an extensive burn zone at the outcrop. Five major faults were encountered in the Bowie No. 2 Mine alone. Igneous sills have penetrated parts of the reserve, coking the coal in place and rendering it difficult to impossible to mine. The immediate roof varies widely, from competent sandstone in some places to very weak mudstone in others. Seam splits and riders also cause local roof problems. Extensive slump faults, caused when the soft sediments slumped shortly after deposition, have been a problem in the Upper B Seam mine in some areas.

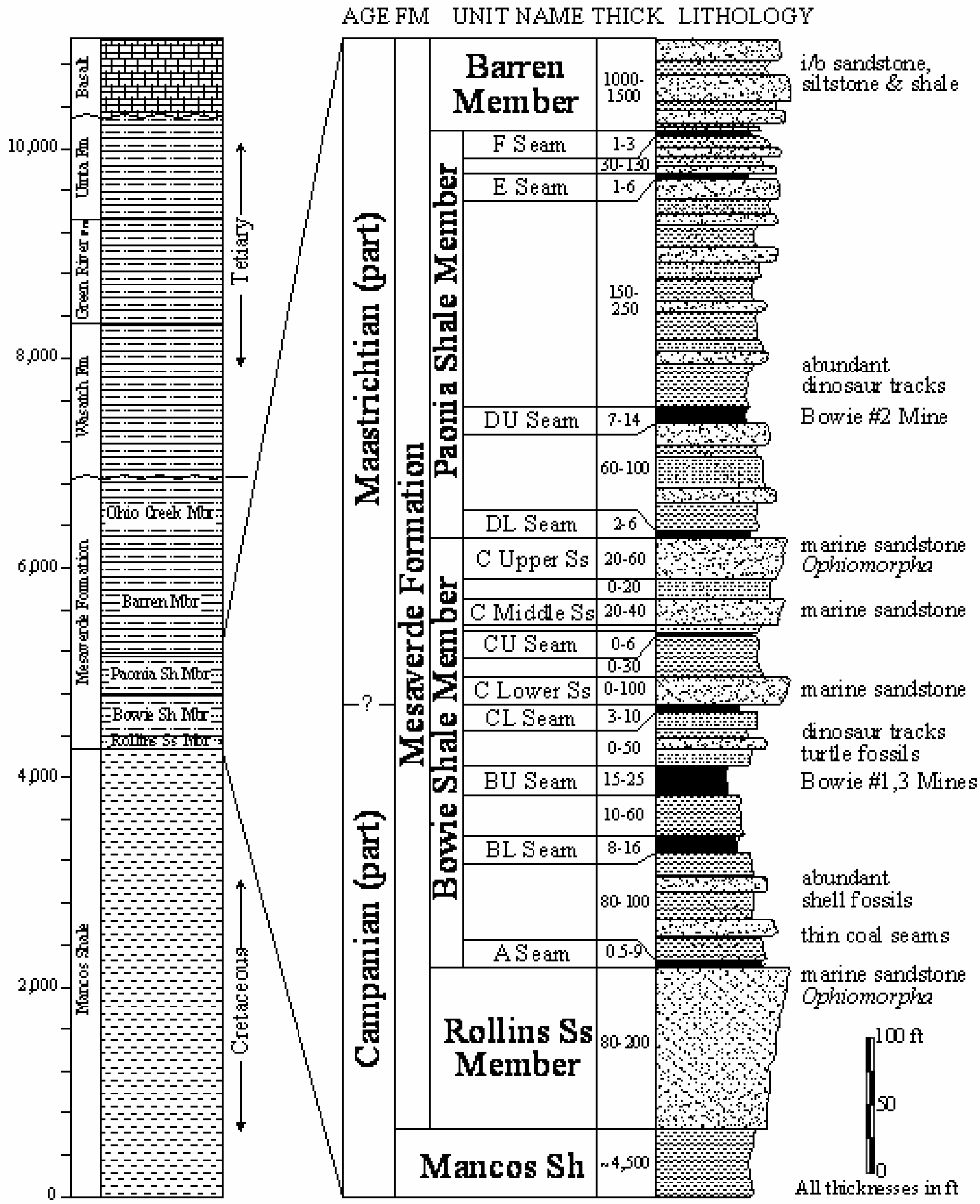


Figure 2. Generalized stratigraphic column for the Bowie Mine (after Robeck, 2005).

In response to these challenges, Bowie Resources has put in place an innovative ground control program. Some elements of the program, such as surface drilling and underground mapping, are widely practiced throughout the industry. Others, such as the routine "lith-graphs" made by the roof bolt operators when they drill test holes, are unique to Bowie. What makes the program effective, however, is the day-to-day involvement of the mine's personnel in ground control, from the mine manager to the production crews. This involvement is maintained through regular, structured, two-way communication between Bowie's geologic staff and its operating personnel.

GEOLOGIC DATA COLLECTION

Ground control begins with geologic information. At Bowie, the geologic data base is considered a living entity, that grows and changes as new information is collected. One important goal is to develop a geologic model that facilitates predictions about conditions in advance of mining. The model provides insight into sandstone channel trends in the roof and floor, seam splits and partings, and fault trends.

Geologic information is gathered at several scales, beginning with pre-mining surface core drilling and geophysics. Underground core drilling has been used to fill many of the gaps between surface holes. Finally, roof lith-graphs and underground mapping provide detailed documentation of the near-seam geology.

Surface Drilling and Geophysics

In planning a surface drilling program, Bowie faces many of the same challenges as most Rocky Mountain coal mines. The steep terrain, great depths, permitting issues, and drillsite reclamation requirements all make exploration drilling an expensive proposition. To maximize the return from each hole, Bowie begins an exploration program with a few widely-spaced holes. The results from this "first-order" drilling then dictate where additional holes will go.

Coal quality is of course a key parameter that is obtained from each hole. Seam correlation is also crucial, and can be quite complex. For example, recent interpretations have shown that the old Orchard Valley Mine was located in the Upper B seam, not the Upper D as was previously thought.

Stratigraphic columns obtained from surface drilling are the first look at the roof and seam conditions that will be encountered during mining. However, many features in the immediate roof occur on far smaller scales than are likely to be picked up from surface holes. Faults are also very difficult to locate.

Bowie has made some use of geophysical techniques to supplement surface drilling. A magnetometer survey was employed to help identify the burn zone to aid in locating the portals for the Upper B Seam Mine. Currently, a seismic survey is being conducted to locate faults in future areas of the Upper B Seam lease.

Underground Core Drilling

During the past few years Bowie has made very effective use of underground drilling to supplement surface core drilling. Portions of the B seam reserve below the existing D-seam workings were proved out by a program of 70 holes drilled from the D seam down into the lower seam. The drilling was done with a "Hagby" wireline drill rig that enabled the entire 300 ft interval to be cored.

One reason for the intensive drilling program was the presence of igneous sills that were thought to have ruined large areas of the Upper B and Lower B seams for mining. The drilling showed that the sills were not nearly as extensive as had been believed. As a result, a completely new mine plan was developed to target the available reserves.

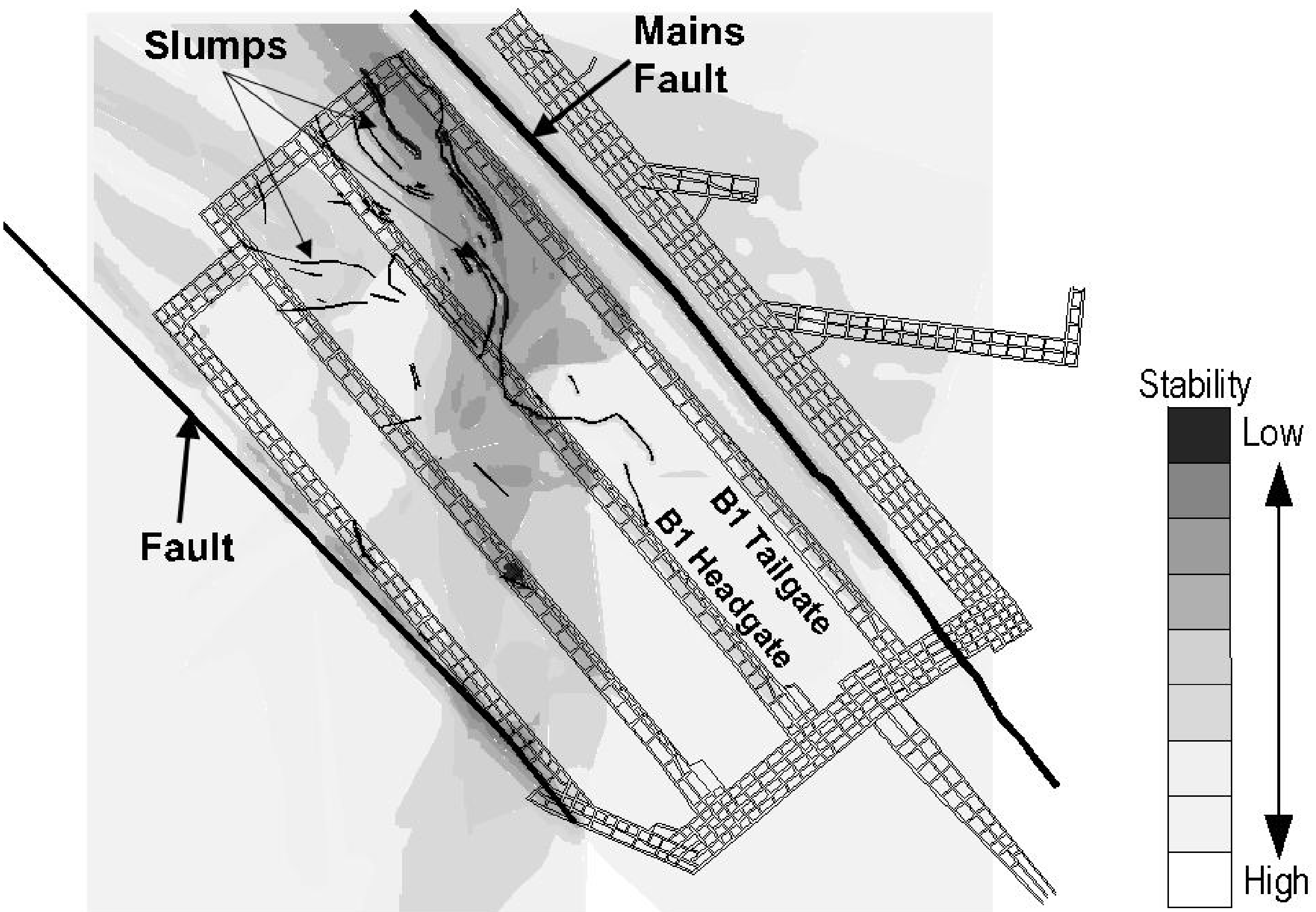


Figure 3. "Stability Map" generated from CMRR and underground mapping data.

Currently, underground horizontal core drilling is being conducted within the Upper B seam using the "Hagby" drill. This horizontal core drilling successfully located the "Mains Fault" that had been previously encountered in the D seam. That knowledge helped locate the B seam mains, provided design information for the fault crossing in the B East Mains and maximized the reserve block for the first sets of longwall panels in the Upper B Seam Mine.

Underground Geologic and Conditions Mapping

One to two times per week, depending on mine productivity, detailed face, rib and conditions mapping is conducted in each continuous miner section and along the longwall face. The results of this mapping is summarized on the various Autocad geologic map layers for the B seam workings.

On a more informal basis, "conditions" mapping is conducted along current and future longewall gateroad entries. This mapping concentrates on the current conditions of ribs, roof, floor heave and water. This information also is entered on AutoCad map layers for the Upper B seam.

Rock Testing and Coal Mine Roof Rating (CMRR)

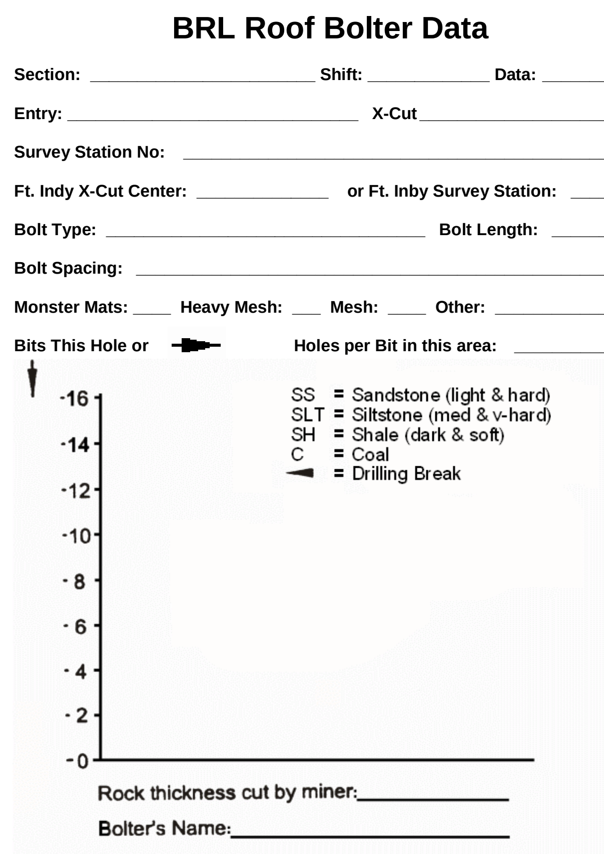
Geotechnical data is collected from all core drilling conducted at Bowie. First, core is logged to show lithologic contacts, fractures, and RQD. Point load tests (PLT) are conducted on the first 10-12 ft above the coal in every hole. To facilitate testing, Bowie purchased its own Point Load Tester, together with a tile saw to prepare samples. Both diametral and axial PLT are conducted. The axial test is used to estimate the rock's unconfined compressive strength (UCS, in psi), while the diametral tests evaluate the strength parallel to bedding. The axial test values are converted to UCS using a site-specific formula developed from past Bowie testing. In general, Bowie has found that the PLT provides consistent results with stronger rocks and coal, but is less reliable with weak mudstones.

The PLT and RQD values are used to determine the CMRR for the bolted roof horizon at each drillhole location. Once the input data has been collected, the NIOSH CMRR program is used to calculate the CMRR values (Mark and Molinda, 2005). The CMRR values are then saved in the Autocad B seam CMRR contour map. As additional values are entered, the CMRR contours are updated.

The CMRR map for the Upper B seam has developed in three stages. The initial hand-drawn contours were based on surface drillholes alone. These were later adjusted with data from the Hagby holes drilled from the D seam. Underground data, from both roof bolter lith-graphs and mapping, is now being used to refine the contours. The result is a detailed view of the immediate roof that is highly valuable to roof support selection as well as to the development of a geologic model for the Upper B seam. The CMRR map also serves as the foundation for a "stability map," with the strongest roof contoured in green and the weakest in red (figure 3).

Roof Bolter Lith-graphs

Perhaps the most unique element of the ground control program at Bowie is the collection of the roof bolter lith-graphs. Lith-graphs are actually stratigraphic logs that are created by roof bolters while they drill 10-18 ft test holes. Figure 4 shows the form that the bolters use to collect the data. The bolters try to identify four different rock types (sandstone, siltstone, shale, and coal) from the degree of difficulty of drilling and the appearance of the cuttings. Cuttings are most easily obtained when an auger drill is used for the test hole in place of the usual dust hog bit. Because the vacuum cannot be used with the auger steel, the roof bolter must wear a dust mask when drilling these holes.


BRL Roof Bolter Data

Section: ______ Shift: ______ Data: ______

Entry: ______ X-Cut ______

Survey Station No: ______

Ft. Indy X-Cut Center: ______ or Ft. Inby Survey Station: ______

Bolt Type: ______ Bolt Length: ______

Bolt Spacing: ______

Monster Mats: ____ Heavy Mesh: ___ Mesh: ____ Other: ______

Bits This Hole or Holes per Bit in this area: ______

-16
-14
-12
-10
- 8
- 6
- 4
- 2
- 0

SS = Sandstone (light & hard)
SLT = Siltstone (med & v-hard)
SH = Shale (dark & soft)
C = Coal
= Drilling Break

Rock thickness cut by miner: ______

Bolter's Name: ______

Figure 4. Form used by roof bolt operators to collect lith-graph data.

The roof bolters also note fractures (drill jumps) and the presence of groundwater on the logs. The number of bits per hole, or holes per bit is noted. The primary support pattern (bolt type, length, and spacing) is also recorded.

After the roof bolters collect them, the lith-graphs are brought outside and filed in a reference book by the office staff. A staff geologist then enters the lith-graphs into a data base and uses them to refine the stratigraphic cross-sections that were previously generated from surface and underground drilling (figure 5). The lith-graphs are also used to refine the CMRR contour map.

Lith-graphs typically recorded once during every shift in every entry that is being developed. Over time Bowie has found that this frequency of data collection provides a sufficient density of geologic information with minimal interruption to the production process.

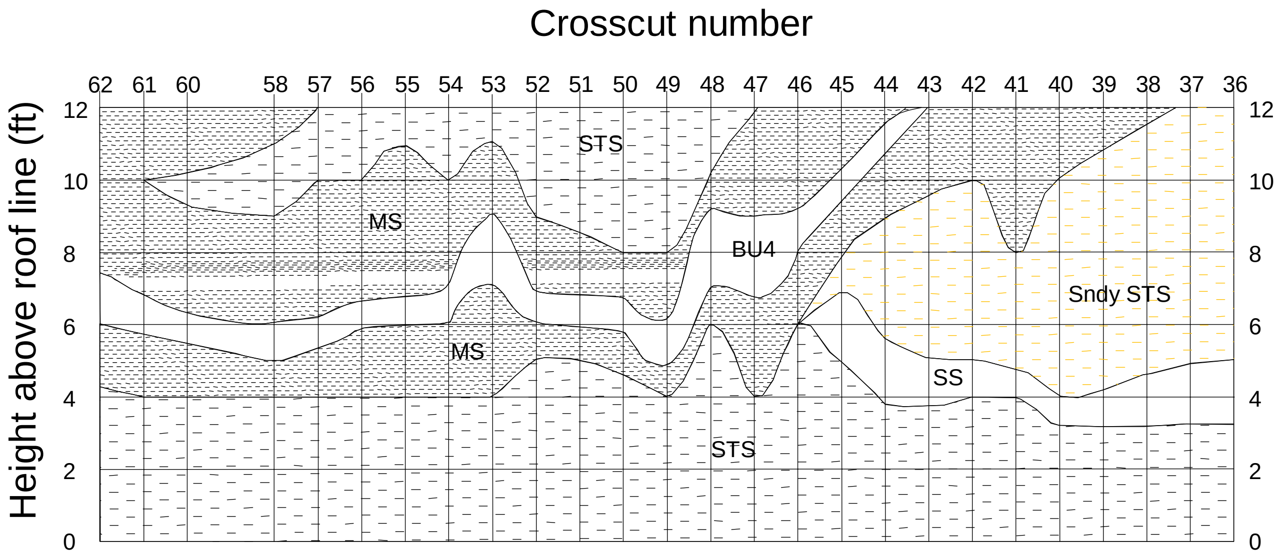


Figure 5. Geologic cross-section generated from core drilling (surface and underground) and lith-graph data. Abbreviations: STS=Siltstone; MS=Mudstone; SS=Sandstone; Sndy STS=Sandy Siltstone; BU4=Upper B Seam, 4th Bench (Rider Coal).

One obvious advantage of the lith-graph program is that it makes a wealth of information available for geologic modeling, mine planning, and decisions about support selection. The cross-sections are particularly valuable for the design of secondary support. Less obvious, but perhaps equally valuable, is that the lith-graphs help focus the attention of the production crew on ground control. As one roof bolt operator put it, "there is no second guessing about what the top is doing." Bowie's roof bolters report that they discuss their observations with the section foreman at least once per day. Based on the information they provide, the foremen may adjust the cut length or the amount and spacing of primary roof support.

Another advantage is that the lith-graphs give the roof bolters themselves ownership in the ground control program. After all, they are ultimately the ones whose efforts protect everyone in the mine from roof falls. The roof bolters know that their logs are being used because they get feedback from the mine's technical staff. One experienced roof bolt operator commented that "there is much more focus on ground control at Bowie then at other mines I have worked at."

Of course, the lith-graphs must be of good quality if they are to be useful. The best lith-graphs are collected by well trained, experienced roof bolt operators. Unfortunately, roof bolting is a difficult job at Bowie, as it is at most mines, so turnover can be high. At Bowie, in a typical year, 4-5 of the 30 or so roof bolt operators will move to other positions. Each new operator must be trained to take the lith-graphs, preferably by a mine geologist.

Stability Map

Bowie has adopted the stability mapping program developed by Dr. Keith Heasley and his graduate students at the West Virginia University (Heasley et al., 2006). The information described above plus model runs from the LaModel program (Heasley, 1997) and overburden depths is combined with the results to produce a stability map of current and projected conditions.

In the case of development mining, the stability maps are used to highlight possible difficult areas in advance, so the crews can be prepared for changing conditions. With respect to the longwall, stability maps are used to design supplemental tailgate support, to design supplemental headgate support, and to project face mining conditions.

The stability map projections are also used to determine run-of-mine coal quality and zones where out-of-seam dilution will significantly increase the ash. These projections are used in budget plans and operational plans for the coal preparation plant.

The stability map projections are also used in the mine scheduling and budgeting processes to estimate zones of lower productivities and higher roof support costs.

MANAGEMENT AND COMMUNICATION

The success of Bowie's ground control program depends on two-way communication between the geologic staff and the operations people. The geologists know that they must acquire credibility by making predictions that are *useful.* To do this, they need to understand the needs of the production side.

The Manager of Technical Services has a key role in the communication process. With extensive experience in production, mine planning, and ground control, he has a unique understanding of how geology can impact the mine. Often, it is his job to ensure that information is flowing smoothly and is being understood by all.

To facilitate direct communication between all parties, Bowie conducts weekly "Quality Meetings." These are attended by the Mine Manager, the Technical Services Manager, the Development Production Coordinator, the Longwall Manager, the Mine Engineer, the Surface Operations Superintendent, the Customer Relations-Shipping Manager and the geologists. As mentioned above, prior to the meeting, a geologist goes underground to map the faces in the development sections and on the longwall and prepares face maps of existing conditions. The attendees discuss the experience of the past week, and the stability map projections and the geologic forecast for the upcoming week regarding conditions, productivity and quality. The updated colored stability map and the relevant cross sections are prominently displayed during the meeting.

At one recent meeting, one of the development sections was encountering a rider seam, while the longwall was dealing with slump faulting on the face. The geologists were able to predict how much longer these features would be present, and what forms they were likely to take. The discussion focused on control techniques, particularly the proper mining horizon for each face.

ROOF SUPPORT

Decisions about roof support in the development sections are made daily at the Bowie Mine. While a set of guidelines has emerged over time, the rapidly changing conditions preclude rigid standards. The primary decision maker is the Production Coordinator, but every member of the ground control team contributes.

The roof bolting cycle at Bowie includes bolting and meshing the roof, meshing the rib on the operator side of the entry, and bolting the rib on the other side. Normally a dual-boom roof bolting machine, with a three-man crew, is employed in each three-entry development section. Roof bolting is typically the production bottleneck, however, so an extra bolting machine is usually assigned to whichever section is on the "critical path."

Four different primary supports are employed, depending on the ground conditions. In normal conditions, six ft, no. 6, fully grouted, non-tensioned needed rebar bolts are employed. Where conditions demand them, three other types of bolts may be installed;

- Eight ft, no. 6, fully grouted, non-tensioned rebar;
- Eight ft, 0.804 inch diameter, fully grouted, non-tensioned rebar, and;
- Seven ft, 0.75 in diameter, resin-assisted mechanical anchor, with four-ft of resin grout.

One universal rule is that two ft of solid anchorage is required for primary supports. Where rider coal, soft drilling, or many slips are encountered in the anchorage horizon, then longer bolts or supplemental support will be installed. Extra support is always installed in the intersections, and in the headgate because later access is difficult. If the roof seems likely to fall in before it can be bolted, the section foreman and the continuous miner operator may also decide to reduce the cut depth and narrow the headings (other than the belt heading).

Cable trusses have traditionally been the preferred supplemental support when difficult conditions are encountered during development, based primarily on their ease of installation. However, cable bolts are increasingly used as supplemental support in "softer" ground conditions where cable truss performance has been problematic. Bowie's philosophy is that "it is easier to put support in early then wait for things to get bad." When possible, supplemental support will be installed on the downshift to minimize impacts on production.

Decisions concerning secondary supports in the tailgate and elsewhere are normally made by the engineering staff. The typical tailgate support for "good" ground conditions consists of one row of 24-inch Burrell ™ Cans on 11 ft centers, with a row of 12 ft cable bolts on five-ft centers. The cable bolts are installed in a "baseball stitch" pattern, with alternating bolts each 2.5 ft off the entry centerline. Cable trusses are also often installed, on 5-ft centers. Where the roof bolter lith-graphs show that weak roof conditions are anticipated, a second row of Cans is installed, and the Can spacing may be decreased to 8 ft. The cable bolt density also is increased to four per row, on 4- to 5-ft centers, with Monster Mats. Cable bolt lengths are varied from 12-ft to 18-ft depending on the conditions.

Case History – Southwest Longwall Mining District

Adherence to the methods and procedures described above allowed BRL to successfully recover over 2 million tons of longwall coal from the B2 and B3 longwall panels in the southwest mining district. Figure 1 illustrates the layout of the development and longwall panels in this district. Details of the stability mapping developed for this area are presented in more detail in Heasley et al. (2006). The stability map of the mining district is shown on figure 3.

The initial core drilling for the area, conducted from the overlying D-seam workings using the Hagby drill, indicated generally good mining conditions for the southwest mining district. However, development mining experience indicated possible gateroad stability problems due to slump faulting (figure 6) and splitting off of a thin rider seam across the mining district. CMRR values, updated continuously with the lith-graph data, showed consistently low values (CMRR<40) for the inby halves of the B1 and B2 longwall panels.

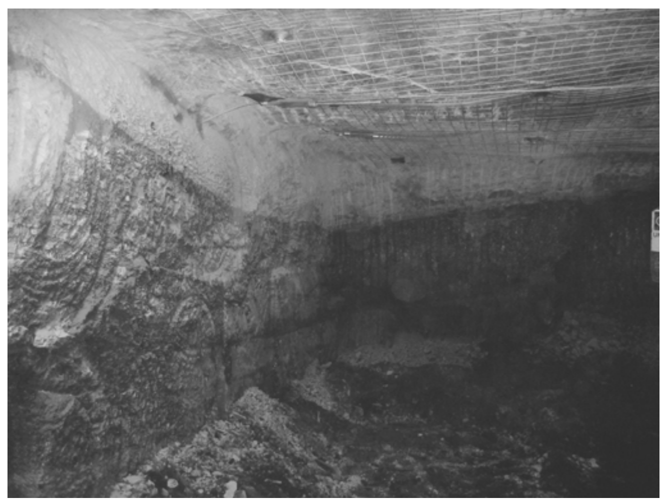


Figure 6. Photograph of a slump feature encountered in the Upper B Seam gate entry development.

Based on this data, significant additional supplemental support was installed in the first third of the B1 tailgate. This support consisted of:

- 12-ft cable bolts, 4 per row, with heavy duty roof mats, 5-ft maximum row spacing
- 24-in Burrell ™ cans, 2 per row, maximum 8-ft skin-to-skin spacing

Mining progressed with minimal tailgate problems as a result of this extra supplemental support. However, problems were encountered along the longwall face due to the slump faults and along the headgate due to the rider seam splitting off into the roof.

Both issues negatively impacted longwall productivity and coal quality in the B1 panel. The slumps caused mid-face falls of the roof ahead of the longwall shields and increased floor heave in the headgate belt line. The rider seam contributed of mid-face falls and increased roof sag in the headgate belt line. Longwall operations were interrupted while the belt line was partially removed for 500 ft and the floor was re-graded.

In preparation for mining the B2 panel, the weekly quality meetings focused on reviewing past mining experience and predicting future ground responses to longwall mining. The Stability Mapping software and procedure presented by Heasley et al. (2006) was implemented, and cross-panel radar imaging was performed to better define possible problems areas along the face. Other preparation included installing pumpable cribs between existing supports in the tailgate, rebolting approximately 2,500 ft of the belt line with 18-ft post tensioned cable bolts and heavy duty roof mats, and installing transfer lines and holding tanks for polyeurathane grout on the longwall face.

Experience on the B2 longwall panel showed that these mitigation measures were adequate to allow continued, safe mining of the B2 longwall panel. The cross-panel imaging and the CMRR-based stability mapping successfully predicted the areas of difficult mining conditions. Based on the B2 panel experience, the future tailgate for the B3 panel was divided into stability zones and supplemental support type and density were defined and tailored to the conditions.

CONCLUSIONS

Bowie Resources maintains a pro-active ground control program that has evolved in response to varying and difficult mining conditions. Its guiding philosophy is that everyone in the organization, from the miners at the face through upper management, are involved in ground control. As a result of this commitment to our pro-active ground control program, Bowie Resources will be able to recover over 2 million tons of developed reserves that otherwise would have been lost to poor ground conditions. Our ground control program allows us to continually match the roof support to the conditions on development as well as for longwall tailgate support. It identifies areas that need extra attention before they interrupt longwall production.

Specific lessons include:

- In our conditions, cross-panel radar imaging has been successful in projecting zones of slumping and weaker roof in the B2 longwall panel.
- Roof bolter operators are a key source of data on changing roof conditions. Use of a lith-graph system allows this experience and information to be captured for use in subsequent analyses. The data is particularly important for CMRR analyses and stability analyses.
- Weekly quality meetings attended by senior operations, engineering, geology and surface personnel are an important tool in determining developing trends and problems in ground control and as-shipped coal quality.

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