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MECHANICAL ORE SAMPLING IN MONTANA

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STATE SCHOOL OF MINES
BUTTE, MONTANA

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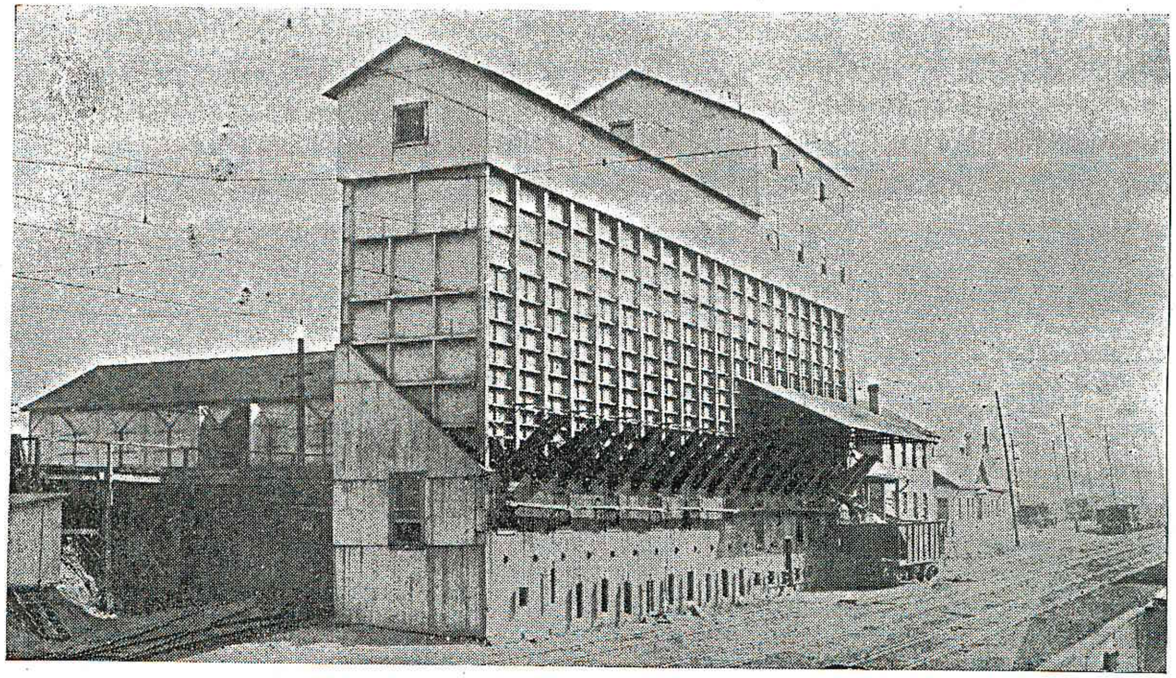

FIG. 1.—THE WASHOE SAMPLER OF THE ANACONDA MINING COMPANY, AT BUTTE, MONTANA.

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CONTENTS

ILLUSTRATIONS

INTRODUCTION

AUTHORIZATION

The bill creating the Montana State Bureau of Mines and Metallurgy, enacted by the Legislative Assembly of Montana for 1919 (Chapter 161, Page 311), states that it is one of the objects and duties of the new bureau, "To study the mining, milling, and smelting operations carried on in the State, with special reference to their improvement", also, "To prepare and to publish bulletins and reports, with necessary illustrations and maps, which shall embrace both a general and detailed description of the natural resources and geology, mines, mills, and reduction plants of the State."

OBJECT

A study of sampling and the sampling facilities of Montana is presented, in accordance with the above authorization, to widen and deepen the general knowledge relating to the common and necessary, yet rather technical work of sampling. It is hoped that prospectors and miners will benefit from the study, for their interests have been kept prominently in view. The sampling mills in which ore sellers will find personal interest have been thoroughly studied and their reliability tested by an expensive series of samplings to demonstrate their precision on an ordinary lot of ore. It is felt that even small advances toward the uniformity, precision, and efficiency of sampling mean so much to the industry as to warrant even far more effort and cost than is represented in this study.

ACKNOWLEDGMENTS

The managements of the American Smelting and Refining Company, the Anaconda Copper Mining Company, and the East Butte Copper Mining Company have heartily welcomed the study and have assisted in every way possible. Each company has put itself to expense and trouble to join in the work.

Particular acknowledgments are due Messrs. Smith, Morse, and Adams of the American Smelting and Refining Company, to Messrs. Laist, Bender, Gillie, Margetts, and Demond of the Anaconda Copper Mining Company, and to Messrs. Rohn and Beaudin of the East Butte Copper Mining Company. The men mentioned have been personally helpful in forwarding and correcting the work.

Dr. Clapp of the State Bureau has taken a strong interest in the work and helpfully directed the preparation of the report.

THE PURPOSE OF SAMPLING

The sampling of a lot of ore is carried out in order to supply the analyst with a 4-ounce envelope of finely ground powder which, when selections are made in from half-gram to thirty-gram portions, shall give the analyst average results with a precision of about one part in fifty for the important components, or elements, moisture excepted. The usual chemical determinations are for gold, silver, copper, lead, zinc, sulphur, iron, silica, lime, and magnesia, and for special elements in particular ores.

Sampling is thus seen to have an amazing purpose in view; to take from a lot of ore—be it one ton, fifty tons, or five hundred tons—only about thirty-two ounces of material which shall uniformly contain all the components of the original lot in exactly the proportions in which they exist in the original lot of ore. Even this final sample of about thirty-two ounces must be capable of division so that the different packets into which it is separated must be chemical duplicates of each other and supply seller, buyer, control analyst, smelter, and umpire analyst with as nearly identical results as possible. Yet, in spite of the enormous difficulties in practice, perfectly satisfactory sampling is actually attained daily.

The lot of ore to be worked upon will likely contain very fine material, sandy material, and sizes up to big chunks; it will contain desirable minerals and undesirable rocky gangue; it may contain free metals, clayey gouge, and crystals in all degrees of purity. It is remarkable that the task can be done at all; it is nothing less than one of the great achievements of modern engineering and industry that it can be done easily, quickly, cheaply, and with precision.

Ordinary sampling mills will secure a 100-pound sample from a 50-ton lot of ore in from fifteen minutes to two hours, and then from this sample the sample man in the bucking room will produce the analyst's packets of thoroughly ground, dried, and mixed pulp in another hour.

The cost of sampling varies from 5 cents to $1.50 a ton, depending upon the amount, character of ore, and the method and equipment used.

Sampling has accomplished its purpose if the small packet will supply the half-gram, fifteen-gram, or thirty-gram selections for the analyst so that he can get his results with the required precision. The sampling is satisfactory if the average results on different selections from the same packet, or on selections from different packets, or on selections from different samplings, agree to one part in fifty parts, or, as they sometimes do, to one part in one hundred parts. The precision may be less with elements present in excessively small amounts, like gold and silver. The chemical work is subject to both constant and chance errors, so that single results, or too many significant figures in the results, have little meaning; error may come as likely from the analytical work as from the sampling operation.

Sampling has failed of its purpose if selections from packets do not agree within the desired limits, or if the different packets from the same sampling do not agree, or if packets from different samplings are discordant. The best test of accuracy in sampling is to resample or sample by another method. It is rarely cheap or practicable to actually extract the desired metal or attempt to separate a compound from an entire large lot in order to determine its amount; in such a case the recovery figure, instead of the composition figure, is obtained, because the losses which the chemist compensates for, the plant operator cannot avoid.

Whoever mines ore, sells it on the results of the analysis of a sample; ore is purchased on its value as determined by sampling; the plants are operated on a basis of results from sampled materials; efficiencies and losses are all based on results from samplings. Sampling is therefore one of the most vital and necessary operations of modern mining and metallurgical industry.

PRINCIPLES OF SAMPLING

*Woodbridge in a recent paper published by the United States Bureau of Mines defines sampling as follows: "The correct sampling of a lot of ore is the process of obtaining from it a smaller quantity that contains, in unchanged percentages, all the constituents of the original lot." He further qualifies and defines the operations in his next paragraph: "The commercial object of sampling is accomplished when the ultimate sample obtained meets the above conditions within an allowable limit of error, and has been obtained with reasonable speed and at a moderate cost. The final sample should be dry and of such bulk and degree of fineness as to be immediately available for the determination by the assayer or chemist of one or more of its constituents."

THE OPERATIONS OF SAMPLING

Four wholly different, yet essential, sorts of work may be done to accomplish the intended purpose of sampling. The four operations are:

1. Crushing, or grinding.
2. Selecting—dividing or cutting.
3. Mixing.
4. Drying.

These essential operations are carried through to varying degrees and in whatever order the conditions require. Thus, with flotation

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*Woodbridge, J. T.; U. S. Bureau of Mines, Technical Paper 86 (1916).

concentrates, which are already finely ground and well mixed in production, the work is largely in cutting out numerous selections, drying, regrinding the lumps made by the drying, mixing the pulp, and dividing it between the several packets. A lot of coarse, rocky ore may be dry and excessively hard; in this case the work is mostly crushing and selecting until the small final portion is dried, finely ground, mixed, and split for the assayers' packets.

Successful sampling demands that a rational sequence be followed and that attention be continually give to certain fundamental conditions, explained later, lest some slip or unexpected influence vitiate the entire work. It is self-evident that the final result cannot be more perfect than the most imperfect step in the sequence; if six divisions are made, and one is imperfectly done, perfect work in the other five does not compensate.

Sampling can frequently be accomplished by different methods or by changing the sequence of the steps; one usually uses the method most feasible or least costly. Thus, if one had a 50-ton lot of lump ore to sample, an imaginary way to get the required results might be to dry the entire lot, then grind it to pass 100 mesh, then mix it thoroughly, then at last take out just enough of the dried, ground, and mixed ore to fill the sample packets. For most metallurgical purposes the cost of such an operation would be absolutely prohibitive; the nearest commercial approach to it is probably the sampling of the Cobalt native silver ores. The usual western practice with lump ores is to crush to 2- or 3-inch size, select a fifth and crush it finer, select a fifth and crush it again; and this sequence is repeated, two, three, four, or more, times, until a small amount is obtained which alone is dried, finely ground, mixed, and distributed between the packets.

The method of making the entire lot uniform and then selecting a few duplicate portions for the analyst is attractive for the ease and simplicity of the few selections involved. In addition, this method is one which may come into use more and more on account of the lines along which metallurgy and industrial chemistry are advancing. Pipe sampling of concentrates is almost an example of this simple method. In fact, this method is actually followed in the most approved manner of sampling lead bullion. A kettle of molten lead ready for casting into bars is stirred for 15 minutes; as the stirring continues the sampler inserts a steel rod, with a row of conical depressions in it. On the withdrawal of the rod each little cone of lead, which fills a depression, will come out of the kettle of the proper weight for the assayer and will contain the correct proportions of all components of the kettle of molten lead. Two lots of 7 little cones, all from the same kettle, were cupelled, and the following results were obtained:

	Series No. 1		Series No. 2	
	Gold	Silver	Gold	Silver
	.30 oz.	81.7 ozs.	.30 oz.	82.1 ozs.
	.30	82.0	.30	82.4
	.30	81.4	.30	82.0
	.30	82.3	.30	81.7
	.32	82.1	.30	82.0
	.30	82.0	.30	82.0
	.30	82.3	.32	81.8
Average:	.30	82.0	.30	82.0

This method of sampling lead bullion has given eminently satisfactory results at a trivial cost. Pipe sampling of a pile, or carload of concentrates, is also a matter of very slight cost and will necessarily give correct results if the lot is uniform. Sampling by taking a few small portions from a uniform lot of fine material, either during its production or after it is in a batch, is a method which should always be borne in mind; and if the proper condition for this is to araise during the treatment of any material, sampling can be profitably delayed until that stage is reached. Unfortunately, the producer of ore seldom has his material in a fine and uniform condition suitable for such sampling.

Crushing and Grinding.—The crushing of ore for sampling purposes is largely a matter of mechanics, power, and capital outlay. It usually does no harm if some of the material is finely divided during the course of crushing the larger pieces to the necessary dimensions. Since a great variety of sizes will inevitably be produced, the making of fines increases the number of particles and favors the sampling when it is done on the probability basis.

Many of the crushing machines on the market are excellent for reducing ore sizes and fulfil most of the expected functions. Capital outlay is always a serious consideration and machines are primarily installed on their gross capacities and not on the basis of how thoroughly they will accomplish the crushing task. Sampling mills do have a strong claim for heavy and powerful machinery, since an unusually large or tough piece of rock slipping through one machine may spoil the sampling because of its excessive mass and one-sided composition. In ordinary ore-dressing practice it means little if slabs fall through machines or if large rocks spring the rolls and fail to be well crushed. Ultimately the pieces will be caught and crushed or returned to the first crushers by the sizing devices. But most sampling mills do not have sizing devices and it is possible for large pieces to get into the sample. It is not uncommon to find a sample which, although 90 to 99 per cent. is properly sized, contains a few unduly large pieces, thus tending to vitiate the results.

Several methods may be proposed for overcoming the sizing difficulty. The idea of using very heavy rolls is neither new nor impressive. Dodge type crushers, which make a finer product than the Blake type, would be only a partial remedy. There appears to be a field for a type of crushing machine which shall be so constructed as to make the passing of thin slabs impossible; capacity could be somewhat sacrificed for the sake of the sizing feature.

In regard to grinding the finest sizes for the final pulp there appears to be an open field for studying the correlation of grinding substance with the work accomplished. A complete study of this detail of sampling and grinding should include the composition, structure, and physical properties of the grinding substance. One important factor would be to accurately determine how much of the grinding substance is abraded to contaminate the sample.

Dividing or Selecting.—The phrase, "selecting the sample," could well be replaced with the words, "dividing the lot," for the idea inherent in SELECT is that a division is made which is based on some property or quality of the portions available. The word select is always used in this paper with the simple meaning of divide. The most vital principle in any and all sampling is that division shall not be dependent on any quality of the parts. Whether one is removing a small portion of a perfectly mixed lot, or whether one is making a thousand mechanical divisions, the separation demands the absence of discrimination.

Mechanical sampling attains its best precision with well-designed equipment which allows no division based on a property of parts, as on the coloring, the sizes, or the relative densities of the ore pieces. If a piece of machinery is to handle pieces of rock several inches across just as impartially as it handles quarter-inch sizes it probably means surprisingly large equipment. When confronted with the problem of sampling very large pieces, the engineer sometimes decides to crush enough to accommodate the sampling machinery; he rarely builds ungainly machinery, but he frequently handles large sizes with too small machinery. To the mechanical engineer a compromise is a "practical" solution of the problem, but to the mining engineer a compromise involving even slight deviations from impartial sampling is a perversion of the whole function.

The precision of modern mechanical sampling, as based on the law of probability brought into play by hundreds and thousands of divisions, is a source of much pride and satisfaction to the engineers and men interested. The demonstrations to be presented in later paragraphs will substantiate this opinion and establish a confidence in the practice. Mechanical cutters in the mills, and riffle dividers in the bucking rooms, allow ores to be sampled without possibility of being influenced either by human craft or stupidity. Also, fortunately, both speed and cheapness are in favor of wholly mechanical sampling.

Mixing the Sample.—The mixing of a large lot of ore consisting of large and small pieces is almost impossible and, besides, is wholly useless. When you try to do this you find that any method of handling assorted sizes allows segregation if the material is dropped, or let roll, or even moved by ordinary implements. The material cannot be properly sampled by small selections of single pieces, because the larger pieces exceed the proportionate composition in all components.

The mixing of large lots of fine ore or mill products is not as difficult an operation as the preceding, but is seldom practicable unless done incidentally to the production or transfer of the material. Even if a lot of fine ore appears to be uniformly mixed there is no easy demonstration of the fact, and it is much safer to depend on a considerable number of cuttings. The frequent division of a fairly uniform material is carried out in practice when mill streams are sampled, either mechanically or by hand, when cars and bins of concentrates are pipe sampled, and in shovel sampling by the tenth- or fifth-shovel method. The three instances last mentioned are really applications of probability sampling, but probability sampling used where the material is known to be nearly uniform, and where from 50 to 500 selections suffice to establish the required precision in the sample.

A thorough mixing of the final portion of pulp previous to its division between the several packets is indispensable. A large number of rollings on a suitable cloth or paper is the almost universal way to do the final pulp mixing. Rolling, when skilfully done, accomplishes the purpose, but the great objection to rolling is that it is tedious and requires both time and patience. If a cloth fabric is used it may well have a pebble-grained surface; a paper should have a matte surface. The surfaces of either fabric or paper are commonly colored black to show the sample more easily.

Substitutes for rolling the pulp on cloth or paper have been proposed; the Anaconda sample mills use cube mixers and at the School of Mines 'a small table riffle answers the purpose. At Anaconda both mills are equipped with 8-inch cube mixers which rotate by power and slowly enough for the contents to undergo practically the same sort of tumbling which a pulp would get when rolled on a fabric. Cube mixers have not proved satisfactory in all cases and their use in the State is limited to the Anaconda mills. Classes in assaying at the School of Mines have recently mixed their final pulps by pouring them, with shakings to and fro, at least ten times through a table riffle. As far as can be determined in the the course of the regular assaying work, the riffle mixing is fully adequate and will be explained in considerable detail.

A riffle cutter may be used to make either a very few or a greater, and almost unlimited, number of cuts during the division of an ore sample. Figure 2 shows an operator pouring a sample through a riffle cutter which has 26 slots. When the sample container rests on the edge of the cutter, and the material is merely allowed to flow through the 12 slots which extend the width of the ore stream,

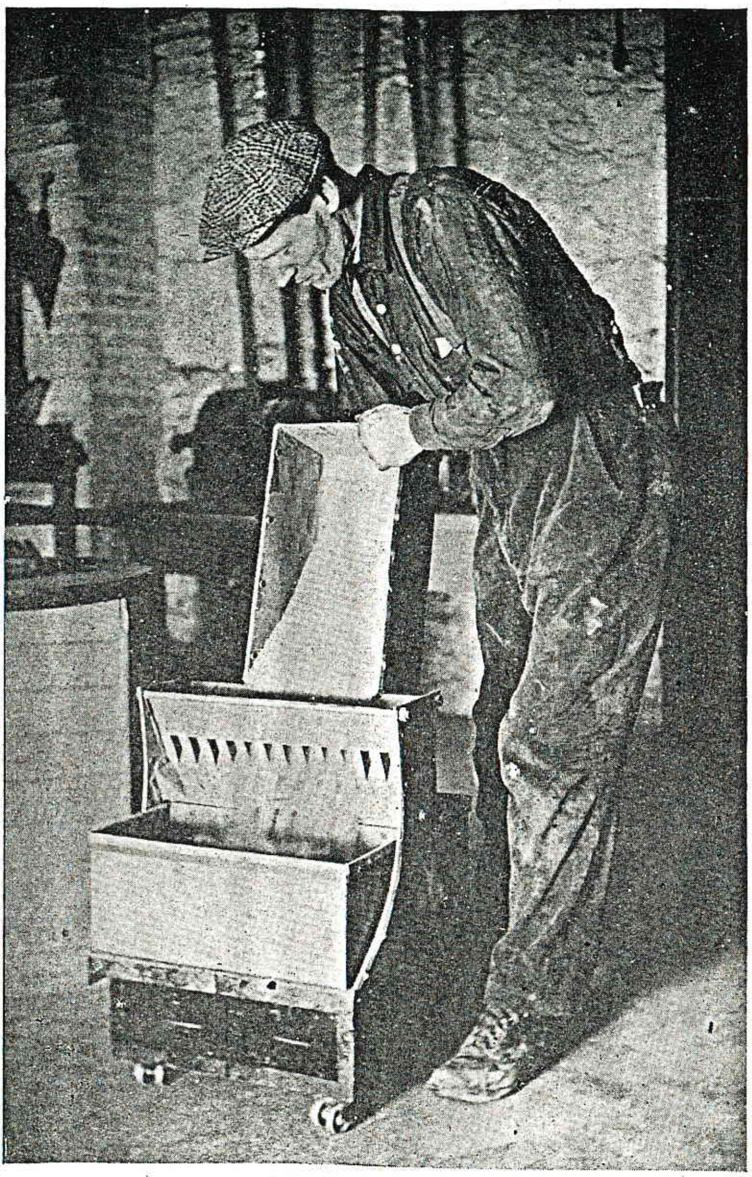

FIG. 2.—STAND RIFFLE CUTTER USED AT THE STATE SCHOOL OF MINES.

The cutter has 26, ⅝-inch slots, and is intended for dividing 8-mesh stock.

there will be 6 streams of ore flowing into the sample half, and the lot may be said to be cut 6 times for sample. When the operator moves the container across the top of the riffle, say 20 times during the pouring, all of the slots are brought into play and the lot may be cut 20x13, or 260, times for sample. The operator might, however, take the ore from the container in a scoop and then pour it through in small portions, shaking each scoopful 20 times across the riffle. If the operator takes a lot of ore in 10 scoopfuls, and pours each across the 26 slots, with 20 to and fro motions, he makes, altogether, 10x13x20, or 2,600 cuts, for the sample.

It is thus seen that a lot of ore is very easily cut into a larger number of portions by merely shaking the ore stream across the riffle. When the two halves of the divided sample have been united the lot of ore has been thoroughly mixed. Both gross and minute inequalities are dispersed throughout the sample by cutting and uniting several times, in other words, the lot has become unusually "well mixed."

The author is of the opinion, that, if a lot of sample pulp is shaken 10 times across a riffle, which makes 1,000 cuts for sample each time, the united pulp will be as well mixed as by rolling 1,000 times on a cloth. The riffle mixing can be done in less than 5 minutes, while the rolling will rarely require less than 15 minutes.

In order to make an exacting test of the mixing that can be done with a riffle the author prepared 500 grams of quartz and 500 grams of iron ore by grinding each and passing them through a 100-mesh sieve. Each lot was, of course, dry and thoroughly mixed. The iron ore was poured over the quartz in a pan and then the material was poured through a 12-slot riffle giving nearly 100 shakes during the 30 seconds required for the powder to flow from the pan. Two grab samples of about half-gram size were taken on a spatula from each half. The two portions were united and the operation repeated. This was done 7 times and each time two grab samples from each half were taken for analysis. The chemical results were as follows:

Quartz, 3.17% iron; iron ore, 43.78% iron; average, 23.48% iron.

PERCENTAGE OF IRON IN GRAB SAMPLES

Mixing	The Four Samples				Average	Ave. Deviation from 23.48
1st	15.72	32.72	6.04	30.80	21.32	10.44
2nd	20.24	20.12	19.24	21.12	20.18	3.30
3rd	20.12	21.40	23.40	22.88	21.95	1.51
4th	23.28	23.50	23.40	23.20	23.34	.15
5th	23.64	23.64	23.44	23.64	23.61	.13
6th	23.56	23.64	23.44	23.64	23.57	.11
7th	23.36	23.44	23.52	23.64	23.49	.09

The chemical analyses show that the first mixing had intermixed the iron ore and quartz to a very considerable extent, although far

FIG. 3.—CONE AND QUARTER SAMPLING.

The cone has been formed over a wooden cross and the men are just beginning to spread the pile.

from enough to be utilized. The second mixing adjusted the composition to within a few per cent. of what it should be. The third mixing brought practically perfect final composition in streaks, while the fourth mixing doubtless rendered the entire batch homogeneous to within 1 part in 100 parts, which is of the order of the chemical analyses, themselves. The 5th, 6th, and 7th mixings changed the composition in an almost inappreciable degree. The chemical determination of iron was chosen because it could be done more easily and with greater precision than almost any other determination or assay.

Material which yields identical composition on haphazard samples fulfills the test of uniformity, in this instance rather a test of the mixing than anything else.

Whenever the riffle cutter has been tested under proper conditions it has given admirable results; it is, accordingly, strongly recommended wherever it can be used. The prospector and miner will find riffles both cheap and handy. Riffles can be used wherever cone and quarter sampling or split shovel sampling is now used. The utmost use of riffles will tend toward uniformity, low cost, rapidity, and the greatest possible precision in sampling.

Drying the Sample.—Two devices are in common use in Montana for drying ore samples; the most common is the cabinet shelf dryer, heated by steam or electricity; steam tables with large flat tops are also found at most mills. The shelves of the cabinet dryers will accommodate pans large enough to hold eight or ten pounds of ore in a thin layer. Larger samples are divided among pans or spread on the steam table. An hour's drying is usually considered enough, although the sample may be left in the dryer much longer while awaiting its turn for fine grinding.

Drying is by far the simplest and easiest of the four mechanical operations in ore sampling.

The drying problem, if indeed there is any, is rather one of procuring a sample to dry, or taking the moisture sample, then drying the sample after it is procured. At some Montana mills the sample for moisture is a composite made up of several cuttings from different places well within the lot, at other mills a somewhat arbitrary correction is made to the moisture on the regular mill sample, or on a portion of the last mill crushings. How to get a moisture sample cheaply and accurately is the same sort of problem as how to cheaply and accurately sample spotty gold ore; both are troublesome.

CONE AND QUARTER SAMPLING

There is a method for sampling ores, handed down through many decades, which is known as the cone and quarter process and is supposed to have originated in Cornwall. The ore is thrown into a conical pile, which is then spread out with a tool as the operator

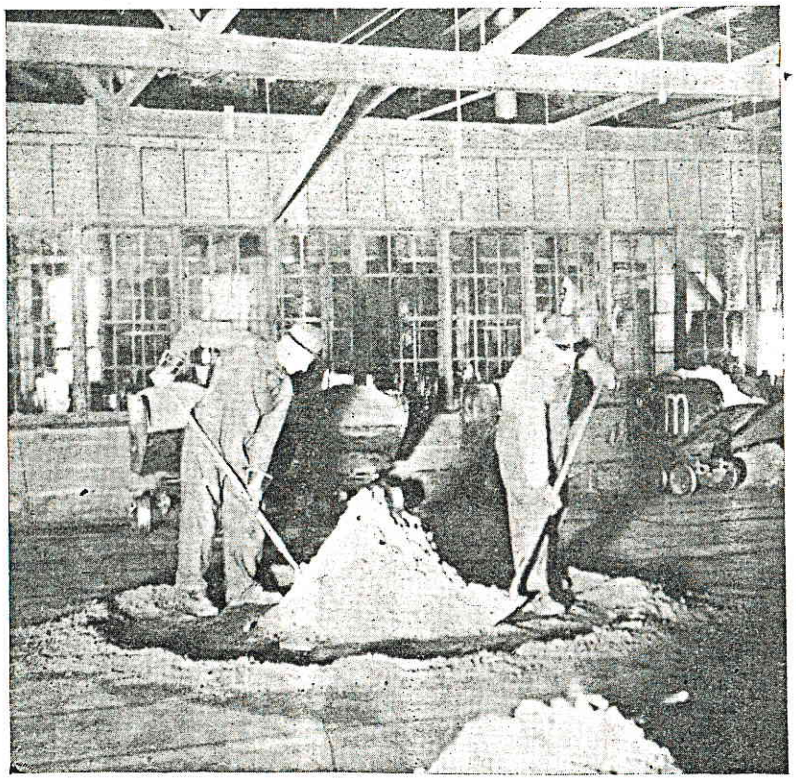

FIG. 4.—CONE AND QUARTER SAMPLING.
The first cone is being ringed to mix the fine, damp material.

circles about the pile. Quarters are marked and two opposite ones are shoveled away, leaving one-half of the original lot as a sample. The coning and quartering is repeated as often as necessary to get the right-sized sample. Figure 3 shows the operation in progress on a steel sampling floor.

The principle involved in cone and quarter sampling is that of symmetry about a vertical axis; an additional and less effective principle is that of compensation of opposite quarters. The idea in the cone and quarter method is that the ideal pile shall be uniform about the center, but, if the pile is not uniform, the opposite sectors across any given diameter may be expected to compensate for each other and so establish a working average. The method of dividing the lot allows the principle of diagonal compensation to apply to both sample and discard.

Although splendid work can be done by the cone and quarter method the principles are not as simple nor is the work as independent of human discrimination as sampling by other methods. An exaggerated segregation of fine and coarse particles always occurs during the coning of the pile; depending entirely on the ensuing distribution of the finer core of the pile, there may be either a fair halving or a preponderance of values in either sample or reject. Mixing the lot by "ringing about" before coning is a common practice (see Figure 4). The use of crosses to help center the pile and hold the sides during the division is also common practice.

PROBABILITY SAMPLING

The law of averages and the theory of probability demonstrate that if either single pieces or small portions of a large lot are chosen at random the composition of the selection will approach, after enough selections and as a limiting condition, the composition of the entire lot. Obviously, if one selects the entire lot, the sample and lot become identical. However, it is not necessary to take the entire lot, for by mixing and taking a sufficient number of single particles, or by making enough cuttings, or by a combination of mixing and dividing, it is possible to take not more than one-fifth, one-tenth, or even one-twentieth of the lot and still get a truly representative sample. Shovel sampling, split shovel sampling, riffle sampling, and all types of mechanical cutters involve more or less of the probability principle.

To make the probability overwhelmingly on the side of precision, a questionable number of divisions is not taken, but thousands of divisions, each portion containing thousands of particles, are commonly made. Furthermore, the possibility of large pieces influencing the results is precluded, and any influence that can interfere with absolutely random division is avoided. Thus any influence which tends to select according to size, weight, shape, density, color, hardness, porosity, or any other imaginable property is eliminated.

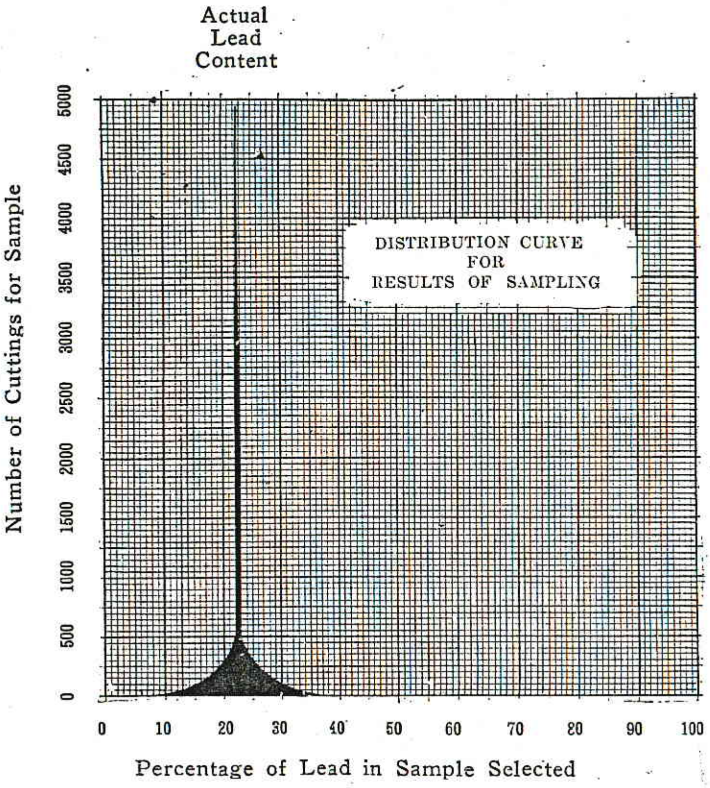

FIG. 5.—PROBABILITY CURVE FOR DISTRIBUTION OF SAMPLING RESULTS.

There is no doubt but that the results of sampling must follow some probability curve, mathematically determinable by the factors and quantities involved; the engineer makes certain that the curve shall be of the shape indicated in Figure 5. The curve means that, depending on the number of divisions or cuttings for sample, the probable result will lie within the extremely narrow, vertical portion of the blackened area. On this basis, if one repeatedly crushes between divisions so as to circumvent the influence of large single particles, the limit of accuracy is not exceeded, although the crushing and dividing is repeated as many times as neessary to sufficiently reduce the size of the sample.

In actual sampling the sequence of crushing and cutting is commonly performed from six to ten times. Each portion of the thousand or more selections made by one machine contains millions of particles and the final result has every assurance of correctness and is capable of proof. The proof consists, not in analyzing the entire lot, which, as already stated, is impossible, but in repeating the process, in getting duplicate samples, or by sampling by an entirely different method.

If a lot of ore weighing 50 tons requires 60 minutes to go through a mill whose mechanical cutters are taking out a fifth at the rate of 60 cuts a minute and are in series of four, the first cutter will make 3,600 selections and take out 10 tons containing millions of particles. After crushing, the second cutter will make its 3,600 selections from the first sample and take out its 2 tons containing again millions of particles. Then the third cutter will divide the 2-ton lot, making its 3,600 selections and taking out 800 pounds containing again some millions of particles. The last cutter will divide the 800 pounds and with its 3,600 selections take out 160 pounds in another sample likewise containing millions of particles. The process of crushing and dividing is then continued with suitable machines, and usually in the bucking room, until the final analysts' packets, each containing millions of particles, represents the original lot with the same precision as that of any previous larger selection or sample.

THE LARGEST PIECES

The goal to be attained in the most economical crushing and dividing is to crush the larger particles no more than necessary to prevent their one-sided composition affecting the accuracy of the results. The limiting size of particle is of course a constant depending on the nature of the material and the quantity of the lot. The earlier sampling mills in the western United States were strongly constrained to crush as little as possible, because the ore was desired coarse for blast furnace smelting. The combined considerations of economy and preserving the ore coarse have given us most of the mill characteristics which are found in western samplers. The mills have been built and operated largely on an empirical basis, with thorough studies on the vital factors conspicuously absent. The limiting sizes for different ores, minerals, and weights of lot is one of the studies on which comparatively little work has been done in a systematic way.

In a general way, and as far as practicable, the present sampling mills are constructed to so crush the larger pieces that when a division is made there shall be no excessively large pieces. An excessively large piece is one which would materially affect the result, depending on whether it enters the sample or the reject. The mills are intended to make thousands of what may be termed the largest-sized pieces. A few of the larger pieces cannot, then, by getting in the wrong division, appreciably affect the result.

Some investigators have supposed that the law of averages would apply to the larger pieces in this way, that even if some excessively large and rich pieces should tend to increase the values in the samples there would be enough large lean pieces to conterbalance. Weld[1], in 1910, clearly demonstrated, by actual tests, that it is not admissible to use this interpretation of the probable distribution of results. A probability curve based on the average obtained by balancing a few, large and individually important quantities would be much broader and flatter than the curve indicated in Figure 5.

The accuracy of the sampling operation is jeopardized in two ways by the presence of unsuitably large pieces; the presence of the piece affects the results, and it interferes with the work of the dividers. The common occurrence of pieces larger than intended is commented upon by Woodbridge[2] in his paper on western sampling practice.

In 1895, Brunton[3] published a paper containing an extensive discussion on the safe size of the largest pieces for lots of ordinary ores and low-grade gold ores. Woodbridge[4] gives a table, based partly on Brunton's work and partly on experiments and practice, designating the smallest permissible weight of sample for different sized material. If it is necessary to have at least a certain amount of material for pieces of a given size, the converse statement must also hold, that if a lot of ore weighs only a given amount, then the largest pieces must have only the corresponding size.

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[1] Weld, "Accuracy in Sampling," J. Ind. Eng. Chem., Vol. 2 (1910), page 426.

[2] Woodbridge, T. R.; "Ore-Sampling Condition in the West." U. S. Bureau of Mines, Technical Paper 86, page 57 (1916).

[3] Brunton, D. W.; "The Theory and Practice of Ore-Sampling." Trans. Am. Inst. Min. Engrs., Vol. XXV., page 826 (1895).

[4] loc. cit.

The table, as given by Woodbridge, follows:

Smallest Permissible Weight of Sample
for Varying Sizes of Crushing

When Crushed To—	Smallest Permissible Weight, Pounds
Two inches	10,000
One and one-half inches	5,000
One inch	2,000
Three-fourths of an inch	1,000
One-half inch	400
Three-eighths of an inch	300
One-fourth inch	200
Three-sixteenths of an inch	100
One-eighth of an inch	75
Six-mesh	50
Ten-mesh	25
Eighteen-mesh	10
Thirty-mesh	4
Fifty-mesh	1

Woodbridge applies the table to ordinary gold ores and suggests that the limits may be too restricted for low-grade silver ores. The relationships expressed in the table may well be adhered to for the sake of allowing a reasonable margin of safety. The common presence of ore pieces larger than the allowable size, frequently seen in Montana practice, is a condition which can be excused only because of the comparatively low grade of the ores.

HIGH VALUE MINERALS

The influence of pieces of coarse gold in a lot of ore is so overwhelming as to make any table of quantity-size relationships of little value. Oxidized surface gold ores and quartz containing coarse gold are in places so rich that single pieces may easily vitiate the sample by whole ounces. Accurate sampling of such materials demands that the entire lot should be finely ground before dividing. It is usually admitted that ordinary sampling mills are not adapated to sampling ores contaning coarse gold; it is also obvious that it would not pay custom plants to install fine-grinding machinery for the small and infrequent lots of "spotty" ores.

The prospector or miner who is getting out rich material and thinks he is not getting fair returns can install a small grinding machine and daily reduce to 20- or 40-mesh the few hundred pounds of ore he produces. A suitable grinder need not cost over $200.00, and with whatever power is available the small operator should be able to pulverize his high-grade ore so that any good method of sampling will give accurate results.

EQUIPMENT FOR SAMPLING

Several really difficult and obstinate conditions are met in the satisfactory execution of the principles of sampling, so that to do the work quickly, cheaply, and above criticism demands high engineering accomplishment. Modern precision and modern standards are always becoming more exacting, and although the last few years have brought few changes in the industry, there is yet opportunity for further work.

CRUSHING AND GRINDING

The following machines are about the only ones used in sampling plants to reduce the size of ore particles:

a. Gyratory rock breakers—for the largest sizes.
b. Jaw crushers, Blake type—for large and medium sizes.
c. Rolls—for intermediate and small sizes.
d. Bell-type grinders—for small and finest sizes.
e. Disk grinders—for the finest sizes.
f. Bucking boards—for the finest sizes.

Baby gyratories and chipmunk crushers are now and then seen in laboratories, but their place is for special samples rather than for routine samples of large lots.

The large crushers used in sampling works are always commercial mill units. The practice is a great convenience to the sample mill designer, but, as already mentioned, the ordinary ore crushers are not perfectly adapted to sampling, because it is possible for flat and rather large pieces to get through the crushers without suitable reduction. Single pieces entering a spring roll may be suitably crushed, but if several pieces enter together, or within a wave of fines, one or more pieces may fail to be crushed because the rolls opened under the strain.

The wear of the hard iron working surfaces is usually compensated by adjusting the opening, but the channeling of the jaws and the corrugation of roll shells takes place just as in any concentrating mill. As the sampling mills do not contain sizing and returning equipment unless for some additional function of the mill, it follows that samples frequently contain pieces far too large for the size of the sample.

The introduction of abraded iron into the sample during the fine grinding is a matter upon which data is apparently rather scanty. Fieldner[1] reports that the ash in five samples of coke was increased, on the average, 2.9% by grinding on a bucking board instead of in a pebble mill. The quartz used in the author's mixing test contained only 0.03% iron extractable from the small rounded grains, but 3.17% iron after grinding in the disk grinder.

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[1] Fieldner, A. C.: "Notes on the Sampling and Analysis of Coal." U. S. Bureau of Mines, Technical Paper 76, page 57 (1914).

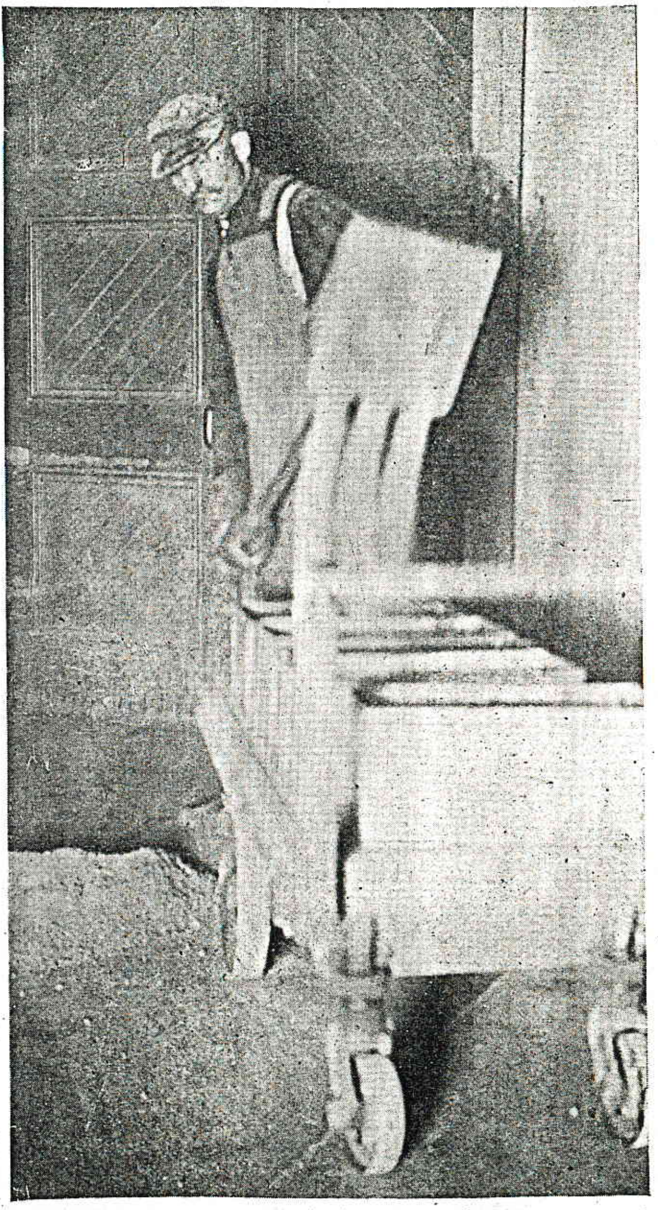


FIG. 6.—SPLIT SHOVEL SAMPLING.
The sample man is sliding the reject into pans; the sample is held in the pockets and will be piled and again divided.

DIVIDING INSTRUMENTS

The Hand Shovel.—The division of a lot of ore into sample and reject by shoveling it over, and putting every fifth or tenth shovelful aside as the sample, is an old and useful method of sampling. The size of the pieces and the richness of the minerals must, of course, correspond with the lot size, while the restricted number of selections infers that the lot has received some mixing.

There are evidently 1,000 selections made for sample if a 50-ton lot of ore is hand shoveled in 10-pound shovelfuls, and every tenth one is put to one side as the sample. As the size of the sample decreases the number of selections gets critically small, but is in a measure compensated for by the mixing.

The method of shovel sampling is easily carried out if the material has to be moved by hand and is fine enough. Crushing must be introduced at the required stage if the material is not fine to start with. It is a common practice to shovel sample for the first, or first two divisions, and finish with the cone and quarter method.

For nearly all large scale metallurgical work shovel sampling is far too slow and costly; the method also suffers because of the carelessness of the workmen and because of an undesirable element of judgment in handling lots of mixed sizes.

The Split Shovel.—The split shovel is in common use in some of the Montana sampling plants. It offers a convenient means of dividing a lot, but the number of independent cutting which can be made is small. It makes no difference how few selections are made if a lot of ore is well mixed, but in practice it is nearly always easier to make many cuts than it is to mix the ore. Figure 6 shows a sample man sliding the reject from a split shovel into discard pans. Material remaining in the closed pockets of the shovel will be piled and cut again.

Riffle Cutters.—The widely-used Jones type of riffle sampler, built either as a floor stand or in table size, is a remarkable instrument for dividing and mixing ore samples. Suitable designs have from 16 to 40 slots, are rigidly made, and have the slots wide enough to safely accommodate the particles poured over them. The ratio of 4 to 1 is generally considered a safe one with which to express the "width of opening" over "diameter of particle" relationship. This ratio is usually greatly exceeded when riffling small sizes and is often far from being attained when riffling coarse material. The instrument well deserves to be given both more variety in manufacture and more use in the industries.

Figure 2 shows the 26-slot stand cutter used at the Montana State School of Mines. Figure 7 shows a riffle with alternate bottoms closed, but as the cutter is fixed on a sharp slope it is a Jones riffle to all intents and purposes; this cutter is in use in several Montana

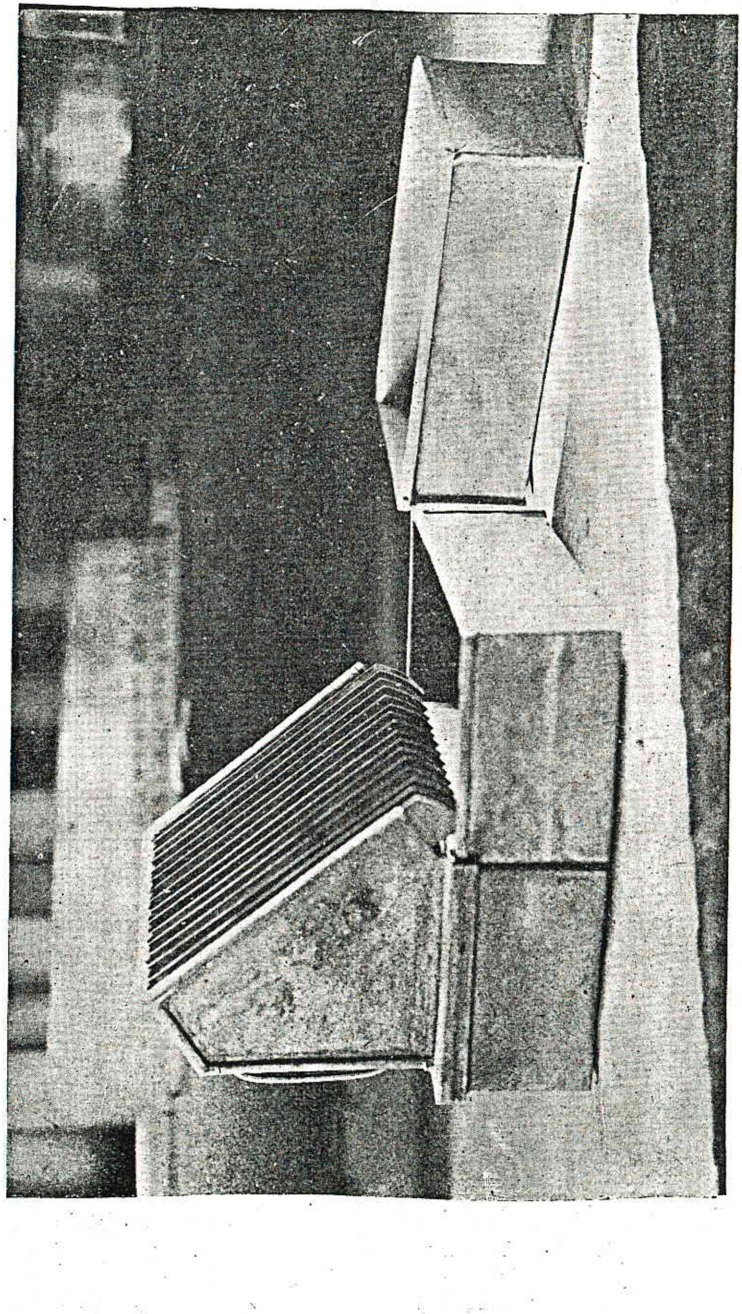


FIG. 7.—INCLINED TABLE RIFFLE.

This cutter has 16 slots. A similar cutter with 30 slots and half the slot width is more often used.

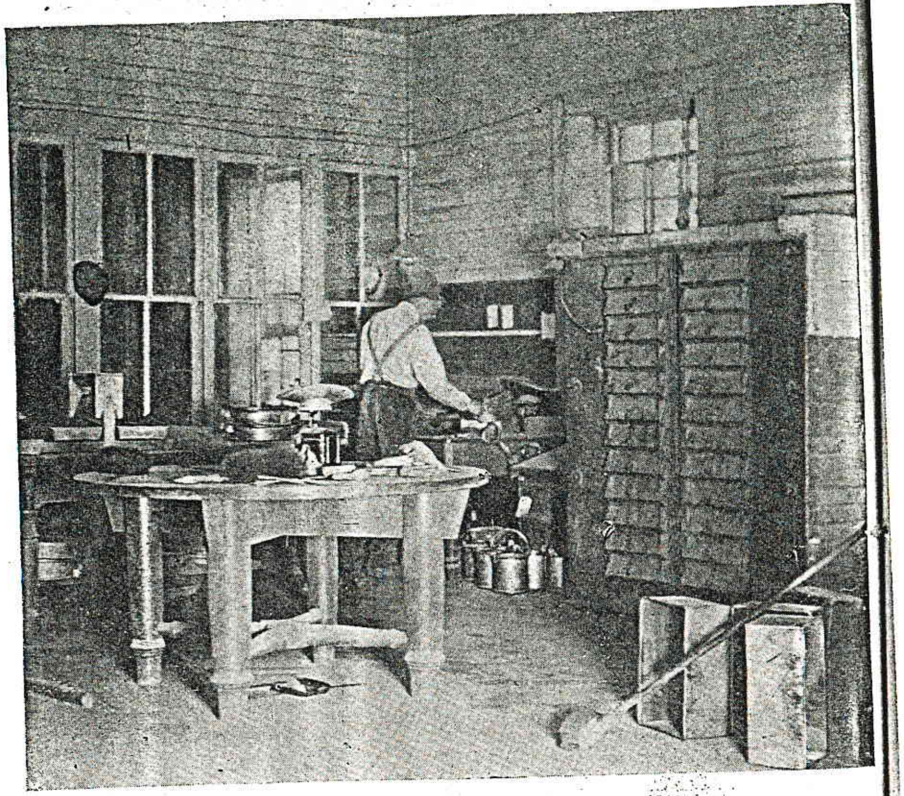


FIG. 8.—CORNER IN EAST HELENA BUCKING ROOM.

Bucking boards, scales, riffles, cabinet dryer, sieves, and sample holders can be seen.

mills. In Figure 8 is seen a neat table riffle at the very left of the picture; this design is in use at the mills of the American Smelting & Refining Co. at East Helena, Montana.

Pipe Samplers.—Pipe samplers have long been used in Montana and in other sections of the country, notably at the zinc mines in Missouri and Oklahoma, where the cars of concentrates are sampled with the "gun," as the pipe sampler is there called, immediately after loading out for the smelters. Since the advent of flotation concentrates, which are notoriously sticky and difficult to handle, pipe samplers have greatly increased in utility in the Butte district.

Ore suitable for pipe sampling consists of concentrates or other fine material which has been produced in a regular and uniform manner, or has been mixed in handling. Flotation concentrates may very in consistency from a thin mud to a dry powder. When sampling carloads of the muddy concentrates men are sometimes barely able to support themselves on the drying crust. Cars which have traveled long distances may have the load so firmly packed that an auger, rather than a pipe, is required to cut out the samples.

According to the Montana practice, lots of concentrates are sampled at the mill by the shipper and later at the custom sampling plant, or smelter. Data as to agreement of assays is not available, but results are said to be wholly satisfactory.

Pipe sampling of a carload of concentrates usually begins at one end of the car, where a row of holes two feet apart and two feet from the end wall is made; a parallel row is then punched two feet nearer the center and this is repeated until samples are taken in a systematic order over the entire length of the car from points about two feet apart. Hopper-bottomed cars have the two deep pits, which are hard to penetrate, but the pipes are long enough to touch the steel bottoms, as in the shallowed portions of the car.

Pipes are commonly four to five feet long, three inches diameter at the top and two inches at the cutting edge. For firm materials, easily cleared, circular tubes are used; for sticky loads the pipe is slotted and provided with a scraper with which the sample man quickly forces the core out into the sample pan. A sample of 250 pounds weight is usually obtained by from 40 to 75 insertions of the pipe. Figure 9 shows three men sampling a car of flotation concentrates at the Washoe Sampler.

Pipe sampling of the fine concentrates may continue in the bucking room until the final samples for moisture and assay are taken. The sample man merely goes over the pans of first sample with a smaller pipe, a foot long and an inch in diameter, and punches from all parts of the pans enough cores to give a sample of the required weight.

The justification of pipe sampling clearly depends on the uniformity of the lot of ore as it is spread in the bin or car. To test the uniformity of a lot of concentrates in a railroad car, the author took

FIG. 9.—PIPE SAMPLING OF FLOTATION PRODUCT.
The pipes are of the slotted variety and cleaned out with a scraper.

40 four-ounce grab samples from the pipes as a car of flotation concentrates was being sampled at a custom plant. Each of the samples was dried, ground, mixed, and analyzed for iron with the following results:

Sample	%Fe	Sample	%Fe	Sample	%Fe	Sample	%Fe
1	14.7	11	14.1	21	13.4	31	14.8
2	14.2	12	14.8	22	15.5	32	16.2
3	13.8	13	14.5	23	13.1	33	15.7
4	14.5	14	13.8	24	13.1	34	16.3
5	14.0	15	14.5	25	13.1	35	17.2
6	14.2	16	14.1	26	18.3	36	15.4
7	14.3	17	13.2	27	13.8	37	14.8
8	14.1	18	13.6	28	14.5	38	15.3
9	15.0	19	12.8	29	14.8	39	17.4
10	13.0	20	15.0	30	15.0	40	14.3

The average of all the figures is 14.7%, and the average deviation of a single analysis is only .9% from the 14.7%. In other words, the average deviation from the mean is approximately 1 part in 15. From the sampling point of view it means that one could take a grab sample anywhere in the car and the probable analysis of that sample would be accurate to better than 1 part in 15.

The main pipe samples, from which the little samples just discussed were taken, weighed 25 to 30 times as much and were piled and again piped before drying, mixing, and grinding for the regular sample. The main sampling work might reasonably be expected to be 10 times as accurate as the author's grab sampling, which would make the main pipe sampling accurate to more than 1 part in 150, a precision considerably greater than ordinary assaying or wet chemical analysis.

Pipe sampling of fine, mixed materials is very rapid and cheap; the test confirms the prevalent opinion that it is also accurate.

The Brunton Vibratory Cutter.—One of the earliest sample cutters used in western sampling mills consists of a thin wedge of steel plates riveted to a shaft and set in the center of the ore stream as it flows from a spout. The thin wedge has the shaft inclosed along its base and points upward into the ore stream; by turning the wedge to one side or the other it deflects the entire ore stream first to one side, then to the other side; separate spouts catch the two ore streams made by the deflector. Spill is taken care of by steel wings on each side of the wedge or blade. The sample can be made any fraction of the lot by the relative periods the deflector remains pointing toward either sample or discard spout. Pins on a rotating disk engage a cam at the far end of the shaft and so throw the blade, first to one side, then to the other; by the adjustment of the pins in holes around the edge of the disk the periods are determined and the periods, in turn, determine the fraction selected for sample.

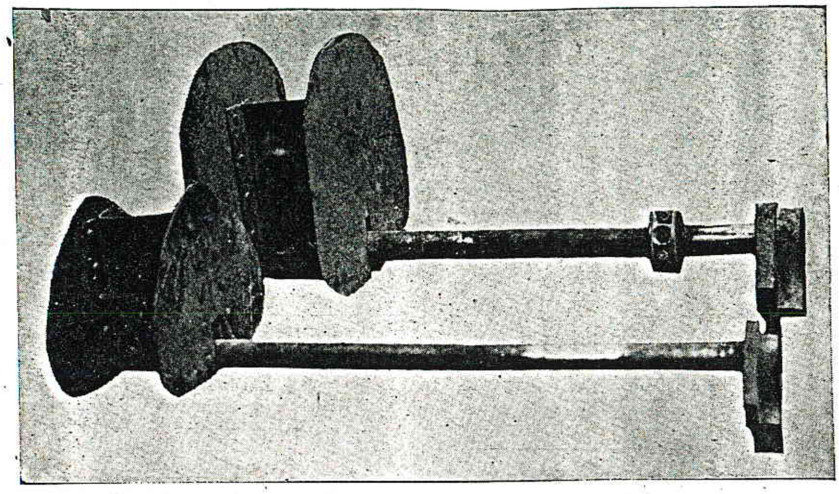


FIG. 10.—BRUNTON VIBRATORY CUTTER BLADES.

Two sizes as used in one of the East Helena Sampling Mills.

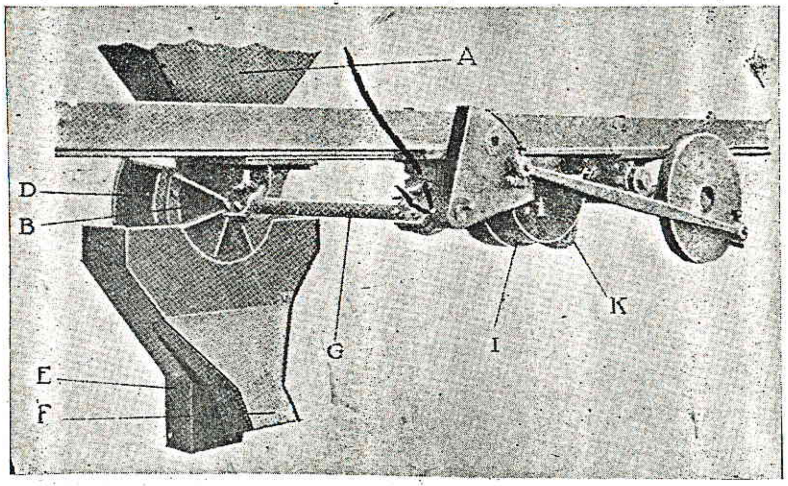


FIG. 11.—MECHANISM OF BRUNTON OSCILLATORY SAMPLER.

A crank arm on a disk changes the rotary motion of a pulley to the oscillations of the cutter.

(After Brunton, Trans. Am. Inst. Min. Engrs., 1909.)

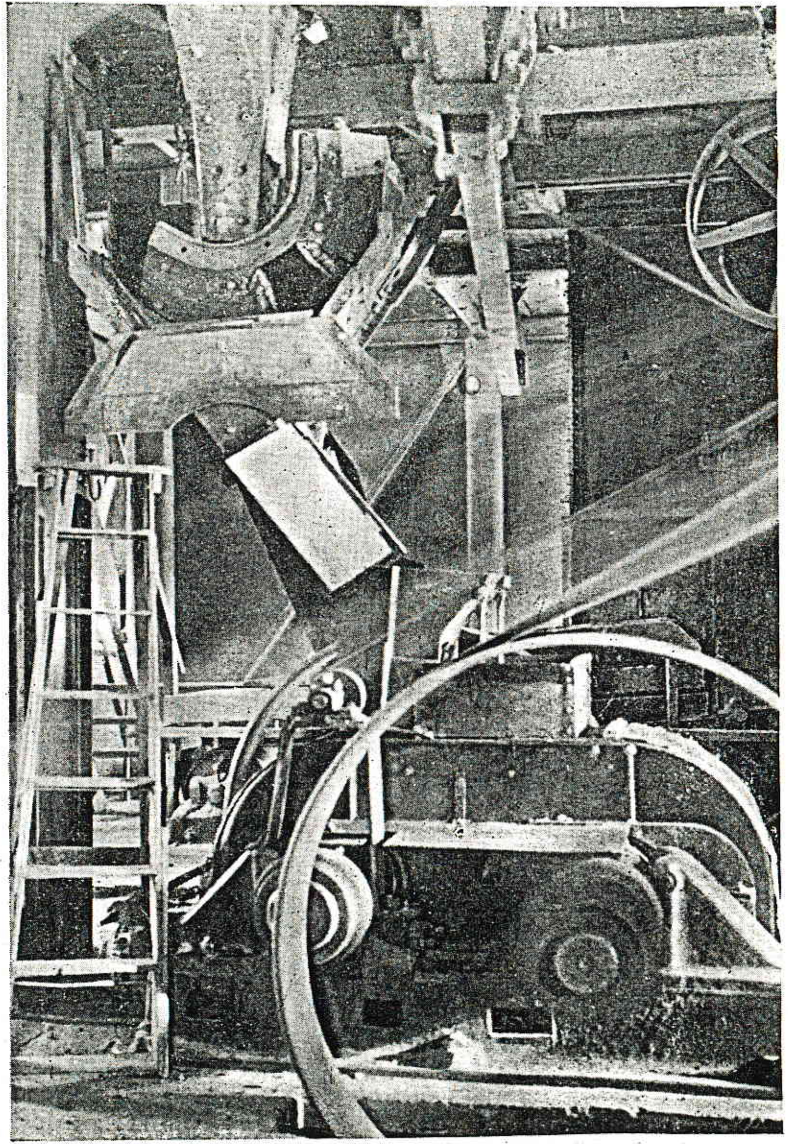


FIG. 12.—FIRST SAMPLER AND ROLLS AT THE WASHOE SAMPLER.

The steel housing in front of the oscillator is turned down to expose the parts. The sample drops through the opening and falls to the rolls, the reject is deflected away to a spout to the conveyor behind the rolls.

Two sizes of Brunton vibratory cutter blades are seen in Figure 10; they happen to be spare parts for the machines now used in only one mill in Montana.

The vibratory cutter slips through the ore stream quickly, which is always an advantage; the blade also cuts the stream in the same direction for sample. If the repeated cutting in the same direction is considered a disadvantage, it is eliminated in the Brunton oscillatory cutter, which is next described. The driving mechanism of the vibratory cutter would doubtless have been further perfected if the oscillatory cutter had not been invented.

The Brunton Oscillatory Cutter.—In the States of Colorado, Montana, Nevada, and Utah are many sampling mills built after the Taylor and Brunton design and equipped with the Brunton "time-sampler", or oscillatory cutter. The general scheme of the driving machanism is plain after studying Figure 11, while a cutter is seen in place in Figure 12.

The cutter is of the general intersecting saucer type, but the machine oscillates back and forth across a 120° arc and its cutting edges enter the ore stream first from one side, then from the other, instead of always from the same side. The small sample cut is plainly made by a division of the stream, the deflecting planes entering first from one side, then from the other. The division of the ore stream is smooth and clean-cut, while the driving mechanism is noiseless and lasting. The wearing parts of the oscillatory cutter are the edges of the sample segment and the floor of the larger reject casting; the small sample casting can be frequently renewed at slight expense, thus maintaining the cutting edges, while the larger casting is renewed as often as worn out.

The East Butte Cutter.—Figure 13 illustrates the mechanical cutter used at the East Butte mill. It rotates in a horizontal plane and is obviously of the intersecting saucer type. The unit seen in Figure 13 has 4 sample openings and would make a 20% selection, the units actually in place in the mill have 2 openings and make about 10% selections. The cutters are entirely suspended from above and the ore stream enters them either vertically or at a steep angle.

The Vezin Cutter.—The Vezin type of mechanical cutter is made in several modifications of the original intersecting cone type. In all forms the lower cone, either real or imaginary, is extended upward on two opposite arcs in a sort of wing design; it is into the rotating wings that the sample falls and is discharged through the restricted lower apex of the cone. It is well to compare this machine (Figure 14) with the East Butte cutter and note that both are closely related; by merely altering the relative sizes of the parts, the sample or the discard is made to fall through the apex of the inverted cone.

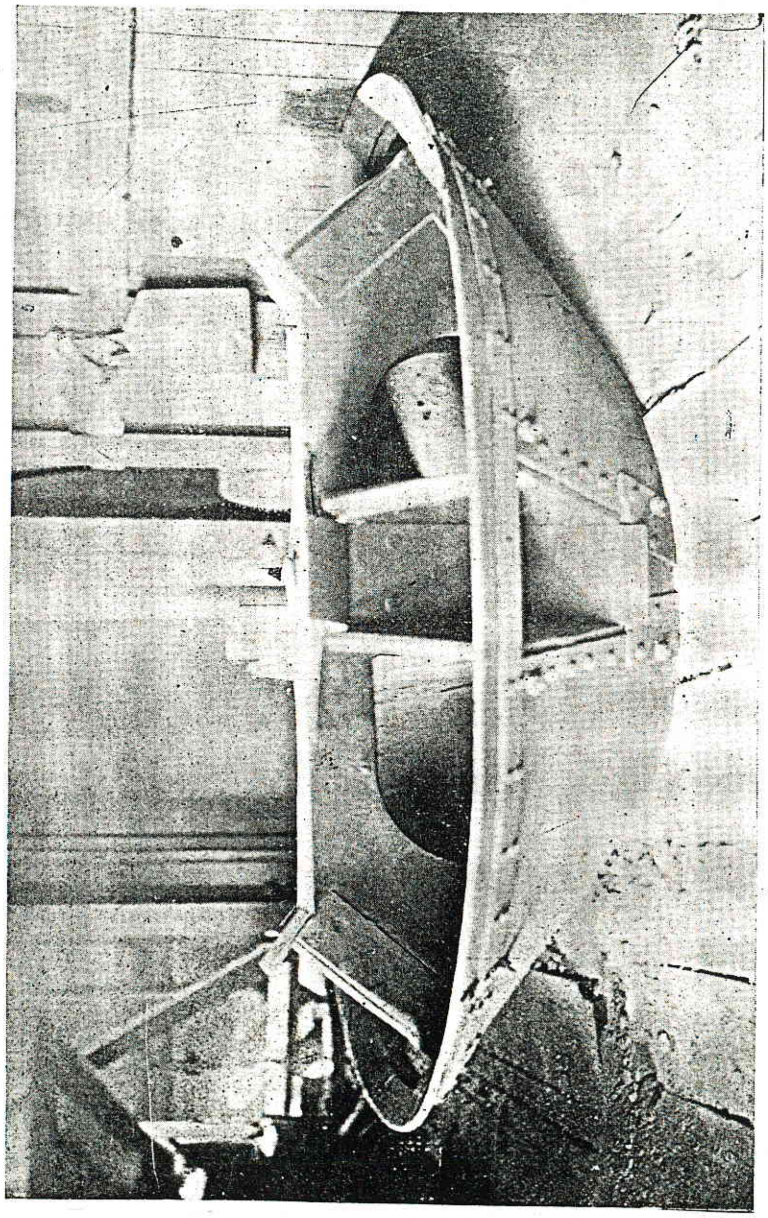


FIG. 13.—EAST BUTTE TYPE OF SAMPLER.

This cutter has four slots; the cutters installed have only two slots.

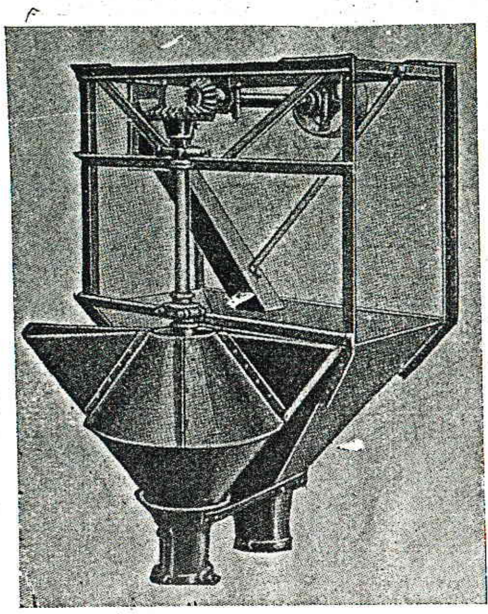


FIG. 14.—VEZIN SAMPLER.
Several modifications of the type are in common use. This is the design supplied by Traylor Eng. & Mfg. Co.

The Snyder Sampler.—A slotted saucer, rotating on a horizonal axis, forms the base idea of the Snyder sampler. A sloping feed spout neatly directs the stream of ore through the inclined opening as the sample slot passes. The similarity to the several other intersecting saucer types is apparent from Figure 15. The machine usually has two sample lots, as seen in the picture, but the only unit known to be installed in Montana, which is a 28-inch machine in the ore-dressing laboratory of the State School of Mines, has a single slot.

The actual amounts of sample cut by the various samplers is an important topic which has not been thoroughly investigated. The only data which the author has seen are figures obtained by the Anaconda Copper Mining Company. These figures indicate that, in their mills, considerably less than the expected amount is selected.

The uniformity of the ore stream on entering the cutter is a large factor in the constancy of the fraction cut for sample. The mixing and retarding drums at the East Butte mill give an exceptionally uniform feed to the cutters and the fraction cut out is reported to be practically constant.

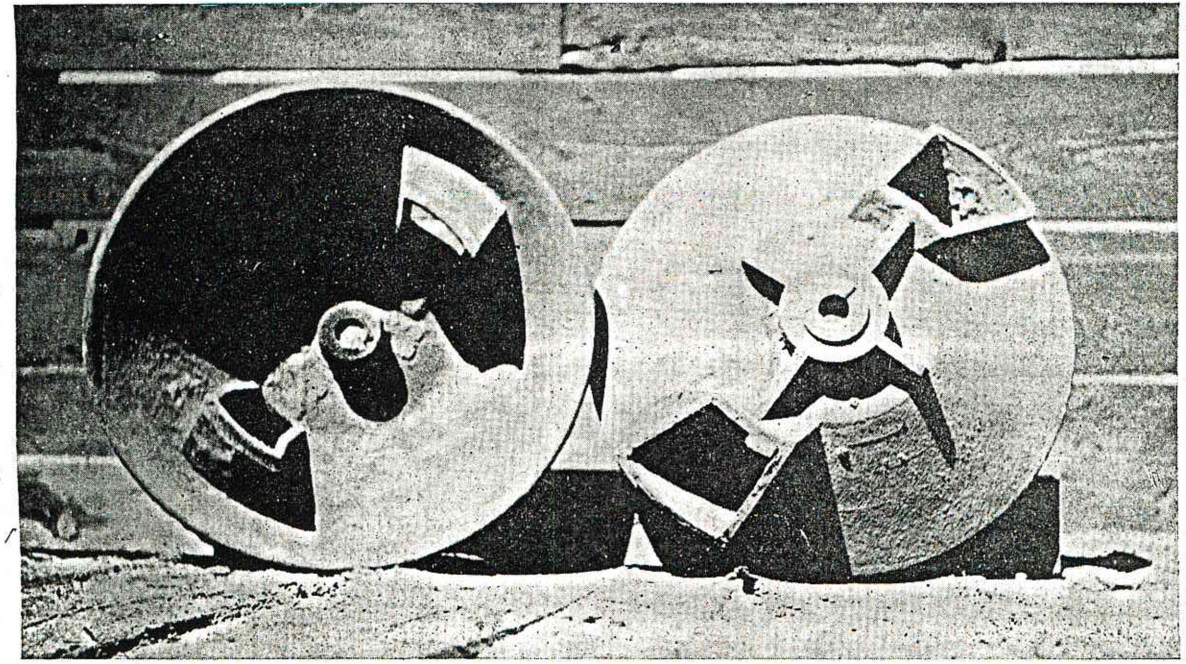


FIG. 15.—TWO-SLOT SNYDER SAMPLER.
The saucer rotates in a vertical plane.

A careful inspection of the relative sizes of cutter openings and ore pieces shows that the ratio of 4 is not often attained in the case of the first cutters. It is believed that attention to this detail will add to the perfection of future mills.

The number of cuts made by mechanical cutters is sometimes insufficient for accurate work, especially if the lot is hurried through the mill. The difficulty with speeding up cutters is the batting and scattering action on the larger pieces as the velocity of the machine increases. Many cutter designs are already on the market, but, if it should be found desirable to make more cuts in a unit time, it may not be too much to expect an improved design for high speed work.

MIXING MACHINES

Henry A. Vezin is commonly credited with first having used mixing and retarding drums in large scale sampling operations. He placed staggered baffles in the drums to mix the ore before it fell in a steady stream to the cutter below.

The mill of the East Butte Copper Mining Company, at Butte, Montana, has two mixing and retarding drums (see Figure 16) before the second and third cutters, respectively. Thus, as the first cutter is fed by the main ore stream, all three cutters are fed with a decidedly well-mixed and uniform stream of ore.

The other Montana mills depend largely on shaking feeders to mix and spread the samples, which one cutter delivers to the next. A revolving disk is, however, found in the No. 2 mill at East Helena, between two Vezin cutters; this feeder gives an especially uniform feed to the lower Vezin.

Retarding machines are highly desirable to elongate and equalize the ore stream after a cut has been made. Natural spreading in the short spouts does not give a smooth ore flow to either rolls or cutters. Synchromatic gaps and irregular fractions are naturally greatest when the stream equalization is least. Aside from the equalizing for rolls and cutter, any mixing of the material may be considered an incidental matter if the number of selections by each machine amounts to more than a thousand, and the values in the large and rich pieces do not exceed the limits for accuracy. The mixing of the ore stream is, however, an assurance of correct results if the number of cuts is reduced to only a few hundred.

It may not be out of place here to analyze just what happens on mixing a small lot of ore with the riffle cutter. We will suppose that a lot is poured over a 30-slot riffle with 50 shakings to and fro, the two halves are then united and the pouring repeated; the entire operation of cutting and uniting is continued until it has been done 10 times.

The slots divide the sample into 30x50, or 1,500 portions, at each pouring. The 1,500 portions are not superimposed but are spread out into 50 layers at each pouring; when the halves are joined the 50 layers from each side get superimposed, or, as may be said, each

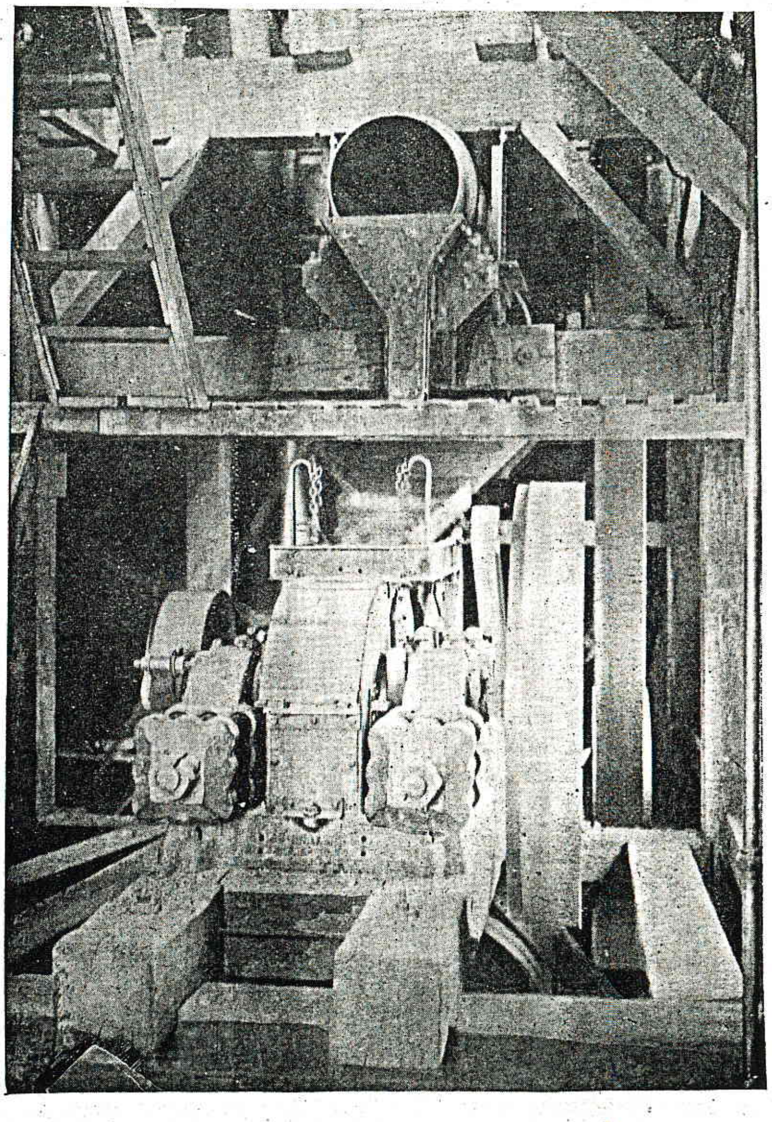


FIG. 16.—DRUM MIXER, SAMPLER, AND ROLLS IN EAST BUTTE MILL

This is the upper drum mixer, and the No. 2 sampler over the No. 2 rolls pouring puts the material in 100 layers when the halves are united. On repeating the work 10 times the material clearly gets divided into 10x1,500 portions and the full numbers of layers increase to 10x100, or 1,000. The 100 layers made by the 1,500 portions at any one pouring give a splendid lateral distribution of any inequality, but cannot possibly equalize throughout the pulp any segregation in either the first, middle, or last of the lot poured. But uniting the halves and repeating does effectually dispense the vertical segregation, as the inequalities in the first, middle, or last of the pouring may be called. Thus, with a few repetitions, the lot becomes uniform laterally and vertically, or is well mixed. The previously described test on the quartz and iron ore is very good proof of the efficiency of riffle mixing.

DRYING MACHINES

It has already been mentioned that the Montana practice uses both steam and electrically heated cabinet shelf-dryers, as well as large steam tables. In all cases the operation is very simple and requires no attention. Although drying requires about the same time as mill sampling, it is, nevertheless, so rapid and simple that there is little incentive to speed up the process. Faster drying would inevitably demand higher and injurious temperatures, as well as moving parts to the drying apparatus. If all other essential operations in sampling were in as satisfactory a status as that of drying it would be fortunate, indeed.

SAMPLING OF TEST LOT BY STATE BUREAU

The results of resamplings and check samplings have been published from time to time, but to test the matter of sampling more exhaustively and at the same time provide tangible evidence that the custom mills in Montana are doing satisfactory work, the State Bureau acquired the use of a lot of ore and had it sampled at the three most important custom mills.

The carload weighed a little over 50 tons, and was from a Montana mine which is producing a silver-lead ore of considerably greater value than the average of the Butte mines. The ore was run-of-mine product and, like many high sulphide ores, more than half of it consisted of rather fine to earthy material. At least a quarter of the material was in lumps over two inches in diameter, and the rest was intermediate.

The minerals varied in size and texture from large pure grains to fine intimate mixtures. The mineral composition was, approximately:

Quartz	30%	Arsenical tetrahedrite (gray copper ore)	15%
Pyrite	25%	Zinc blende	5%
Galena	15%		
Other gangue minerals	10%		

The lot typified Montana ore of the better sort, with commercial values in gold, silver, copper, and lead; an ore suitable for demonstrating the precision of sampling on customary and average materials.

The lot of ore was sampled twice at the Washoe Sampler, resulting in two independent final pulps. The lot was sampled in the No. 1 mill at East Helena, using the coarse by-pass; it was tenth-shovel sampled at East Helena, and then finally ground to pass the 2-mesh screens and again sampled in the No. 1 mill, this time in the ordinary way. The lot was sampled once at the East Butte mill while in the coarse condition, but duplicate portions were taken from the mill product before fine grinding.

Six different samplings were thus made, giving seven pulps; three different types of mechanical cutters were used and once the lot was hand-sampled. The hand-sampling was first by the tenth-shovel method, and it was then coned and quartered until the final splitting for packets was made with a table riffle.

The actual sampling time at the different mills varied; at the Washoe Sampler the lot required 20 and 30 minutes at each respective sampling; at the East Butte mill 50 minutes were required for the sampling; at East Helena fully 2 hours were taken each time the lot was run through the mill.

The final sampling at East Helena, after crushing to half-inch size, afforded a good standard test, since the material was then all in small sizes, had undergone repeated dispersions and retardations in the mills, and was cut at least 3,500 times by each of the mill samplers.

The lot was sampled in the presence of the author in each instance; no particular arrangements were made at the mills, nor was the sampling carried out in any way differently from the routine procedure which the author has repeatedly observed when he has happened into the mills.

The seven final pulps were analyzed under as nearly identical conditions as possible in the State School of Mines laboratories. Lest too few results might involve deviations in the chemical work instead of in the sampling, the analyses were checked over from 6 to 8 times so as to furnish average figures for each component. Pulp inequalities, chemical influences, and manipulations all introduce deviations, which repeated analyses alone can eliminate so as to show the precision or lack of precision in the sampling.

The results of the analytical work follow:

Sample	Silver, oz. per ton	Gold, oz. per ton	Lead, per cent.	Copper, per cent.	Iron, per cent.	Insoluble, per cent.
A	37.8	.21	12.73	1.74	14.49	32.58
B	37.3	.22	12.46	1.69	14.43	33.07
C	37.0	.23	12.50	1.74	14.46	32.87
D	37.9	.21	12.64	1.78	14.77	32.01
E	37.3	.21	12.64	1.76	14.52	32.83
F	37.4	.21	12.72	1.70	14.35	32.50
G	37.5	.22	12.91	1.73	14.72	32.22

One conclusion, only, can be drawn from the results in the table: namely, that the sampling was well done in each instance. The difference between the several pulps is less than excellent analysts might report on one and the same pulp.

The individual items and gross values of the lot may be calculated for each sampling, reckoning silver at $1.25 an ounce, gold at $20.67 an ounce, lead at 8 cents a pound, and copper at 18 cents a pound.

Sample	Silver	Gold	Lead	Copper	Total	Deviation From Mean
A	$47.25	$4.34	$20.37	$6.26	$78.22	$0.44
B	46.62	4.55	19.94	6.08	77.20	0.58
C	46.25	4.75	20.00	6.26	77.26	0.52
D	47.38	4.34	20.22	6.41	78.35	0.57
E	46.63	4.34	20.22	6.34	77.52	0.26
F	46.75	4.34	20.35	6.12	77.56	0.22
G	46.88	4.55	20.66	6.23	78.32	0.54

The total values range from $77.20 to $78.35, an extreme difference of $1.15; the average deviation from the mean of all the totals is $0.45. Ore producers should certainly be well satisfied with custom sampling which shows this degree of precision.

MILL FLOW SHEETS

To indicate the treatment by which each of the samples was obtained in the State Bureau test, the following flow sheets have been prepared.

Washoe Sampler—

Cars unloaded over hopper; 18'x20'x11' deep
Shaking grizzly feeder; 1.5"x2.0" holes in 24"x20" section
Crusher; 20"x10" opening
Shaking tray
Elevator to top of mill
No. 1 cutter; Brunton oscillatory, 7.0"x10.5" opening, 40 cuts per minute
Sample; 20%, or 20,000 lbs. on 50-ton lot
Shaking tray; 12" effective length
No 1 rolls; 16"x36"
No 2 cutter; Brunton oscillatory, 6.0"x8.0" opening, 28 cuts per minute.

Sample; 20%, or 4,000 lbs. on 50-ton lot
Shaking tray; 9" effective length
No. 2 rolls; 14"x30"
No. 3 cutter; Brunton oscillatory, 4.5"x6.75" opening, 63 cuts per minute

Sample; 20%, or 800 lbs. on 50-ton lot
Bell distributor
No. 3 rolls; 12" x 24"
No 4 cutter; Brunton oscillatory, 3.5"x5.0" opening, 68 cuts per minute.

Sample; 160 lbs. on 50-ton lot
Trolley bucket
Steel sampling floor in bucking room
Split shovel to 8 to 10 lbs.

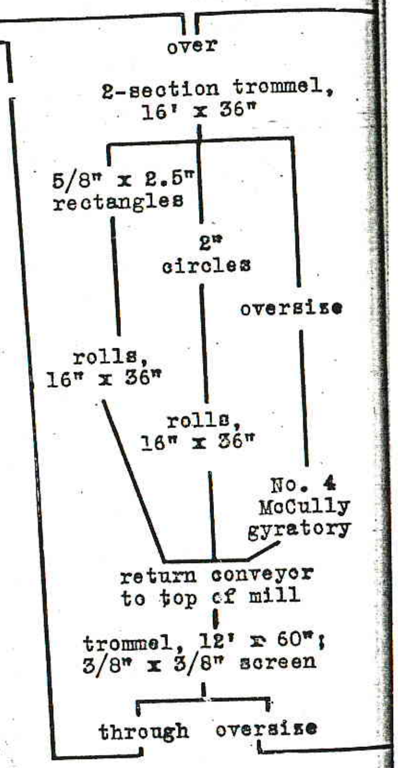
Sample; 8 to 10 lbs.
Dried in shelf cabinet, electric heat
Engelbach grinder
Riffle cutter; 26 slots, each .64"x2.0"

Sample; 32 ounces
Braun disk grinder
Hand sieves; 100, 120, 150, and 200 mesh
Rolled on pebble-surfaced oil cloth 1,000 times
Sample split for 4 packets with inclined riffles

East Helena No. 1 Mill—

Cars unloaded onto steel pan conveyor; pans 18"x18"x6"
Chute to No. 5 McCully gyratory crusher
Belt conveyor, 16" belt, to top of mill, under magnet
Chute to

A (fine grinding and sampling)
Trommels; 12'x60", 3/8"x3/8" mesh



under

No. 1 cutter; Vezin, wings 14" and 3"x20", 30 cuts per minute

Sample; 20%, 20,000 lbs. on 50-ton lot
Shaking tray; 4' effective length
No. 2 cutter; Vezin, wings 7" and 1.5"x10", 34 cuts per minute

Sample; 20%, 4,000 lbs. on 50-ton lot
Shaking tray; 4' effective length
Rolls; 12"x12"
Shaking tray; 4' effective length
No. 3 cutter; Vezin, same as No. 2 cutter, 40 cuts per minute

Sample; 20%, 800 lbs. on 50-ton lot
Shaking tray; 3' effective length
No. 4 cutter; Vezin, same as No. 2 cutter, 40 cuts per minute

Sample; 20%, 160 lbs., on 50-ton lot
Locked sample hopper

Sample; wheelbarrow to steel sample floor in or near bucking room
Cone and quarter, or riffle cut, to 10 to 12 lbs.
Dried in shelf cabinet or on steam table
Bell grinder
Hand sieves; 100, 120, and 150 mesh
Table riffle to 24 ounces
Rolled 15 minutes on special paper
Sample split with table riffle to 4, 6-oz. packets

B (coarse sampling)
No. 1 Vezin cutter

Sample; 20%	Discard, out of mill on conveyor

Return conveyor to top of mill
Chute to No. 2 trommel, 12′x60″, ⅜″x⅜″ mesh

under	over
No. 2 Vezin cutter	2-section trommel and closed circuit, as above

Same as under A to finished sample

East Butte Sampling Mill—

Cars unloaded over mill hopper
Shaking feeder
Crusher; 12″x24″ opening
Spout to elevator
Elevator to top of mill
No. 1 cutter; East Butte, 8″x12″ openings, 28 cuts per minute

Sample; 10%, 5 tons on 50-ton lot
Shaking tray; 3′ effective length
No. 1 rolls; 16″x36″
Drum mixer; 6′x2′, 16 r.m.p.
No. 2 cutter; East Butte, 6″x7.75″ openings, 26 cuts per minute
Sample; 10%, 1,000 lbs. on 50-ton lot
Shaking tray; 3′ effective length
No 2 rolls; 10″x24″
Drum mixer; 5′x23″, 10 r.p.m.
No. 3 cutter; East Butte, 4.5″x5.5″ openings, 16 cuts per minute

Sample; 10%, 100 lbs. on 50-ton lot
Shaking tray; 3′ effective length
No. 3 rolls; 9″x9″
Sample can
Cast iron riffle cutter to 15 to 20 lbs.

Sample; 15 to 20 lbs. to bucking room
Riffle cutter to 8 to 10 lbs.
Sample to shelf cabinet or table dryer
Bell grinder
Table riffle to 16 ounces
Hand sieves, 100, 120 and 150-mesh
Rolled on cloth
Table riffle; split to 4, 4-oz. packets

SAMPLING MILLS IN MONTANA

THE WASHOE SAMPLER

The $150,000 steel-concrete custom ore sampling plant of the Anaconda Mining Company is known as the Washoe Sampler and is situated on the main line of the Butte, Anaconda, and Pacific Railroad at Butte, Montana. The main mill portion is absolutely fireproof; it was put in operation in 1911, after a fire had destroyed the previous structure. The new mill was designed and built by the company engineers following the Taylor and Brunton system, which had been successfully demonstrated in the first mill.

Figure 17 is a diagram of the Taylor and Brunton system, which, in a general way, is the scheme followed in the present sampler. The Brunton oscillatory time samplers are, of course, the cutters installed. The types of machines used and the fractions cut at the several stages have already been indicated in the flow sheet of the mill, and are repeated in Figure 17. The main machinery tower has floors 35 feet by 45 feet; the main elevator pit floor is 28 feet below the ground floor, and the ridge of the building is 68 feet above, a total elevation of 96 feet thus being used.

The arrangement of the mechanical, power, and switching facilities is such that 500 tons of ore can be sampled in an 8-hour shift, and 1,200 tons can be put through in 24 hours. A 50-ton lot has been sampled in 9 minutes, but the usual running time is from 20 to 30 minutes; if ore comes in box cars the sampling depends on how long the unloading takes.

Figure 18 shows a portion of the tracks serving the plant. After weighing on the upper set of Fairbanks 100-ton recording beam scales, the cars are lowered by cable to the right hand side of the mill and unloaded in the shed over the mill hopper. As soon as a car is unloaded it can be pulled back with the electric hoist and let down on the left side of the mill to receive the same lot of ore it originally contained. On the loading side of the mill is a second scale; cars can thus be switched from one side of the mill to the other in a minute or two. They can be weighed after loading and then let down farther on the same track for delivery to the railroad.

A wagon and truck unloading shed is seen at the right in Figure 18; below the floor of the shed are fourteen 50-ton hoppers over a conveyor which delivers to the mill hopper. The brick structure seen between the tracks in the foreground of Figure 18 houses the blacksmith shop and change room. Figure 19 shows how massive cast iron pipe may be used for permanent and tight spouting in mill equipment.

The mill normally selects 0.16% of the original lot for the bucking room; by using a special cam arrangement in the mechanism of the second cutter only 0.04% need be cut out. The smaller cut is convenient on large lots. Four cutters will be used on lots weighing between

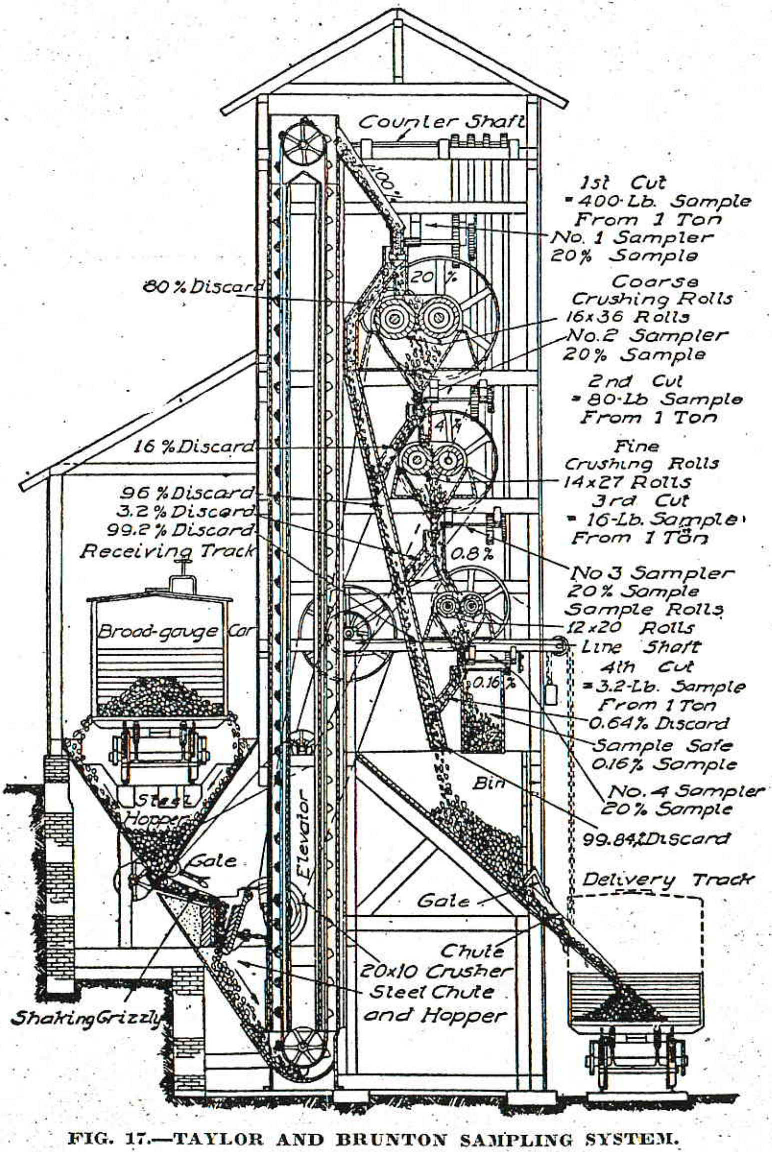


FIG. 17.—TAYLOR AND BRUNTON SAMPLING SYSTEM.
The Washoe Sampler follows this general diagram closely.
(After Brunton, Trans. Am. Inst. Min. Engrs., 1909)

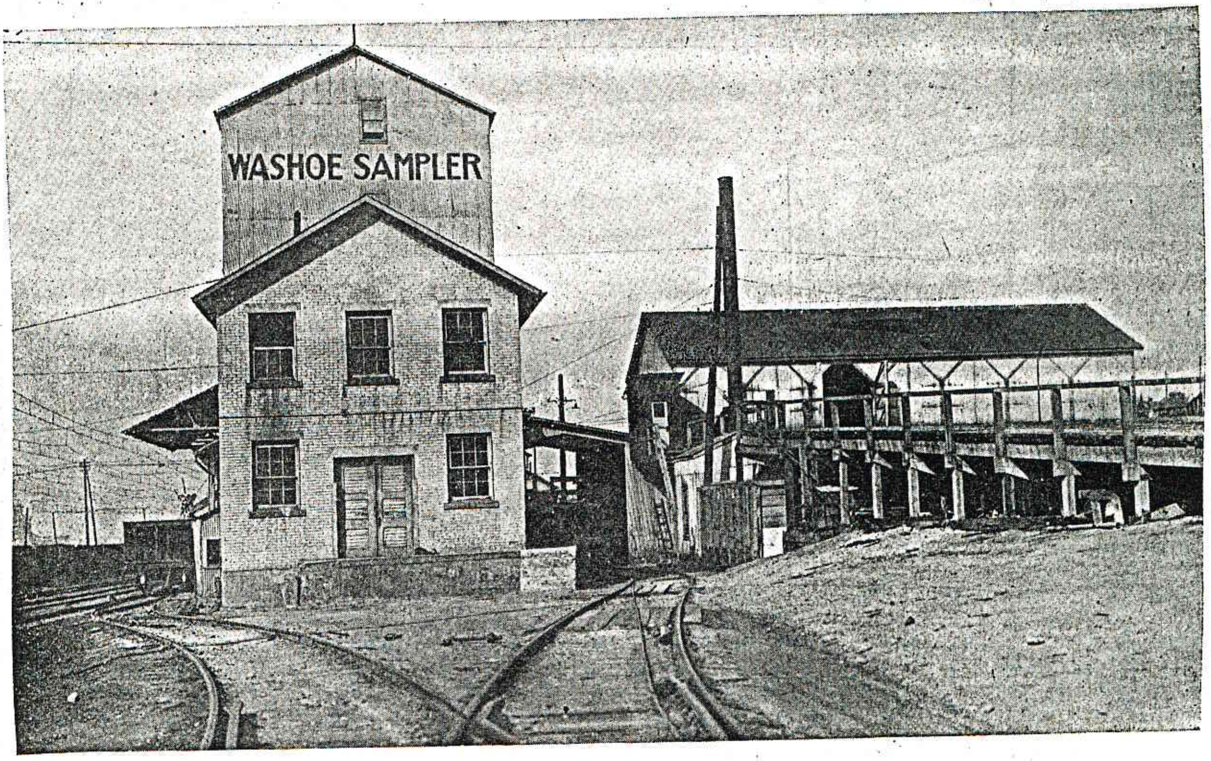


FIG. 18.—VIEW OF WASHOE SAMPLER FROM THE EAST.

A car of ore is unloading in the shed at the right of the sampler, and another is loading out on the left side. The change room is over the blacksmith shop in the brick structure.

50 and 12.5 tons. Smaller lots require less cutters in the following gradations: on lots weighing from 25,000 pounds down to 5,000 pounds three cutters are used, on lots weighing from 5,000 pounds down to 1,000 pounds two cutters are used, and on lots weighing less than 1,000 pounds only one cutter is used. The 1/40th of the entire lot, which must be held 30 days according to the Montana law, is usually the reject from the third cutter on large lots; with smaller lots it may be the reject from the fourth cutter or even the entire lot itself.

The frontispiece shows that the whole front section of the mill is merely a row of 50-ton steel bins; these bins are, of course, available for storing large lots whenever necessary. Beneath the large bins are 48 small bins on the ground floor of the mill, which are in continual use for storing the 1/40th portions. When the legal period has elapsed, the reserve bins are emptied in groups and a composite lot is run through the mill and then sent to the smelter. Superintendent Margetts states that the reserve samples are very rarely called into service; whenever one is used particular attention is given to properly cutting down the entire sample in the presence of the shipper. The shipper is never allowed to take a small grab sample for control assay. When the reserve samples are properly worked down to the final packets, in the same manner as the original sample was, the assay results prectically always check the first assaying. Only in the rarest instances is a complaint carried further.

The tendency to increase the fineness of grinding has been marked in the case of the Washoe bucking room. The 80-mesh sieve once used has been entirely discarded. Copper ores are ground to pass 100-mesh, silver ores are ground to pass 120-mesh, high-silver ores, lead ores, and zinc ores are ground to pass 150-mesh, and high-gold ores to pass 200-mesh. The mill experience has been that lead and zinc ores, as well as the rich gold ores, require the finer grinding for satisfactory chemical results on the pulps. If gold metallics are encountered they are ground with some of the pulp on the bucking board until everything passes the screen. Local experience is that metallics in ores tributary to the Anaconda smeltery easily yield to disintegration when ground with sample pulp; after rolling on the cloth the metallics become uniformly dispersed throughout entire pulp.

THE SAMPLING MILLS OF THE AMERICAN SMELTING & REFINING COMPANY AT EAST HELENA, MONTANA

The American Smelting & Refining Company provides extensive sampling facilities for the custom ores which maintain its lead smeltery at East Helena, Montana. The smeltery started operations just 30 years ago, and some of the sampling mill construction dates from about that time, although many improvements and large additions have been made meanwhile. The plant maintains three distinct sampling mills and a steel sampling floor, 55 feet by 65 feet in the clear, for cone and quarter sampling.

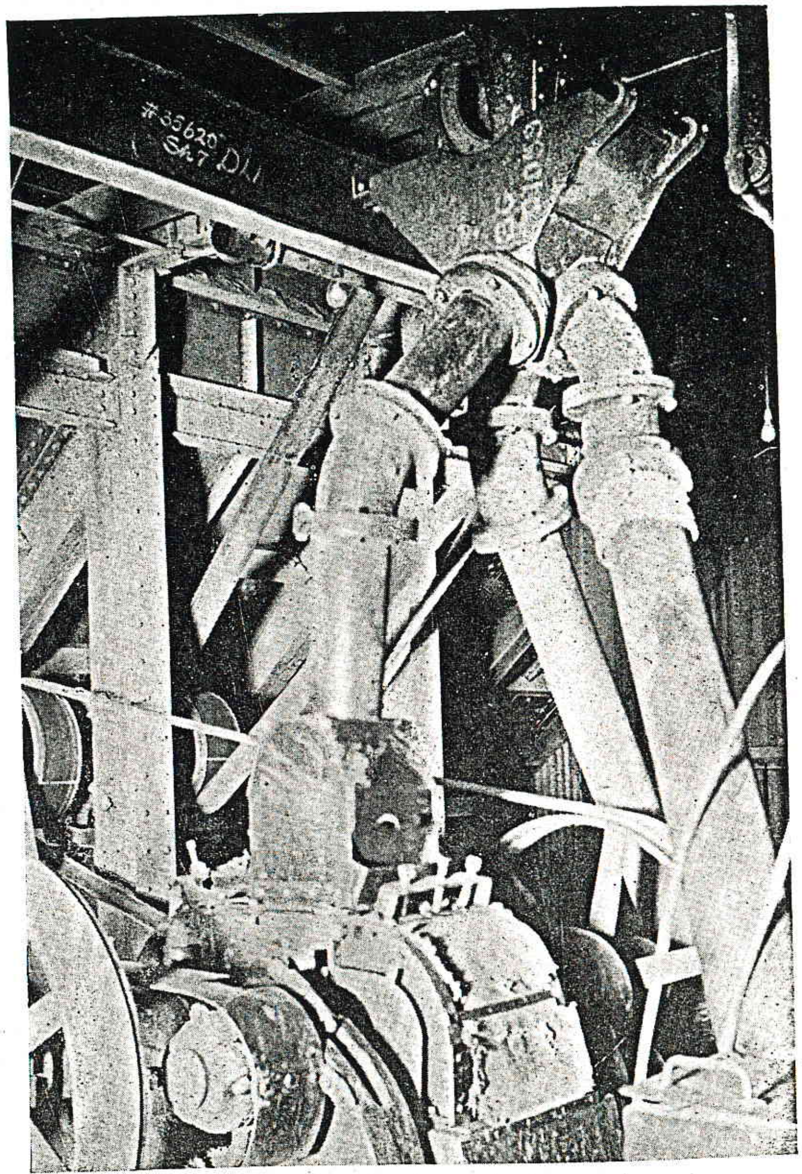


FIG. 19.—THIRD SAMPLER AND THIRD ROLLS IN WASHOE SAMPLER

This set of rolls has the bell distributor inside the housing over the rolls. The pipe at the back of the cutter carries reserve sample to the trolley bucket on the first floor.

The East Helena practice largely demands grinding ores and flux to pass 3/8-inch mesh to meet the roasting requirements. The company has, accordingly, fitted both the No. 1 and No. 2 sulphide mills to crush to this fineness and then to make the sample selections. The fine-grinding not only accounts for the peculiar flow sheet of the No. 1 and No. 2 mills, but consolidates the cutters in small space and assures highly satisfactory mechanical division for sample. The No. 1 mill has provision for either grinding the entire lot to pass the 3/8-inch mesh trommels before sampling, or, after the preliminary crushing in the big gyratory, 1/5th of the lot may be cut out with the first sampler and then reduced to pass the 3/8-inch screen on its way to the last three samplers. The No. 2 mill is also for sulphide ores and furnace products; it has no by-passes in its closed circuit, which grinds to pass a 5/16x3/8-inch screen before sampling with two machines in close series. Both the No. 1 and No. 2 mills are provided with excellent models of the Vezin sampler. The No. 3 mill is for oxide ores and has Brunton vibratory cutters. The No. 1 mill delivers 1/625th of the lot as sample; both of the other mills deliver 1/25th of the lot as sample.

The No. 1 mill is conspicuous in that it contains no elevators; the transfer and elevation of materials is entirely by conveyor, of which there are five in use. The steel pan conveyor, onto which all incoming ores are unloaded, is well indicated in Figure 20. It will be noticed that the conveyor rises at the far end; Figure 21 makes the nature of this rise apparent, for in this cut one sees that the conveyor enters the building which contains the No. 5 McCully gyratory. After passing the gyratory, the ore goes up the long incline to the top of the main mill building. The main building covers a space 63 by 30 feet; the structure is steel and concrete and houses the equipment which has been indicated in the flow sheet of the mill on page 44. Figure 22 is a picture taken on the ground floor of the mill; the two 16x36-inch rolls and the No. 4 McCully gyratory are seen from left to right in the foreground, and the sample cabinet is farther back to the left. The first Vezin is on the second floor above the cabinet, and the three Vezin samplers following are in this cabinet on the ground floor. The two upper drawings of Figure 23 indicate the dimensions, the configuration, and the spout approach to the Vezin samplers in the No. 1 mill. The first Vezin makes 30 sample cuts a minute, the second makes 34 a minute, and the last two make 40 cuts a minute.

The No. 2 mill is a massively-built wooden structure, with floor dimensions 63x36 feet, built to crush sulphide materials to pass 5/16x3/8-inch rectangles before sampling with two Vezin samplers in tandem. After the mill feed passes the crusher, whose opening is 9 by 15 inches, the material is elevated and dropped to a 14x27-inch set of rolls. The material is again raised and enters the trommel with 5/16x3/8-inch openings, from which the undersize falls to the Vezin samplers and the oversize to a set of 14x26-inch rolls in a closed circuit with the trommel. The upper Vezin makes 35 sample cuts a

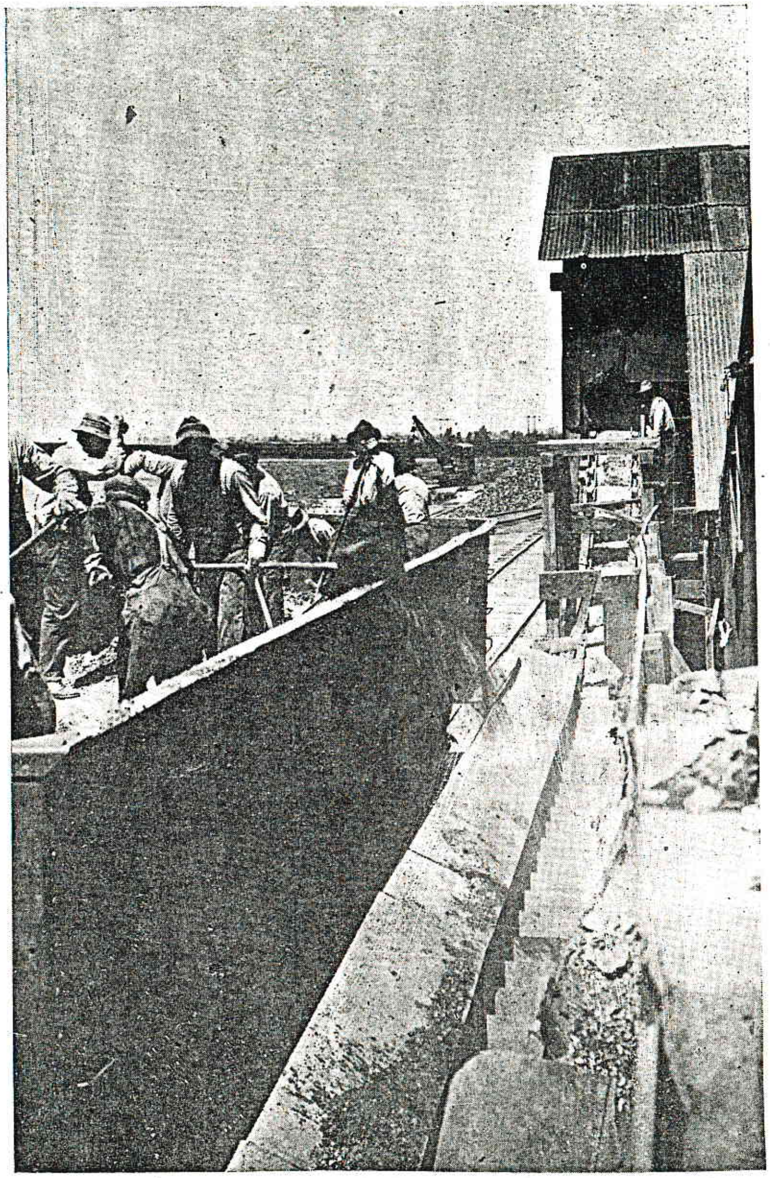


FIG. 20.—UNLOADING ORE AT EAST HELENA NO. 1 MILL.

Steel pan conveyor delivers to the No. 5 McCully gyratory in the shed.

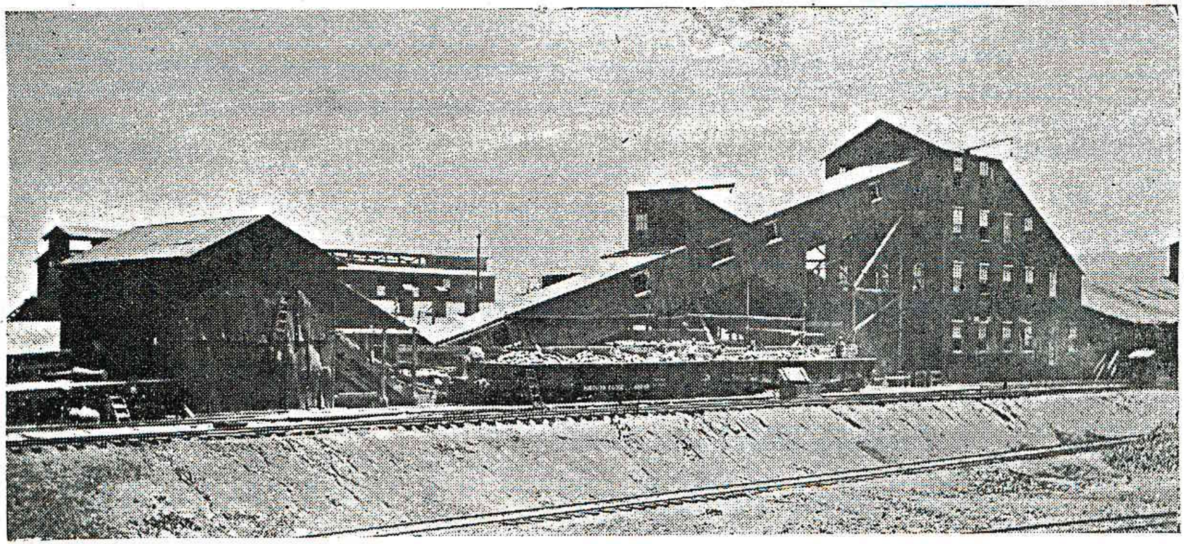


FIG. 21.—SAMPLING MILL NO. 1 AT EAST HELENA.

Men are unloading limestone flux onto the conveyor to the coarse crushing shed.

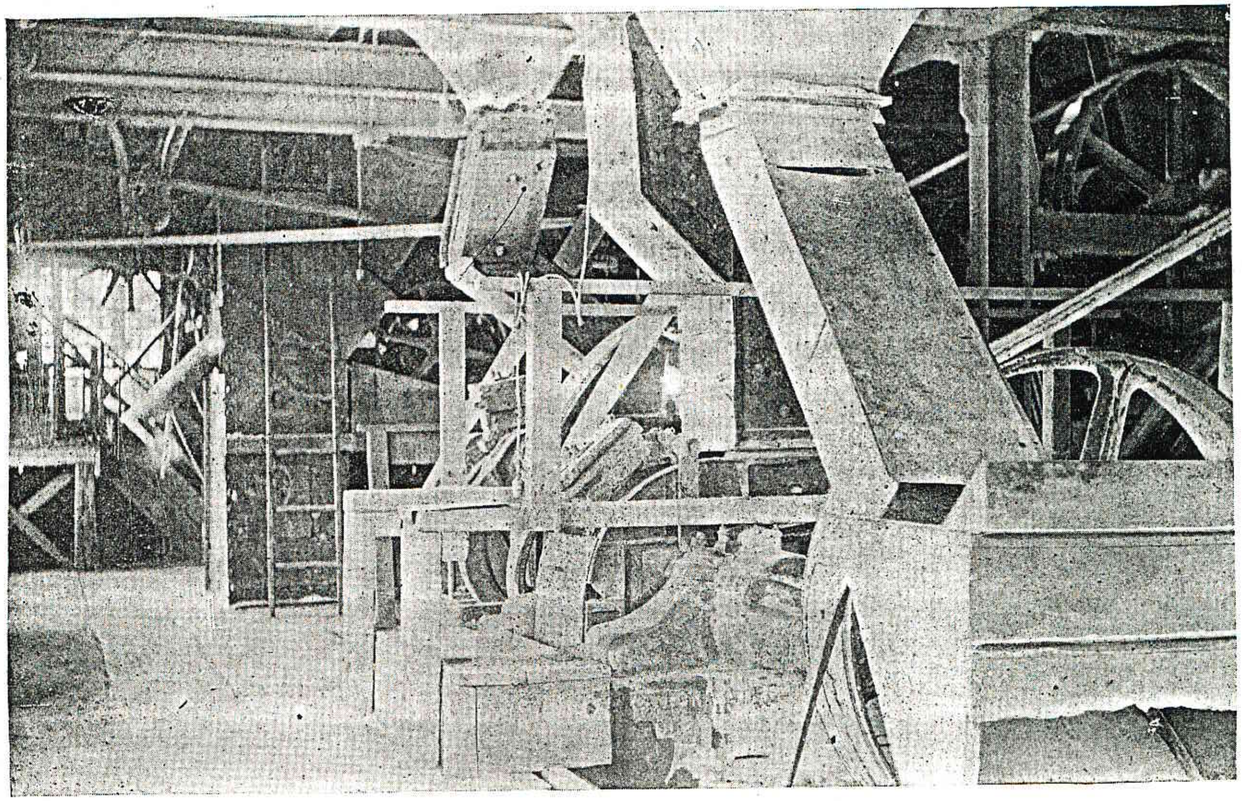


FIG. 22.—FIRST FLOOR EQUIPMENT AT EAST HELENA NO. 1 MILL.

The three-hoppered spouts from the trommel on the floor above lead oversize to the three large crushing units in a row. The cutter cabinet is in the background at the left.

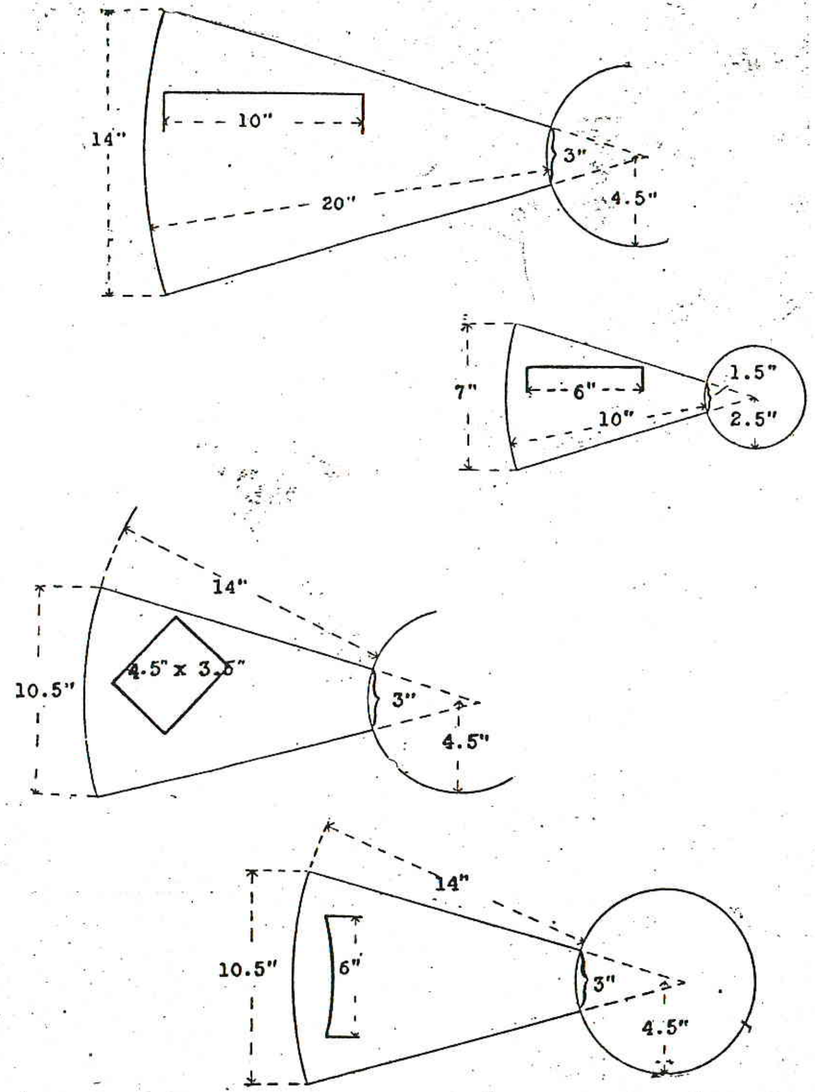


FIG. 23.—VEZIN SAMPLER WINGS AT EAST HELENA SAMPLING MILLS.

The two upper drawings are of the cutter wings in the No. 1 mill; the two lower drawings are of the wings of the tandem cutters in the No. 2 mill. The measurements were taken from the machines and show satisfactory design.

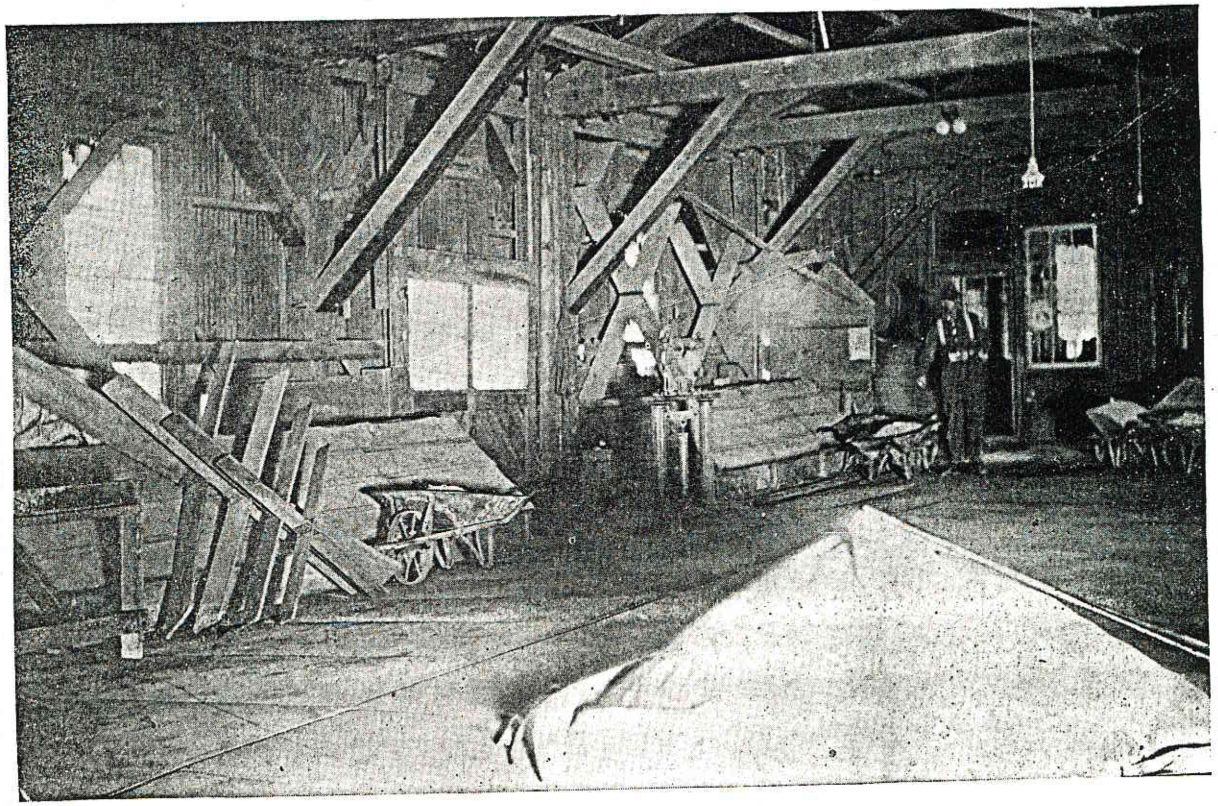


FIG. 24.—STEEL SAMPLING FLOOR AT EAST HELENA.

A platform scale is near the door; quartering crosses and reserve sample bins are along the walls.

minute and discharges onto a slowly rotating circular plate feeder, which pushes out a uniform stream to the Vezin below. The second Vezin makes 60 sample cuts a minute.

The oxide, or No. 3 sample mill, is a small machinery tower at one side of the large steel sampling floor adjacent to the No. 2 sample mill. The oxide mill is provided with two jaw crushers, a set of rolls and No. 2 and No. 3 Brunton vibratory cutters. One-fifth of the original lot is delivered as sample.

The steel sampling floor has a set of platform scales, a 10x7-inch crusher and a 12x12-inch rolls. Screens are provided for breaking up lumpy ores and numerous crosses allow several hand-sampling operations to take place simultaneously. Figure 24 is a view along one side of the steel floor; a cone of ore covered with canvas is in the foreground, wooden crosses are along the wall, while around the entire room is a row of covered bins to store the reserve samples. The mills are provided with 58 wooden reserve bins similar to those in Figure 24, and near the No. 1 mill is a group of 42 steel pockets for the same purpose.

The East Helena mills are provided with commodious fine-grinding and finishing facilities. The bucking room is 27x57 feet; it has an all-steel floor and the following pieces of equipment:

One Sturtevant, 3"x8", roll jaw crusher
One F. M. Davis, 12"x20", rolls
Two steam drying tables, each 30"x72"
Two Engelbach type, fine grinders
Three steel bucking boards
One round steel table, 5' diameter
One cabinet shelf dryer, 12 double shelves
Two stand riffle cutters, 26, 5/8" slots each
Two table riffle cutters, 36, 5/16" slots each.

The bucking room, as well as each of the mills, is, of course, provided with pressure air for cleaning. Ores are commonly ground to pass 100-mesh, high-silver ores to pass 120-mesh, and gold ores to pass 150-mesh. Ground and sieved samples are rolled on a special black surfaced paper before cutting for the final packets with a table riffle.

THE EAST BUTTE COPPER MINING COMPANY'S SAMPLING MILL

The East Butte Copper Mining Company samples all of its second-class ore and custom ore in a mill adjacent to its smeltery at Butte, Montana.

The mill building is a wooden structure some four stories high, with a main sampling section 33 feet long and 18 feet wide. The crusher is under the hopper, over which the elevated track passes beside the mill. The crushed ore is elevated to the first sampler,

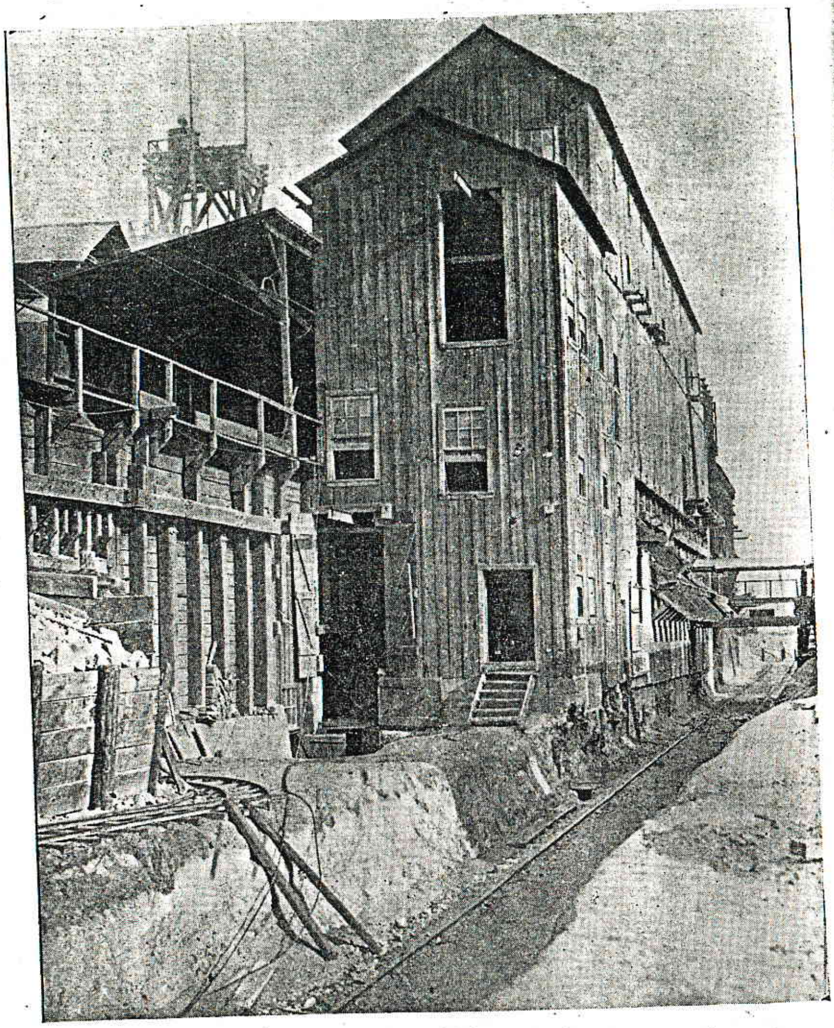


FIG. 25.—EAST BUTTE SAMPLING MILL.

Lots of ore are received over the "high line" above the bins to the left. Outgoing cars may be loaded on the receiving line or from pockets over the depressed track at the right.

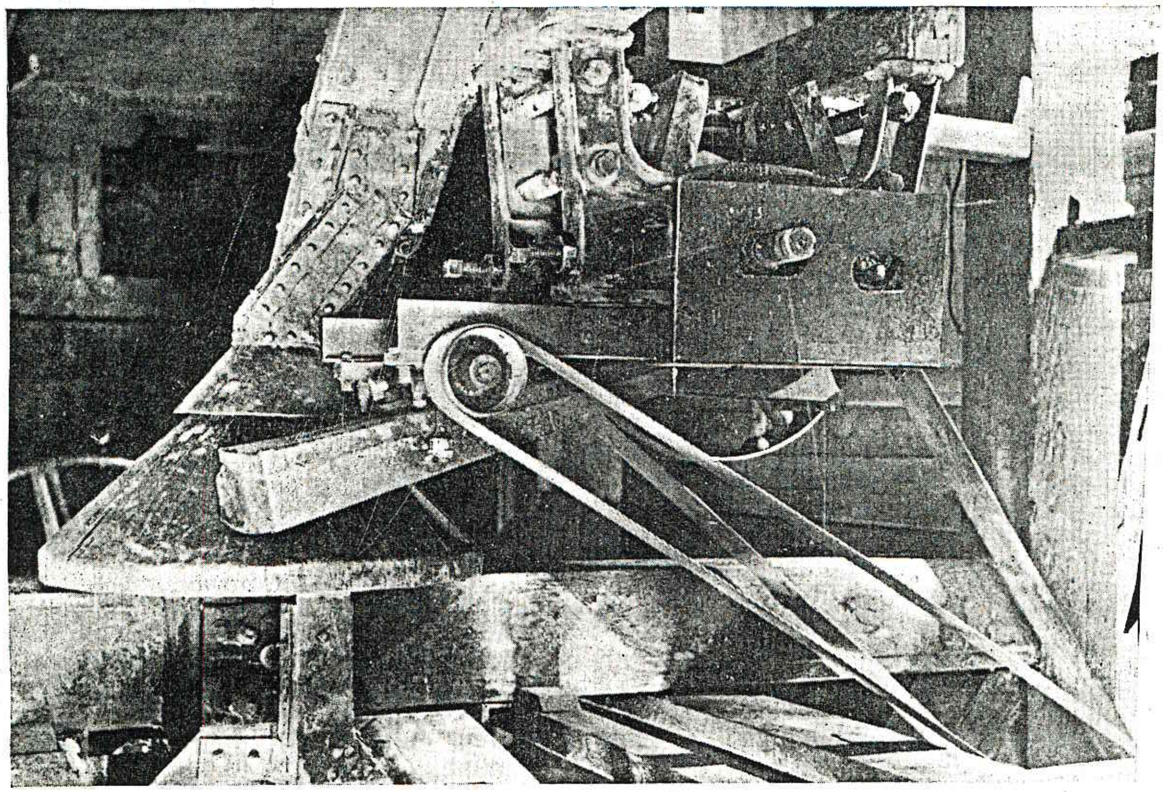


FIG. 26.—THIRD SAMPLER AND THIRD ROLLS IN EAST BUTTE SAMPLER.

The sample can is placed directly under the rolls. Notice the vertical spout to the sample saucer, and the long shaking trough from the sampler to the rolls.

which is in the top of the mill over the bin section which adjoins the main machinery section of the structure. A conveyor over the bins extends along the more elevated part of the building and allows sampled ore to be dropped in any one of the series of bins, to be sent back to cars on the high unloading line, or to be screened, and crushed, and dropped in special bins. Figure 25 shows the main machinery sections in the center of the picture; behind and to the right is the bin compartment, which is a story higher and has the series of spouts to load cars on the depressed track. The unloading line and mill hopper are under the roof at the left of the picture.

The cutters used in the mill have already been described as the East Butte type, and the mill-flow sheet has been indicated on page 45. The large cast iron stand cutter used to finish the mill samples ready for the bucking room, is a prominent piece of equipment; it is the largest and most substantial riffle cutter in use at any of the sampling mills. Figure 16 gives an excellent idea of the drum mixers and the way they are placed over the samplers. The final sampler is pictured in Figure 26, where it is seen suspended between the spout from the last drum mixer and the shaking trough feeding the last set of rolls.

A peculiar method is used in this mill for handling the sampler rejects. The reject from the first sampler, which is in the top of the mill under the dump of the single elevator, is run to final disposal as the lot is sampled. The rejects from the second and third cutters drop to a hoppered bin under the first floor, from whence, after the entire lot is sampled, they are conveyed to the elevator and follow the rest of the lot to its final disposal.

Compressed air is used for cleaning. The bucking room contains the usual equipment for fine grinding, drying, mixing, and dividing.

THE SAMPLING MILLS AT ANACONDA, MONTANA

The Anaconda Copper Mining Company maintains two sampling mills in its great smeltery at Anaconda, Montana. The mills are almost exclusively used for sampling ores from its own mines, since custom ores are sampled in the Washoe Sampler at Butte.

Figure 27 shows the huge main double sampler. It is probably the largest sampling mill in the world, having an 8-hour capacity of 2,000 tons. The mill is constructed and operated in two entirely independent but identical units. Most of the ore handled comes from the Butte mines and averages about 3.2% copper, 2.5 ozs. silver, and 0.01 oz. gold. As the ore runs fairly uniform, the cut-offs between lots are indistinct, and the cleaning of equipment between lots, which is a very important feature in all the other mills, is dispensed with.

The Anaconda mill is of frame construction, with a sprinkler system for fire protection. The floor section is 45 feet by 63 feet; there are four floors and a small basement under the crushers. The general mill scheme is given in Figure 28, which correctly represents

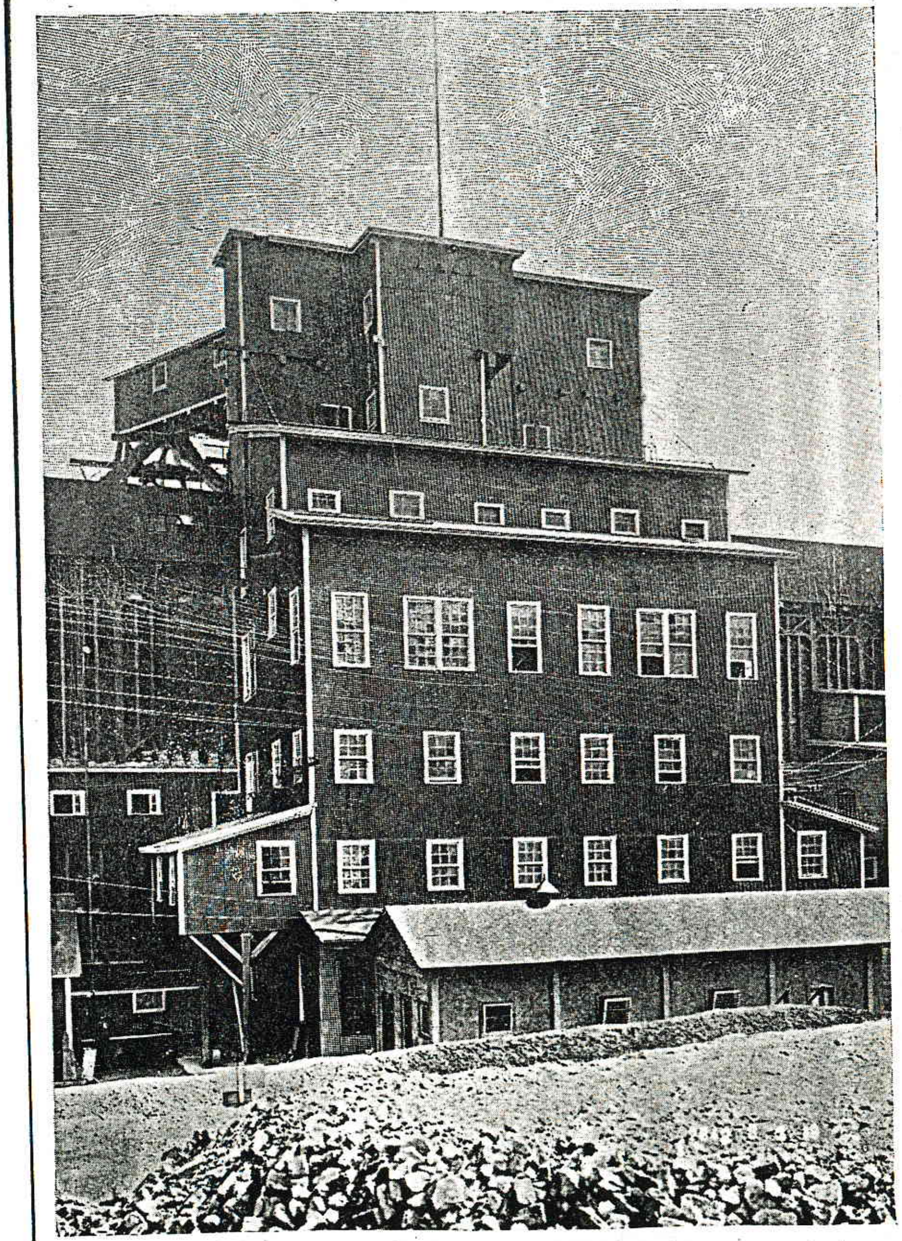


FIG. 27.—THE ANACONDA SAMPLING MILL.
—Photograph by Baker, A. C. M. Co.

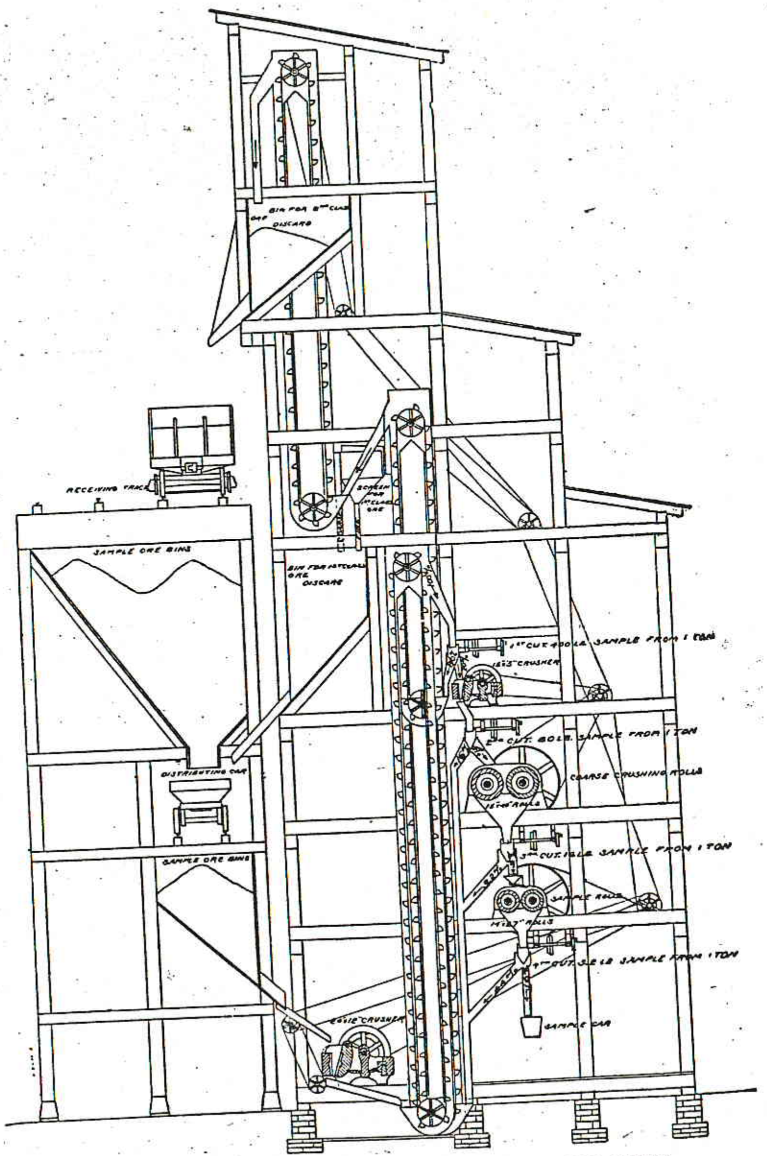


FIG. 28.—DIAGRAM OF ANACONDA SAMPLING MILL.
(Courtesy of A. C. M. Co.)

The uppermost elevators now deliver to conveyors carrying to bins across the tracks.

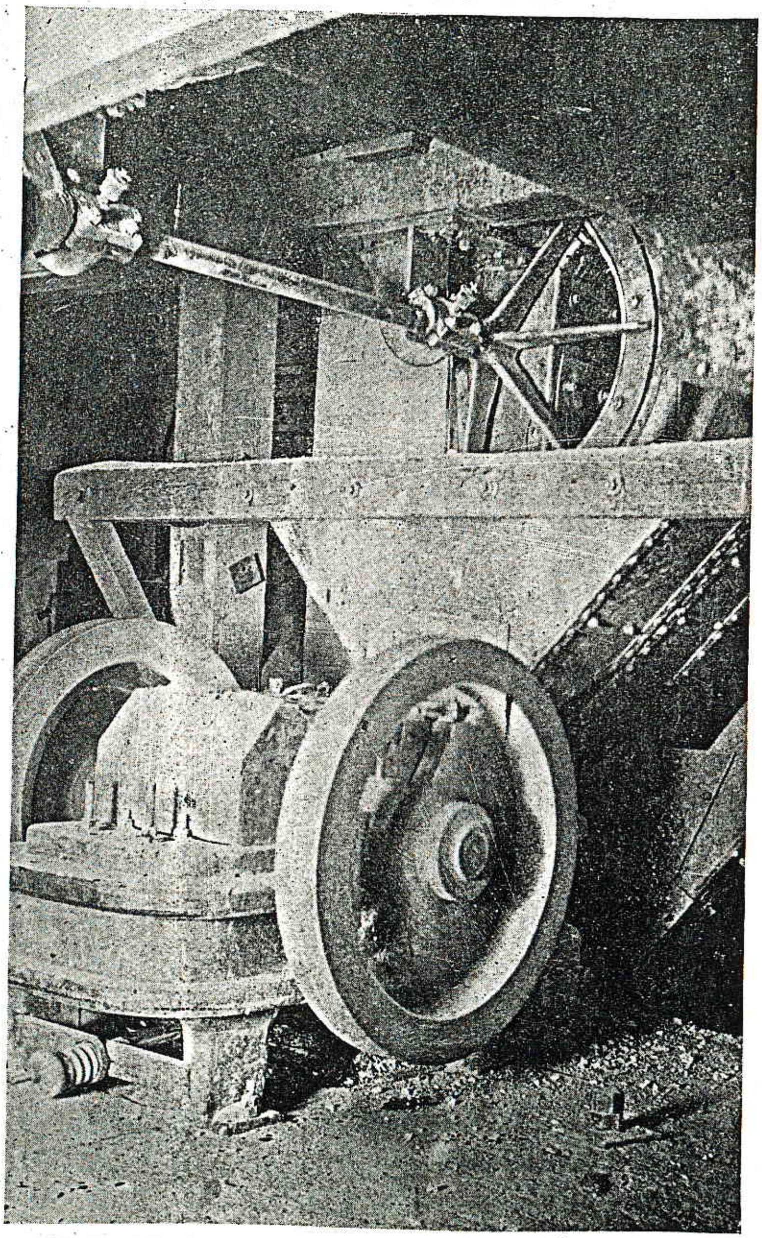


FIG. 29.—FIRST SAMPLER AND SECOND CRUSHER IN ANACONDA MILL.

The sampler is placed close to the crusher. The oscillator has a diameter of nearly six feet, which makes it by far the largest cutter in the State.

all but the more recent conveyors from the top of the mill across the tracks to the spouts delivering to the concentrator feed bins.

The equipment is characterized by its large size and close spacing of cutters over the next lower crushing machine. The latter feature is well indicated in Figure 29, which shows one of the first Bruntons over its 8x18-inch crusher. The mill also has a partial dust-collecting system with suction intakes at the most dusty points, and a cyclone separator outside the building.

The bucking room is equipped with the following units in duplicate:

Engelbach grinders
Braun disk grinders
Bucking boards
Stand cutters; 26 slot
Table riffles; 16 slot
Power (air) screens
Cube mixers; 8" sides

Figure 30 is a splendid picture of the bucking room and its equipment. A 15-horsepower motor drives the equipment, while another small motor in the far corner is coupled to a fan which exhausts the hood above the two Engelbach grinders and delivers the dust outside of the building. The room beyond, which is just through the double doors seen in Figure 30, contains the steel floor for split shovel work, a 10 by 4-inch jaw crusher, moisture scales, and a large steam drying cabinet.

The Southern Cross sampling mill is a plant addition made to the smeltery some three years ago by the company. The mill covers an area 25 by 48 feet, and has four floor levels; it is placed between two columns and under the "high line," which tracks lead to the main sampling mill and the concentrator bins. The mill has been used only for sampling Southern Cross gold ore, which was not conveniently sampled in any other way.

The crushing of the ore is done entirely by jaw crushers. The cutters are of special design; they have a wing much like the Vezin wing, but oscillate back and forth in a horizontal plane by means of a gear-and-crank mechanism.

The Southern Cross mill is sprinklered for fire protection; it is cleaned with compressed air, as other mills. It has its own bucking room equipped much as the larger Anaconda mill, but with single units.

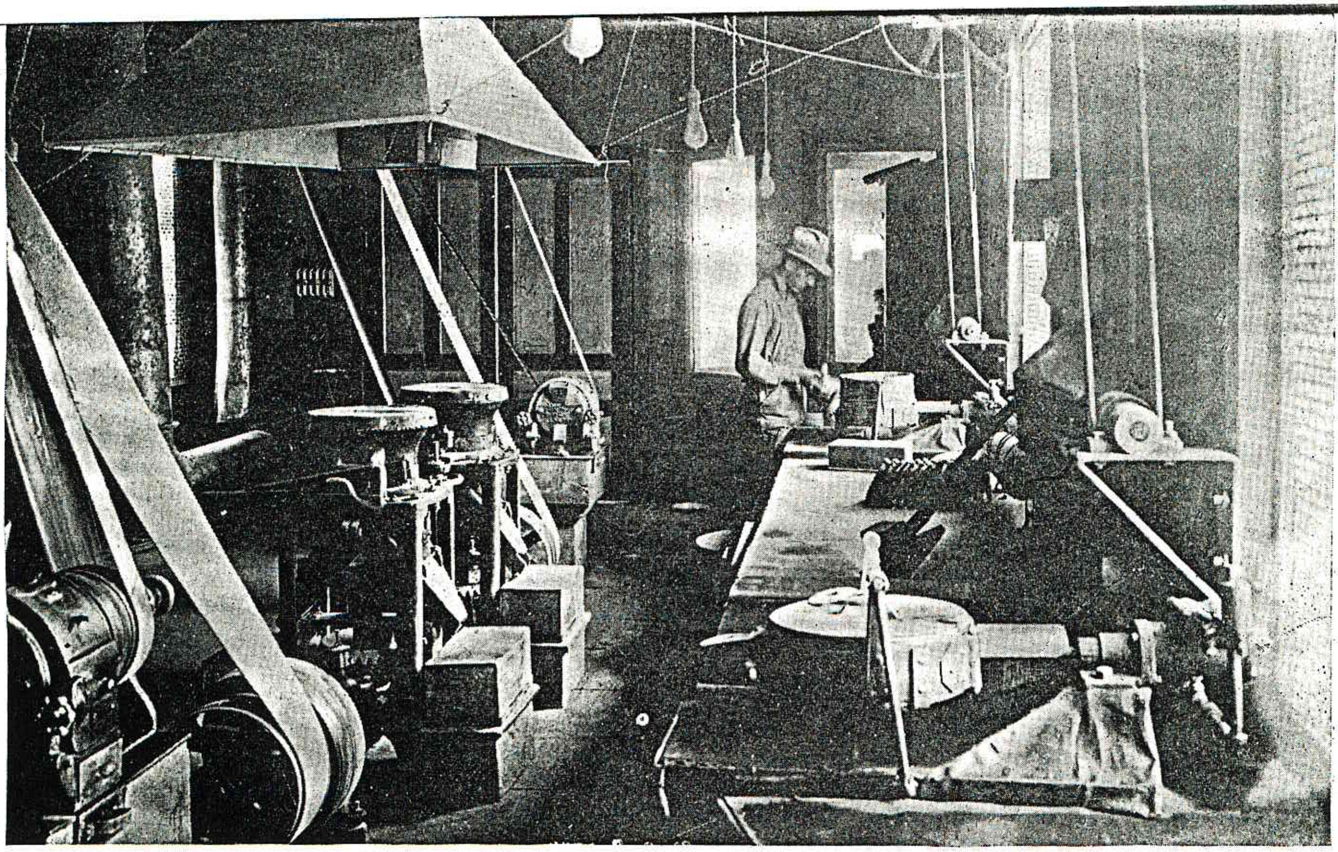


FIG. 30.—BUCKING ROOM AT ANACONDA SAMPLING MILL.

The duplicate and orderly arrangement of the equipment is prominent. The air-driven shaking sieves are on the bench at the right, the cube mixers are on the wall over the bench.

—Photograph by Baker, A. C. M. Co.

Flow Sheet of the Anaconda Sampling Mill—

Cars dump into bins under "high line"
Collecting car under bins supplies two 50-ton mill hoppers
Shaking trays
Jaw crushers; 12"x24"
Conveyors to elevators
Elevated to top of 4th floor
No. 1 cutter; Brunton oscillatory, 11"x15" openings, 24 cuts per minute

Sample; 20%
Jaw crushers; 8"x18"
No 2 cutters; Brunton oscillatory, 7"x11" openings, 36 cuts per minute

Sample; 20%
Shaking trays
No. 1 rolls; 15"x40"
No. 3 cutter; Brunton oscillatory, 5.5"x8" openings, 44 cuts per minute

Sample; 20%
Distributing boxes
No. 2 rolls; 14"x26"
No. 4 cutters; Brunton oscillatory, 3.5"x5" openings, 76 cuts per minute

Sample; 20%
Trolley bucket or wheelbarrow to steel floor
Brunton split shovels
Sample

Steam cabinet dryers
Engelbach grinders
Stand cutters; 26-slot
Sample

Disk grinders
Mechanical sieves (air)
Cube mixers
Table riffles; 16-slot
Sealed packets

SAMPLING IN MONTANA CONCENTRATING AND CYANIDING MILLS

A great deal of sampling is done as part of the daily routine in all concentrating and cyaniding mills. In ore treatment plants conditions are decidedly favorable for cheap and accurate work. The greatest difficulty is unquestionably in the sampling of mill heads where hardly less than a full observance of all the rules for crushing and dividing can be expected to supply precise data.

Every tenth car of ore for the great Anaconda 17,000-ton concentrator is sampled in the Anaconda sampling mill which has already been described. All the ore going to the East Butte concentrator is sampled in the East Butte sampling mill, also one of the mills described in this paper. The Butte and Superior concentrator feed is hand sampled every half hour; 50 pounds are taken at each interval. The Timber Butte concentrator is equipped with a hand operated device which cuts out samples from the crushed feed as the stock pours from one conveyor head to another conveyor. The Shannon mine of the Barnes King Company is equipped with mechanical contrivances which automatically cut out portions of the ore at the tramway loading station; the sample is worked down to final pulp in the customary way.

The sampling of the different streams of mill pulp is carried out in different degrees by various means in the several mills. Usually hand samples are taken at designated intervals. Swinging stream samplers are built in a variety of models and frequently used. A complete automatic stream sampling system is in use at the Butte and Superior mill; an electrical timing and operating installation swings samplers across a half-dozen streams at exactly 8-minute intervals. Milling work inevitably smooths out inequalities in the raw ore; the material is abundantly crushed; mixings and dispersions occur throughout the line of pulp flow. The required precision of the sampling operation is obtained with slight expense for installation, upkeep, or attendance.

Mill products can be sampled as pulps while the concentrates are flowing to collecting bins; they can be pipe-sampled as lots in bins or in railroad cars, or they can be hand-sampled by shovel and cone and quarter methods.

As a rule, ordinary mill sampling, except for the sampling of the heads, is far easier to accomplish than the sampling of lots of custom ore; mill heads require practically the same treatment that lots get in the best of custom samplers.

SUMMARY AND CONCLUSIONS

The principles involved in ore sampling have been more or less expressed by several writers, but no thoroughly adequate and mathematical treatment has yet been given. The present paper attempts to analyze sampling methods with the theory of probability and the distribution of results strongly in mind, although a mathematical treatment is not attempted. A lot of ore is a very complex aggregate, and to the sampling deviations are added those of chemical analysis; constants in an equation of errors, or for qualifying Woodbridge's table of size-weight relationship.

The equipment for ore sampling which is described in these pages is only that equipment found in actual use in Montana at the present time; the range of the types is wide but by no means includes excellent machines in use elsewhere.

The figures given in connection with the descriptions of riffle mixing and pipe sampling may give a better insight into the character of those two operations.

Sampling is now carried on extensively in Montana in seven sampling mills and in at least five large and important ore-dressing mills. It has been attempted to outline the procedure used in the different sampling mills, but a full account of the sampling in the twelve places would require a much larger bulletin than this can presume to be.

Although sampling of ores and mill pulps is a perfectly practical and common operation, certain features are clearly open to change and improvement. The more obvious possibilities group about precision, cost, efficiency, fire risk, safety, welfare, and hygiene. There always lurks the suspicion that, for the work done, and the end attained, present plants are extravagant in elevations, size of buildings, and general capital outlay for equipment and attendance. Montana sampling mills rank high in most of their technical features, with certain attentions toward improvement in conditions of safety, welfare, and hygiene they would probably become the most advanced types in their field of technology.

The excellent results obtained by the State Bureau on the different samplings of the 50-ton lot of ore demonstrate the precision of the mills and the satisfaction and usefulness of mechanical sampling.

IMPORTANT PUBLICATIONS ON SAMPLING

1884—Brunton, D. W. "A New System of Ore-Sampling." Trans. Am. Inst. Min. Engrs., Vol 13, p. 639.
Brunton's first vibratory cutter is described.

1895—Brunton, D. W. "The Theory and Practice of Ore-Sampling." Trans. Am. Inst. Min. Engrs., Vol. 25, p. 826.
An extended study of the influence of large particles and rich minerals on the precision of sampling. Demonstrates the necessity for crushing between successive divisions.

1898—Hofman, H. O. "The Metallurgy of Lead." Hill Publishing Co., New York, 5th Ed., 9th Imp.
Chapter 5 is a lengthy discussion of hand and mechanical ore sampling.

1902—Johnson, Paul. "An Automatic System of Sampling." Eng. & Min. J., Vol. 73, p. 514.
Describes mill at Greenwood, B. C., with cuts and results.

1908—Argall, Philip. "Machine Sampling." Eng. & Min. J., Vol. 86, p. 291.
Refutes statement that retardation causes error in sampling.

1908—Woodbridge, T. R. "Sampling by Machine." Eng. & Min. J., Vol. 86, p. 917.
Discusses mechanical sampling with data.

1909—Bailey, E. G. "Accuracy in Sampling Coal." J. Ind. Eng. Chem., Vol. I., p. 161.
Discusses probability curves involving large errors.

1909—Richards, Robert H. "Ore Dressing." McGraw-Hill Book Co., New York. Vol. III., pps. 1570-1578.
Principles and practice of sampling are discussed.

1909—Brunton, D. W. "Modern Practice of Ore-Sampling." Trans. Am. Inst. Min. Engrs., Vol. 40, p. 567.
The Taylor and Brunton system is explained. Brunton's oscillatory cutter is described.

1909—Woodbridge, T. R. "Sampling by Machine." Eng. & Min. J., Vol. 87, p. 269.
Discusses mechanical sampling with data.

1910—Weld, Fred C. "Accuracy in Sampling." J. Ind. Eng. Chem., Vol. 2, p. 426.
Discusses application of probability curves to sampling.

1910—Huntoon, Louis D. "Accuracy of Mechanical and Riffle Ore Samplers." Eng. & Min. J., Vol. 90, p. 62.
Gives screen analyses and assays after riffle dividing.

1916—Woodbridge, T. R. "Ore Sampling Conditions in the West." U. S. Bureau of Mines, Technical Paper 86.

An excellent study of the more important aspects of hand and mechanical sampling. A general summary of western practice is given as well as flow sheets of the mills.

1919—Rice, Claude T. "Sampling Practice at Independence Mill." Eng. & Min. J., Vol. 107, p. 641.

Describes the Coard mixer and divider for final pulps.

INDEX

INDEX—*Continued*