Review of Mining Technology

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SCIENTIFIC inquiries concerning phenomena that may influence mining technology were widely publicized during the year. The deep-hole drilling project "Moho," ³ the use of nuclear explosives underground, and the recovery of minerals from the depths of the sea became subjects of scientific and general discussion. The mining industry continued to watch these developments with keen interest, but its more immediate concern was the increasing tempo of competition between mineral commodities, the domestic producers of these commodities, and foreign sources of supply. The competitive situation has intensified the industry's efforts to develop more efficient new mining methods, as well as to improve the efficiency of present practices.

The attitude of the industry was well illustrated by rapidly expended use of low-cost ammonium nitrate explosives, the establishment of rigid schedules for equipment maintenance, and close attention to the detailed costs of production. The complexity of planning a new coal mine is aptly illustrated by the editors of Mechanization in the April 1959 issue, in which they outline the cost of developing a mine and the various problems, factors, and decisions involved. ⁴

EXPLORATION AND SAMPLING

While largely unheralded, the unprecedented improvements in surveying techniques have made major contribution to exploration efforts. New instruments and methods have increased productivity, maintained accuracy, and decreased costs. ⁵ Aerial photography, an essential part of modern photogrammetry, continued to improve. The latest device was a super-wide-angle lens with a 122° angle of coverage. Rapid and accurate surveys were attained with the new high-resolution, low-distortion, wide-angle cameras, projectors for aerotriangulation and compilation, and plotters that may be linked to systems for electronic-computer analysis of the results. The Stereomat, an

³ Chief mining engineer.
⁴ Assistant chief mining engineer.
⁵ Drilling Magazine, Probing the Mysteries of the Earth's Interior: Vol. 21, No. 1, November 1959, pp. 74–76, 98.
electronically activated plotting instrument, does automatic profiling and semiautomatic contouring.

Accurate instruments have been developed in the past few years for economic measurement of distance for triangulation base lines and traverse courses. The Geodimeter uses the velocity of light to measure distances. A modulated beam of light is directed from the apparatus to a reflector at another station. The distance between the two stations is determined as a function of the phase difference between the emitted and reflected beam. Distances up to 30 miles have been measured with accuracy acceptable for a geodetic base line. The Tellurometer uses the known velocity of radio waves to measure distances. Utilizing a radio signal transmitter at one station and a receiver at the other station, the distance is measured from the phase difference of the signal and the known velocity of the wave. The Micro-Dist uses the basic principle of the Tellurometer, but the master and remote units are interchangeable and readings are taken from a direct-reading counter rather than a cathode-ray tube.

Revived interest in adapting the gyro principle to surveying has led to development of several gyrotheodolites. Miniaturization of parts has decreased bulk and weight, objectionable features of earlier models. Some of the new gyrocompass designs approach a size that may be utilized for surveying small-diameter boreholes. A gyrotheodolite designed by C. Platt of Hamburg, Germany, is based on the floating pendulous north-seeking system with electrostatically centered spherical float. The bulk, weight, and cost of the instrument deter its general acceptance for mine surveying, but the marked improvements in this respect over the earlier German models should lead to eventual acceptance for special survey applications.

The new Federal mining-claim-assessment law recognizes geophysical exploration as valid assessment work. This should invite a more universal use of geophysical methods now and in the future. Exploration departments of most of the large mining companies employ geophysical methods, but their limited use in mining as compared with petroleum exploration results in a great divergence of opinion among mine management as to when, how, and where to use specific methods and equipment. Hand magnetometer, surface electromagnetic, natural potential, and other electrical methods still prevail in most mining work. Recent improvements in geophysical technique and equipment tend to make geophysical methods attractive despite their cost, especially as costs for other types of explorations are rising.

Geophysical equipment costs range from about $25 for an inexpensive magnetic dip needle to more than $35,000 for a continuous-recording magnetometer or electromagnetometer. Aerial continuous traverse work costs approximately $6 per mile per method. Average mobile continuous traverse charges are $4.50 per mile. Large reconnaissance surveys can cost less than 10 cents per acre; a limited detailed survey may run more than $200 an acre. An average cost is about $20 per acre per method.

Preliminary results with an airborne gravity meter indicate that the techniques employed overcome some of the former difficulties caused by the large forces imposed on the meter by the motion of the plane. One method uses a balanced system of two masses with a highly stable source of energy. A frequency-controlled timing unit periodically locks the two masses in a central position in their housing coincident with the natural frequency of the oscillating beam system. The distance between one of the masses and a fixed plate is measured by a capacity bridge. Still in the stage of developing equipment, techniques, and interpretive data, the method has been used to outline a large iron ore deposit at Iron Mountain Lake, Quebec.

Induced polarization or overvoltage surveying used in conjunction with resistivity surveys has been successfully applied by Newmont Mining Corp. in exploration for disseminated sulfide deposits. The earth-resistivity method was used more widely to explore for sand and gravel deposits, but the prevailing philosophy that it is a do-it-yourself cure-all for location of deposits often produces disappointing results. The method is based on comparison, and correlation results are dependent on a reliable correlation table. With the use of good techniques and reliable interpretation, the method can be used to contour (1) types of soil by textural classifications, (2) relative quantities of each type of material, (3) location with respect to depth, and (4) lateral extent of each type. An interesting application of geophysical methods is the shock-wave technique used to determine the rippability of soil and rock layers. A shock wave is generated by striking a steel plate laid on the rock surface with an 8-pound hammer. The wave is recorded on a geophone receiving instrument, and the time and distance data are related to applicable tables to indicate depth and rippability of the material.

At the Otanmäki mine in Finland magnetic borehole instruments and survey techniques were used to outline the magnetic-ilmenite ore bodies. Ore lenses are essentially vertical. The ore zones are investigated by diamond drill holes 130 to 650 feet long, drilled from the haulage drifts. However, information from diamond drilling is not adequate for drawing up mine layouts and is supplemented from 200-foot holes drilled by long-hole methods. The magnetic instrument, which is essentially a permeameter, is inserted in these holes to provide information for classifying material as high- or low-grade ore, disseminated ore and waste rock. The equipment consists of two principal components, a probe and a receiver, connected by a cable. The probe is an electronic oscillator housed in a 1-inch-diameter plastic tube 15 inches long. The receiver is a preset amplifier indicating the frequency variation. The probe is attached to and inserted by a rigid rod assembly. The assembly is made up of 1-inch aluminum rods.
with a milled groove down the side into which the cable connecting the probe and meter is pressed. The rods are joined by tongue and locking pin.

As mineral explorations probe deeper, the problems of deep drilling become more evident, together with the inadequacies of existing equipment and techniques to meet them. Recognition of the problem by both mining and petroleum exploration engineers is resulting in a more general evaluation of the techniques employed by the two groups. During the past several years the petroleum engineer has made increased use of "slim hole" drilling and has revived interest in methods similar in many respects to exploratory diamond drilling in mining. Air and gas as circulating medium for diamond drilling are used in drilling for oil and gas to increase speed of penetration and reduce cost. On the other hand, the conventional oil field practice of using mud as a drilling fluid is being used in mineral exploration. While drilling with mud requires some special equipment and controlled operating techniques, it improves core recovery, prevents caving, and reduces the need for casing. Successful techniques using mud drilling (40- to 45-second viscosity), bottom-discharge bits, and step-face bits have been applied to core the friable and blocky western Mesabi ores in Minnesota. The ores are characterized by hard ore bands and a more or less cherty iron formation enclosed in a soft decomposed silica matrix. The coring problem is not only to sample the soft material without loss but to prevent blocking and grinding due to the hard seams.

The major advantages of air and gas drilling are increased bit life and speed of penetration. However, when small quantities of water are encountered the cuttings tend to ball and stick, thus reducing penetration rate. The removal of large quantities of water requires prohibitively large air pressures. The use of low-density drilling mud formed by foaming agents has been introduced, and in a sense the advantages both of air drilling and of mud as a circulating medium are obtained.

At the instigation of South African mining groups, an equipment manufacture began designing for early production a diamond core drill capable of working to 15,000 feet. Again the know-how of the oil industry in relation to deep drilling has been called upon in the design. The derrick, known as a jackknife type, is of tubular welded construction, designed to be assembled on the ground and hoisted to a vertical position. The hoist is a separate unit with a 3-foot-diameter drum, chain-driven and fitted with hydraulic braking for lowering the drill rods.

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The need for deeper exploration drilling and the increased costs of recent years have intensified interest in optimizing exploration techniques and refining sampling procedures. To obtain the most detailed and accurate information possible from exploration efforts at a minimum cost is a universal goal. Papers on the subject were presented at the Ninth Annual Drilling Symposium, Pennsylvania State University, and will be published in the Proceedings of the Symposium. The use of mathematical approaches, such as operations research and statistical analysis, was pursued as one means of reaching that goal. Dr. Robert J. Uffen suggested a number of relationships that may be applicable to optimizing a prospecting plan.\(^{19}\) Three relationships stressed were (1) prospecting profit ratio, (2) completeness of search ratio, and (3) drilling coverage ratio. It is obvious that much work must be done to refine and give meaning to these ratios, but they do offer a rational guide to extensive and expensive prospecting ventures.

Another possible approach is the application of search theory, which was used extensively for military purposes.\(^{20}\) Search theory considers the tactics of target-seeking and the strategy for allocation of effort, a very close analogy to mineral exploration. Development of electronic computers relieves an onerous aspect associated with the use of mathematical techniques. The combination was used with some success on a magnesite deposit at Gabbs, Nev., to correct the estimates of ore tonnages falling within desired ranges of quality.\(^{21}\) The Federal Bureau of Mines continued its program of investigation on the theory of sampling with a major emphasis on the application of statistical methods.\(^{22}\) Working in cooperation with several mining companies, the Bureau analyzed exploration and sampling data to investigate the validity and application of statistical methods. Studies were made of tests for random distribution of the mineral, changes in grade and their effects on randomness of sample data, and minimum number of samples for a range of volume required to sample to a specified degree of accuracy.

**DEVELOPMENT**

Sinking and equipping a shaft, an operation required in the early stages of developing most underground mines, is often difficult and expensive. As such, it is a subject of concern to many mining engineers, who have watched with interest the recent improvements in domestic and foreign shaft-sinking practices. A competitive aspect was added to this interest during the past year by claims and counterclaims from the Union of South Africa and the U.S.S.R. to the world's record for speed in shaft sinking. The Russian record in

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April of sinking the new Boutoff No. 3 shaft 868 feet in 30 days was shattered in October, when the Vaal Reefs gold mine shaft in the Union of South Africa was sunk 922 feet in 30 days. By the end of the year a record of over 1,000 feet in 30 days was achieved in South Africa. The Vaal Reefs shaft was sunk at an average rate of 7.09 feet per shift, with an average shift time of 5 hours 15 minutes. Russian statistics show an average advance per shift of 7.5 feet, but the average shift time was 6 hours 28 minutes. The South African achievement was credited in large part to a careful study of time-consuming bottlenecks so that a fast operating cycle could be maintained. For the future any substantial increase in sinking speed is dependent on a breakthrough in the depth that can be broken per round. The record established at Vaal Reefs is even more impressive in that they excavated 55,000 tons compared with 25,000 at the New Boutoff mine.

Mechanical grabs were used by both Russians and South Africans to excavate broken rock. Vaal Reefs employed an electrically operated cantilever boom-type machine of 20-cubic-foot capacity. The unit consists of a boom suspended from the center of the bottom deck of the sinking platform and arranged to be rotated in either direction. The grab hoist is on a traversing carriage which moves radially in the boom. The Russians used five pneumatic grabs, each of 5-cubic-foot capacity. Winches are mounted on the lowest platform of a multiple-platform shaft-sinking cylinder.

An international shaft-sinking and tunneling symposium was held in London during July. The 25 papers presented at the meeting included reports on recent practices in Australia, Belgium, Canada, Czechoslovakia, France, Germany, Great Britain, the Netherlands, Hungary, Poland, South Africa, Sweden, the U.S.S.R., and the United States. The papers will be published by the Institute of Mining Engineers, 3 Grosvenor Crescent, London S.W.I., as a volume on proceedings at the symposium. A subject of general interest was the mechanical shaft mucker developed in the past few years. In Canada the Riddel Clam is widely used in shafts designed with the compartments in line, particularly in shafts with four or five compartments. The Cryderman shaft machine is more commonly used in three-compartment shafts, shafts with compartments arranged in a square or rectangular pattern, and circular shafts, and occasionally in inclined shafts. Until about 15 years ago, shafts sunk in South Africa gold mines were generally rectangular sections lined with timber sets.

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The advantages of concrete-lined circular shafts were not then sufficient to offset their low sinking speed, except under special conditions of difficult ground or when the time factor was unimportant. Since that time, however, the South Africans have become recognized masters in techniques that allow rapid and efficient sinking of circular concrete-lined shafts. An important advancement was the development of a multiplatform shaft staging designed for concurrent sinking and lining. Beginning with experiments in 1946, efficient mechanical mucking equipment using pneumatically operated cactus-type grabs has been developed. Various methods have been used to maneuver the grab. The oldest type still in use is a centrally pivoted boom traversing circumferentially along the perimeter of the shaft on a monorail fitted below the bottom deck of the stage. A later type featured a centrally pivoted electrically operated cantilever boom with rope and sheave arrangement in the boom for radial and vertical movement of the grab. The latest development eliminates use of ropes and sheaves by using hydraulic rams for all movements of the grab.

Driving raises is an important part of mining in Sweden, and considerable research was directed to improving raising practice. Innovations included a steel ladder platform with the ladder advanced upward by air cylinder, a drilling platform hoisted through a borehole from above, raising with long-hole drilling, and more recently a drilling platform elevator consisting of a steel platform raised by a compressed-air motor which has a pinion climbing and a rack-equipped guide rail. The rack-equipped guide rail is fastened to the rock wall of the raise with expansion bolts. At the Kiruna mine the drilling platform has been adapted to a shaft loading apparatus by attaching a telescope feeder to operate a polygrab controlled by an operator on the platform.

A report by two members of the Academy of Mining, Ostrava, Czechoslovakia, described model tests and theoretical studies leading to design of a proposed shaft-sinking machine. The machine would consist of a housing with a bell-shaped bottom designed to fit the cross section of the shaft. A liquid bath would be maintained in the lower part of the housing at the shaft face. Rock breaking would be accomplished by electrically powered hydraulic ramming with cavity effects. Broken rock would be removed by pumping the liquid out as new liquid is added.

A report on sinking the Lens Shaft No. 19 in France described a drilling platform that allowed drilling 8-foot holes without changing steel. Drillers stand on four plank-type platforms about 4 feet high disposed radially in the shaft. The platforms are supported at the center of the shaft on a four-leg table arrangement and by the shaft-support channel along the circumference.


Most of the remaining papers at the symposium were on practice in Europe and concerned rock-solidification methods for shaft sinking. Of the 55 shafts completed or started in Britain since 1947, all have used pre cementation or freezing to some extent. Ordinarily, cementation is used where the bands of water-bearing strata are not thick enough to warrant freezing or where there are no impermeable strata in which to anchor the ice wall. Advances which have taken place in the freezing process since World War II have been due to improvements in refrigeration equipment, drilling techniques, and shaft-lining method used in conjunction with the process. Probably the most important advance was a change from conventional cast-iron liners to lining with bulk concrete backed by corrugated sheets. An interesting alternative to the freezing method of shaft sinking used at Statemine Emma and Beatrix in the Netherlands is shaft boring using drill mud, patterned on the principles of the Honigmann shaft-boring process. The two Beatrix shafts are to be drilled 25 feet in diameter to a depth of 1,500 feet. A 6-foot pilot hole is successively reamed to full dimension using drilling mud in the hole to seal out water and prevent caving. A shaft lining consisting of two concentric steel shells filled with concrete is floated into place down the bored shaft.

Neither the high-speed shaft-sinking procedures developed and used in the Union of South Africa and the U.S.S.R., and recently in Britain, nor the complex shaft-lining systems used in Europe have a general counterpart in U.S. and Canadian mining practice. Mining conditions differ in many respects, including political and economic aspects, mining procedures, and operating requirements. A full-scale production shaft is seldom sunk in the initial period of mine development, and many shafts are sunk deeper in stages as the mine develops at depth. As it becomes economically feasible to mine the deeper large low-grade deposits, conditions will more nearly parallel those in foreign countries, and similar techniques will apply.

In the United States and Canada conventional shaft-sinking practices are the rule, with major improvements being in the mechanization of procedures. A typical example of current practice was the deepening of the Yates and Ross shafts at the Homestake mine in South Dakota. Continuation of sinking and raising-and-stripping extended the mine workings from the 4,100 to the 6,200-foot level. Work was planned for the least possible interruption of production. Equipment included a six-drill shaft jumbo and mechanical mucker. At Shattuck Denn’s Barden shaft in Utah a jackleg drill jumbo suitable for use in the rectangular shaft section was devised. The conventional round sinking skip was replaced with a square, 70-cubic-foot skip of special design to reduce time in dumping. Another

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rather typical shaft-sinking operation is the Burgin shaft of the Bear Creek Mining Co. in Utah.35 The three-compartment shaft was sunk to a depth of 1,100 feet as part of an exploration program. The major departure from older conventional methods was the use of a Cryderman shaft mucker. The shaft was completed in 142 days with a crew of 10 shaft men and 10 surface men. Direct cost of labor and materials per foot was $82.30.

Boring was used to an increasing extent to sink small-diameter shafts. The 66-inch calyx core drill, originally designed by J. B. Newsome and used at the Idaho Maryland mine in California in 1936, has been rehabilitated to core an air shaft at American Zinc’s Young mine in Tennessee.36 Rotary oil-drilling rigs were used to bore ventilation shafts.37

At Mercur, Nev., an oil-drilling contractor is boring a 44-inch-diameter hole through 965 feet of granite by a concurrent combination of drilling and reaming. The composite borer uses a conventional Hughes Tri-Cone bit in the center as a pilot. Fanning out from the pilot are two roller shaft cutters in the first 20-inch path, three cutters in the 30-inch path, three cutters in the 40-inch path, and four cutters in the 44-inch path. They cut a sloping face 20° from the horizontal with a certain amount of overlap cutting. The same contractor is drilling and reaming a 40-inch-diameter air shaft to a depth of 1,046 feet at the Rare Metals Corporation San Mateo mine in New Mexico.

A down-the-hole shaft-drilling machine has sunk twin shafts, each 76 inches in diameter, to a depth of 500 feet at the C. H. Mead Coal Co. in West Virginia.38 The machine is an improved version of the original Zeni core drilling machine and is designed to drill out the entire hole. The cutting head is basically an oversized version of the oil-field-type rotary drill bit. Hydraulic jacks are used to anchor the drill housing to the wall of the hole and provide the downward thrust for drilling. Average drilling rate was 50 feet per 8-hour operating shift. Cuttings were discharged through predrilled holes to the mine working below. The Shell Oil Co., used a similar bit to sink a 52-inch shaft for construction of a large underground LPG-storage cavern in Illinois.39

Chemical solidification methods were used with varying degrees of success to sink through water-bearing strata. The newest combination, AM-9, made by American Cyanamid, was used by the Meremec Mining Co. in Missouri 40 and at the Cliffside shaft of Phillips Petroleum Co. in New Mexico. While use of the material is still in an experimental stage, it has a major advantage in being able to penetrate and seal materials impervious to cement grout. A 10-percent

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39 Mechanization, Shaft Sinking 30 feet Per Day: Vol. 23, No. 8, August 1959, pp. 76–78.
solution of AM-9 costs about $1 per gallon. Care must be exercised in mixing and handling as the ingredients are corrosive and toxic.\textsuperscript{41}

**DRILLING AND BLASTING**

Theoretical consideration of the physical actions involved in drilling and blasting has been the subject of much research, but the numerous variables in practice make application of theory to operating problems extremely difficult. The Bureau of Mines has established a Mining Research Center at Minneapolis, Minn., and assigned to that center the study of rock penetration and fragmentation. This will concentrate at one center the major Bureau responsibility for theoretical and applied research on drilling and blasting for better correlation of theory and practice.

Hartman reviewed some of the major theoretical studies of drilling action and reported his more recent investigations\textsuperscript{42} with the comment that rock drilling remains an art when it should become a science. He relates lack of progress in percussion-drilling techniques directly to ignorance of the nature of impact failure and fundamentals of rock penetration.

Mine operators sought improved efficiency in drilling and blasting practice through selection of efficient equipment, improved explosives, and design of the drill round. A specially designed drill pattern with two 5-inch-diameter burn holes was used at the Snowy Mountain project in Australia to advance a 12.5 by 12.5-foot tunnel a record 526 feet in 6 days.\textsuperscript{43} A new method has been tried in Sweden, utilizing the more efficient slabling action to advance a heading.\textsuperscript{44} Holes are drilled parallel to the face from an adjacent parallel drilling gallery. A ring cut round is claimed to give promise of an efficient universal drift round.\textsuperscript{45} The proposed round consists of six ring holes spaced radially around a center hole. All holes are parallel and drilled normal to the face. The ring holes are fired first, followed by the center hole at a 50-millisecond delay.

A novel method of drilling and blasting rock without removing overburden has been used successfully on canal construction in Sweden.\textsuperscript{46} Special 52-foot-feed rigs were used for drilling. A special device substituted for the rotation mechanism gives increased torque and rotates both the drill pipe and the drill steel running inside the pipe. Hammer blows are also transmitted to both drill pipe and steel, which are sunk simultaneously through the overburden with powerful jetting. The pipe is collared in bedrock and then uncoupled from the drill, after which the rock is drilled in conventional manner. When a hole is completed, plastic pipe is inserted inside the drill pipe and


\textsuperscript{42} Hartman, H. L., Basic Studies of Percussion Drilling: Min. Eng., vol. 11, No. 1, January 1959, pp. 69-75.

\textsuperscript{43} Engineering and Mining Journal, Australians Use Burn-Cut for Record: Vol. 160 No. 2, December 1959, p. 105.


\textsuperscript{45} Haber, George B., Ring Cut Proves Promising Basis for Universal Drift Round: Eng. and Min. Jour., vol. 160, No. 7, July 1959, pp. 78-81.

\textsuperscript{46} Brandstrom, Sten, Blasting Without Removing the Overburden: Civil Eng., vol. 29, No. 11, November 1959, pp. 44-45.
the drill pipe is removed and reused. The first blast, consisting of 4,750 holes, broke 36,000 cubic yards of rock covered with 90,000 cubic yards of overburden. The overburden and broken rock were removed by a specially designed bucket dredge.

Recent tests of fertilizer-grade ammonium nitrate (AN) blasting agents by manufacturers, users, and research establishments were reported at the Fifth Annual Symposium on Mining Research at Rolla, Mo. Test results by the various researchers, agreed closely and can be generally summarized as (1) the higher the density of the prill the lower its sensitivity, (2) sensitivity increases with age of mixture, (3) detonation velocity ranges from 12,000 to 15,000 feet per second, increasing with increased density, and (4) effective fuel oil mixture ranges from 3 to 6 percent. John L. Ryon described the underground use of AN at the Detroit, Retsof, and Avery Island mines of International Salt Co.47 The face is first undercut; then 2\(\frac{1}{4}\)-inch holes are drilled to a depth of 8 feet. A mixer mounted on a forklift unit mixes enough AN and fuel oil to load one hole. The hole is bottom-primed with high-velocity dynamite and electric detonator. The AN-fuel mixture is then blown into the hole by a pneumatic loader. Possibly economy of the process is indicated by the respective costs of AN at 3½ cents a pound and dynamite at 18 cents a pound. Tests to determine generation of fumes and static electricity were made, and no serious hazard was indicated. However, the question of safety in the handling, mixing, and use of AN explosives, particularly underground, has not been resolved. The manufacturers, the users, and the Bureau of Mines are collaborating to establish satisfactory safety standards.48

Experiments in Sweden have led to a method of "smooth blasting" to minimize blasting cracks in the walls and roofs of underground openings.49 The work was prompted by the need to construct a number of permanent underground structures. Essentially the method employs closely controlled hole spacing, charge size, explosive distribution in the hole, and ignition of the charges. Unloaded guide holes can be helpful in directing the line of break. Criteria for control were developed by model tests and practical experiments.

**MECHANICAL FRAGMENTATION**

Breaking rock for mining without the use of explosives has many advantages, which stimulate effort to achieve this purpose economically. Equipment has been developed and used successfully in softer rock formations, but no general-purpose tool has been devised. Interest in hydraulic methods was revived, particularly for mining coal.50 Bureau of Mines experiments on hydraulic coal mining have advanced a working face by cutting with a hydraulic jet, but research

remains to be done on design of nozzle, jet action, and various conditions affecting efficient application of the method. As a result of the performance obtained with the Robbins tunnel-boring machine in driving the 25-foot 9-inch tunnel at Oahe Dam, a larger model has been made to drive the new 29½-foot tunnel now under construction.\(^{51}\) At Vandenberg Air Force Base in California, a Badger tunneling machine excavated personnel tunnels for an underground Titan Missile base.\(^{52}\) Using a cutter head equipped with chisel-shaped hard-metal-tipped knives, the machine cuts a 10-foot-diameter tunnel in shale. Chalky limestone at the Arkansas Cement Corp. quarry is being broken by rippers.\(^{53}\) The broken material is picked up by a 33-yard pan scraper and hauled directly to the quarry hopper.

**MATERIALS HANDLING: LOADING, TRANSPORTATION, HOISTING**

The Kolbe wheel excavator, one of the world's largest earth-moving machines, was demonstrated in June at the Cuba, Ill., mine of United Electric Coal Co.\(^{54}\) With a theoretical digging capacity of 4,800 cubic yards an hour, they expect to obtain an output of 3,500 cubic yards per hour on a yearly basis. For underground loading, the Transloader, a more sophisticated model of the Gismo, has been developed and shows lower loading and hauling cost than earlier models of the machine.\(^{55}\)

In comparing the three basic open-pit haulage systems—rail, truck, and combination—used on the Mesabi, the basic factors of selection are cost and safety.\(^{56}\) Truck haulage permits a higher degree of flexibility in mining, but rail haulage provides lower transportation cost. A comparison shows that despite an average haulage distance of 4.3 miles and elevation of 271 feet for rail haulage against a distance of 0.78 miles and elevation of 144 feet for trucks, rail haulage costs are 8 percent below those for trucks. Experience with electric-truck haulage at the Crestmore underground limestone mine shows that these units can carry about 50 percent more rock in about half the time required with diesel trucks.\(^{57}\) Cost is lower, and ventilation problems are reduced.

A belt conveyor system used in conjunction with a bucket-wheel excavator transports 3,000 tons per hour at the Nehanga copper mine.\(^{58}\) The initial lift is 170 feet, and this will be increased in 86-foot increments to a total of 1,000 feet. The total length of the

\(^{51}\) Karolevitz, R., World's Largest Mole Tunnels at Oahe Dam: Excavating Engineer, vol. 53, No. 6, June 1959, pp. 31–32.

\(^{52}\) Construction Methods and Equipment, Unusual Tunnelling Machine Bores Tunnels for Missile Base: Vol. 41, No. 12, December 1959, p. 99.

\(^{53}\) Pit and Quarry, New 1,400,000-Bbl. Plant of Arkansas Cement Corp.: Vol. 51, No. 10, April 1959, pp. 80–83.


\(^{56}\) Matheson, W. N., Jr., Selecting an Open Pit Haulage System: Min. and Eng., vol. 11, No. 4, April 1959, pp. 409–413.

\(^{57}\) Nalle, P. B.; Electric Truck Haulage at Crestmore: Min. Eng., vol. 11, No. 4, April 1959, pp. 405–408.

conveyor system from bench to stacker dump is 11,709 feet. The Ada, Okla., plant of Ideal Cement Co. has a 5 1/2-mile conveyor system between the quarry and plant. Reported to be the longest permanent belt conveyor system ever built, it consists of seven separate belt conveyors. The entire production process, including the conveyor system, is controlled from a central control room. The longest of the seven belt conveyors is 2 1/2 miles long; the shortest is 550 feet long. The system transports 1,000 tons of crushed limestone per hour. Elaborate steps have been taken to insure adequate power for starting under all conditions of load and to control the inertia forces that would be released in case of power failure. Individual conveyors have a longer coasting time progressively from the quarry to the plant.

GROUND SUPPORT AND CONTROL

Numerous reports were published during the year, reviewing the effects of rock properties and stress conditions in relation to mining. The Bureau of Mines has prepared for publication a bulletin on design of underground openings in competent rock which summarizes its research in this field. A symposium on rock mechanics at the Colorado School of Mines in April also reviewed the subject, while attempting to relate factors common to comminution, underground rock failure, and rock breakage by explosives. The various attempts to review the subject of rock mechanics are spurred by the large volume of information published since the end of World War II. The information published to date has been largely theoretical from investigations to establish applicable principles. Greater application of these data to mining problems is becoming evident as the information becomes better disseminated and understood. One application has been reported at Cananea Consolidated Copper Co. mine, where drill-core data are used to aid ground-control planning. Combining factors of core recovery and modulus of rupture of the rock, a graph was obtained to indicate the relative competence of the rock in the area of a proposed drift. Studies of photoelastic models were helpful in shaft planning at the Champion Reef mine in the Kolar Gold fields.

Increased application of rock mechanics is evident in underground civil engineering works. The Snowy Mountains Hydro-Electric
Authority in Australia utilized rock-physical-property tests, rock-stress analysis, model studies, and instrumentation for rock-mechanics investigations of underground structures included in the project. Excessive rock work in construction of the Niagara power project by the Hydro-Electric Power Commission of Ontario made it desirable to obtain data on the structural-stability characteristics of the rock formations. Careful measurement of rock movements were made, and the data were interpreted in terms of rock stability and effect on installed structures.

The difficulty of translating theoretical stress analysis to variable in situ rock conditions is a major problem. Model studies offer one possible solution; another is in situ measurement of stress and fracture patterns. Several methods of measuring fractures by sonic-wave propagation are being investigated.

Experimental mining of pillars by St. Joseph Lead Co. at Bonne Terre, Mo., was carefully instrumented to obtain quantitative measurements of rock action in the affected area. It was determined that reasonable stope convergence and pillar loading can be detected and measured by means of extensometer, seismotron, and convergence warning lights. The Bureau of Mines continued experiments on cementation of roof strata in coal mines. Epoxy- and polyester-type resins have been injected as bonding material. Tests indicate that a method of strengthening mine roofs by injecting bonding material can be developed as a system of roof support. The Silver Mountain project of Hecla Mining Co. in Idaho has used a combination of spilling and yieldable supports to drive through extremely heavy ground. A similar combination was used at the Sunnyside coal mine No. 3 in Utah to reopen caved development slopes.

**DRAINAGE**

Large quantities of water contained in the dolomites of the South African Far West Rand have been a major problem of mining in the area. Although extensive pre cementation has been carried out in connection with shaft sinking, heavy flows of water have been encountered. Ultimate pumping capacity at the Western Deep Level is scheduled to be 30 million gallons a day. Individual pumps capable of delivering 168,000 g.p.h. will operate in parallel against a static head of 3,400 feet. Experiments also have been made on the de-
sign of underground bulkheads to control water at high pressures.\textsuperscript{72} Local and foreign practices were investigated, and specially designed bulkheads were tested for leakage and failure. It was determined that the required length of a concrete plug depends more on leakage than on the structural strength of the plug.

An aspect of water control that is gaining increased attention is the possible effect of water on the stability of mine openings. It has been found that the instability of slopes in open-pit mines is the result of excess hydrostatic pressure behind the face of the pit.\textsuperscript{73} Effective stabilization can be accomplished in many cases by subsurface drainage to relieve hydrostatic stress. The effect of a saturated rock formation on the stability of an underground opening has not been determined, but obviously this condition will affect the transfer of pressure and stress within the rock.

**VENTILATION**

High temperatures encountered at depth in mines on the Rand in South Africa continue to pose serious ventilation problems. Excluding capital redemption, total ventilation cost at the East Rand Proprietary mines is about 38 cents per ton mined.\textsuperscript{74} As mining progresses to 12,000-foot depths, this cost is expected to increase to about 65 cents. At a depth of 12,000 feet, rock temperature will be approximately 130° F., and at air velocities of 500 to 600 feet per minute maximum permissible wet-bulb temperature will be 92° F. Heat flow from the rock will be 200 B.t.u.'s per minute for each 5 square feet of rock face.

A high dust concentration in mine air at the Pronto mine in Canada was reduced by changes in the ventilation pattern, ore handling practices, and arrangement of ore pass, dumps and grizzly station.\textsuperscript{75} Dust generation and air surges caused by dumping in the original ore-pass system were the major contributing sources of air contamination. Plans to deepen the shaft included dust-control measures to correct the faulty conditions introduced by the original ore-pass system.

An idea of the ventilation requirements of the deep gold mines in South Africa can be gained from recent contracts for ventilation plants.\textsuperscript{76} A contract for Harmony Gold Mines specifies four units each of 400,000 c.f.m. at 30-inch water gage, each driven by a 2,600-h.p. motor. Western Deep Level has specified four units each of 550,000 c.f.m. at 24-inch water gage. Vaal Reefs has ordered two units each of 575,000 c.f.m at 25-inch water gage.


\textsuperscript{73} Wilson, S. D., Slope Stabilisation in Open Pit Mining: Pres. at Min. Cong., Denver, Colo., September 1959.


\textsuperscript{76} South African Mining and Engineering Journal, Big Fans for Big Mines: Vol. 70, No. 3483, Nov. 15, 1959, p. 1263.
HEALTH AND SAFETY

Papers were presented by authors from eight countries at the 10th International Conference of Directors of Safety in Mines Research held at Pittsburgh, Pa., during September. Primarily concerned with coal mine safety, the subjects covered included safety of explosives, testing of explosives, hazards of blasting, gas and dust explosions, ignition, ventilation and fire hazards.

In comparing fire protection facilities of coal mines and industrial plants, the plants place much greater emphasis on fire protection. On a comparative basis of capital investment in fire protection versus total mine or plant investment, the least equipped plant spends as much as the best equipped mine.

MINING PRACTICE AND PERFORMANCE

Mechanization and mobility are being introduced wherever possible into mine operations. This has been particularly evident in open-pit and trackless room-and-pillar mining. One result has been a shift in supervisory responsibility to increased concern with machinery. Productivity may be directly related to machine operating time, as is evident in the extreme case of the giant excavators now used in strip mining. Equipment selection for an efficient balanced production schedule is of prime importance for a successful operation. Equipment maintenance and replacement is an integral part of production cost. Reported experience at the Bagdad open-pit mine in Arizona gives an idea of the complexity of balancing equipment capacity for maximum efficiency. With various types of equipment, loading costs varied from 3 to 22 cents, and hauling costs from 3.6 to 10.6 cents, per ton. At the Anaconda Co. Berkeley pit at Butte, Mont., nearly 19 percent of total man-hours and 23 percent of total operating costs are charged to repair of capital equipment.

The New York Trap Rock Corp. has adopted an approach to equipment replacement that evaluates the factors necessary for a sound decision. Using the basic pattern developed by the Machinery and Allied Products Institute, Washington, D.C., an individual plan was evolved to evaluate a request for equipment replacement. To the basic formulae comparing estimated operating cost of present and new equipment is added the difference between cost of continuing ownership and of acquiring new equipment. For present equipment, consideration is given to such items as restorative repairs, salvage value, salvage-value loss, and interest or cost of money. For proposed equipment, consideration is given to actual depreciation, cost of money, and anticipated salvage value. After replacement a periodic appraisal of new equipment is made. F. G. Kuehl, of International

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Talc Co., proposes a method of calculating “pay-out time” for machinery replacement.\textsuperscript{81}

Two of the newer Canadian mines, one mining a steeply dipping and the other a flat lying ore body, have achieved high productivity. The Geco Mine in Ontario uses a system of sublevel blasthole stoping and has eliminated tramming by a combination of scram-drift slushing, transfer raises, ore pass to an underground crushing station, and conveyor system from the crushe to the hoisting shaft.\textsuperscript{82} A production of 25 tons per underground manshift is obtained. At Gaspe Copper, experimental stoping operations established that with patterned rock bolting mining widths of 50 feet could be maintained.\textsuperscript{83} The B ore body is mined fullface in stopes 45 feet wide and 20 to 36 feet high. In the C ore body, an upper heading 45 feet wide and 18 to 50 feet high is mined fullface, followed by benching the lower portion of the ore using horizontal drilling. Production of 32 tons per manshift is obtained.

\textsuperscript{81} Kuehl, F. G., Economics of Equipment Replacement in the Mining Industry: Pres. at American Min. Cong., Denver, Colo., September 1959.
\textsuperscript{82} Marshall, G. M. T., Blasthole Mining at Geco: Min. Eng., vol. 11, No. 8, August 1959, pp. 797–802.
\textsuperscript{83} Brissenden, W. G., Mining at Gaspe Copper: Min. Eng., vol. 11, No. 9, September 1959, pp. 899–903.