COAL MINE GEOLOGY IN THE U.S. COAL FIELDS: A STATE-OF-THE-ART

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ABSTRACT

During the past quarter century, coal mine geologists have evolved from providing a qualitative description of drill core and coal reserves into quantitative geotechnical specialists who bridge the gap between geology and engineering. In the late 1970's and early 1980's, hazard prediction mapping was in its infancy. At best, hazard maps identified rudimentary structures and conditions such as stream valley locations, sandstone/shale transition zones, and lineaments. A "technical disconnect" had existed between geologists and mining engineers as each profession operated largely independent of each other. Engineers did not readily integrate geology and geologic conditions, with the exception of coal thickness, into mine planning. Geologists were relied upon for reserve estimates and did not participate in mine planning or design. The employment and market slump of the 1980's and 1990's combined with mining more challenging reserves mandated that this gap be bridged and forced geologists to learn to speak more "numerically" to engineers so they could be understood. The purpose of this paper is to describe the procedures and thought processes used by coal mine geologists when determining various mineability and reserve extraction feasibility issues. The paper will also address underground geologic hazard mapping and prediction techniques. To achieve these objectives, the opinions and experiences of leading coal mine geologists, geotechnical and strata control specialists across the United States were solicited.

INTRODUCTION

The duties and responsibilities of a coal mine geologist have changed considerably since the First Conference on Ground Control in Mining was held. A quarter century ago, a geologist's primary concern was to locate the coal and to determine its thickness, quantity and quality. Stratigraphic correlations were also made between core holes to delineate rock unit positions and locate geologic anomalies like stream channels or faults. These cross-sections were hand-drawn on mylar and hung from the office walls for engineering and operations personnel to review. Resident mining engineers were never at a loss for derogatory remarks about following the dots or playing with colored pencils. Engineers had a basic lack of understanding for depositional environments and facies changes which often resulted in orienting mine headings into unfavorable roof and horizontal stress conditions. Engineers widely held the belief that geologic conditions including seam splitting, facies changes, sandstone channels, and horizontal stresses and therefore ground control conditions were unpredictable. A mining engineer typically had two undergraduate geology courses that was limited to memorizing the different eras, basic geologic structures, plate tectonics, mineralogy, and the identification of igneous, metamorphic, and sedimentary rocks. The lack of knowledge and understanding of coal measure geology left the engineer able to recognize poor roof conditions through experience but unable to correlate current in-mine conditions to future conditions through drill core. A new coal mine geologist quickly learned that mining engineers knew little about the strata above and below the seam of interest. The concept of using hazard prediction mapping in order to identify zones of potential roof instability was fairly novel (Peng, 1978; Custer and Gaddy, 1981) at the time of the First Conference. The more sophisticated maps may have included geologic structures and conditions like transition zones, lineaments, stream valleys and topographic information.

Nearly all the people queried during this study indicated that to the best of their recollection, most geologists spent very little time underground prior to the early 1980's. If there was a problem that was geologic in nature, geologists would sometimes go underground to make observations and render opinions. But, for the most part, geologists spent the majority of their time on drill rigs, logging core, or in the office working on reserve analyses. Subsequent to that, due to financial constrictions that occurred during the 1980's and 1990's and when the true cost of a roof fall was calculated, geologists started spending more and more time underground mapping hazards and establishing viable answers to roof falls. Many companies quickly realized the cost-effectiveness and other advantages of having a well trained eye underground observing subtle structures and other details that were lost on engineers, some of which were precursors of geologic hazards or conditions which dramatically affect mining. Previously, these details went unnoticed until the mine hit a sandstone channel, fault, or poor roof conditions which necessitated the operator to aimlessly turn headings left and right without success until the area had to be abandoned. Other mine operators were made aware of the benefits of underground mapping and geologic forecasting techniques through presentations delivered at the International Conference on Ground Control in Mining over the past quarter century.

The purpose of this paper is to present an assessment of the current state-of-the-art in coal mine geology. To this end, 12 senior coal mine geologists, geotechnical and strata control specialists from across the United States were questioned regarding their "day-to-day" duties and responsibilities. It isn't surprising that the majority of the respondents were from larger companies that operate longwalls. Longwall mining is the most sensitive and least able to adapt to geologic changes. By its nature, longwall mining is a capital intensive commitment to a 1,000 by 14,000-foot block of reserve that are the typical dimensions of the modern panel. The panel requires approximately 6 to 7 months to develop and nearly the same amount of time to mine. Because 80 to 90 percent of a large mine's production is dependent upon a longwall, a failure to understand the geology can be a financial catastrophe.

RESERVE EVALUATIONS

The amount of effort that goes into a reserve evaluation is somewhat proportional to its relative value and variability. For example, in a one-section hill top operation in central Appalachia, once the necessary drilling for coal thickness and acid/base (NP/PA) testing is conducted for permitting, the drill rig is moved to the next mine. Hill top reserves are generally small (200,000 to 1,000,000-tons) and short lived (1-3 years). If the continuous miner encounters a sandstone washout or a fault, the operator will normally back out a few breaks, and drive a new butt off the crosscut. The reserve evaluations are normally based upon 3 to 5 drill holes and confirmed by the ripper head of the miner. If the operator runs out of headings, they will backfill the drift mouth and move on to the next hill top. The diametrically opposite philosophy is reflected in one northern Appalachian longwall mine where the coal quality is variable and the geologic conditions change routinely. Coreholes are drilled on 800-foot centers along the center of each panel. Conversely, at a longwalling operation located in the Yampa Coal Field of Colorado, there is quite frequently very little variation in the core from holes drilled more than a mile apart. However, to be conservative, holes are drilled on one-half mile centers. The reason for variation, or lack thereof, in these longwall examples is the depositional environments in which these formations were deposited and later lithified. Depositional modeling was a relatively new concept 25 years ago because the majority of the principles were introduced in the mid 1970's (Donaldson, 1974; Ferm, 1974; and Horne et al, 1978). Today, depositional modeling is a cornerstone of coal mine geology and is routinely used to spot drill hole locations, explain underground variations, and even predict geologic anomalies.

In general, it was reported that a wider exploratory drill hole pattern was employed for room-and-pillar operations due to the greater flexibility of the equipment. Conversely, a tighter plan is utilized for longwall operations because the financial viability of the mine is totally dependent upon the longwall panel and the ability to mine in excess of 20,000 clean tons/day. Therefore, drill hole spacing is a function of economic components, the regularity or uniformity of the reserve and the abundance or lack of anomalies, partings, seam splitting, etc. Corehole placement is also subject to restrictions such as land ownership, physical access, surface topography, and even political constraints.

Once the core has been collected, the geologist must provide an accurate description that should be understood from a "mining" viewpoint as well as determining what type of testing should be done on it. Normally, a proximate analysis is conducted on selected coal samples at an analytical laboratory. In addition, customers may also request that an ash mineral analysis, trace element analysis or grindability test be performed. Less than half of the geologists reported regularly sending coal samples to commercial laboratories for compressive strength and shear strength testing. While other geologists indicated that uniaxial compressive or shear strength tests were only conducted when pillar design problems occurred or when requested by an engineering consultant. Depending on the geologist, anywhere from 10 to 100-feet of roof rock core is retrieved and closely examined. The most common answers were from 20 to 30 feet. When the core is removed from the core barrel, all the fractures are marked with an indelible marker or lumber crayon to delineate naturally occurring fractures from those induced to fit the core into boxes. Fracture spacing and Rock Quality Designation (RQD) measurements can then be taken in the field or later to determine the inherent quality of the immediate roof. Approximately one half the geologists responded that uniaxial compressive strength testing was routinely performed on immediate roof rock members within and slightly above the bolted horizon. A few geologists stated that tensile and shear strength testing was also conducted on the roof rock. Other geologists indicated that physical properties testing was expensive and time consuming, and that the only time samples were sent for analyses was on rare occasions.

All the geologists, except two, reported that they analyzed the first 10 feet of floor rock. The other two examined the first 20 feet of floor rock. It should be noted that it is important to identify weak floor units, which have a low load bearing capacity and/or are moisture sensitive. One of the problems with these units is that they can heave on development causing reject and out of seam dilution issues.

A tremendous asset in bridging the gap between geologists and engineers, which has come into widespread usage since the First Conference, is the Ferm code for coal measure rocks (Ferm and Melton, 1977; Ferm and Smith, 1981; Ferm and Weisenfluh,1981). The code provides a unique number for common coal measure lithologies and has established a common language for the two professions. An engineer can immediately form a mental image of a 322-FLT or a flat dark gray shale and interbedded sandstone. In the engineer's vernacular 322-FLT is "Zebra-rock" or "stack rock", and associated with poor roof, especially in high horizontal stress conditions. Prior to the Ferm code's, a typical qualitative geologic description may have been something on the order of a gray to dark gray medium to fine grained, thinly laminated shaley micaceous sandstone with plant fossils on the bedding planes. The "Ferm" books have a "dry" and "wet" picture for each numbered lithology for reference. Core photography may be done is some cases. This provides for an excellent record for later review and presentation to operations personnel. Though photographing core in the field can be difficult at times, the advent of digital photography has made this more effective from the standpoint of being able to see the photo when it is taken and make adjustments if necessary. Also it allows for easy storage and transfer of the photos.

All the geologists stated that geophysical/electric logs (E-logs) were routinely run on every drill hole. A few of the geologists pointed out that these logs provided a good method of double-checking or verifying the driller's core log depths, rock unit types, and for making various geologic correlations. As for sonic velocity logs, approximately one third of the geologists responded that they always ran them, while approximately the same number said they never used sonic logs. The remainder indicated that they have run sonic velocity logs from time to time, for example, if requested by a consultant, when exploring a new reserve, or for seismic profiles when looking for faults. Sonic velocity logs are also run to determine in situ rock strength and density, Young's modulus, and

Poisson's ratio. Gas desorption testing may also be carried out at the drill site. This data may be utilized during ventilation design or when considering methane drainage techniques if necessary.

Other physical property determinations of roof or floor core that may be conducted by the geologist or in a laboratory include: Slake Durability, Point Load Testing (PLT), Fracture Analyses, or Coal Mine Roof Rating System (CMRR) analyses. The CMRR is a rock mass classification system designed to estimate the inherent strength of bedded coal measure rocks. It utilizes a number of rock mass properties including estimated uniaxial compressive strength (UCS), moisture sensitivity, and the presence of strong strata within the bolted horizon. It recognizes the importance of bedding to rock mass stability by placing special emphasis on the tensile strength, cohesion, and frequency of bedding planes within defined units in the roof. Bedding strength of rock core is measured using the point load index test. Data entry is made and strength values are calculated with the National Institute of Occupational Safety and Health's CMRR software.

At this point, the geologist must turn into a detective. Every possible information resource on the reserve being investigated needs to be examined. This includes any available oil and gas E-logs, County Reports, professional papers, theses, dissertations, and Federal and State Geological Surveys. Geologic Surveys have various types of geological quadrangle maps. Abandoned mine maps may be obtained from the State Geologic Survey or the Office of Surface Mining. Maps of active mines may be examined at State and the Mine Safety and Health Administration (MSHA) District offices. A few State Geologic Surveys, most notably Kentucky, have excellent web site locations. Sometimes relevant data can be found on mine maps adjacent to the reserve in question like mining heights. One can also try to inspect the mining extents near the proposed reserve, are they erratic, headings dropped off, panels abandoned, or maybe the coal was not developed, why? Possibly a section was advanced, but was not retreated, or only partially retreated, again, why? Or, the area was advanced and retreat mined cleanly. Each of these scenarios has pertinent information and needs to be considered. Also, maps that show overmining or undermining need to be scrutinized for future multiple seam load transfer problems associated with remnant structures. If the proposed mine will be conducting full extraction in an undermining situation, the possibility for water inflow occurring must be closely examined. Although a lot can be said for a well-trained eye when reviewing these maps, it is advisable to question someone who actually worked at the mine with map in hand. Normally, the mine manager, superintendent, foreman and/or engineer would be solicited for an interview. Some of the geologists questioned indicated that it was surprising how much pertinent information can be obtained through this kind of process. While other geologists remarked that some of their experiences with second party perspectives have proven to be distorted and that hindsight is not always 20/20. Like history, if you don't understand the circumstances and mining conditions in an adjacent abandoned mine, you may be doomed to repeat the failures of the previous mine.

Once all this information has been correlated and analyzed by the geologist, it will be forwarded to property acquisitions management personnel for consideration. If the reserve was previously acquired, the package will usually be sent to the Engineering Manager.

Exploration drilling, analytical testing, geological data collection and interpretation all play keys roles is allowing a coal geologist to define a particular coal deposit. An accurate definition of the attributes of a coal deposit is essential in order for engineers to formulate a viable economic mine plan. The vast amounts of data collected must be able to be stored, retrieved, analyzed, updated and re-stored for future use. This effort has been made possible with the ever increasing improvement in computer databases, geographic information systems (GIS) and geological modeling / mine planning software. Today a coal geologist must be well versed in computer applications in order to be effective. Gone forever are the days of hand drafting maps and cross-sections.

There also needs to be a close collaboration between geologists and mine planning engineers. It is the task of the geologist to define the coal deposit from which the engineer can design a mine. Just as the engineer needs to strive to understand geologic processes, the geologist should seek to gain an increasing knowledge of mine operations in regards to equipment selection, productivity, coal haulage and coal preparation. This engineering knowledge will assist the geologist from exploration data collection through reserve modeling to provide for the best definition of the coal deposit from which a successful mine plan can be developed.

TROUBLESOME GEOLOGIC STRUCTURES AND CONDITIONS

Throughout the history of coal mining, geologic structures and conditions have been responsible for serious injuries and fatalities. Prior to the First Conference on Ground Control in Mining, published investigations on troublesome underground features were not common. Consequently, geologic structures were routinely misidentified and frequently inadequately supported. For these reasons, the MSHA prompted the former U.S. Bureau of Mines (USBM) to investigate several hazardous geologic structures and conditions during the late 1970's and 1980's. The purposes of these studies were 1) to examine the physical characteristics of the geologic anomalies in order to make support and other mining recommendations to help mitigate the problems associated with each feature. And 2), to determine methods to predict the hazards in advance of mining, if possible. Detailed investigations were conducted on clay veins (clastic or sedimentary dikes), faults, hill seams, kettlebottoms, paleochannels, and slickensides. All the geologists interviewed indicated that they had experienced problems with one of more of these structures to varying degrees. The most difficulties were reportedly associated with faults, one of which had a displacement of 200 feet. In another example given, no anomalies were detected in the mains, gateroads, or in the setup rooms during development. However, the shearer mined into a fault midway through the panel which wreaked havoc on the face for scores of feet of retreat. Roof control problems and face ignitions related to clay veins were also pointed out.

Problems with delineating paleochannels over a mile wide were also mentioned. The Galatia channel in southern Illinois is perhaps the best known most studied channel in coal mine geology. This channel is so extensive that it determines the boundaries between mine properties. Troubles were cited even when trying to mine through small channels. For example, a lesser known unnamed channel exists across three counties in southeastern Kentucky. Instead of drilling to locate the thinnest portions of the channel to develop across, lack of geological guidance led the company to repeatedly mine against the want, defining the perimeter using a continuous miner. When no other options existed for crossing the channel, a continuous miner was used to drive a three entry system through the channel. Eighteen months and a worn-out JOY 12 CM later, the project was completed. Therefore, in order to avoid production interruptions, it is imperative to delineate the extent of channels, faults, and other major geologic anomalies so that their location can be incorporated into the mine layout and planning process. All the geologists indicated that they employ surface drilling to identify geologically disturbed zones from minable coal reserves. Depending on the structure trying to be pinpointed, geologists reported drilling holes as closely spaced as 50 feet apart.

Other structures which the geologists interviewed stated having problems with included undetected slickenslided slips or intersecting slickenslided slips which are commonly referred to as being horsebacks. On average, several serious injuries and a fatality occur each year due to undetected slips or horsebacks. A few geologists also indicated that they have experienced problems with well-defined roof joints which disrupt the lateral continuity of the roof beam. These joints can cause the roof to cantilever and/or segment it into blocks and necessitate a change in the heading orientation. Some of the respondents also had problems with well-pronounced face cleat. This is difficult for someone to understand until they have stood in a ten plus foot high entry of coal at 1,500 feet of cover or more and experienced the magnitude of a rib roll. In this situation, the general consensus is that roadways should be driven at 45 degrees to the face cleat.

Almost universally, it was reported that roof control problems occurred under stream valleys and shallow cover. These poor ground conditions have been attributable to stress relief (Fergusen, 1967), and are commonly referred to as “snap top” by the miners. Snap top, because when initially undermined, the roof makes a snapping sound. Bedding plane faults, which sometimes occur in areas which were tectonically active, were only mentioned as being troublesome by a few geologists but still warrant being addressed due to the lack of published material on the topic. Bedding plane faults are thought to occur when rock units are subjected to compressive forces and flexural slip folding occurs. During the folding process, rock units move relative to each other as shown in figure 1. A good analogy would be to consider a series of rock units as being a deck of playing cards. Now, bend the cards and you can visualize how the cards move or slide over one another. The same is true with rock units. Supposing prior to folding the rock units, you have a geologic structure, for instance a clay vein, penetrating through the roof and coalbed. After folding, this clay vein is segmented and displaced along the various bedding plane faults as shown in figure 1. As illustrated in figure 1, when this type of flexural slip folding occurs, roof rock is displaced up dip relative to floor units. In addition, supplemental support should be considered up dip because seemingly good top could be masking disturbed roof rock.

Most of the geologists from the Western Coalfields and to a lesser extent the Midwest mentioned difficulties with igneous dikes and sills. The concern is so great that they have gone to the expense of conducting airborne magnetic surveys to locate deep seated intrusions. Although not strictly limited to Western Mines, igneous dikes are rare in Eastern Mines but have affected operations in Eastern Illinois.

Several of the geologists questioned indicated that high horizontal stresses pose a major operational concern at their mines. Since the First Conference was held, considerable insight has been acquired through field studies examining the affects of high horizontal stresses in underground coal mines. This Conference has provided a forum for many of these investigations which have examined several important issues including panel orientation, advance and retreat directions, panel sequencing, and various other related topics. The majority of the geologists surveyed reported having experienced significant mining related problems associated with one or more of the following rock types or structures: sandstone/shale transition zones (roof brows), splay deposits (stack rock conditions), slumps, rock partings in the coalbed, rider coalbeds, and/or inherently incompetent roof rock.

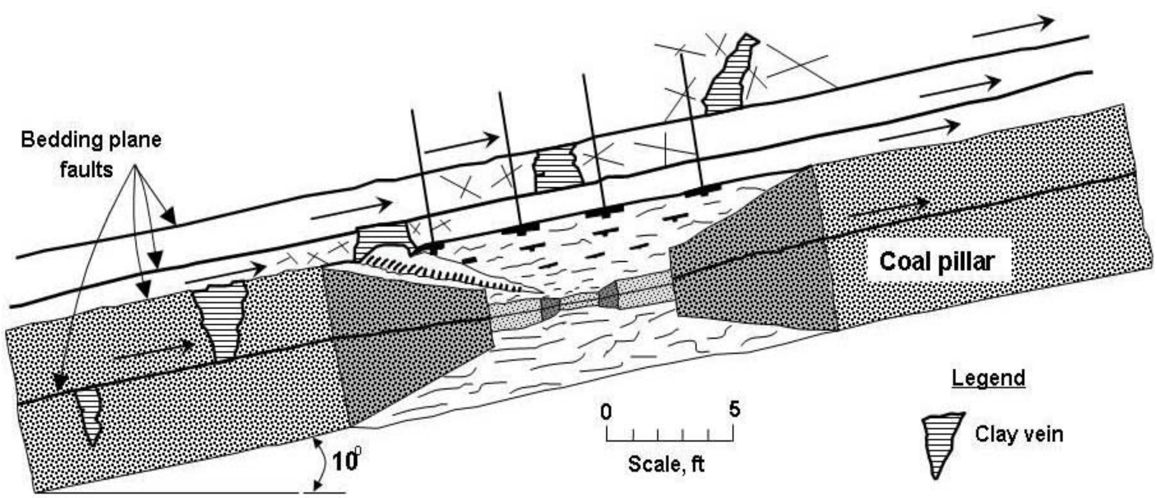

Figure 1. Bedding plane fault diagram.

UNDERGROUND GEOLOGIC MAPPING AND PREDICTION TECHNIQUES

A considerable amount of pertinent information can also be obtained from underground observations and mapping. These examinations are best made at the working faces prior to rock dusting. Roof bolt operators can often provide a wealth of knowledge on rock types and quality and always seem to be willing to share their perspectives with you when asked. It is critical that a geologist earn some degree of credibility and gain the respect of the section personnel. As one geologist remarked, “you can’t be underground every day so the section personnel have to be your eyes and ears.” Information gathered underground can be used to augment and refine previous correlations and to fill in the blanks from drill holes surrounding the adjacent workings. Another geologist stated that “underground mapping goes hand in hand with exploratory core hole drilling, you refine the maps as you mine and you drill when you need additional data, it’s an evolutionary process.” When it comes to underground mapping, one geologist summed it up well by saying “a good geologist observes everything, measures everything, and writes down everything.”

Once a troublesome geologic anomaly is identified, the feature’s lateral extents need to be defined through vertical drilling, underground mapping, and sometimes, commercially available geophysical techniques are employed. Economically driven decisions on how to cross these structures also need to be addressed, for example, is it cheaper to sink a new shaft? The majority of the geologists reported routinely constructing geologic conditions/forecast/projections maps which are generated on a weekly or biweekly basis. Commonly, these maps are colored green, yellow (orange), and red indicating the likelihood of encountering mine impeding geologic anomalies or other problems in the highlighted areas. The geologist’s explanation for the color coding should be understandable and well documented. For example, in an area shaded yellow, the presence of a rider coal at or slightly above anchorage might be anticipated based on drill logs. Therefore, the face boss will be instructed to have the bolter operators drill a test hole one or more feet above the anchorage horizon at every crosscut for instance. Addition descriptions and details on the roof can be obtained through the use of a fiberscope or camera to examine the test holes. Red zones are mineable, but normally warrant some kind of precautionary measures and/or supplemental support. Geologic conditions maps are typically posted in the mine manager, superintendent and mine foreman’s offices. Some mines also display them in the shift change areas, underground dinner holes, and even in the bath house. Face personnel should be made aware geologic conditions if impending changes are anticipated. Further, the crew should report back as to what they encounter while mining and roof bolting during their shift.

At this point, the reader may be asking how do you construct these geologic conditions maps or project structures into unmined portions of the coalbed? The most appropriate response is probably a good working knowledge of depositional environments and an experienced past history. One needs to have a familiarity with the characteristics of the features encountered on the property. For example, normally are they linear or curvilinear? Usually, how wide are they? Generally, are they persistent or do they scour down out of the roof and just as quickly disappear? Is there anything observable in the coalbed or roof that will forecast an impending problem structure or condition? Where do I drill to pinpoint the extent of the structure or find the coal? Therefore, to try to answer the question at the beginning of the paragraph requires intitution, and almost a “sixth sense.” As previously indicated, 12 geologists were surveyed and each was asked if they had gathered any rules of thumb or tricks of the trade when it came to underground mapping and predicting geologic structures and conditions in advance of mining. The responses are summarized below:

- When approaching a paleochannel, rock spars and channel lag deposits may occur in the roof and coalbed. The coal seam may thicken within 1-3 crosscuts from the channel.
- Highly stressed ground conditions can occur at greater depths near paleochannel and igneous dikes and might cause bumps/thumps in the roof, coalbed, or floor.
- When excessive water starts dripping from the roof, mining is near the margins of a paleochannel.
- The size of plant fossils increase the closer you get to a paleochannel. That is to say, one should expect to find larger plant components like preserved trunks closer to the channel; whereas, fossilized branches are found further away from the channel. Also, the nearer you are to the channel the better aligned the fossils become.
- Normally vertical coal cleat is sometimes inclined toward the trough of paleochannels. The more inclined the cleat is, the closer you are to the channel. Also, steep coalbed rolls are associated with channels and the coalbed can double in thickness.
- Minor fracturing and faulting can be encountered just prior to mining into a major fault.
- There is an increase in ground stresses as you near a major fault. In other operations, just the opposite was reported and approximately 50 feet from the fault the workings appeared stress relieved.
- In southern West Virginia, most of the faults that occur outside of the overthrust belt are normal faults. A geologist at a large mining complex instructed the miners that in order to find the missing coalbed that they should locate the dip of the fault plane and go with or follow the dip in order to find the coalbed.
- Kettlebottom concentrations will occur near paleochannel levees.
- When a normally bright coal band turns dull, it may soon turn into a rock parting.

The geologists were also questioned on what their experiences with lineaments have been. The general consensus was that they were another information source to examine. The critical question was, and always has been, are the linear features vertically penetrating and do they extend straight down all the way to the coalbed? For the most part, the geologists indicated good success with linears locating large scale regional structures like faults and igneous dikes. Some geologists also reported good correlations with linears locating straight and narrow stream valleys which are fracture controlled. One geologist stated that below these valleys poor roof conditions were prevalent when the depth of cover was less than 500 feet. Another geologist had good success with linears finding hillseams on his mine property. A straight segment of a normally sinuous stream, creek, or river is correlative with a linement. Across the board, the geologists were skeptical of using lineaments as problem indicators of small scale features at greater depths.

GEOTECHNICAL SPECIALIST: THE NEXT GENERATION

In addition to previously mentioned responsibilities, the respondents indicated technical involvement to varying degrees with planning shafts, slopes, impoundments, dams, and surge binds. One geologist stated, that "if it has anything to do with rocks, I work on it." Other reported duties include permitting and environmental work, hydrology, subsidence, underground instrumentation, and ventilation. To this end, the geologists surveyed suggested that those contemplating a career as a geotechnical specialists consider gaining a background in rock mechanics, geotechnical engineering, computer aided design (CAD), and in the various mining and geologic software modeling packages available. In addition, several geologists stressed the importance of acquiring a solid understanding of deltaic environments and sedimentation fundamentals, basic geologic field mapping techniques and good note taking abilities, and isopach mapping skills.

SUMMARY

Since the First Conference on Ground Control in Mining was held, the role of a coal mine geologist has changed dramatically. Todays geotechnical specialists are so to speak "wearing multiple hats" and time constraints have virtually mandated them to rely on software programs to construct cross-sections, isopach maps and other vital maps necessary for day to day mining operations. This was unheard of a quarter century ago, when this kind of information was generated by hand. Considerable time is also spent underground collecting the base-line data necessary for the engineer to make well-informed decisions. One geologist likened it to "handing a blind man a cane." As far as the next quarter century is concerned, there is no doubt that the reserves will become more challenging from both geologic and mining induced causative factors. Our shallower cover, more easily mined reserves have been and are being depleted. We have no other choice than to go deeper. Some are mentioning mines on the drawing board exceeding a depth of 3,000 feet, which is indeed a different realm. In order to assess these demanding environments, geotechnical specialists who are well trained in geophysics and the engineering disciplines will be needed. One of the geologist surveyed summarized the role of a geologist well when she stated, "you have to look at the entire rock package, how does it look, will it get better, is there somewhere else we should be?"

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