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Geologic data collection and assessment techniques in coal mining for ground control

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Abstract

The identification and mitigation of adverse geologic conditions are critical to the safety and productivity of underground coal mining operations. To anticipate and mitigate adverse geologic conditions, a formal method to evaluate geotechnical factors must be established. Each mine is unique and has its own separate approach for defining what an adverse geological condition consists of. The collection of geologic data is a first critical step to creating a geological database to map these hazards efficiently and effectively. Many considerations must be taken into account, such as lithology of immediate roof and floor strata, seam height, gas and oil wells, faults, depressions in the mine floor (water) and increases in floor elevation (gas), overburden, streams and horizontal stress directions, amongst many other factors. Once geologic data is collected, it can be refined and integrated into a database that can be used to develop maps showing the trend, orientation, and extent of the adverse geological conditions. This information, delivered in a timely manner, allows mining personnel to be proactive in mine planning and support implementations, ultimately reducing the impacts of these features. This paper covers geologic exploratory methods, data organization, and the value of collecting and interpreting geologic information in coal mines to enhance safety and production. The implementation of the methods described above has been proven effective in predicting and mitigating adverse geologic conditions in underground coal mining. Consistent re-evaluation of data collection methods, geologic interpretations, mapping procedures, and communication techniques ensures continuous improvement in the accuracy of predictions and mitigation of adverse geologic conditions. Providing a concise record of the work previously done to track geologic conditions at a mine will allow for the smoothest transition during employee turnover and transitions. With refinements and standardization of data collection methods, such as those described in this paper, along with improvement in technology, the evaluation of adverse geologic conditions will evolve and continue to improve the safety and productivity of underground coal mining.

Keywords

Roof contro; Database; Mapping; Hazards; Geology

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1. Introduction

There is no doubt that recognition and mitigation of roof control hazards has improved over the past 30 years. Technology and methodology of roof support implementation has made mines safer. However, ground failures still happen and in many cases can be linked to local geologic conditions. A series of steps should be taken to incorporate geologic data into a geologic database which can be further processed into hazard maps and finally used to make ground support decisions in mines (Fig. 1). This paper focuses on the steps of data collection, sources of geologic data, and the process of incorporating information into a geologic database.

It is common to have very little information on the geologic conditions that contributed to a ground control failure. The usual source of information on geologic conditions is core-holes that can be as far as 915 m or more apart. Additional geologic reconnaissance is needed to provide data in between the gaps of core-hole data. Methods for this purpose are often cited in literature and can include in-mine mapping, fiberscope observations, electronic logs, and many more. How to collect and interpret data from sources other than core-holes is based on experience and is rarely published. Most geologic reconnaissance can be performed at very little cost. A geologist walking down an entry with a trained eye making observations can reveal potential problems that can be mitigated to enhance safety and production. A camera, rock hammer, measuring tape, and a focus on changing conditions can provide a wealth of valuable data to enhance safety by revealing trends that can be linked to geological hazards.

It is always important to collect data at regular intervals. It can become difficult to notice trends in geologic data if there are large gaps of missing information. As trends start to develop, it becomes increasingly important to maintain the regular data collection intervals along with additional higher density data collection at points where geologic features of interest exist. Many times, it can be just as helpful to know where a geologic hazard is absent versus where it is present. When tracking geologic features, one should always consider the paleo-environment during the time of deposition to help determine direction and behavior of trends.

The differences between geologists and engineers have lessened over the decades as the two fields have started to merge. Geologists are expected to understand basic mining engineering concepts along with engineers understanding basic geologic concepts [1]. The relationship between the disciplines is highlighted best when years of experience are shared and geologists and geotechnical engineers work together as one unit. By working together, confusion between lithologic descriptions and support recommendations can be eliminated. Rocks can be described in many different ways, and it can become difficult for a geo-mechanical engineer to sort through the descriptions to provide roof support recommendations which is why it is critical for geologists to be consistent with lithology descriptions to ensure hazard areas can be identified on a consistent basis.

2. Data sources

No geologic information is always better than bad geologic information. Engineers plan for the worst conditions when geologic data is limited. If conditions are falsely reported as favorable when they are not, potential implications to miner safety and production could be impacted. Data quality is absolutely critical to allow for geologic hazard mapping. In some cases, core logging and other data collection methods are performed by drillers or engineers that are not qualified to properly describe lithology, especially for predetermining conditions for ground control. An experienced geologist with knowledge of ground control should examine all sources of geologic data and determine if the source is credible to add to the geologic hazard mapping model.

Today, geological information is available from a variety of sources. Federal government sources, such as the United States Geological Survey (USGS), and state sources, such as the Depart ment of Environmental Protection (DEP) and state geological surveys, along with universities, provide reliable data to the public. Many of these institutions also provide data files and publications that can be integrated into geospatial maps that not only contain geologic data, but also previously mined areas. These sources also may provide real-time data for hydrogeology, seismic, and remote sensing investigations. Other sources of information can include the National Institute for Occupational Safety and Health (NIOSH) publications and software tools to assist with data collection and best practices. Also, the Mine Safety and Health Administration (MSHA) provides case histories and a digital library for geologic case studies and other mining topics. Ultimately, the data that you control from collection to processing, such as core-hole, electronic logs, and in-mine data, should be the most trustworthy. These sources of data should be given the most consideration when modeling for geologic hazards.

3. Data organization

The first step of developing any geologic database is the process to record any data collected and to organize it so that it can be recalled quickly and efficiently. All geologic data should be recorded in both paper and digital formats so that redundancy is established. The naming convention of data points should be consistent, so others know from where the data point was measured. For example, if a fiberscope observation hole was observed at 3E longwall panel in crosscut 25 in the number 2 entry, then the data point could be labeled 3EX25E2 with the time and date that the observation was made. In-mine measurements should be labeled using a similar approach. Core-holes should be labeled by year and the order sequentially drilled or by another method that will allow future geologists to quickly understand when the core-hole was drilled and logged. A consistent naming convention will also allow faster analysis when creating cross sections and modeling.

The language to log geologic information needs to be standardized to ensure that other geologists can understand a given rock description. Most geologists use the Ferm classification for a description of lithology, which provides a basic description of the strata [2]. This description works well for an exploration geologist, but it is becoming more commonplace for geologist to work underground as well where a more detailed classification is needed. Describing strata for roof and floor support requires an expanded description for geotechnical engineers to properly recommend additional roof support where necessary. This can be accomplished by slightly modifying the original Ferm description to include modifiers for more detail. For example, Ferm code 124 is described as a dark grey shale which does not tell geo-mechanical engineers much about the rock they are trying to support. However, if a new rock description system is implemented and uses the same 124 dark grey shale and adds descriptors such as laminated, sandstone streaks, coal streaks, and a sharp contact, then the rock type is much better defined and better support recommendations can be implemented. Another description of the 124 grey shale could be described as thickly bedded, silty, rare sandstone streaks, and gradational lower contact, and the support recommendations could be very different since the second rock type is theoretically stronger that the first description. The modifiers can be abbreviated to aid in notetaking or inputting the data into a geological database (Fig. 2).

4. Drill hole information

Most coal exploration begins before any mining actually takes place. The most common method to accomplish this is by drilling core-holes. It is not uncommon for core-holes to be drilled just to obtain coal thickness and quality information describing moisture, sulfur, and ash contents, along with other useful information to determine the value of the coal to potential customers. However, limiting core to just these descriptors does not utilize the full potential of the core. The roof and floor lithology should be examined because the roof and floor are critical coal mine structural members and this can help detect weak roof in future reserves.

Of all the commonly used geotechnical investigation methods, drilled core provides the best quality data when mapping for geological trends. When examining the core for ground control purposes, many points of data can be collected. The immediate roof and floor lithology are extremely important along with the bottom of coal elevation. Detailed geologic descriptions, including any features that would strengthen or weaken the lithology should be kept within at least 15 m above the coal for typical gob-forming heights (Fig. 3). Floor lithology can be just as important as the roof lithology as highlighted by Van Dyke et al., so it is important to drill at least 6 m into the floor and not stop at the bottom of the coal seam [3]. Detailed floor core descriptions can provide valuable information about floor heave potential. Rock quality designation (RQD) can also provide useful information about rock quality that was recovered when taking the core sample. High-resolution photographs of the core with a tape measure used for scale can also be helpful for future analysis.

Guides to core identification and classification are available for most major coal basins in the United States. J.C. Ferm wrote guides to classify cored rocks for the Pittsburgh, Pocahontas, Southern Appalachian and Rocky Mountains and high plains coal fields. These guides give colored photographs and descriptions for classifying the core using Ferm's rock classification method [4–7]. Many of these guides can be found online at the Kentucky Geological Survey website, along with a wealth of mining information. The Indiana Geological Survey also published a core book of the Illinois Basin [8]. This core book layout differs slightly from the Ferm core books, but the Ferm number classification system is still used. The core book provides additional information on gamma logs, stratigraphic columns, and detailed lithologic descriptions that were not included in the Ferm series of core books.

5. Core testing

In addition to core classification and quality information for the target coal seam(s), physical property testing of the core provides valuable information for both the geologist and the mining engineer responsible for the pillar and support design of the mine. Physical property testing can be minimal or very extensive and is typically focused on the strength and deformation properties of the core. The numerous tests available have tradeoffs between property details, accuracy, time, and cost. As expected, the more accurate detailed tests typically require more time and money to perform. Typical tests of core samples include uniaxial compressive strength (UCS), triaxial compressive strength test, point load strength index test, Brazilian indirect tensile strength test, direct shear test, slake durability, and various moisture sensitivity test procedures. In addition, there are very specialized test procedures that have not yet received universal acceptance.

For determining strength and deformability of rock specimens, the most common type of core testing in mine planning is the uniaxial compressive strength to determine the Young’s Modulus, Poisson’s ratio, and peak strength of intact rock specimens. Triaxial compressive strength tests provide some information on the post peak strength and deformability of the rock specimen, which can be beneficial but more complicated. On the other end of the spectrum, the point load strength index test is extremely simple and quick. The point load test provides the opportunity to test both axially and diametrically multiple times on the same specimen, providing a sense of the compressive and tensile strength of the rock specimen. Both the Brazilian and direct shear test provide tensile strengths of the specimen [9].

The slake durability test provides some measure of the rock specimen strength in relation to its moisture sensitivity. The slake durability test involves rock abrasion, and as a result, the test results may be influenced by the specimen strength more so than the moisture sensitivity. The mining community has developed tests specifically to assess the rock specimens’ moisture sensitivity, such as the University of Kentucky Weather ability Test, the Consol Energy Water Sensitivity test, and the NIOSH Immersion test. The NIOSH immersion test tends to overestimate the likelihood of deterioration, whereas the other two tests tend to agree and provide a relatively good assessment of the rocks’ likelihood to deteriorate due to water exposure associated with mining activities.

6. Well logging

Geologic information derived from well logging can supplement core-hole data at a fraction of the cost. Traditional rotary or percussion style drilling methods can be performed at a cost of 2–3 times less than core drilling. Well logging should never completely replace core-hole drilling, but it is very effective in complementing core-holes to determine lithology and potential geological anomalies.

Typically, the standard suite of geophysical logs conducted by the coal industry include natural gamma, density, caliper, temperature, and resistivity. Sonic, acoustic televiewer, neutron, and spontaneous potential logs are also used, but only in special applications. When geophysical logs are incorporated into the geological database, they allow for the identification of lithology, provide depth and thickness measurements, verify coal recovery, and help correlate strata between core-holes. Typically, geophysical methods are much cheaper to employ than traditional core drilling. Geophysical methods are effective, but core-holes are still recommended periodically to provide physical evidence to back up geophysical logs. Additionally, core-holes are still needed to obtain quality data.

Gamma logs are the most widely used geophysical borehole method by the coal mining industry. Gamma logging records the gamma radiation naturally occurring from a rock. Natural gamma is used to detect the presence of potassium-40, which occurs mostly in shales. Because potassium-40 is very common in shales the natural gamma signature when all shales are correlated to the shale line (Fig. 4).

Density logs are also commonly used and are especially useful when combined with natural gamma on the same log. The density tool induces gamma radiation into a rock and measures the amount of radiation reflected back. Typically, denser rocks tend to absorb radiation and low-density rock reflects it back to the probe. The density tool contains a nuclear source, so it is not common for coal companies to have the tool in their inventory. Because of the source, some companies will not use density logs in case a tool gets lost in the borehole. A source lost in a borehole will sterilize the coal so that it cannot be mined without major expense to remove the source. The value of gamma and density run in the same borehole is that it highlights the coal beds and separates them from sandstones and limestones (Fig. 5).

Seismic reflectance can be used to locate larger geological features, such as faults, coal seam rolls (depressions), and sandstone channels, that can cause problems for safety and production. Results of seismic studies can provide an insight to potential problems in reserves. In a paper by Gochioco, 3D seismic reflectance was used with success to find a coal seam roll that allowed the mine to adjust mine planning to avoid it [12]. High-resolution seismic surveys have been proven to detect faults with throws as small as 4–5 m, depending on the depth [13].

The acoustic televiewer (ATV) log (Fig. 6) is an imaging tool that uses an ultrasonic pulse-echo configuration that records the transit time and amplitude of the reflected acoustic signal to produce a 360° oriented image of the borehole wall [14]. The ATV log can be used to identify geologic features such as fractures, foliation, bedding planes, joints, strike and dip, etc. Also, the ATV log can be used to determine the in-situ fracture frequency and to calculate an in-situ version of “RQD” for the strata. Fractures generated from drilling and core removal can introduce errors in traditional RQD calculation. The ATV log can eliminate error and confirm in-situ “RQD” values without the need to extract core [15]. When estimating RQD values from an ATV log, it is possible to overestimate the RQD values due to the confined nature of in-situ borehole versus the unconfined nature of the rock core [16]. The ATV log requires some interpretation time from the logging contractor. Along the log, each feature is identified with a color-coded line and tag that indicates the feature type, dip, and azimuth. All of the features are then summarized and placed on a rose diagram for easy interpretation. Adding this tool to your exploration program can enhance data acquisition by maximizing all available information. Using more advanced downhole geophysical survey types, such as ATV, has the potential to help reduce the amount of expensive core-holes required to conduct a thorough geotechnical evaluation.

Another geological well-logging tool used less commonly in the U.S. coal industry is sonic logging. Sonic logging requires fluid in the borehole to transmit high-frequency sound waves through the fluid and the formation and displays the travel time of P waves versus depth (Fig. 7). Traditionally, sonic logs have been used for porosity, permeability and cement bond logs calculations. However, sonic travel times have been correlated to Poisson’s ratio, Young’s modulus, and the estimation of uniaxial compressive strength (UCS) numbers in coal mine rocks in Australia and the United States [17].

7. In-mine data collection

One can never collect too much data when making geological observations. A good geologist will write every observation down because something that might seem insignificant now could be part of a trend that will cause problems in the future. Data collection points and observations should be dated, categorized, and digitized as soon as conveniently possible. Many times a single geologist is in charge of multiple mines, and it becomes difficult to keep data from one mine separate from the others.

Most geologic data collection begins with the drilling of core-holes. However, core-holes are only one source of information, and they are very costly to drill. In-mine observations are made with very little cost and can be made at a higher data point density. The limitation of in-mine observations is that they obviously cannot be collected in unmined areas. The true value of in-mine observations is easily observed when combined with core-hole information and other geophysical sources, as illustrated in Table 1.

In-mine observations can be quickly performed and should be made with consistent spacing. Usually, the only tools needed for in-mine observations are a mine map, measuring tape, and compass. Observations should be performed at every intersection. However, observation points can be increased depending on the accuracy desired. An observation needs to be as detailed as possible because it can become easy to question the data later if it seems incomplete. Some of the features that should be described during an in-mine observation are all rib, roof, and floor lithology. Any features such as faults, cutters, changes in the bottom of coal elevation, floor heave, fractures, kettle bottoms, water, slickensides, clay veins, joints, spalling ribs, and shale or sandstone channels should be plotted on the observation map.

In-mine observations should always be performed when indications of stress are present in an entry, regardless of when the last data point was taken. Some of the features that are stress driven are roof falls, cutters, roof bolt hole offset, roof potting, and fractures. It is critical to note the shape and orientation of all of these features because they will assist in determining the local horizontal stress fields and allow geologists to determine a predictable pattern of roof failure that can be addressed by adding additional support or by changing mining geometries. Mucho and Mark published a paper that gives a simple procedure to follow to determine horizontal stresses by mapping [18].

Fiber or video scopes are excellent tools to fill in gaps of missing roof or floor data in-between core-holes. The scope holes must be drilled at a regular interval to provide consistent coverage. Typical spacing of the scope holes should be about every 60–180 m and drilled 6 m deep to be able to observe the strata above the bolting horizon. The scope hole should be cleaned with water to wash away dust and cuttings to allow maximum visibility.

A case study published by Van Dyke describes the identification and effects related to transitional geology [19]. The study highlights how fiberscopes can be deployed along with other methods to plan and forecast ground control issues and recommendations. The mine roof lithology contained a limestone to sandstone geologic transition zone (Fig. 8) that was generally expected, but the exact location was unknown. Mine geologists utilized a fiberscope to identify the exact location of the transition zone and recommend the installation of supplemental support. The weak strata within the transition zone caused a roof fall in the first panel of the district before additional support could be installed. Geologists used the fiberscope to identify the transition zones during development of additional gate roads within the district. The mine deployed additional support at these locations identified by the geologists scoping program at the mining face during development. As a result, no additional roof falls occurred within the transition for 7 additional panels that were mined since the paper was published.

The logging of the scope hole should be performed by a geologist who is familiar with the lithology of the area. It is essential to have accurate and consistent geologic interpretations so that geotechnical engineers can better determine appropriate support based on the description. Changes in the lithology, such as rock type, bedding, grain size, mica, coal, clay, shale streaks, as well as some other features, all contribute to the understanding of the expected behavior of the rock. The geologist should also have an assistant with them to write down notes and ensure that the area is safe from traffic and other hazards while the geologist is occupied making observations [20].

Another option that can be utilized in-mine or in a borehole to evaluate geological anomalies is the radio imaging method (RIM). The system utilizes radio waves broadcasted from a transmitter across a longwall panel or between boreholes to a receiver strategically placed on each side of a potential geological anomaly. The radio signal will be absorbed, refracted, and scattered when encountering changes in materials between the transmitter and receiver. The data can be used to create an image through tomographic inversion that can be viewed by the end user [21].

8. Geologic database

All of the lithology information collected should be entered into a geologic database for quick recall and assessment. Many different types of geologic databases exist in utilizing different software programs such as Microsoft Excel and Access, while some databases are completely customized to an individual company. Despite the differences in software, many geological databases contain similar information needed to display information in geologic modeling software.

The information will vary based on the data sources available, but all geologic information should contain coordinates, coordinate system, dates, type of data source, drill depths, accurate lithology descriptions, and key maker beds to correlate between data points. Coal quality and any additional important information, should be noted as well. All of the information in the geological database needs to be updated on a regular basis so that models can be updated with the latest data, especially when analyzing adverse geologic trends. Databases can be set up to maintain special information such as geotechnical data, analysis of strata for environmental purposes, geophysical logs and hole plugging and abandonment documentation.

Many software options are available to create and organize geologic information within a database. One example of database software is the DHDB (drill hole database) geologic database (Fig. 9) that was developed by Highland Geo-Computing. This user-friendly access based program provides a comprehensive drill-hole database that can export data into various formats used by some of the most common geologic modeling software packages in the industry. When selecting or developing a geologic database it is important to look for a user friendly, secure, compatible and easily adaptable databases that provides all the necessary data requirements for the mine application.

As noted in Fig. 9, it is used with permissions granted by highland geo-computing, LLC, and drill hole database-DHDB.

9. Conclusions

Data collection and assessment techniques are the basis for any geological database. When examining geologic data for ground control purposes, it is important to include as many descriptors as possible so that engineers can make the best decisions possible. Features that can strengthen or weaken strata should always be noted because the smallest inclusions can be the reason why the roof or floor can fail. Implementing a geological reconnaissance program that is dedicated to ground control is an effective approach to limiting ground control failures.

There are many methods that can be used to collect geologic data, but ensuring confidence in the data is an important step to allow one to truly understand the lithology. Core-holes will always be the most comprehensive method for data collection because the core can be examined and tested in a variety of ways that characterize the rock. Well logging and seismic surveys can provide excellent data given that the proper tools are used and nearby core-holes can verify the lithology with less cost than drilling additional core-holes. Underground exploration methods can provide effective results by a combination of mapping and scope-hole analysis and can supplement core-hole information and well log analysis. However, the best results are achieved when all three methods are combined into one geologic database.

Efficient geologic data collection methods and a strong geologic database can save time, money, and most importantly lives, when incorporated into ground support decision-making.

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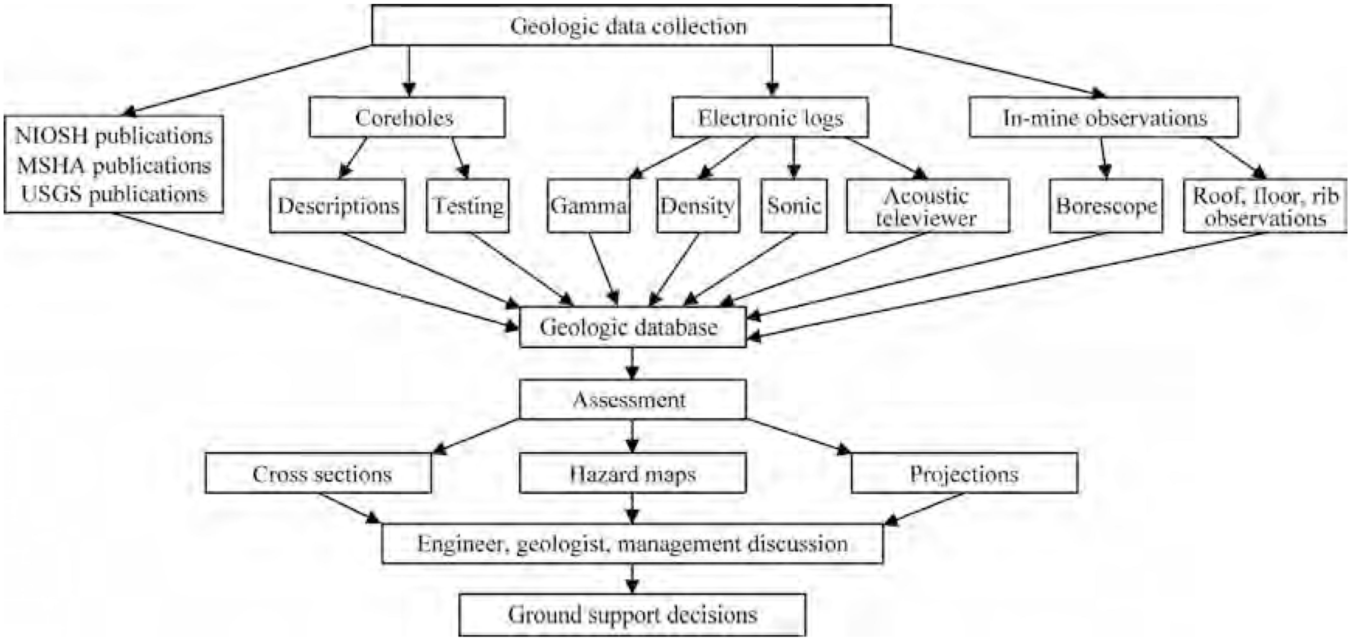
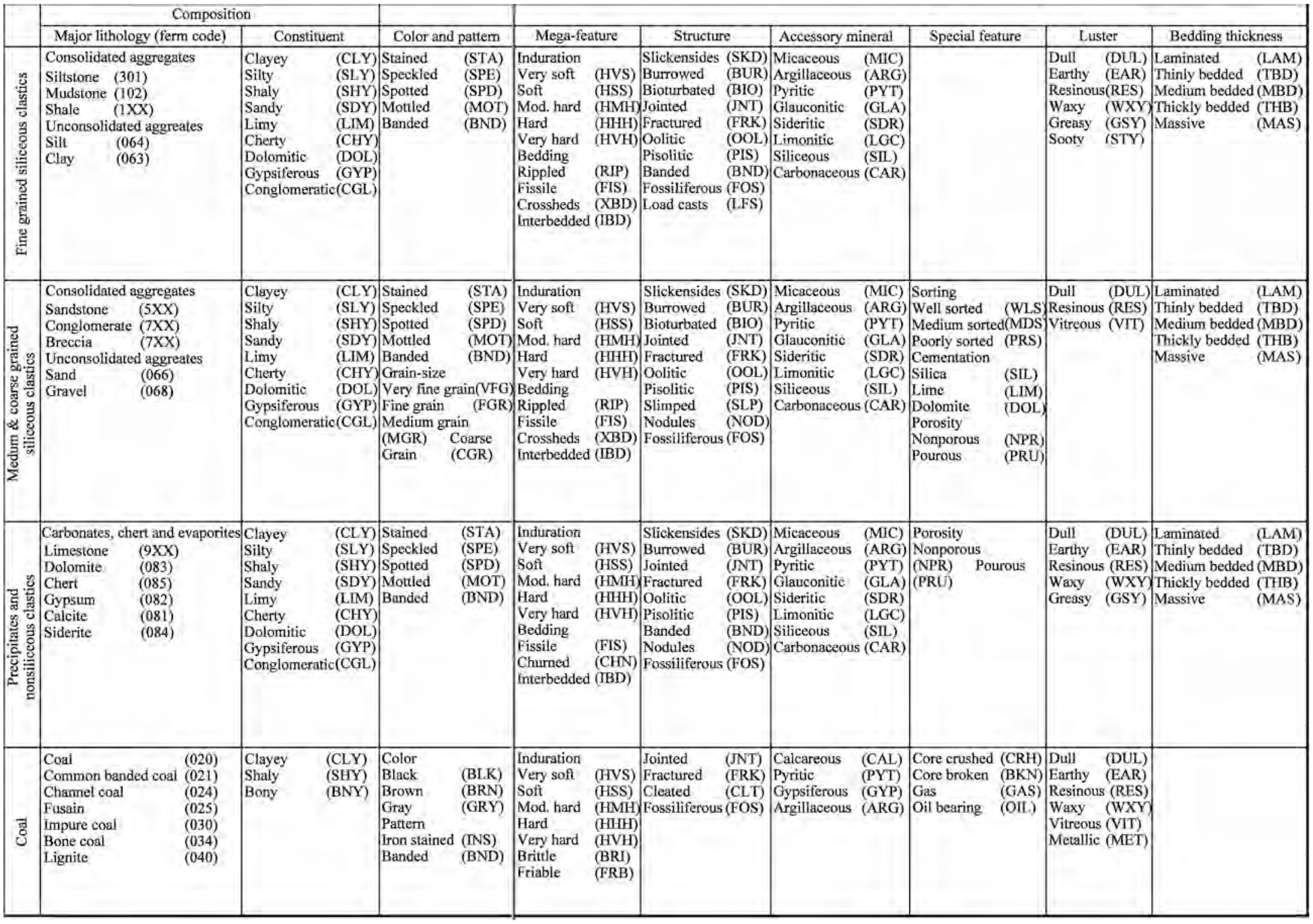


Fig. 1.

Geologic data flow chart.



	Composition								
	Major lithology (ferm code)	Constituent	Color and pattern	Mega-feature	Structure	Accessory mineral	Special feature	Luster	Bedding thickness
Fine grained siliceous clastics	Consolidated aggregates Siltstone (301) Mudstone (102) Shale (1XX) Unconsolidated aggreates Silt (064) Clay (063)	Clayey (CLY) Silty (SLY) Shaly (SHY) Sandy (SDY) Limy (LIM) Cherty (CHY) Dolomitic (DOL) Gypsiferous (GYP) Conglomeratic(CGL)	Stained (STA) Speckled (SPE) Spotted (SPD) Mottled (MOT) Banded (BND)	Induration Very soft (HVS) Soft (HSS) Mod. hard (HMH) Hard (HHH) Very hard (HVH) Bedding Rippled (RIP) Fissile (FIS) Crossheds (XBD) Interbedded (IBD)	Slickensides (SKD) Burrowed (BUR) Bioturbated (BIO) Jointed (JNT) Fractured (FRK) Oolitic (OOL) Pisolitic (PIS) Banded (BND) Fossiliferous (FOS) Load casts (LFS)	Micaceous (MIC) Argillaceous (ARG) Pyritic (PYT) Glauconitic (GLA) Sideritic (SDR) Limonitic (LGC) Siliceous (SIL) Carbonaceous (CAR)		Dull (DUL) Earthy (EAR) Resinous(RES) Waxy (WXY) Greasy (GSY) Sooty (STY)	Laminated (LAM) Thinly bedded (TBD) Medium bedded (MBD) Thickly bedded (THB) Massive (MAS)
Medum & coarse grained siliceous clastics	Consolidated aggregates Sandstone (5XX) Conglomerate (7XX) Breccia (7XX) Unconsolidated aggreates Sand (066) Gravel (068)	Clayey (CLY) Silty (SLY) Shaly (SHY) Sandy (SDY) Limy (LIM) Cherty (CHY) Dolomitic (DOL) Gypsiferous (GYP) Conglomeratic(CGL)	Stained (STA) Speckled (SPE) Spotted (SPD) Mottled (MOT) Banded (BND) Grain-size Very fine grain(VFG) Fine grain (FGR) Medium grain (MGR) Coarse Grain (CGR)	Induration Very soft (HVS) Soft (HSS) Mod. hard (HMH) Hard (HHH) Very hard (HVH) Bedding Rippled (RIP) Fissile (FIS) Crossheds (XBD) Interbedded (IBD)	Slickensides (SKD) Burrowed (BUR) Bioturbated (BIO) Jointed (JNT) Fractured (FRK) Oolitic (OOL) Pisolitic (PIS) Slimped (SLP) Nodules (NOD) Fossiliferous (FOS)	Micaceous (MIC) Argillaceous (ARG) Pyritic (PYT) Glauconitic (GLA) Sideritic (SDR) Limonitic (LGC) Siliceous (SIL) Carbonaceous (CAR)	Sorting Well sorted (WLS) Medium sorted(MDS) Poorly sorted (PRS) Cementation Silica (SIL) Lime (LIM) Dolomite (DOL) Porosity Nonporous (NPR) Pourous (PRU)	Dull (DUL) Resinous (RES) Vitreous (VIT)	Laminated (LAM) Thinly bedded (TBD) Medium bedded (MBD) Thickly bedded (THB) Massive (MAS)
Precipitates and nonsiliceous clastics	Carbonates, chert and evaporites Limestone (9XX) Dolomite (083) Chert (085) Gypsum (082) Calcite (081) Siderite (084)	Clayey (CLY) Silty (SLY) Shaly (SHY) Sandy (SDY) Limy (LIM) Cherty (CHY) Dolomitic (DOL) Gypsiferous (GYP) Conglomeratic(CGL)	Stained (STA) Speckled (SPE) Spotted (SPD) Mottled (MOT) Banded (BND)	Induration Very soft (HVS) Soft (HSS) Mod. hard (HMH) Hard (HHH) Very hard (HVH) Bedding Fissile (FIS) Churned (CHN) Interbedded (IBD)	Slickensides (SKD) Burrowed (BUR) Jointed (JNT) Fractured (FRK) Oolitic (OOL) Pisolitic (PIS) Banded (BND) Nodules (NOD) Fossiliferous (FOS)	Micaceous (MIC) Argillaceous (ARG) Pyritic (PYT) Glauconitic (GLA) Sideritic (SDR) Limonitic (LGC) Siliceous (SIL) Carbonaceous (CAR)	Porosity Nonporous (NPR) Pourous (PRU)	Dull (DUL) Earthy (EAR) Resinous (RES) Waxy (WXY) Greasy (GSY)	Laminated (LAM) Thinly bedded (TBD) Medium bedded (MBD) Thickly bedded (THB) Massive (MAS)
Coal	Coal (020) Common banded coal (021) Channel coal (024) Fusain (025) Impure coal (030) Bone coal (034) Lignite (040)	Clayey (CLY) Shaly (SHY) Bony (BNY)	Color Black (BLK) Brown (BRN) Gray (GRY) Pattern Iron stained (INS) Banded (BND)	Induration Very soft (HVS) Soft (HSS) Mod. hard (HMH) Hard (HHH) Very hard (HVH) Brittle (BRI) Friable (FRB)	Jointed (JNT) Fractured (FRK) Cleated (CLT) Fossiliferous (FOS)	Calcareous (CAL) Pyritic (PYT) Gypsiferous (GYP) Argillaceous (ARG)	Core crushed (CRH) Core broken (BKN) Gas (GAS) Oil bearing (OIL)	Dull (DUL) Earthy (EAR) Resinous (RES) Waxy (WXY) Vitreous (VIT) Metallic (MET)	

Fig. 2.

Expansion of the Ferm geological code system.

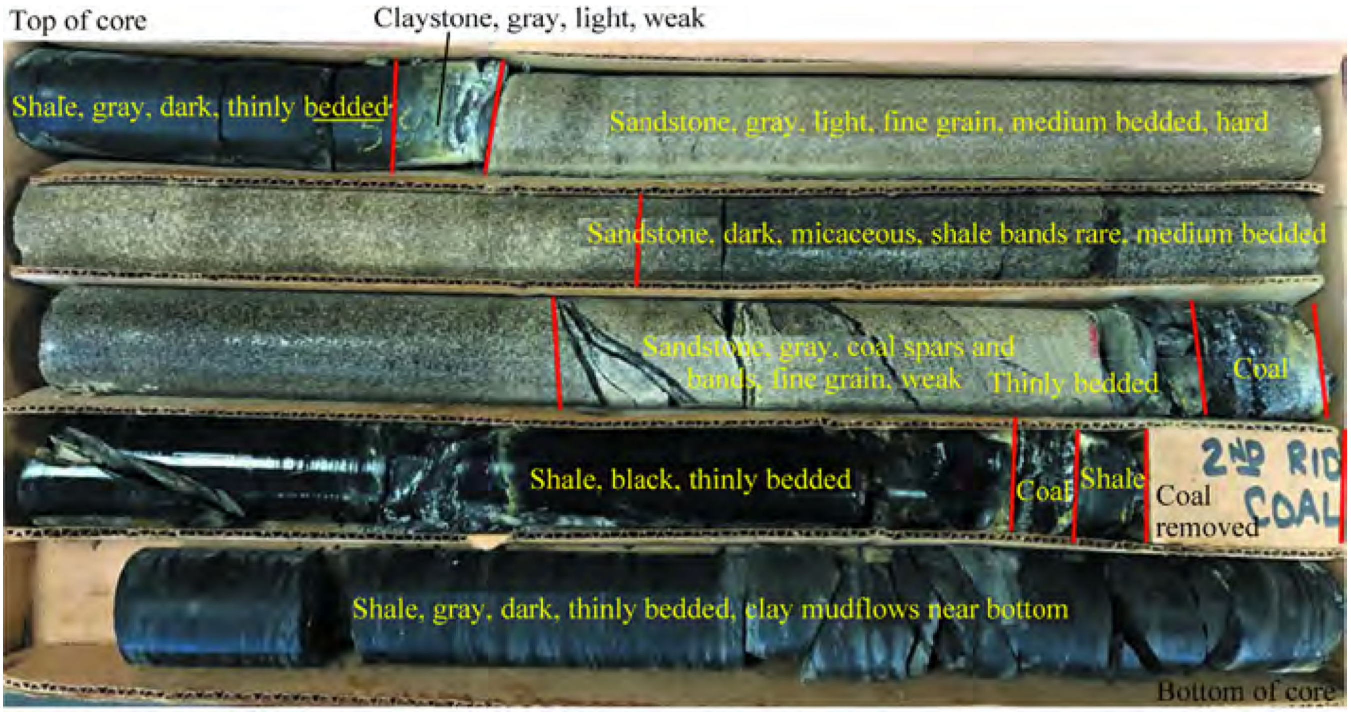


Fig. 3.

Roof core lithology (dampened for contrast).

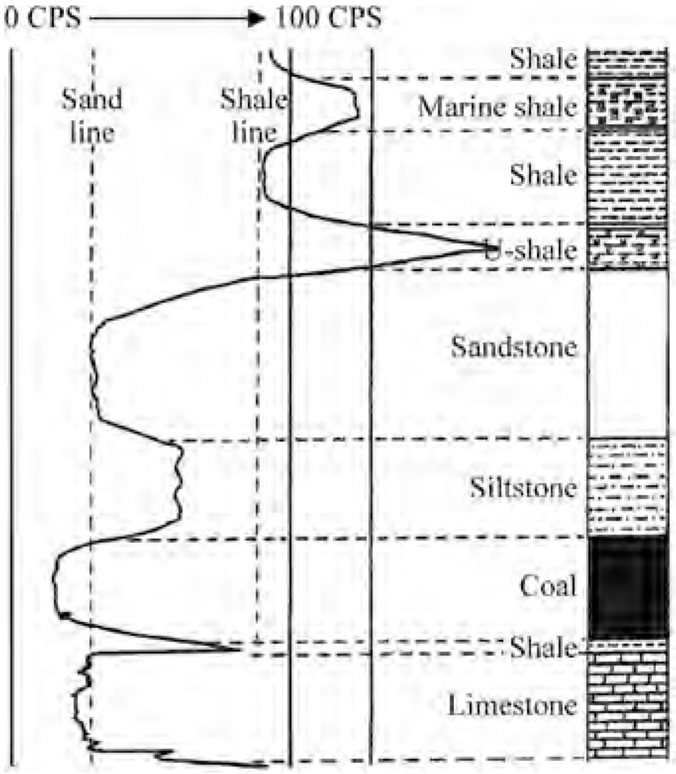


Fig. 4.
Lithology versus natural gamma response [11].

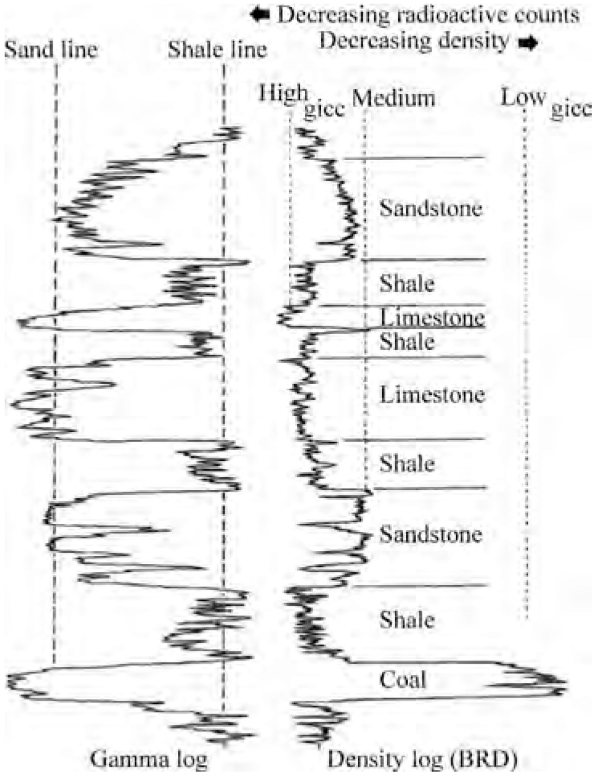


Fig. 5.

Density and gamma geophysical log [11].

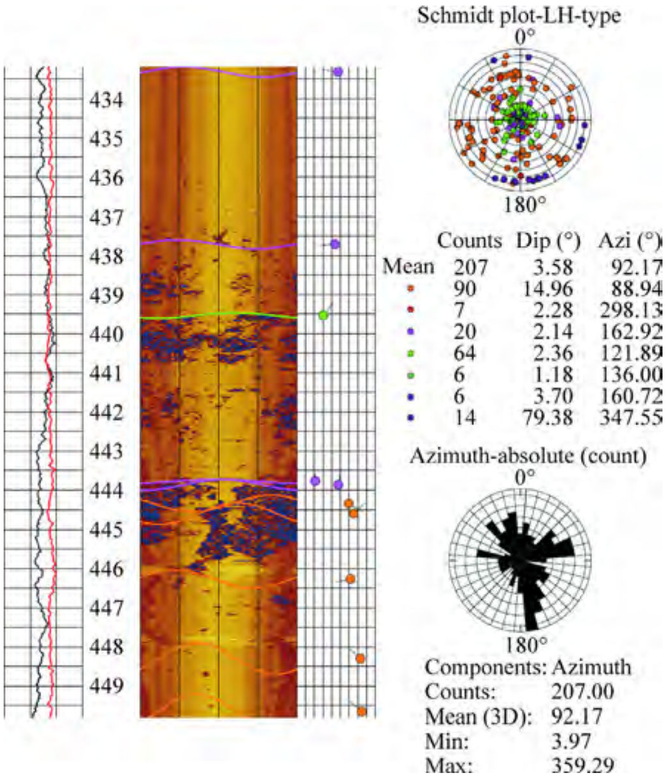


Fig. 6.

Acoustic televiewer with gamma (black) and density (red).

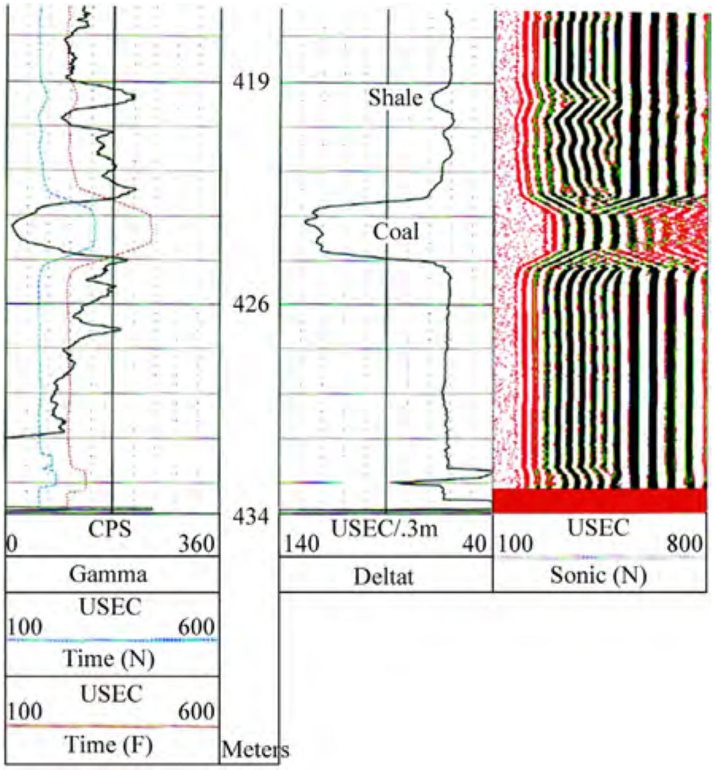


Fig. 7.

Sonic logging.

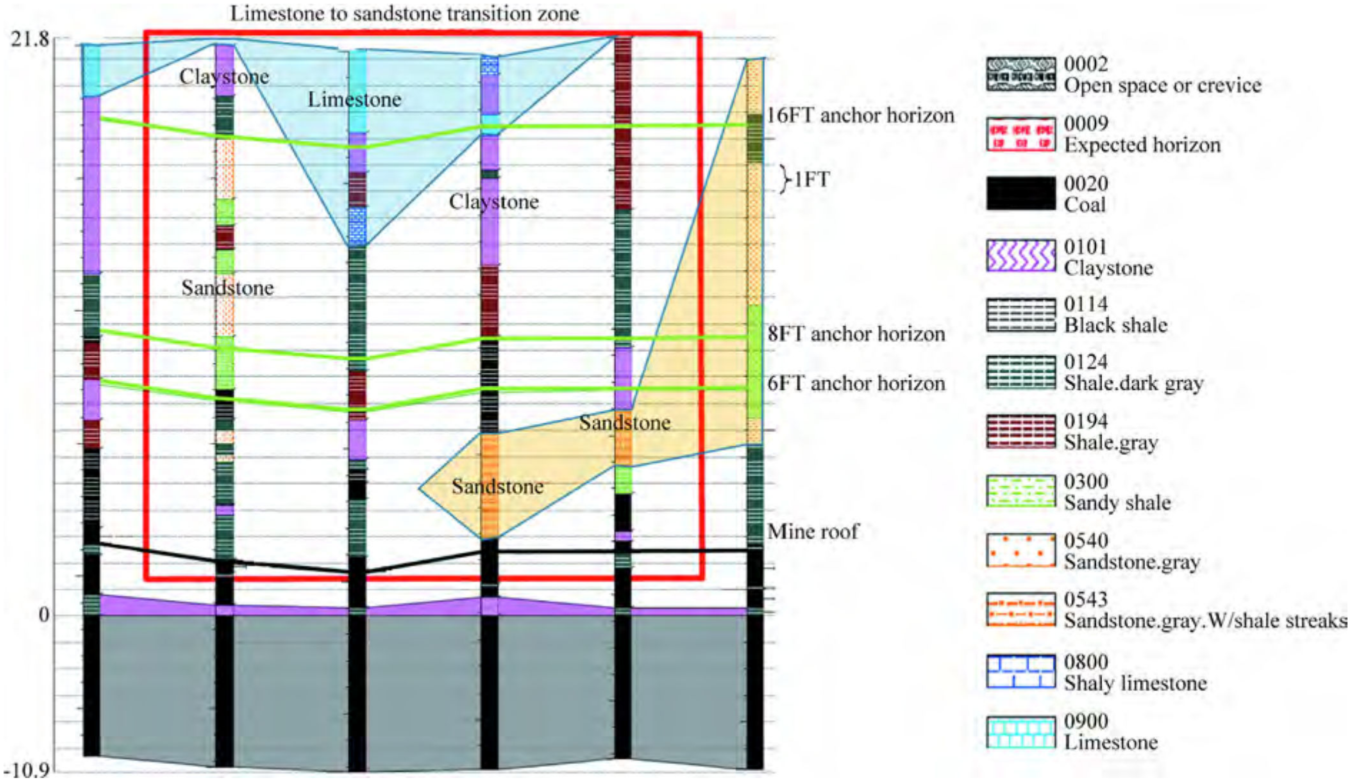
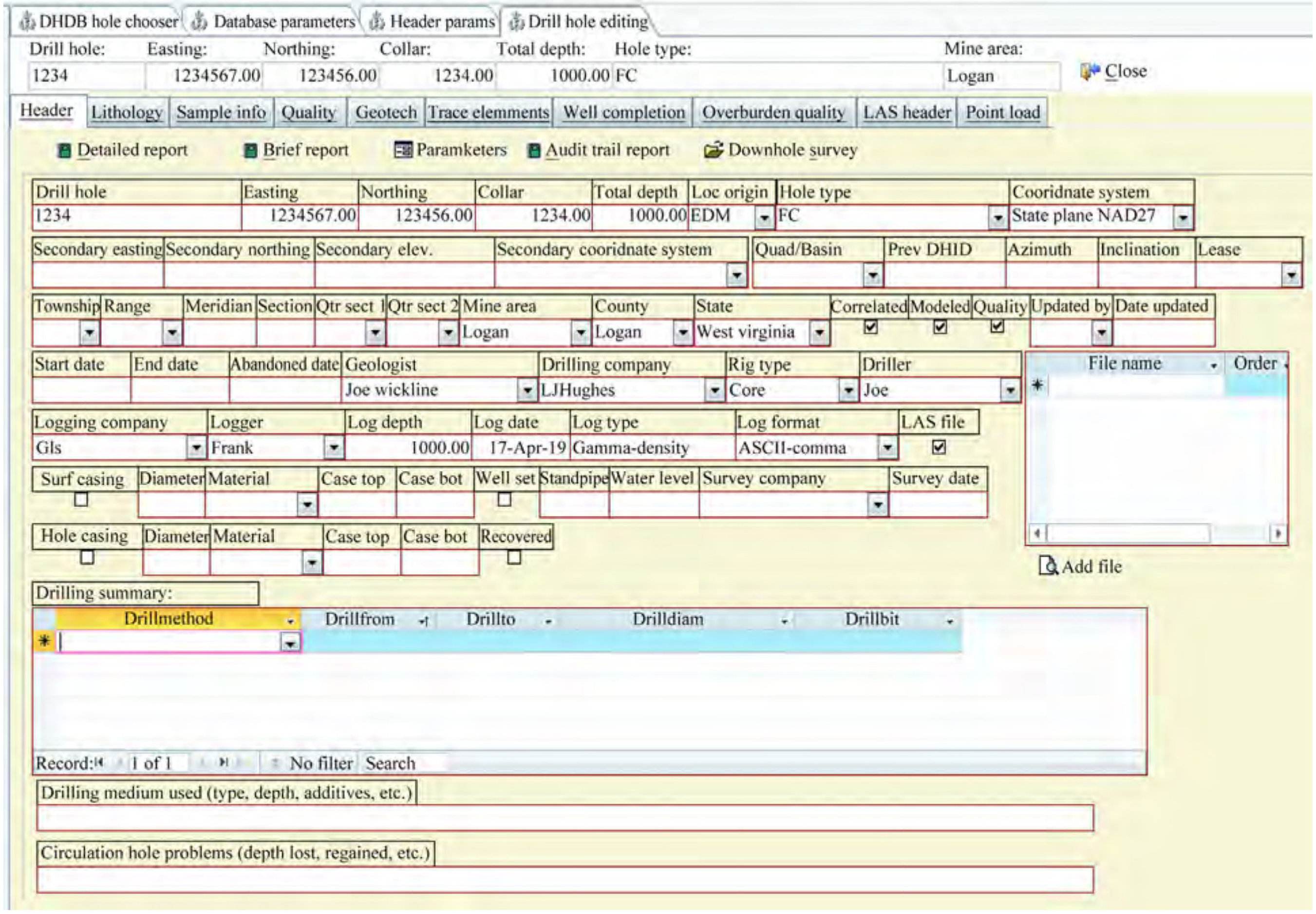


Fig. 8.

Fiberscope results that identify a limestone-to-sandstone transition zone [19].



Drill hole:	Easting:	Northing:	Collar:	Total depth:	Hole type:	Mine area:
1234	1234567.00	123456.00	1234.00	1000.00	FC	Logan

Drill hole	Easting	Northing	Collar	Total depth	Loc origin	Hole type	Cooridnate system
1234	1234567.00	123456.00	1234.00	1000.00	EDM	FC	State plane NAD27

Secondary easting	Secondary northing	Secondary elev.	Secondary cooridnate system	Quad/Basin	Prev DHID	Azimuth	Inclination	Lease

Township	Range	Meridian	Section	Qtr sect 1	Qtr sect 2	Mine area	County	State	Correlated	Modeled	Quality	Updated by	Date updated
						Logan	Logan	West virginia	☑	☑	☑		

Start date	End date	Abandoned date	Geologist	Drilling company	Rig type	Driller
			Joe wickline	LJHughes	Core	Joe

Logging company	Logger	Log depth	Log date	Log type	Log format	LAS file
GIs	Frank	1000.00	17-Apr-19	Gamma-density	ASCII-comma	☑

Surf casing	Diameter	Material	Case top	Case bot	Well set	Standpipe	Water level	Survey company	Survey date
☐					☐				

Hole casing	Diameter	Material	Case top	Case bot	Recovered
☐					☐

File name	Order
*	

Drilling summary:

Drillmethod	Drillfrom	Drillto	Drilldiam	Drillbit
*				

Record: 1 of 1 No filter Search

Drilling medium used (type, depth, additives, etc.)

Circulation hole problems (depth lost, regained, etc.)

Fig. 9.

Microsoft access geologic database.

Table 1

Example of geologist's rib description.

Thickness (m)	Description
0.44	Sandstone; brown, medium grained, hard, cross bedded, micaceous, medium bedded, sharp lower contact
0.15	Coal; black, bright, abundant vertical fractures, pyrite streaks
0.17	Clay; dark grey, soft, plant fossils
0.02	Pyrite band
0.10	Shale; slightly silty, black, fissile, carbonaceous, thinly bedded
1.60	Coal; black, bright, calcite-filled fractures