PREPRINT NO. 65AU323

SOCIETY OF MINING ENGINEERS
of AIME
345 EAST 47TH STREET, NEW YORK 17, N.Y.

CONCRETING AT THE SAN MANUEL MINE, SAN MANUEL, ARIZONA

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This paper is to be presented at the SME Fall Meeting - Rocky Mountain Minerals Conference, Phoenix, Arizona, October 7 to 9, 1965

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***Preprint Availability List* is published periodically in MINING ENGINEERING.**

SAN MANUEL PROSPECT

H. J. Steele and G. R. Rubly

This paper describes the exploration by churn drilling of the San Manuel disseminated copper deposit in Arizona. The discussion covers the generalized geology and mineralogy, tonnage and grade developed to date, and the drilling and sampling operations.

SAN MANUEL PROSPECT

LOCATION AND HISTORY

The San Manuel property is located in townships 8-south and 9-south, range 16-east, Gila and Salt River Base and Meridan, State of Arizona. This area is in the Old Hat mining district, southern Pinal County, and is about 3-1/2 miles southwest of the town of Mammoth on the San Pedro River and one mile south of the Mammoth Mine at Tiger, Arizona. The property consists of over 150 contiguous lode claims.

The Old Hat district was prospected prior to the Civil War, but there was little or no production until 1881[1]. The chief producers have been the Mammoth and Mohawk Mines, now consolidated and operating as the St. Anthony Mining Development Company, Ltd. Production to 1936 was $5,200,000, of which 83% was gold[2]. Since 1940 the production has been chiefly lead and zinc, and some molybdenum and vanadium. There are a few small properties in the vicinity that have produced very minor tonnages of copper ore.

In the San Manuel group there are claims, located in 1906, that have been held continuously to the present time, and at least two churn drill holes were put down on or near the outcrop in 1917. No logs for these holes are available, but it is assumed that the grade of copper encountered was not sufficient to encourage further exploration.

A small amount of ore has been shipped from open cuts on the San Manuel outcrop area, but there is no record of the tonnage or grade. It is estimated that not more than 50 tons were mined. These cuts, plus a few shallow shafts and some short adits indicate limited and unenthusiastic prospecting at San Manuel.

In 1942, through the efforts of James M. Douglas, R. B. Giffin, Victor Erickson, and Henry W. Nichols, owners of the San Manuel group, the Reconstruction Finance Corporation and War Production Board authorized the United States Geological Survey to investigate the property, and by their recommendation, the United States Bureau of Mines was authorized to put down a limited number of churn drill holes. The Bureau of Mines drilling carried on from November, 1943 to February, 1945. Seventeen holes were drilled, varying from 305 to 1990 ft. in depth.

The property was brought to the attention of Magma Copper Company in June, 1944, and an option agreement was made with the owners. Subsequently, a group of claims lying north of the original group and held by the Apex Lead Vanadium Mining Corporation, and a group to the east held by the Quarelli family, were optioned. A drilling program was laid out to conform to the Bureau of Mines pattern, and drilling started in December of 1944. San Manuel Copper Corporation was incorporated in September of 1945, and has carried on the exploration program to the present time.

GEOLOGY

General

The mineralized outcrop, chief copper mineral of which is chrysocolla, is a triangular area with a northeast-southwest base of 380 ft. and with the apex of the triangle 400 ft. to the southeast. Northwest of the base is Red Hill, so called because of the prominent gossan coloration. With a few exceptions, conglomerate and alluvium cover the rest of the property. The elevation varies from 2900 ft. to 3500 ft. above sea level. The area slopes gently to the east, with the exception of a small rugged and precipitous portion around the south side of Red Hill, and is cut by numerous dry washes with easterly courses toward the San Pedro River. The cover is sparse brush and cactii characteristic of this portion of the state.

Rocks

Relatively few rock types are found in surface exposures or are encountered in drilling. These formations were mapped by Dr. G. M. Schwartz of the United States Geological Survey, and the logging of all drill holes has conformed to his classification[3]. The rocks are quartz monzonite, monzonite porphyry, diabase, felsite, and felsite breccia, Gila conglomerate and recent alluvium.

The quartz monzonite found in the drilling area is granitic in texture, showing varying degrees of hydrothermal alteration. Quartz is abundant; the feldspars and biotite are extremely altered in most cases. Rutile is common, and the rock in general is sericitized and kaolinized.

The monzonite porphyry has a fine groundmass composed largely of a mosaic of quartz and feldspars. There is an abundance of biotite but less quartz than in the quartz monzonite. The feldspar phenocrysts are usually well altered, and the biotite is often bleached or chloritized. Secondary quartz flooding is fairly common, especially near the ore zone. A distinct phase of dark grey, fine-grained porphyry, containing an abundance of biotite in the form of phenocrysts recrystallized to aggregates of grains and much disseminated secondary hydrobiotite in the groundmass, is found in the hanging wall of the ore body to the south of the outcrop area.

Alteration products found in thin section in both the quartz monzonite and monzonite porphyry, as reported by G. M. Schwartz, include the following minerals: the hydromicas, allophane, epidote, leucoxene, montomorillonite, dickite, chlorite, potash clays, and calcite.

Diabase occurs as dikes cutting both the quartz monzonite and monzonite porphyry. The rock is well altered, grading from fine to coarse diabasic texture, and is mineralized with chalcopyrite and pyrite, or with chrysocolla and iron oxides in the oxidized zone.

The felsite, which is unmineralized and which cuts the diabase and the monzonites, is light grey to light cream in color, fine-grained, with occasional small quartz and feldspar phenocrysts in a finely crystalline groundmass.

The diabase occurs infrequently, and the felsite, while more abundant than diabase, is relatively unimportant in the overall rock distribution.

The Gila conglomerate consists of alluvial material interbedded with lava flows, breccias, and tuffs. The coarse conglomerate on San Manuel is composed of boulders of acid and basic volcanics cemented with clay. A phase of the Gila conglomerate, designated as granitic conglomerate and composed largely of fragments of relatively unaltered quartz monzonite, has been found in drilling to the southwest.

Structure

The structure at San Manuel, interpreted largely through drilling results, can only be generalized at the present time.

The Gila conglomerate, which covers the major part of San Manuel, strikes northwest and dips northeast at 20° to 45° . The San Manuel fault, striking northwest, more or less parallel to the strike of the conglomerate, and dipping southwest at 25° to 35°, forms the contact of the monzonite and the conglomerate. The San Manuel fault is in turn cut by two 60° to 75° northeast dipping faults striking northwest. The most westerly of these faults is designated as the west fault, and the most easterly as the east fault. (Fig. 1). This step faulting of the conglomerate is illustrated in Fig. 2, and has been substantiated by drilling to the northeast. Minor outcrops of hematite-stained, altered monzonite porphyry occur at intervals along the surface exposure of the most northeasterly segment of the San Manuel fault. Drilling northeast of these exposures indicates that the contact of the conglomerate with the old erosion surface dips northeasterly at 20° to 25°. The indicated vertical displacement of the west fault is in the neighborhood of 400 ft., and of the east fault, 200 ft. The east fault has been considered to be the southward extension of the Mammoth fault as mapped by Peterson[4] and others. A more complex fault system may be expected and is indicated by the drilling, but correlation of evidence of faulting is not possible from the churn drill results.

The outcrop area, as shown in plan in Fig. 1, is bounded on the southwest leg by the San Manuel fault and on the northeast leg by the west fault. The base, as indicated in cross section in Fig. 3, is controlled by decreasing copper mineralization, and is therefore, an assay boundary. A diabase dike, striking northeast and nearly coinciding with this cutoff of copper mineralization, was originally thought to be a diabase filled pre-Gila fault which abruptly cut off the northwestern extension of the ore body. Drilling northwest of this line has indicated a gradational decrease of copper mineralization in the projected ore zone rather than faulting.

The persistency of the San Manuel fault on both strike and dip is unusual, and it is difficult to visualize a low angle normal fault of this magnitude. The most feasable explanation, with the limited data at hand, can best be presented by this possible sequence of events:

1. Intrusion of the monzonite, and mineralization of the intrusive masses.
2. Oxidation and secondary enrichment.
3. Deposition of the Gila conglomerate. (Events 2 and 3 may be contemporaneous).
4. San Manuel fault formed, dipping 60° to 65° to the southwest.
5. Regional tilt of 25° to 35° to the northeast and development of the fault system, which strikes northwest, and dips to the east.

The San Manuel ore body has been described as a tabular mass, striking north 60° east, and dipping southeast at 50° to 60° ; and is shown this way in Figs. 2 and 3. It must be remembered, however, that this strike and dip is largely due to an assay boundary. Any arbitrary cutoff figure selected would change the attitude of the ore body. The strong pyritic mineralization below the outlined ore body has not been bottomed by any drilling to date. The upper portion of the hanging wall rock is very lightly mineralized; alteration and mineralization increases at depth until the zone of better copper mineralization is encountered.

Copper mineralization has been proved by drilling for 5000 ft. in the northeast-southwest direction, and 1400 ft. in the northwest-southeast direction. Pyritic mineralization is known for 2200 ft.

northwest of the ore zone.

Mineralogy

In the oxidized zone the chief ore mineral is chrysocolla; cuprite is present locally; malachite and azurite are rare. The chrysocolla is generally found in joints and fracture planes.

Chalcocite is the predominate copper mineral in the secondary zone. Residual primary chalcopyrite, occurring chiefly as intergrowths with the secondary minerals, and secondary chalcopyrite are found. Some native copper is found as well as minor amounts of bornite and covellite. There is very conclusive evidence of one or more stages of partial oxidation of the secondary zone in parts of the ore body. This may be due to variations of the water table and regional tilting.

Chalcopyrite and minor amounts of chalcocite are the chief copper minerals of the primary zone. The proportion of chalcopyrite to pyrite determines the footwall of the ore body. Slight oxidation is found relatively deep in the primary zone, and is thought to coincide with fault planes. The sulphide minerals are well disseminated throughout the monzonite, as well as occurring as veinlets. Chalcopyrite and chalcocite are frequently found as films on pyrite. Molybdenite is present in sufficient amount to be of economic importance, and can be seen megascopically in a large proportion of samples in the primary zone. Gold and silver are found in small quantities throughout the deposit, but sufficient work has not been done toward determination of the gold and silver content to state the average assay at this time. Rutile is fairly abundant throughout, and is thought to be present as an alteration product of biotite.

Polished sections of the concentrates, selected at intervals in the sulphide zone, are prepared and examined by G. M. Schwartz of the United States Geological Survey.

CHURN DRILLING

General

A grid co-ordinate system, bearing 29°-50' west of true north, controls the churn drilling pattern. The orientation was set by the Bureau of Mines, and was based on the strike of the apparent northwesterly limit of copper mineralization of the outcrop. The drilling done by the Bureau of Mines and the early drilling by San Manuel Copper Corporation was spaced rather widely over the area to establish probable continuity of the ore body and to determine the required spacing of holes for future drilling. When intermediate holes were drilled and the general attitude of the ore zone became apparent, the present drilling pattern evolved. This pattern is based on a 400-ft. interval in the direction of strike, which is from east to west on the drilling grid, and a 200-ft. interval in the north-south direction. All holes since the beginning of exploration have been controlled by the grid co-ordinate system. The few exceptions are due to rugged terrain making the correct location impractical.

The drilling grid is extended from permanent reference points by transit and tape traverse; elevations are carried to the collar of each hole by a line of levels from established reference points. Elevation datum is from the United States Coast and Geodetic Survey bench marks. The drilling grid is tied to the San Manuel co-ordinate system, which is based on a true north meridian. Holes are spudded in as near the intersection of grid co-ordinate lines as practical, and the error in hole location is rarely more than one foot in either direction.

Statistics

At the present time 67 holes have been completed, and 11 are in progress for a total of 110,854 ft. of drilling since exploration of the property began. The Bureau of Mines drilled 15,824 ft., and San Manuel Copper Corporation has drilled 95,030 ft. The deepest hole drilled to date has been 2600 ft. All drilling is done on contract, with the contractor furnishing all equipment and tools.

The average drilling conditions at San Manuel are illustrated by the following tabulation of statistics for a three-month period. Drilling shifts refer to time actually spent in drilling; total shifts worked refer to drilling shifts plus the time spent moving and setting up on new locations, repairs, fishing, and miscellaneous lost time:

	Average	Best Drill	Poorest Drill
Elapsed Time	91 days	91 days	91 days
No. of Drills Operating	6	1	1
Total Footage Drilled	13296 ft.	3439 ft.	71 ft.
Drilling Shifts	698.6	116.5	13.8
Advance per Drilling Shift	19.0 ft.	29.5 ft.	5.1 ft.
Total Shifts Worked	825	133.8	23.7
Advance per Shift Worked	16.2 ft.	25.7 ft.	3.0 ft.

The average time required to move to a new location was 4.6 shifts. This includes pulling casing from the completed hole, moving, and rigging up preparatory to spudding in.

Equipment

The selection of churn drills for exploring this property was based on the record of accurate tonnage and grade estimates computed from data obtained by churn drilling at other well-known disseminated copper deposits. Exploration by diamond drill was rejected because of probable low core recovery if the formations proved to be highly fractured.

Several types of churn drills are operating on the property; Bucyrus-Erie machines being in predominance. Models 24-W, 24-L, 29-W, 29-T, and 36-L, with drilling capacities ranging from 1500 ft. to 3600 ft. are represented. These are all-steel machines, very compactly built, and ideal for working in rough terrain. The space required for a set up is comparatively small, and the machines can be handled over fairly steep grades. There are four Ft. Worth Spudders in operation: Models Super D, F, Jumbo H, and Super J; having drilling capacities ranging from 2500 ft. to 5000 ft. These are larger machines of wood construction, and require considerably more room for a set up, as the engine is usually set back of the rig some 20 to 30 ft. Power transmission is by flat belt drive. They are more awkward to move, and take longer to set up and tear down than the Bucyrus-Erie machines.

The drilling contractors, operating under similar contracts, hire all help required to run the rigs. A crew usually consists of a driller, a tool dresser, and welder. Since all bits are built up by electric welding, the tool dresser is more of a general helper than his name implies. Some contractors work on a three 8-hr. shift basis; others on two 12-hr. shifts. All drills are now operating 24-hr. per day, and 7 days a week.

DRILLING

As the early drilling was comparatively shallow, holes 8-in.

in diameter were started, reduction to 6 and 4-in. holes then being possible. When it became evident that deeper drilling would be required, with the possibility of having to case and reduce size of hole several times before reaching bottom, the starting hole was increased to 10-in. and finally to 12-in. diameter. This permits running 10-in. casing followed by 8-in., 6-in., and 4-in. casing when necessary.

There has been considerable discussion regarding the advisability of starting holes with 12-in. bits. It was thought that the larger diameter hole and the greater shock produced by heavier tools would increase caving in fractured ground. The drill contractors preferred the 8-in. bit because a larger bit would probably slow the drilling speed in the upper portion of the hole, where contract prices per foot are relatively low. It has been our experience, however, that the larger sized hole does not decrease speed of drilling greatly, and that caving would be encountered at about the same place in the hole regardless of size of bit used. The larger hole gives one better assurance of being able to drill to the depth required. The 12-in. hole is never carried to more than 1200 ft., and casing is usually required before this depth is reached. The 10-in. hole is carried to 1500 or 1600 ft. if possible, allowing the hole to be completed with either an 8-in. or 6-in. bit. The deepest hole, which was 2600 ft., was finished with a 4-in. bit after having set a 400 ft. liner of 4 in. pipe at 2400 ft. Some of the ground seems to stand well, as three holes, the deepest of which was 2200 ft., have been drilled without the use of any casing.

Drill locations and access roads are constructed to meet the requirements of the type of machine that will occupy the site. The

Bucyrus-Erie machines dump the sludge on the left side, facing the machine, while the Ft. Worths dump on the right side; thus necessitating a different type of location. All roads and locations have been made by bulldozer and scarifier, on contract; no drilling and blasting have been required.

Fishing for lost tools is taken care of by the contractors, with the exception of some long difficult jobs below 1000 ft., in which case the company has assumed part of the burden of cost. This situation has not come up often.

Unless casing is ordered by the field engineer to shut off possible caving and the resultant contamination of samples, especially in or near the ore zone, its use is usually left to the discretion of the contractors. The contractor is required to make every effort to recover all of the casing, but there are times when several joints have to be cut off the bottom in order to salvage any. This is accomplished by setting off a bomb, fired electrically at a coupling near the bottom, or by using a "collar buster"; a device lowered on the string of tools to a predetermined depth, which punctures and slits the pipe until a collar is reached and cut. The bombs are not too satisfactory because they tend to swell the casing in one or more places, making withdrawal of the pipe difficult.

The use of any drilling muds or Aquajell is, in general, prohibited. The exceptions to this rule are to permit the use of Aquajell, plastered on casing couplings when being run into the hole to make later withdrawal easier, and during fishing operations in caving ground. In crooked holes it is occasionally necessary to drop surface rocks in the hole and redrill in order to straighten it. In any of these operations the driller is required to thoroughly clean the hole before sampling operations are resumed.

In order to accurately establish the depth from which samples are coming, the holes are measured frequently with a special measuring device consisting of a reel of 3/32 in. galvanized aircord marked with lead buttons every 10 ft. The 100 ft. marks are identified by a code of elongated buttons. The measuring cable was calibrated by attaching a 7-lb. lead weight to the zero end; lowering it down a vertical shaft; and marking off the units on surface. When measuring, a very definite jerk is felt when the weight is pulled off the bottom of the hole.

Frequency of measurement varies. Holes are measured when they near the contact of the conglomerate and monzonite, so this point can be closely determined. After that, measurements are made at about 200 ft. intervals, and again when the hole is completed.

SAMPLING

Equipment

Sampling equipment consists of a dump box, a 6-ft. launder, a sample splitter, and 5-gal. milk cans to catch the samples.

The dump boxes are built of 2 in. by 12 in. plank, lined with 1/4 in. steel plate welded at the joints. The boxes are 12 in. wide, 36 in. long, and 24 in. high--inside dimensions. The launder is constructed of 1/8 in. steel plate, and designed to fit securely, with a 3-in. overlap between the steel lining and wood exterior, at the open end of the dump box. The discharge end of the launder lies on the upper edge of the splitter unit. The slope of the launder is adjusted to insure an even flow of sludge to the splitter, which is a modification of the Ray Consolidated Company splitter[5]. It is, essentially, 3 or more Jones splitters arranged in series to facilitate gravity flow of the sludge through the successive individual units. The upper two tiers of slots of a four cut splitter are 1-1/4 in. wide, and the lower two tiers are 3/4 in. wide; the slots being staggered by 1/2. The sample portion of the sludge passes straight down and is discharged at the front. The rejects gather underneath and are discharged at the side.

Personnel

It is desirable to have as samplers young engineers or geologists. This type of help has not been available, so it has been necessary to employ less skilled men, which in turn has meant special training and supervision for the sampling crew. Every detail of catching, preparing, washing character samples, and panning for concentrates had to be taught in most cases. Sampling is supervised by shift bosses and engineers who visit the rigs periodically during sampling operations.

Technique

The churn drill holes are sampled at 5-ft. intervals, from the contact of the conglomerate and the monzonite, to the bottom of the hole. Character samples are taken at 20-ft. intervals in the conglomerate.

The sludge is dumped from the bailer into the dump box, and flows through the splitter. The driller is cautioned to ease the bailer into the box to avoid surge and splash. The sample portion is caught in a 5-gal. milk can and a bucket of rejects is caught; a portion of which is washed free of slimes and saved as a character sample. A uniform volume of rejects from each 5-ft. interval is panned to obtain a concentrate which is dried and sacked. An engineer examines both the character sample and concentrate to determine, megascopically, the rock type, alteration, kind, and relative amounts of mineralization. The character samples are filed for future reference, and the concentrate is sent to G. M. Schwartz of the United States Geological Survey for selected samples to be polished and examined by microscopic methods.

The sampler fills out a "Churn Drill Report", noting the depths at which the samples are caught, color of sludge, condition of hole, depth at which water was encountered, fault zones as evidenced by gouge, and any other pertinent data relative to the hole. The spaces for rock type and mineralization are filled in by the engineer who examines the character and concentrate samples.

The size to which the sample is cut depends largely on the size of hole being drilled, and if drilling is under water. A 12-1/2 in. hole may require a cut to 1/256 of the total volume of sludge bailed, and a 4 in. hole is cut to 1/8 or 1/4 of the original volume of sludge. The sample is cut so there is a minimum of about 15 lbs. of dry solids.

Drillers are required to bail holes clean. This is relatively simple above the water table, and takes about 3 or 4 trips into the hole. However, after the holes are under water, it is never possible to get a really clean hole, as there is always a certain amount of slimes in suspension. In this case, a few tests are made to determine how many bailings are required to pick up the largest part of the sample, and leave the hole relatively clean for the next run. On numerous occasions it has been possible to obtain samples of the slimes in suspension by carefully bailing a hole after it had been shut down for periods of 24 to 48 hrs. Assays of this material have agreed very closely with the assay of the last run made, so that no serious errors are introduced by leaving this material in the hole.

No attempt is made to shut the water off by casing.

Drying & Preparing Pulps

The samples caught in milk cans are gathered up, usually at the end of the shift, and hauled to a centrally located drying room. They are dried on a series of 9 heavy steel drying tables, each about 3 ft. square. Steam, which is generated to 20 lbs. gauge pressure in a manually-operated vertical fire tube boiler, using diesel oil for fuel, supplies the heat for the drying tables.

Other drying room equipment consists of a Jones dry splitter, 2 Braun type UA pulverizers, small platform scales, and a table for rolling pulps.

The operating personnel of the drying room consists of a foreman on day shift, with three dryers and grinders; and lead men on afternoon and graveyard shifts, with 2 or 3 helpers. The drying room operates 24 hrs. per day for 7 days a week.

As samples are brought in from the rigs, they are lined up in sequence and dried on the steam plates. Since there is such a large amount of sludge to be dried, the time of drying is more than an hour per sample, and may extend to 3 hrs. for exceptionally heavy, slimy samples. After drying, the sample is scraped off the table into a large pan and quarted by means of a Jones splitter. Three of these cuts are put in paper sacks; the fourth being set aside for pulverizing. Each of these cuts will weigh from 2-1/2 to 3 lbs. Paper tags are used, designating the sample number by hole as well as by footage. The cut which is pulverized and then thoroughly rolled, is divided between five different pulp sacks holding from 150 to 200 gms. each. One of these pulps is sent to the assay office of the St. Anthony Mining and Development Company for field control.

The other four are sent to the Magma Copper Company in Superior where one pulp is assayed directly for total and oxide copper; two are used in making up composites for total copper, oxide copper, gold, silver and molybdenum determinations. The fourth pulp is held in reserve.

Two of the three sacks of rejects are stored in tunnels at San Manuel, and one is stored at Superior. These are held in reserve for possible future examinations, or for further assay.

Records of the holes, listing each individual sample number, depth of footage, date of sample, weight of cut, number of splits made to obtain this cut, and the name of the sampler are kept in the bucking room. These records are all filed.

ASSAYING

The pulp sent to the St. Anthony Mining and Development Company is assayed for total and oxide copper. The method of assay used is a modified procedure of the short iodide method, wherein the end point of the starch-iodine blue was made much sharper, and gives results close enough for field control.

At the Magma Copper Company the total copper content is determined by standard electrolytic methods; oxide copper is determined by the long iodide method. Results of these assays check very closely with those of Ledoux & Company and Union Assay Office.

Gold, silver and molybdenum are determined from composites. These composites are made up of pulps representing portions of the hole of the same general mineralization or assay character, but do not usually exceed 100 ft. of hole.

If the average of individual assays of total copper checks within 0.03 percent with the total copper determination of the composite by Magma Copper Company and an umpire assayer, those values are accepted as being correct.

In the office at Superior, records of each hole are compiled showing all determinations made on individual and composite samples, the accepted assay, rock type, and mineralogy.

TONNAGE & GRADE

Churn drilling to May 1st has blocked out approximately 119,170,000 tons of ore, which will average 0.80 percent copper. This total contains 14,600,000 tons of low grade oxidized material which averages 0.65 percent total copper, 0.36 percent oxide; 29,640,000 tons of mixed oxidized and sulphide ore which averages 0.82 percent total copper, and 0.58 percent oxide copper; and 74,930,000 tons of sulphide ore which averages 0.82 percent total copper, and 0.05 percent oxide copper.

These tonnage and grade figures are of a preliminary nature, and are kept up to date with the drilling as closely as the required checking of assays allows.

The following procedure is used to compute the tonnage and grade:

The drilling area is divided into rectangles and triangles as the spacing of drill holes demand, with a drill hole at each corner of the rectangles, and at the apices of each triangle. Care is taken to arrange the pattern of geometric figures so that one drill hole is not a common corner for more figures than necessary. The area, calculated from the horizontal distance between holes, is multiplied by the average of the thickness of the columns of ore encountered in the holes making up the corners of the figures.

Twelve and one-half cu. ft. per ton is the factor used to convert the volume to tonnage. The grade for each block is the weighted average of the ore columns of the holes used.

The bottom sample, or in some case, more than one sample is thrown out as a precaution against salting of marginal material by higher grade samples above. The cut back at the bottom of an ore column depends on the condition of the hole, grade of ore, and whether there is a gradational change in copper content at the bottom of the column, or a sharp break. The tonnage is calculated from drill hole data with no allowances for an extension of the ore body beyond the boundaries of completed holes. This eliminates the necessity for constant revision of such an estimated extension of ore, due to the continually changing drilling pattern.

At intervals tonnage and grade calculations are computed by two other methods as checks. In the second method, the average area of adjacent cross sections is multiplied by the distance between the sections to compute the volume. The grade is computed from the weighted average of the ore columns of holes in the two sections. The ore columns are adjusted as in the first method.

The third method involves plotting the area of influence of each hole, and using the adjusted ore column for thickness, to compute a tonnage and grade figure for each area.

ACKNOWLEDGEMENT

Acknowledgement is due the officers of San Manuel Copper Corporation for permission to use the information presented.

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