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PROBLEMS IN "VOID" DETECTION IN COAL MINE WATER HAZARDS

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ABSTRACT

One of the most dangerous events in underground coal mining is unexpectedly encountering water inrushes from undetected abandoned mines in the same seam. The surest and most confident method is probe drilling either from the mine or from the surface. However, drilling is expensive and may even miss the suspected mine voids entirely by drilling through pillars. Many operators rely upon one or more of several remote sensing techniques for detecting mine voids. However, mine "voids" often are not air- or water-filled open cavities, but are collapsed, rubble-filled chimneyed columns in the strata. Geophysical techniques, such as seismic reflection and refraction, electrical resistivity, magnetics, ground-penetrating radar, and others, often assume a continuous or fractured rock mass that has varying properties which provide the signatures that allow discrimination of one strata from another, or of strata from voids. However, a rubble-filled cavity has rock block-to-rock block contact throughout its volume and can still respond as a continuous rock mass with the rock blocks allowing signal transmission or mass detection, rather than a void space. Hydraulically, a rubble-filled cavity is essentially as transmissive to water as an open mine void. Thus, the problem of detecting a mine void with confidence is significantly compounded.

INTRODUCTION

The United States Mine Safety and Health Administration (MSHA) estimates that there are 226 coal mines in the U.S. that are within 500 ft horizontally or 100 ft vertically of other coal mines (1), and that from 1995 through June 2002 mine operators reported 181 mine inundations, of which 107 were unplanned cut-throughs into other mines that resulted in water inundations (2). Much attention has been focused on the issue of coal mine inundations since the Quecreek Mine near-disaster in Pennsylvania in July 2002 (3), with entire conferences dedicated to the problem of detecting mine voids such as in "Geophysical Technologies for Detecting Underground Coal Mine Voids" in Lexington, Kentucky (July 2003) and the "IMCC/MSHA/OSM Benchmarking Workshop on Underground Mine Mapping," in Louisville, Kentucky (June 2003).

Many technologies have been suggested or utilized for detecting mine voids by remote sensing, including seismic reflection/refraction, electromagnetics, electrical resistivity, microgravity, ground-penetrating radar, and others. However, the only method of positively detecting a void in advance of mining is by probe drilling. Probe drilling from within a mine is required by MSHA and several states. The MSHA requirement is:

30 CFR §§ 75.388 Boreholes in advance of mining.

(a) Boreholes shall be drilled in each advancing working place when the working place approaches--
- (1) To within 50 feet of any area located in the mine as shown by surveys that are certified by a registered engineer or registered surveyor unless the area has been preshift examined;
- (2) To within 200 feet of any area located in the mine not shown by surveys that are certified by a registered engineer or registered surveyor unless the area has been preshift examined; or
- (3) To within 200 feet of any mine workings of an adjacent mine located in the same coalbed unless the mine workings have been preshift examined.

(b) Boreholes shall be drilled as follows:
- (1) Into the working face, parallel to the rib, and within 3 feet of each rib.
- (2) Into the working face, parallel to the rib, and at intervals across the face not to exceed 8 feet.
- (3) At least 20 feet in depth in advance of the working face, and always maintained to a distance of 10 feet in advance of the working face.

(c) Boreholes shall be drilled in both ribs of advancing working places described in paragraph (a) of this section unless an alternative drilling plan is approved by the District Manager in accordance with paragraph (g) of this section. These boreholes shall be drilled--
- (1) At an angle of 45 degrees to the direction of advance;
- (2) At least 20 feet in depth; and
- (3) At intervals not to exceed 8 feet.

and

(f) If mining is to be conducted within 50 feet above or below an inaccessible area of another mine, boreholes shall be drilled, as necessary, according to a plan approved by the district manager.

or

(g) Alternative borehole patterns that provide the same protection to miners as the pattern established by paragraphs (b) and (c) of this section may be used under a plan approved by the district manager.

However, drilling from within the mine is both expensive (albeit cheaper than an inundation) and likely to slow or halt mine development and profit.

As demonstrated at Quecreek (3), at the Sextet Mine in Kentucky (4), and others, existing and archived mine maps of abandoned coal mines can be inaccurate, out-of-date, or falsified. To avoid slowing mining operations, many mines choose to drill from the surface to detect mine voids. However, such drilling can be very expensive, upwards of $25 per foot, and obviously hole costs increase with depth. One difficulty with surface drilling, aside from costs, is the limited ability to find a void. The drill hole is, at most, sampling a 4- to 6-inch diameter column through the strata and, if the actual mine void locations are not known with any degree of surety, the method is literally a "hit or miss" proposition. Figure 1 shows a hypothetical drilling pattern in search of mine voids, and the limited success obtained.

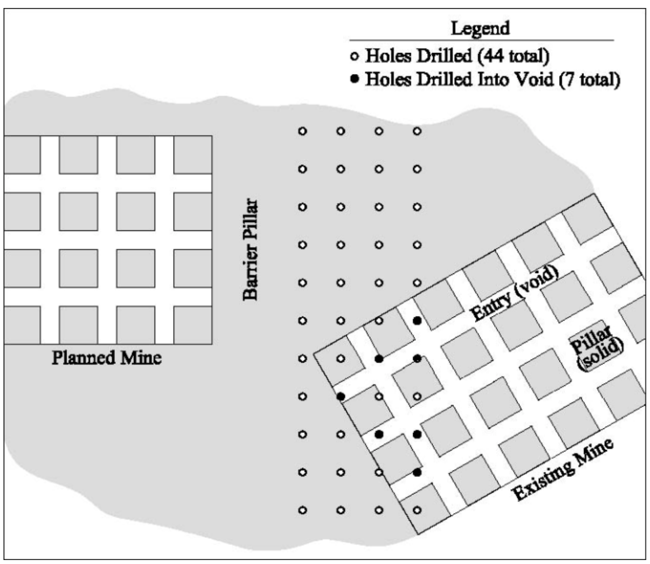

Figure1. Problems Probe Drilling from Surface

REMOTE SENSING

Remote sensing should never be used without "calibration" or "ground truthing" by a drill hole or other direct, verifiable, subsurface measurements of strata conditions. All of the remote sensing techniques mentioned above have one or more inherent assumptions that are often not well understood by the mining company contracting for such services. The methods are measuring variations of some property of the strata along the path or in the vicinity of the method's examination. That property is only indirectly indicative of a mine void, and often, especially in seismic and electrical methods, its field results are compared to a computer-generated "model" of what the mine void is anticipated to look like to the sensing method. Results are usually couched in probabilities or uncertainties. All technologies are sensitive to encountered field conditions, and may have greater or lesser degrees of success (or failure) depending on encountered conditions. In some instances the technician must be prepared to "walk away" and conclude that the technique just is not working. All remote sensing technologies lose resolution with distance from the source energy, often dramatically, and the limitation of each technology must be appreciated. The skill, experience, and practical knowledge of the technicians collecting and interpreting the field data are paramount for success, if success is, indeed, possible.

The applicators (remote-sensing technicians) and end-users of such techniques (mining personnel) must understand what the potential targets are and how they will appear to the remote sensing methodology. A mine void is a hole in the earth and strata that are fundamentally an extremely heterogeneous and discontinuous medium, containing many differing, discontinuous layers, beds, and formations, with varying degrees of mineralogical composition, fracturing, water contents, and mining disruptions.

Fundamentally, a hole in the ground is a void in the literal sense –a "nothing." The techniques cannot find the "nothing," but, rather, are searching for disruptions, disturbances, or differences in the materials surrounding the "nothing." Those who are well-versed in many geophysical techniques, term the procedure "looking for porosity enhancement," –an excellent term and concept (5). A clean, empty, smooth-walled void can act as a reflector or shadow to energies being transmitted or measured that attempt to pass through the void to a sensor. Figure 2 shows such an ideal case.

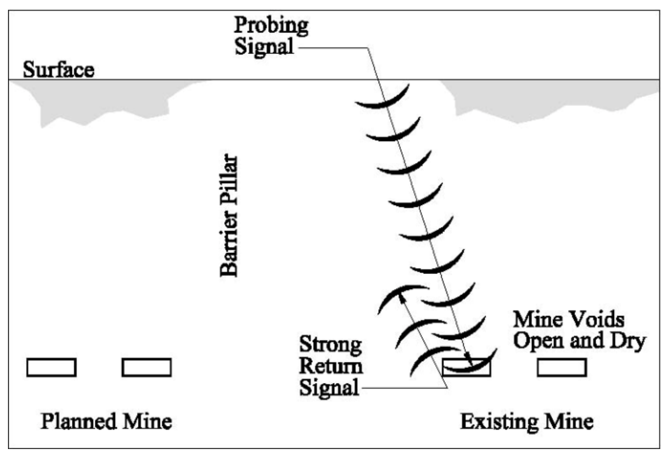

Figure 2. Remote Sensing of Open Mine Void

COAL MINE ROOM COLLAPSE PHENOMENA

Most abandoned coal mine openings, rooms, or entries eventually collapse due to deterioration of the roof, floor, or supporting pillars. The configuration and progression of the collapse of a coal mine entry has been well-understood in mining engineering for a very long time (6, 7 and 8). The immediate roof of the coal mine entry first collapses, and the immediately overlying strata also collapses, progressing ever higher depending on the ability of the individual encountered strata layers to arch or bridge the void, "stoping" or "chimneying" upwards.

"Strong" strata limit vertical development, while "weak" strata encourage or allow great vertical development, even for hundreds of feet. The controlling factors are the ability of some overlying strata to arch or bridge, such as a sandstone or limestone layer, or to "bulk" or develop significant pore space within the breaking and disaggregating collapsing strata. Strata which allow arching or bridging can even develop an upper void below the top of the arch or bridge well above the coal seam (for remote sensing technologies originating from the surface, this "upper void" will mask the features below), while bulking strata will develop the collapse until the underlying broken material begins to support the chimney top, preventing further collapse, and very weak and cohesionless strata can progress to considerable vertical extents due to no mechanisms to limit continued collapse. Bulking strata also vary in their ability to will create pore space with thinly laminated shales bulking very little due to the "platey" and flat nature of the disaggregated pieces, with harder rocks such as sandstones and limestones breaking into angular fragments with considerable pore space in the rubble. Nonetheless, an abandoned and collapsing coal mine entry or, more often, intersection is, in reality, a rubble-filled cavity.

PROBLEMS IN "VOID" DETECTION

None of the discussion above is new to experienced mining engineers and geologists. However, what this author has observed several times is that the realization of the existence of rubble-filled cavities is not appreciated in the application of the remote-sensing techniques. What the technique will measure is a gradual loss of energy or signal from the method as the "undisturbed" strata transitions to the rubble-filled cavity. As in Figure 3, the rubble provides a rock block-to-rock block path for the energy to be transmitted along, but at a weaker rate and increasing signal attenuation. Marino and Widup (9) report similar results for cross-hole radar. Thus, a clear and distinct "hole" is not detected, or if arching or bridging has occurred, the void is at the wrong elevation.

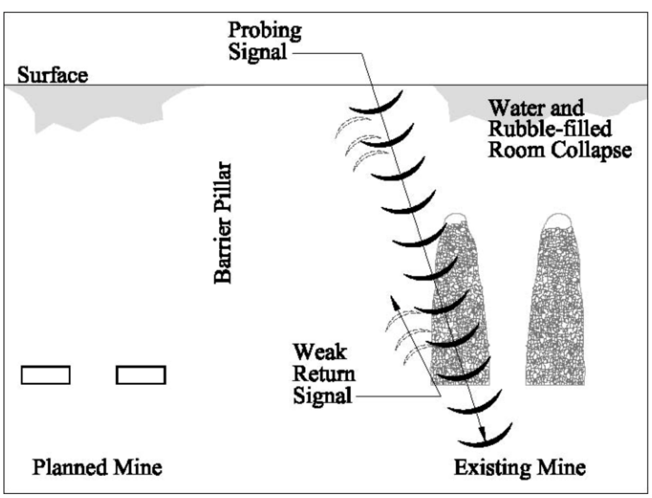

Figure 3. Remote Sensing of Rubble-filled Mine Collapse

Inexperienced remote-sensing technicians, who, we must remember, are interpreting and comparing field results to a "model" of what the mine void is anticipated to look like to the sensing method, have, in the author's experience, discarded such observations as variations in intact strata characteristics, confusing, spurious equipment faults, or anomalies. One instance the author is familiar with had identified the consistent tops of rubble-filled cavities, but dismissed the data because the indications were above the known coal seam elevation, when, in fact, the technique did a pretty fair job of locating the rubble-filled cavities, just not where the technician anticipated them.

In one instance, the original mine maps were found from many decades ago; however, unbeknownst to all, at some time in the intervening decades the last operators or, more likely, trespassers, had extended the mine outwards with no maps produced, state inspections allowed, or coal production reported. This situation reinforced the remote-sensing technician's faith in his results, as there should not have been a mine in the location that later was breached.

Unfortunately, rubble-filled cavities, when water-filled, are very hydraulically transmissive and can flood a penetrating mine with great efficiency.

CONCLUSIONS

Inasmuch as a coal mine void is more likely a rubble-filled chimney, the mine operator in the situation near a suspected water-filled abandoned coal mine must be aware of the characteristics of the target of the exploration for the mine void to avoid an inadvertent mine inundation. When suspected of being in the vicinity of an abandoned underground coal mine at or below the water table, the operators of such a mine must:

- Follow the applicable laws and regulations.
- Not have blind faith in the accuracy of mine maps and the honesty of men.
- Drill probing holes as much as economically affordable compared to the lost profit from abandoning the coal.
- Have knowledge of the likely room collapse phenomena in the seam being extracted.
- Have full knowledge of the methodology and limitations of the remote sensing techniques employed.
- Follow this author's recommendations to the Pennsylvania Governor's Commission on Abandoned Mine Voids and Mine Safety in Pottsville, Pennsylvania (10) and the guidance in Kendorski, Khosla, and Singh (11):
  - Plan the mine to minimize the effects of an inundation.
  - Allow safe evacuation of all mining personnel.

If we can plan mine ventilation systems for an explosion, why can't we plan mine water handling systems and mines for an inundation?

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REFERENCES

1. MSHA, Inundation Potential at Specific Mines, 2004, at http://msha.gov/readroom/foia/inunation/inundationpotentialfoia.htm.

2. Wu, K. K.,"MSHA Perspective," in *IMCC/MSHA/OSM Benchmarking Workshop on Underground Mine Mapping*, 2003, Louisville, KY.

3. MSHA, *Report of Investigation Underground Coal Mine Nonfatal Entrapment, July 24, 2002, Quecreek No. 1 Mine, ID 36-08746, Black Wolf Coal Company, Inc., Quecreek, Somerset County, Pennsylvania*, U. S. Department of Labor, 2003, Arlington, VA, 133 p.

4. *Coal Outlook*,"Water from Old Works Floods Sextet Mine," June 14, 1999, p. 4–5.

5. Roggenthen, W. M., Personal Communication, Professor, Department of Geology and Geological Engineering, South Dakota School of Mines and Technology, Rapid City, South Dakota, 2004.

6. Bateman, A. M.,"Subsidence," in R. Peele, ed., *Mining Engineers' Handbook*, 1st Ed., John Wiley & Sons, Inc., 1918, New York, p. 737–750.

7. Briggs, H., *Mining Subsidence*, Edward Arnold & Co., 1929, London, 213 p.

8. Karfakis, M. G.,"Mechanisms of Chimney Subsidence over Abandoned Coal Mines," in S. S. Peng, ed., *Proc. 6th International Conference in Mining*, West Virginia University, 1987, Morgantown, WV, p. 195–203.

9. Marino, G. G., and Z. R. Widup, "Borehole Radar Determines Solid Coal and Mined-Out Areas for a Construction Site, Society for Mining, Metallurgy,and Exporation Annual Meeting, 2004, Denver, CO, *Preprint 04-96*, 11 p.

10. Kendorski, F. S., "Testimony before the Governor's Special Commission on Abandoned Mine Voids and Mine Safety," Pottsville, Pennsylvania, October 9, 2002, PowerPoint Presentation (available from the author).

11. Kendorski, F. S., I. Khosla,, and M.M. Singh, *Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining*, Final Report on United States Bureau of Mines Contract J0285011, 1979, Engineers International, Inc., Downers Grove, IL, 366 p.