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Techniques of Underground Sampling and Calculation of Ore Reserves

James E. Cleveland

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TECHNIQUES OF UNDERGROUND SAMPLING
AND
CALCULATION OF ORE RESERVES

A Thesis
Presented to
Koehler S. Stout
Assistant Professor of Mining
Montana School of Mines

In Partial Fulfillment
of the Requirements for the Degree
Bachelor of Science in Mining Engineering

by
James E. Cleveland
May 10, 1957
Butte, Montana
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AND
CALCULATION OF ORE RESERVES

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May 10, 1957
Butte, Montana
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Mr. Koehler S. Stout
Assistant Professor of Mining
Mining Department
Montana School of Mines
Butte, Montana

Dear Mr. Stout:

In compliance with your request in February, 1957, I submit the following report on the techniques of underground sampling and the calculation of ore reserves.

The following report is partly based on library research and partly on my own experience with the Anaconda Company as a sampler.

Very truly yours,

JAMES E. CLEVELAND
<table>
<thead>
<tr>
<th>PART</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. EXPLORATION AND DEVELOPMENT</td>
<td>2</td>
</tr>
<tr>
<td>New tools in ore search</td>
<td>2</td>
</tr>
<tr>
<td>Drilling techniques and sampling</td>
<td>4</td>
</tr>
<tr>
<td>Churn drilling</td>
<td>5</td>
</tr>
<tr>
<td>Core drilling</td>
<td>11</td>
</tr>
<tr>
<td>Hammer drilling</td>
<td>13</td>
</tr>
<tr>
<td>II. TECHNIQUES OF UNDERGROUND SAMPLING</td>
<td>20</td>
</tr>
<tr>
<td>Methods of sampling</td>
<td>21</td>
</tr>
<tr>
<td>Channel sampling</td>
<td>21</td>
</tr>
<tr>
<td>Chip sampling</td>
<td>23</td>
</tr>
<tr>
<td>Drill samples</td>
<td>24</td>
</tr>
<tr>
<td>Grab sampling</td>
<td>25</td>
</tr>
<tr>
<td>Sample Evaluation and Recording</td>
<td>26</td>
</tr>
<tr>
<td>Averaging assays</td>
<td>26</td>
</tr>
<tr>
<td>Sample recording</td>
<td>32</td>
</tr>
<tr>
<td>III. MINE GRADE AND ORE RESERVE CALCULATIONS</td>
<td>36</td>
</tr>
<tr>
<td>Calculation of mine grade</td>
<td>36</td>
</tr>
<tr>
<td>Calculation of ore reserves</td>
<td>38</td>
</tr>
</tbody>
</table>
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>DESCRIPTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Spring-pole Drill</td>
<td>7</td>
</tr>
<tr>
<td>2.</td>
<td>Sample Cutters Used on Churn Drills</td>
<td>7</td>
</tr>
<tr>
<td>3.</td>
<td>Form Used to Determine Activities on Churn Drill</td>
<td>10</td>
</tr>
<tr>
<td>4.</td>
<td>Sample Collector</td>
<td>17</td>
</tr>
<tr>
<td>5.</td>
<td>Methods of Catching Deep-hole Sludge</td>
<td>19</td>
</tr>
<tr>
<td>6.</td>
<td>Method of Calculating Average Assay</td>
<td>29</td>
</tr>
<tr>
<td>7.</td>
<td>Sample Cards</td>
<td>34</td>
</tr>
</tbody>
</table>
INTRODUCTION

Webster defines a sample as "a part of anything presented for inspection, or shown as evidence of the quality of the whole." Sampling is defined as "the act, process or technique of selecting a suitable sample, as for chemical analysis or psychological examination."

In the mining industries, samples and the technique of sampling play an important role in the life and production of a mine. From the initial prospect to the final pound of ore produced, the production depends on the grade of ore coupled with a mining system that will realize a profit, the one thing a mine cannot survive without.

Not only the grade of the ore, but also the width plays an important part in the profit of a mine. Here we can differentiate between two types of ore, that is, "minable" ore and geological ore. "Minable" ore can be extracted from its place in the earth at a profit while geological ore is of high enough grade to be determined ore but is too narrow to mine with the present system of mining. However, with the development of new methods of mining and new markets, the present geological ore may become "minable" ore.

The sample is also vital to the mining geologist. With the use of a sample and the generalized structure, the geologist may be able to forecast the results of future exploration and development.
PART I
EXPLORATION AND DEVELOPMENT

The days of the picturesque prospector with the gold pan and the donkey are rapidly drawing to a close. The easy to find outcropping mineral deposits are no longer existent in the areas of easy accessibility. With the increased demand for minerals and products during and after World War II, new techniques and ore search had to be developed to meet these demands. The mineral industry started on new types of prospecting about 1940 and has made great strides in development. The method used before 1940 might be termed primitive. Probably the incentive to search for new ore deposits to meet the expanding markets for mineral products will surely bring forth better techniques of ore search. When the potential rewards are great enough, the new techniques will surely be forthcoming. This has been very graphically illustrated on the Colorado Plateau where the search for uranium has come into major focus.

NEW TOOLS IN ORE SEARCH

One of the newest tools of ore search is the use of geophysics. Many techniques of geophysical prospecting has been used by the petroleum industry for the past number of years. However, the occurrence of ore deposits until recent developments could not be detected with geophysical techniques. The petroleum industry searches for broad general structure where oil might be trapped. The mining geologist has to deal
with structures that are much smaller and in many cases do not differ greatly from the surrounding country rock.

Since the discovery of uranium on the Colorado Plateau, great strides have been made with the use of radiometric methods of exploration. The development of hand-portable Geiger counters, gamma ray logging meters, and carbone equipment has been a great advance in the search for radioactive minerals. The portability of these instruments plus the modes of modern travel have greatly increased the potentiality of the modern prospector and geologist in the discovery of mineral deposits.

Outside the radiometric method, geochemical prospecting has become one of the major tools in prospecting for the base metals used in our economy. Geochemical prospecting has been used with a great degree of success in finding and pinpointing ore deposits. Geochemical prospecting is basically the determination of the quantity of trace elements in soil, water, and vegetation to determine a place where ore deposits might be concentrated. Geochemical prospecting might be a scientific application of the age-old principle of tracing float and can be used with the same principles. Very delicate techniques have been developed to detect the quantity of trace elements present in streams, underground water, soils and vegetation. However, here one must be careful to collect his samples in the same manner so that foreign elements will not interfere with the process and false conclusions will not be drawn.
With the development of new methods of prospecting, we cannot forget the basic principles of general geology. By the principles of general geology, it is meant the old established techniques of routine mapping, sampling, studies of structure, mineralogy, petrography, and geologic reasoning and deduction coupled with new methods of ore search, can be utilized to the maximum in the search for ore deposits.

With the development of the air age, the industry has been slow to realize the potentiality of the airplane and the helicopter in the use for ore search. Aerial photography has become increasingly popular in the past few years and with the development of color photography, it has become important in identification of structure and alterations. The use of the helicopter has become important to transport the modern prospector and his equipment to places where prospecting would have been long and tedious, if not impossible.

DRILLING TECHNIQUES AND SAMPLING

Drilling has long been recognized as one of the major tools of ore search and determination of the limits of the ore body. New techniques of drilling and more portable equipment have made the drill an even more versatile tool in ore search and development. Churn drills, core drills, hammer drills and very recently the rotary type drill have been used for quickly determining samples from formations and mineralized zones with a high degree of success. We may classify drilling, as far as the mining industry is concerned, into two classes; namely, (1) drilling to
obtain the geologic structure, and (2) drilling to determine the grade of the ore body.

Drill samples, if taken with a little precaution and care, can be relied upon to determine the grade of a large deposit where the mineralization is regular and uniform, such as the horsetail area in Butte, the iron ranges in Minnesota and the disseminated lead-zinc deposits in the tri-state district. However, in smaller vein deposits and spotty, erratic deposits, drill samples cannot be used to determine the grade of ore but only to determine the limits of mineralization and the structure of the area to be explored.

Churn Drilling

Churn drilling cannot be used to determine structure. The only reason a prospective ore body is churn drilled is to determine the metal content and whether or not an ore body is large enough to warrant investment on the basis of a profitable mining enterprise. Churn drilling has a wide application in the exploration of mineral deposits but is limited to verticle holes.

Churn drills may be of three types which are (1) jump drills, (2) spring pole drills, and (3) power drills. Jump drills are simply a long piece of steel or pipe fitted on one end with a chisel bit. The tools are simply raised and dropped by two or more men. The tools are slightly rotated each time. The jump drill is limited to shallow holes in soft or unconsolidated rock.
The spring pole drill is the next step of churn drilling and is used in remote areas by prospectors for shallow exploration work. When the rock is soft but not fissured, two or three men can drill up to 300 ft. However, with bad or fissured rock, only approximately 150 ft can be drilled. The drill simply consists of a string of pipe with a chisel bit suspended from a spring pole by means of a cable. Drilling is accomplished by simply springing the pole up and down (Figure 1). After two or three feet are drilled, the tools are raised by means of the windlass and the sludge is pumped out with a sand pump. The prospector must determine before the type of drilling is done which would be easier or cheapest, drilling or test pitting. If large quantities of water are present, then drilling would be the easiest and probably the cheapest. However, if no water is present, then test pitting would probably be the best.

Portable churn drills are the most popular in the mining industry and in the last decade have been used extensively for sampling ore bodies. The churn drill works basically on the same principle as the standard oil well cable tool except the churn drill is usually mounted on a portable frame and the mast is attached to the frame instead of separate; the rigs are smaller and are not designed for the heavy work or deep holes as the cable tools.

It must be remembered at all times the basic reason for drilling is to procure an accurate sample from the rock
Figure 1  Spring-pole drill  (After Jackson and Kanebel)  
(U.S.E.M. Bulletin 356)

Figure 2  Sample cutters used on churn drills
below. Therefore, the speed and cost of drilling are secondary to the importance of sampling. For this reason, a sampler should be placed on all rigs and have the authority to see that the hole is being drilled properly, and the samples are being properly taken. If at any time the sampler feels the driller is not drilling the hole properly, he must have the authority to shut down operations and call the geologist and drill foreman.

The sampler must at all times exercise precautions against any factors that may cause any inaccurate samples which would lead to erroneous results. The basic factors to watch against sample salting are (1) caving of hole, (2) loss of water through cracks and fissures, (3) settlement of heavy minerals to the bottom, (4) portions of the gangue and ore minerals dissolved in the drilling water, and (5) breaking off of pieces of rock above the sample by action of the tools and bailer. These factors should be immediately corrected when discovered by the sampler, and he should have the power to see that they are corrected.

Caving of the hole and salting of the sample by the tools can be kept to a minimum by keeping the casing as close to the bottom of the hole as possible. However, here we must consider the economics of what we are after and the results desired. If the ground is solid and the mineralization fairly uniform, the amount of caving and salting would be negligible. Loss of part of the sample through cracks and settlement of the heavy minerals can be kept at a minimum
by keeping the sludge as thick as possible; however, when the hole is "making" a large quantity of water, this would be impossible. Concreting the hole and then drilling through the concrete can be used to prevent this, however, it may prove expensive and the economics of what you are after must be considered.

Sampling techniques are basically the same on all rigs. The whole sample is very seldom kept, but is split into two or more samples rejecting the major portion of the sample. Figure 2 shows the different types of splitters used for churn drill sludge. The selection of the type of splitter would depend on the judgment and personal preference of the geologist. All three types of splitters shown in Figure have been used in different areas with very good success. In many cases, the geologist may know enough about the structure to determine where the sampling should start. From this point, it is the sampler's duty to follow the sampling procedure as determined by the geologist in charge of the operation. Also, it is a good idea for the geologist to print a small booklet on rules and regulations of the sampling procedure. This will eliminate any minor points that may arise between the sampler and the driller.

The sampler should be furnished with a form to record the activities on the drill and the formations encountered in the drilling process (Figure 3). Also, a drill log should be kept by the sampler. For each sample, the sampler
<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Formation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:00-8:30</td>
<td>Good burnt sig.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:30-8:45</td>
<td>Drilling 100-115</td>
<td></td>
<td>Ground fairly soft.</td>
</tr>
<tr>
<td>8:45-8:55</td>
<td>Bore hole</td>
<td>Quartzite</td>
<td>No ore minerals.</td>
</tr>
<tr>
<td>8:55-9:15</td>
<td>Dress bit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9:30-9:40</td>
<td>Bore hole</td>
<td></td>
<td>Drilling Fault.</td>
</tr>
<tr>
<td>9:40-10:00</td>
<td>Drilling 110-115</td>
<td></td>
<td>Drilling Poor</td>
</tr>
<tr>
<td>10:00-10:30</td>
<td>Bore hole</td>
<td>Fault structure on Quartzite</td>
<td>Slight amount of Sulphides CO_3, Fe_5</td>
</tr>
<tr>
<td>10:30-10:30</td>
<td>Drilling 115-120</td>
<td></td>
<td>Drilling Poor</td>
</tr>
<tr>
<td>10:30-12:00</td>
<td>Bore hole &amp; Casing hole</td>
<td>Fault structure on Quartzite</td>
<td>117' Casing</td>
</tr>
<tr>
<td>12:00-12:30</td>
<td>Drilling 120-130</td>
<td></td>
<td>Drilling Adir</td>
</tr>
<tr>
<td>12:30-12:45</td>
<td>Bore hole</td>
<td>Felsmite, with ore minerals</td>
<td>CO_3, Fe_5, ZnS, (Fe_3, Fe_2)</td>
</tr>
</tbody>
</table>

**Figure 3** Form used to determine activities on churn drill
should catch part of the reject in a small pan. The mud can be panned off of the sample and the larger particles are then dried and glued to the log. Assays can then be posted alongside the sample. With this, the geologist can tell almost at a glance where ore is encountered and in what formation it is localized.

Core Drills

Before the advent of the highly portable churn drills and the efficient lightweight hammer drills, core drilling or rotary type drilling was used very extensively in the United States for sampling ore bodies and the determination of their limits. There have been many types of core drills used in this country which include shot drilling, calyx drilling, diamond drilling and very recently the rotary drill adopted from the oil fields. The core drill consists of a circular cutting edge that cuts a circular groove leaving the center a solid core, which is allowed to pass through the bit into the core barrel. The core is then extracted from the hole. The core is very valuable for geological data and is an excellent sample of the material being drilled. It is theoretically a true-channel sample where the core recovery is 100 per cent. When the ground is irregular in hardness, brecciated or fractured, or very soft altered material, core recovery is extremely difficult and in many cases impossible. In this case, the sludge should be caught and treated in much the same manner as churn drill sludge.
Where very accurate samples are desired, the ground may be grouted and the hole then redrilled. This will give very good core recovery but is a slow and expensive process. However, here one must consider what is wanted from the sample and what the samples are worth.

In the past years, diamond drilling has been used almost exclusively because the other methods were slower and more expensive. However, in the past few years, the development of the portable rotary oil rig has been used with a high degree of success. Diamond drilling still remains the most popular because it will cut the hardest rocks and it can be used to cut any angle from horizontal to vertical.

When core recovery is low, it may become necessary to use the sludge as a sample. Most authors recommend, in all cases, that the sludge be assayed as a check against the core sample. Mathematical methods have been designed to combine the sludge and core to give a complete sample of the hole drilled. This is generally done on a volume for volume or a weight for weight basis.

When the core recovery is not complete and the sludge must be used to calculate the grade of the cutting, the percent recovery of the core must be found in order that the correct weight can be given to both parts. A convenient way for finding the percent of the core recovered is expressed in the following formula:

\[
\% \text{ core recovery} = \frac{\text{wt. core} \times 100}{\text{Length of run} \times \pi (\text{diam}/2)^2 \times \text{Sp. gr.} \times 62.5}
\]
Here the sampler and the geologist must see that the specific gravity does not differ very greatly in a single run and if it does, it should be corrected to give an accurate percentage of core recovery. Sludge recovery can be determined by weighing the dried sludge and setting up the same ratio against the theoretical value. If the combined percentages of the sample are over 100 per cent, this means the hole is caving and the hole should be cased. If the combined samples are less than 100 per cent, then some of the sludge is being lost in vugs and open fissures in the rocks being drilled. This can be corrected by either casing the hole and keeping the casing as close to the bottom of the hole as possible or cementing the hole and then drilling through the concrete. If the purpose of drilling is not to determine the grade but to determine whether further exploration by underground method is warranted, then the factor can be corrected if the loss or gain is not too great. However, in all cases, we must keep in mind that the sludge is never free from contamination; a high degree of contamination will give a poor sample and no amount of mathematical computation can make a poor sample a good one.

**Hammer Drills**

In the past few years, hammer drills have been used with a high degree of success in localized prospecting and production. We shall deal here only with prospecting; production phase will be discussed later in the paper. The development of the air leg and the tungsten-carbide
bits has been the main factor in the use of hammer drills for prospecting. The portability and the low investment cost make the hammer drill an extremely valuable machine for exploration. In the present day, there is no operation outside of the smallest prospect without a hammer drill of some sort.

Hammer drills are used where it is impractical to set up a diamond drill, or ground conditions are such that core recovery would be impossible. Ranges of the hammer drill vary depending on the ground drilled and the geological structure that has to be passed through. In Butte, the range varies up to 125 ft in the hard quartz-monzonite country rock. However, in other places, up and over 250 ft have been reached with large lyners. With the use of tungsten-carbide bits and sectional steel, the bit does not have to be changed and as a result, no time is lost in pulling steel. In 1956 experiments were run at the Lexington and Anselmo Mines with a 4 in. lynер and a jackhammer mounted on an air leg, and in both cases maximum ranges were about 150 ft. The lyner used a 2 1/2 in. tungsten-carbide bit and the air leg used a 1 1/8 in. tungsten-carbide bit. In both cases, samples were taken every five feet in the country rock and every two and a half feet in fault structure or vein structure. Both gave very good results and checked fairly well with chip samples when the structure was explored by crosscuts and drifts. In the Butte district, stopes, air legs, and jumbo-mounted lyners are used
to explore walls of drifts, raises, and stopes whenever management deems it necessary. In many cases, this will eliminate expensive blasting of waste and often additional timber and rock bolts. Wagon drills have also been used quite extensively for shallow exploration. The development of the light portable wagon drill and compressor has made the wagon drill a very useful tool for prospecting. A mineral deposit may be fully explored by a few holes, thus eliminating more expensive trenching and pitting.

Collecting the sample is probably the most important part of the drilling operation. If the hole is worth drilling at all, it is worth sampling properly. In nine times out of ten, poor sample returns may be traced directly to poor sampling techniques at the collar of the hole. However, in some cases, poor samples may result from the type of ore and ground being drilled. These cannot be corrected and in many cases would make the hammer drill unsatisfactory for sampling. When the errors can be traced directly back to the techniques of sampling at the collar, then steps should be taken to correct them. To get the best sample from a hole, there are two things that must be followed stringently. They are (1) all of the material broken by the bit must be removed from the hole, and (2) all the material removed from the hole must be collected for the sample. This does not present too serious a problem when the hole is horizontal or less than 45° above the horizontal. When the hole is above 45°, then collection of the sample
becomes a serious problem since the drillings tend to run
down the drill steel and are lost. Many setups have been
tried to eliminate this, however, no method to the present
date has been satisfactory for preventing it. When the hole
is drilled below the horizontal or vertically downward, then
the major difficulty is cleaning all of the sludge out of the
hole. Water will not do this alone unless it is under very
high pressure. A combination of air and water has been used
with good results for cleaning the hole. The sample can then
be collected by extending the collar casing above the hole
and having a collecting ring around the pipe to collect the
sample. Air alone has been used to collect the sample, how-
ever, when underground water is encountered, it would be
impossible to collect the sludge in this manner.

The U.S. Bureau of Mines has developed a sample-collecting
machine utilizing a suction type blower to lift the cuttings
out of the hole (Figure 4). This apparatus was fairly
successful to a depth of about 66 ft. When depth is required
for exploration drilling, then it would be more logical to go
to core or churn drilling.

Drilling horizontally or at an angle up to 45° above
the horizontal does not present too much of a problem for
collection of the sample providing the proper precautions
are made. Dry drilling, which may not only be injurious to
the men working around the drill, creates a serious error
in dust loss. Several methods have been devised to correct
this but up to date very little success has been made. Wet drilling is the simplest way to collect the sample provided proper settling facilities are available so that no fines are floated off. In Butte operations, a 55 gal barrel was cut in half and used to catch the sample. With fairly good drilling, the barrel would very seldom overflow. However, when ground was extremely hard, two barrels had to be used. Two men can transfer the barrels very easily so that very little of the sample is lost. The barrels are marked with chalk and set to one side. After the water was clear, it was siphoned off and the sample was cleaned out of the barrels and put into one gallon ice cream cartons. The U. S. Bureau of Mines also developed a system of collecting the sample which proved very successful (Figure 5). It consists simply of a series of carbide cans at different levels, which are baffled to help the settling. Another problem is to keep the sludge running into the collecting apparatus and not down the wall to the bottom of the working. One method, as illustrated in Figure 5, is to collar the hole in the line wanted. After the hole has been drilled about two feet, then a smaller hole is drilled up to intersect the drill hole. The drain hole is then fitted with a pipe cut in the shape of a spout. This gave very good results with the experiment conducted by the U. S. Bureau of Mines and the Anaconda Company.
Figure 5 Method of catching deep-hole sludge
(After Knaebel, U.S.B.M. I.C. 6594)
PART II

TECHNIQUES OF UNDERGROUND SAMPLING

The production and development of a mine depend on the grade of the ore and where it is located. The modern manager must watch this grade in order to stay in business. Most modern smelters demand the grade be kept at a constant value and even if a mill is owned by the mining company, the grade must be kept fairly constant in order to keep mill operations in balance. Here we will deal with techniques of underground sampling and the meaning of such samples. The mine management must work hand in hand with the mine geologist and the mine sampler. In order for the management to keep the highest grade possible, he must know the grade of ore in place and where the next ton of ore is to be mined so that it can be properly developed and be made ready for mining when the time comes; thus, preventing costly shut-downs and delays in production.

Methods of sampling are probably as varied as there are samplers and mining districts in the world. If the sampling is done scientifically and basically honest, then the samples should not be too far from being correct. The sampler should study the structure and then decide what sampling technique should be used. In this paper, the discussion shall be that of the basic techniques used and try to arrive at a scientific conclusion.
METHODS OF SAMPLING

Underground sampling is in itself an art. The sampler must constantly judge the structure and the method of sampling to get the best results. Often the geology department may give instructions for the sampling method and the way it should be used. The rules and regulations should be flexible enough to allow the sampler to use his own judgment when a situation arises that is not in the book.

Training is of the utmost importance in creating a sampler and only through proper guidance and experience can the sampler take a good sample. The sample must be a representative of the chemical composition of the structure being sampled. The sampler must at all times see that this is done and the human factor is eliminated as far as possible in all cases.

Channel Sampling

The channel sample simply consists of cutting a groove of uniform depth and thickness across the face of a working and collecting the chips, fragments and dust for the sample. Channel sampling is generally a two-man job. It takes a man to use the hammer and mool and the other man to catch the chips and fragments with a canvas bucket or a canvas sack of some sort. A canvas tarp can be spread on the floor of the working to catch the sample chips. However, this may prove disadvantageous because unwanted chips outside the channel and dust from the miners working may be caught, salting the
sample. It is always wise to use a gauge of some sort to insure uniformity of the channel. A wooden block or a small piece of steel would serve the purpose very well. The gauge is simply fitted into the groove checking for width and depth.

A good channel can be cut in almost any type of rock except heavily brecciated ground where the material is not cemented together. Channel sampling is particularly good for hard quartz-vein material. The channel may be cut with a large amount of "sweat" and "elbow grease." Channel sampling is probably used most extensively in underground sampling practices where accuracy is the most important thing needed. It eliminates almost entirely the human element in sampling. In all cases, the same channel sample should not be taken across structures of very different composition and mineralization. The chips from different structures should be caught separately and sacked separately so that the geologist may know what each structure is composed of and the grade of one structure in relation to another.

Several new tools are on the market now to eliminate the old style hammer and moil. It not only eliminates the manual labor, but also eliminates the errors in sampling due to tiredness of the sampler or his helper. Several pneumatic tool companies have on the market small chippers weighing somewhere between 10 and 20 lbs. This type tool has been used with a high degree of success for cutting
samples. A small portable diamond saw has also been used to cut grooves in each side of the channel with varying success.

**Chip Sampling**

Chip sampling is simply the practice of taking chips from the structure being sampled. The most scientific method of taking chip samples would be to draw a grid on the structure being sampled and taking a chip from the corner of each square. In most cases, this would prove too time consuming and tedious. Chip samples in some cases will not give the high result that a channel sample would but for uniformly mineralized structures, the chip sample would be faster and would in the majority of cases give good results.

Chip sampling is usually left to the discretion of the sampler. With experience in the sampling process and the type of mineralization, most of the time this type of sample is equal to a channel sample. The sampler simply pick chips off the structure and catches this in a canvas sack looped over a wire ring or a collapsible canvas bucket.

The chip sample is good for uniformly mineralized deposits and will give a high degree of accuracy. However, when the deposit is erratic and spotty, then channel sampling or drill sampling generally gives the best results. Most authors recommend that the sample not be over 5 ft in length and not more than 5 ft between samples.
Drill Samples

Hammer drills have been used with good results to control mining operations. In many cases, the hammer drill is the only method of keeping drifts and raises in the best ore. The hammer drill theoretically cuts a perfect channel sample. However, some of the cuttings may be lost in fissures and vugs in the ground.

The manner of taking the sample depends on the purpose for which it is used. If the sample is taken for visual examination or for assay to give management a clue as to what direction to go or where a stope wall should end, then great care in catching the sample would be a waste of time and energy. In this case, a canvas sack held under the hole would be enough to catch most of the sample for a rough assay. However, if the sample is going to be used for ore reserve and mine grade calculation, then great care should be used in catching the drill sludge. (See long hole drilling, Part I.)

In many types of ore, hammer drills are used exclusively for sampling ore in place. Where chip samples or channel samples would give erroneous results, then the drill is used to determine the grade of the ore in place and direct mining operations. In very friable ores, the vibration of the drill steel will tend to salt the samples and give erroneous results. In this case, it would be better to try to devise a technique of cutting chip or channel samples.
The hammer drill is used in various mines when the vein is wider than the drift to outline the ore body. Where the ore is not friable and ravelly, the drill sample can be used not only for outlining the vein, but also for determining the grade of the ore if proper techniques are used in catching the sample.

**Grab Sampling**

Grab sampling is chiefly used to determine mine grade and in many cases as a control on high production type mining systems. Grab sampling simply consists of taking a portion of broken material from muck piles, chutes, cars, skips and ore bins from various scattered points.

Several techniques have been devised to take grab samples. There are two things that must be watched when grab sampling is used. They are (1) the sample must contain the lumps as well as the fines, (Too often grab samples only consist of the fine material and no account is taken for the coarse particles.) and (2) the sample must be a composite of the entire load. The human tendency is, much too often, to select the richer material in excess of the amount in the ore, however, when a man is over cautious, the reverse is often true. Probably the most used method of grab sampling is to throw a series of knotted ropes over the muck pile, and a sample is taken at each knot. When a knot falls on a large piece of rock, a hammer is used to knock off a piece of the rock for the sample. Another method that is used in ore cars
is to draw a grid on top of the muck and a sample is taken at the corner of each square. Often small augers are used so that a three-dimensional sample is taken. Probably the most common type of grab sampling used in underground work is the haphazard type. With this method, the sample is taken at random from points on top of the rock. This type of sampling is used when chutes are being pulled and cars are being dumped.

SAMPLE EVALUATION AND RECORDING

Sampling not only entails underground work but the sampler must also know how to post his work and figure the grade of ore shipped. The sample must be representative of the ground broken and the ground yet to be broken. Bad samples and wrong interpretations of good samples can lead to costly mistakes.

The sample should be posted in such a way that all mine management and mine geologists have easy access to the sample and can read it. Simplicity and uniformity are the two most important factors in sample posting. Many methods have been devised for posting samples and in this paper a few ways of posting samples will be discussed.

Averaging Assays

Peele defines ore as "a metal-bearing mineral or aggregate of such minerals, mixed with barren matter, called 'gangue,' and capable of being mined at a profit." In this paper we shall refer to ore as having two meanings, namely,
"minable" ore and geological ore. The term "minable" ore refers to any mineral aggregate that is of sufficient width and grade to be mined at a profit. Geological ore is that section of the deposit that is high enough grade, but ground conditions or width of the structure would prohibit mining at a profit. In many cases, as has been shown in the Butte district many times, geological ore may become "minable" ore due to new markets and different mining methods.

To determine grade, all the material that is shipped for ore has to be sampled and assayed. Mining costs and shipping charges in the area will determine what grade and width of ore can be mined at a profit. This is termed the "cut-off point", which is the lowest grade that can be shipped for ore. This gives rise to two types of averages used in sampling, the assay average and the mining average. The assay average is the average of all the samples that are above the "cut-off point." The mining average is the average of the entire mining width. When the entire mining face is above the cut-off assay, then the assay and the mining averages are the same. When averages are not the same, then waste has been broken and shipped for ore.

Waste can also be classified into two classes, overbreak and included waste. Overbreak would be any waste broken outside the vein or assay limit, and cannot be eliminated completely in many cases, but should be held to the lowest possible width. Many times when
overbreak is too excessive, the mining operation becomes unprofitable. Included waste is waste bounded on both sides by ore. In some cases, the included waste is figured in the assay average. When the included waste is 1.0 ft or less, then it is generally added to the assay average. However, when the included waste is over 1.0 ft, then the included waste and overbreak are generally added to give a general figure of total waste broken.

Assays are figured in two principal ways for channel, chip and drill sampling. The first and simplest way is to take the width times the assay to get a product. The summation of the width is then divided into the summation of the product for the average assay (Figure 6). In many cases, this type of analysis will not give the right answer, where large tonnages are figured. When specific gravities differ greatly, then they must be taken into account to give the correct results. The second method (Figure 6) is to take the width times the specific gravity to obtain a product. Then the product is taken times the assay to give an assay product. The summation of assay products is divided by the summation of the first product to get an average grade. The first product is divided by the total width to arrive at the average specific gravity. (Note: See examples 1 and 2, Figure 6).
Sample No. | Width | Sp.gr. | % Cu.
---|---|---|---
1 | 1.7 | 2.75 | 0.6
2 | 1.2 | 3.65 | 8.9
3 | 0.6 | 3.00 | 1.5
4 | 0.5 | 3.15 | 4.1
5 | 2.0 | 2.80 | 0.4

cut off point = 1.2% cu.

EXAMPLE #1

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Assay Average W X A</th>
<th>Mining Average W X A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>---</td>
<td>1.02</td>
</tr>
<tr>
<td>2</td>
<td>10.58</td>
<td>10.58</td>
</tr>
<tr>
<td>3</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>4</td>
<td>2.05</td>
<td>2.05</td>
</tr>
<tr>
<td>5</td>
<td>---</td>
<td>0.80</td>
</tr>
<tr>
<td>Total</td>
<td>13.53</td>
<td>15.35</td>
</tr>
</tbody>
</table>

assay width = 2.3 mining width = 6.0
assay average = 13.53/2.3 = 5.9% Cu. min. average = 15.3/6.0 = 2.6%

Figure 6 Method of calculating average assay
(Example 2 Page 30)
EXAMPLE 2

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Assay Average</th>
<th>Mining Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W X sp.gr.</td>
<td>W X A X sp.gr.</td>
</tr>
<tr>
<td>1</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>2</td>
<td>4.62</td>
<td>4.67</td>
</tr>
<tr>
<td>3</td>
<td>1.80</td>
<td>1.80</td>
</tr>
<tr>
<td>4</td>
<td>1.58</td>
<td>1.58</td>
</tr>
<tr>
<td>5</td>
<td>****</td>
<td>5.60</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8.00</strong></td>
<td><strong>18.27</strong></td>
</tr>
</tbody>
</table>

assay width = 2.3     mining width = 6.0
assay average = 50.28/8 = 6.2% Cu.  min. average = 55.32/18.27 = 3.0% Cu
assay sp.gr. = 8.0/2.3 = 3.48    min. sp.gr. = 18/27/6.0 = 3.04
Often straight averages are taken of grab samples. When grab samples are taken from cars of different grade, this would give erroneous results. The method employed most often is to multiply the number of cars times the assay to get a product. Then the total number of cars is divided into the summation of the products to find the average result. We can see here if we have 10 cars of 10 per cent rock and 5 cars of 5 per cent rock, the straight average of the assays would be 7.5 per cent. From the following example we get the correct average of the total cars of rock.

Example:

<table>
<thead>
<tr>
<th>No. Cars</th>
<th>Per Cent</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>15</strong></td>
<td><strong>125</strong></td>
</tr>
</tbody>
</table>

\[
\frac{125}{15} = 8.33 \% \text{ true average}
\]

In many smaller mines, the mine management may want to know the day-by-day grade of the mine. In this case, the sampler can keep a special ledger concerning the mine grade. The sampler sees all the working places in a mine and is in close contact with the returning assays. From previous samples and by having seen the face that day, the sampler can generally give a good estimate of what the grade will be. From the car tally sheet, the sampler can determine the number of cars pulled
from the working places and shipped as ore. With the use of the example above, he can determine the mine grade and carry a cumulative grade for a week's product. Often this checks very well with the mine grade figured by the sampler, which will be discussed later in this paper. From this simple ledger, the mine management can keep a day-to-day check on the grade of ore. If a working place starts to produce low grade ore, management can take steps to correct the situation and thus prevent costly low grade ore production.

Sample Recording

After the sampler gets back to the surface, he must know where and when the samples were taken. Therefore, tagging is one of the most important factors of sampling. Many samplers use a wooden block to number their samples. However, tags of good quality paper with the writing in soft pencil will generally hold up well enough until the sample reaches the assayer. Often the samples are recorded in a small notebook and the tags are torn from a small tablet, however, many mines standardize on a small tag book which serves both for the notebook and tablet. Figure 1 is an example of such a tag book. The tag books can be printed in a standard form and then in case the sampler is ill or away from the mine, any other sampler or geologist may calculate his samples.

A sketch of the working can also be used to good advantage by the sampler, particularly in stopes and raises.
Before the sampler takes his sample, he will first sketch the working. The sampler marks where the sample was taken and the number of the sample. This not only eliminates mistakes in tagging, but also gives the sampler a picture of what was sampled to prevent double sampling. Figures 7A and 7B represent two types of sample cards that may be carried by the sampler.

Ledgers for all development work should also be kept by the sampling department. In most cases, the assay average and the mining average would be enough for the development ledger. However, many geologists prefer that the entire sample be ledgered. Ledgers are generally kept as permanent records by the mine, therefore, the ledger sheet should be of good quality paper and the samples recorded in ink so that normal wear and tear will not destroy the records.

Long sections can also be kept by the sampler. Samples should be posted as close to the present work as possible. This will greatly aid the mine management and the mine geologist in ore development. Colors can be used to signify the difference between ore and waste; with color, the grade of the material mined can be told at a glance and mining operations may be controlled accordingly. Figure shows a typical long section used by the mine sampler. Maps can also be used for the same purpose. The samples in this case can be posted alongside the drift. Colors can be used in the same method as described for the long sections.
A. Plan card used by sampler

B. Long section card used by sampler

Figure 7 Sample cards
Assay averages are generally all that is posted on a long section or map, however, mining averages can be posted, but in most cases this only leads to confusion. When there is no assay average, the mining average is posted.

Each metal should be posted separately and never added up and reported in dollars and cents. The price of the metal may change and unless the prices are quoted, the long section and maps would soon become worthless. In general practice, the width is posted first so that you can read the sample in feet of per cent metal. In any case, standardize on one system and keep the posting uniform.
PART III

MINE GRADE AND ORE RESERVE CALCULATIONS

There are two general questions generally asked any mine manager by an investor. What is the mine grade, and how much ore is in sight? The life of a mine depends entirely on ore reserves and the prospective ore in sight. Grade is always an important factor for grade will determine whether or not the operation is profitable.

CALCULATION OF MINE GRADE

Mine grade is generally calculated by the week, and can be derived from two sources, mill returns and sample returns. In many cases, the mine grade is simply an average of mill samples, however, if the grade can be calculated ahead of time, it may save management a lot of headaches. If the mine manager can control the grade as it is being produced, he cannot only cut costs of operations but keep the upper management happy.

The sampler can calculate the grade of the ore broken each week accurately. Mine grade must be calculated from all material that is shipped for ore. In general, he must figure rock produced from all raises, stopes, drifts and cross-cuts. However, cross-cuts and laterals, when driven in waste, need not be figured if the rock broken has not been shipped for ore. In many cases, the mine management
may want to know the grade of the waste hoisted. This can be done by car sampling and in most cases a straight average will do.

When the sampler calculates the mine grade, he must calculate the grade on the basis of the ground broken. In many cases, this will cause a lag in the actual rock produced. In large shrinkage stopes, for example, the lag may develop into months and years. However, with other types of mining such as cut or fill, the ore is removed from the stope almost as soon as it is broken. In this case, the lag would be nil. Regardless of the lag, calculation of mine grade by the sampler will allow the mine manager to keep a diligent watch over the grade of ore.

Many methods have been devised to calculate mine grade, most of which are too lengthy to cover in this paper. The methods have been devised by the mine personnel with close cooperation of the mine geologist. A mine grade will also allow the mine geologist to keep the ore reserve factor corrected. By simply subtracting the grade and amount of ore from the ore reserve, he can keep mine management posted on definite ore reserves at all times.

To calculate the mine grade, the sampler must determine the amount of rock broken during the week and where it was broken. Both mining and assay averages would be figured into the mine grade separately. Overbreak is generally
figured with the mine average. With a detailed grade analysis sheet, the mine foreman can pin down the excessive overbreak. When the sampler determines where the rock was broken, he can then find its grade. In many cases, a tonnage factor is figured and used in the mine grade with the same method as the specific gravity in the previous example of assay averages.

CALCULATION OF ORE RESERVES

Ore reserves are very important whenever the mine changes hands or is evaluated for taxation purposes. Ore reserves should be kept on a ton for ton basis; that is, one ton of ore should be developed for every ton mined. When a ton of ore is not developed for every ton mined, costly shutdowns and loss of production will occur when the developed ore is mined out. If too much ore is developed, then repair bills to keep working places open may become excessive.

Ore may be classified into three types, developed ore, probable ore, possible or extension ore. Developed ore is completely exposed and the existence of the ore is certain. Possible ore is that ore which is reasonably assured but not absolutely certain. This type of ore may be discovered through drill holes or small dog holes of some sort. It is not readily available for mining but could be made ready in the near future. Possible or
extension ore is ore forecasted by the geologist and
based only on the continuity of geologic and mineralogic
relationships. In most cases, the ore reserve of a mine
is only based on developed ore which is ready for immediate
mining with the present mining system.

The geologist can use the long section posted by
the sampler to good advantage for ore reserve calculation.
Generally, the geologist will make his own long sections to
a smaller scale, and use combined averages where averages
are near the same width and grade. Each block of ore should
be analyzed separately as to area encompassed and sample
control. There is no hard and set rule for dictating how
much a sample controls. This is generally left up to the
geologist who is in direct contact with the ore body at
all times. However, the width and grade of the sample
should in all cases be used according to its weight. For
example, if one sample is uniform for twice the length of
another sample, then a factor of 2 should be used to determine
both value and grade. Tonnage in each block is then calculated
by dividing the product of the assay width and area of the
block by a tonnage factor previously computed. To arrive
at the final ore reserve, the tonnage is multiplied by the
assay average to get a product. Then the total product is
divided by the total tons to arrive at the average grade.

Plan maps are also used to determine grade and ore
reserves for flat lying deposits and lenticular deposits.
with much of the same procedures as used with the long section. However, cross-sections are often used as an accessory to plan maps for calculating grade. Plan maps are also used for bore hole calculation of ore reserves. With this method, the bore holes are generally in some geometric pattern, however, where the terrain will not permit a geometric pattern, the polygon or triangular systems are used. In all cases, the same method would be used to calculate ore reserves. The length of the hole in the ore is multiplied by the assay to get a product. Then the product is divided by the total length to get the average assay. The product of the area of the figure and the average length of the holes in the ore are divided by a tonnage factor previously calculated. This gives the tons and grade for each of the grid block. These can be combined by multiplying the assay times the tons and dividing the total product by the total tonnage to get the average assay.
BIBLIOGRAPHY


