MINING INCLINED BEDS OF PHOSPHATE ROCK,
SAN FRANCISCO CHEMICAL CO. MINES,
RICH COUNTY, UTAH

By Frank L. Wideman
MINING INCLINED BEDS OF PHOSPHATE ROCK, SAN FRANCISCO CHEMICAL CO. MINES, RICH COUNTY, UTAH

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MINING INCLINED BEDS OF PHOSPHATE ROCK,
SAN FRANCISCO CHEMICAL CO. MINES,
RICH COUNTY, UTAH

by

Frank L. Wideman

INTRODUCTION AND SUMMARY

This information circular describes methods used in mining inclined beds of phosphate rock in mines operated by San Francisco Chemical Co. in Rich County, Utah.

The mines are on the western flank of the Crawford Mountains, a short, narrow range in northern Utah near the Idaho-Wyoming corner (fig. 1). The western front of the range is a conspicuous wall of folded and faulted sedimentary rocks that rise abruptly 300 to 600 feet above the floor of the adjacent Bear River Valley. Rex Peak, highest point in the range, is approximately 8,000 feet above sea level.

The area surrounding the mines is sparsely populated. Randolph, the county seat of Rich County, has a population of 650. It is 10 miles southwest of the mines by road and the only town in their vicinity.

A main line of the Union Pacific Railroad passes 4 miles north of the Crawford Mountains. A branch of the railroad extends to Leefe, Wyo., the shipping point nearest the mines. Hard-surfaced main highways traverse Bear River Valley, and improved secondary roads lead to the mines.

Streams flow intermittently from the Crawford Mountains, and a few perennial streams rise in the mountains that border the valley on the west. Summers are mild and pleasant but of short duration; winters are long and severe.

No suitable mine timber grows in the Crawford Mountains. Timber used at the mines is trucked from forests in Wyoming.

Phosphate rock is produced from two adjacent beds in the Permian Phosphoria formation. The beds are prospected with trenches, diamond-drill holes, and underground work.

Differences in the phosphate content of the beds, their inclination, and the hardness of the hanging wall require use of different mining methods.

In the Arickeree mine open stopes are employed, with or without supporting pillars. In the Pawnee mine conditions permit the use of shrinkage stopes. At the Mandan mine phosphate beds are too low grade to be mined where explored by underground working. Shrinkage stoping has not proved successful in the Tuscarora mine;

1/ Work on manuscript completed March 1956.
and a sublevel mining method, leaving thin, horizontal pillars for ground support, finally was evolved. This method is used in the Emma mine.

The combined maximum production from the Arickeree, Pawnee, Tuscarora, and Emma mines is about 31,000 tons of phosphate rock a month. The average underground man-shift production is 25 tons.

Rock is shipped by truck to Leefie, Wyo., where it is stockpiled. From there, it is shipped by railroad to fertilizer-manufacturing plants; most of the rock is of direct-shipping quality, and some requires beneficiation before it can be used.

ACKNOWLEDGMENTS

The author is indebted to D. L. King, president and general manager of San Francisco Chemical Co., for the opportunity to observe the company mining operations and for permission to publish the data that follow. Appreciation is also expressed to J. S. Wright, mine superintendent, and to J. Haun, mine foreman, who gave their time freely and supplied much of the information assembled in this circular.

HISTORY

Outcrops of phosphate rock in the western fields first were prospected for coal because of their resemblance to coal blossom. In 1897 the phosphatic nature of the rock was recognized in samples from Woodruff Canyon, about 20 miles southwest of Randolph, Utah.3/

A few tons of rock were produced from deposits in Woodruff Canyon, but exploitation was hindered by inaccessibility; however, identification of the rock stimulated location of mining claims on many more easily accessible deposits.

Hoyt S. Gale and Ralph W. Richards4/ wrote that rock had been mined from the Arickeree5/ mine for several years before 1909. The nearby Mandan mine was idle at that time.

The bed of phosphate rock, now referred to as the A bed, was mined selectively with open-stope methods during the early activity. The stepped sections across this bed, where seen in old stopes, indicated that mining was accomplished in three stages. The upper stratum of good-grade rock was extracted first; then rock from the low-grade middle stratum was removed and discarded; lastly, rock from the high-grade lowest stratum was mined. Tool marks along the walls and backs of drifts and stopes indicate that the rock had been mined by picking and moiling. Records in the courthouse at Randolph, Utah, show that 1,444 long tons of phosphate rock was produced from the Arickeree mine in 1907, for which $5,776.85 was paid f.o.b. Sage, Wyo. Mining in the northern part of the Crawford Mountains stopped soon after 1909, and operations were not resumed until 1953, when San Francisco Chemical Co. began developing the Arickeree, Pawnee, and Mandan mines. The company began to develop the Tuscarora and Emma mines during the summer of 1954.

5/ Current spelling of the name of this mine by the San Francisco Chemical Co. is Arickeree.
DESCRIPTION OF DEPOSITS

Two beds of phosphate rock referred to as the A and the B are mined in the Crawford Mountains. The A bed is the uppermost one in the phosphatic shale member of the Permian Phosphoria formation and is overlain by the Rex chert member (fig. 2). The A bed is about 5 feet thick and composed of at least three strata, upper, middle, and lower. The upper and lower strata are phosphate ore; but the hard middle stratum, which ranges from 5 to 11 inches in thickness, contains little phosphate. The A bed overlies the B bed and is separated from it by a thin shale seam of good phosphate content. The B bed is about 5 feet thick and fairly uniform in composition. It is usually softer than the A bed and is generally too poor in phosphate content to be ore.

The chert that overlies the A bed is hard and brittle and forms a good hanging wall, except where it is weakened by folding, faulting, or weathering.

The beds strike northerly along each limb of the Crawford syncline. They dip east or west at various angles, depending on their position on the structure. Folding and faulting that brought the Phosphoria formation into outcrop position resulted in much deformation of the beds. Transverse and step faults that caused various amounts of displacement are encountered in mine workings.

Improvement of the P2O5 grade by weathering is a characteristic of the deposits. In some places grade improvement is limited to near the surface; but in others, weathering progresses downdip to greater depths.

No uniform plan of mining can be adopted because of local variety of deformation and grade. Therefore, mining methods are modified to meet conditions as they are encountered.

The phosphate rock is dense, oolitic, brown, gray, or black. It is brittle enough to break well when blasted. The rock on the lower levels of the Arickeree mine is denser and darker than that near the surface. The weight of 1 cubic yard of rock in place ranges from 4,300 to 4,500 pounds.

The phosphate content of the rock is reported as phosphorus pentoxide (P2O5) or as tricalcium phosphate (Ca3(P04)2). The latter is 2.18 times the atomic weight of the former. Most of the rock from the A bed contains 31.5 percent or more P2O5 and can be used directly in manufacturing acid-type fertilizers. Rock from the B bed contains 27 to 30 percent P2O5. It has to be beneficiated by attrition and aeration before use in fertilizer manufacture.

EXPLORATION

Outcrops of phosphate beds are explored with bulldozer trenches across the strike. Samples from the surface exposures are not reliable indicators of the phosphate content of rock at depth, as they contain a greater proportion of phosphate than the deeper, less weathered rock.

Subsurface extensions of the deposits are explored in places by core drilling from the surface. Core recovery varies considerably, depending on the type and condition of the rock drilled.

Core samples are not entirely representative of the rock penetrated in the weathered zone. Calcium has been leached from the rock, leaving it somewhat porous.
FIGURE 2. Geologic Map of Crawford Mountains Phosphate Deposits.
Much of the calcium, deposited as aragonite and calcite in fractures caused by folding, is washed out during drilling, causing analyses of core samples to be misleading.

Drifts, raises, and a winze were driven along the beds and offered a more accurate means of sampling the beds than either trenching or diamond drilling. This work was done almost wholly in ore, preparing the ore blocks for mining, and was considered to be development work.

**SAMPLING**

Development headings and stopes are sampled by cutting channels after each round is blasted. Each ore stratum is measured and sampled separately. Grab samples are taken from cars as the stope chutes are drawn. Composite samples are taken from stockpiles accumulated near the shipping point.

**ARICKERE MINE**

The Arickeree mine is in the Crawford Mountains on the east limb of the Crawford syncline, near the northern end of the outcropping phosphate beds. The main haulage level is driven into low hills that rise on the east side of a gulch that roughly follows the trough of the syncline.

**Development**

A crosscut adit driven during the earliest period of mining in the district is the main entrance to the mine. The phosphate beds are intersected about 250 feet from the portal. A drift off the adit follows the beds to a point beneath a gulley, beyond which the stopping height is too small to warrant further development in that direction. The adit level is called the 100 level.

Below the 100 level the beds are developed through an inclined winze, and 2 levels are driven at 175-foot intervals along the dip (fig. 3). The 200 level is a service, and the 300 a haulage level.

Three-compartment raises are driven in the A bed for about 30 feet above the back of the 100 level. The raises are spaced at 150-foot intervals. Sublevel drifts are driven from the raises, leaving 15-foot pillars between haulageways and sublevels. All raises except one were advanced above the sublevel as mining progressed. One raise was driven to the surface before any rock was mined.

The phosphate content of the rock varies at different depths below the 100 level, and development below that level is designed to permit mining higher and lower grade ores simultaneously. Three-compartment raises are driven from the 300 to the 100 level, at 150-foot intervals, before mining. The amounts of ore shipped from blocks of different grades are controlled at the chutes. Sublevels are driven, leaving 15-foot pillars above the drifts, and mining begins at the backs of the sublevels.

**Winze**

The inclined winze, 6 feet by 12 feet, has been driven 408 feet in dip length below the 100 level.

The only timber in the winze is the stuffs and lagging between the manway and hoisting compartments. The manway compartment contains ladders, air and water lines,
FIGURE 3. - Cross Section Through Winze, Arickeree Mine.

ventilation tube, and power cables. The hoisting compartment has tracks for two skips.

The winze first was sunk in the A bed with a 6- by 6-foot cross section but enlarged to 6 by 12 feet by sideswiping. Handheld rock drills were used for sinking and airleg drills for sideswiping. Broken rock was hand loaded during sinking; but when the winze was being enlarged, it was blasted onto temporary bulkheads and loaded into skips through temporary chutes.

The raise driven to the surface was in line with the winze. A hoist was installed on the surface, and the raise-winze combination became a shaft through which rock was hoisted from the 300 to the 100 level.

Drifts

Drifts are driven for two purposes: (1) For haulage and access and (2) as sublevel drifts from which stoping begins.

Haulage and access drifts are driven 9 feet high by 10 wide, the latter being the combined width of the A and part of the B beds. The backs of the drifts are
arched, and the walls conform to bedding planes where the deposits are steeply inclined. Ground support is not required, and the only timbering in the drifts is at chutes.

The drifts are advanced by 3-hole burn-cut drift rounds, usually having a total of 22 holes drilled 7 feet deep. Airleg-type rock drills are used to drill most of drift rounds, but column-mounted rock drills are needed to drill unusually hard faces. Cross-shaped tungsten carbide insert bits are used with both types of rock drills. Each round is loaded with approximately 50 pounds of 45-percent dynamite. Standard-delay electric blasting caps are used to detonate the charges. The same-type explosives are used for blasting stope rounds.

Early in the development program a slusher scraper and ramp were used in loading broken rock into the mine cars. Later, a compressed-air-powered, wheel-mounted rocker shovel was provided.

Sublevel drifts have cross sections 6 feet wide by 12 high. Pillars, 15 feet in dip dimension, are left between the sublevel drifts and the haulage level. The sublevel drifts are driven on the A bed in both directions from the raises. The backs of the drifts are arched, and the walls conform to bedding planes (fig. 4).

Sublevels are advanced by drilling 3-hole burn-cut rounds having a total of 12 to 20 holes 6 to 7 feet deep. Airleg-type rock drills and tungsten carbide insert crossbits are used in drilling. The bits are sharpened by grinding.

Rock broken in the sublevels is slushed into the chute compartments of the raises. A pin for the tail sheave is driven into a hole drilled in the face of the sublevel. Air-powered, double-drum hoists are mounted in the manway compartments of the raises at the elevation of the sublevel. The hoists are mounted on turntables to permit slushing from either side of the raises. The hoist remains on the sublevel during mining by open-stope methods. Arc-type scrapers, 3 feet wide, are used for slushing.

Drifts are driven on one shift, during which the crew usually muck out, drill, and blast.

Rises

Three-compartment raises, to develop the ore block above the 100 level, are driven to a height of about 30 feet before mining begins. The blocks are prepared for mining by driving sublevels from the raises. With one exception, the raises have been advanced above the sublevel as stowing progressed, and the backs of the raises usually are maintained 7 to 14 feet above the backs of the stopes.

The phosphate content of the rock is less in places in the lower part of the mine than nearer the surface. Rises are driven from the 300 to the 100 level before any ore is in mined. This method permits simultaneous mining of separate blocks of higher and lower grade rock. Rock of different grades can thereby be blended and the grade of the mine production regulated.

Rises are driven in the A bed with a cross section of about 5 by 12 feet. The hanging wall seldom requires support, but the manway compartment is separated from the chutes with 3- by 12-inch lagging nailed to 6- by 8-inch stulls. The manways are lagged completely between the, level and sublevel drifts to provide for storage of rock between train trips; but above the sublevel, only the footwall half of the
sides of the manways are lagged. This permits access to the stopes at any place (fig. 5).

Raise rounds are 3-hole burn-cut type, having a total of 22 holes. The cut is drilled over one of the chutes, and the remaining holes break toward the cut. Rounds are drilled with airleg-type drills. Cross-shaped and Carr-type tungsten carbide insert bits are used.

The pipelines for water and compressed air end at the sublevels.
FIGURE 5. - Open Stope Without Pillars, Arickeree Mine, San Francisco Chemical Co., Rich County, Utah.
Mining

The open-stope system of mining is used. Extraction of rock from the A bed is the primary objective, because its phosphate content is generally sufficient to permit direct use in manufacturing fertilizer. In some parts of the mine the condition of the deposit permits mining of rock from the B bed. In those areas all rock that can be won from the A bed is removed from a stope; then as much rock as can be mined rapidly is stripped from the B bed on the footwall.

The condition of the hanging wall determines the requirements for ground support, and the dip of the beds governs methods of drilling and slushing. Stopes are classified as: (1) Open stopes without pillar support and (2) open stopes with pillar support. Class 2 stopes are divided into two subclasses, according to the method of extraction, as: (a) Sublevel-and-pillar and (b) raise-and-pillar. Mining begins at the backs of the sublevels in all types of stopes. Adjacent stopes are connected on and above the sublevels.

Airleg-type rock drills are used for drilling stope rounds. Drill steel ranges in length from 6 to 12 feet and is provided with cross-shaped and Carr-type tungsten carbide insert bits. Bits that have an insert broken when drilling in hard rock might be used for drilling in softer rock.

In stopes without pillars the practice is to drill rounds updip of the beds (fig. 5). The holes are drilled about 24 inches apart, in 3 rows along the A bed. The row along the hanging wall is drilled about 8 inches from the wall to insure breaking all the ore. Drilling is done from ladders set on a 4- by 6-inch lashing laid along the footwall and supported on pins driven into holes drilled into the footwall. The lagging also serves as a catwalk to other parts of the stope. As many holes as can be drilled in a shift are blasted at the end of the shift.

Where the dip of the beds is steep enough to enable broken ore to run to the bottom of the stope, the ore is slushed directly into the chutes; but where the footwall is too flat for that, it is necessary first to slush the ore downhill to the bottom of the stope and then along the strike of the stope into the chutes (figs. 5, 6, and 7).

A sublevel-and-pillar method of mining is used in areas where the hanging wall needs support and the dip of the beds is greater than the angle of repose of the broken ore (fig. 6). Stoping begins by taking one or more rounds from the back of the sublevel above the haulage drift. Raises, about 15 feet long by 5 feet across the bed, are run at 25-foot intervals along the sublevel. The raises are connected with drifts driven through the pillars between them at 12- to 18-foot intervals along the dip. One or more rounds are taken from the backs of these drifts, and the process repeated. The resulting pillars are not of uniform size but are about 10 feet in strike length and 6 to 12 feet in dip length. The flow of broken rock abrades the pillars and decreases their sizes as mining progresses. Broken rock is slushed along the lowest sublevel to chutes.

A raise-and-pillar mining method is used where the hanging wall requires support, and the dip of the beds is less than the angle of repose of the broken ore (fig. 7). There, a sublevel is driven from the working raise on a slight incline. Finger raises, spaced at 25-foot intervals, are driven from the sublevel. The raises are really 15-foot-wide rooms, and their height is the thickness of the A bed (about 5 feet). The raises are interconnected by "dogholes" as they are advanced (fig. 8). "Dogholes" are driven to increase the percentage of extraction and permit access to the raises above the sublevel. Pillars, of somewhat irregular spacing and
Cross Section A - A'

Generalized Section Through Stope on Plane of Beds

FIGURE 7. - Open Stope Raise-and-Pillar Stope, Arickeree Mine.

FIGURE 9. - Car Dump and Shovel Loader, Arickeree Mine.
varying dimensions, result from this method. Airleg-type rock drills are used for drilling; they are usually supported on a 4- by 6-inch timber on the footwall. Two-way slushing, down the dip in the raises and across the strike in the sublevels, is required to remove the broken rock.

Figure 10 is a map of the levels and a longitudinal section through the stopes, which are shown in generalized sections (figs. 5, 6, and 7).

**Underground Transportation**

Chutes are timbered on the manway side only. Chute mouths, chute gates, and check boards are made of 3- by 12-inch plank. Drift sets that support the chute mouths are made from unframed 8- by 8-inch posts and caps.

Side-dump cars, with capacities of 176 cubic feet, and an 8-ton diesel-powered locomotive are used on the 100 level. On the surface the loads are dumped automatically to a slide by engaging a wheel on the side of the car body with a track on a "camelback" dumping device (fig. 9). The locomotive is equipped with an exhaust scrubber in which limestone and water are used.

Rock is hauled on the 300 level with a battery-powered locomotive and cars similar in type to those used on the 100 level but of 90-cubic-foot capacity. The loads are dumped automatically over a grizzly above the skip pocket. The grizzly slopes from the track to permit boulders to roll free of the car doors.

Tracks on both levels are 40-pound rail laid at 24-inch gage. Ties are rough 6- by 8-inch timber.

Shaft pockets above the 100 level and below the 300 level have capacities of approximately 250 tons. The pockets are unlined and have compressed-air-operated, steel chute gates. The chutes from the pocket above the 100 level are so spaced that the front half of a car can be loaded from one chute and the back half can be loaded from another chute without moving the car.

Rock is hoisted from the 300-level pocket to the 100-level pocket in 40-cubic-foot-capacity skips. The skips travel on 36-inch-gage, 60-pound rails. The skips are dumped with the conventional skip-dumping device used in inclined shafts. An electrically powered, double-drum, 125-horsepower hoist is housed on the surface near the collar of the raise.

**Auxiliary Operations**

Compressed air is delivered through a 4-inch pipeline laid from the compressor plant at the Pawnee mine. The pipeline is laid on the surface and has water traps at low places.

Explosives are stored in underground magazines, isolated from the mine workings. Daily requirements are withdrawn from the magazines, and no explosives are stored in mine workings.

At the surface, a shovel loader is used to load the phosphate rock into 10-cubic-yard-capacity, diesel-powered trucks, which haul it to Leefe, Wyo., where it is stockpiled. Rock from the stockpile is shipped directly to fertilizer-manufacturing plants or first beneficiated and then shipped, depending on its grade.
FIGURE 10. - Plan and Longitudinal Section, Arickeree Mine.

(Courtesy, San Francisco Chemical Co.)
Most of the mine workings are in the phosphate beds. Waste rock, resulting from cutting shaft stations and pockets, is dumped on the surface near the portal of the adit.

Ventilation

The mine is ventilated by natural and mechanical means. The adit, stopes above the 100 level, and fractures in the rock serve as airways. A 3-foot, 20-horsepower, electrically powered blower is set near the portal of the adit. Air is forced through an 18-inch tube to workings below the 100 level. No data are available on the quantity of air circulated.

Mine Drainage

The mine has little water; most of it is encountered on the 300 level. Electrically powered centrifugal pumps, with a total capacity of 70 g.p.m., pump water intermittently from the 300 level to the 100.

Water for drilling and for the changeroom is obtained from a well north of the mine.

Communications

A bell-and-flash system is used to signal the hoistman to raise or lower the skips in the winze. Hand-operated bell lines are provided for emergency signaling. The skiptenders are the only employees authorized to signal the hoistman.

Telephones at winze stations are connected with a telephone at the surface plant.

Percentage of Extraction and Production Rates

The percentage of extraction varies with the method of stoping. Extraction of rock from the A bed, in stopes without pillar support, approaches 100 percent of the reserve above the sublevel. In stopes with pillar support, the extraction is as low as 70 percent. The average extraction of A bed rock is approximately 85 percent.

About 75 percent of the estimated reserve of rock from the B bed is recovered from stopes without pillars. No attempt is made to win rock from the B bed, where pillars are required.

Extraction of pillars has not been successful, because the hanging wall sloughs as rapidly as pillars are blasted.

The maximum monthly production from the mine is 16,000 tons.

Other Mining Methods Used in Nearby Mines

Phosphate rock is extracted from other deposits in the immediate vicinity by underground or opencast mining. The underground mining methods are discussed in sections of this circular that relate to the individual mines. Opencast methods were used in mining deposits on Rex Peak, Utah, and are being used at Leefe, Wyo. Rex Peak is 6-1/2 miles south and Leefe 4 miles north of the Arickeree mine.
Overburden at the opencast mines is removed with bulldozers or with power shovels and trucks. The phosphate rock is loaded into trucks with power shovels and hauled to railroad shipping points.

**Pawnee Mine**

The Pawnee mine is on the west limb of the Crawford syncline, approximately half a mile southwesterly from the Arickeree mine (figs. 1 and 2). A road turning off Utah State Highway 51 leads to both mines. The Pawnee mine is entered through a short adit whose portal is on the steep north slope of a V-shaped gulch that falls rapidly to the west.

**Development**

This mine is not developed extensively. The plan of development is similar to that at the Arickeree mine - a haulage level and three-compartment raises to a sublevel from which stoping begins.

The adit, called the 100 level, has been driven northerly along the A and B beds. Drilling and blasting practices are similar to those employed at the Arickeree mine. A diesel-powered shuttle car is used for haulage, and early in the development program a slusher hoist and scraper were used for loading (fig. 11). Later, a shovel loader mounted on mine-car wheels was used. The loader is operated on a short fly-track advanced with the heading. The mine is dry, and little maintenance is necessary on the road bed over which the shuttle car operates. A solution of hydroquinone and sodium sulfite is used in the shuttle-car scrubber.

The methods of spacing and driving three-compartment raises and sublevel drifts are similar to those used at the Arickeree mine. Manways in raises are completely lagged above the sublevel drifts.

**Mining**

The steepness of the phosphate beds and the hard hanging wall are factors that permit using shrinkage stoping in extracting ore from the A bed (fig. 12). The miners stand on the broken ore while working in the stopes; when ore-breaking is completed, the stopes can be emptied without appreciable dilution due to hanging-wall slough. Raises are advanced at least one round above the backs of the stopes as mining progresses. Stopes rounds are drilled updip. Holes are drilled 24 inches apart, in 3 rows along the beds, and usually are blasted at the end of the shift.

Broken rock accumulates in the stopes, and enough is scraped to the chutes to provide the miners with working room between the broken rock and the backs of the stopes. One member of the mining crew slushes rock from the stope on one side of a raise while other miners are drilling on the opposite side. The slusher hoists are moved up the raises from time to time as mining progresses. After all rock has been broken, the slushing operation progresses downward until the stope is emptied. It is estimated that approximately 90 percent of the rock broken in the shrinkage stopes has to be slushed to the chutes, and 10 percent reaches the chutes by gravity.

**Auxiliary Operations**

The compressor for the Arickeree, Mandan, and Pawnee mines is housed across the gulch from the portal of the Pawnee adit. It has a rated capacity of 2,100 cubic feet per minute and is a direct-driven, 2-stage L-type. The vertical cylinder is
FIGURE 11. - Shuttle Car at Chute, Pawnee Mine.
FIGURE 12. - Shrinkage Stope, Pawnee and Tuscarora Mines.
the low-pressure cylinder, and the horizontal cylinder is the high-pressure cylinder. The compressor is cooled by water circulated through a large, air-cooled radiator. Permanent-type antifreeze compound is circulated through the cooling system during the rigorous winters.

Ore is hauled from the mine with the shuttle car and stockpiled on the surface.

Electric power is supplied by Utah Power & Light Co., which owns plants in Utah and Idaho. A 44-kv. line approximately 6 miles long transmits the power from Leefe, Wyo., to transformers at the Arickeree and Pawnee mines. The average monthly power-load is 360 kilowatts.

**Ventilation**

Ventilation is provided by natural and mechanical means. The adit and fractures in the rock serve as exhaust airways. A 3-foot, electrically powered blower is installed on the surface near the portal of the adit. It forces air into the mine through an 18-inch tube.

**Mine Drainage**

There are no drainage problems at the mine because little water has been developed underground, and the mine workings do not extend below the adit level.

**Percentage of Extraction and Production Rates**

It is estimated that over 90 percent of the ore broken in the shrinkage stopes is recovered before the stopes are abandoned. That occurs when the stopes become unsafe. Because only 2 chutes are provided for each stope - 1 on each side of the manway - only about 10 percent of the broken rock falls directly into the chutes; the rest has to be slushed. The maximum monthly mine production is 2,000 tons.

**MANDAN MINE**

The Mandan mine is on the west limb of the Crawford syncline, approximately a quarter of a mile west of, and across the gulch from, the Arickeree mine (figs. 1 and 2). A crosscut through hanging-wall formations and two short drifts along the phosphate beds comprise the mine workings. The first section of the crosscut was driven before 1909, probably by hand. In 1953 an air trammel and 1-ton-capacity end-dump cars were being used. The cars were loaded with a scraper that pulled the broken rock onto a ramp. Faces were drilled with a column-mounted rock drill, using cross-shaped tungsten carbide insert bits. As many as 33 holes were required to break some rounds in the hard Rex chert.

No shipments were made from the mine, because rock from the phosphate beds was too low grade to sell.

**TUSCARORA AND EMMA MINES**

The Tuscarora and Emma mines are in Emma Canyon about 3-1/2 miles southerly from the Arickeree mine (figs. 1 and 2). The mines are reached over a graded road about 1 mile long in Emma Canyon, from a county road running along the western front of the Crawford Mountains.
The mines are on the east limb of the Crawford syncline. The dips of the phosphate beds range from 58° to 65°, which is steeper than at other underground mines in the district.

Development

Development of the mines was begun in the summer of 1954, and the Emma mine became one of the larger underground operations in the district. It is developed through an adit driven into the ridge on the north side of Emma Canyon. The Tuscarora mine is developed through an adit driven into the ridge on the south side of the canyon.

Development work in the two properties is similar to that in other underground mines in the district. The adits are 9 feet high by about 10 wide and expose the A and B beds. Drilling and blasting practices are the same as those in the other underground mines. A shovel loader on track is used for loading.

Three-compartment raises are driven at 150-foot intervals from the adit level to sublevels about 15 feet above the back of the haulage drifts. Above the sublevels the raises are advanced as part of the stopes. The sides of the manways are completely lagged.

Sublevels from which mining begins are driven about 12 feet high along the A bed. Methods used in driving them are similar to those used elsewhere in the district.

Mining

The choice of mining methods at the two mines is governed by the steep inclination of the beds (58° to 65°) and by the prevalence of faults that displace the beds slightly and weaken the hanging wall. Three methods of mining were used at the Tuscarora mine: (1) Shrinkage-stope mining (fig. 12), (2) sublevel mining (fig. 13), and (3) sublevel-and-pillar mining (fig. 14).

Shrinkage stoping was the first method tried. The stopes were begun by blasting down the back of the sublevel. Enough broken rock was slushed to the chutes and drawn to provide working space for the miners between the back of the stope and the top of the broken rock. Other cuts were taken across the back, and the slushing operation was repeated between each cut. It soon became apparent that it was difficult to draw all rock from the stopes before it became diluted with waste that sloughed from the fractured hanging wall. Also, it would not have been feasible to strip the B bed, which lies on the footwall; therefore shrinkage stoping was discontinued.

Sublevel stoping was then tried but was discontinued soon afterward, when it was found this method did not leave adequate support for the hanging wall. By this method, a sublevel about 10 feet high was driven the entire length of the ore block to be mined. Then 2 cuts 12 feet high were taken from the back of the sublevel. The rounds were drilled by breasting holes into the vertical faces of the cuts. A pillar about 6 feet in dip dimension was left, another sublevel was begun, and the process was repeated.

The method now used is called sublevel-and-pillar stoping. A sublevel about 10 feet high is driven the entire length of the ore block and cleaned out by slushing. The back of the sublevel is then blasted with holes drilled updip. The sublevel is
FIGURE 13. - Sublevel Mining (Horizontal Stope Rounds), Tuscarora and Emma Mines.
cleared of broken rock again. A pillar with a minimum dip dimension of 5 feet is left along the entire stope. The spacing and size of the pillars is sometimes influenced by step faulting, and the resulting pattern is irregular.

Slusher hoists are moved upward in the raises as mining progresses. Scraping and drilling are conducted simultaneously on opposite sides of the manway.

Figures 12, 13, and 14 are generalized to illustrate the three mining methods that have been tried. Figure 15 is the plan and longitudinal section of the Emma and Tuscarora workings.

Underground Transportation

A diesel-powered shuttle car was used in the first 1,000 feet of drift. Since track was installed, a 176-cubic-foot-capacity side-dump car and an 8-ton diesel-powered locomotive have been used for hauling.

Chute construction is similar to that at other mines in the district.

Auxiliary Operations

Electric power is not available at the mines in Emma Canyon. Compressed air is supplied by three 600-cubic-foot, diesel-powered compressors and delivered through 6-inch pipelines.

Explosives are stored in an isolated underground magazine. Daily requirements of explosives are issued from the magazine, and no explosives are stored in the mine.

Ventilation

Ventilation methods are similar to those used at the other underground mines.

Mine Drainage

Drainage is not a problem because the mines have virtually no water, and there are no workings below the adit level. Water for drilling is pumped into a 10,000-gallon-capacity storage tank at the mine from a well near the mouth of Emma Canyon.

Percentage of Extraction and Production Rates

It is estimated that approximately 80 percent of the rock in the A bed is recovered by sublevel-and-pillar stoping. No attempt has been made to mine the B bed or to extract pillars. The maximum monthly production from the mines is 15,000 tons.

Communications

The general offices of San Francisco Chemical Co. are at Montpelier, Idaho, approximately 60 miles from the mines. Automotive equipment used by company officials is equipped with short-wave two-way radios, so officials can communicate with their office personnel.

Wages and Bonuses

The mines are operated two shifts a day, but it is the management's policy to work but one shift in a working place. This eliminates dissension that might arise between crews working in the same place on different shifts.
FIGURE 15. - Plans and Longitudinal Sections, Emma and Tuscarora Mines.
(Courtesy, San Francisco Chemical Co.)
Advancing of development headings and mining are done under a plan whereby, in addition to wages, bonuses are paid on the basis of linear footage advanced in drifts, and volume of rock extracted from stopes.

CONSUMPTION OF SUPPLIES

Consumption of explosives ranges from 0.75 to 1 pound per ton, depending on the hardness of the rock. An average of 7 pounds of explosive per foot advance is required in the development headings.

The main use of timber is in constructing chutes and manways, the catwalks in stopes, and track ties. One board-foot of timber is consumed per ton of ore produced.

Data on consumption of drill steel and drill bits in each mine are not available, as these items are interchanged frequently between mines operated by the company in this district and in southwestern Wyoming and southeastern Idaho. Cross-shaped bits, from which 1 or 2 tungsten carbide inserts are broken when hard rock is drilled, can be used to drill the softer rock in the stopes.

A breakdown of the cost dollar for the underground mines operated by San Francisco Chemical Co. is given below:

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<td>Mill depreciation</td>
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