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UNDERSTANDING AND SOLVING ROOF CONTROL PROBLEMS IN STONE MINES

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ABSTRACT

Several startup or longtime underground stone mines have experienced unanticipated roof control difficulties due to the variable geologic character of the roof strata. Careful mapping of roof conditions, and identification of controlling geologic and mine geometric factors, lead to an understanding of the mechanisms causing roof problems. Factors such as unexpected rolls of the roof strata resulting in a gradual change from strong to weak roof; encountering open water-filled master joints; roof strata delamination due to internal water pressures; local karst features with mud, sand, and water hazards; and sudden loss of limestone roof due to paleo-channel erosion are some recent problems described. Strategies for overcoming these problems are discussed and detailed.

INTRODUCTION

Underground mining of stone for aggregates, Portland cement feedstock, and industrial mineral applications is an expanding technology in the United States. It has been reported that more than 150 underground stone mines are now operating. The economy of scale of larger loading and hauling equipment drives the mine layouts to be expansive, with rooms at least 40-ft wide and 25-ft high. Few stone formations exist where ground control is not an issue. The Greenbriar Limestone in Appalachia is extremely competent in many areas, with little or no roof control often being needed. Some mines have been standing open with no roof falls for many decades. However, the usual case is that some degree of roof control is the norm.

ROOF MAPPING

When a mine experiences roof control problems, such as extensive and damaging roof falls, the mine management and often MSHA investigate the causes, so as to respond to existing and future roof areas and minimize roof problems. This author advocates mapping roof conditions using some locally-relevant coding system, so as to learn the different roof characteristics in a mine. Sedimentary strata can vary quite a bit laterally. When a particular strata parting is chosen as the roof horizon because it breaks well or is competent, the drillers will attempt to follow this parting. However, the actual roof strata may, or will, change its character as the mine expands laterally. What in one area is a competent, massive limestone roof, may, at the same horizon, change to a shaley, laminated roof that tends to ravel.

A roof conditions map of a stone mine is shown in Figure 1, where a simple system of roof horizon type nomenclature has been developed and found to be effective. By studying a roof conditions map, patterns can begin to emerge which help explain the behavior of the roof.

PALEO-CHANNEL IN ROOF

In the mine shown in the roof map figure, large roof falls (such as shown in Figure 2) extending over 20 ft into the roof occurred, causing serious concerns. After securing the immediate roof fall area, examination of borehole logs, the roof fall area, and the mine roof throughout the mine, it was discovered that the limestone that was picked for the roof horizon, which was generally at least 5-ft thick, had thinned to a few inches in a local area. Upon detailed roof probing and mapping, the mine operators and consultant realized that the limestone that formed the good roof, in one local area where the large fall occurred, had been eroded away by a paleo-channel after it was deposited and replaced by very weak shale. Recognizing the limited extent of such a roof condition, and that the paleo-channel's course could be mapped by probing the roof, a roof control strategy of noting the roof character when drilling roof bolt holes and pattern bolting installed as early in the mining cycle as practicable proved effective.

KARST

At another mine the roof was very good, but a good clean parting was seldom available at the desired roof horizon, which was based on stone quality considerations. More careful blasting was necessary along with pattern rock bolting. Figure 3 shows this roof, along with a "cavern" that was revealed after blasting. Such karst solution features are not uncommon in this stone mine and are nuisances. The caverns are found filled with water and mud, which rushes out after blasting. The caverns do not extend into the limestone being mined, but occur only in the roof horizon formation. For safety precaution reasons, a barricade is placed around the base of each cavern to keep personnel and equipment from being directly underneath in case more mud and water fall out, which has not yet happened.

WATER

In a stone mine in the Midwest, water was a nuisance and could be quite a spectacular feature as the water gushed out of the roof from open solution-widened joints, as shown in Figure 4. However, after completing a detailed map of roof characteristics, it was realized that water played more than just a nuisance role. The mine is relatively shallow and is developed under several bedrock and sand and gravel aquifers. Roof problems had been occurring when the roof horizon broke back from a usual very good, massive limestone roof (such as shown in Figure 5), to a roof characterized by angular jointing and strata compaction shears (as shown in Figure 6). The roof shown in Figure 6 was more difficult to control, with the angled joints and shears leading to relatively small fallouts. The roof would sometimes break even higher into the overlying strata, forming a very uneven, angular surface, which was usually shaley and weak (as shown in Figure 7).

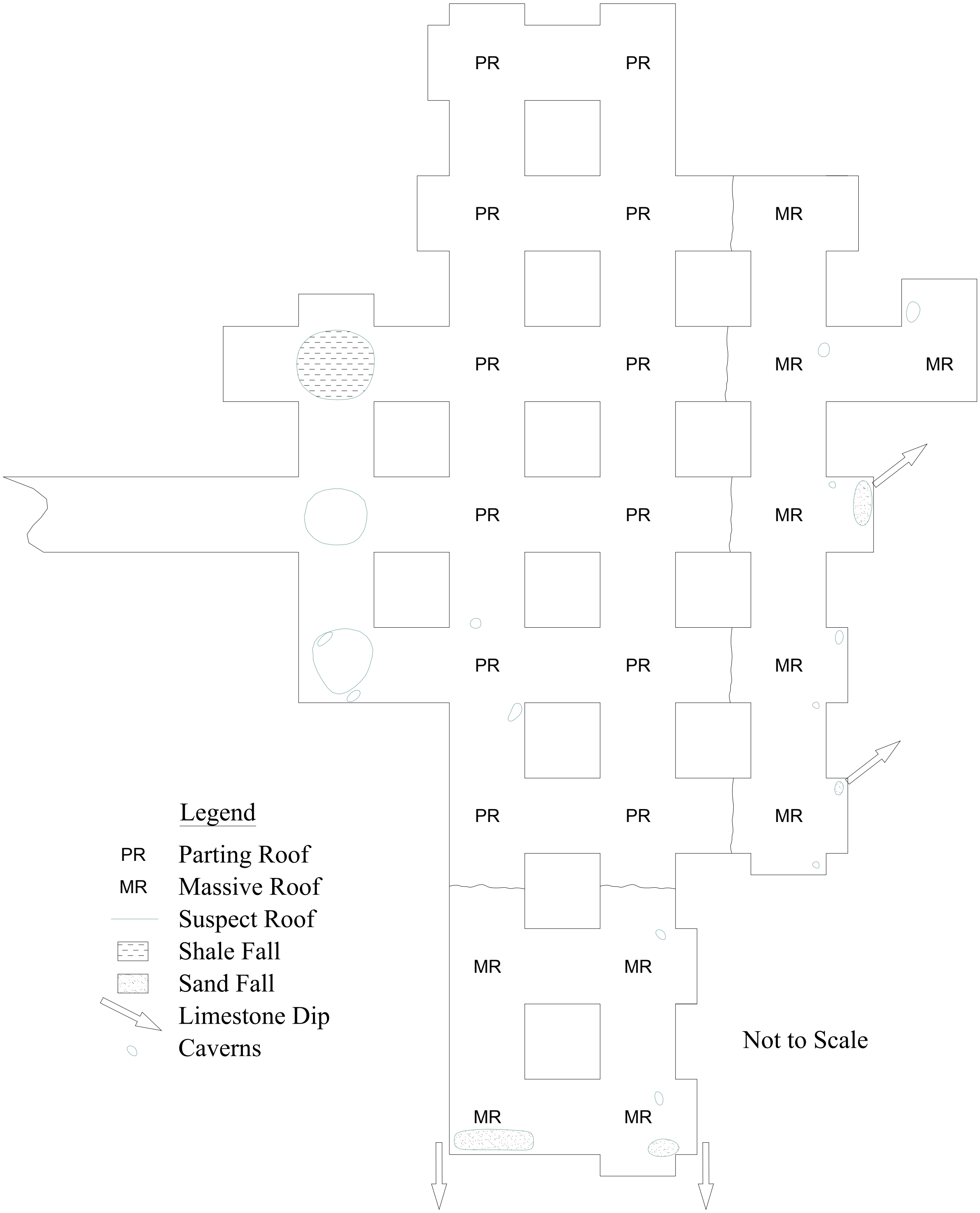

Figure 1. Sample Mine Roof Characteristics Map

Figure 2. Large Roof Fall from Paleo-Channel

Figure 3. Uneven and Karst Feature Roof

Figure 4. Water Emanating from Open Joint

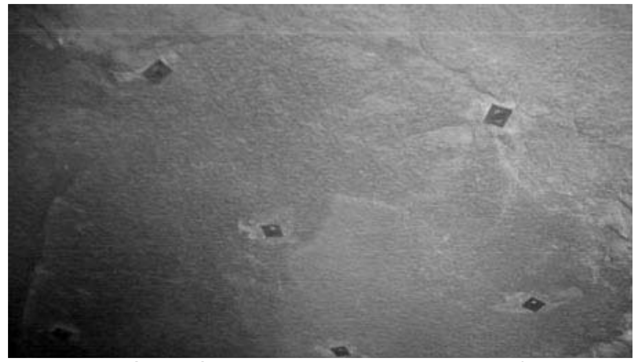

Figure 5. Good, Sound, Massive Limestone Roof

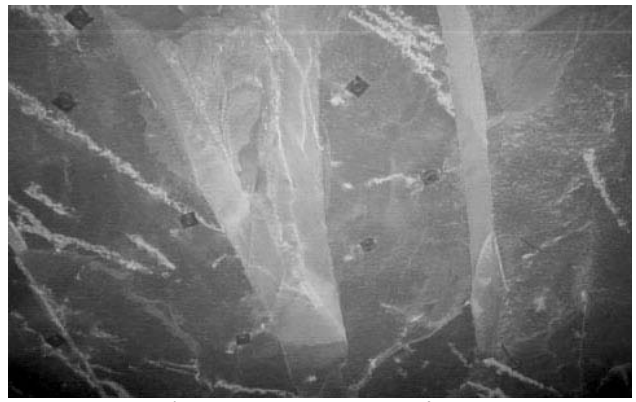

Figure 6. Roof with Angled Joints and Shears

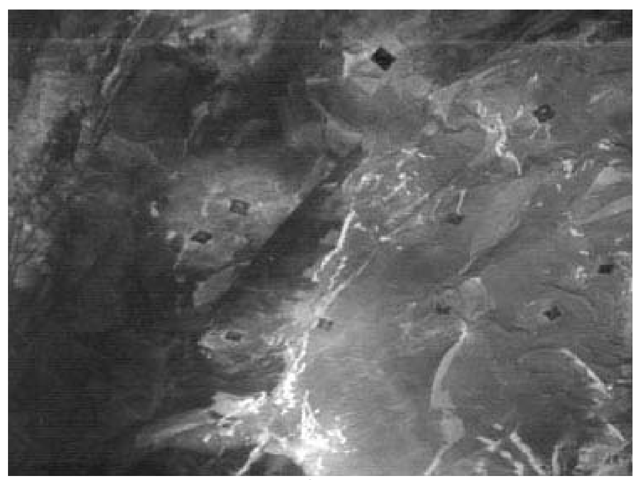

Figure 7.Very Uneven Roof with Many Angled Joints and Shears

When the different roof types were mapped out, it was realized that the higher-breaking angular type of roof only occurred in mine areas away from the surface quarry wall that was the mine's entrance portals. As it happened, the ground-water flow in the region was from a direction away from the quarry wall where the portals were located. The surface quarry was intercepting the ground water before it reached the mine. However, the mine extended beyond the quarry surface "footprint," laterally perpendicular to the ground-water flow direction. Where the mine extended beyond the quarry footprint, the roof exhibited the higher-breaking and angular features. Furthermore, as the mine extended farther away in the direction of the ground-water flow, the higher-breaking and angular features reappeared. In this more distant mine area, the ground water was able to begin to flow around the surface quarry.

The ground water, when not intercepted by the surface quarry, appeared to be pressurizing the roof strata leading to roof failure to a more-angular and less-competent strata more difficult to reinforce. With this knowledge, the mine can anticipate the effect of water and provide drain holes in the roof. Also, the mine adopted hemispherical roof bolt washers that helped the rock bolts hold the roof better in the weaker angular-feature roof.

FORMATION DIP

A stone mine was developed in a high-quality limestone, with a good roof of about five feet of the same limestone left in place. There was no clear, clean-breaking parting to drill and blast to form a consistent roof. To keep the mine on grade with no roof marker, the mine used high-quality laser survey sighting to align heading direction and grade in the nearly flat-lying limestone. At the perimeter of the expanding mine, several roof falls occurred and exposed a thin limestone roof that fell out, allowing a run of a soft wet friable sandstone from above. Carefully mapping the mine, and re-plotting original borehole stratigraphic data, it was discovered that the mine limestone horizon was entering a gentle monocline or limb of an anticline (as shown in Figure 8). When the mine elevation was kept at a consistent level grade, the mine roof horizon moved stratigraphically up into the weak sandstone. With no good stratigraphic marker bed, the mine had inadvertently developed into a weak roof condition. The mine management had the unpleasant dilemma of accepting increasingly poorer roof conditions and dilution, or substantially increased pumping and water nuisance as the expanding mine perimeter became increasingly deeper than the decline bottom if the mine horizon stayed in the target limestone level.

CONCLUSION

These few case histories illustrate the importance of geologic roof mapping and gaining an understanding of the geologic factors that control the roof behavior. Once understood, the roof conditions can be dealt with strategically with carefully planned and successful approaches to roof control using a variety of simple techniques.

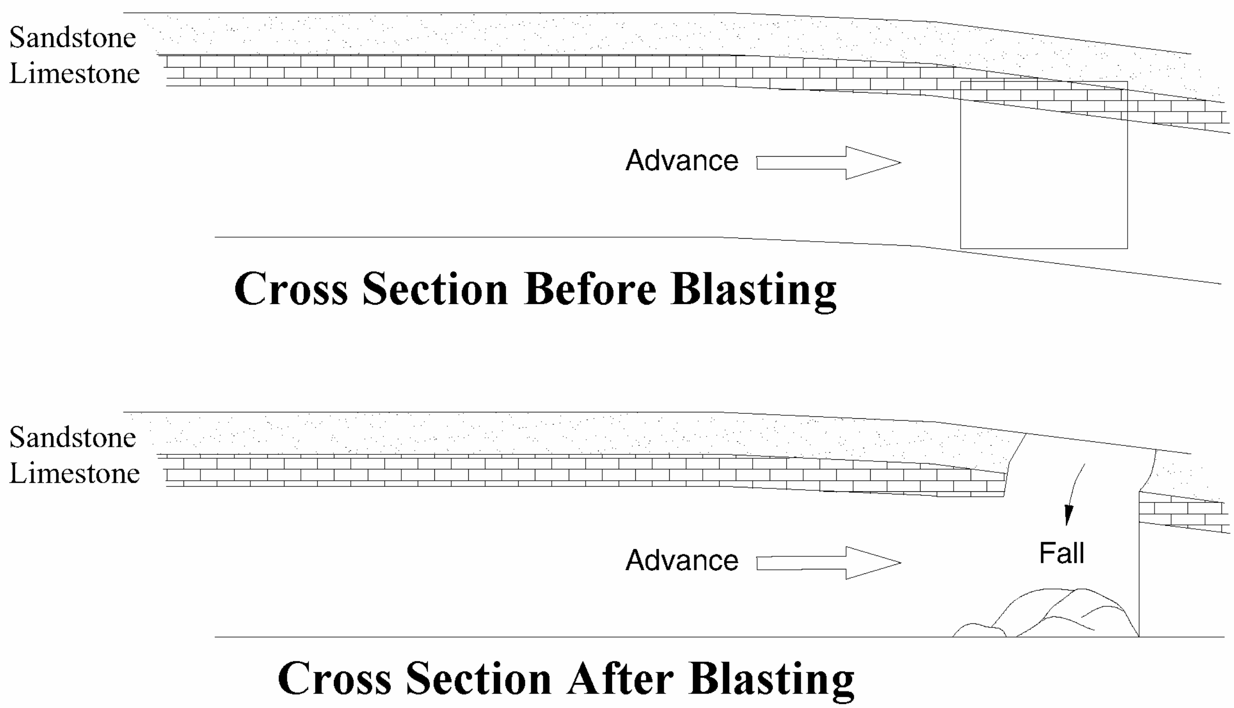

Figure 8. Effect of Formation Dip on Consistent Level Mine Roof