Shotcrete: A Key to Advances in Safety and Productivity in Mining

By J. Denis P. O'Donnell, Sr.

In 1969, when I bid farewell to work in field exploration, I knew I would miss the outdoors. I wasn't sure if my love for geological mapping, and my penchant for using geophysical equipment to probe the earth for her riches, would be fulfilled. The truth was, I embarked on my new career in an underground mine with a major metal mining company seeking the opportunity to be at home with my family in the evenings and to have access to a university to complete my BSc in Geology.

As my family blossomed, I completed the BSc the easy way, nine years at night at Laurentian University's Extension Division. As my knowledge of mining increased, my career developed in a direction I would have never dreamed possible. The challenges of mining at depths of 7,000 ft (2130 m) presented me with the need and challenge to work on rockburst mitigation. It was in this second career as a ground control, and later rock mechanics specialist, that I was bound up with that strange product which for elusive reasons supported rock in unexpected ways. The strange product was, of course, shotcrete.

Poured Concrete to Sprayed Concrete

As one travels in the older portions of the area mines, it becomes clear—concrete was king in the 1930s, '40s, and '50s. Major structures such as underground hoist rooms and even lunchrooms were formed and reinforced with poured concrete. The construction crews took great pride in forming arches, dividers, and even alcoves for placing lunch pails. They were true works of art, always with a date, and occasionally an initial, formed into the wall. The late '60s and early '70s brought mechanized mining methods with larger openings. They also brought the need for less labor-intensive methods of ground support, and the use of shotcrete increased. Large permanent openings, crusher stations, multi-bay garages, and repair shops all clamoured for shotcrete as an alternative to building forms and pouring concrete. What a job it was, with 50 lb (22.7 kg) bags hand bombed and dust of unbearable proportions.

The questions arose like dust, and the answers fell like rebound. Does it really work? It's only painted on; it's only camouflage. Do we put it on bare rock or over mesh? One answer rang true: shotcrete worked like nothing else, especially in crucial fixed location openings in very poor ground.

Vertical Retreat Mining

Enter the '90s. This is when I made my mark in the use of shotcrete. A bulk mining method called vertical retreat mining (VRM) made remarkable gains in safety and productivity. The method consisted of developing two access openings known as sills: a top sill from which the ore would be drilled and blasted, and a bottom sill from which the broken ore would be removed. The norm was 6.25 in. (160 mm) holes drilled on a 9 x 9 ft (2.7 x 2.7 m) pattern and 100 to 200 ft (30.4 x 61 m) high panels that were blasted and removed 10 ft (3 m) at a time. The envelope was expanded and 8.5 in. (216 mm) holes were drilled in 400 ft (122 mm) high panels. This required 40 blasts of up to 60 holes. Two hundred pounds (91 kg) of explosives were placed at 3 ft (0.9 m) from the bottom of the holes. Crushed slag and water were then placed over the explosives as stemming to concentrate their energy. The stemming has a shotgun effect, which peels the screen off the back (roof) of the topsill. For safety reasons, blasting had to be curtailed to allow crews to recondition the backs of the top sills. In extreme cases this could take up to a week.

The mine superintendent shuddered at my recommendation to shotcrete the backs before blasting, and, if they become damaged, recondition them with shotcrete. It was successful; there was no turning back. From a business sense, it paid off in the elimination of a safety hazard; a reduction, and in many cases, the elimination of reconditioning delays; and an overall productivity increase. When these shotcreted topsills became extraction horizons, they were more stable and safer. Again a savings in reconditioning costs was experienced.

Six months after initiating the project, I was almost ready to cancel it. George, one of our miners, was shotcreting a topsill and it was impossible to find him in the dust cloud. A few phone calls were made and in came the predampeners and 500 lb (227 kg) capacity tote bags of shotcrete. Conditions improved considerably. Dry-mix shotcrete can produce a lot of dust when it is applied. If a water spray curtain is used, the dust does not reach other miners on the level. They generally are not wearing dust masks and have a negative attitude towards shotcreting. Modern equipment that is well maintained does not require the use of a predampener. However, persons in the immediate area must wear dust masks and face shields. Wet shotcrete does not produce as much dust, and the mist created doesn't affect other workplaces along the mine ventilation stream.

Mesh Reinforced Shotcrete in Fourth and Final Recovery Phase of Mining

A few years later I was assigned as the ground control specialist at two mines: one a bulk mine and the other a mine in its third and possibly final phase of recovery. To achieve this final phase of recovery, mesh reinforced shotcrete was being used to replace steel sets (arches). At this property, another challenge presented itself. Certain portions of the mine had experienced poor recoveries and a lot of ore was left in the mine. If we could mine through broken rock to the areas where the ore was located, then there was a potential for a fourth and final phase of recovery. By augmenting our two-phase mesh-reinforced shotcrete with a pregrouting program, we developed a method to access the previously unrecoverable ore at the hanging wall. Miners are a resilient and innovative bunch. Within a year we were accessing the areas without even pregrouting. Ten years later we are still recovering ore, and mine closure has been postponed for another two years.

Wet-Mix Steel Fiber-Reinforced Shotcrete as a Boltless Primary Support

During the past six years, I have been the on-site rock mechanics specialist monitoring, evaluating, and documenting the performance of wet-mix steel fiber-reinforced shotcrete (SFRS) as a boltless primary support in sublevel cave mining. As part of the management team, I must ensure that the test phases are conducted without risk to our employees, and document the performance of the products to promote sound business decisions when the tests are completed. The project involves placing 5.9 yd³ (4.5 m³) loads of wet-mix shotcrete down an 1800 ft (550 m) lined 6 in. (150 mm) inside-diameter borehole into a transmixer. The product is transported to a waiting robotic spray arm and applied to a 15 x 15 ft (4.6 x 4.6 m) development heading as primary support without bolts, and recently, in 20 x 15 ft (6.1 x 4.6 m) headings with 8 ft (2.4 m) rebar installed on a 4 x 4 ft (1.2 m x 1.2 m) pattern. In the latter case, the bolts are deemed necessary during the production phase as blasting and extraction proceeds. To date, several thousand feet of drifts supported with only SFRS have been brought to production as have hundreds of feet of the wider drifts supported with SFRS and rebars. The growing pains associated with this project have included:

- Defining the thickness of shotcrete required, and the admixture combinations required to keep the product in place (the admixture supplier has partnered with the local ready mix supplier and the mining company to supply this expertise);
- Acceptance of shotcrete by the operators and production phase miners; and
- Increasing the productivity to make it a competitive support system.

The benefits have been:

- Safer workplaces for production and development miners who are now confident in the performance of shotcrete as a primary support element;
- Productivity gains with up to four headings supported in a shift by two people;

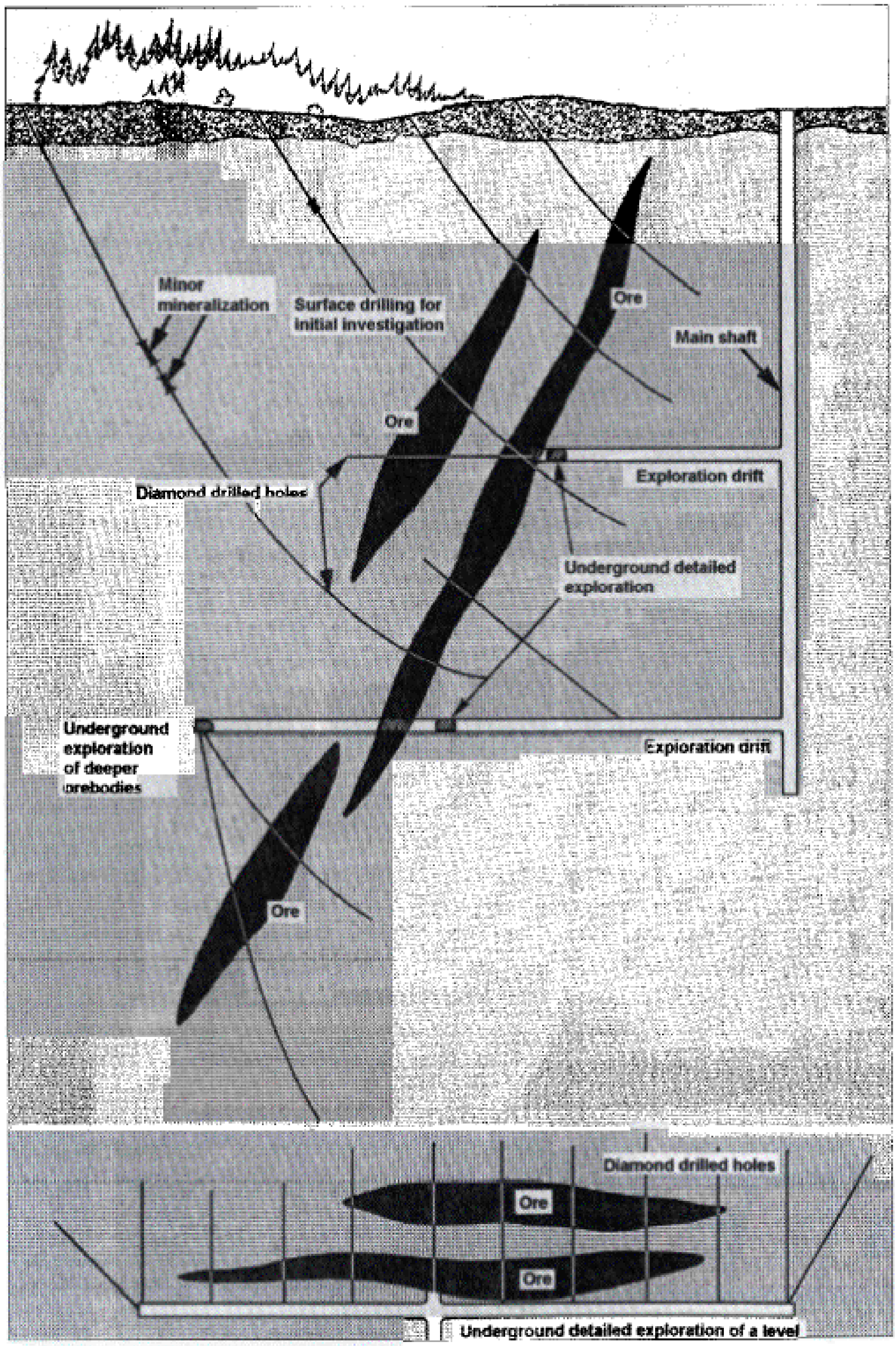


Figure 1. Exploration of orebodies using surface and underground techniques. Illustration courtesy of the Society for Mining, Metallurgy and Exploration, Inc. (SME) www.smenet.org

- A reduction in reconditioning costs;
- Verification that 84 lb/yd^3 (50 kg/m^3) of hooked end 1.2 in. (30 mm) long steel fiber is an adequate dosage for the deformations experienced in the test sites;
- Quicker and safer remediation work, when damage occurs at the brow; and
- Stability of drill hole collars that would permit loading and priming of holes using telerobotic equipment as the technology is developed. (Currently the drilling of the blast holes is computer controlled and managed teleremotely from a central site located on the surface 9.3 mi. [15 km] away.)

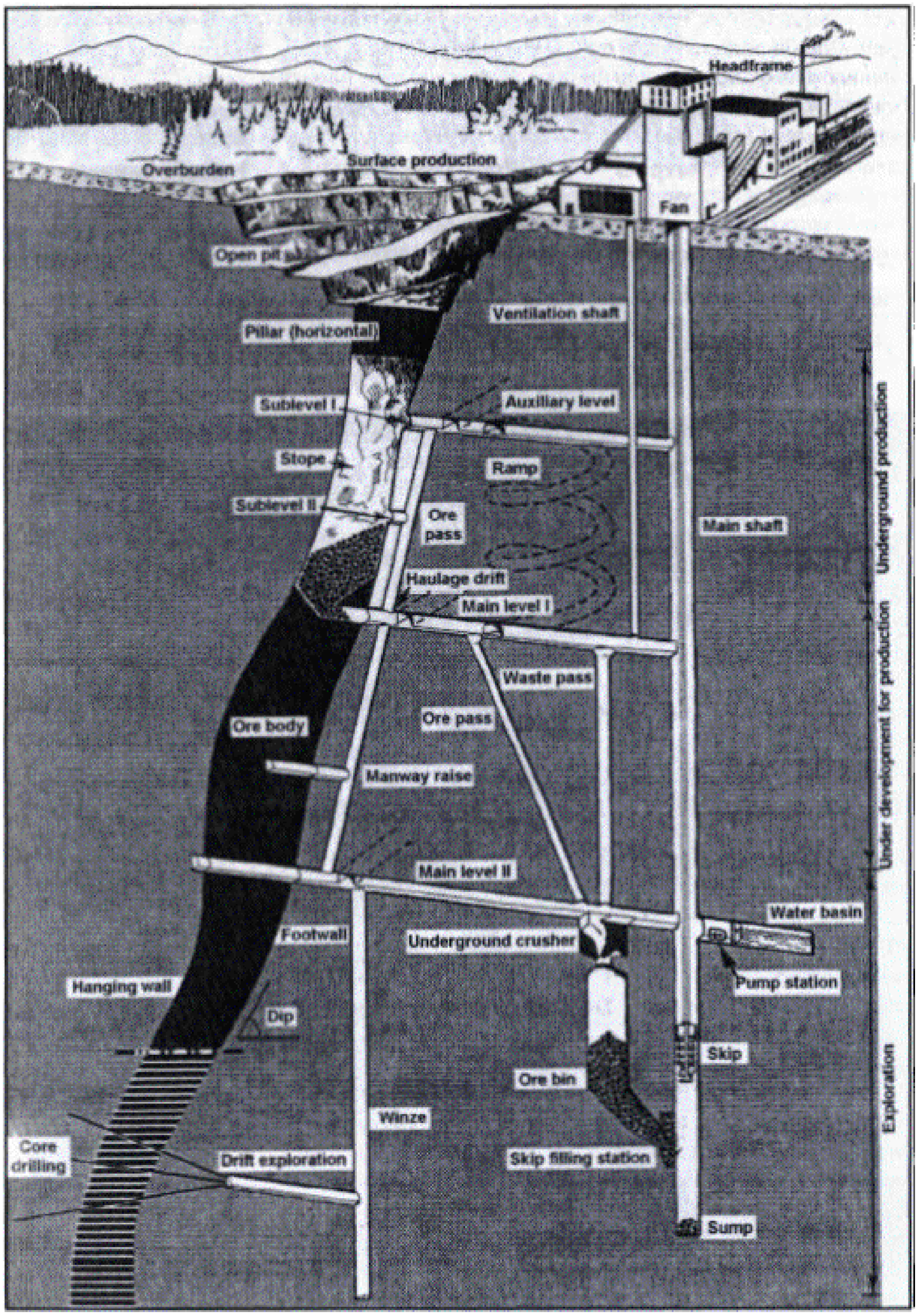
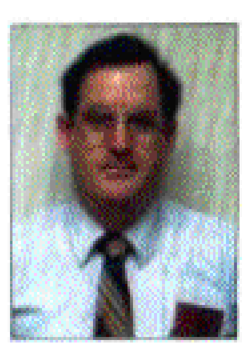


Figure 2. Sample layout of an underground mine, identifying various mining operations and terms. Illustration courtesy of the Society for Mining, Metallurgy and Exploration, Inc. (SME) www.smenet.org

The current challenge associated with this project is the identification of the portions of the mine where deformation exceeds the capability of SFRS, and applying standard mesh-reinforced shotcrete or, if on-site tests are successful, the application of mixed steel and synthetic fiber combinations.

SFRS with 6 ft (1.8 m) rebars on a 4 x 4 ft (1.2 x 1.2 m) pattern has been tested in a VRM topsill at depths of 3,200 ft (975 m). The test was successful, with the shotcrete withstanding the blasting of a 47 ft (14 m) crown and undergoing 4 in. (100 mm) of convergence in the topsill. (The final or break-through blast in a VRM stope is referred to as a crown blast and it is usually 25 to 35 ft (7.6 x 10 m) thick. A 47 ft (14.3 m) crown isexceptional and would have impacted the topsill severely.) Future testing in adjacent sills may determine the amount of deformation this support combination can withstand.

The use of welded wire mesh and SFRS to overcome challenges, particularly in the last ten of my 31 years in underground mining, has enabled me to contribute to advancements in safety and productivity to an extent I had only dreamed possible. Today we can "mine through muck piles" to access otherwise unattainable ore; and two men, on a good day, can support four development headings in an 8 hr shift. **Shotcrete works—it is not camouflage!**



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